FLORIDA INTERNATIONAL UNIVERSITY

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ANALYSIS OF FORESTS UNDER DIFFERENT MANAGEMENT REGIMES IN THE WESTERN TERAI OF NEPAL AND ITS RELATION TO ENVIRONMENT AND HUMAN USE

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To: Interim Dean Mark Szuchman
College of Arts and Sciences

This thesis, written by Nilesh Timilsina, and entitled Analysis of forests under Different Management Regimes in the Western Terai of Nepal and its Relation to Environment and Human Use, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

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DEDICATION

I dedicate this thesis to my parents for everything they did to bring me to this level.

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ABSTRACT OF THE THESIS

ANALYSIS OF FORESTS UNDER DIFFERENT MANAGEMENT REGIMES IN THE WESTERN TERAI OF NEPAL AND ITS RELATION TO ENVIRONMENT AND HUMAN USE

by

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This study was done to understand the forest structure, composition and dynamics of the Sal forest, the relationships of forest communities with environmental variables, and ecological differences between community forests and forests inside protected areas in the western Terai of Nepal. Forest sampling was done along transects in two protected areas and two community forests, and sampling locations were established every 200 m to sample trees, saplings, shrubs, seedlings and herbs. Soil samples from each plot were analyzed. Agglomerative cluster analysis, non-metric multidimensional scaling, ANOVA, Kruskal-Wallis, Mann-Whitney and t-tests were all used to analyze data.

The sampled forest had lower tree diversity, density and lower basal area compared to forests in other areas of India and Nepal. Three different associations of Sal Forest were identified, but none of the soil variables tested identified the distribution of communities. Community forests were in poorer conditions compared to protected forests and require additional protection to resemble the structure and diversity of protected areas.

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ACRONYMS

TAL	Terai Arc Landscape
RBNP	Royal Bardia National Park
RSWR	Royal Suklaphanta Wildlife Reserve
HMGN	His Majesty's Government of Nepal
ASD	Average Stand Diameter
SDI	Stand Density Index
IVI	Importance Value Index

1. INTRODUCTION

1.1 Background

Forests covered 73.3% of the total area of the Terai (the subtropical lowlands) between central and western Nepal during the 1950s (Joshi 2002). Due to the importance of these forests for both commercial and subsistence purposes (Webb and Sah 2003), in the past few decades, heavy human pressures have reduced the forested area resulting in degradation and fragmentation of historically contiguous landscapes and posing threats to biodiversity conservation and local livelihoods. Between 1958 and 1988, forests cover in the lowland Terai between central and western Nepal declined from 73.3% to 45.8% of the total land area (Joshi 2002). In such a human dominated environment, it is necessary to have baseline ecological information on forests for their management in the future.

A major part of these subtropical areas are covered by seasonal broad leaved forest which are typical of monsoonal climates (Wesche 1997). Sal (*Shorea robusta*) is the single most important species. Sal Forests are important for both commercial purposes and local livelihoods. Its sustainable management and utilization is necessary to meet the broad objectives of biodiversity conservation and sustenance of the rural economy.

Despite widespread occurrence of Sal Forests and its importance both from economic and ecological points of view, little information exists on the eological aspects of this forest. Past studies on the forests and flora of Nepal (Stainton 1972; Dobremez 1976), a few floristic studies inside protected areas (Dinerstein 1979; Shrestha and Jha 1997; Sharma 1999) and a study in central Nepal (Wesche 1997) provide information on Sal Forest, but there is a dearth of information in Sal Forests of the western Terai, and especially outside protected areas. The present study is an attempt to fill this gap and provide important information on the structure, composition and dynamics of Sal Forests in protected areas and community forests of the western Terai.

Physical factors such as climate and rainfall, soil physical and chemical properties and existing disturbances play a significant role in the distribution and diversity of plant communities (Tilman 1982; Kozlowski et al. 1991; Swaine and Becker 1999). Recognition of soil heterogeneity is important for analysis of plant community patterns in tropical forests (Huston 1980; Villers-Ruiz et al. 2003). In the western Terai of Nepal, the length of monsoon, total rainfall, seasonal flooding and soil conditions, and other factors such as grazing, clearing for cultivation, burning, selective cutting, logging and lopping have been considered as factors modifying vegetational composition and succession (Dinerstein 1979). In the present study, I also make an attempt to understand the relationship of forest communities with physical environmental factors.

Forests exist under different conditions and are managed with different objectives. Forests inside protected areas are managed with protection as the main objective and maintained for environmental services, biodiversity conservation, to provide habitat for wildlife and promoting tourism. Community forests are managed by communities with the goal of sustainable utilization of forests resources such as timber, fodder, firewood and other non timber forest products (NTFPs). Other forests (for example national forests) are open access (Ostrom 1990) and will face the tragedy of the commons (Hardin 1968). Several studies have found that forests managed under different objectives show significant differences in ecological conditions (Shankar et al. 1998; Nagendra 2002; Web and Sah 2003). Structure and composition of natural forests differ from secondary forests and plantation forests. Forests inside protected areas differ from community forests and national forests.

Protected areas and forests outside protected areas in the western Terai are part of the Terai Arc Landscape (TAL), which is a government initiative to take landscape approach to protect biodiversity in protected areas and outside forests and to link protected areas with forest corridors (HMGN 2004). Since the protected areas in the western Terai are under strict protection for nearly three decades, a comparative study between the two provides important ecological information on the outside forests. The information will be useful in assessing the existing biodiversity and the habitat quality of outside forests, and management interventions required to bring them to the same richness and diversity level as protected areas. This study also compares protected area forests with community forests. For the success of TAL, information on ecological conditions of outside forests in comparison to protected areas will be useful for biodiversity conservation and to secure additional wildlife habitats.

1.2 Topography and Physiography

Here I want to provide general information on topography and physiography of the country to make readers aware of geographical settings of the study location.

Nepal is a Himalayan country situated on the southern slopes of the Himalayas. It is located between the latitudes 26^{o} 22’ and 30^{0} 27’ N and longitudes 80^{o} 40’ and 88^{o} 12’ E. The shape of the country is roughly rectangular covering an area of 147, 181 sq km. Average east west length of the country is 885 km and average north-south width is 193 km. About 83% of the country is occupied by mountains and nearly 17% by the lowland Terai. The altitude ranges from 60m above the sea level to 8848 m on Mt. Everest, the highest peak in the world.

Nepal is classified into many different physiographic zones. The Terai and Bhabar, which are the main focus of the present study, lie between 60-300 m elevation. The Terai is the northern extension of alluvial gangetic plains and is highly productive in terms of agriculture. The Bhabar abuts the Terai on the south and the Siwalik on the north and consists of large boulders that have been brought down by the rivers from the mountains to the north. The Churia or Siwalik hills rises to the north of the Bhabar and reach 1500 m in elevation. It extends from east to west. It is mainly composed of sedimentary rocks and big boulders. These areas have been subjected to severe soil erosion due to intensive removal of forest cover. Dun valleys are gently sloping valleys to the north of the Churia. The Mahabharat and Midlands range from 600 m to 3500 m. The Mahabharat lies between the Churia in the south and midlands in the north. The elevation varies from 1500m to 2700m. The Midlands lie at the base of the Himalayas and north of the Mahabharat range and cover most of the central region of the country. Elevations range from 600 m to 3500 m with an average of 2000m. The Himalayas lie in the northern part of the country and extend from east to west. They consist of the major peaks of the world and are covered with snow year-around over 5500m in elevation. Between the greater Himalayas lie several inner Himalayas with a dry and monsoon-less climate.

1.3 Vegetation Zones of Nepal

Since this study deals with forest communities, this section provides an introduction to the past studies on flora and classification of vegetation zones to make readers aware of the existing information on the flora as well as the plant communities that can be found in the country.

The study of vegetation in Nepal was started by Buchanan and Hamilton in 1802 and later continued by Nathaniel and Wallich in 1802-21 (HMGN 1976). Other studies on Nepalese flora were done by Schweinfurth (1957), Stearn (1960), Stainton (1972), Dobremez (1972) and HMGN (1976). Stainton (1972) did a detailed classification of forest types in Nepal. For the description of vegetation he classified Nepal into Terai, Dun Valleys and Outer Foothills, the Midlands (West, East, Central and Country to the south of Annapurna Himal), Humla-Jumla area, Dry River Valleys, Inner Valleys and the arid zones. He classified forests of Nepal into six divisions on the basis of ecology and vegetation, namely tropical and subtropical forest, temperate and alpine broad leaved forest, temperate and alpine conifer, minor temperate and alpine association. The factors that determine vegetation distribution are climatic conditions, altitude, geographical location, natural composition of the soil and biotic factors. The major zones are:

- Tropical Zone: This area lies between 200 to 1000m. It consists of the lowland Terai and Bhabar zone. It is characterized by a hot climate and heavy monsoonal rain. The major vegetation types of this region are Sal Forest, Tropical Deciduous Forest and Tropical Evergreen Forest.
- Subtropical Zone: This zone lies between 1000- 2000m. There is no clear distinction between tropical and subtropical zone in Nepal (Shrestha 1997), but for convenience these two groups are kept separately. This region encompasses the Siwaliks, lower Mahabharat ranges, midland areas to 2000 m. This region

consists of mixed tropical evergreen and broad-leaved forest. At high elevations one may find mixed hard wood forest.

- Temperate Zone: This zone lies at an altitude between 2000 to 3000 m. It includes the southern slopes of the Himalaya and higher elevations of the Mahabharat range. The forests types consist primarily of temperate mixed broadleaved and evergreen forest, and upper temperate mixed broadleaved forest.
- Subalpine Zone: This is a transitional zone between the temperate and alpine zones and consists of part of the greater himalyas between 3000 to 4100 m. Silver fir and Rhododendron forests are found in this zone. The treeline in western Nepal is 3850 m and for eastern Nepal it is 4000 m (Chaudhary 1998).
- Alpine Zone: This is the zone above 4100m. It is characterized by strong winds, cold and snow. Vegetation comprises the association of Juniper-Rhododendron and alpine meadows.

1.4 Legal Protection of Forests in Nepal

According to Nepal's Forest Act of 1993, forest has been defined as an area which is completely or partially covered by tree species. In Nepal forest covers approximately 5.6 million hectares, which is about 37% (including forests and shrub) of the total land area of the country (15 million hectares). Land use classes other than forest include agricultural land, eroded land, water, stream, river bed, flooded areas, urban and industrial area, grassland, barren land, snow and ice. Forest resources play a crucial role in socio-economic upliftment of the people of Nepal. About 15% of the country's GDP comes from forest resources (HMGN 1996) and more than 75% of total energy used is derived from fuelwood from forests and shrublands (HMGN 1998).

Forests were managed traditionally until the mid 1950s in the hilly regions of Nepal (Thapa and Weber 1995). The Forest Nationalization Act of 1957 brought all forested land under government ownership and alienated local communities (Neupane 2000). This resulted in the conversion of limited-access community-controlled forests into open access resources (Ostrom 1990). The National Forest Act of 1976 attempted to return ownership to communities to a certain extent but was unsuccessful largely due to administratively-defined government structures such as village Panchayats (equivalent to parish; Thapa and Weber 1995). Rather than true community involvement, Panchayat representatives and officials had influence in decision making. Realizing the need for community participation in forest management, the Government of Nepal introduced the Community Forestry Act in 1993 (Varughese 2000). The major thrust of the act was to provide communities with the rights to protect and manage forests, to utilize forest products and to derive income from forests. Over 8500 forest user groups had been formed and about 620,000 ha of forest area had been handed over to user groups by 1999 (Chaudhary 2000). Community forestry has been successful in improving the conditions of forests and people in the midhills, but increased inequalities in the distribution of agrarian resources and greater ethnic diversity because of migration from the hills have been attributed as causes of infeasibility of community forestry in the Terai region (Chakraborty 2001).

According to the 1993 Forest Act, five categories of forests are identified in Nepal. These are Government Managed Forest, Protected Forest, Community Forest, Leasehold Forest and Religious forest.

- **Government Managed Forest:** The forest type is strictly managed by His Majesty's Government of Nepal (HMGN) with production as the main objective. It is illegal to collect any forest resources from this category without permission of authorized person with HMGN. A certain amount of money should be paid to HMGN for resource utilized.
- **Protected Forest:** Under the act, government forests with any cultural, environmental or scientific importance are declared by HMGN as protected forest.
- **Community Forests:** National Forests that are handed over to community "users groups" for their conservation, management and utilization are community forests. The major goal of this policy is to initiate community participation in forest management. Forests are handed over to community user groups, who are granted the right to manage and protect forests and the right to forest produce and income derived therefrom.
- **Leasehold Forests:** These are National Forests handed over to institutions, industries or communities established under the current law. The main objective is to provide raw materials needed for forest industries, and to encourage plantation forestry, ecotourism and agroforestry.
- **Religious Forests:** These are national forests in and around religious sites that are handed over to religious groups for their conservation, utilization and development. Religious groups can utilize resources for religious causes but not for commercial use.

According to the Act, the term national forest includes all forests, excluding private forests whether the boundaries are delineated or not; it also includes waste or unregistered or uncultivated lands in or around forests as well as paths, ponds, lakes, streams or rivers and riverine lands within forests. The term Private Forest denotes any forested land that is planted, nurtured or conserved on private land owned by an individual under the current law.

Realizing the need to manage forests sustainably for the long term fulfillment of local needs, the Government of Nepal endorsed The Master Plan for the Forestry Sector in 1989. The plan, which was prepared in 1988 (HMGN 1988), presents up to date strategies for the management of forests in Nepal for the next 21 years. The primary goal of the Plan was to foster community and private participation and partnership with the Ministry of Forest and Soil Conservation for the management and sustainable utilization of trees, shrubs, grasses and medicinal plants. Long term strategies for the management of the forestry sector according to the plan were to: meet people's basic need; increase agricultural production through forest management; protect against land degradation (soil erosion, landslides, desertification and flooding); provide economic upliftment of both local and the national economy; and conserve ecosystems and genetic resources. There were management plans in the early sixties but they were not implemented because of lack of resources and government initiative. Operational Forest Management plans for 18 districts of the Terai were prepared in the late 1980s but were also not implemented (Kanel and Shrestha 2001). Forest management has been provided great emphasis during planning and documentation phases, but implementation has been insubstantial in Nepal.

1.5 Protected Areas Management and Landscape Approach to Conservation

The National Parks and Wildlife Conservation Act was enforced in Nepal in 1973, which provided the legal base for the declaration, conservation and management of protected areas in Nepal. The main purposes of this act are to protect wildlife and its habitats, control hunting, and promote the conservation and management of important natural areas. The 1973 Act and its amendments identified five categories of protected areas in Nepal: strict nature reserves, national parks, wildlife reserves, hunting reserves and conservation areas. There are now nine national parks, three wildlife reserves, one hunting reserve and three conservation areas in the country, which cover approximately 18% of the total area (Heinen and Shrestha in press). Although 18% of the land area of Nepal is protected, protected areas are not enough to conserve the full array of biodiversity and significant levels of biodiversity exists outside the system (Hunter and Yonzon 1993).

Forests outside protected areas are being depleted. Between 1978 and 1991, about 99,000 ha of Sal (*Shorea robusta*) forest in the Terai were cleared with an average deforestation rate of 1.3% (8,300 ha per year; FRISP 1994). If Nepal were to lose its remaining humid tropical forest, there would be a loss of ten species of highly valuable timber, six species of fiber, six species of edible fruit trees and shrubs. This would severely alter habitat for 200 species of birds, 40 species of mammal and 30 species of reptiles and amphibians (HMG/IUCN 1998).

The advent of the concept of landscape ecology (Forman and Gordon 1986) has changed the way that managers, ecologists and conservation biologists think about the conservation of biodiversity. It introduced the idea of protecting whole landscapes rather than protecting species or single ecosystems. It has been realized that protecting biodiversity inside reserves is not a panacea, and it is necessary to extend conservation efforts outside protected areas. Connectivity of historically contiguous landscapes should be maintained to provide more habitats for wildlife outside reserves.

To address the issue of protecting ecosystems and habitats outside reserves, the Government of Nepal has embarked on a landscape level approach to conservation and endorsed the Terai Arc Landscape program (TAL) in April 2001 (HMGN 2004). TAL is the outcome of the government's initiative, with support from World Wildlife Fund, to connect four lowland protected areas of Nepal with forests outside protected areas that act as movement corridors for the larger mammals such as tigers, elephants and rhinos. The broader vision of TAL is to manage larger areas through participatory landscape planning based on the ecological, economic and social needs of the region.

TAL covers 49,500 square kilometers, encompassing 11 protected areas and forest corridors in India and Nepal, and extends from Nepal's Bagmati River in the east to India's Yamuna River in the west. The Nepalese portion of TAL is 23,199 sq km and covers 14 Terai districts. TAL is also important for its rich biodiversity. It provides habitat for fascinating megafauna such as the Royal Bengal Tiger (*Panthera tigris*), One-horned Rhinoceros (*Rhinoceros unicornis*) and Asian Elephant (*Elephas maximus*) as well as 11 species of ungulates and 550 species of birds (HMGN 2004). TAL covers 75% of the forests of the Terai and foothills of Churia. The population within TAL borders is 6.7 million, most of whom depend on forests for their livelihood. Sixty percent of the households in TAL rely on agriculture as their main source of income, 69% of households own livestock and depend on forests for fodder and 61% of households use fuelwood for cooking (HMGN 2004). The present study encompasses two districts of TAL and includes two protected areas, Royal Bardia National Park and Royal Suklaphanta Wildlife Reserve, and two community forests in between. The outcome of the present study will provide valuable ecological information regarding forest management within TAL.

1.6 Forest and environment relationship

Forests are important natural resources both ecologically and economically. They are repositories of biodiversity and provide habitat for flora and fauna. Several ecosystem services such as nutrient recharges, rainfall, prevention of landslides and soil erosion, watershed services, and more are provided by forests. They are complex ecosystems (Lal 1992) because forests contain many more species per unit area than other ecosystems; are subjected to human disturbances such as fire and grazing; go through successional changes; show geographical variability; and interact and influence other systems such as rivers, lakes, pastures and agricultural land. This complexity makes it difficult to establish cause and effect relationships and predict the results of human intervention in forested ecosystems (Lal 1992).

Plant species show a varied range of requirements of and tolerance to environmental conditions, which is evident from their abundance and distribution along environmental gradients. The establishment of a forest in an area is determined by many factors. The local and regional climate, topographic position, disturbances, environmental factors and biotic interactions determine forest structure and composition (Spurs and Barnes 1980).

The most obvious factor that limits the establishment of vegetation in an area is the amount of solar radiation, which determines the climate of an area. Since light is the main source of photosynthesis in plants, the amount of solar radiation also determines the availability of light for photosynthesis. In the temperate zone, photoperiod affects processes such as dormancy and germination of seeds, leaf fall and flowering (Champion and Seth 1968). The amount of available light also determines the amount of understory in a forest community; shade tolerant species grow under less illuminated conditions but shade intolerant species require more light. Plants of the same species growing under different light conditions show different morphology (Lal 1992). Herb species richness in stands of lower ages can be high because of the large canopy gaps and sufficient amounts of light penetrating the forest floor (Harcombe and Marks 1977).

Temperature, soil nutrients and rainfall are limiting factors for plant function (Ogutu 1991). Associations between species distribution and average rainfall suggest that the complex moisture gradients underlie vegetation distribution (Ogutu 1996). Other studies also relate floristic characters with amount of rainfall (Belsky 1987; Boutton et al. 1988). The classification of Nepalese forest into topical, subtropical, temperate, sub alpine and alpine (Stainton 1972; Chaudhary 1998) is based on temperature, moisture and rainfall. Several global vegetation mapping systems (Holdridge 1967; Prentice et al. 1993) use temperature and moisture relations as predictors of the type of vegetation that occurs in different areas. Forests are established in soils that are rich in moisture and grasslands are established in drier soils (Spur and Barnes 1998).

The variety of soil types, their structure, parent material, pH, water and moisture holding capacity and nutrient content also limits plant species richness and distribution

(Lal 1992). Many soil nutrients (e.g. carbon, nitrogen and zinc) increase from grassland to forest, suggesting the influence of soil nutrients on vegetation types (Barnes et al. 1998). Tree species composition in La Selva, Costa Rica is significantly related to soil type and topographic variation, but both of the environmental variables explained small percentages of variation in species distribution (Clark et al. 1999). Species richness in tropical forest has been related to substrate (Richards 1961; Ashton 1971) and other factors such as chemical fertility and soil moisture (Hart et al. 1989). Low forest diversity and occurrence of few species have been attributed to low nutrient levels in some cases (Ashton 1971; Janzen 1974). Rainfall (Gentry 1982) and soil moisture (Hall and Swaine 1981) are related to an increase in diversity. Tropical rain forest structure and biomass varies with different variables such as soil type (Tuomisto et al. 1995), soil nutrients (Laurance et al. 1999), climate (Gentry 1982), disturbance regime (Lugo and Scatena 1996), successional status (Saldarriaga et al. 1988), topographic position (Austin et al. 1996), and human impacts (Laurance et al. 1997). A comparison of forest structure and composition on different soil types in La Selva Biological station in Costa Rica showed lower density and larger average tree diameter on the more nutrient rich old alluvial soils than residual soils, but there was no difference in basal area and above-ground biomass (Clark and Clark 2000).

