Ecological Studies on the Grasslands of Eravikulam National Park, Kerala

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CERTIFICATE

I have great pleasure in forwarding the thesis of ***Mr. P.V. Karunakaran*** *titled* ***"Ecological studies on the Grasslands of Eravikulam National Park, Kerala"*** *for the award of the degree of* ***Doctor of Philosophy*** *in* ***Wildlife Science (Botany)****. The thesis embodies original findings and interpretation of facts. This research was carried out by Mr. Karunakaran under my supervision and has not been submitted in part or full to any other University/Institution for the award of any degree.*

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CONTENTS

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SUMMARY

1. An ecological study on the montane grasslands of Eravikulam National Park (ENP), the Western Ghats, was conducted during 1992-1996, with the following objectives: (i). to prepare a complete floristic inventory of the grasslands of ENP, (ii). to identify the grassland communities, their structure, function and successional trends along the anthropogenic gradient, (iii). to determine the forage quantity in different ecological conditions and (iv). to study the effect of fire and tree plantations on the grasslands.

2. The ENP lies between 10° 5' to 10°20' N and 77° to 77°10' E with an area of 97 km² in the Southern Western Ghats. The average altitude of the plateau is 2000 m and the highest peak, Anamudi, reaches 2695 m. Soil was acidic with pH ranging from 4.6 to 4.8. The climate was dominated by monsoon. During the study period the annual rainfall ranged from 4697 to 5540 mm. Winter days (Nov- Jan) were cooler and frost was common. The two distinct physiognomic units of vegetation are grasslands and sholas, unique to the Western Ghats.

3. The study area was stratified into eight landscape units viz., slope without rocky outcrops, slope with rocky outcrops, flat top, valley, bog, shola-grassland edge, cattle grazed and scraped areas. Systematic surveys and vegetation parameters such as species association, frequency, diversity, evenness and richness were studied in each landscape unit by laying relevés of 5 m radius.

4. 308 plant species were collected from the grasslands, adding 106 new species to the earlier list. 51 species were found to be endemic to the grasslands and 29 were listed as rare and endangered species. There were 64 species common with Eastern Ghats, 30 species with Patanas of Sri Lanka, 35 with Western Himalaya and 35 with Naga and Khasi hills indicating phytogeographical affinities with different biogeographic zones.

5. Vegetation association was derived using 'TABLE TRANSFER METHOD' and TWINSPAN (computer packages). TABLE TRANSFER method identified 23 vegetation associations and TWINSPAN identified 15 associations. In both the analyses it was found that *Chrysopogon zeylanicus* and *Sehima nervosum* were the two dominant species. The diversity index (H') of the associations ranged from 1.38 in the *Artemisia nilagirica-Heteropogon contortus-Cymbopogon flexuosus* (cattle grazed area) to 2.90 in *Agrostis peninsularis-Eulalia phaeothrix-Chrysopogon zeylanicus* in the shola-grassland edges. Vegetation ordination i.e., Canonical Correspondance Analysis (CANOCO) indicated that clay, pH and sand were important environmental factors which determined the species distribution and abundance.

6. Biomass study was conducted at three sites in three dominant communities viz., *Chrysopogon zeylanicus, Sehima nervosum* and *Cymbopogon flexuosus*. Clipping was done both inside the exclosure and outside to obtain net primary productivity (NPP). The NPP values showed that these grasslands are between tropical and temperate grasslands . Outside the exclosures NPP was maximum at Eravikulam and minimum at Lakkamkudi. But inside the exclosures all the three sites were having nearly equal amount of NPP. Above ground biomass (ANP) was maximum at Eravikulam inside the exclosures and less at Rajamala, where as below ground (BNP) biomass was more at Rajamala and less at Lakkamkudi. Rate of biomass production was more (3.1 g $m^{-2}day^{-1}$) at Eravikulam inside the exclosure and less (0.8 g m^{-2} day^{-1}) at Lakkamkudi outside the exclosures. In all the communities monocots contributed more to the ANP (59-97 %) than dicots (3-41%). In Lakkamkudi *Pteridium aquilinum* (fern) contributed 10 % to the ANP. *Sehima nervosum, Heteropogon contortus* and *Chrysopogon zeylanicus* were the three dominant grass species according to ANP. The annual removal of ANP by cattle and wild ungulate from Lakkamkudi was 68 %.

7. Burning (early and late) was done in *S. nervosum* (Anamudi) and *C.*

zeylanicus (Rajamala) community. It was found that both in the early and late burnt areas no significant changes were noticed on species diversity, richness and evenness. Regarding the structure of the vegetation, cover value of dicots showed significant difference between early and late burnt in different months. Both early and late burning affected the regeneration of *Phlebophyllum kunthianum*.

8. A comparison of various sites with different density and age of wattle plantations with unplanted area showed that the number of endemic species and food species of Nilgiri tahr decreased with increase in the age of plantation. The increase in weed abundance with the age of plantation indicated more harm to the natural vegetation. The diversity index (H') was 2.64 in 10 year old plantation and 1.87 in 3 year old. TWINSPAN identified two plant species associations each in unplanted, 3 year old and five year old plantations, and four in 10 year old plantation.

9. The study recommends the following research and management strategies for the long term conservation of Shola-Grassland ecosystems and endangered Nilgiri tahr: (a) inclusion of adjecent reserved forests with shola-graslands in the park, (b) boundary verification and better patrolling to check the illegal activities and fire hazards, (c) early burning in selected areas on experimental basis, (d) control of black wattle spreading, (e) eco-development measures for the Lakkamkudi village, (f) better tourism management and (g) long term monitoring of exclosures and representative shola-grassland patches.

List of Tables

List of Figures

List of Plates

Chapter 1

INTRODUCTION

1.1 The grasses and grasslands

The grasses (Poaceae) form a natural and homogenous group of plants with remarkable diversity in morphology. Grasses have a cylindrical hollow stem strengthened at intervals by transverse septa called nodes. The leaf blades are borne on sheaths, encircle the stem, arise alternately at the nodes, and are serially arranged. The inflorescence consists of one or more spikelets, each made up of a series of scales in the axils of which are found the flowers. Poaceae (Graminae) forms the fourth largest family among flowering plants, with *ca.* 10,000 species in 700 genera (Bor, 1960). It is an important group of plants playing a vital role in the life of human beings and animals in the form of food, fodder, medicine, oil, etc.

Mankind is sustained more by grasses than by any other group of plants. Man's intimate relationship with grasses dates back to the Paleolithic time when he learnt to burn the forests, domesticate livestock and cultivate cereals (Leafe, 1988). His existence, in the present numbers and quality of life, would be rather impossible without grasses. A major part of wild fauna, e.g., 477 (20 % of the total) species of birds and 245 (6% of the total) species of mammals are solely dependent upon grasslands (Groombridge, 1992). Yet grassland ecosystems have not received the desired attention and have been largely neglected in terms of conservation and proper management, except grazing lands, especially in developing countries including India (Rahmani, 1989).

Grassland is a landscape unit dominated by grasses (Coupland, 1978, Yadava & Singh, 1986). On the other hand, savanna vegetation is characterised by a continuous graminoid stratum, interrupted by trees or shrubs (Johnson & Tothil, 1985). Grasslands extend over about 24% of the world's vegetation (Shantz, 1954). In the tropical and sub tropical plains and mountains of the world, nearly 23% of land is covered by the grassland vegetation. In Asia they account for about 20% of land cover (Premadasa, 1990). It has been estimated that grasslands covered approximately 40% of the earth's land surface prior to the impact of man and domesticated animals (Clements & Shelford, 1939).

The physiognomy, phenology and diversity of grasses varies with rainfall, topography and type of soil. Temperate savannas are called prairies and steppes and tropical ones are paramos (Sarmiento, 1992). The grazed pampas of South America are richer than tropical savannas in diversity. In Africa, the average species richness in the savanna is not far below that of rainforests (Groombridge, 1992).

The richest grassland regions of the world, in descending order of indigenous plants and animals, are African savanna, Eurasian steppe, South American savanna, North American prairies, Indian savanna and Australian grasslands. In Asia, Mongolia supports the most extensive and natural grasslands (Groombridge, 1992). The seral nature of Indian grasslands due to reclamation (clearance), fire, overgrazing, erosion or abandonment has greatly influenced the composition of flora and fauna (Yadava & Singh, 1986).

The biodiversity of grasslands are usually enhanced by moderate land uses such as grazing and periodic fire (Risser, 1991). But overgrazing, conversion of natural areas into croplands, hunting, monoculture plantations and ill-planned developmental activities have caused loss of biodiversity in the grasslands, especially in the Indian subcontinent. For example, birds like Great Indian Bustard (*Ardeotis migriceps*) and Bengal Florican

(*Houbaropsis bengalensis*) have become locally extinct in several grasslands where they were present earlier (Goriup & Karpowiz, 1985).

The study on Canadian prairies by Mondor & Kun (1982), on Lesser Florican (*Eupodotis indica*) in India by Goriup & Karpowiz (1985) and the IUCN (1991) review on semi-natural grasslands of the world have identified the ever increasing intensive agricultural practices as the major factor responsible for the loss of grasslands. Similarly, it is estimated that the Canadian prairies are vanishing at the rate of 500 km^2 per year due to agriculture, and plantations (Bakker-Gabb & Lunt, 1990).

The role of protected areas (PAs) in conserving biodiversity is unquestionable. While the majority of the PAs (national parks and sanctuaries) do contain grasslands, yet these are too small to conserve the whole range of biodiversity. The network of PAs has done relatively little to conserve biodiversity of the grasslands, for only 0.3% of the original area throughout the world has come under such network, that too with little of the original diversity (Groombridge, 1992).

1.2 The grassland vegetation of India

The Indian subcontinent supports highly diverse ecological conditions, ranging from warm humid plains of the west coast to cold arid regions of Ladakh abutting the Tibetan plateau. The subcontinent is located at the junction of three major biogeographic regions viz., Palaearctic, Malayan, and Ethiopian. It has a wide latitudinal zonation, varied topography and climatic zones (Mani, 1974). Owing to its biogeographic affinities and topographical diversity, the sub-continent is blessed with different types of biota that make India one of the 12 megabiodiversity centres of the world (Khoshoo, 1994).

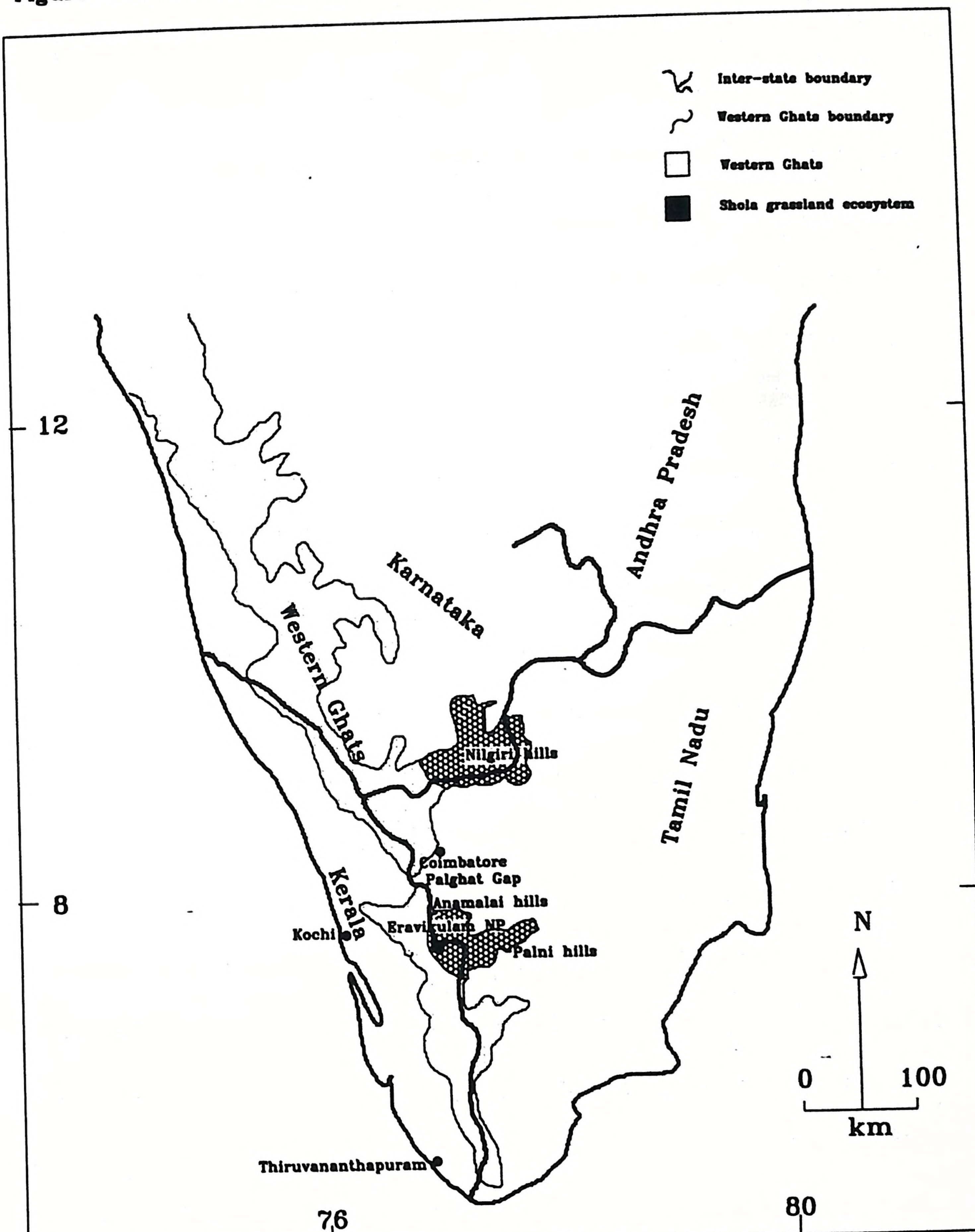
In India, grasslands constitute one of the major biomes. These grassland formations are categorised into five major types (Dabadghao & Sankaranarayan, 1973), viz., i) *Sehima-Dichanthium* type covering tropical regions such as peninsular India, Central Indian Plateau, Chota Nagpur plateau, and Aravalli ranges, ii) *Dichanthium-Cenchrus-Lasiurus* type distributed over sub-tropical and semi-arid regions comprising portions of Gujarat, whole of Rajasthan (excluding Aravalli ranges), Western Uttar Pradesh, Delhi and Punjab, iii) *Phragmites-Saccharum-Imperata* type covering Gangetic and Brahmaputra plains, iv) *Themeda-Arundinella* type found in the north western montane tracts, and v) Temperate-Alpine type covering high altitude regions of Himachal Pradesh, Jammu & Kashmir and Uttar Pradesh.