Disturbances are also important factors that shape the structure and composition of forest communities. Different factors cause disturbances; strong winds, fire and land slides destroy vegetation, open up the canopy and remove vegetation and soil cover. Human induced disturbances include removal of biomass and intentional fires. Other forms of disturbance such as herbivory also affect the natural course of forest regeneration and growth. Maintenance of forest cover is important to prevent the loss of nutrients, because the vegetation adsorps nutrients and holds soil particles, so removal of vegetation and reduced soil fertility will affect the inter-dependence of soil and vegetation. Disturbance is interactive with moisture, only in sites with high moisture (forests and bushlands) the effect of disturbance is significant (Ogutu 1996). Vegetation disturbance, especially grazing, increases species richness in some situations, due to the greater occurrence of non-endemic species (Green and Kauffman 1995). Low intensity and sustained human disturbance through selective logging, firewood extraction, grazing and land clearing for permanent agriculture may influence plant communities and their successional patterns (Attiwill 1994; Fujisaka et al. 1998). Within forests, disturbances influence the availability of resources such as light, water and nutrients necessary for the survival and growth of seedlings (Marks 1974; Carlson and Groot 1997). Fire can alter both the structure and composition of forests, especially in the understory (Rodgers et al. 1986). In both Corbett and Dudwa National Parks (India), adjacent communities of very different understory structure have arisen due to differential fire frequency (Rodgers et al. 1986). The influences of past human disturbances on forests and ecological processes have been observed even after fifty years (Xiaoming et al. 1995).

1.7 Forests in the Western Terai

The Western Terai is located in the subtropical zone of Nepal. Forest types that occur there are: Sal Forest, Tropical Deciduous Forest and Tropical Evergreen Forest (Staintion 1972). Some workers have also classified Sal Forest as moist deciduous forest (Dinerstein 1979). Tropical Deciduous Forest occurs in a variety of climatic conditions, but alternating wet and dry periods favor their establishment. Various factors such as the length of the wet period, total rainfall, latitude, longitude and altitude affect the structure and composition of deciduous forests (Shankar 2001). More than half of the Terai in Nepal is dominated by *Shorea robusta* (locally known as Sal; Webb and Sah 2003). It is a light demanding large deciduous tree growing up to 45 m in height on a wide range of soil types (Rautiainen and Suoheimo 1997). It belongs to the Dipterocarpaceae family, which is found in tropical and sub-tropical Asia. In Sal, leaves fall for a very short period of time before the emergence of new foliage, resembling a deciduous species (Pande and Shukla 2001). The Sal forest develops in well drained soil and is regarded as a climax community (Dinerstein 1979, Banerjee et al 1992). This forest is not inundated during the monsoon period, and the ground water table is very low (Bolton 1976).

In Nepal, Sal is considered to be the most valuable tree species and is used in construction and carpentry work, and is also the main source of fuelwood in the lowland areas. Sal leaves are valuable as fodder and for making disposable plates by local people (Jackson 1994). Most of the rural communities in Nepal, which constitute 80% of the total population of the country (World Resource Institute 1996), depend on Sal Forest for subsistence needs. Before 1950s, the vast tract of *Shorea robusta* forests of the Terai remained unutilized. The Forest condition changed after people started migrating into the fertile Terai because of the eradication of malaria, establishment of resettlement offices in the districts, construction of the East-West Highway and political disturbances in the mountains (HMGN1996; HMGN 1998). The districts of Western Nepal (Bardia, Kailali and Kanchanpur) are major recent migration districts. Almost all of the 545,900 ha of forests outside protected areas in the Terai and Siwalik region have been converted into secondary forests because of intensive use by both the government and local people

(Kanel and Shrestha 2001). These forests are declining at a fast rate with negative consequences on surrounding temperatures, land stability, soil and biodiversity, and on the livelihood of local people who are directly dependent on them (Zomer et al. 2001). Local people collect fodder, firewood, poles, timber and wild vegetables (ferns, mushrooms, medicinal plants. etc) from these forests. In addition to primary forests, conservation and management of these secondary forests is essential to provide most of the resources for local livelihoods and protect biodiversity.

It is essential to understand the composition, functioning and dynamics of the system to identify the major determinants of forest health within human dominated environments and to manage these resources for the future. The present study examines the structure and composition of Sal Forests in the western Terai of Nepal to provide valuable ecological information on the forests that exists under variable degree of human disturbance.

Various biotic and abiotic factors have been recognized that contribute to plant succession in the region. Abiotic factors include the length of the monsoon, total rainfall, seasonal flooding, and soil conditions, whereas biotic factors are previous land-use practices such as grazing of domestic stock, burning, clearing for cultivation, selective cutting of trees, logging, lopping for fodder and thatch grass cutting (Dinerstein 1979). The study also analyzes the relationship between plant communities with the abiotic environment to identify the major environmental conditions influencing forests.

The main objective of TAL is to conserve biodiversity in protected areas and outside forests and to link protected areas with corridors; for this to be successful, ecological integrity of forests outside protected areas must be taken into consideration.

The study compares between protected forests and community forests outside protected areas so that information on the ecological health of community forests, which have been under more severe human pressures, can be incorporated in planning efforts.

1.8 Objectives of the study

The goal of the present study is to provide more ecological information about forest for management of areas under the TAL program. The broad objectives of the study are:

1) To study the structure, composition and dynamics of Sal Forest in the western Terai of Nepal
2) To understand the relationships between forest communities and environmental conditions
3) To determine the ecological differences between community forests and forests inside protected areas.

To address these objectives, I posed several questions 1) What is the structure and composition of the forests sampled? 2) What are the different associations found within these forest types? 3) What are the structural and compositional differences between different associations? 4) What explains the variation between the associations identified? 5) How are the different structural variables such as tree size and density, tree abundance and seedling density and percent cover of different layers related to each other? and, 6) What are the differences in structure and composition of protected forests and community forests?

2. **THE STUDY AREA**

The study area is located in the south-western part of Nepal in Bardia and Kanchanpur Districts. Bardia District lies in the Midwestern Development Region and Kanchanpur in the Far Western Development Region of Nepal. This study was carried out in Royal Bardia National Park (RBNP) in Bardia District, and Royal Suklaphanta Wildlife Reserve (RSWR) and Birendra and Mayur Jagdamba Community Forests in Kanchanpur District (Figure 2). Although these community forests have been officially demarcated and user groups defined for the last two years, they have not been formally handed over to communities for management. The elevation of the study area ranges from 150m to 220 m. The study area is composed of alluvial flat land, commonly referred as Terai.

Bardia district lies between 28^{o} 36' - 28^{o} 50' N and 81^{o} 30'- 81^{o} 45' E. The district lies in western Nepal and is bordered by Banke District in the east and Kailali district in the west. The district is 64 km long and 63 km wide. According to the Operational Forest Management Plan of the district, out of 201,677 ha total area, RBNP covers the majority of the area (87,936 ha). Agricultural land and settlements cover 33.7% (68,075 ha) of total area (Table 1).

The district can be divided into Terai and Siwalik. The Terai extends towards the southern portion of the district. The Terai is composed of flat and highly fertile alluvium deposits. The northern portion of the district is the Siwalik Range, which extends from east to west and is fragile and undulating. The elevation of the district ranges from 150 m in the south to 1457 m in the north.

The geological formation of the district is alluvium in the south which is similar to the Gangetic Plain of India. The northern part of the district is similar to tertiary Siwaliks. The Siwaliks are composed of coarsely bedded stone, crystalline rocks, clays and conglomerates (HMGN 1996). The rocks of the Siwalik are fragile and composed of sandstones. The disintegration of these sandstones forms sandy soils in the region. The foothills of the Churia or Siwaliks are known as Bhabar. They are comparatively dry, consisting mainly of boulders, cobbles and coarse sand layers. The Bhabar soils are relatively well drained and deep. The Terai or the southern extension of Bhabar is composed mainly of alluvium soils. The soil type is mainly sandy loam (FSRO 1971) throughout the district with some local variation. Soil depth is great in flat lands and shallow in the hills.

The climate of the district is sub tropical monsoonal in the Terai and Siwaliks. Four distinct seasons occur: winter, spring, summer and rainy. The mean minimum temperature varies between 10^{o} C (January) to 26^{o} C (June). The mean maximum temperature ranges from 20^{o} C (January) to 37^{o} C (May). Rainfall recorded in the Chisapani Station from 1987 to 2001 shows that mean monthly rainfall varies from 23 mm (March) to 635 mm (July). The mean total annual rainfall recorded from 1987 to 2001 was 2100 mm. Most rain occurs between the months of June and September followed by 7 to 8 months of dry season (Figure 1a and Figure 1b).

2.1 Royal Bardia National Park

This study was carried out in the southwestern section of Royal Bardia National Park (81^{o} 20’ E and 28^{o} 35’ N; Figure 2). The park is 968 sq km not including the proposed extension area and is the largest park in the Terai. It started as a Royal Hunting

Reserve in 1969 and later in 1976 was declared Royal Karnali Wildlife Reserve (386 sq km; HMG 2001). In 1984 the area was extended to the east to include a total area of 968 sq km. It was officially designated as Royal Bardia National Park (RBNP) in 1988. The park consists of Bhabar, Terai and Riverine Flood Plains. Most of the park lies in the Bhabar zone which contains rocks, boulders and sand interbedded with clay and silt driven down from Churia hills. Soils in this zone are young and shallow and are very prone to erosion. The alluvial soils deposited by the rivers like Orai, Karnali and Babai are deep.

The vegetation of the park is early successional floodplain grassland in alluvial floodplains to climax Sal community in the relatively dry flat lands. Dinerstein (1979) classified the vegetation of the park into six major types and later modified by Jnawali and Wegge (1993) into seven types. The major vegetation types are Sal Forest, Khair-sissoo Forest, Moist Riverine Forest, Mixed Hardwood Forest, Wooded Grasslands, Phantas and Tall Alluvial Floodplain Grassland.

Sal Forests are found in relatively well drained upland areas and the major species is *Shorea robusta* with other associated species such as *Buchanania latifolia*, *Terminalia sps* and *Lagerstroemia parviflora*. Khair-sissoo Forests are established on old floodplains and consists of *Dalbergia sissoo* and *Acacia catechu* as dominant tree species. Along the water courses are Moist Riverine Forests with tree species such as *Syzygium cumini*, *Mallotus phillippnensis* and *Ficus glomerata. Adina cordifolia*, *Casearia tomentosa, Lagerstroemia parviflora* and *Mitragyna parviflora* are common species of Mixed Harwood Forest that grows in well drained areas. It resembles *Bombax* savannah (Wooded grasslands) due to similarity in composition of the trees and the understory, but consists enough tree density and conspicuous shrub layer to qualify as forest (Dinerstein 1979). Wooded grasslands are similar to Savannah and contain grasses with interspersed trees. Trees such as *Bomabx ceiba, Adina cordifolia* and *Mallotus phillippensis* are scattered amongst grasses such as *Saccharum spontaneum, Imperata cylindrica, Desmostachia bipinnata and Vetiveria zizanoides.* Previously cultivated lands where grasses established after the resettlement of villages and farms have been identified as Phantas. They are dominated by grasses such as *Imperata cylindrica, Saccharum spontaneum and Narenga porphyrocoma*. On the river beds are found Tall Alluvial Floodplain grasslands which are dominated by *Saccharum spontaneum, Saccharum bengalensis, Phragmites karka and Arundo donax*.

The park is home to many endangered species of flora and fauna. There are 53 species of mammals including five species of deer, approximately 400 species of birds, 25 species of reptiles and amphibians and 121 species of fishes (Basnet 1995). The Royal Bengal Tiger (*Panthera tigris*), One-horned Rhinoceros (*Rhinoceros unicornis*) and Asian Elephant (*Elephus maximus*) are also found in Bardia. Endangered avifauna such as Bengal Florican (*Houbaropsis bengalensis*; Baral et al. 2002) and Giant Hornbill (HMGN 2001) are present.

2.2 Kanchanpur District

Kanchanpur District is located between 80^{o} 3' – 80^{o} 33' E longitude and 28^{o} 32'-29^{o} 8' N latitude. The district borders Kailali District in the east and India in the west and south. It lies in the Mahakali zone of the Farwestern Development Region. The total geographical area covered by the district is 163, 678 ha. Of the total area, forests cover 88,200 ha (53 %) and agriculture, urban areas and other land use types cover 74,478 ha

(46.1% ; FSD/FORESC 1993). The topography of the district is similar to Bardia as described above. Most of the district lies in the Terai region and the northern part is covered by Siwaliks and Bhabar. The elevation ranges from 169m in the south to 1528 m in the north.

The climate of the region is subtropical monsoonal with four distinct seasons: winter, spring, summer and rainy. Winters are cold and summers are very hot. The mean maximum temperature varies from 21^{o} C (January) to 37^{o} C (May) and the mean min temperatures ranges from 7^{o} C (January) to 25^{o} C (July). The mean total annual rainfall for the period of 1987 to 2001 was 1579 mm, about 75% of the annual precipitation falling at Bardia (RBNP). The lowest amount of mean monthly rainfall recorded was 3 mm in March and the highest was 636 mm in August. Most of the rainfall occurs in the four months from June to September. The climatic data from 1987 to 2001 are shown in Figure 1a and Figure 1b.

2.3 Royal Suklaphanta Wildlife Reserve

RSWR lies in Far Western Nepal in Kanchanpur District and covers an area of 305 sq km (Figure 2). In 1969 it was declared as Royal Hunting Reserve and it was officially gazetted as Royal Suklaphanta Wildlife Reserve in 1973. The reserve lies between 28^{o} 45'- 28^{o} 57' N to 80^{o} 07' to 80^{o} 21' E and is bordered by the Chaudhar river on the east and by forests and cultivated fields on the north. It has a common boundary with the Indian State of Uttar Pradesh on the south and borders the Mahakali River on the west. The Reserve has a similar climate, topography and soil as described for Kanchanpur District above. It consists mostly of Terai and some areas lie in the Bhabar zone. The elevation varies from 162 m to 237 m. A number of rivers such as the Mahakali, Bauni, Chaudhara and Syauli drain the reserve.

Vegetation types that are found in RSWR are forests, grasslands and wetlands. Sal Forest is the dominant forest type in the Reserve, and is found in well drained upland areas. Species such as *Shorea robusta, Terminalia tomentosa, Lagerstroemia parviflora* and *Mallotus philippensis* are found. The other forest types present within the reserve are: *Acacia catechu-Dalbergia sissoo* forest in floodplains and *Bombax ceiba, Holarrhena pubescens* and *Grewia disperma* in the interior; Mixed Deciduous Forests are present in the poorly drained soils and species such as *Adina cordifolia, Trewia nudiflora, Syzygium cumini* and *Celtis tetrandra* are found. The reserve is famous for its large tracts of grasslands, locally known as *Phanta*. The name Suklaphanta was derived from one of the grasslands found inside the reserve. The major phantas are Sukla, Haraiya, Barkaula, Singhpur etc. *Imperata cylindrica, Vetiveria zizanoides* and *Saccharum spontaneum* are the major species found in the grasslands. Wetlands such as Rani Tal and Sikari Tal are present and dense grasses such as *Phrgamites karka* and *Saccharum spontaneum* predominate.

A total of 267 species of birds has been recorded in the reserve (Inskipp 1989). The reserve is important for endangered birds such as Swamp Francolin (*Francolinus gularis)* and Bengal Forican (*Houbaropsis bengalensis)*. This reserve is the last stronghold of the endangered Swamp deer (*Cervus duvauceli*) in Nepal. An estimated population of about 3000 individuals lives in the reserve (Chaudhary 1998). It is home to endangered megafauna such as tiger, one-horned rhinoceros and Asian elephants.

2.4 Community Forests

The community forests sampled were located in Bank area of Kanchanpur district. Two community forests were studied, namely Birendra and Mayur Jagdamba. Both of the community forests lie north of east-west highway between 28^o 52' 12'' to 28^o 52' 54" N latitude and 80^o 24' 55" to 80^o 25' 32" E longitude. The Banda River runs along the eastern side of the forests. The forest type was Sal Forest dominated *Shorea robusta* and *Terminalia tomentosa*. The area was heavily used by locals for grazing, fuelwood and fodder. Although logging and cutting of trees was legally not allowed, locals reported that there are instances of illegal logging. There were cut stumps and dead trees. Several species of birds and a hare were observed during the field survey. I did not find any tracts of nor did I observe any large mammals during the survey.

3. METHODS

3.1 Forest Sampling

The forests of the study area were sampled between February and April 2005. Woody vegetation was sampled at three levels; trees (> 5 cm dbh), saplings (1-5 cm dbh and > 1m height) and seedlings (<1m height). Shrubs and herbs of the area were also sampled. Three sites were selected for the study; two sites were inside protected areas and the third site included the two community forests. Sites were chosen to encompass forests under different management regimes. Altogether 7 transects were laid in the study areas. Three transects were in Royal Bardia National Park (RBNP) in Bardia District, and three were in Royal Suklaphanta Wildlife Reserve (RSWR) in Kanchanpur district. A single transect encompassed the two community forests (Birendra and Mayur-Jagadamba Community Forest) in Kanchanpur District. The two protected areas were approximately 150 km apart and the community forests were more than 10 km east of RSWR and more than 130 km west of RBNP. The study areas were at a similar elevation and extended from east to west. Sampling locations were established every 200 m within each 2 km transect. Starting points of transects were selected randomly, within the fire line for National Parks and along the east-west highway for community forests determined from a topographic map of the study area. Altogether 30 locations were sampled in RBNP, 30 in RSWR and 10 in the community forests. The continuing Maoist insurgency in Nepal posed security problems and made it difficult to collect enough samples from community forests.

For sampling trees, a plotless technique or variable plot cruising (Grosenbaugh 1952) was used. This technique is more efficient and useful than fixed plots for one-time estimation of forest structure in areas where there are a few large trees and numerous small trees (Zhang et al. 2005). With the sampling point as center, all trees around were observed through a prism of known dioptre. A tree was counted "In" if its diameter at breast height was large enough to subtend the fixed critical angle of the prism, or "Out" if it was not. Each "In" tree was identified to species and diameter at breast height (dbh; 1.3m above the ground) was measured. The height of the three tallest trees was also measured with a clinometer. Using the diameter of "In" trees basal area and density were estimated for each sampling point. Each "In" tree represents a fixed basal area equal to the Basal Area Factor (BAF) associated with the prism. Density was calculated by dividing BAF by the basal area of the tree. The basal area and density associated with each tree was summed to estimate the basal area and density of each sampling point, then later converted into basal area and density per ha.

For saplings and shrubs (> 1m and < 0.5 cm dbh), a five meter radius circular plot was established with the tree sampling point as the center. Within each plot, saplings and shrubs were identified to species and the number of individuals of each species was counted. Two 1 sq m circular plots nested within sapling and shrub plots were used for sampling herbs and seedlings. Herbs and seedlings were also identified to species and their numbers within each plot were estimated. Specimens were collected for unidentified species, which were later identified in the Central Department of Botany, Tribuvan University, Kathmandu and The National Herbarium and Plant Laboratory, Godavari. Nomenclature follows Hara and Williams (1979), Hara et al. (1978, 1982) and Press et al. (2000).

Fixing tree sampling point as the center, percentage canopy closure was estimated. Canopy closure percentages were estimated in all the four directions with the help of a densiometer and the average of the four values was used to calculate the final percent closure. Ocular estimation of undertstory and ground cover was done using a modified Braun Blanquet system (< 1%, 1-4%, 4-16%, 16-33%, 33-66% and >66%).

3.2 Soil sampling and analysis

Soil samples (0-15 cm depth) were collected from each plots. The composite sample used for the analysis was a mixture of samples collected from four directions. Samples were collected in polyvinyl bags and were analyzed at the laboratory of Department of Agriculture, Lalitpur, Nepal for pH, texture, organic matter (%), total nitrogen (%), available phosphorous (kilogram/hectare) and available potassium (kilogram/hectare). For the determination of pH, mixtures (1:1) of air dried soil samples and distilled water were measured with a pH meter.

Organic matter content was determined by Walkley and Black's method following Bray (1945). For the process, a mixture of 10 ml potassium dichromate (1N), 20 ml concentrated sulfuric acid and 1 gm of 0.2 mm sieved soil samples were titrated with 0.5 N ferrous ammonium sulphate. Total nitrogen was estimated by micro-Kjeldahl method (Jackson 1958). The procedure used was auto digestion and auto distillation, and titration with 0.01 N hydrochloric acid. Available phosphorous was estimated following Olsen's method and the extraction solution used was 0.5 N sodium bicarbonate at pH 8.5 (Hesse 1994). For available potassium the soil was extracted with 1 N ammonium acetate at pH 7.0 and potassium was determined by flame photometer method. Soil texture was determined by soil a expert in the Department of Agriculture by feeling the samples between his fingers.

3.3 Data Analysis

Density and basal area per ha were calculated for all tree species. Relative values for frequency, density and dominance of trees was calculated by dividing individual values for frequency, density and basal area by sum of frequencies, densities and basal areas of all species. All relative values were multiplied by 100 to express them as percentages. The Importance value index (IVI) was calculated for all the tree species by summing the relative frequency, relative density and relative dominance values of individual species. For the analysis of population structure, individuals were classified into following dbh classes; 5-10 cm, 10-15 cm, 15-20cm, 20-25cm, 25-30 cm, 30-35 cm and > 40 cm. For some species, population distribution in two dbh classes, 50-80cm and > 80 cm, was also calculated. Densities of saplings, shrubs, seedlings and herbs per plot and per ha were estimated.