All the natural and semi-natural grasslands maintained by livestock/wildlife are collectively known as Rangelands and in India 39.8% (13,813 km^2) of the land falls under this category (Singh, 1988). Of all the states in India, Madhya Pradesh and Andhra Pradesh have the largest extent of grasslands with 46 and 41 percent of total land under them respectively (Singh, 1994). In Kerala, grasslands extend over an area of about 200 km^2 (Anon. 1991). Grasslands are called as *Pulmedu* in Kerala, *Bugyal* for alpine meadows in Uttar Pradesh, and *Marg* in Kashmir.

1.3 The montane grasslands of the Western Ghats

The upper reaches of the Western Ghats (WGs) are considered as one of the most diverse and interesting biomes in India (Nair, 1994). Of all the formations, the montane (above 1500 msl) grasslands of the WGs are the most interesting, due to their physiognomy. These grasslands are located in the high plateaus of the WGs, mainly in the Nilgiris, Anamalais and Palni hills (Figure 1.1). The distribution of these grasslands were governed by complex topography, high rainfall, wind, fire and other factors (Gadgil & Meher-Homji, 1985). These grasslands are dotted with montane evergreen forests

Figure 1.1: Distribution of Shola-Grassland vegetation in the Western Ghats



which are restricted to the valleys or depressions. These mosaics of vegetation are popularly known as *shola*-grassland formations and are comparable to the south African montane grasslands (Meadows & Linder, 1993) and *Patanas* of Sri Lanka (Premadasa, 1984).

The distinct structure and stability of these grasslands have produced different theories regarding their origin and ecological nature. Studies by Menon (1967), Gupta (1971), Blasco & Thanaikamoni (1971), Vishnu-Mittre & Gupta (1971), Vasanthy (1988) and Sukumar *et al.* (1993) emphasized the evolution of this vegetation in relation to global climatic changes i.e., shift from cooler epoch to warmer epoch. Later, anthropogenic factors such as fire played a major role in maintaining their stability (Nair, 1994). Ranganathan (1938), on the other hand, believed that these are climax formations.

The *shola*-grassland formations were extensive during the past (Vishnu-Mittre & Gupta, 1971). But increasing demands for food, industry and other developmental activities jeopardised this unique ecosystem by converting the land into agricultural and forestry areas. A few residual stretches are now found only in the Nilgiri, Anamalai and Palni hills covering an area of about 400 km^2.

Although these tracts fall latitudinally in the tropics, they exhibit extra tropical climate due to altitudinal influence. This change in bioclimate and geological stability enhances endemic values of the area (Karunakaran *et al.*, 1994). High elevations of the WGs are considered botanically rich areas in India (Shetty & Vivekanandan, 1971). With respect to the balsams (*Impatiens*), the High Ranges of Anamalai hills are the richest in the world (Barnes, 1939). The montane flora of WGs show affinities with the Assam, Malayan and Indo-Chinese biota. There are many temperate species such as *Mahonia leschnaultii, Gaultheria fragrantissima* and *Berberis tinctoria.* Medicinal and wild varieties of cultivated plants such as sundew (*Drosera peltata*), pepper (*Piper schmidtii*) and cardamom (*Elateria cardamomum*) add to the conservation significance of this area. The highly endangered Nilgiri tahr (*Hemitragus hylocrius*), is a typical animal of these grasslands. Besides, the aesthetic values of these landscapes are of utmost importance. Col. Douglas Hamilton, the first explorer of this area, described the Eravikulam plateau as "surpassingly grand and incomparably beautiful" (Baig & Henderson, 1978). The tranquillity and the "charisma" of this landscape has always been an attraction to people who would like to hike and seek the pleasure of the land.

1.4 Justification for the present study

The vegetation along the hill tops of the WGs is interesting in terms of species composition, phytogeography, physiognomy and the characteristic ecological conditions which have led to the evolution of relatively stable grassland-forest interphase. In recent times these areas have degraded drastically due to the cultivation of cash crops such as tea and monoculture plantation of exotic *Eucalyptus* and wattle (*Acacia* sp) for pulp wood and tannin industries. In Kerala, between 1985 and 1990 about 16.25% of rich forests were cleared for raising commercial plantations of rubber, oil palm, coffee, cardamom etc (Basha, 1990). The World Bank aided Social Forestry Scheme of the 1980s is reported to have severely changed the structure and composition of the *shola*-grassland complex in Kerala through plantation of exotic species (Nair, 1994). As a result, the once vast stretch of montane grassland vegetation in the Nilgiris, Anamalais and Palnis remains only as small isolated patches (Nair, 1994). The effect of these plantations on vegetation and natural resources has not been studied properly. Incidentally nearly 400 km^2 of partially disturbed and undisturbed patches are protected throughout the WGs in the form of sanctuaries, national parks and reserved forests.

The floral characteristics and the ecological aspects of the montane grasslands in the WGs have been described by many authors, e.g., Fyson (1932), Bor (1938), Sankaranrayanan (1958), Gupta (1960), Meher-Homji (1965,1967), Sebastine & Vivekanandan (1967), Blasco (1970), Legris (1963, 1972), Shetty & Vivekanandan (1971), and Sreekumar & Nair (1991). But quantitative information on the patterns of diversity, vegetation structure and function under various ecological conditions are inadequate. The effect of fire, which can be an excellent management tool but goes out of control in these grasslands, on soil or on natural biota is also unknown. Information on the above aspects is a prerequisite for the conservation and management of biodiversity in these areas.

Therefore, the present study was undertaken in Eravikulam National Park (ENP), which is one of the few remaining areas with a continuous stretch of less manipulated vegetation where a population of 600-800 (total population is nearly 2000) highly endangered Nilgiri tahr exists (Mishra & Johnsingh, 1995). It is expected that the findings of this study will add to the present day knowledge on the ecology of these grasslands. It will also help the protected area managers to evolve better conservation strategies for the montane grasslands of the WGs.

1.5 Objectives

The objectives of the present study are:

1. To prepare a floristic inventory of the grasslands of ENP.
2. To identify the grassland communities, their structure, function and successional trends along the anthropogenic gradient.
3. To determine the plant biomass in different ecological conditions.
4. To study the effect of fire and tree plantations on the grasslands.

1.6 Organisation of the Thesis

This thesis is composed of nine chapters. The following chapter is based on available literature pertaining to montane vegetation in general, and on taxonomy, ecology and palynology in particular. The third chapter describes the study area in the context of topography, geology, climate, vegetation, past management practices, existing human pressure, and research input. The fourth chapter broadly describes methods, both field and analytical. Apart from this, detailed methodology is given in each concerned chapter.

The fifth chapter describes floral inventory, phytogeographical affinities with different biogeographic regions and conservation status of grassland species. The sixth chapter is on vegetation composition, structure, phenology and species ordination with edaphic factors. The results are presented in detail for each landscape unit. The seventh chapter describes biomass production in three different communities where the grazing pressure is different. This chapter explains the effect of exclosures and grazing on productivity. The eighth chapter is on the effect of fire and black wattle plantation on the structure and composition of grassland vegetation. The last chapter concludes the findings and gives specific management recommendations.

Chapter 2

LITERATURE REVIEW

The high altitudes of the Western Ghats (WGs) represent one of the most interesting vegetation types in India. Scientists, foresters, and naturalists including hunters and explorers have contributed significantly towards the advancement of our knowledge on the flora, fauna and natural history of this region. A persual of the published literature on the ecology of the *shola*-grassland ecosystem of the WGs shows that Nilgiris and Palnis are better studied regions compared to Anamalai hills. An overview of the literature on this ecosystem is presented below.

2.1 Floristics and phytogeography

After the publication of "Hortus Malabaricus" by Rheede during 1678-1703, numerous botanical expeditions have been undertaken in the Kerala section of the WGs. Sir J.D.Hooker (1872-1897) published the plants of WGs in the Flora of British India. Initially, British officials such as Logan (1883), Bourdellon (1908) and Rao (1914) explored and compiled lists of plants of this area. Some species of montane region were described by Gamble (1935). The first detailed floristic work exclusively on south Indian hill tops was published by Fyson (1915). This is perhaps the only extensive study on the floristics of montane regions of the WGs. According to him the representation of *Impatiens* sp., and the numerous varieties of orchids indicates that the WGs are one of the botanically richest areas in south India. Later, Pallithanum (1957) updated the flora of this region by collecting plants from the Palni (Kodaikanal) hills. Mathew (1959) enumerated the flowering plants of grassy slopes around Kodaikanal. Gupta & Rege

(1965) described two major types of grasslands in the Nilgiris dominated by *Chrysopogon zeylanicus* and *Dichanthium polyptychum*. Hooker (1897), Fyson (1915) and Razi (1955) observed a number of species common to the south Indian hills and Eastern Himalayas, particularly the Khasi hills. Gupta (1962) explained the similarity between the vegetation of Western Himalayas and South Indian hill tops with the help of common species found in these two widely separated mountain ranges. Sebastine & Vivekanandan (1968) listed the species in and around Devikolam, Kerala. Later, a detailed study on the flora of Anamudi and surrounding region was published by Shetty & Vivekanandan (1969, 1970, 1971, 1972, 1973a,b,c, 1981, 1991). They recorded a total of 400 species from *shola* and grasslands, of which 143 are from grasslands alone. Eight new taxa were described by them in addition to twenty eight rare and endangered species. Of the three montane regions of WGs, i.e., Nilgiris, Palnis and Anamalais, Blasco (1970) found more endemics in the Nilgiris (82 species) than in Palnis (18 species) and Anamalais (13 species). He concluded that the Nilgiris is an important centre of speciation in south India, next only to Travancore and Tirunelveli. Meher-Homji (1975) opined that a slow rate of migration during the Pleistocene glaciation was the reason for the floral affinities between WGs and the Himalaya, rather than long distance dispersal by birds and wind from the Himalaya. Henry *et al.*, (1979) found 92 rare and threatened species from south Indian hill tops. Jain (1986) briefly discussed the floristics, phytogeography, status and uses of grassland species of south India. From Eravikulam National Park, grasses were collected by Rice (1984) and Sreekumar & Nair (1991). But their lists are incomplete. Mathew & Mathew (1991) described 75 threatened species from the high altitude region of Kodaikanal.

Chandrasekharan (1968) classified high altitude vegetation of WGs as Wet Temperate Forests and Montane Grasslands. According to Champion & Seth (1968), the vegetation of montane region of south India is classified under Southern Montane Wet Temperate Forest (2A/C), Southern Montane Wet Scrub (2A/DS1) and Southern Montane Wet Grassland (2A/DS2). Gadgil & Meher-Homji (1985) classified these forests under the biogeographic region of Wet Evergreen Forest of WGs, and the vegetation type as Montane Shola.

2.2 Ecological studies

The juxtaposition and apparent stability of the *shola*-grassland ecosystem has been a subject of varied interest and controversy over the years. One school of thought (Bor 1938) believes that grasslands represent the sub-climax vegetation that is anthropogenic in origin. On the contrary, Ranganathan (1938) is of the view that both *shola* and grasslands represent climax communities that are harmoniously placed. It has been observed that *sholas* are more abundant on the morning sun protected (western) slopes where the danger of freezing is neutralised by moving water (von Lengerke & Blasco, 1989), confirming the role of frost on regeneration. The frost bitten grass recoups owing to its perennial root stocks. Bor (1938) considered Ranganathan's theory as untenable and opined that the *shola* forests are the relicts of evergreen forest climax which have been pushed back to their last stronghold by fire and grazing. According to Jaydev (1957) grasslands represent a pre-climax stage. Puri (1960) stated that in India the monoclimax theory of Clements (1928) holds good. The edaphic and bio-edaphic communities were recognised to be seral in nature. Meher-Homji (1965, 1967, 1969) studied the ecological status of *shola* grassland in the Nilgiris and Palni Hills. He described south Indian hill top vegetation comprised of *shola*, shrub zone and shrub-savanna. While accepting the adverse effect of fire on the distribution of *shola*, he feels that the explanation of fire as the only agent limiting the spread of *shola* is inadequate. According to him the climate of these hill stations is not temperate, but tropical montane in nature. He further explained that destruction of *shola* leads to scrub savanna which, on further degradation, gives rise to grasslands and ultimately to barren rocks. Dabadghao & Sankaranarayan (1973) justified that grasslands rarely occur as climatic climax in India and generally represent secondary seres. They also opined that relatively more stable grasslands constitute a biotic climax that can be converted into disclimax under the influence of fire and grazing in varying intensities and combinations. They concluded that *Andropogon polyptychus* forms climax vegetation at high altitudes in the Nilgiris and with *Chrysopogon zeylanicus* is a subclimax stabilized by biotic factors such as fire, grazing, frost and erosion. This is considered to be the montane phase of the broad *Sehima-Dichanthium* type. Puri *et al.* (1989) believe that any seedlings of the forest species that may have germinated in the savannas are eliminated because of low humidity and frequent fire. Nair (1994) stated that the extensive grassy downs in the upper ghats are most possibly the result of recurrent fire and the consequent modified local edaphic conditions. Jose *et al.* (1994) studied the structural, floristic and edaphic attributes of the *shola*-grassland vegetation in Eravikulam NP and described this vegetation as an expression of complex environmental interactions. They observed that *Arundinella vaginata* contributes more to the grassland productivity than any other species.

Pascal (1988) argued that frost may have been the cause of formation and maintenance of some savannas at high elevations prior to human influence. Grasslands in the lower altitudes are normally tree or shrub savannas. On the other hand, in the upper plateaus ligneous elements are represented by herbs and few shrubs such as *Hypericum mysorense* and *Phlebophyllum kunthianum*. Apart from this, the grasslands of lower reaches are characterised by tall grasses of 1-2 m, while those in the upper reaches are below 1 m (Misra, 1983).

Although the physiognomy of *Patanas*, the tropical montane grasslands of Sri Lanka, is strikingly similar to high altitude vegetation of peninsular India, Premadasa (1984, 1990) strongly argued against their common origin. Some *patanas* are biotically derived disclimaxes, while others are climatically derived edaphic climaxes where the soil conditions for the development of forest vegetation is unfavourable. Multivariate analysis with soil fungi confirms the classification of *patanas* into different sub-groups (Premadasa, 1984).

2.3 Palynological studies

Palynological studies of WG montane plateaus have been carried out by the French Institute, Pondicherry and Birbal Sahni Institute of Palaeobotany, Lucknow. Most of these studies have been carried out in the Nilgiris near Kakathope, Rees Corner and Sandyanallah Sheep Breeding Station (Gupta, 1971). The Anamalais and Palnis have not been extensively explored for pollen grain studies. Menon (1967) studied the peat bogs of Pykara and concluded that the dominant vegetation during late Quarternary period was graminaceous, indicating warmer climate, and it gradually gave way to the arboreal species when the temperature decreased. When the climate became warmer again, the forest vegetation degraded and grasslands took over the plateau. The formation of *shola* forest commenced about 35,000 years ago through gradual invasion of grassland under a regime of low precipitation, and the absence of frost and high wind. The present distribution of *shola* forest is either due to the destruction by man, and the formation most of the grasslands are due to anthropogenic activities (Vishnu-Mittre & Gupta, 1971). Blasco & Thanikaimoni (1971) stated that the issue of discontinuous distribution of species common to south Indian hill tops and the Himalaya, whether it is due to recent migration of species, Pleistocene glaciation, or a result of polytopism remains to be settled unequivocally. While comparing the pollen samples of Kakathope and Rees Corner, Ootacamund, Gupta (1971), concluded that the grasslands are pioneer groups in the Nilgiri plateaus. The prevalence of open vegetation during early stage decidedly indicates the pioneer status of grasslands. The formation of *shola* forest commenced in seral stages with a few shrubs and *Rhododendron* in grasslands, to a dense tropical vegetation characteristic of *shola* forest. Gupta (1971) expressed that deterioration of *shola* forest started during warm and humid climate. According to Vasanthy (1988), the montane grasslands existed in the area since *ca*. 30,000 years BP. It is probable that frost and soil factors have been the important determinants in maintaining and stabilizing the swampy upland savanna. Grazing and periodic burning appear to have been much less significant.

Sukumar *et al*. (1993, 1995), in the study conducted in the peat bogs of Nilgiris, confirmed that key climatic shifts are known to have occurred during the last glacial maximum and the subsequent deglaciation. In addition, they observed an arid phase from 6000-3500 years BP and a short dry phase about 600 years ago. The oscillating climate and vegetation has influenced the structure and composition of the montane ecosystem. Grasslands dominated by C_4 type grasses were prevalent 18000 to 20000 years BP. The intervening periods were dominated by forest and grasslands of C_3 grasses. During later years, the expanding of grasslands and diminishing of *sholas* are presumed to be related to changes in moisture and atmospheric CO_2 levels (Sukumar *et al*., 1995).

2.4 Studies in Eravikulam National Park

The *shola*-grassland complex of Eravikulam National Park (ENP) and associated animals have been studied by different authors. Shetty & Vivekanandan (1971) conducted a survey of vascular plants in and around Anamudi. Rice (1984) studied the ecology and behaviour of Nilgiri tahr. Sreekumar & Nair (1991) collected grass species as part of a taxonomic study on the grasses of Kerala. Jose *et al.* (1994) studied the structural, floristic and edaphic attributes of the *shola*-grasslands, but largely described *shola* forests. Madhusudan (1995) studied the post rutting behaviour of Nilgiri tahr. Easa (1996) studied prey-predator relationships in ENP. However, no study has been undertaken on the structure, function and successional trends of grassland communities, from the management point of view. Therefore, a study was initiated in ENP by the Wildlife Institute of India on the ecology of the grassland communities, successional trends, and the effect of fire and wattle plantations on this ecosystem.

Chapter 3

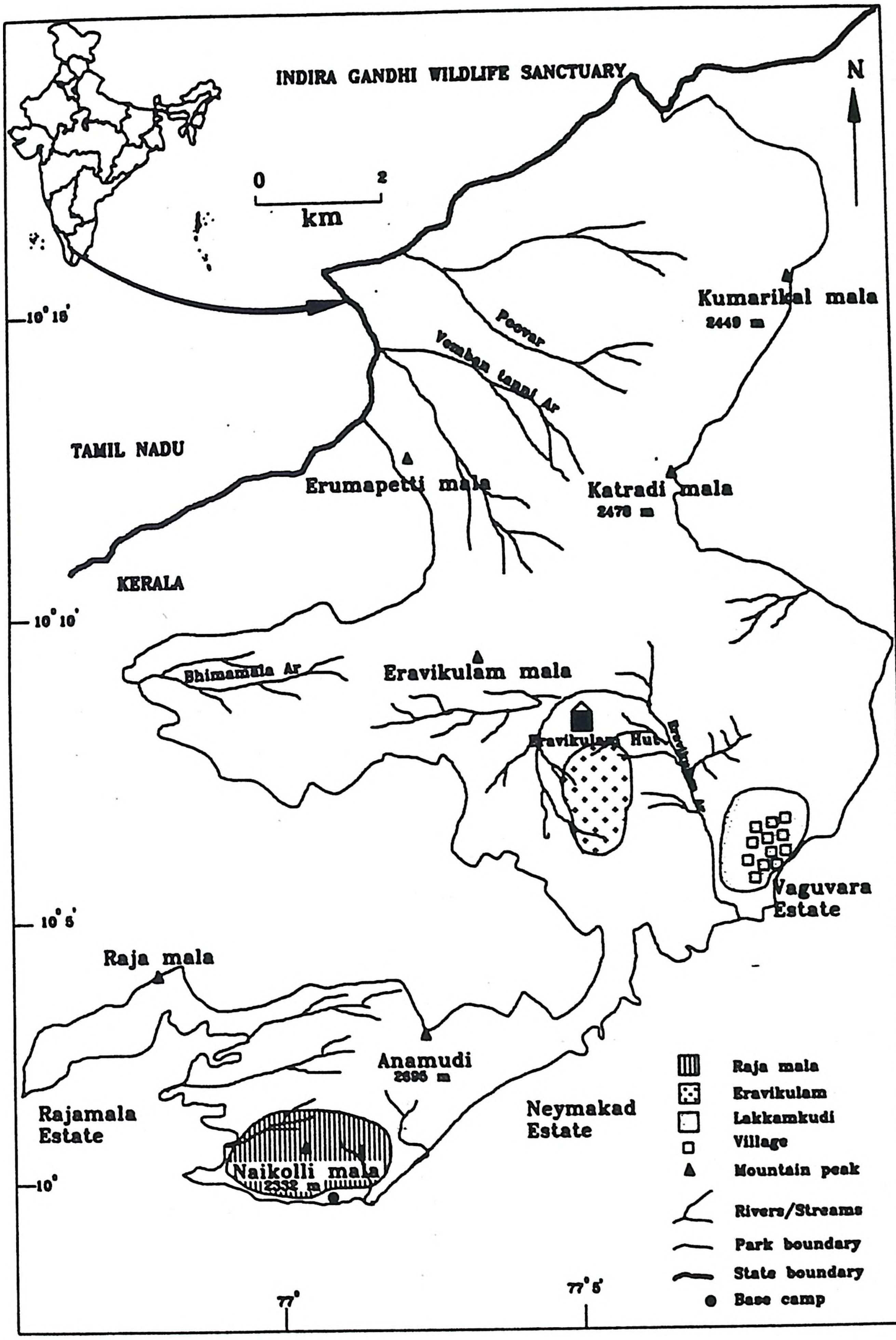
3.0 THE STUDY AREA

This study was conducted in Eravikulam National Park (ENP), Kerala. The park is well known for the largest population of Nilgiri tahr (*Hemitragus hylocrius*, Ogilby) an endangered mountain goat, endemic to south India, and for an important landmark i.e., Anamudi, the highest peak (2697 msl) in peninsular India. The park represents one of the least disturbed *shola*-grassland ecosystems in the Western Ghats. The high plateau forms an important catchment for the east and west flowing hill streams of south central Kerala.

3.1 Geography

The Western Ghats (WGs) run along the west coast of peninsular India along a north-south gradient, beginning at the Tapti river in the north and extending up to Kanyakumari in the extreme south. The only major gap in this stretch is known as the Palghat Gap (*ca.* 33 kms). The Ghats abruptly rise from sea level in the west to a highly dissected plateau up to 2700 m in height. This mountain range blocks the south-west as well as north-east monsoons, causing an extreme gradient in precipitation on either side. In the 1500 km stretch of the WGs, three divisions are recognised: (i) Tapti river to Goa, (ii) Goa to Nilgiris and (iii) Palghat gap to extreme south, known as southern WGs which comprise Anamalais, Nelliyampathis, Palni hills, High Ranges, Cardamom hills, High Wavies and Ashambu hills (Nair, 1991). These hills together form the richest centre of endemism in peninsular India (Ahmedullah & Nayar, 1985). Among them, Anamalai and Palni hills are well known for their rich montane vegetation. However, montane habitats of Palni hills have been severely modified by plantations of exotic species.

Figure 3.1: Location and details of Eravikulam NP with intensive study areas



Eravikulam National Park is situated in the High Ranges of the southern WGs in Idukki district of Kerala state. It lies between 10°5' to 10°20' N and 77° and 77°10' E, and covers an area of 97 km^2 (Figure 3.1). Anamudi is situated in the southern corner of the park, and the central plateau is known as Hamilton's plateau. There are three mountain ridges radiating from this peak, viz., Anamalais towards north, Palnis to the east and Cardamom (Elamalai) Hills to the south-west. The average altitude of the Eravikulam plateau is about 2000 m and there are a few peaks and knolls that rise from this table land and reach an altitude of 2300 m or more e.g., Kattumala (2478 m), Kumarikkal (2449 m), Umayamala (2368 m) and Naikollimala (2332 m). The vast expanse of undulating grasslands that lie below Anamudi is roughly divided into two halves *viz.*, south-east and north-west by a deep valley (about 600 m) called Turner's valley. The plateau is contiguous with Grass Hills, a similar *shola*-grassland habitat in Indira Gandhi Wildlife Sanctuary of Tamil Nadu state to the north and Chinnar Wildlife Sanctuary of Kerala to the north-east. The park is bordered by private tea estates (Vaguvara) and Munnar Reserved forest to the east. The southern boundary is shared by Neymakad and Kadalar Tea Estates. The western limit of the park is marked by Munnar & Malayattoor Reserved forests of Kerala.

The park is accessible from Kochi and Coimbatore airports which are located at about 140 km each. Munnar is the nearest town, located 14 km south of Anamudi peak. Munnar in Malayalam means three rivers (*munnu*=three, *ar*=river) which are Nullathanni Ar, Palar and Muthirapuzha, all of which drain into the Periyar river. The park lacks a network of motorable roads but there is one road passing through the southern boundary (Rajamala) to the Pettimudi tea estates on the western side. From the east, entry to the park is through Vaguvara tea estate. A trail is connected from Vaguvara to Eravikulam hut (the only accommodation) in the centre of the plateau and further to Poovar in the northern sector of the park.

The southern fringe of the park is mostly precipitous with broken cliffs descending from Anamudi, Umayamala and surrounding massifs. The cliffs are usually round with exposed surfaces. The sharp escarpments and cliffs on all sides of the park make this area an isolated table land that is responsible for the unique microclimate. The unsuitability of soil for agriculture, inaccessibility and extreme climate has helped the land remain free from human developmental onslaught.

3.2 Geology and soil

The underlying rocks in the High Ranges are of Archaean igneous origin consisting of granite and gneiss (Koshy, 1970). The crystalline rocks consist of minerals such as silica, feldspars, muscovite and biotite with small amounts of accessory ferro-magnesium minerals. The soil is basically a relic of a much thicker soil cover that developed formerly under pedo-dynamic conditions prevailing from late Jurassic to early Tertiary times. It is composed of different layers, black to dark grey in colour, granular, friable, sandy loam interspersed with a little gravel. The soil is rich in organic matter. Soil is sandy-clay with sand (79.43 to 94.14%), silt (1.43 to 11.00%), clay (2.71 to 5.57%) and some gravel, altogether approximately 30-100 cm in depth (present study). Along the slopes and crests, soil depth is considerably low when compared to that of valleys, bogs and *shola* margins. The soil moisture in the month of May ranges from 12.30 to 39.97% in different landscape units (Table 3.1). The chemical composition of the soil shows a high percentage of organic carbon and nitrogen (Figure 3.2 and 3.3). The high percentage of organic carbon indicates low decomposition of organic matter due to

Figure 3.2. Organic carbon (%) in different landscape units in the grasslands of ENP.