Following the method described in PC-ORD statistical package (McCune and Mefford 1999), species richness, eveness and Shannon's diversity index (H') were calculated for each plot. These values were calculated separately for different life forms; trees, saplings, shrubs, seedlings and herbs. Numbers of species per plot was taken as a measure of species richness. The Shannon diversity index (Shannon and Weaver 1949) was calculated by the following formula:

$$H' = - \sum p_i \ln p_i$$

where p_i represents the proportional abundance of ith species in the community.

Pielou's J (Pielou 1966, 1969) was used as an index of evenness, which is expressed as:

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

where H' is Shannon's diversity measure and S is the species richness.

Hierarchical agglomerative cluster analysis (McCune and Grace 2002) was used to define grouping among the 70 plots sampled. Cluster analysis was performed using the importance value of tree species. The agglomerative clustering method builds hierarchically from bottom to top. It calculates a distance between any pair of entities and merges groups with some criteria of minimum distance. Results of a cluster analysis are presented in a dendrogram. The Wishart objective function in a dendrogram indicates the amount of information lost during merging of each group. It is the sum of the error sum of squares from the mean of variables in a cluster to the individual observations of variables in that cluster. For the process, Sorensen (Bray- Curtis) dissimilarity was used as the distance measure and flexible beta was used to calculate relatedness among the groups (McCune and Grace 2000). Species occurring in less than 5% of the samples and two outliers were deleted. The remaining 68 plots and 18 species were used for the analysis. Groups were selected from the dendrogram using information provided by the Wishart objective function with approximately 40% of the information remaining after the merging of groups.

I analyzed the interrelationships between plant communities by ordinating sample plots in species space using non-metric multidimensional scaling (NMS). The advantages of NMS over other ordination techniques are: 1) it is not based on the assumption of multivariate normality and, 2) it is robust to large numbers of zero values (Minchin 1987). The same data set used for cluster analysis with 68 plots and 18 species was used for ordination. Among the 29 species recorded, species present in less than 5% of the plots were deleted. Following this criterion, 18 species were used for the ordination. I tried to explain relationships between plant communities and environmental variables by overlaying and contouring environmental variables on the NMS ordination of plots. Correlations between the ordination and environmental variables were calculated with Pearson's r (Peterson and McCune 2001). PC-ORD statistical package was used for the cluster analysis and ordination.

One way analysis of variance was used to test the difference in environmental variables between the groups if the data were normal. Normality was tested by plotting histograms and with the Shapiro-Wilk test (Shapiro 1980). If the data were not normal and the assumption of equal variance was violated, I used the Kruskal-Wallis test statistic, a non-parametric anova equivalent (Sokal and Rohlf 1995) to determine if the values of environmental variables between the groups differed. I used Kruskal-Wallis to test the difference among groups, identified by cluster analysis, in parameters related to trees, saplings, shrubs, seedlings and ground layer. For the multiple comparisons I used one-tailed Mann-Whitney U test (Nagendra 2002) with the alpha level fixed by dividing 0.05 by number of groups compared. Most of the techniques I used in the analysis are non- parametric except few parametric ANOVAs and two sample t tests. Non-parametric methods are well suited to data that are non-normal, are on discontinuous scale and contain a large proportion of zero values (Peterson and McCune 2001). Variables tested among the groups are sapling density, richness and diversity; shrub density, richness and diversity; seedling density; canopy closure, and understory and ground cover percentages; and herb diversity and richness. I used Spearman's rank correlation to test the association between different cover percentages. Data on forests inside the two protected areas were pooled together and compared with pooled data from community forests. For comparative purposes, I used two sample t-tests in the case of normal data, and for the non-normal data, I used Mann-Whitney U test.

To understand the stand dynamics, I tested three different kinds of relations:

1) Average tree size and total tree density relationship 2) tree structure (maturity and stocking %) with seedling density 3) and species abundance in tree layer and seedling density.

To test the first relationship, I calculated the stand density index (SDI; Reineke 1933) for all the stands. Reineke (1933) discovered that the most important factor determining stand density is the average stand diameter (ASD- diameter at breast height of a tree with average basal area). He found a straight line relationship with a slope of -1.6 between log transformed values of tree density and ASD. Based on this, he proposed a stand density index (SDI) which provided information on maxiumum tree density at full stocking of stands in any stages of development having any ASD. He revealed that the number of trees per acre of any pure, even-aged and fully-stocked stand having a certain average stand diameter is approximately equal to the number of trees per acre of another pure, even aged and fully stocked stand of the same species having the same average stand diameter. SDI (stand density index) values provide the full stocking of stands of certain ASD and are useful to compare stands with different ASD values. Reineke's SDI is also more useful in comparing of the stocking among uneven-aged stands than is basal area (Stage 1968 cited in Daniel et al. 1979). For the present study the metric equivalent of Reineke's index provided by Daniel et al. (1979) was used for calculating SDI.

The second relationship was tested by plotting ASD (maturity) and SDI (stocking %) values of each plot against its seedling density. To test the third relation, I used a scatterplot of *Shorea robusta* tree relative density and its seedling relative density for each plot. Relative density was calculated as a percentage of maximum observed for the species in all transects.

4. RESULTS

4.1 Average forest structure and composition

Altogether 121 species were recorded: 28 species of trees, 10 species of shrubs, 6 species of climbers and 87 species of herbs. The forests sampled in this study were Sal Forests, the canopy layer was dominated by *Shorea robusta* and *Terminalia tomentosa*. Occassionally *Adina cordifolia* and *Terminalia bellirica* were present in the canopy layer. The sub canopy was dominated by *Buchanania latifolia*, *Dillenia Pentagyna*, *Cleistocalyx operculatus* and *Lagerstroemia parviflora*. The understory was quite sparse and dominated by *Shorea robusta* saplings and shrubs such as *Flemingia strobilifera, Clerodendrum viscosum* and *Indigofera pulchella*. The mean density across all plots was

220 trees per ha. The highest density was recorded for *Shorea robusta* (64 stems ha^{-1}), followed by *Buchanania latifolia* (50 stems ha^{-1}), *Cleistocalyx operculatus* (25 stems ha^{-1}), *Lagerstroemia parviflora* (22 stems ha^{-1}), *Terminalia tomentosa* (16 stems ha^{-1}) and *Dillenia pentagyna* (11 stems ha^{-1}). The density distribution of the most common tree species among different dbh classes for the seven transects is presented in Figure 3.

Shorea robusta was present in all dbh classes but was in higher density in the lower 5- 10 cm dbh class and above 30 cm dbh classes. The highest density was in > 40 cm dbh class. *Terminalia tomentosa* was completely absent from the lowest dbh class, but was present in other dbh classes in low density. The most abundant species in 5-10 cm dbh class was *Buchanania latifolia* (47%) followed by *Lagerstroemia parviflora* and *Cleistocalyx operculatus*. The largest dbh class was represented by *Shorea robusta* and *Terminalia tomentosa* and very rarely by other species. Species such as *Buchanania latifolia, Cleistocalyx operculatus, Lagerstroemia parviflora* and *Dillenia pentagyna* were more abundant in less than 30 cm dbh class and rare in classes above 30 cm. I also classified trees into 5 cm -25 cm, 25 cm -50 cm, 50cm-80 cm and > 80 cm classes. *S. robusta* and *T. tomentosa* were present in > 50 cm diameter classes. Density of *S. robusta* in the 50- 80 cm dbh class was 14 trees/ha and *T. tomentosa* was 3 trees/ha. *S. robusta* was 2 trees/ha and *T. tomentosa* was 0.5 tree/ha in above 80 cm dbh class. Other tree species that were present in the dbh class >50 cm were *Adina cordifolia*, *Terminalia bellirica* and *Syzygium cumini*. All the other tree species had < 50 cm dbh.

The average total basal area across all plots was 13.2 sq m/ha, the minimum was 3.4 sq m/ha (RSWR) and the maximum was 22 sq m/ha (Community Forest). The highest basal area was for *Shorea robusta* (9 sq m/ha) followed by *Terminalia tomentosa*

(2 sq m/ha) and other species covered less than 1 sq m/ ha. Tree height was measured for the three tallest trees in each plot. The minimum tree height for the tallest trees was 20.7 m and the maximum was 42 m, with a mean tree height of 28.5 m. More than 80 % of the tallest trees were *S. robusta* and *T. tomentosa*. Other trees that were present in the tallest category were *Adina cordifolia*, *Terminalia bellirica*, and *Syzygium cumini*. There were altogether 3.6 tree species per plot and the Shannon Diversity Index (H') was 0. 82 for the trees.

4.2 Classification

The hierarchical agglomerative cluster analysis separated three groups (Figure 4) among the seventy plots that were sampled. The three groups or associations were identified based on the presence or absence and importance values of different species in each group. There were 18 plots in Group 1, 13 plots in Group 2 and 37 plots were in Group 3. All but three plots in Group 1 were from RBNP. Similarly in Group 2, all but three plots were from RBNP. Of 37 plots in Group 3, 6 plots were from RBNP and all others were from RSWR or Birendra and Mayur Jagdamba Community Forests of Kanchanpur district. Table 2 presents the importance value of the different species for the three groups.

***Shorea robusta-Buchanania latifolia* association**

Group 1 was defined by the *Shorea robusta–Buchanania latifolia* association based on the importance value (Table 2) of the two species. Other species abundant in this group based on their importance values were *Dillenia pentagyna, Terminalia tomentosa* and *Semecarpus anacardium*. Twenty-one species of trees were present in this association. Ten species were abundant and the remaining 11 species had frequencies less than 11%. *Engelhardtia spicata, Ficus benghalensis, Holarrhena pubescens*, and *Acacia catechu* were present exclusively in this association. The minimum density for this association was 21 trees/ha and the maximum was 308 trees/ha with the mean density of 289 trees/ha. *B. latifolia* (111 trees/ha) had the highest density, followed by *S. robusta* (33 trees/ha), *L. parviflora* (31 trees/ha) and *C. operculatus* (30 trees/ha). Other species such as *Schleichera oleosa, Adina cordifolia, Syzygium cumini, Terminalia bellirica* and *Careya arborea* were less than 2 trees/ha. The minimum basal area for this community was 5.7 sqm/ha and the maximum was 18.3 sqm/ha with the mean basal area of 12.8 sqm/ha (Table 4). *S. robusta* was the dominant species with the basal area 6.2 sqm/ha, other species had basal area less than 2 sqm/ha. The basal area for S. robusta varied between 2.2 sq.m/ha to 11.4 sq.m/ha (for details see Appendix 1 and Appendix 2).

For Group 1, the smallest diameter class was represented by *Buchanania latifolia* and *Lagerstroemia parviflora* (Figure 5). *Shorea robusta* was present in both smaller (very few in number) and larger diameter classes but was most abundant in the largest diameter class. *Terminalia tomentosa* was present in the larger diameter class (above 20 cm) and the highest density was in > 40 cm dbh class. *Dillenia pentagyna* was most abundant in the diameter class 15-20 cm. The density of *Cleistocalyx operculatus* was highest in the diameter class 10-15 cm. As is common in many forests, density distribution was skewed towards the left.

***Terminalia tomentosa-Shorea robusta* association**

Group 2 was *Terminalia tomentosa-Shorea robusta* association which was explained by the higher importance value (Table 2) of *Terminalia tomentosa* followed by *Shorea robusta*. Other species abundant in the group were *Buchanania latifolia*, *Mallotus philippensis*, *Myrsine semiserrata*, *Dillenia pentagyna* and *Lagerstroemia parviflora*. *Anogeissus latifolius* which was present in the first group was absent in this group. Nineteen species of trees were present in this community. Seven species were abundant and the rest had frequencies of less than 15%. Species such as *Picrasama javanica, Desmodium oojeinense* and Paruli (local name) were present exclusively in this community. The mean density of trees was 297/ha with density varying between 13 trees/ha to 938 trees/ha. *B. latifolia* (96 trees/ha) had the highest density followed by *T. tomentosa* (46 trees/ha), *M. semiserrata* (46 trees/ha), *L. parviflora* (42 trees/ha) and *S. robusta* (25 trees/ha). *Adina cordifolia* (0.23/ha) had the lowest density in this community. The mean basal area was 13.5 sq m/ha with the basal area ranging from 6.8 sq m/ha to 18.3 sq m/ha. *S. robusta* and *T. tomentosa* were the dominant species in terms of basal area, representing 5.1 sq m/ha and 4.5 sq m/ha respectively. Other species comprised less than 1 sq m/ha basal area. The basal area for *S. robusta* varied between 2.2 sq m/ha to 8 sq m/ha and for *T. tomentosa*, between 2.2 sq m/ha to 6.8 sq m/ha (Table 3).

The smallest diameter class in Group 2 was represented by *Buchanania latifolia*, *Myrsine semiserrata* and *Lagerstroemia parviflora* (Figure 6). The density of *Terminalia tomentosa* was higher in 10-15 cm than in the largest diameter class. *T. tomentosa* was evenly distributed in the dbh classes > 10 cm. The largest diameter class was represented by *Shorea robusta*, *Dillenia Pentagyna* and *Terminalia tomentosa*. Tree density was higher either in smaller diameter classes or in the largest diameter class. *S. robusta* was completely absent from < 20 cm dbh classes and was present in 20- 25 dbh class and in larger dbh classes.

***Shorea robusta-Cleistocalyx operculatus* association**

The third group was identified by the *Shorea robusta-Cleistocalyx operculatus (Eugenia operculata)* association. *Shorea robusta* was highly dominant in this group as shown by its importance value (Table 2). Other species that were abundant are *Mallotus philippensis, Lagerstroemia parviflora, Buchanania latifolia, Dillenia pentagyna, Terminalia tomentosa*. *Semecarpus anacardium*, which was present in the other two groups, was completely absent from this group. Altogether 18 species of trees were recorded in this community. Four species were abundant and the remaining 14 species had frequencies of less than 9%. Jingar (local name) was present exclusively in this community. The mean density of trees was 163 trees/ha with densities ranging from 13 trees/ha to 567 tress/ha. *S. robusta* (94 trees/ha) had the highest density of trees followed by *C. operculatus* (31 trees/ha). Other species had densities of less than 6 trees/ha. The mean basal area was 13.7 sq.m/ha with a range between 3.4 sq.m/ha to 20.6 sq.m/ha (Table 4). *S. robusta* was the dominant species with the basal area ranging from 2.2 sq.m/ha to 19.5 sq.m/ha (Table 3). All the other species had basal areas less than 1 sq.m/ha. See Appendix 1, 2 and 3 for detailed descriptions of density, basal area, frequencies and relative frequencies of tree species in different groups.

The density of *Shorea robusta* in the largest diameter class was the highest for this group compared to other two groups (Figure 7). *Shorea robusta* was present in all diameter classes but was most abundant in the smallest and largest diameter class. *Cleistocalyx operculatus* was well represented in the smallest diameter class and was found up to 35-40 cm dbh class. *T. tomentosa* was present in most of the dbh classes except the lowest and 15-20 cm dbh class.

Tree height was similar in all the three groups. A one-way ANOVA showed no significant difference in the height of the tallest trees between groups ($F = 2.10$, $p = 0.1307$).

4.3 Forest-environment relationships

Plots were ordinated using the importance value of individual species. Nonmetric Multidimensional Scaling (NMS) was used for the ordination (Figure 8). Among 29 species recorded, species present in less than 5% of the plots were deleted. Following this criterion, 18 species were used for the ordination. Two outliers were deleted and minimum stress of 10.2 for two dimensional solutions was used for the final ordination. Axis 1 separated *T. tomentosa*-*S. robusta* (Group 2) association from *S. robusta*-*B. latifolia* (Group 1) association and *S. robusta*-*C. operculatus* (Group 3) association. Axis 2 separated *S. robusta*-*C. operculatus* association from *T. tomentosa*- *S. robusta* association and *S. robusta*-*B. latifolia* association. I overlaid contour plots of environmental variables on NMS site ordination to explain the variation with the environmental gradients. None of the variables tested in the study explained distribution of the groups in the ordination space (Fig 9a- Fig 9f). Pearson's correlation showed that axis 1 was significantly correlated with pH and available phosphorous, but the correlation was minimal. None of the environmental variables were correlated with Axis 2. The environmental variables measured were pH, percent organic matter, total nitrogen, available phosphorous, available potash and soil texture (Table 4).

The soil in the forest was acidic, with pH ranging from 4.8 to 7.5 and a mean pH of 5.52. The percent organic matter content of the soil varied from 0.59% to 4.08% with mean organic matter content of 2.19%. Total nitrogen varied from 0.03% to 0.2% with a mean of 0.11%. Available phosphorous (kg/ha) and available potassium (kg/ha) varied from 3.14 to 370.27 and 104.79 to 456. 51 respectively, with a mean value of 78.06 for phosphorous and 77.74 for potassium. Soil texture varied from Sandy loam to Clay. Among the 68 plots, 26% were Sandy loam, 30 % were Clay, 25% were Clay loam and rest were Loam, Sandy clay and Sandy Clay loam. Soil texture was converted to an ordinal scale, to generate contour plots, based on the percent of Sand, Silt and Clay. Sandy loam, which is the most important soil type of the Sal forest (Dinerstein 1979) was given a score of 6 and Clay soil received a score of 1. All the other soil types received scores between 6 and 1. One-way ANOVAs and Kruskal-Wallis tests were performed to see the difference in environmental variables between the groups. None of the environmental variables measured were statistically different between the groups ($P > 0.05$).

4.4 Saplings and Shrubs

Altogether saplings of 17 tree species were recorded. *Grewia sp.*, *Cassia fistula* and Kaphale (local name) were absent in the tree layer but were present as saplings. Mean sapling density was 1797 plants/ha (Table 5). Sapling species richness was 2.4 species / plot and Shannon's diversity index was 0.56 (Table 5), which indicates low richness and diversity. Mean sapling density per ha for the *Shorea robusta-Buchanania latifolia* forest (Group 1) and *Terminalia tomentosa-Shorea robusta* forest (Group 2) were close but mean sapling density for the *Shorea robusta-Cleistocalyx operculatus* (Group 3) was less than the two other groups (Table 5). A Kruskal-Wallist test showed a significant difference in sapling density between groups ($\chi^2_2 = 12.53$; $p = 0.0057$). There was no significant difference in sapling density between Groups 1 and 2, and Groups 2 and 3, but Group 1 had higher density than Group 3 ($z = 3.48$; $p = 0.0005$). Table 6 presents sapling density of different species in the three groups. A Kruskal-Wallis test showed a significant difference in *Shorea robusta* sapling density for the three groups ($\chi^2_2 = 15.983$, $p = 0.0003$). A Mann-Whitney (one tailed) pairwise analysis of difference between groups indicated that the difference in sapling density between Group 1 and Group 2 was insignificant ($z = 0.533$, $p = 0.0003$), but the difference was significantly greater in Group 1 than Group 3 ($z = 4.685$, $p = 0.000$) and, Group 2 than Group 3 ($z = 3.498$, $p=0.0005$). Sapling density of *Lagerstroemia parviflora* was not significantly different between the groups. Likewise, *Buchanania latifolia* sapling was insignificant between Group 1 and Group 2. Refer to Table 7 for detailed descriptions of the sapling density difference between groups among species that are present in all three groups. Sapling species richness was 14 for group 1, 13 for group 2 and 11 for group 3. Sapling species richness was significantly different between the groups ($F= 5.58$, $p = 0.0058$). Results of Bonferroni multiple comparison showed that the difference was not significant between Group 1 and Group 2, and Group 2 and Group 3 ($p = 0.05$), but was significantly higher in Group 1 than Group 3 ($p = 0.004$). Shannon's diversity index for sapling was not significantly different among the groups ($\chi^2_2 = 1.303$, $p = 0.5214$).

Altogether 10 species of shrubs were recorded. Average shrub density across all plots was 337 plants/ha (Table 8). Per plot species richness, Shannon's diversity index and eveness all were low (Table 8). Six species were present in Group 1, three species in Group 2 and seven species in Group 3. Shrub species diversity was low in all three groups as shown by the Shannon diversity index (Table 8). *Flemingia strobilifera* was the abundant shrub species in Group 1 and Group 2. This is considered to be an indicator shrub species of the Terai-Sal forest (Shrestha and Jha 1997). In Group 1 other shrubs such as *Phyllanthus sps* and *Indigofera pulchella* were also abundant. In Group 2, the most abundant shrub species was *Flemingia strobilifera* followed by *Indigofera pulchella* and *Flemingia chappar*. Another indicator species of Terai Sal forest, *Clerodendrum viscosum,* was present in Group 1 and Group 3 but absent from Group 2. *Clerodendrum viscosum* was the most abundant shrub species in Group 3, followed by *Flemingia strobilifera, Elsholtzia blanda, Pogostemon benghalensis* and *Indigofera pulchella*. Mean shrub density per plot for the three groups were significantly different (P = 0.05) but Shannon's index and species richness between the groups were not significantly different (Table 9).