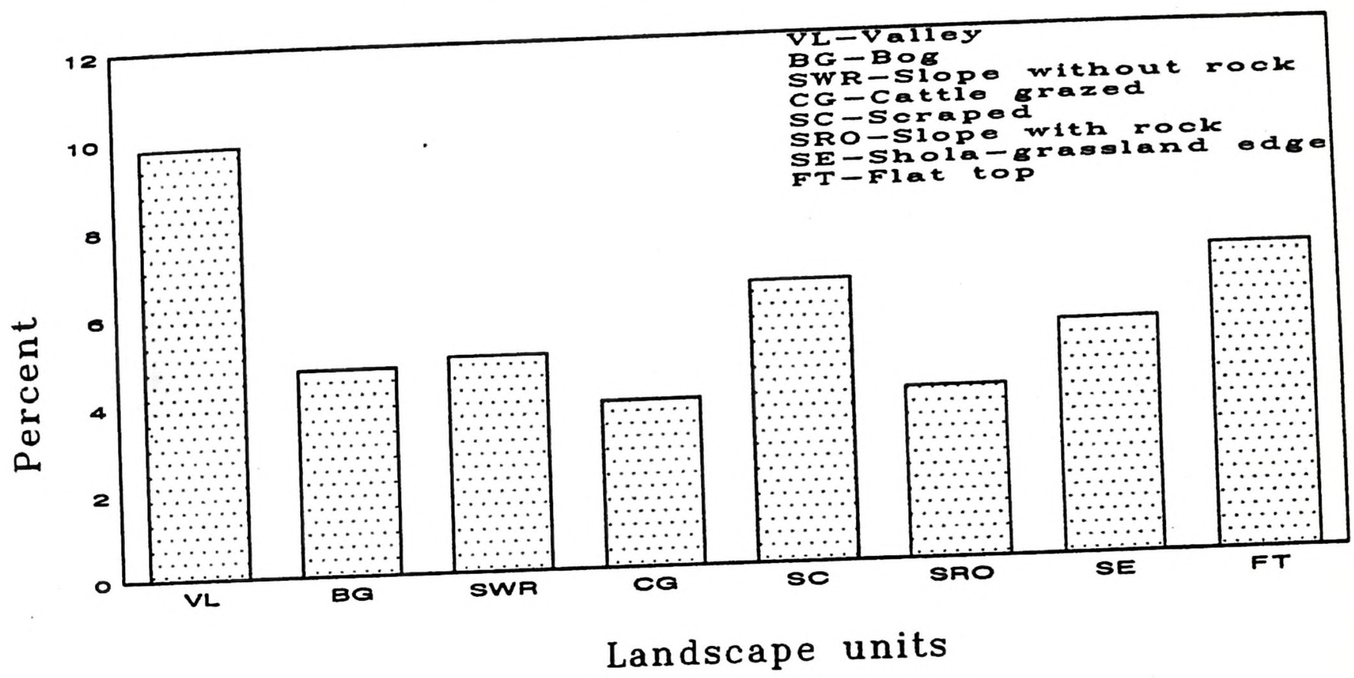
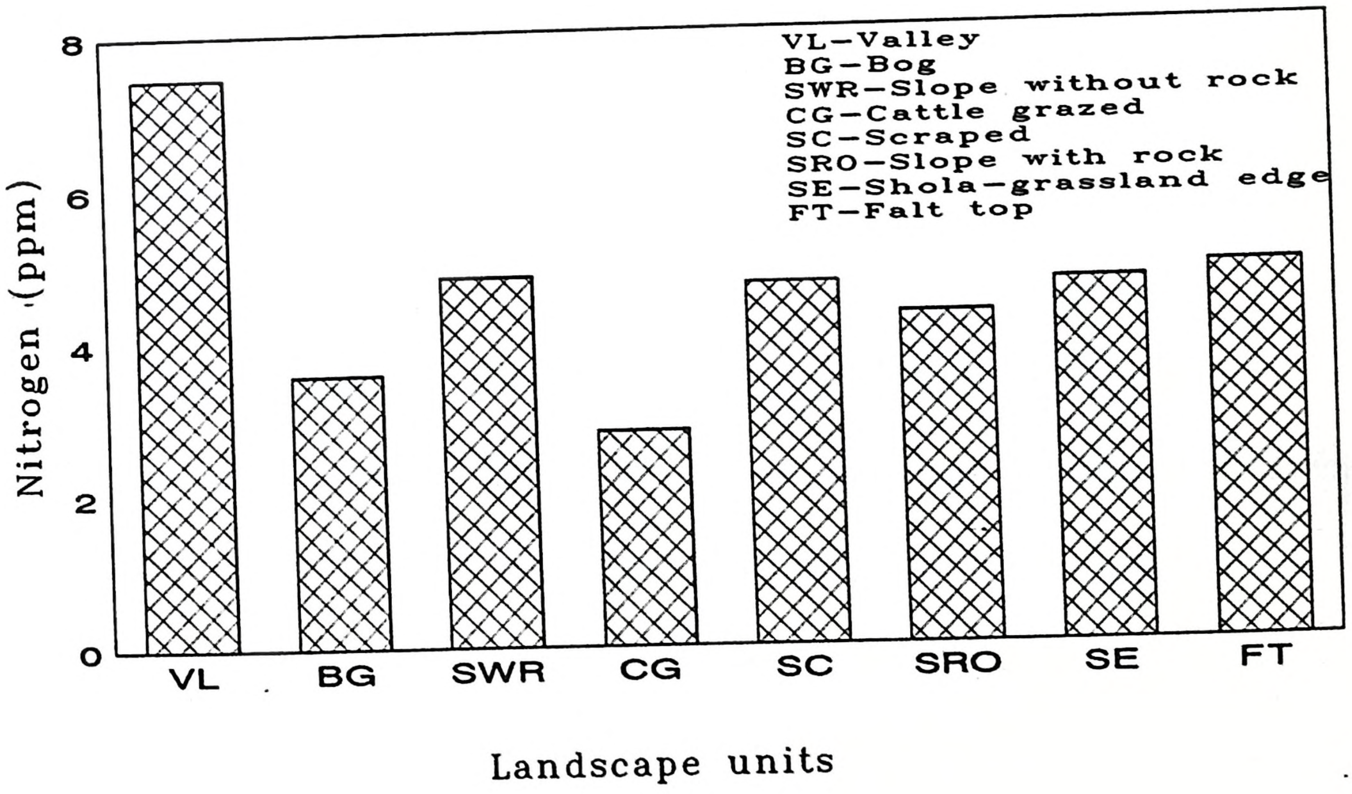


Figure 3.3. Nitrogen (ppm) in different landscape units in the grasslands of ENP.



cool climatic conditions. The soil is acidic with pH ranging from 4.13 to 5.34 (Table 3.2).

3.3 Climate

The park receives its major precipitation during the south-west monsoon (June-August). High lashing winds up to 55-60 km/hr during this period is a common phenomenon. The data on rainfall between 1992 and 1995 showed the highest annual precipitation (5540 mm) during 93-94. More than 60% of the annual rainfall was contributed by the south-west monsoon. Mean monthly rainfall was maximum in the month of July (Figure 3.4). The mean minimum temperature was low during monsoon and winter due to the lack of penetration of solar radiation. Following the south-west monsoon, a season of lower rainfall often called the north-east monsoon commences by September and accounts for nearly 30% of the total precipitation. During the north-east monsoon, the clouds build up along the eastern margin of the plateau leaving the central and western edges clear resulting in a change in microclimate. There is no fully dry month in ENP. Summer rains are common in the month of February, March and April which account nearly 10% of the total rainfall. The winter starts by November and reaches its peak in December and lasts until February. The clear mornings of winter days usually turn misty as the sun moves from east to west. Frost is a frequent phenomenon during winter nights and the radiant heat loss from the surface results in drop a in temperature to near freezing point. The day temperature during this period goes as high as 25-29°C. At Rajamala, where the base camp for this study was situated, the monthly mean minimum temperature recorded was 6°C in December and the mean maximum was 30°C in April (Figure 3.5). This high diurnal variation in temperature in the tropical

Figure 3.4. Mean monthly rainfall at Rajamala (ENP) during 1992–95.

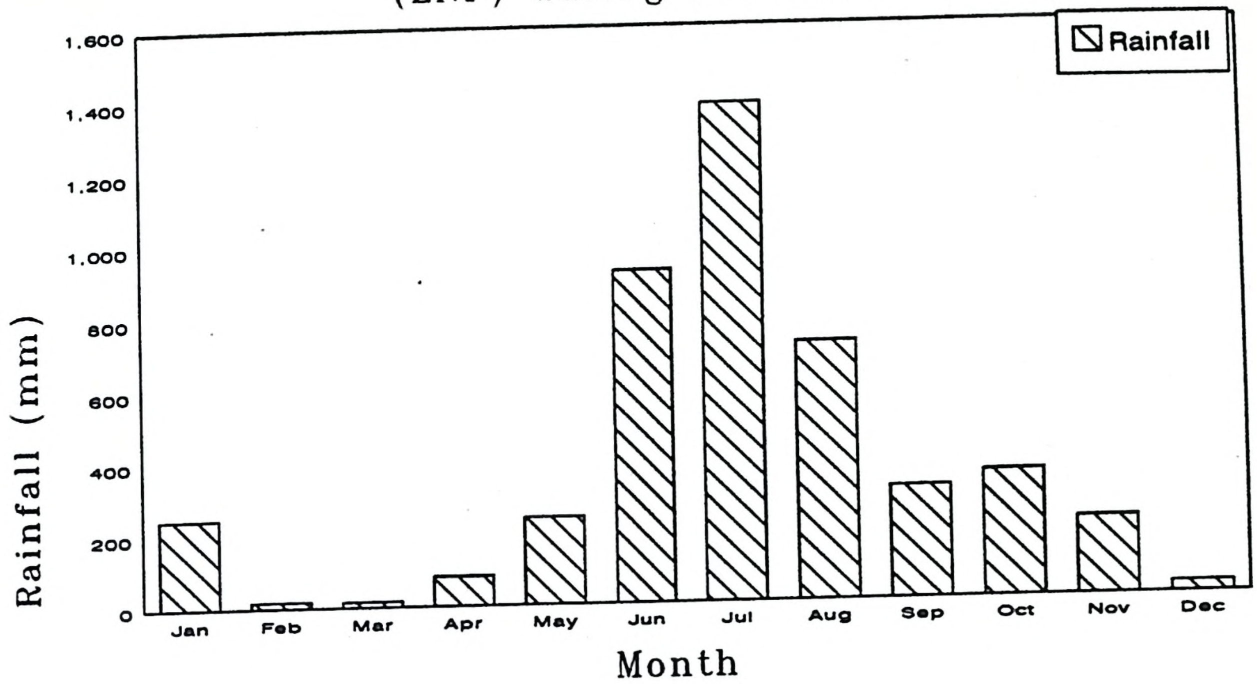


Figure 3.5. Mean monthly minimum, maximum temperature (°C and relative Humidity (%) at Rajamala (ENP) during 1992–95

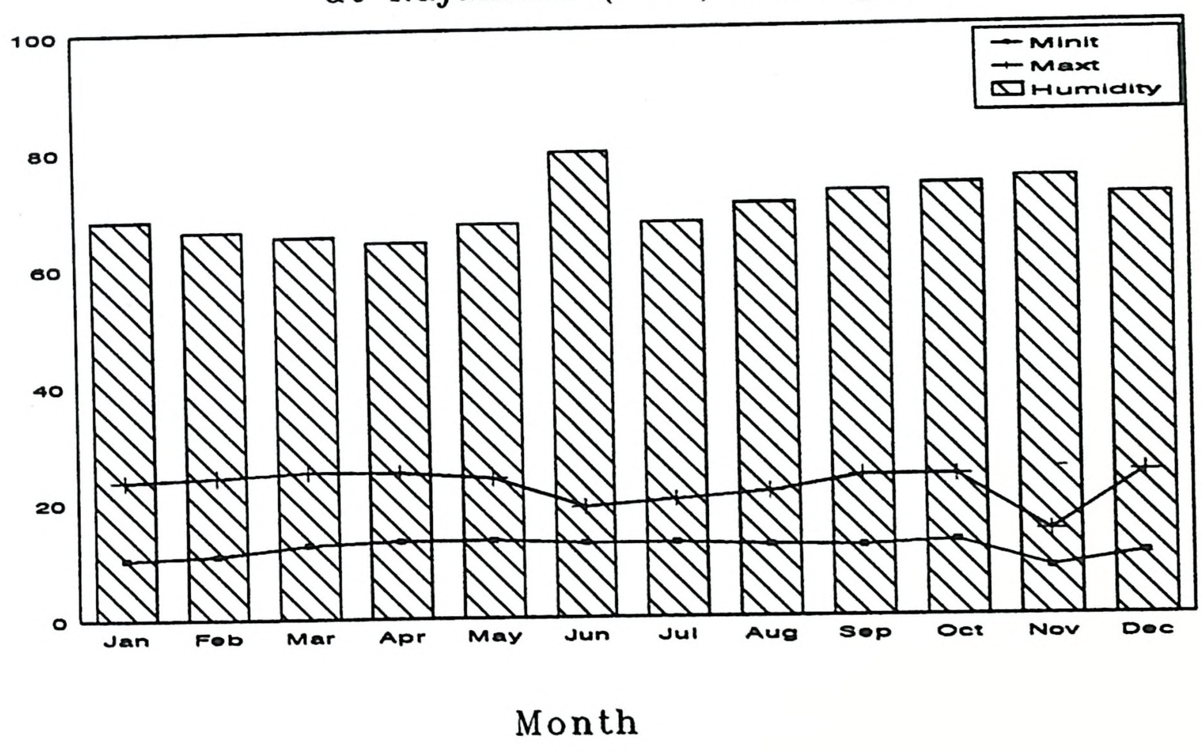


Table 3.1. Physical properties of soil in the grasslands of ENP.