4.5 Canopy closure and Cover percent

The mean percent overstory (Table 10) canopy closure, as measured by densiometer, was highest for Group 2 (69.92) followed by Group 1 (68.9) and Group 3 (62.57). Most of the plots belonging to Group 1 and Group 2 were from RBNP; they did not show much variation in tree canopy closure percentage, in contrast, mean percentage understory cover (ocular estimation) in Group 1 (38.17) was much higher than in Group 2 (34.77) or Group 3 (19.97). The mean percentage ground cover (ocular estimation) in Group 3 (57.17), which had lower mean canopy closure and understory cover, was highest among the three groups.

Percent canopy closure was significantly different (Table 11) between the groups. There was no difference between Group 1 and Group 2, but both the Groups had significantly higher canopy closure than Group 3. The difference between groups for both understory and ground cover was non-significant at p = 0.05 but both variables differed siginificantly at p = 0.1. Understory cover in Groups 1 and 2 were significantly higher than Group 3, but the ground cover was higher in Group 3 (Table 10).

4.6 Ground vegetation

4.6.1 Seedlings

Seedlings were recorded for 25 tree taxa, though three taxa could not be identified to species. The seedlings that were present for the important canopy and sub canopy species were *Shorea robusta, Terminalia tomentosa, Buchanania latifolia, Dillenia pentagyna, Cleistocalyx operculatus, Lagerstroemia parviflora and Mallotus philippensis.* Seedling density was 79071 per ha. The highest seedling density was found for *S. robusta* (70462/ha), *B. latifolia* (1071/ha), *M. philippensis* (1500/ha), *C. operculatus* (571/ha), *D. pentagyna* (214/ha) and *L. parviflora* (357/ha). Other less abundant species included *Picrasma javanica, Syzygium cumini, Schleichera oleosa, Careya arborea* and *Zizyphus sps*.

Seedlings of only 11 tree species were found in Group 1, with *S. robusta* having the highest density (49166/ha). Seedlings of *C. operculatus* and *D. pentagyna* were absent in Group 1, but *P. javanica* (2222/ha), *Engelhardtia spicata* (1388/ha) and *B. latifolia* (1111/ha), *M. philippensis* (555/ha), *S. oleosa* (555/ha), *Zizyphus sps* (555/ha), *T. tomentosa* (277/ha) and *L. parviflora* (277/ha) were present. In Group 2, seedlings of only 7 tree species were found. *S. robusta* (61538/ha) was the most abundant species. Seedlings were absent for *T. tomentosa*, the tree species with highest IVI in this group. *B. latifolia* (2692/ha) and *C. operculatus* (3076/ha), which were associated with *S. robusta* in Group 1 and Group 3 respectively, were abundant in the seedling category in Group 2. Besides these, *M. philippensis* (1923/ha) and *S. oleosa* (769/ha) were also present. Seedlings of 14 tree species were present in Group 3 with *S. robusta* (87432/ha) as the most dominant species in this group. The importance value of *S. robusta* in the tree category was exceedingly high for this group compared to other two groups. This was also shown in its seedling density (87432/ha), which is the highest for all the groups. *C. operculatus* (405/ha), the second most dominant tree species in this group had lower seedling density compared to *M. philippensis* (1891/ha) and *T. tomentosa* (945/ha). Out of the 25 species of seedlings recorded, Group 3 had the higher percentages of the total number of species followed by Groups 1 and 2 (Figure 10). A Kruskal-Wallis test showed that the seedling density was not significantly different between groups (χ^2_2 = 2.734, p = 0.2549). See Appendix 4b for detailed on density and presence and absence of seedlings in different groups.

The status of regeneration was determined using the following criteria (Shankar 2001): a) 'good', if seedling > sapling > trees b) 'fair', if seedling > sapling ≤ trees c) 'poor', if a species survives in only sapling stage but not as seedlings d) 'none', if a species is absent in both in sapling and seedling stages e) 'new' if a species has no adults, but only saplings or seedlings or both. Following the criteria, *S. robusta* showed good regeneration in all the three groups. *B. latifolia* showed fair regeneration in Group 1, good regeneration in Group 2 and no regeneration in group 3. *T. tomentosa* showed fair regeneration in Group 1 and Group 3, but no regeneration in Group 2. *C. operculatus* was regenerating well in Group 2 and Group 3 but not in Group 1. Six species are new to Groups 1, 2 and 3. Table 12 presents the status of regeneration of different species in the three groups.

4.6.2 Herb layer

Eighty-seven different species were found in the ground layer. Among 65 forbs (non-graminoid herbs), 18 species were distinguished to be different but could not be assigned to a genus or species because of the lack of reproductive parts at the time of sampling. Among 20 species of grasses, seven species could not be identified to the genus and species level. Two species of sedges, one orchid and one pteridophyta were identified. Species richness was 4.38 species/plot, evenness was 0.68 and Shannon's diversity index was 0.983 (Table 13).

Altogether 53 species of herbs were found in Group 1. Thirty-nine species of forbs, 14 species of grasses, 2 species of sedges, one orchid and one pteridophyta were present in Group 1. In Group 2, among 38 species of herbs found, 22 were forbs, 13 were grasses, 1 was sedge, 1 was an orchid and 1 was a pteridophyte. Sixty-five species of herbs were present in Group 3. Among them 43 species of forbs, 19 grasses, 1 sedge, 1 orchid and 1 pteridophyte were present. A Kruskal-Wallis test showed that there was no significant difference in per plot species richness between groups ($\chi^2_2 = 3.274$, $p = 0.1945$). There was also no significant difference in Shannon's Diversity index between groups ($\chi^2_2 = 1.250$, $p = 0.5353$).

Imperata cylindrica was the most abundant grass species in all three groups. *Evolvulus nummularius* and *Justicia procumbens* were the most abundant forbs in Group 1. Among graminoids, *Desmostachya bipinnata*, an unidentified grass and *Cyperus rotundus* (sedge) were also abundant. In Group 2, *Ageratum houstoniaum* was the most abundant forb followed by *E. nummularius* and *J. procumbens*. *Desmostachya bipinnata*, *Veitveria zizanoides* and Barhan (local name) were the abundant grasses after *I.*

cylindrica. In Group 3, *Evolvulus nummularius* was the most dominant forb followed by *Justicia procumbens*, *Desmodium sp.* and *Ageratum houstonianum*. An unidentified grass species was the most abundant after *I. cylindrica,* followed by *D. bipinnata*, Karonj (local name), *V. zizanoides* and *C. rotundus*. Seedlings of shrubs were treated as forbs. Altogether 20 species of shrub seedlings were present. Seedlings of *C. viscosum*, *I. pulchella*, *F. strobilifera* were present in all the three groups. *Desmodium contertum* was a new addition in seedlings in all the three groups. *Murraya koenigii* was found only in Group 2 and Group 3. Apart from *S. parviflorus*, seedlings of two other climbers were present. *Millettia fruticosa* was found only in Group 2 and *Bauhinia vahlii* only in Group 3.

4.7 Stand dynamics

To understand stand dynamics properly, one should take temporal variation of the variables into account, but one-time surveys provide information to formulate hypothesis that can be tested in the future with sufficient temporal data (Zhang et al. 2005).

During stand development (after disturbance), competition among trees and other associated vegetation for light, water and nutrients causes mortality. This mortality tends to be concentrated among smaller and slower growing individuals, and may depend on the density of seedlings and being greatest where seedling density is highest per unit area (Barnes et al. 1998). The mortality of individuals causes less competition, and remaining individuals become larger as smaller ones are continually removed from the population. This results into a predictable decrease in the density of trees as the average stand diameter (ASD) increases. This relationship was used to derive SDI, which provides stocking level of stands in any stages of development. Calculation of SDI value provides a standard measure to compare densities of stands with varying ASD. The plot of Average Stand Diameter against density of trees (stems/ha) labeled by SDI values was used to measure and compare the stocking level of stands (Figure 11). SDI ranges from 50 (Plot 46 in Group 3) to 423 (Plot 5 in Group 1). If SDI 423 is taken to represent full stocking in Sal Forests, then stocking in stand varies from 12% to 96 % of full stocking. Thirty six of the 70 plots had less than 60 % of full stocking. Among them were 7 out of 18 plots in Group 1, 6 out of 13 plots in Group 2 and 23 out of 37 plots in Group 3. Stands in Group 1 averaged 68%, Group 2 70% and Group 3 38 % of full stocking.

Seedling establishment and survival in a stand depends upon biotic interactions and environmental factors such as light, nutrients, water and space, which themselves may be affected by other community components. The competition from adults for resources, and their capacity to act as a local seed source also play an important role in seedling establishment. In places where disturbances are frequent and environment is harsh, species are known to regenerate mainly by vegetative means (Charpentier et al. 1998 cited in Pandey and Shukla 2001). I examined the relationship between tree abundance (SDI) and tree size (ASD) with seedling density. It was expected that 1) seedling density would be higher in stands of higher ASD because of the availability of mature trees for seed production, and 2) it would also be higher in stands of lower SDI because of incomplete site occupancy, which means less competition (Zhang et al. 2005). There was no statistically significant relation between ASD value for plots and seedling density, although there was visually negative relation between seedling density and ASD values (Figure 12). The relationship between SDI value for plots and their seedling density was also non-significant. No trend was observed between SDI value for plots and their seedling density (Figure 13). It shows that seedling establishment is not dependent upon the density and presence and absence of mature trees in the area.

Since availability of trees as a seed source affects the seedling density, I also tested the relation. The relationship was tested by looking at the species abundance in tree layer and its seedling density within each plot. Since *S. robusta* was the most dominant species in the tree and the seedling category, this relationship was tested for *S. robusta* only. This was done by calculating relative density of tree and seedling relative density, which was expressed as the percentage of maximum observed for the species in all the transects (Zhang et al. 2005), within each sampling location. The two variables were plotted (Figure 12). No statistically significant relationship was observed.

I also tested canopy-understory relationship between all life forms present in the three layers by looking at the association between percentages of canopy closure, and understory and the ground cover. Spearman's rank correlation showed a negative relationship between percentage canopy closure and ground percentage cover (Spearman's rho = -0.51, $p < 0.001$), showing the importance of canopy openness for the establishment of sufficient ground vegetation. There was positive correlation between overstory cover and understory cover (Spearman's rho = 0.6, $p < 0.001$), which suggests that most of the species in the understory are shade tolerant. Ground cover is also negatively correlated with understory cover (Spearman's rho = -0.32, $p = 0.0056$) but the association was not strong as with the overstory.

4.8 Comparison between management regimes

To get a general idea about how the forests differ between management regimes, plots from protected areas (RBNP and RSWR pooled together) were compared with plots from the community forests. Although there were 60 samples from the protected areas and only ten samples from community forests, the comparison gives some indication of the differences between the forests that are protected for nearly 30 years and forests under continuous anthropogenic influences. The results derived from this study can be tested with sufficient sample sizes in the future. Because of security reasons, sufficient numbers of plots could not be sampled in the community forests.

Altogether 28 tree species and a climber (*Spatholobus parviflorus*) were present in protected areas but only 7 species of trees were present in community forests. Although comparison of species numbers based on different areas sampled should consider rarefactions, the difference in number of species found in the protected area forests and the community forests gives information on the status of community forests. Comparison of total number of tree species per plot with a Mann-Whitney U test showed that the protected area forests had significantly higher number of species per plot than the community forests ($z = 1.956$, $p = 0.05$). Tree species that were common in protected areas such as *Dillenia*, *Buchanania*, *Myrsine* and *Lagerstroemia* were completely absent in the community forests. A two sample t-test with an assumption of unequal variance indicated that the tree density in protected areas (245 trees/ha) and community forests (71 trees/ha) were significantly different ($t = 5.1574$, $p = 0.00$), but the density of a dominant canopy species, *Shorea*, was not significantly different. The density of *Terminalia* was higher in protected areas than community forests ($t = 2.60$, $p = 0.005$). A two sample t-test indicated that basal area per ha was not significantly different between protected areas and community forests ($t = 0.7689$, $p = 0.4589$).

A Mann-Whitney test showed that the sapling density for protected areas (2053 plants/ha) was significantly higher than community forests (268 plants/ha) ($z = 3.355$, $p = 0.0008$). Community forests had only three species of saplings (*Mallotus*, *Zizyphus sp*. and Kaphale) whereas saplings of 17 species were present in the protected areas. Sapling species richness per plot for the protected area forests was significantly higher than the community forests ($t = 2$, $p = 0.02$). Although density of shrubs in protected areas (374 plants/ha) was higher than community forests (128 plants/ha), the difference was not significant at alpha = 0.05. Altogether 10 different species of shrubs were present in the protected forests compared to a species in the community forests. *F. strobilifera* (181 plants/ha) was the most abundant shrub in protected areas. *C. viscosum* (128 plants/ha) was the only shrub species present in community forests and was abundant in community forests compared to protected forests (36 plants/ha).

Seedling density per ha was compared with a Mann- Whitney test of difference. The test showed that seedling density in protected areas (84000 plants/ha) was significantly higher than the community forests (49500 plants/ha) ($z = 2.50$, $p = 0.01$). Seedlings of 21 species were present in protected areas with *S. robusta* (75334 plants/ha) as the most abundant species followed by *M. philippensis* (1417 plants/ha) and *B. latifolia* (1250 plants/ha). The community forests had seedlings of five species only: *S. robusta*, *M. philippensis*, *T. tomentosa*, *Zizyphus sp*. and *H. pubescens*. The seedling density of the dominant tree species, *S. robusta*, was significantly higher in protected areas than the community forests (42500 plants/ha), but the densities of *Mallotus* and *Terminalia* were higher in community forests compared to the protected areas.

In protected areas, 79 different species were recorded in the ground layer, whereas only fifteen species were recorded in community forests. Protected areas had 61 species of forbs, 15 species of grasses, a sedge, an orchid and a fern. In community forests, 9 species of forbs, 4 species of grasses and a sedge were recorded. Density of ground vegetation was significantly greater in community forests (679500 plants/ha) than protected areas (393584 plants/ha). Forbs such as *Oldenlandia corymbosa*, *Lippia nodiflora* and *Sida sp.* and the grass *Dactyloctenium aegypticum*, were exclusively present in the community forests. *Imperata cylindrica* was the most abundant grass species in the protected areas. In the community forests, an unidentified grass was the most abundant followed by *Imperata cylindrica*. *Cyperus rotundus*, the only sedge found in the study, was present in both community forests and the protected areas.

A Mann-Whitney test was performed to see the difference in cover percentages for protected forests and community forests. The percentage canopy closure was significantly higher in protected forests (67%) than community forests (55%; $z = 2.610$, $p = 0.009$). The percentage understory cover for protected forests (32%) was significantly higher than community forests (5%; $z = 3.481$, $p = 0.0005$) and the ground cover percentage for the protected forests (56%) were also significantly higher than in the community forests (39%; $z = 2.004$, $p = 0.045$).

5. DISCUSSION

Shorea robusta (Sal) is considered climatic climax (Champion and Seth 1968). Sal is an extremely gregarious species (Champion and Seth 1968) and rarely occurs as a component of other forest types (Stainton 1972). This forest is not rich in other associated species and epiphytes and climbers are rare (Stainton 1972). The present study recorded 28 species of trees and one species of climber, and a lower overstory Shannon Wienner Diversity index compared to similar forests in India (Singh et al. 1995, Pandey and Shukla 2003).

Density of trees (220 trees/ha) was low, which also indicates the openness of the sampled forests. The openness of these forests is further demonstrated by the SDI results, which showed that 53% of plots have stocking percentages of less than 60% of full stocking. Singh et al. (1995), in their study on the woody vegetation of Corbett National Park, found density to be higher in the *S. robusta*-dominated communities and lowest in the *Anogeissus latifolia-Acacia catechu* community; density ranged from 197 to 728 trees/ha. Density of trees of *Shorea robusta* forest in RBNP was 348 stems/ha (Shrestha and Jha 1997) and the Sal Forest in Gorakhpur, India had 408 trees/ha for the trees ≥ 30 cm dbh (Pandey and Shukla 2003). The stem density of more than 80 year old pure Sal Forest in the Bhabar-Terai zone of Nepal ranged from 152 to 264 trees/ha (Rautiainen 1999), which is consistent with the findings of the present study. The present forest stands appeared to be mature forest as shown by their low density, tall canopy and presence of trees in the larger diameter classes (>50 cm).

Average basal area of 13 sq m/ha was low compared to Terai *Shorea robusta* forest (36 sq.m/ha) of RBNP (Shrestha and Jha 1997). The upper limit for the basal area (22 sq m/ha) was within the range for Corbett National Park (Singh et al. 1995), where basal area ranged from 16.0 sq.m/ha to 61.1 sq.m/ha. The lower basal area was due to the presence of a higher number of trees in the lowest dbh class. In the historical past, most of the Terai that extends between the Bhabar and the Indian border were covered with *S. robusta* as homogenous forest stands (Stainton 1972). However, due to selective logging in the past, influences of burning, overgrazing and indiscriminate cutting of firewood and building timbers, old growth *S. robusta* forests have been reduced leaving a mixed type of Sal Forests with other tree species such as *T. tomentosa* (Dinerstein 1979; Shrestha and Jha 1997). In most stands, bigger *S. robusta* trees have been felled resulting into a change in the proportion of *S. robusta* to other species. The higher density of trees in the lowest and highest dbh classes, and very few in between indicated that the forest is still recovering from past disturbances. These forests were protected after the 1970s, and trees left after selective logging in the past were found in the larger dbh classes.

Sal forest has been divided into three different types *Shorea robusta-Buchanania latifolia* forest, Dry Sal Forest and Hill Sal Forest (Dinerstein, 1979; Upreti 1994). Another Sal forest type; Terai Mixed *Shorea robusta* (Shrestha and Jha 1997) has been identified in RBNP. Among the three communities identified by the hierarchical cluster analysis, the first is similar to *Shorea robusta-Buchanania latifolia* community and the second community is similar to the Dry Sal Forest community identified by Dinerstein (1979) in the southwestern section of RBNP. The first and the second community included most of the plots from RBNP (Bardia District) and only a few plots from RSWR and community forests (Kanchanpur District) sampled. The *S. robusta-B. latifolia* (Group 1) association has been described as Dense Sal forest and the *S. robusta-T. tomentosa* association as Open Sal Forest in RBNP (Sharma 1999). The third community identified was the *S. robusta-C. operculatus* (Group 3) and included most of the plots from RSWR and community forests in Kanchanpur district. The groups were clearly separated as two groups from Bardia District comprising RBNP and a group comprising plots from Kanchanpur District which included RSWR and community forests. This shows the difference in the Sal forest of RBNP and RSWR.

Groups 1 and 2 differed little in tree density, but Group 3 had lower tree density than other two groups. All three groups had similar values for basal area per ha. Group 3 had the highest density of *S. robusta* in the largest dbh class (Figure 7) and a higher density of *S. robusta* trees. It also had greater species representation in lower dbh classes. It indicates that the pure Sal stands at present might turn to mixed forest in the future, or the survival of other species is lower. The diameter distribution of *Shorea robusta* for Group 1 and Group 2 shows fewer trees in the smaller diameter classes and higher densities in the largest diameter class indicating the characteristics of an established pioneer successional community. It is also indicative of disturbance, which may have posed recruitment problems. The presence of *S. robusta* in both the larger and smaller dbh classes in Group 3 indicates ongoing reproduction. The density of *T. tomentosa* was lowest in Group 1 and its complete absence from lower dbh classes suggests recruitment problems, whereas its presence in most of the diameter classes in Group 2 and Group 3 indicates ongoing reproduction. In all three groups *B. latifolia* had higher densities in lower dbh classes and a progressive decline in density in higher dbh classes. A "reverse J" distribution, with few trees distributed among large dbh classes and many smaller-diameter trees, suggests shade tolerance and continuous recruitment (Sugita et al. 1994). The distribution of *C. operculatus* also showed progressive decline in density from lower to higher dbh classes in both Group 1 and Group 3, but it was nearly absent in Group 2. *L. parviflora* had a similar distribution as shown by *C. operculatus*.

Comparison of SDI values among the three groups showed that all three groups had low percentage stocking, with Group 3 most understocked. This suggests that the sampled forests are recovering from past disturbances with Group 3 (Kanchanpur District) having suffered higher disturbance compared to Groups 1 and 2.

Some tree species were confined only to certain associations. Four tree species were exclusively present in Group 1 and Group 2 and one species was exclusively present in Group 3. Based on this, it can be said that *Engelhardtia spicata, Ficus benghalensis, Holarrhena pubescens*, and *Acacia catechu* are the species found in Group 1. Those restricted to Group 2 were *Picrasma javanica, Desmodium oojeinense* and Paruli (local name). Jingar (local name) was recorded in Group 3 only.