SL.NO.	Landscape units	Soil			Gravel in monolith	% Moisture (in May)
		% Sand	% Silt	% Clay		
1	Valley	92.00	5.43	2.71	30.14	29.70
2	Bog	94.14	1.43	3.71	12.57	39.97
3	Slope without rock	88.14	8.00	3.57	10.14	29.31
4	Cattle grazed	85.86	8.43	5.57	13.43	12.30
5	Scraped	88.14	8.86	3.00	29.86	21.32
6	Slope with rock	85.86	10.00	4.14	21.00	38.51
7	*Shola*-grassland edge	87.57	8.29	4.14	7.71	28.12
8	Flat top	79.43	11.00	3.71	10.71	28.89

Table 3.2. Chemical properties of soil in the grasslands of ENP.

SL.NO.	Landscape units	Carbon(%)	Nitrogen(ppm)	Potassium	Calcium	pH
1	Valley	9.80	7453.71	195.86	0.04	4.50
2	Bog	4.74	3557.57	91.57	0.01	5.34
3	Slope without rock	4.94	4807.14	251.43	0.00	4.69
4	Cattle grazed	3.86	2791.00	216.29	0.01	4.74
5	Scraped	6.47	4684.57	52.14	0.01	4.34
6	Slope with rock	3.94	4280.57	74.29	0.00	4.99
7	Shola-grassland edge	5.39	4679.29	157.71	0.01	4.13
8	Flat top	6.92	4857.71	168.43	0.01	4.79

latitudes due to altitudinal influence brings about ecological peculiarities. Humidity varies with season. During monsoon it is as high as 80-90% (Figure 3.5). The winter days are marked by very low humidity which further declines with high wind velocity.

3.4 Hydrology

The High Ranges contribute more than 25% of the total surface fresh water available to Kerala, serving as a major water catchment (Nair, 1994). The word Eravikulam means rivers and pools (*eravi*=stream, *kulam*=pool). There are many streams criss-crossing the landscape, and all have their origin in the *shola* patches. Vembanthanni Ar and the main tributary of Kannimala Ar which start from this plateau drain into the Periyar river. The east flowing Eravikulam and Bheeman Ar, make the two main tributaries of Pambar that join Amaravathi and drain into the Tamil Nadu plains. Apart from this, there are many winding rivulets that contribute greatly to the hydrology of this area.

3.5 Vegetation

The two distinct physiognomic units of vegetation found within the park are the grasslands and *shola* forests. Nearly 80% of the land mass is covered by grasslands and the remaining area by forests and rocky slopes (Figure 3.6). The dominant shrub present on the bouldery slopes is *Phlebophyllum kunthianum*, Neelakurinji. This species blooms once every twelve years. The deeper valleys are extensively wooded and the balds and plateaus are covered by grasslands. Shrubby species predominate near tea estates, forest undergrowth and bouldery slopes.

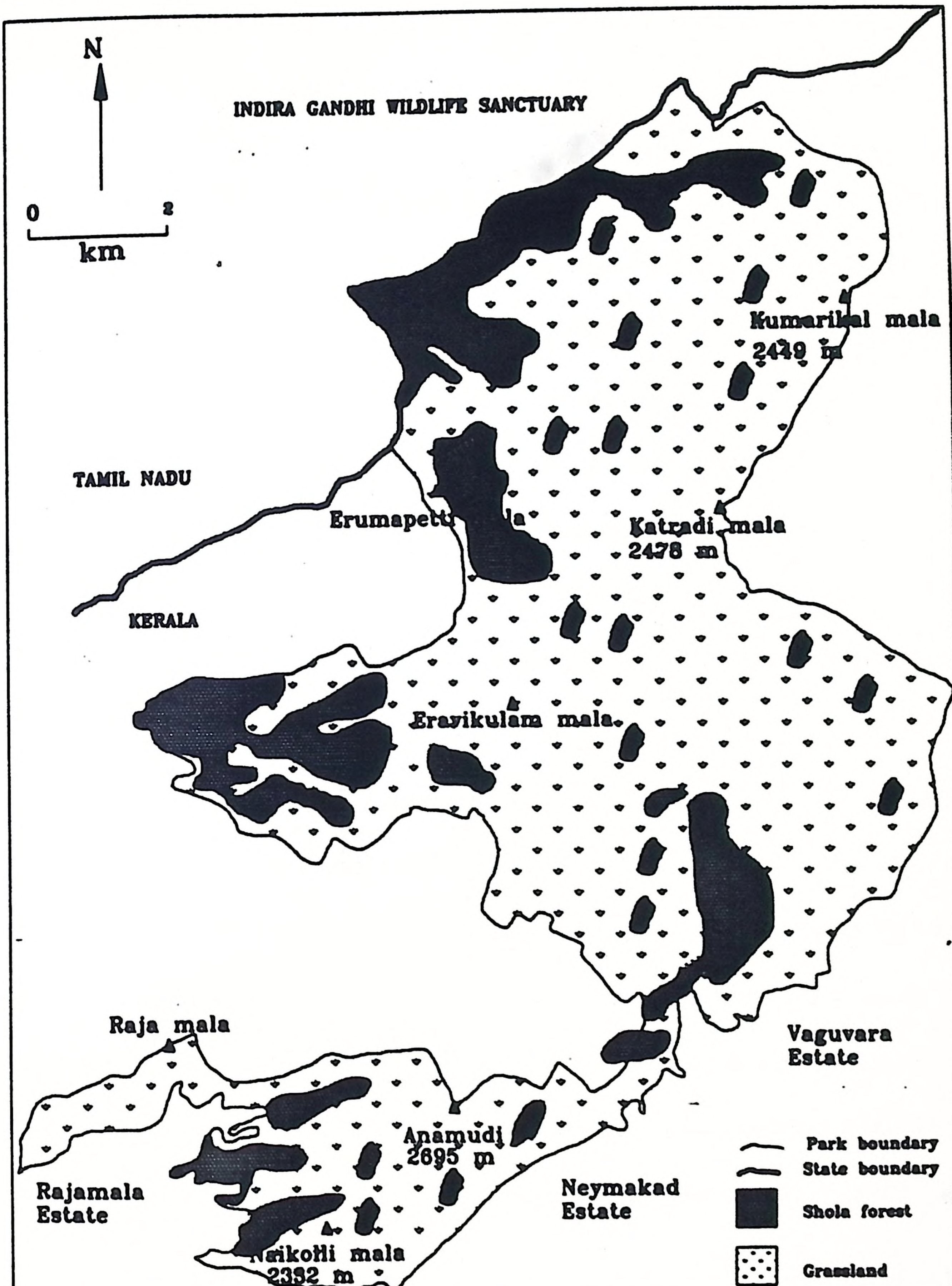
The forests are classified as Southern Montane Wet Temperate forests (Chandrasekharan, 1968). The forests in the plateau occupy glens, hollows or valleys which are locally called *shola*. The *shola* vegetation includes both the Subtropical Broad Leaved Hill Forests (8A) and Southern Montane Wet Temperate Forests (11A) classes of Champion & Seth (1968). Broad leaved forests are found on the slopes descending from the plateau. Tree species found in this type of forest are *Pittosporum tetraspermum, Elaeocarpus munroii, Apollonias arnotti, Symplocos spicata, Gomphandra coriacea, Garcinia gummi-gutta, Litsea coreacea, Prunus ceylanica* and *Photinia notoniana*. Major shrubs include *Begonia subpeltata, Osbeckia lineolata, Polygala arillata, Strobilanthes homotropus, Maesa perrottetiana* etc. Forests in the highly disturbed areas near the tea estates are characterised by woody species such as *Macaranga peltata, Vernonia arborea, Rubus ellipticus*, and *Rauwolfia densiflora.* An exotic weed *Ageratina adenophora* has invaded shola edges, gaps, moist slopes and other places in recent years. The herbaceous flora include Balsam (*Impatiens* sp), *Justicia simplex, Elatostemma lineolatum*. Terrestrial orchids such as *Malaxis versicolor, Peristylis densifolia* are also common in the forests.

The shola forests in the upper plateau are dense and floristically rich with many endemic and rare species. The tree layer comprises short boled evergreen species with canopy height up to 15m and bark covered with lichens, orchids, mosses and climbers. The crowns are generally rounded and dense. Common tree species in the shola forests are *Ilex denticulata, I. wightiana, Michaelia nilagirica, Elaeocarpus recurvatus, Microtropis ramiflora, Actinodaphne bourdellonii*, and *Symplocos pendula*. The edges of the *shola* are marked by species such as *Rhododendron arboreum var. nilagiricum, Ternstroemia japonica, Ligustrum perrottettii*, and *Turpinia cochinchinensis*. Shrubs and herbs found in the shola margins are *Mahonia leshenaultii, Rhodomyrtus tomentosa, Berberis tinctoria, Vaccinium neilgherrense, Gaultheria fragrantissima, Moonia heterophylla, Jasminum bignoneacium, Smithia blanda, Valeriana hookeriana* and a few species of *Strobilanthes*. The undergrowth in the *shola* is represented by *Strobilanthes* sp., *Impatiens phoenicea, I. coelotropis, Psychotria congesta, Viola patrinii, V. serpens, Asplenium* sp., *Impatiens* sp., and *Arundinaria densifolia*. Epiphytic orchids in the *sholas* include *Aerides ringens, Coelogyne nervosa, C. mossiae, Eria dalzelli, E. pauciflora*, and *Schoenorchis filiformis*. The common climbers are *Piper schmidtii, Rubia cordifolia*, and *Connarus wightii. Rapanea capillata, Vaccinium leschenaultii, Impatiens tangachee, Sonerila grandiflora, Osmunda regalis* and *Eurya japonica* are usually found along streams.

The grasslands occupy the plateau and descending slopes. These plateau and slopes are dominated by *Chrysopogon zeylanicus* and *Sehima nervosum,* whereas in the cattle grazed areas, unpalatable *Cymbopogon flexuosus* is frequent. Other dominant grasses are *Eulalia phaeothrix, Andropogon lividus, Arundinella purpurea, Agrostis peninsularis*, *Ischaemum indicum*, *Heteropogon contortus* and *Tripogon bromoides*. The common herbs and shrubs in the grasslands include *Anaphalis lawii, A. bourneii, A. meeboldii, Swertia corymbosa, Polygala japonica,. Curculigo orchioides, Micromeria biflora, Bupleurum distichophyllum, Crotalaria fysonii, C. ovalifolia, Ranunculus reniformis, Hedyotis swertiodes, Senecio lavandulaefolius, Parnassia mysorense, Pedicularis zeylanica, Wahlenbergia gracilifolia, Impatiens pandata, I. modesta, Phlebophyllum kunthianum, Hypericum mysorense, Pteridium aquilinum, Ageratina adenophora*, *Gaultheria fragrantissima* etc. The water logged areas are dominated by species such as *Eriocaulon robustum, E. collinum*, and *E. geofreyii*. The summit of the Anaimudi is sparsely vegetated with isolated patches of stunted *Arundinaria densifolia* and *Gaultheria fragrantissima* (wintergreen).

The *shola*-grassland formations of Nilgiris, Palnis and Anamalais of WGs and Adam's peak of Sri Lanka bear strong similarities (Subramanyam & Nayar, 1974).

Figure 3.6: Approximate distribution of *Shola* and Grassland vegetation in ENP



Twenty seven genera are common and endemic to these two regions (Ahmedullah & Nayar, 1985). These two regions are more striking in the presence of peat bogs characterized by species of *Eriocaulon, Exacum* and *Utricularia*.

3.6 Fauna

The undulating terrain and dominance of unpalatable grasses make this area less habitable for a large population of any animal other than Nilgiri tahr (Rice 1984). The park does not hold a resident population of Asiatic elephant (*Elephas maximus*), but it serves as a migratory route for elephants from Anamalais to Cardamom hills (Easa *et al*, 1994). Tiger (*Panthera tigris*), leopard (*Panthera pardus*), wild boar (*Sus scrofa*), Asiatic wild dog (*Cuon alpinus*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), Nilgiri marten (*Martes gwatkinsi*), stripe-necked mongoose (*Herpestes viticollis*), ruddy mongoose (*H. smithi*), brown mongoose (*H. fuscus*), common mongoose (*H. edwardsii*), barking deer (*Muntiacus muntjak*), mouse deer (*Tragulus meminna*), Nilgiri langur (*Presbytis johnii*), sambar (*Cervus unicolor*), gaur (*Bos gaurus*), Malabar giant squirrel (*Ratufa indica*) and dusky striped squirrel (*Funambulus sublineatus*) are seen in the park (Rice, 1984). An elusive cat, as big as the common leopard, with smoky grey coat has been reported from the park, and does not match the description of any other species reported from the area (Easa, 1996). The species, locally known as *Pohayan* has been sighted by earlier workers also (James Zakaria and A. Veeramani, *pers. comm.*). The endemic reptilian and avifauna include Anamalai salea (*Sallia anamallaina*) and Nilgiri pipit (*Anthus nilghiriensis*) respectively.