Sal forests are found on better-drained and more developed soils (Dinerstein 1979; Banerjee et al.1992). The ground water table in these forests is very low and inundation does not occur during monsoon (Bolton 1976). Dinerstein (1979) attributed variation in physiognomy and composition of Sal forests to differences in topography, drainage and soil conditions. Topography might be the factor that separates the above described types from the hill Sal forest. Since the forests sampled above were all on flat terrain, the effect of topography is negligible. The soil variables tested in the study were not significantly different among the three communities identified. The pH at my sites (mean = 5.5, range = 4.8 to 7.5) was in line with the pH of Sal forest in the Bhabar-Terai zone of Nepal (pH = 5.7- 5.9; Rautiainen and Suoheimo 1997), of in the Moist Bhabar Forest in India (pH = 6.0; Yadav and Sharma 1967) and in *S. robusta* forests in Uttar Pradesh (Bhatnagar 1965). The percentage of organic matter (0.59 % to 4.08 %) with mean organic matter of 2.19 %, indicates lower fertility of Sal Forest. The value of 1.7-

2.33% of organic matter is an indicator of low fertility (Suoheimo 1995). The percent organic matter content of the present study is in line with 2.5 % organic matter for Terai Sal Forest (Shrestha 1992). The low amount of organic matter present may be a result of good drainage and dry conditions in Sal Forest. Total nitrogen for all three groups was medium and was similar to Sal forests in Uttar Pradesh, India (Bhatnagar 1965). In his study, Bhatnagar (1965) didn't find variation in total nitrogen from quality I to quality IV Sal Forest in both good and poor Sal regeneration areas. Available phosphorous and available potassium content was high in all three groups.

The soil variables relationships reported here (Table 4, Figure 9a- 9f) suggest that soil texture and other chemical properties do not determine the difference in the three forest communities. Distribution of plant communities is generally determined together by a wide range of factors, including soil moisture, soil nutrients, rainfall, topographic position and past disturbances (Barnes et al. 1998). Due to logistic problems, other variables could not be measured and further studies including a broad range of factors are desirable in the future. Since most of the plots in Group 1 and Group 2 are from Bardia District and Group 3 contains plots from Kanchanpur District, the amount of rainfall (Fig 1a), which is higher in Bardia (RBNP) compared to Kanchanpur District (RSWR), and its subsequent effects on soil moisture conditions could be one factor. Swaine and Becker (1999) observed similar results in Ghana, where the amount of rainfall explained the variation in structure and compostion of forests better than the other environmental variables. As previously explained, these forests were exposed to different intensities of disturbance in the past and are still burnt annually, past disturbances and fire could also have shaped these communities. Factors that can influence species distributions are local environmental heterogeneity, stand disturbance history (Clark et al. 1999), mass effects (Shimda and Wilson 1985), and chance (Hubbell and Foster 1986).

Altogether 17 species were present in the sapling layer. The high density of saplings indicated good regeneration, but the per plot species richness and diversity were lower. This shows less representation of species in the sapling layer. New species are being added to these communities because *Cassia fistula*, *Grewia sp* and Kaphale (local name) were present in the sapling layer but not on the tree layer. *T. tomentosa*, an important tree species, was completely absent in the sapling layer. This may be due to the fact that the seeds of this species have low germinating power (Lal 1992). Fifteen tree species were completely absent in the sapling. It might suggests that *Shorea*, *Buchanania*, *Terminalia*, *Dillenia*, *Lagerstroemia*, *Mallotus*, *Holarrhena*, *Cleistocalyx*, *Semecarpus*, *Schleichera*, *Engelhardtia* and *Zizyphus* are the tree species associated with Sal Forest and other species might have been introduced due to the past disturbances or they are not regenerating.

All three communities identified in the study showed good regeneration in the sapling layer. Sapling density was higher than recorded in Corbett National Park, India, where it varied from 90 to 1240 plants/ha (Singh et al. 1995). *S. robusta* had the higher density of saplings in all three groups. Less representation of S. *robusta* sapling in Group 3 compared to Groups 1 and 2 shows lower *Shorea* sapling density in Sal Forest of RSWR. *B. latifolia* was the dominant tree species after *S. robusta* in Group1, but in the sapling, density of *M. philippensis*, *Engelhardtia spicata*, *Zizyphus*, *Grewia sp*., *C. operculatus* were higher than *B. latifolia*. It might be that the survival rate between sapling and tree stages in other species is lower than *B. latifolia*. In Group 2 also, the most abundant sapling species after *S. robusta* was *M. philippensis* followed by *Buchanania*, *Cleistocalyx*, *Zizyphus sp*. and *Lagerstroemia*. Absence of *Terminalia* saplings and higher density of *Buchanania* saplings might suggest that Group 2 (*T. tomentosa–S. robusta* association) is a successional stage which might eventually lead to Group 1 (*S. robusta-B. latifolia* association). The dominance of *Terminalia* in moist deciduous forest indicates presence of moisture- retentive heavy soil (Lal 1992). The absence of *Terminalia* saplings in Group 2 and increase in *Buchanania* saplings suggest the loss of moisture retentive capacity probably due to low organic matter and clay content. In Group 3, after *S. robusta* saplings, *Grewia sp.*, *Holarrhena*, *Cleistocalyx* and *Mallotus* were the most abundant respectively. Group 3 showed lower regeneration in the sapling layer compared to Group1 and Group 2. Although Group 3 was highly dominated by *S. robusta* (IVI-178.69) in the tree layer, the sapling layer showed a mixed group of different species. These forests are heavily burnt during the dry season (Dinerstein 1979; Shrestha and Jha 1997) and burning might have significant impacts on the density of saplings. Group 3 consisted most of the plots from RSWR and community forests in Kanchanpur district, the density of saplings indicated the lower regeneration in these areas. All three associations were equally diverse in saplings, but Group 1 was rich in saplings compared to Group 3.

Seedling density (79072 plants/ha) here was higher compared to seedling density (2360 to 8591 plants/ha) of Corbett National Park, India and natural forests (31,250/ha) in the Darjeeling Himalayas (Singh et al. 1995; Shankar et al. 1998). *S. robusta* showed good regeneration in the seedlings (70463 plants/ha) and is close to the *S. robusta* seedling density (73,542 to 91,125 plants/ha) in Makwanpur District of central Nepal

(Rautiainen and Suoheimo 1997). *S. robusta* was the dominant species in the tree, sapling and seedling categories and represented approximately 90% of all seedling density. Although *M philippensis* was not as abundant in the tree category, it was well represented in sapling and seedling categories. *M. philippensis* replaces other species as associates in dry areas (Champion and Seth 1968; Singh and Singh 1992).

The analysis of regeneration status showed that the most dominant species *S. robusta* was regenerating well in all three groups. *B. latifolia* which is an associate of Sal in Group 1 showed regeneration in both Groups from Bardia, but it was not regenerating in Group 3 which represents RSWR. *T. tomentosa* was regenerating in Group 1 and Group 3, but its lack of regeneration in Group 2 confirms the above-mentioned idea that Group 2 (*Terminalia tomentosa-Shorea robusta* association) might transform into Group 1 (*S. robusta-B. latifolia* association) over time. The addition of six new species in all the groups shows that the communities studied are not stable.

Many species showed low regeneration and only a few species showed good to fair regeneration. The species that were associated with Sal in all three groups were regenerating well except for *T. tomentosa* in Group 2. The higher dominance of Sal in all three layers is because of its resistance to fire and potential to grow on a wide range of soil types (Dinerstein 1979; Rautiainen and Suoheimo 1997). Die-back has been observed during natural regeneration of *S. robusta* (Troup 1921; Jackson 1994). Although the shoot portion dies during the recruitment phase, the root system remains alive and continuously sends new shoots every year. Finally a strong root stock develops, which eventually sends a shoot that grows further. Ramet producers such as *M. philippensis* (Pandey and Shukla 2001) showed good regeneration in all three groups. *H. pubescens*, another ramet producer, showed poor regeneration in Group 1, was completely absent in Group 2 and was new to Group 3. *Zizyphus sp*. that grows on drier areas was regenerating well in Group 1 and 3 but not in Group 2. The dominance of *T. tomentosa* in the tree layer and poor regeneration of *Zizyphus sp*. in Group 2 characterizes the community as developing on moist soil. *Adina cordifolia*, *Syzygium cumini* and *Lagerstroemia parviflora* increased in abundance after conversion to taungya plantation in dry mixed deciduous forests of the Darjeeling Himalaya (Shankar et al. 1998). Except for fire, other kinds of disturbances in the present study areas were rare in the recent past, not including the 10 plots sampled in community forests. The rarity of species such as *A. cordifolia* and *S. cumini* in the tree layer and their complete absence from the sapling and seedling layer suggests that the communities sampled are successional forests.

Sal forests sampled in Chitwan had sparse understory (Lehmkuhl 1994). The understory in the Sal forest remains dense in Bardia and visibility remains poor for most of the year, and it improves only in the hot season after the annual fire burns the understory (Dinerstein 1979). The findings of the present study indicated that shrub density (338/ha) was low in Sal forest. Both species richness and diversity of shrubs were also low. This result is contrary to the findings of Pandey and Shukla (2003) in the Sal forest of Gorakhpur, India, where the density of a single species was 2669/ha. None of the shrubs they described as having high densities were present in this study area. This may be because sampling in the present study took place after annual burning had occurred. Low species diversity and low density (676/ha) of shrubs in the Terai *Shorea robusta* Forest of RBNP have been attributed to heavy dry season fires (Shrestha and Jha 1997). Rodgers et al. (1986) didn't find a significant difference between burnt and unburnt Sal forest in Dehradun India. In their study, the shrub density in burnt forest was 33366/ha and unburnt forest was 27865/ha. Their study used a structural definition of shrub rather than a taxonomical definition. Tree saplings of *S. robusta* and *M. philippensis* were regarded as shrub. *Flemingia strobilifera* was the most abundant species in all three groups. Forty-five percent of the total number of individuals per ha was represented by this species. This species, along with *C. viscosum* has been regarded as an indicator species of Sal forest (Shrestha and Jha 1997). *C. viscosum* was absent in Group 2. The presence of *C. viscosum* indicates favorable condition for Sal regeneration in India (Champion and Seth 1968). Absence of *C. viscosum* and dominance of *T. tomentosa* over Sal in Group 2 indicates poor Sal regeneration.

The three groups did not show significant differences in shrub density, although the mean shrub density was higher in Group 1 followed by Group 2 and Group 3. Only three species were present in Group 2. Group 1 had a higher density than Group 3, but the highest number of species occurred in Group 3. Evenness was lower in Group 2 compared to Group 1 and Group 3. Group 1 species are the most evenly distributed followed by Group 3. Diversity was highest in Group 1, but the difference between the groups was not statistically significant. It can be concluded that all three communities are equally diverse and rich in terms of shrubs, although the overall shrub diversity and richness were low. Fifty-five percent of the plots in Group 1, 39% in Group 2 and 54% in Group 3 didn't have a single species of shrub. Shrub density, diversity and richness were low because the understory was either open or dominated by saplings. *Callicarpa macrophylla* and *Hedyotis sp.* were present in Group 1 only. *Elsholtzia blanda*, *Pogostemon benghalensis* and *Grewia sp.* were present in Group 3 only. *Callicarpa* was present in all size classes in the unburnt forest of Dehradun, India but was absent on burnt sites (Rodgers et al. 1986). The presence of Callicarpa in Group 1 and its absence in other groups might suggest more influence of fire in other Groups than Group 1.

The abundance of *Imperata cylindrica* among the grasses and Sal among seedlings in all groups suggests the effects of fire in these communities. Frequent fire promotes the growth of fire resistant species such as *S. robusta* and *I. cylindrica* (Wesche 1997). Group 3 had the highest total species richness in the herb layer with 63 species followed by Group 1 with 53 species. Group 2 had the lowest species richness with 38 species. Percent canopy closure was significantly different between the Groups, and was the highest for Group 1 and the lowest in Group 3. The high species richness of the herb layer in Group 3 suggests low canopy closure and understory cover, and more light to the species growing on the ground. This was also confirmed by the significant negative correlation between canopy closure and ground cover. Per plot species richness between groups was not significantly different and neither was Shannon's diversity index. There was not much difference in evenness between the groups. The low Shannon's diversity index is due to the low evenness in distribution and dominance of a few species such as *Imperata cylindrica*, *Justicia*, *Evolvulus* and *Desmostachya*. The density of the herbaceous layer (Table 12) was higher in all groups than the herbaceous layer in natural forest (0.165 million/ha) and forest recovering after taungya plantation (0.098 million/ha) of Mahananda Wildlife Sanctuary, West Bengal, India (Shankar et al. 1998).

Following stand initiation after disturbance, self thining occurs as slower growing individuals are replaced and remaining individuals grow in size. This results into predictable decrease in density as the ASD increases. The relationship between ASD and tree density can be used to calculate SDI, which gives full stocking of stands at any ASD. Calculation of SDI showed that most of the plots sampled are understocked. Stands in RSWR are the most understocked among the three groups. The reasons for lower stocking might be due to: (1) insufficient recruitment after disturbances in the past (2) subsequent minor disturbances because of fire (3) the stand structure is not even aged (Zhang et al. 2005). All the three reasons discussed above could explain the lower stocking of stands. As explained previously, these forests are burned annually. The density distribution among dbh classes suggests the uneven-aged structure of stands. During the field study a number of herbivores such as *Axis axis, Cervus unicolor, Muntiacus muntjak, Cervus duvauceli, Axis porcinus* and *Boselaphus tragocamelus* were sighted in the protected area forests sampled. Herbivory might have affected recruitment processes.

There was no relation between ASD and SDI values and seedling density suggesting no effect of density (stocking %) and presence and absence of mature trees on seedling density. There was also no relation between the availability of seed source (tree relative density) and seedling density. This might also suggests the countervailing effect of seed source and canopy cover. Higher tree density may act as a sufficient seed source but at the same time increase in canopy cover may prevent seedlings from growing because of low light condition. These results are may be due to the fact that most of the species present in these forests regenerate by non-seed methods as well (Pandey and Shukla 2001). The die-back phenomenon of *Shorea robusta* seedlings increases the time of establishment of a new generation up to 60 years under irregular systems and without protection, even if the recruitment of new seedlings were satisfactory (Troup 1921). The longer time for germination, recruitment and establishment of *Shorea robusta* seedlings might have also affected the relationship, although sufficient seed sources were available.

The community forests sampled were declared under community protection only two years ago. Although User Groups and the boundaries of these forests had already been defined, the official hand-over process is still to come. These community forests have been subjected to illegal cutting of timber, non-timber forest products, collection of fuelwood and fodder, grazing and intentional fires. The author observed cattle grazing during field work. Community forests were species poor and 20 tree species and a climber found in protected areas were completely absent in community forests. This shows that community forests are in a highly-degraded condition and need protection for a number of years to reach the species richness found in protected areas. This is also supported by the fact that the per plot species richness in protected area forests were higher than community forests. In their study in the Nepalese Terai, Webb and Sah (2003) found that a 20 yr successional Sal forest had 84% of the total species richness of natural forest. It has been found that, after clear cutting, 40 years is required for a tropical rain forest tree community to return to its pre-cut diversity levels (Faber-Langendoen 1991 cited in Webb and Sah 2003). Community forests had 29% of tree density compared to protected areas. Although density was different, the basal area/ha was not significantly different between community forests and protected areas. This may be due to the fact that the higher percentage of basal area in community forests was represented by trees in larger dbh classes.

Absence of trees in lower dbh classes, lower species richness and density of saplings, lower shrub richness and density and lower density of seedlings suggest that the understory in community forests is highly disturbed and regeneration is low due to frequent disturbances. Low intensity and sustained human disturbance through selective logging, firewood extraction, grazing and land clearing for permanent agriculture may influence plant communities and their successional patterns (Attiwill 1994; Fujiska et al. 1998). A similar study done in and around Royal Chitwan National Park (RCNP), Nepal found community forests to be in poorer conditions than national forests and national parks (Nagendra 2002).

The higher density of *M. philippensis* in the community forests compared to protected areas suggests the impact of disturbance. Species such as *M. philippensis* can produce ramets and regenerate well in areas of high disturbances (Pandey and Shukla 2001). The presence of good amount of *S. robusta* seedlings in community forests may be due to the nature of the species in response to fire as described above. The lower ground cover and species richness in community forests compared to protected areas also suggests the impacts of grazing. Grazing was common in these forests and had significant impact on the regeneration and establishment of plant communities in the ground layer. This suggests that community forests sampled were highly degraded compared to protected areas. Adequate protection is necessary to ensure that the structure and composition of community forests resemble that of protected areas.

The community forests had poor species richness, density and cover values for all the layers sampled. The poorer condition along with competition from cattle grazing rule out the possibility of supporting sufficient herbivore population, because of lack of food and sufficient cover. *Imperata cylindrica, Vetiveria zizanoides, Saccharum spontaneum and Desmostachya bipinnata* are the most important grazing species for ungulates in

RBNP (Dinerstein 1979a). Absence of all other species except *Imperata* in community forests also suggests lack of food. Seedlings, fruits and flowers of tree species such as *Acacia catechu, Bombax ceiba, Ficus benghalensis, Syzigium cumini, Schleichera oleosa* etc. are consumed by herbivores, these species were absent in the community forests. Adequate prey density (herbivores) and sufficient cover is necessary for good quality tiger habitat (Karanth and Sunquist 1995; Smith et al. 1998). Different vegetation types inside protected areas provide diverse habitat for mammals, which they utilize according to seasons and phenology of plants (Dinerstein 1979a). This kind of diversity is lacking in community forests. At the present condition, the role of these community forests as additional wildlife habitats outside protected areas and as movement corridors is bleak. Ecological conditions of community forests outside protected areas are important for biodiversity conservation and for long- term success of landscape level programs such as TAL.

TABLES

Table 1: Area (ha) under different land uses in Bardia District.

Land Use	Area (hectares)	Area (%)
Agriculture and Settlements	68,075	33.7
Forest	33,452	16.6
Royal Bardia National Park	87,936	43.6
Scrub and Grass	294	0.1
Rivers (Water Bodies)	11,920	6.0
Total	2,01,677	100.0

Source: HMGN 1996

Table 2: Importance value of trees for the three different associations identified by cluster analysis. Species are coded (see Appendix 1 and 2 for detailed description of tree species, their density, basal area, frequency and relative frequency in different groups).

Species	Group 1	Group 2	Group 3
Shorob	81.7	74.2	178.69
Dilpen	24.46	19.62	9.76
Tertom	28.07	81.44	22.56
Buclat	37.55	32.53	4.81
Anolat	3.56	0	1.22
Myrsem	16.88	20.08	1.21
Malphi	4.63	9.24	6.92
Lagpar	19.84	13.68	4.74
Schole	4.86	2.05	1.39
Cleope	29.39	2.42	27.32
Adicor	1.58	5.07	4.52
Syzcum	2.67	3.3	3.61
Antchi	2.2	4.09	0.28
Semana	8.25	4.41	5.77
Terbel	1.4	4.49	3.23

Table 3: Basal area (m^2 ha^{-1}) of the different tree species among groups

Species	Groups	Obs	Mean	SD	Min	Max
Shorob	1	18	6.25	2.56	2.29	11.48
	2	13	5.12	1.79	2.29	8.04
	3	37	10.89	3.55	2.29	19.52
Dilpen	1	18	0.83	0.95	0.00	2.29
	2	13	0.53	0.76	0.00	2.29
	3	37	0.25	0.72	0.00	3.44
Tertom	1	18	1.47	1.23	0.00	3.44
	2	13	4.50	1.28	2.29	6.88
	3	37	0.81	1.26	0.00	4.59
Buclat	1	18	0.89	1.22	0.00	3.44
	2	13	0.79	1.18	0.00	3.44
	3	37	0.12	0.53	0.00	2.29
Myrsem	1	18	0.32	0.53	0.00	1.14
	2	13	0.53	0.89	0.00	2.29
	3	37	0.03	0.19	0.00	1.15
Lagpar	1	18	0.45	0.69	0.00	2.29
	2	13	0.35	0.72	0.00	2.29
	3	37	0.06	0.26	0.00	1.15
Cleope	1	18	1.02	1.52	0.00	4.59
	2	13	0.09	0.32	0.00	1.15
	3	37	0.40	0.67	0.00	2.29

Table 4: Mean, minimum and maximum values for soil variables tested for three different associations.

Variables	Group 1			Group 2			Group 3		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
pH	5.5	5	6.5	5.6	5	6.5	5.4	4.8	7.5
OM (%)	2.28	1.15	3.45	2.18	0.59	4.08	2.15	0.94	3.61
N (%)	0.114	0.06	0.17	0.108	0.03	0.2	0.107	0.05	0.18
P_20_5 (kg/ha)	114.64	32.67	212.36	83.77	21.77	185.14	132.5	3.14	370.27
K_20 (kg/ha)	290.04	104.79	445.37	271.44	129.46	406.08	271.47	115.83	456.51

Table 5: Mean sapling density per ha, Species richness per plot (S), Shannon's Diversity Index (H') and Evenness (E) for all forests sampled and the three different associations identified by cluster analysis

Groups	Mean	Min	Max	S	H'	E
All sampled forests	1797	0	10063	2.4	0.56	0.55
Group 1	2851	127	9935	3.2	0.69	0.59
Group 2	2733	0	10063	2.3	0.52	0.51
Group 3	1019	0	5732	2.0	0.52	0.55

Table 6: Mean sapling density of different species per ha in different groups. Species are coded (see Appendix 4 for detailed description of species).

Group 1			Group 2			Group 3		
Species	Mean	SD.	Species	Mean	SD.	Species	Mean	SD
Shorob	2045	2589	Shorob	1969	3122	Shorob	278	1139
Lagpar	56	89	Lagpar	78	176	Lagpar	24	84
Buclat	77	132	Buclat	137	204	Cleope	79	148
Cleope	99	135	Cleope	107	293	Picjav	6	29
Picjav	14	41	Picjav	29	76	Malphi	82	175
Malphi	134	372	Malphi	205	741	Holpub	210	475
Holpub	56	186	Zizphy	88	190	Zizphy	89	143
Zizphy	120	328	Baslat	29	105	Grewia sp	213	559
Baslat	113	289	Grewia sp	9	35	Schole	3	21
Semana	21	48	Schole	9	35	Syzcum	3	21
Grewia sp	92	221	Casfis	29	106	Kaphal	27	68
Schole	7	30	Dilpen	9	35			
Casfis	7	30	Kaphal	29	106			
Kaphal	7	30						

Table 7: Kruskal-Wallis and Mann-Whitney results showing the difference in sapling density of different species among groups.

Species	Kruskal Wallis test	Mann Whitney test of difference
Shorob	χ^2 =15.983, p = 0.0003	Group1>Group3, Group2 > Group3
Lagpar	**	
Cleope	**	
Picjav	**	
Malphi	**	
Zizphy	**	
Schole	**	
Kaphal*	**	

* Unidentified (Local name), ** Insignificant.

Table 8: Mean shrub density per ha, Species richness per plot (S), Shannon's diversity index (H') and evenness (E) in all forests sampled and in different groups.

Groups	Mean shrub density	SD	Min	Max	S	H'	E
All forests sampled	337.18	640.79	0.00	3057.12	0.69	0.11	0.14
1	467.06	839.28	0.00	2420.22	0.83	0.346	0.23
2	362.54	418.76	0.00	1146.42	0.80	0.085	0.077
3	265.09	599.26	0.0	3057.12	0.60	0.082	0.118

Table 9: Comparison between groups in terms of shrub density, Shannon's diversity and species richness.

	Kruskal-Wallis test	Mann-Whitney test
Mean shrub density per hectare	$\chi^2 = 5.728$, p = 0.05	Gr1 < Gr2 > Gr3, Gr1 > Gr3
Mean Shannon diversity per plot	$\chi^2 = 0.0570$, p = 0.5909	
Species richness per plot	$\chi^2 = 0.4480$, p = 0.7992	

Table 10: Mean, minimum and maximum cover percentages for overstory, understory and ground cover of three groups identified by cluster analysis.

Cover types	Group 1			Group 2			Group 3		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Overstory (Trees)	68.9	33.18	82.4	69.92	44.36	79.46	62.57	32.66	78.68
Understory (Saplings and Shrubs)	38.17	0.5	83	34.77	0.5	83	19.97	0.5	83
Ground (Herbs)	43.69	10	83	49.38	12.5	83	57.17	6.25	83

Table 11: Comparison of cover percentages between the groups identified by cluster analysis.

Cover	Kruskal Wallis test	Mann Whitney
Overstory	$\chi^2 = 10.533$, $p = 0.005$	Gr 1& Gr 2*, $p = 0.857$ Gr1& Gr 3, $p = 0.005$ Gr 2 & Gr 3, $p = 0.017$
Understory	$\chi^2 = 5.081$, $p = 0.078$	
Ground	$\chi^2 = 5.431$, $p = 0.0662$	

*Significant, Gr= Group

Table 12: Status of regeneration of different species in the three Groups.

Status	Group 1	Group 2	Group 3
Good	16.6%	15%	18%
Fair	12.5%	15%	18%
Poor	12.5%	10%	4.5%
No	50%	55%	41%
New	6 sps	6 sps	6 sps

Table 13: Species richness, Evenness, Shannon's diversity index and Density/ha of herbs for the three associations and all sampled forests

	Group 1	Group 2	Group 3	All forests sampled
Species richness per plot	4.48	3.96	4.49	4.38
Evenness	0.73	0.69	0 .65	0.69
Shnannon's diversity (H)	1.04	0.91	0.97	0.98
Density	314722.2	482692.3	470000	434428.6

FIGURES

Figure 1a: Average monthly precipitation and average annual precipitation for Bardia District (RBNP) and Kanchanpur District (RSWR). Data were taken for fifteen years, from 1987 to 2001

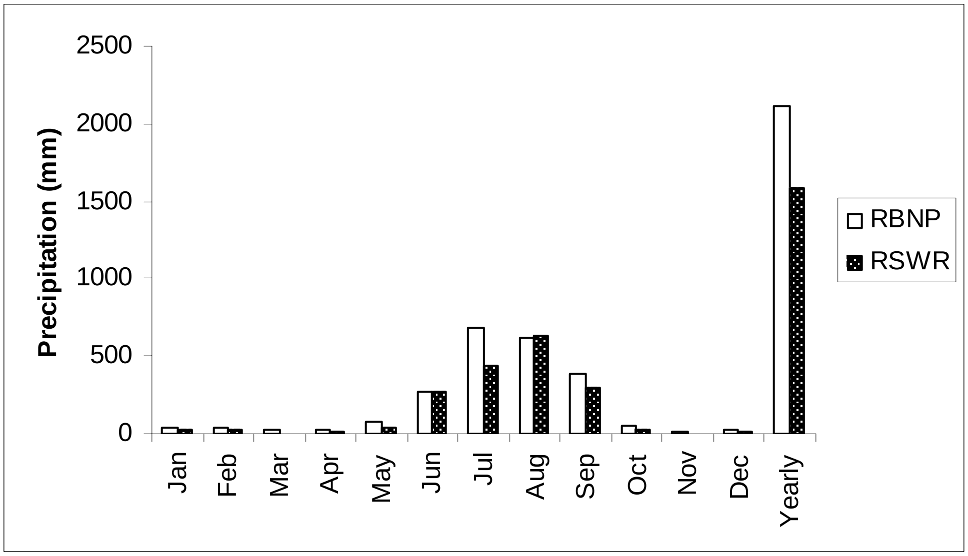


Figure 1b: Mean monthly maximum temp (^{0}C) and mean monthly minimum temp (^{0}C) for Bardia District (RBNP) and Kanchanpur District (RSWR). Data were taken for fifteen years, from 1987 to 2001. Source: Department of Hydrology and Meteorology, Kathmandu.

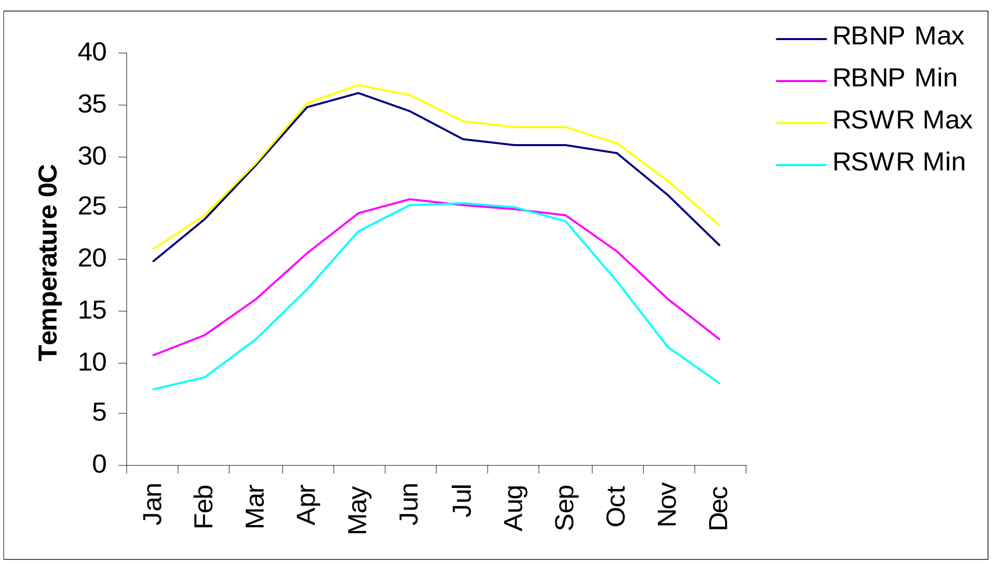
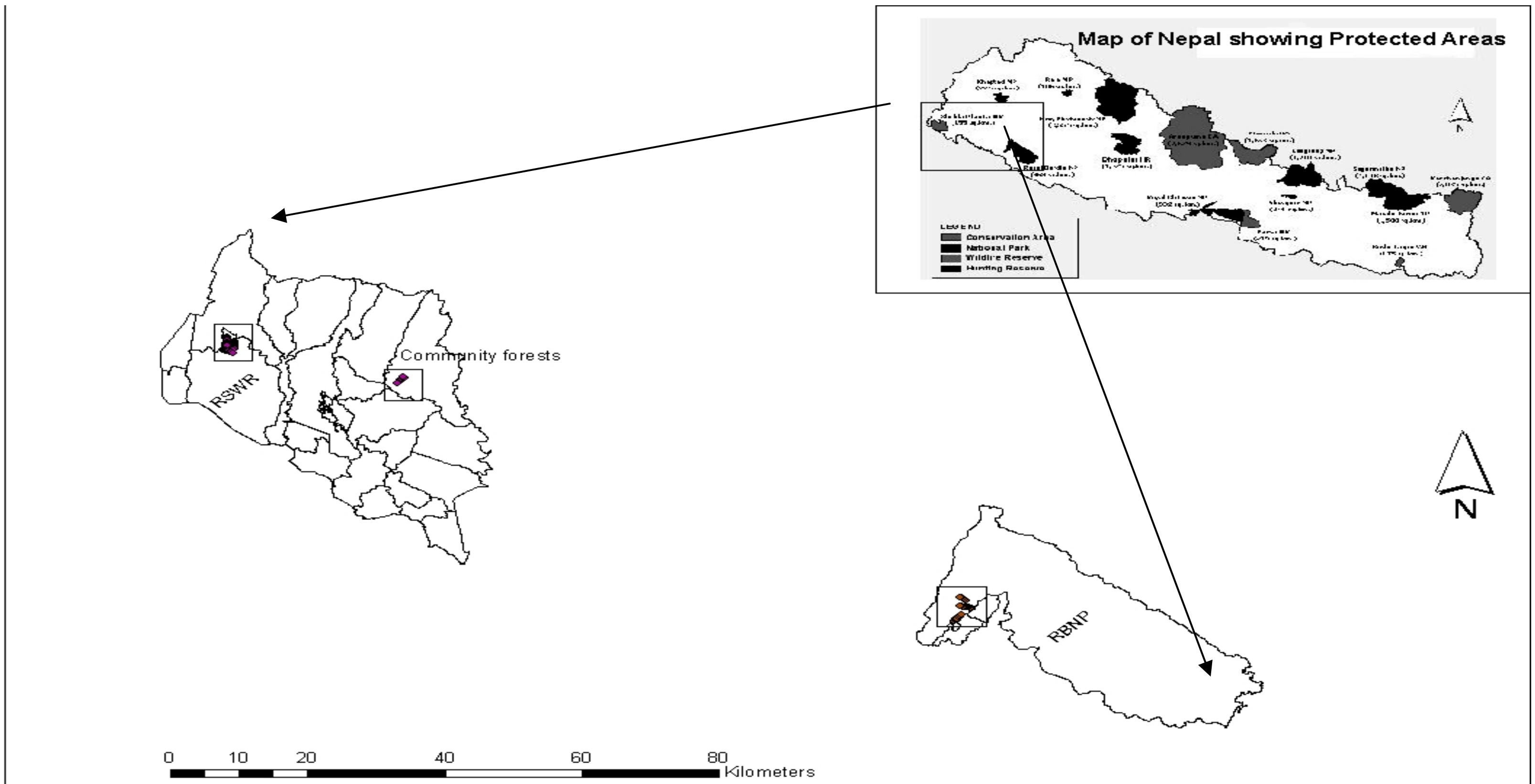


Figure 2: Map of the study area



Map of the study area showing location of RBNP, RSWR and Community Forests. Square boxes show location of forests sampled

Figure 3: Diameter distribution of trees (> 5cm dbh) for RBNP, RSWR and the Community Forests sampled.

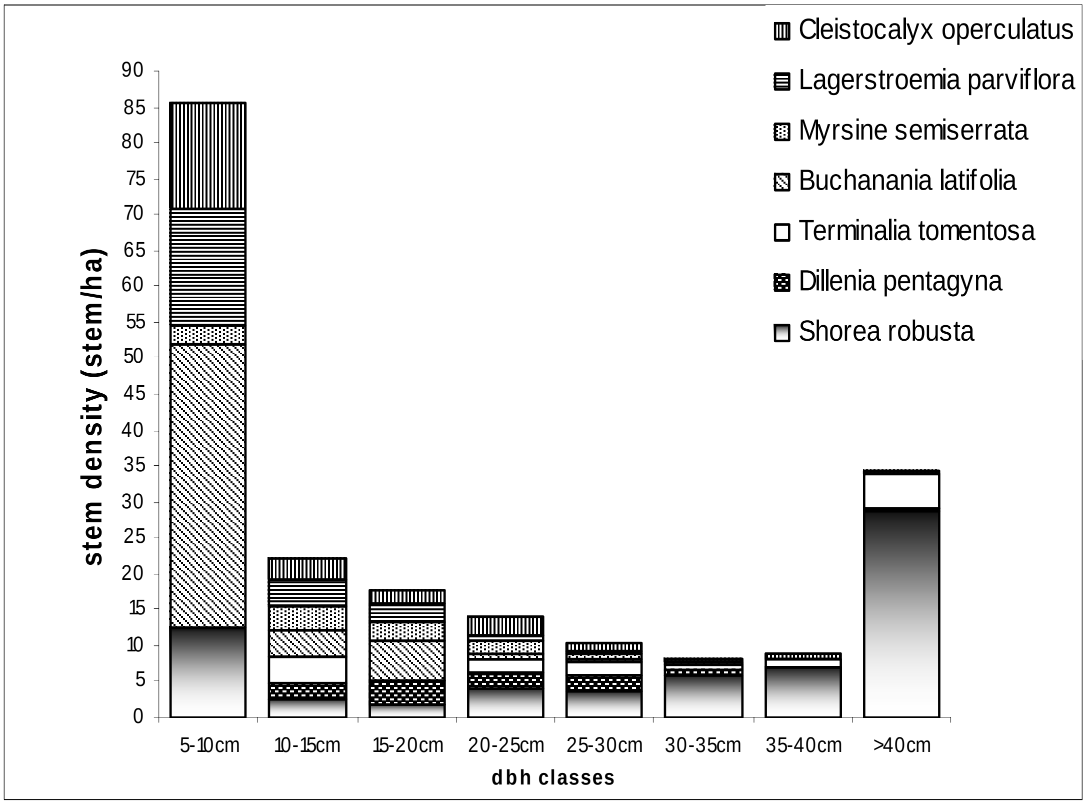


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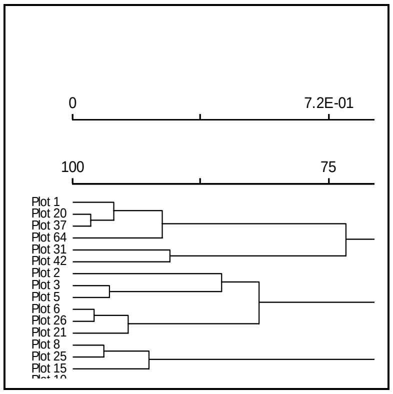
Figure 4: Dendrogram showing the different associations identified by the hierarchial agglomerative cluster analysis based on importance value of trees. Groups are described in the text.



Group 1

Group 2

Group 3

Figure 5: Diameter distribution of trees (> 5 cm dbh) for *Shorea robusta-Buchanania latifolia* association (Group 1).

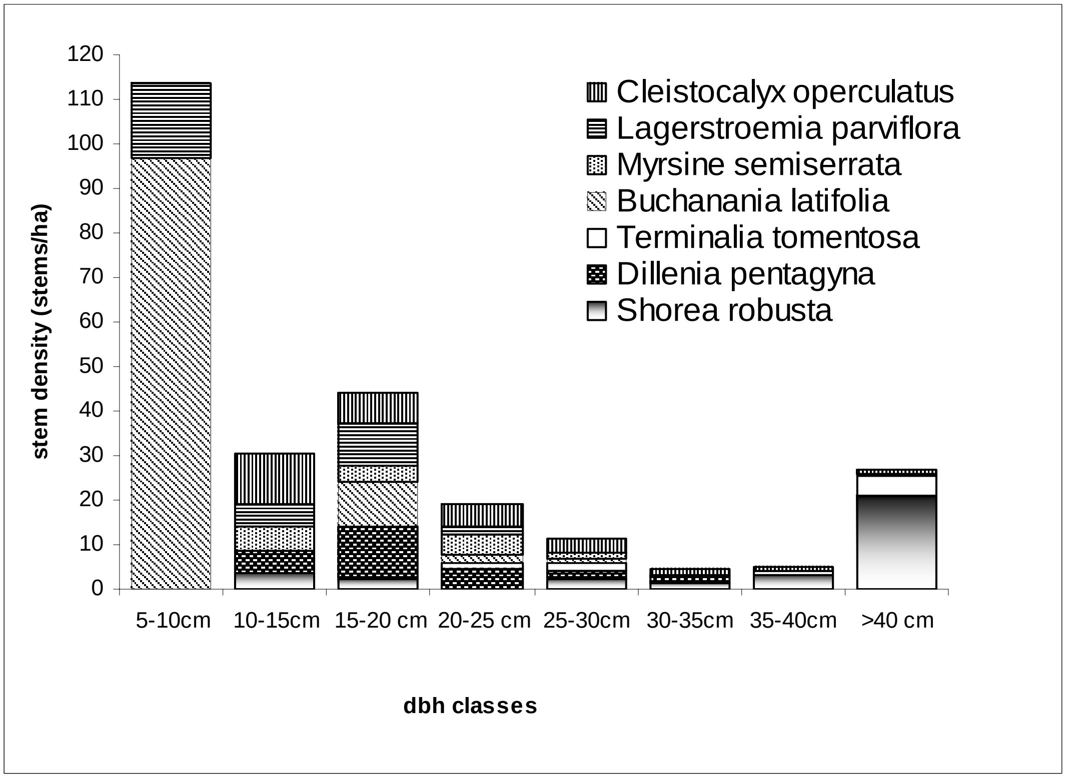


Figure 6: Diameter distribution of trees (> 5 cm dbh) for *Terminalia tomentosa-Shorea robusta* association (Group 2).

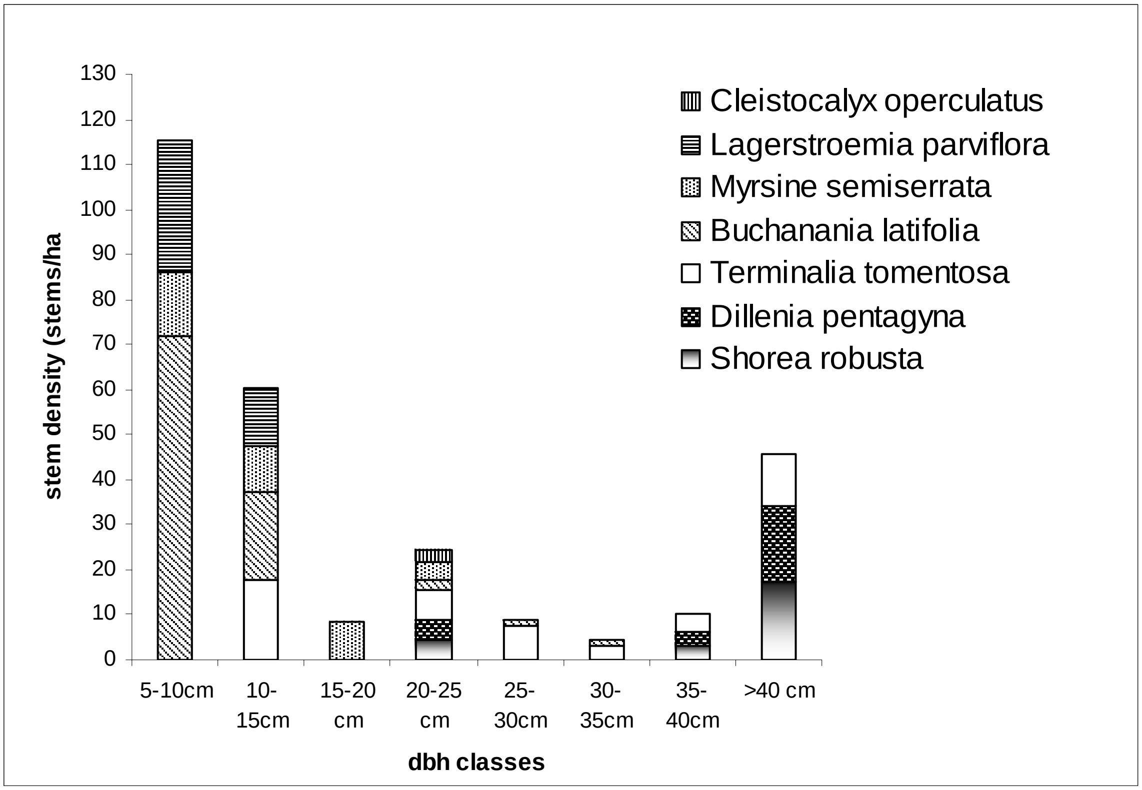


Figure 7: Diameter distribution of trees (> 5 cm dbh) for *Shorea robusta-Cleistocalyx operculatus* association (Group 3).