3.7 The local human communities

The eastern flank of the park is inhabited by a small population of tribals called 'Muthuvans'. These are hill cultivators who originally belonged to Madurai, Tamil Nadu, and migrated to the High Ranges in the 14th century (Singh, 1994). Their hamlets are called *Kudis,* and each kudi has a dormitory for boys (*Chavadi*), girls and widows (*Palapura*). The men above the age of 16 normally wear a white turban. The hamlet, Lakkamkudi, situated at the eastern boundary of ENP, supports nearly 30 families and a population of 200 individuals. When Kannagi, a divine woman and principal character of the Tamil epic *Silapathikaram,* destroyed Madurai by her curse, a group of people migrated with her to the hills, carrying her on their back (*Muthuku*). Thus the name muthuvan originated from this legend meaning "those who carried something on their back" (Singh, 1994). Even today, they carry their children and belongings on their back. The Muthuvans practise slash and burn agriculture and cultivate rice (*Oryza sativa*), ragi (*Eluesine coracona*), samai (*Panicum milliare*), and many varieties of vegetables including yams, roots and tubers. Under the wake of commercial farming, they started cultivation of lemon grass (*Cymbopogon citratus*) and cardamom (*Eletaria cardamomum)*.

In the early 20th century, the population of Muthuvans was as low as 500 in the High Ranges and when the population increased, the number of hamlets also increased. Over the years, many of them have begun to practise livestock keeping. Besides, a few men were employed by High Range Game Preservation Association (HRGPA) as game watchers (K.N. Chengappa, *pers. comm.*), and when the area was notified as National Park, eight Muthuvans were employed as protection watchers, and every year during the fire season, 15-20 people are hired as labourers for a period of 4-5 months (Sivadas (Assistant Wildlife Warden), *pers. comm.*).

3.8 Management history

Till 1970, ENP was under the Kannan Devan Hill Produce Company (KDHPC) which maintained it as a Game Reserve. The responsibility for the management and protection of the area was vested with the HRGPA, a pioneer non-governmental organisation in this area, which was formed in 1928. Due to the unique land features, climate and remoteness, this high land attracted the attention of many hunters, naturalists, and scientists. One of the early European visitors was Col. Douglas Hamilton who described the beauty and grandeur of this area in 1854.

Modern settlements began with the establishment of North Travancore Plantation and Agricultural Society (NTLPAS) in 1879. J.D. Munro on a hunting expedition in 1877, recognised the possibilities of raising plantations in these ranges and acquired about 227 sq. miles (581.12 km^2) of land on concession from Poonjat Raja, chief of the local kingdom of Anjanad (Baig & Henderson, 1978). Later, the land was distributed among the members of NTLPAS, and cultivation of coffee, cardamom, cinchona and rubber was started. It was realized later, that tea was the most suitable crop for this area. The first tea in the High Ranges was planted by Sharp in 1890 (Muthiah, 1993). Passing through the stress and strain of raising plantations, the members of the society merged and a majority of the estates were transferred to James-Finlay, a European company. Later, extensive cultivation of tea and *Eucalyptus* was carried out by clearing natural vegetation. Apart from cultivation, the English game hunters among the old planters had taken an interest in hunting activities and set aside some areas for recreation. The present day Eravikulam National Park was one such area. The game included Nilgiri tahr, sambar, barking deer, gaur, wild pig, leopard and tiger. The area also offered excellent opportunity for angling of Brown and Rainbow trouts (*Salmo trutla* and *S. gardnerii* respectively) which were introduced. The HRGPA was the regulatory body which used to manage such activities with the help of tribals who were employed by them as game watchers. The Managers of the nearby estates were appointed as Wardens for managing the various recreational and game areas.

Under the Land Reforms Act 1969, and the Governments of Kerala's Kannan Devan Hills (Resumption of Lands) Act 1971, all lands that were not under cultivation by the company were vested to the Government of Kerala. The Government's intention to divert this land for agricultural purpose, primarily for the landless people caused some concern among interested people especially in view of its ecological uniqueness. The constant pressure from naturalists, scientists, and other environmental activists prevented the Government from doing this. In 1975, realizing the values and merits of the area, the Government of Kerala declared it as Eravikulam-Rajamala Wildlife Sanctuary for the protection of the highly endangered Nilgiri tahr and its habitat. Subsequently, in 1978 it was upgraded to a National Park. Over the years, the management of the company has shifted from James-Finlay to Finlay-Tata and Tata alone by mid 1970s. With the increase in awareness about the importance of wildlife conservation, the objective and name of the game association also changed to High Range Wildlife and Environmental Preservation Association (HRWEPA). Even now the association helps the Forest Department of Kerala in managing this area.

3.9 Ecological significance of the High Ranges

The Western Ghats in general and the high altitude regions in particular, act as an important watershed to many hill streams of Tamil Nadu and Kerala. Of the 44 rivers in Kerala, three (Kabani, Bhavani, and Pambar) are east flowing and form the tributaries of Cauvery which have their origin in the montane region (Nair, 1991). The river Pambar is the southernmost among these, and has one of its main tributaries originating from Eravikulam Plateau. The Muthirapuzha in the central High Ranges, Pooyamkutty and Idamalayar in the western flank (all tributaries of river Periyar) have their origin in the grassy plateau of High Ranges. The major industrial belt of Kerala, Kochi-Udyogmandal, depends on river Periyar, and any ecological instability in the High Ranges leading to the dryness of hill streams would bring disaster for the whole of Kerala.

3.10 The intensive study sites

Three intensive study sites (Figure 3.1) were selected, representing the various features such as species composition, disturbance regimes, and accessibility, after a thorough reconnaissance of the area.

Rajamala: Situated on the southern boundary of the park, this area supports the largest population of Nilgiri tahr within the High Ranges (Rice, 1984). As the area is well approachable by road, it is open to tourists. During the study period, nearly three lakh people visited this area. The combined activities of tourists and grazing by a large population of Nilgiri tahr might have affected the vegetation here, more than any other part of the park. The dominant grass species are *Chrysopogon zeylanicus*, *Ischaemum indicum*, and *Arundinella purpurea*. Rajamala, being the operational headquarters of the park, also served as the base camp for this study (Figure 3.1).

Eravikulam: This is a plateau located in the core area of the park, and connected by a bridle path of about 13 km from the Vaguvara estate. The area is less disturbed than the other two sites. The dominant species of grass found in this area are *Sehima nervosum* and *Eulalia phaeothrix*.

Lakkamkudi: This is a degraded (cattle grazed) site close to Muthuvan village, located on the eastern side of the National Park and represents a rain shadow region. The slopes and valleys drain in the northeast direction, and join river Amaravathy. The cattle of local tribals as well as of estate dwellers graze in this area, apart from Nilgiri tahr and other ungulates. The dominant grass species are *Cymbopogon flexuosus* and *Heteropogon contortus*.

Chapter 4

METHODOLOGY

Field work for this study was carried out from June 1992 to April 1996. The following field and analytical methods were used. Detailed methods on field and analytical are explained separately in the concerned chapters.

4.1 Field methods

The initial three months were spent on reconnaissance of the area. The entire ENP was traversed thoroughly on foot to get an idea about the topographic and vegetation features. Survey of India toposheets (58 F3 and 58 F4) of 1:50,000 scale were used to verify various landscape units, and confirm the boundary and other permanent features such as vegetation, drainage, cliffs, paths, and roads.

4.1.1 Stratification

The following criteria were used for the stratification of the study area: (a) presence of rocks and boulders, (b) presence or absence of perennial streams, (c) distance from *shola* patch, (d) disturbance (cattle grazing, scraping for fireline, and introducing new grass species), (e) degree of slope. Altitude was not considered as a major criterion because most of the area, forms part of a table land where altitudinal differences are insignificant. Rajamala in the south, and Lakkamkudi in the east of the park represent the low altitude (about 1600 msl) regions. Lakkamkudi located in the east, can not be considered as a true rain shadow area because it receives high precipitation during the south west monsoon, and the areas east of it are contiguous with Mannavan *shola*, Vattavada, Kanthallor and Palni Hills, all of which have montane vegetation. Based on the stratification criteria, the park was divided into the following strata or landscape units.

i) Slopes with rocky outcrops (SRO): The slopes with >25% rocks that are mainly located in the southern and eastern fringes of the park (Plate 1).

ii) Slopes without rocky outcrops (SWR): The large stretches of rolling grasslands where rockiness is <25% fall into this category (Plate 1).

iii) Flat tops (FT): the knolls of smaller hills with thin soil.

iv) Valleys (VL): These are characterised by the meeting points of two slopes which are well drained (Plate 2).

v) Bog (BG): The water retaining areas of the park which are limited in extent but important due to characteristic plant species composition (Plate 1).

vi) *Shola* edges (SE): The edges of the *shola* represent the transition of grasslands and forests hence are grouped as a landscape unit (Plate 3).

vii) Disturbed (cattle grazed-CG) sites: The cattle grazed hill slopes in and around Lakkamkudi (Plate 4).

viii) Disturbed (scraped-SC) sites: Frequent scraping of firelines to clear the vegetation is practised in the park to control fire. Although such areas are small in extent, they show distinct communities and species composition from the rest of the vegetation units.

4.1.2 Abiotic variables

Rainfall data were collected at two locations, Rajamala and Lakkamkudi, using a rain gauge. Rainfall was measured every morning (0700 hrs), and during peak rainy days, measurements were taken both in the morning and in the evening. Minimum and maximum temperatures were recorded at Rajamala base camp. Humidity (at 0700 hrs) was measured by a hygrometer. Soil samples were collected from different vegetation units at three depths viz., 0-10 cm, 11-20 cm and 21-30 cm (Allen, 1989). In some areas, samples only from the upper two strata were collected due to the presence of underground rock. Altitude was measured using an altimeter corrected to 5m.

4.1.3 Biotic Variables

Floral inventory

Different landscape units were surveyed extensively to make a floral inventory. The inventory was made during the first two years of the study covering all seasons. All the specimens were brought to the base camp for the preparation of herbarium and for subsequent examination and identification. Flora by Bourdellon (1908), Gamble (1915-35), Fyson (1932), Shetty & Vivekanandan (1971), Joseph (1987), Abraham & Vatsala (1981), Sreekumar & Nair (1991), and the vegetative keys for identificaiton published by Rice (1984), Pascal & Ramesh (1987), and Bennet (1987) were used for plant identification and verifying changes in the names. Identity of doubtful specimens were verified at the Herbarium of the Botanical Survey of India, Southern Circle at Coimbatore, Tamil Nadu.

Phytosociology

Nested plot method (Mueller-Dombois & Ellenberg, 1974) and species area curve (Rice & Kelting, 1955) were used to determine the plot size and sample size respectively. Community classification and analysis of species associations were done according to Zurich-Montpellier (Braun-Blanquet) phytosociological or relevé approach (Mueller-Dombois & Ellenberg, 1974; Kent & Coker, 1992). The term relevé refers to identical stands of vegetation. Each relevé covered a circular plot of 5 m radius. Vegetation parameters such as species, cover, sociability and phenology were recorded, from the centre of the relevé. Species cover is defined as the area of the ground covered by a vertical projection of the foliage and stems of a species (Shimwell, 1971). In many ecological studies, herbaceous vegetation cover has more significance than density (Mueller-Dombois & Ellenberg, 1974) because it gives a better measure of biomass. Cover was estimated occularly in each relevé and in plots, point gridded frame (Plate 5), were used (Goodall 1952, Mueller-Dombois & Ellenberg 1974, Kent & Coker 1992). The sociability of a species (defined as its tendency to be found in association with individuals of its own kind) and tussock and tiller form among grasses, were recorded within each relevé. Relevé method was found to be more useful in this type of grassland where the dominant structural element is tussock form of grasses and there is no layering of cover. Familiarity with the flora is a prerequisite for the relevé approach. A large area can be surveyed by this method in a short time. Data on the effect of burning on grassland and biomass production were collected using random quadrats of 1 m^2 (Misra, 1968, Mueller-Dombois & Ellenberg, 1974; Kent & Coker, 1992). Vegetation cover within these plots was measured using gridded quadrat frame Goodall (1952).

Biomass

Above-ground and below ground biomass for different communities were estimated using the harvest method (Singh & Yadava, 1974). Clipping was done close to the ground, and biomass was separated into litter and standing crop (Plate 5). Each species was collected separately and oven dried at 80°C till constant weight was obtained. Below ground biomass was collected from monoliths of 30 cm^3 and the material collected was washed in running water over a fine sieve, dried and weighed.

Phenology

The phenology of species in the grasslands was recorded along fixed transects. A transect of 4 km covering an altitudinal gradient of 1600 m to 2695 m was laid, and 150 common species were identified along the transect. Three individuals of each species were marked with plastic tags and phenophases were recorded once every month for one year.

4.1.4 Effect of fire

The effect of fire on different communities was studied in winter and summer. In both the seasons, two sites were selected for early as well as late burning. Eight circular plots of 10 m radius were burnt at four sites, four in early (December), and four in late (April). From each burnt site, soil was collected for analysis and eight one metre quadrats were laid in eight directions to avoid bias due to aspect. Species enumeration and cover of various species was quantified using gridded quadrat frame. Data was collected for every month in the first six months after burning and then at an interval of six months, for eighteen months.

4.1.5 Effect of wattle plantation

The area under black wattle (*Acacia mearnsii*) plantation around the national park was randomly sampled for studying its effect on the diversity of grassland flora. The relevé approach was used for phytosociological data collection. Four sites were selected based on different age of plantation. In each area, ten 5 m radius relevés were laid and data were collected as mentioned in Section 4.1.3.

4.2 Analytical Methods

Soil was tested for colour, texture and chemical properties. Soil analysis was carried out at the Kerala Forest Research Institute, Peechi, Kerala. Colour was recorded with the help of Munsell soil colour chart. pH was measured by pH meter. Soil texture like gravel, clay silt, was determined by sieve method (Pandeya, 1968). Organic carbon was estimated by Walkey & Blacks rapid titration method. Calcium, Magnesium were estimated by Ethylene Diamine Tetra Acetic Acid (EDTA) method. Nitrogen, potassium, and phosphorus estimation was done following Jackson (1973).

Flora and Vegetation

Angiosperms and Pteridophytes were catalogued along with their habit, habitat, conservation values, and frequency of occurrence. For various landscape units species richness, evenness and diversity (Magguran, 1988; Kent & Coker, 1992) were calculated. Data analysis was carried out using SPSS/PC+ (Marija, 1986), LOTUS 1-2-3, TWINSPAN (Hill, 1979) and CANOCO (ter Braak, 1987). Two Way Indicator Species Analysis-TWINSPAN, (Hill, 1979) was used for identifying vegetation associations. TWINSPAN is a species ordination method that results in community segregation through dichotomous division. The whole division is based on similarity index (Eigen values) between plots and weightage to each species, which is derived from abundance value. Apart from software application, plant associations were worked out using table transfer method described by Shimwell (1971), Mueller-Dombois & Ellenberg (1974), and Westhoff and Maarel (1978). The relationship between environmental variables and species distribution was determined with the help of computer package, CANOCO (ter Braak, 1987). CANOCO was used to determine the relationship between environmental factors and vegetation. This multivariate method of direct ordination, results in the correlation of environmental data as well as species variability.

Biomass

The computation of biomass data was done using SPSS/PC+ (Marija, 1986) software package. Simple correlations between environmental factors and biomass production was done with the help of Pearson's correlation matrix. In all cases, the significance level was set at 0.05.

Chapter 5

FLORISTIC STRUCTURE AND PHYTOGEOGRAPHY

5.1 Introduction

Information on the patterns of plant species diversity and species composition helps in understanding the ecological nature of any region. Detailed floristics and phytogeographic analysis also reveals the past and present trends in vegetation dynamics and conservation status of various species. This chapter deals with the floristic structure and phytogeography of high altitude (montane) grasslands in Eravikulam National Park, Kerala.

5.2 Material and methods

To prepare a floral inventory of grasslands we used two approaches: (a) systematic floral surveys covering various habitats and seasons, (b) Braun-Blanquets' phytosociological approach (Mueller-Dombois & Ellenberg 1974). All plants were collected (2-3 specimens each) and brought to the base camp. Subsequently the specimens were dried and labelled for preparation of herbarium, and further identification following the standard techniques (Jain & Rao, 1976). The identity of specimens were confirmed by cross-checking the specimens at the Herbarium of Botanical Survey of India, Southern Circle, Coimbatore. The specimens have been submitted to the Herbarium, Wildlife Institute of India, Dehradun, for future reference. Identification and phytogeographical analysis were worked out with the help of relevant taxonomic literature viz., Rao (1914), Fyson (1915), Gamble (1935), Meher-Homji (1967), Menon (1967), Blasco (1970), Shetty & Vivekanandan (1971), Mani (1974), Dassanayake &

Fosberg, (1980) Deb (1981), Premadasa (1984), Naithani (1984), Haridasan (1987), Vasanthy (1988), and Kala *et. al.*, (1997). The plant species were grouped into different life forms and biological spectrum was prepared according to Raunkiauer (1934), Misra (1967), Mueller-Dombois & Ellenberg (1974), Moore & Chapman (1985), and Smith (1990). Grasses have been grouped into C_3 and C_4 types using secondary information (Waller & Lewis, 1979).

5.3 Results

5.3.1 Floristic structure

Three zero eight species of vascular plants (angiosperms and pteridophytes) belonging to fifty nine families and one seventy nine genera, were collected from the grasslands (Appendix-I). Of these, sixty five species belonged to Poaceae and sixteen were Sedges (Cyperaceae). Trees, shrubs, climbers and herbs were represented by seven, thirty eight, three and one seventy nine species respectively. We added one zero six species of vascular plants to the earlier checklist of grasslands prepared by Shetty & Vivekanandan (1971). Among fifty nine families of the flowering plants in the grasslands, thirty five are monogeneric, and twenty three are monotypic (Table 5.1). Poaceae represents the largest group with thirty eight genera and sixty five species followed by Asteraceae and Orchidaceae. *Impatiens* (eight species), *Anaphalis* (nine species), *Crotalaria* (seven species) and *Habenaria* (seven species) are among the largest genera. Although the number of dicot species is greater (183) the structure of the vegetation is predominantly graminaceous. The dominant grasses are *Sehima nervosum, Chrysopogon zeylanicus, Arundinella purpurea, Andropogon lividus, Eulalia phaeothrix, Ischaemum indicum, Cymbopogon flexuosus*, and *Heteropogon contortus*. Of the sixty five grasses collected fourty two (66%) are C_4 and the remaining twenty three are C_3 (34%) type (Appendix II).

Table 5.1. Family wise distribution and conservation status of species in the Grasslands of ENP.

Family	No.of genera	No.of species	No.of endemic species
Ranunculaceae	5	6	
Menispermaceae	1	1	
Berberidaceae	2	2	
Brassicaceae	1	3	
Violaceae	1	2	
Polygalaceae	1	1	
Caryophyllaceae	1	1	
Hypericaceae	1	3	1
Tiliaceae	2	2	
Linaceae	1	1	
Geraniaceae	1	1	
Balsaminaceae	1	8	4
Oxalidaceae	1	2	
Sapindaceae	1	1	
Fabaceae	5	13	3
Caesalpiniaceae	1	1	1
Mimosaceae	1	1	
Rosaceae	3	6	
Saxifragaceae	1	2	
Crassulaceae	1	1	
Droseraceae	1	2	
Melastomaceae	2	6	1
Apiaceae	5	6	3
Rubiaceae	6	11	4

Valerianaceae	1	3	2
Asteraceae	21	32	6
Campanulaceae	3	4	1
Vacciniaceae	1	1	
Ericaceae	2	2	
Myrsinaceae	1	1	
Oleaceae	1	1	
Gentianaceae	3	5	1
Scrophulariaceae	5	6	
Lentibulariaceae	1	3	
Gesneriaceae	1	1	
Acanthaceae	3	5	2
Lamiaceae	11	15	1
Plantaginaceae	1	1	
Chenopodiaceae	1	1	
Polygonaceae	1	2	
Thymelaeaceae	1	1	
Euphorbiaceae	2	3	
Urticaceae	2	3	
Orchidaceae	8	17	6
Hypoxidaceae	2	2	
Liliaceae	3	3	
Xyridaceae	1	1	
Juncaceae	2	3	1
Palmaceae	1	1	
Commelinaceae	3	5	2
Eriocaulaceae	1	3	
Cyperaceae	10	16	1
Poaceae	38	65	11
Aspleniaceae	1	1	
Gleicheniaceae	1	1	
Lindsiaceae	1	1	

Lycopodiaceae	1	2
Osmundaceae	1	1
Pteridaceae	1	1

The genus *Strobilanthes* is represented by more than 50 species in the WGs (Gamble, 1935). Of these, nineteen species are confined to the higher altitudes (above 1500 m). Interestingly, only one species, i.e. Neelakurinji, *Strobilanthes kunthianense,* syn., *Phlebophyllum kunthianum*, is found in the grasslands. This is a pleitial shrub that flowers once in twelve years (Plate 6) and occupies the open grassland, especially the bouldery slopes. The dominance, patchiness and gregariousness of Neelakurinji during blooming period contribute much to the beauty of grassy slopes. The latest event of flowering was observed in 1994. Other than Neelakurinji almost all other species of *Strobilanthes* in the high elevations grow typically as undergrowth of forests. Other shrub flora in the grasslands include *Hypericum mysorense*, wintergreen (*Gaultheria fragrantissima)*, *Phoenix humilis*, *Arundinaria densifolia*, *Artemisia niligirica*, etc.

Insectivorous plants are represented by two genera, *Drosera* and *Utricularia*. Two species of Drosera (*D. peltata* and *D. burmanni*) were collected. *D. peltata*, the common sundew plant of WGs, has been facing threats due to illegal and bulk collection by local people for selling to drug factories in Tamil Nadu. The bracken (*Pteridium aquilinum)*, a cosmopolitan fern, is dominant around tea estates, especially in burnt and trampled areas. *Osmunda regalis*, the royal fern, is prominent along the stream courses. Two species of *Lycopodium* (*L. cernum* and *Lycopodium* sp.) were seen on the moist areas.

Ten exotic species which have naturalised in the grasslands of ENP are: *Bidens pilosa*, *Galinsoga quadriradiata, Erigeron mucranatum*, *Ageratina adenophora* (all from South America), *Acacia mearnsii* (from Australia), *Setaria glauca, Sonchus wightianus* (both Eurasian), *Emilia sonchifolia, Eragrostis tenella* (both Afro-Asian) and *Drymaria cordata* from Paleotropical stock (Rao, 1994).

The two genera typical of high alpine vegetation, and found in the grasslands of ENP are *Cnicus* and *Artemisia* (Shetty & Vivekanandan, 1971; Mani 1974). The species richness varies according to microhabitats and landscape units (Table 5.2). *Shola* edges were represented by highest mean number of species (36) per relevé with tropical elements. The least number of species (22) were encountered in the cattle grazed and scraped areas (Figure 5.1).

Table 5.2. Species richness (mean number of species per relevé i.e. 5 m radius plot) within various landscape units of ENP.

Landscape unit	Species Richness (per 78.5 m^2)
Slope without rocky outcrops	23 ± 4
Slope with rocky outcrops	24 ± 3
Bog	31 ± 6
Shola-grassland edge	36 ± 5
Flat top	23 ± 3
Disturbed site - Scraped	22 ± 4
Disturbed site - Cattle grazed	22 ± 2
Valley	24 ± 5

5.3.2 Life form and biological spectrum

The grasslands of ENP were dominated by therophytes. Of the 308 species collected from the grasslands, one twenty (39%) are therophytes. Chaemophytes and hemicryptophytes were almost equal in number (Table 5.3). Only two lianas and one succulent were present. The species (149) collected exclusively from the plateau also showed a similar pattern of distribution. Although the number of geophytes is lower on the plateau, their % contribution to total life form of the plateau is greater than that of all grasslands (Table 5.3).

Table 5.3. Distribution of Raunkiauer's life forms in the grasslands of ENP and its comparision with the Eravikulam plateau:

	All Grasslands		Eravikulam Plateau	
Life forms	No. of species (n=308)	%	No.ofspecies (n=149)	%
Chaemophytes	65	21	36	24
Hemicryptophytes	68	22	28	19
Phanerophytes	13	4	10	7
Therophytes	120	39	53	36
Geophytes	35	11	19	13
Succulents	1	0.3	-	-
Hydrophytes	4	1	1	0.7
Lianas	2	0.6	2	1.3

5.3.3 Endemism

Analysis of the flora revealed that seventeen percent (51 species) of the total species collected were endemic to high altitude vegetation of Western Ghats (Table 5.1). The genus *Impatiens* had 4 species (50%) endemic to grasslands. Members of Orchidaceae and Rubiaceae also showed high habitat specificity in their distribution. 29 species of grasslands are regarded as rare and threatened (Appendix III). Of these, Poaceae and Orchidaceae had 6 species each. Nine species are described in the Red Data Book of Indian Plants (Nayar & Shastry, 1990). They are *Anaphalis barnesii, Campanula alphonsii, Commelina hirsuta, Habenaria barnesii, Hedyotis buxifolia, Impatiens pandata, Isachne fischeri, Pimpinella pulneyensis* and *Vanasushava pedata. Brachycorytis wightii*

Figure 5.1 Species richness (78.5m²) in different landscape units in the grasslands of ENP.

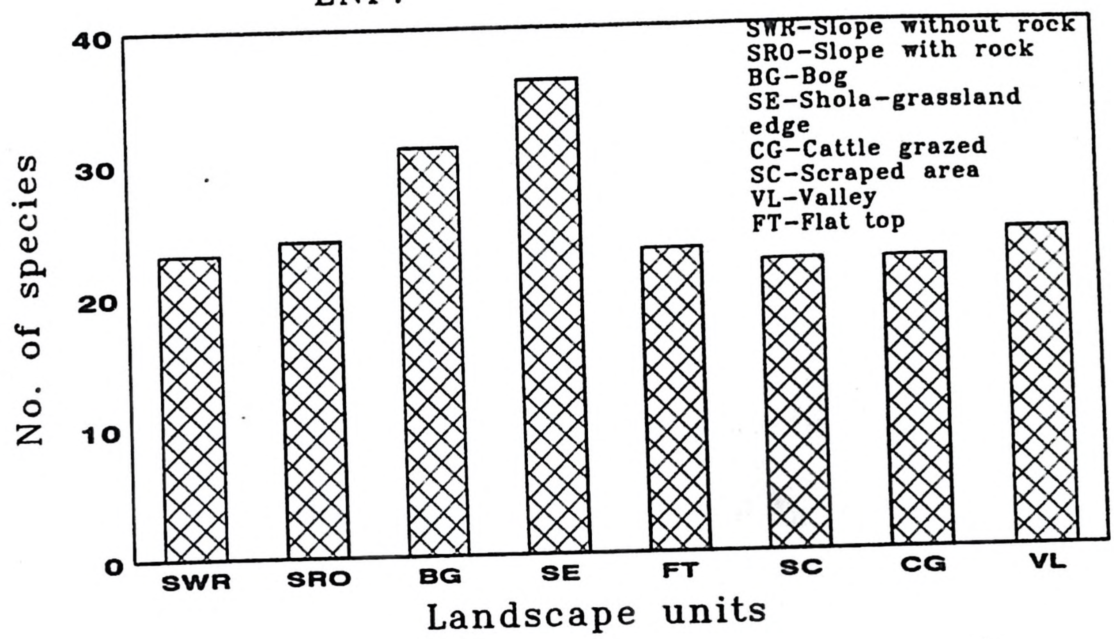
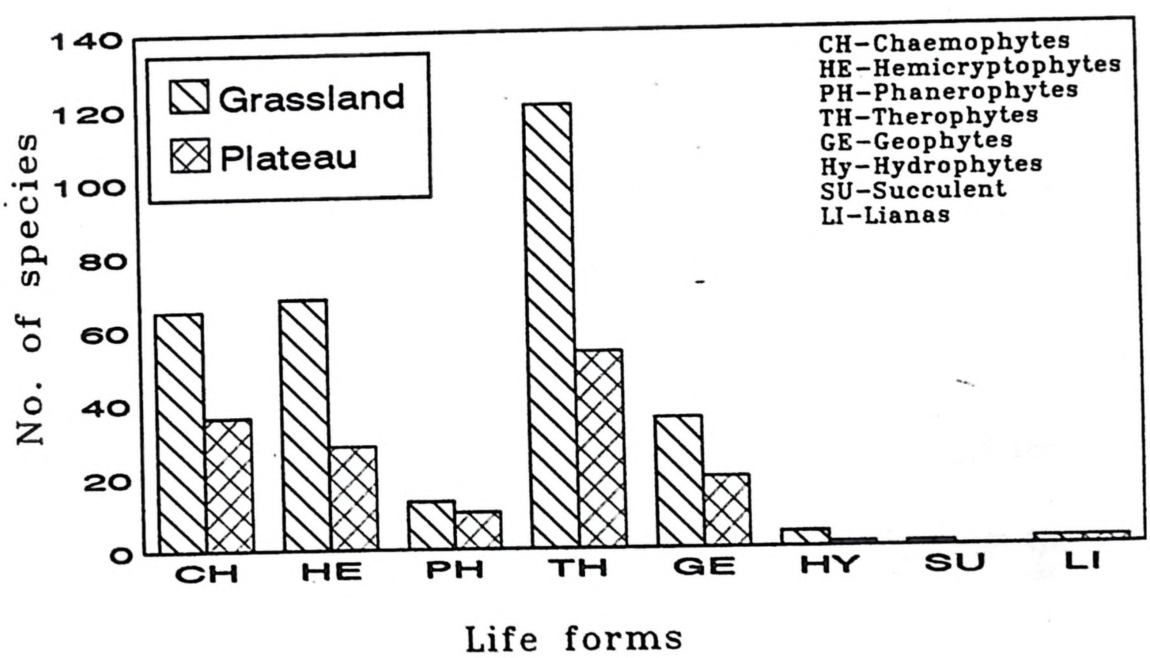