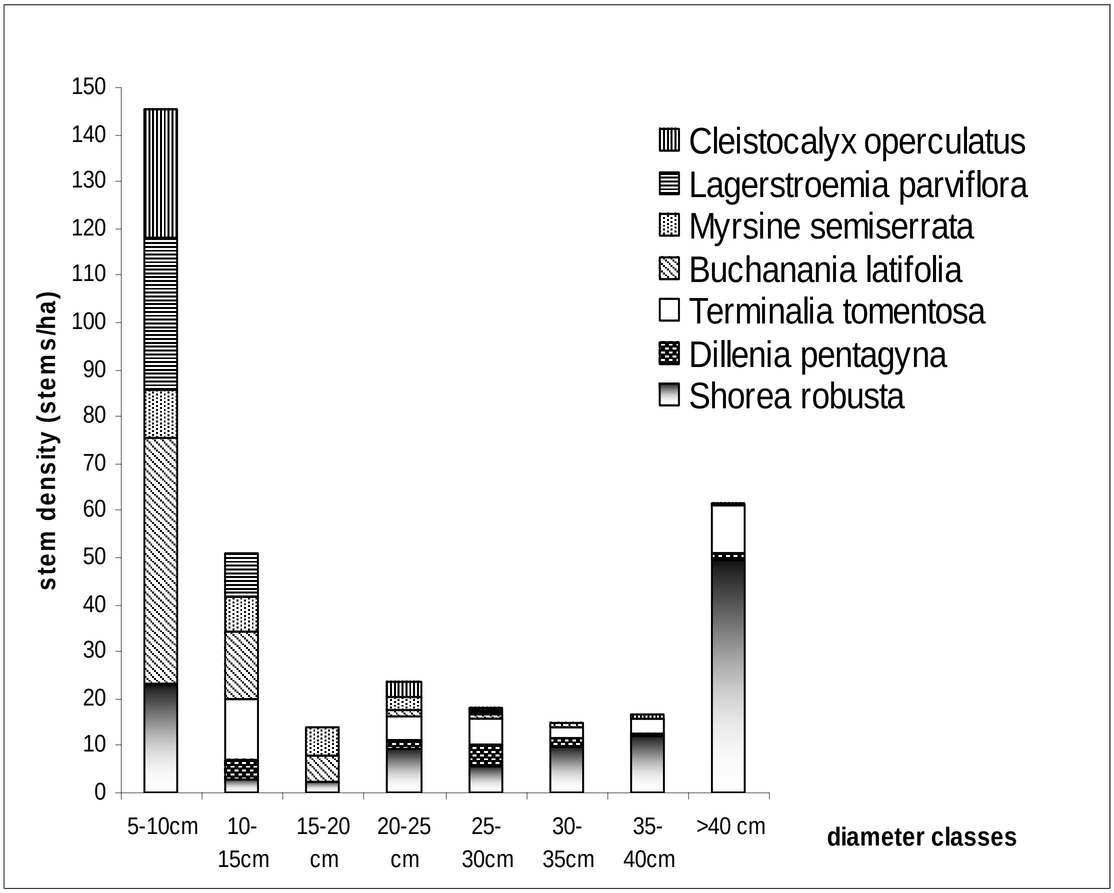


Figure 8: Site scores from 2 axis non-metric multidimensional scaling (NMS) ordination, based on importance value of trees.

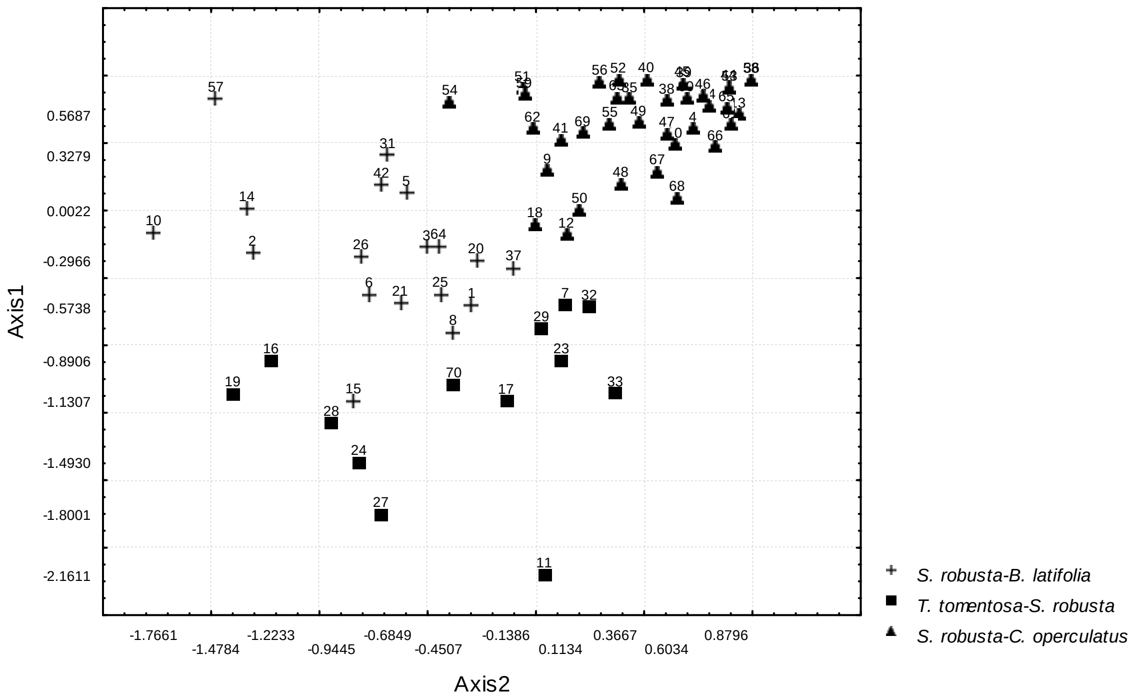


Figure 9a: Relationship between different associations identified by cluster analysis and soil pH. Contour plot of pH is superimposed upon NMS ordination of trees. (▲ *Shorea robusta-Cleistocalyx operculatus*, ■ Terminalia *tomentosa-Shorea robusta*, + *Shorea robustaBuchanania latifolia*).

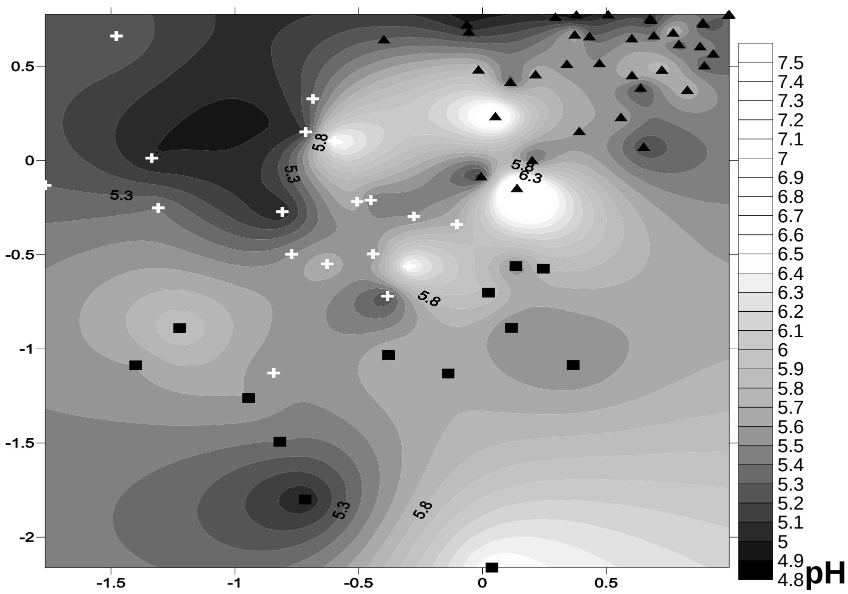


Figure 9b: Relationship between different associations identified by cluster analysis and soil organic matter. Contour plot of soil organic matter is superimposed upon NMS ordination of trees. (▲ *Shorea robusta-Cleistocalyx operculatus*, ■ *Terminalia tomentosa-Shorea robusta*, + *Shorea robusta-Buchanania latifolia*).

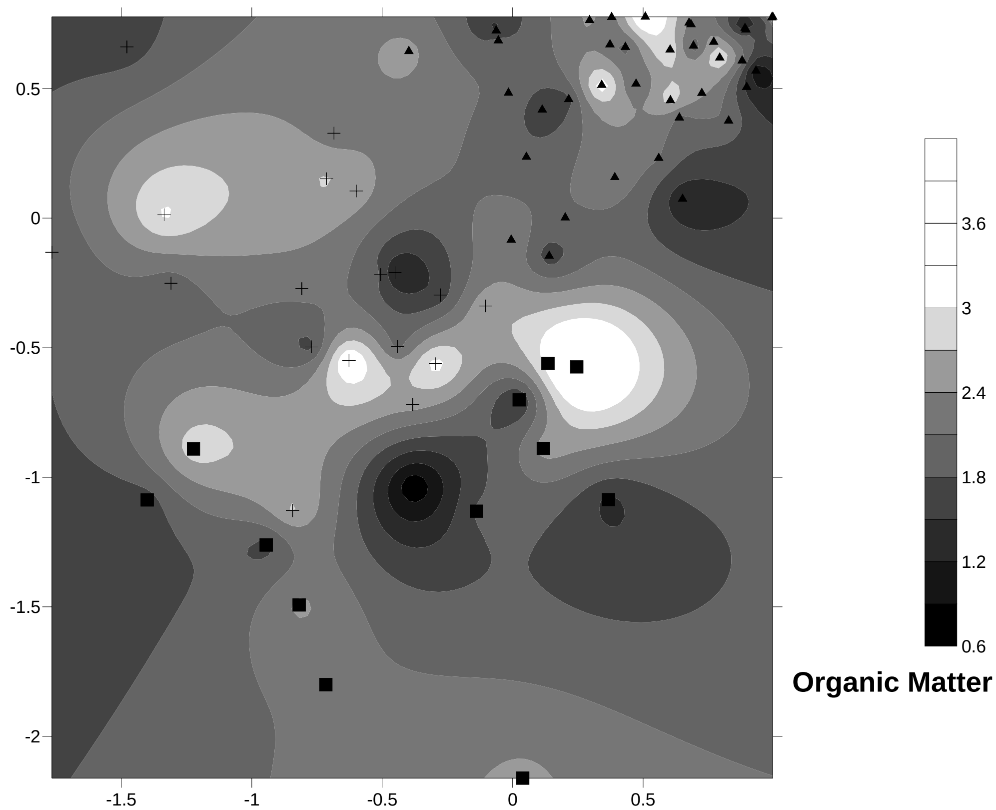


Figure 9c: Relationship between different associations identified by cluster analysis and total nitrogen. Contour plot of total nitrogen is superimposed upon the NMS ordination of trees. (▲ *Shorea robusta-Cleistocalyx operculatus*, ■ *Terminalia tomentosa-Shorea robusta*, + *Shorea robusta-Buchanania latifolia*).

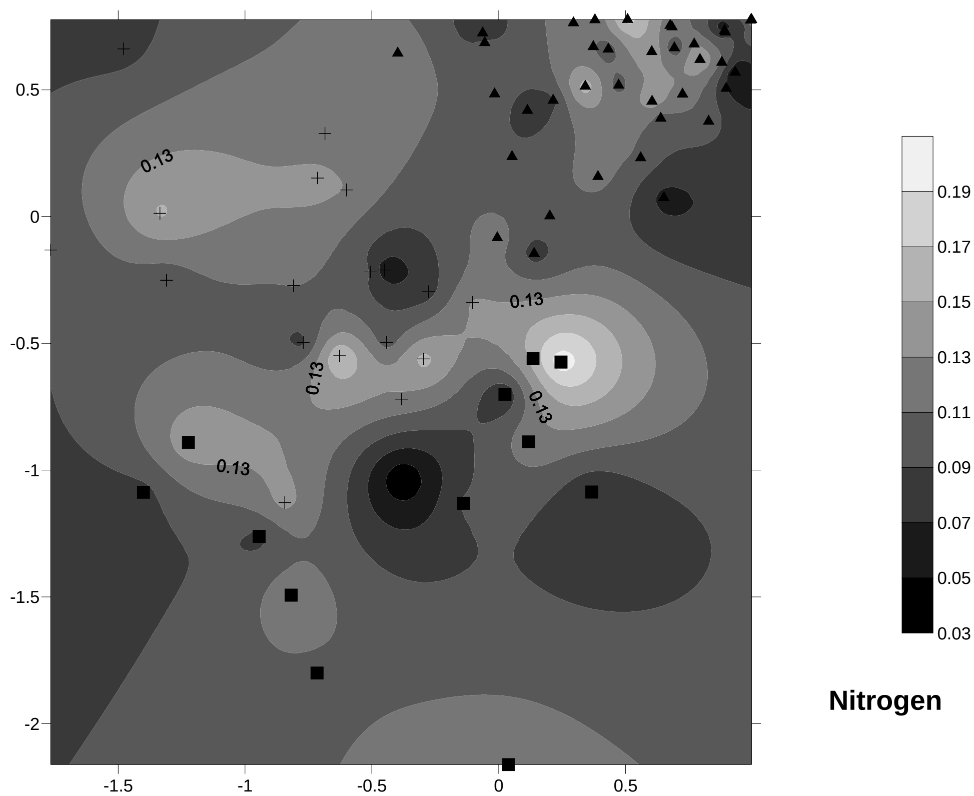


Figure 9d: Relationship between different associations identified by cluster analysis and available phosphorous. Contour plot of available phosphorous is superimposed upon NMS ordination of trees. (▲ *Shorea robusta-Cleistocalyx operculatus*, ■ *Terminalia tomentosa-Shorea robusta*, + *Shorea robusta-Buchanania latifolia*).

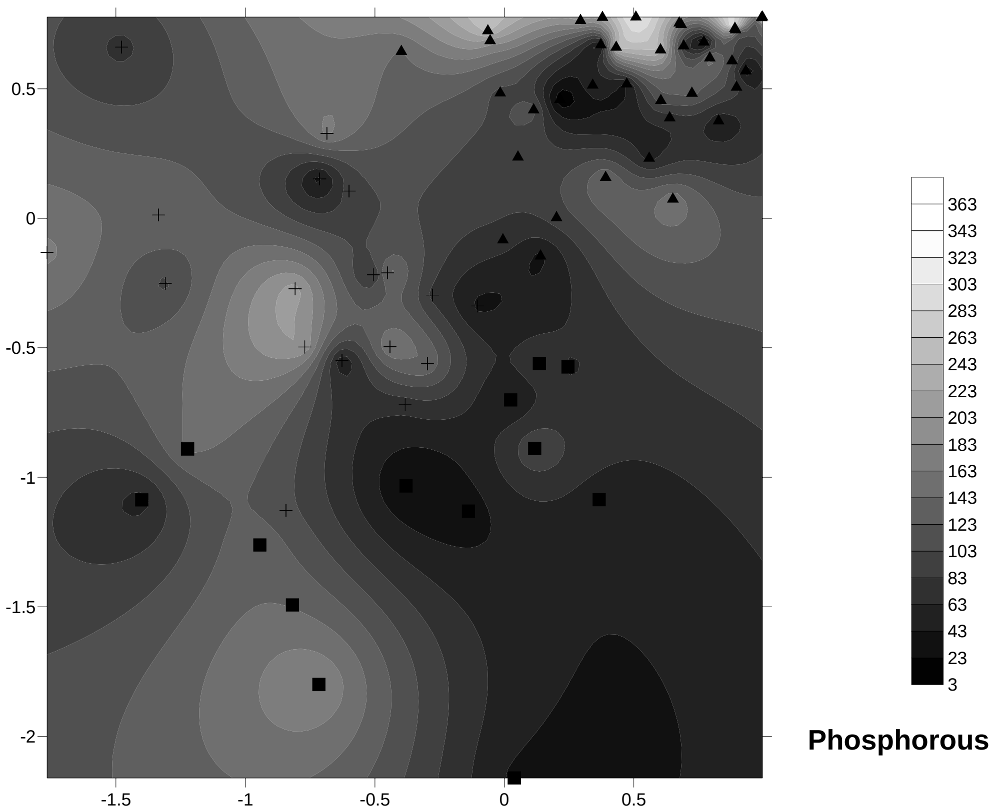


Figure 9e: Relationship between different associations identified by cluster analysis and available potassium. Contour plot of available potassium is superimposed upon NMS ordination of trees. (▲ *Shorea robusta-Cleistocalyx operculatus*, ■ *Terminalia tomentosa-Shorea robusta*, + *Shorea robusta-Buchanania latifolia*).

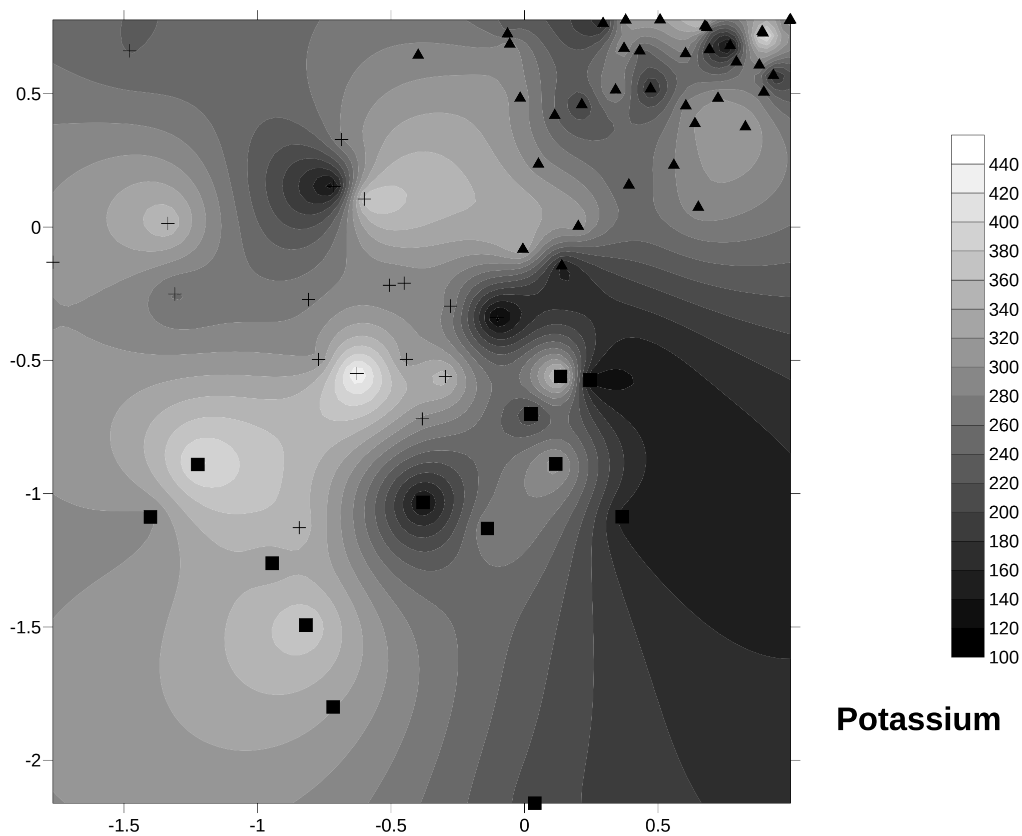


Figure 9f: Relationship between different associations identified by cluster analysis and soil texture. Contour plot of soil texture is superimposed upon NMS ordination of trees. (▲ *Shorea robusta- Cleistocalyx operculatus*, ■ *Terminalia tomentosa- Shorea robusta*, + *Shorea robusta- Buchanania latifolia*).

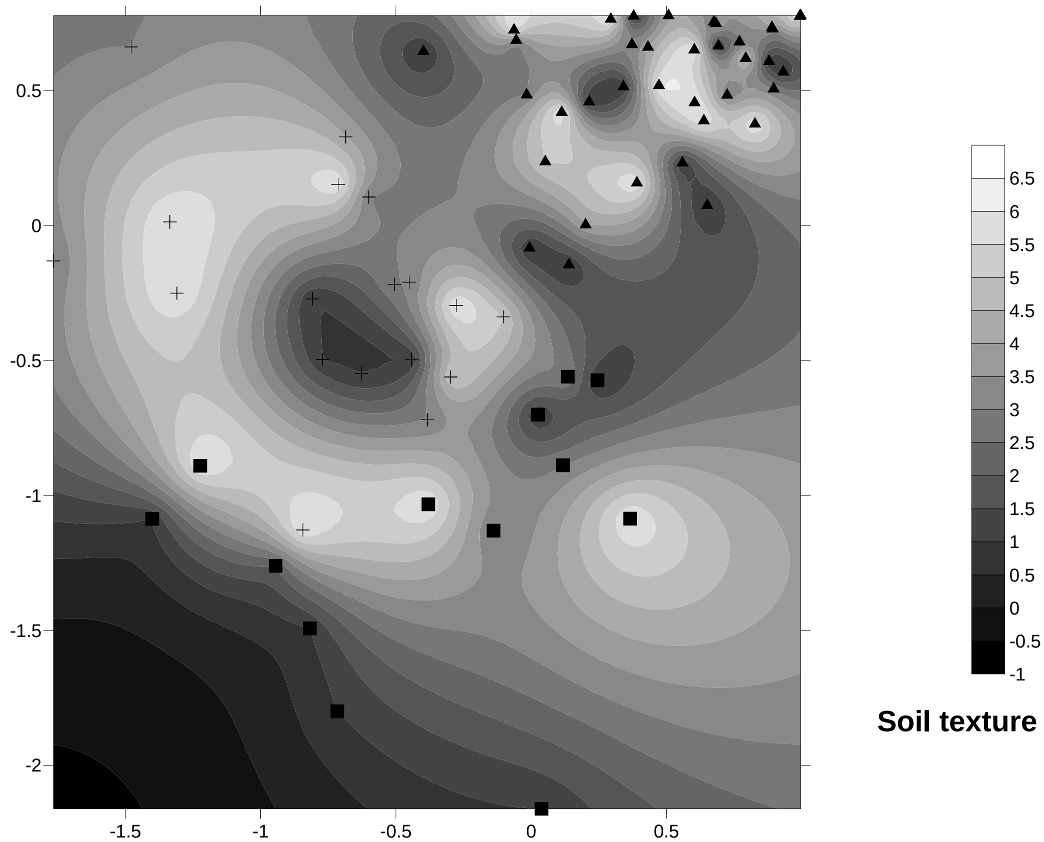


Figure 10: Seedlings of tree taxa present in each group as the percentage of total tree taxa recorded in seedlings.

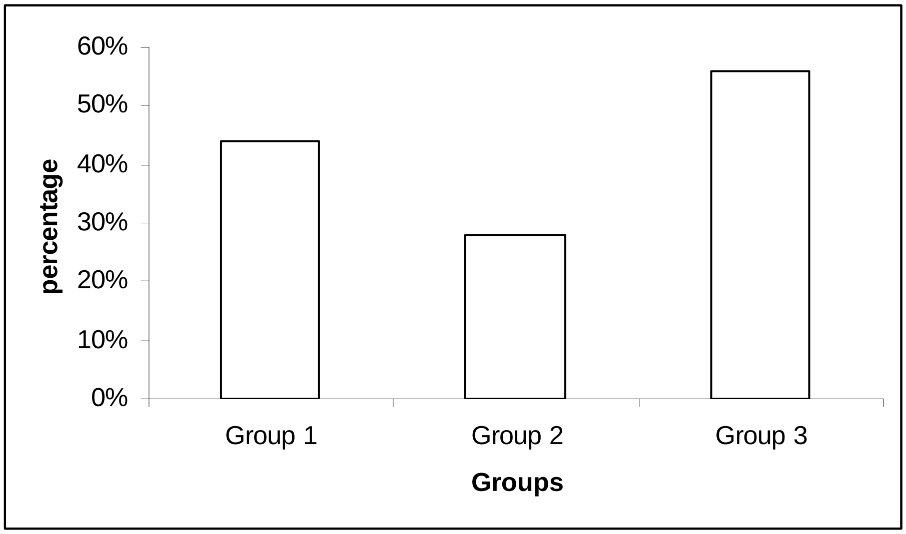


Figure 11: Log density of trees (stems ha^{-1}) plotted against log Average Stand Diameter (ASD) for all the plots sampled. Plots are labeled by Stand Density Index. The diagonal line asserts the maximum stocking for the forest sampled. (Axes are in linear scale)

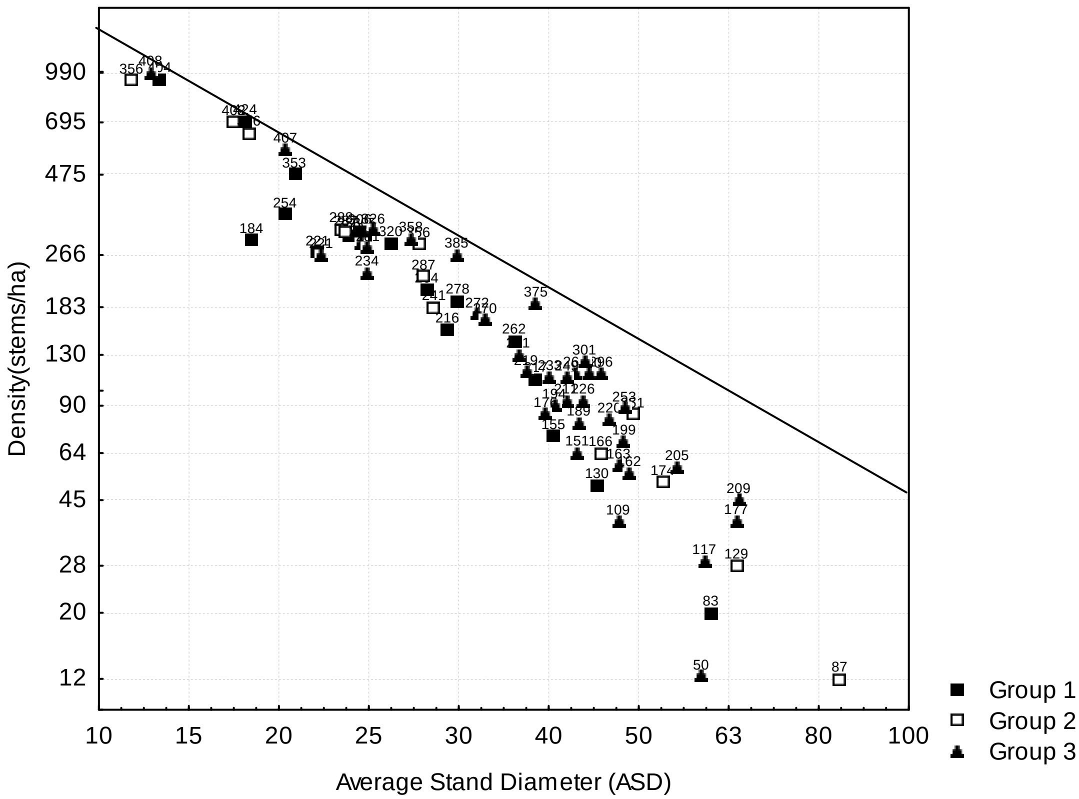


Figure 12: Plot of total seedling density against SDI and ASD.

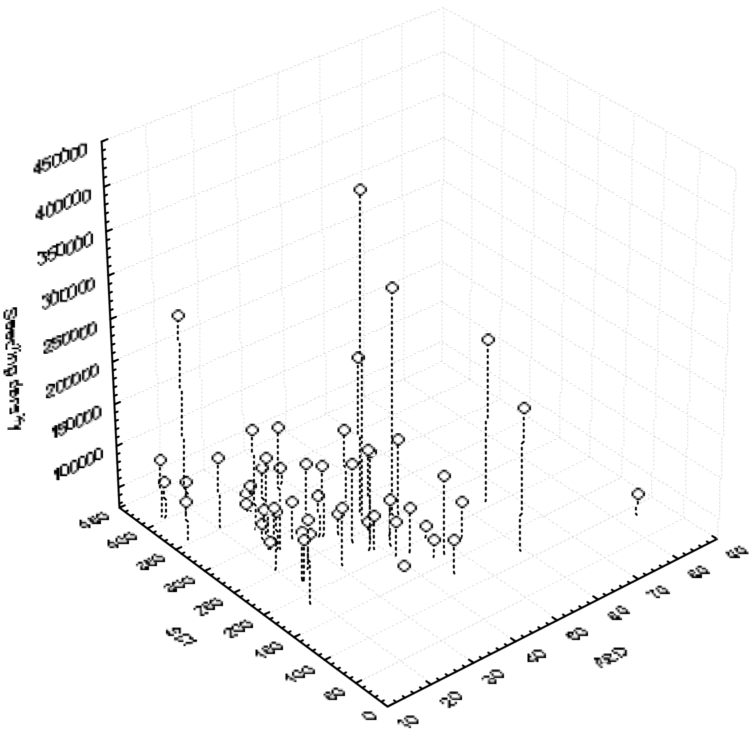
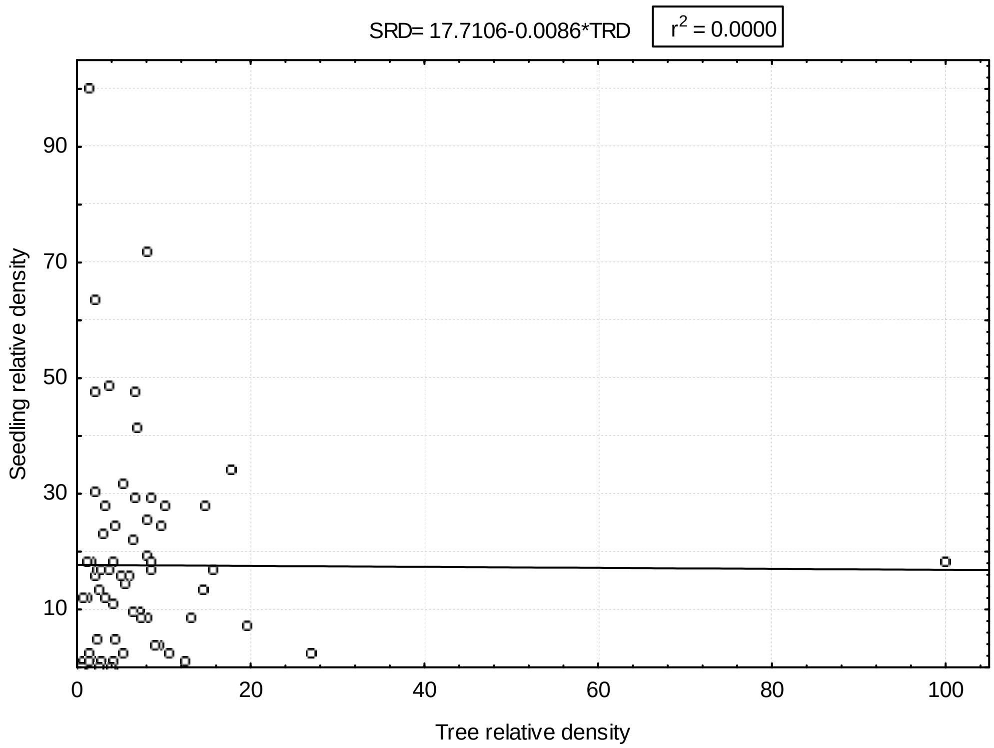


Figure 13: Scatter plots of Sal seedling density vs Sal tree relative density for Sal Forest in the western Terai of Nepal.



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Appendix 1

List of trees species with their codes, species names corresponding to the code and density (stems ha^{-1}) of trees species in different groups. Group 1 (*Shorea robusta-Buchanania latifolia*), Group 2 (*Terminalia tomentosa-Shorea robusta*) and Group 3 (*Shorea robusta- Cleistocalyx operculatus*).

Codes	Species	Density (stems ha^{-1})		
		Group 1	Group 2	Group 3
Shorob	*Shorea robusta*	33	24	94
Dilpen	*Dillenia pentagyna*	20	16	4
Tertom	*Terminalia tomentosa*	8	46	3
Buclat	*Buchanania latifolia*	110	96	5
Anolat	*Anogeissus latifolius*	0.5	-	0.1
Myrsem	*Myrsine semiserrata*	21	46	0.45
Malphi	*Mallotus philippensis*	5	2	4
Lagpar	*Lagerstroemia parviflora*	31	42	11
Schole	*Schleichera oleosa*	1.3	0.17	0.11
Cleope	*Cleistocalyx operculatus*	30	3	31
Adicor	*Adina cordifolia*	0.15	0.23	0.84
Syzcum	*Syzygium cumini*	1.58	0.59	0.46
Antchi	*Anthocephalus chinensis*	-	1.09	0.076
Semana	*Semecarpus anacardium*	20	6	-
Terbel	*Terminalia bellirica*	0.85	0.81	0.94
Picjav	*Picrasma javanica*	-	0.28	-
Baslat	*Engelhardtia spicata*	0.43	-	-
Desooj	*Desmodium oojeinense*	-	0.62	-
Paruli*	*Local name*	-	1.96	-
Cararb	*Careya arborea*	1.05	6	5
Ficben	*Ficus beghalensis*	0.4	-	-
Butmon	*Butea monosperma*	1.02	-	0.58
Holpub	*Holarrhena pubescens*	2.09	-	-
Acacat	*Acacia catechu*	1.07	-	-
Zizyph	*Zizyphus sps.*	0.46	0.58	2.01
Banrit*	*Local name*	-	-	0.05
Jingar*	*Local name*	-	-	0.20
Spapar**	*Spatholobus parviflorus*	0.35	2.58	-

'*'= Local name
'**'= Climber
'-'= absent

Appendix 2

List of trees species with their codes, species names corresponding to the codes and basal area (m^2 ha^{-1}) of trees species in different groups. Group 1 (*Shorea robusta-Buchanania latifolia*), Group 2 (*Terminalia tomentosa-Shorea robusta*) and Group 3 (*Shorea robusta- Cleistocalyx operculatus*)

Codes	Species	Basal area (m^2 ha^{-1})		
		Group 1	Group 2	Group 3
Shorob	*Shorea robusta*	6.25	5.12	10.89
Dilpen	*Dillenia pentagyna*	0.83	0.53	0.25
Tertom	*Terminalia tomentosa*	1.47	4.50	0.81
Buclat	*Buchanania latifolia*	0.89	0.79	0.12
Anolat	*Anogeissus latifolius*	0.13	-	0.03
Myrsem	*Myrsine semiserrata*	0.32	0.53	0.03
Malphi	*Mallotus philippensis*	0.13	0.18	0.13
Lagpar	*Lagerstroemia parviflora*	0.45	0.35	0.06
Schole	*Schleichera oleosa*	0.19	0.09	0.03
Cleope	*Cleistocalyx operculatus*	1.02	0.09	0.40
Adicor	*Adina cordifolia*	0.06	0.18	0.09
Syzcum	*Syzygium cumini*	0.06	0.09	0.12
Antchi	*Anthocephalus chinensis*	-	0.09	0.03
Semana	*Semecarpus anacardium*	0.13	0.09	-
Terbel	*Terminalia bellirica*	0.13	0.18	0.22
Picjav	*Picrasma javanica*	-	0.09	-
Baslat	*Engelhardtia spicata*	0.06	-	-
Desooj	*Desmodium oojeinense*	-	0.09	-
Paruli*	*Local name*	-	0.18	-
Cararb	*Careya arborea*	0.13	0.09	0.25
Ficben	*Ficus beghalensis*	0.06	-	-
Butmon	*Butea monosperma*	0.13	-	0.09
Holpub	*Holarrhena pubescens*	0.06	-	-
Acacat	*Acacia catechu*	0.13	-	-
Zizyph	*Zizyphus sps.*	0.06	0.09	0.09
Banrit*	*Ban ritha*	-	-	0.03
Jingar*	*Jingar*	-	-	0.03
Spapar**	*Spatholobus parviflorus*	0.13	0.18	-

'*'= Local name
'**'= Climber
'-'= absent

Appendix 3

List of trees species with their codes, species names corresponding to the codes and their frequency and relative frequency in different groups. Group 1 (*Shorea robusta-Buchanania latifolia*), Group 2 (*Terminalia tomentosa-Shorea robusta*) and Group 3 (*Shorea robusta- Cleistocalyx operculatus).*

		Frequency			Relative frequency		
Codes	Species	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Shorob	*Shorea robusta*	1.00	1.00	1.00	0.20	0.20	0.36
Dilpen	*Dillenia pentagyna*	0.50	0.46	0.14	0.10	0.09	0.05
Tertom	*Terminalia tomentosa*	0.67	1.00	0.41	0.13	0.20	0.14
Buclat	*Buchanania latifolia*	0.44	0.46	0.05	0.09	0.09	0.02
Anolat	*Anogeissus latifolius*	0.11	-	0.03	0.02	-	0.01
Myrsem	*Myrsine semiserrata*	0.33	0.38	0.03	0.07	0.08	0.01
Malphi	*Mallotus philippensis*	0.11	0.15	0.05	0.02	0.03	0.02
Lagpar	*Lagerstroemia parviflora*	0.33	0.31	0.05	0.07	0.06	0.02
Schole	*Schleichera oleosa*	0.17	0.08	0.03	0.03	0.02	0.01
Cleope	*Cleistocalyx operculatus*	0.44	0.08	0.30	0.09	0.02	0.11
Adicor	*Adina cordifolia*	0.06	0.15	0.08	0.01	0.03	0.03
Syzcum	*Syzygium cumini*	0.06	0.08	0.05	0.01	0.02	0.02
Antchi	*Anthocephalus chinensis*	0.11	0.08	-	0.02	0.02	-
Semana	*Semecarpus anacardium*	0.11	0.15	0.16	0.02	0.03	0.06
Terbel	*Terminalia bellirica*	-	0.08	0.03	-	0.01	0.01
Picjav	*Picrasma javanica*	-	0.08	0.03	-	0.01	0.01
Baslat	*Engelhardtia spicata*	0.06	-	-	0.01	-	-
Desooj	*Desmodium oojeinense*	-	0.08	-	-	0.01	-
Paruli	Local name	-	0.15	-	-	0.03	-
Cararb	*Careya arborea*	0.11	0.08	0.16	0.02	0.01	0.06
Ficben	*Ficus beghalensis*	0.06	-	-	0.01	-	0.00
Butmon	*Butea monosperma*	0.11	-	0.08	0.02	-	0.03
Holpub	*Holarrhena pubescens*	0.06	-	-	0.01	-	-
Acacat	*Acacia catechu*	0.06	-	-	0.01	-	-
Zizyph	*Zizyphus sps.*	0.06	0.08	0.08	0.01	0.01	0.03
Banrit	Local name	-	-	0.03	-	-	0.01
Jingar	Local name	-	-	0.03	-	-	0.01
Spapar	*Spatholobus parviflorus*	0.11	0.15	-	0.02	0.03	-

(- = absent)

Appendix 4

a) List of saplings with their codes, species names corresponding to the codes and density (stems ha^{-1}) in different groups.

Codes	Species	Density (stems ha^{-1})		
		Group 1	Group 2	Group 3
Shorob	*Shorea robusta*	2045.16	1969.49	278.86
Lagpar	*Lagerstroemia parviflora*	56.61	78.39	24.10
Buclat	*Buchanania latifolia*	77.84	137.18	-
Cleope	*Cleistocalyx operculatus*	99.07	107.78	79.18
Picjav	*Picrasma javanica*	14.15	29.40	6.89
Malphi	*Mallotus philippensis*	134.46	205.77	82.62
Holpub	*Holarrhena pubescens*	56.61	-	210.00
Zizphy	*Zizyphus sps.*	120.30	88.19	89.51
Baslat	*Engelhardtia spicata*	113.23	29.40	-
Semana	*Semecarpus anacardium*	21.23	-	-
Phorsa	*Grewia sps.*	92.00	9.80	213.45
Schole	*Schleichera oleosa*	7.08	9.80	3.44
Syzcum	*Syzygium cumini*	-	-	3.44
Casfis	*Cassia fistula*	7.08	29.40	-
Dilpen	*Dillenia pentagyna*	-	9.80	-
Kaphal	Kaphale*	7.08	29.40	27.54

('*'= Local name; - = absent)

b) List of seedlings with codes, species names corresponding to the codes and their density (plants ha^{-1}) in different groups. (- = absent)

Codes	Species	Density (plants ha^{-1})		
		Group 1	Group 2	Group 3
Shorob	*Shorea robusta*	49166.67	61538.46	87432.43
Picjav	*Picrasma javanica*	2222.22	-	-
Schole	*Schleichera oleosa*	555.56	769.23	405.41
Malphi	*Mallotus philippensis*	555.56	1923.08	1891.89
Aegmar	*Aegle marmelos*	-	384.62	-
Syzcum	*Syzygium cumini*	-	-	270.27
Tertom	*Terminalia tomentosa*	277.78	-	945.95
Buclat	*Buchanania latifolia*	1111.11	2692.31	-
Unid 15	*Unidentified*	-	384.62	-
Cleope	*Cleistocalyx operculatus*	-	3076.92	405.41
Semana	*Semecarpus anacardium*	1111.11	-	-
Desooj	*Desmodium oojeinense*	555.56	-	-
Engspi	*Engelhardtia spicata*	1388.89	-	-
Dilpen	*Dillenia pentagyna*	-	-	135.14
Lagpar	*Lagerstroemia parviflora*	277.78	-	540.54
Unid29	*Unidentified*	-	-	135.14
Cararb	*Careya aroborea*	-	-	270.27
Unid37	*Unidentified*	-	-	675.68
Zizyph	*Zizyphus sps.*	555.56	-	810.81
Ficrac	*Ficus benghalensis*	-	-	135.14
Holpub	*Holarrhena pubescens*	-	-	135.14

Appendix 5

List of shrubs with their codes, species names corresponding to the codes and shrub density (plants ha^{-1}) in the different groups.

			Density(plants ha^{-1})	
Codes	Species	Group 1	Group 2	Group 3
Flestr	*Flemingia strobilifera*	254.76	215.57	82.62
Calmac	*Callicarpa macrophylla*	14.15	-	0.00
Phupha	*Indigofera pulchella*	35.38	117.58	20.66
Phylan	*Phyllanthus sp.*	148.61	-	-
Flecha	*Flemingia chappar*	-	29.40	6.89
Clevis	*Clerodendrum viscosum*	7.08	-	86.07
Hedyo	*Hedyotis sp.*	7.08	-	-
Elsbla	*Elsholtzia blanda*	-	-	37.87
Pogbeg	*Pogostemon benghalensis*	-	-	27.54
Grewia	*Grewia sp.*	-	-	3.44