Figure 5.2. A comparison of biological spectrum (Raunkiaeur's life forms) between overall ENP grasslands and Eravikulam Plateau.



(Plate 6) of Orchidaceae is a species which showed very narrow distribution in the montane grasslands of High Ranges.

5.3.4 Phytogeography

There are 35 genera and 28 species (AppendixIV) common to the Valley of Flowers National Park (Western Himalaya) and Eravikulam National Park of. It was found that there are 30 species common to the high altitude grasslands (Patanas) of Sri Lanka and grasslands of Eravikulam National Park (Dassanayake & Fosberg 1983). Although Eastern Ghats do not have major high peaks and plateaus, they show floristic affinities with ENP. The Yercaud hills of Eastern Ghats, which is close to WGs shows maximum similarity in species composition. The farther ranges in the Eastern Ghats are less similar to WGs due to discontinuity of these ranges. Sixty four species are common to these two ranges. The Khasi and Naga hill ranges (north east India) and the grasslands of ENP have 35 common species (Mani, 1974; Shetty & Vivekanandan, 1971).

5.4 Discussion

5.4.1 Floristic structure:

Earlier workers (Shetty & Vivekanandan, 1971; Sreekumar & Nair, 1991) covered *shola* forests as well as grasslands of ENP. In addition, Rice (1984) collected food plants of Nilgiri tahr from ENP. The addition of 106 species exclusively from the grasslands during the course of this study, reveals that floral the inventory of the park is not yet complete. Systematic surveys of *shola* vegetation during various seasons are likely to add many species to the existing checklist of plants from ENP. The occurrence of exotic weeds in ENP, might be due to hectic plantation activities by Europeans in the nearby areas in the 1800s. The species richness on *shola* edges is due to microsite features like high atmospheric humidity, favourable edaphic conditions, and partial protection from frost and wind (Shetty & Vivekanandan, 1971). In the cattle-grazed and scraped area, soil depth is comparatively low. The physical property of soil such as high % of gravel also indicates the preponderance of therophytes (Misra & Misra, 1979) which usually form pioneer communities.

Table 5.4. Comparison of biological spectrum of ENP with other regions of India.

Author(s)	Place	Pha.	Che.	Hem.	Geo.	The.
Raunkiauer (1934)	World	46.0	9.0	26.0	4.0	13.0
Pandeya (1964)	Sagar	-	16.3	18.3	18.3	51.0
Singh (1967)	Varanasi	-	3.1	20.3	7.8	68.7
Singh & Yadava(1974)	Kuruskhetra	-	10.4	18.7	6.2	62.5
Singh & Ambasht (1975)	Varanasi	-	4.2	19.1	6.3	70.2
Misra & Misra (1979)	Berhampur	5.7	25.7	14.3	5.7	48.6
Present study	Eravikulam NP	4.0	21.0	22	11	39

5.4.2 Life forms and biological spectrum:

The biological spectrum of species brings out the operative environmental factors in an area (Barucha & Dave, 1944; Pandeya, 1953). Raunkiauer (1934) opined that high annual rainfall and temperature in the tropical region favours the phanerophytic spectrum. But the therophytic nature of the grasslands of ENP is a deviation from normal biological spectrum described by Raunkiauer (Table 5.4). A community dominated by therophytes would be characteristic of dry area (Meher-Homji, 1981; Smith, 1990). The therophytic nature of grasslands of ENP is possibly due to the frequent incidents of fire in the plateau, grazing, scraping, and overall shallowness of the soil (Misra & Misra, 1979).

Rockiness in the slopes also favours more annuals (therophytes). The dominance of C_4 grasses over C_3 indicate the arid nature of the area (Killeen & Hinz, 1992). C_4 species were a conspicuous part of the grass flora only in the xeric microenvironments of granite outcrops. Baruch & Dave (1944) found therophytic grasslands in Bombay which is an indication of disturbance by man and animals. Pandeya (1964) reported high percentage of geophytes and therophytes in grasslands of Sagar due to heavy grazing.

5.4.3 Endemism:

There are over 1500 endemic vascular plants in WGs (Mani, 1974; Pascal & Ramesh, 1991). It is substantially high considering its geographical area. The Himalaya, Peninsular India, and Andaman and Nicobar islands have, 3169, 2100 and 185 endemic species respectively. The high level of endemism in the WGs is due to the unique microclimate created by their high degree of isolation in terms of mountains, deep valleys, hills and tableland formation, flanked on all sides by deep slopes. The cumulative effect of both wet and dry climate on these mountain ridges limit the dispersal of many species. According to Razi (1955) 14% species of the south Indian hill tops are endemic. Blasco (1970) observed 82 species endemic to Nilgiris, 18 to Palni, and 13 species to the Anamalai hills, in grasslands above 1700 m. Of all the species collected from ENP the endemic numbered to 51 (17%). The endemic species such as *Isachne fischeri, Impatiens pandata, I. chinensis, I. coelotropis, A. barnesii,* and *Didymocarpus macrostachya* listed by Shetty and Vivekanandan (1971) were also confirmed during this study. Species such as *Brachycorythis splendida* and *B. wightii* have their distribution only in Cardamom and Palni hills (Satheeshkumar, 1986; 1991). According to Jain (1986), about 30% of grass flora are endemic to India. He confirmed 172 endemic species to peninsular region. Twelve species (17%) of Poaceae collected from ENP during this inventory were found to be endemic. Out of 51 genera endemic to the WGs (Tewari, 1995) only one (*Vanasushava*) was found in the grasslands of ENP.

5.4.4 Rarity:

Henry *et al.* (1979) described 92 rare and threatened species from the montane ecosystem of the WGs. Twenty nine rare and threatened species were encountered in the grasslands of ENP during this survey (Mathew *et al.* 1991, Rao 1994). The plantation activities throughout the montane region, hydroelectric dams (e.g., Bhavani Reservoir in Nilgiris, Madupetty, Munnar, and Anayirangal Reservoirs in the High Ranges), and other anthropogenic factors are responsible for the rarity and dwindling status of many species (Ahmedullah & Nayar, 1985). The threat due to the large scale exploitation of medicinal plant has not been observed so far, but if the collection of *Drosera peltata*, *Anaphalis* sp. and *Eriocaulon* sp. continues at the present rate, these species may soon become locally extinct.

5.4.5 Phytogeography

Phytogeographically, Eravikulam NP falls under Malabar region of the Western Ghats (Clarke, 1898; Chatterjee, 1939; and Razi, 1955). The tropical montane climate in the high reaches of the WGs makes this region phytogeographically distinct.

Fyson (1915) reported that 17% of the south Indian hill tops species are common with those of the Khasi hills, and 12% with the temperate parts of the Himalaya, but none occur in the intervening country. Shetty & Vivekanandan (1971) reported 20 species common to Patanas of Sri Lanka, 28 to Himalaya, and 35 to the Eastern Ghats. Blasco

(1971) reported 17 common species with northern India (Himalaya), whereas 36 species extend to different countries of Asia. This study found that twenty eight species (9%) of ENP grassland are common with Western Himalaya, thirty five (11%) species common with Eastern Himalaya, Naga, Khasi and Assam hills, sixty four (21%) species with Eastern Ghats, thirty (10%) species common with Patanas of Sri Lanka.

Phytogeographic affinities of WGs have been explained by several authors. These explanations are based on the following theories: (1) Pleistocene Glaciation Theory (Medlicott & Blanford, 1879), (2) Satpura Hypothesis (Hora, 1949), (3) Route across the Bay of Bengal Theory (Croizat, 1968) (4) Coramandel Route Theory (Legris, 1963) (5) Ecological Pocket Theory (Mani, 1974) (5) based on birds and animals (Blasco, 1970, 1971).

The Pleistocene Glaciation Theory (Medlicott & Blanford, 1879) stresses on the change of climate (temperature) in the peninsular region with glacial movement, as a result of which, floral and faunal elements that were in the temperate Himalaya migrated towards WGs through the low mountain stretches which were free from ice. The presence of Nilgiri tahr (*Hemitragus hylocrius*), the congeneric of Himalayan tahr (*H. jemlahicus*), on the hill slopes of the WGs strongly supports this view. The main criticism to this theory is the total absence of conifers in the south Indian mountain tops, where, pine plantations were, however, raised successfully.

Blasco (1970, 1971) questioned this theory by saying that such direct contacts between the various high peaks due to the Pleistocene glaciation is ruled out in India due to long distances involved, by taking the example of East Africa. Evidently, the distances involved between the mountains of East Africa are considerably shorter than India and there is no evidence of past continuity in the hills of E. Africa. He emphasised the role of migratory birds for the distribution of species. But most of the migratory birds are largely insectivorous or omnivorous (Ridley, 1990). Therefore, it is unlikely that birds would have carried seeds from temperate regions to the WGs. Meher-Homji (1967, 1972) questions zoochorous migration of plants to the WGs since they differ at the species level. He favours the Pleistocene glaciation theory.

Hora (1949) did not agree that temperature is the only factor responsible for the discontinuous distribution and emphasized the role of humidity which may be more important than temperature. This makes the important postulate of the Satpura Hypothesis which envisaged that during Pleistocene, the Satpura and Vindhyan ranges had an altitude of 1500-2000 m. forming a continuous range of mountains between the Eastern Himalaya and the northern Western Ghats. The high rainfall (above 2500 mm) supported this migration. The migration route was from Assam and Eastern Himalayas to the plateau of Chota Nagpur across the Garo-Rajmahal gap. The migration from Chota Nagpur to south India and Ceylon was probably along the Vindhya-Satpura-Western Ghat route. He explained that the present day climate and topography are not suitable for migration of plants and animals from Assam and Eastern Himalaya but such favourable conditions existed in the Pliocene and Pleistocene periods. The palynological studies carried out in Palnis and Nilgiris established the role of Pleistocene Glaciation in the distribution of plant species on high altitudes of the Western Ghats, with evidence of pollen grains of Pleistocene flora (Vasanthy, 1988). Auden (1949) questioned the continuity of the ranges on geological reasons, and supported the theory of Pleistocene glaciation.

Croizat (1968) considered a connection across the Bay of Bengal (Route across Bay of Bengal Theory) for the migration of species from tropical Africa, Asia, Malaysia and Australia, taking the example of birds, tortoises, lizards and plants such as *Rhododendron*. However, the near absence of Indo-African, Sino-Indian and

Mediterranean elements in the north east and west coast regions does not support this theory (Puri *et al.* 1983).

Legris (1963) postulated that the migration of the floral elements from Assam to the Western Ghats probably was through Bengal, the hills of Orissa, Eastern Ghats, the Mysore plateau and Nilgiris, based on climatic, geological, palaeobotanical and phytogeographical grounds (Coromandel Route Theory). He emphasised the more humid nature of this tract during the Pleistocene. Regarding climate change and vegetation, he pointed out that the critical differences in hydric balance and temperature separating two vegetation types could lead to the elimination of one vegetation type and the invasion of the other. The distribution of *Dillenia pentagyna* in this tract is supportive of Coromandel Route theory.

Mani (1974) put forward the Ecological Pocket Theory to explain the past and present distribution of plants in the country. The evolution of special habitats through continental movement, folding and faulting of the Himalayas, the gradual filling up of Indo-Gangetic plain through rift provided direct contact between the oldest and youngest landmasses, facilitating the movement of plants and animals. The Pleistocene glaciation further diversified the region of uniform climate by the introduction of colder regions. The erosion and sedimentation process in the intervening period developed the peninsular mountains into distinct ecological pockets. The Garo-Rajmahal Gap in the north-east, separating the Himalaya from the peninsula, is envisaged as the major route of faunal and floral movement.

Razi (1955) was of the opinion that migration of species occurred in two ways, i.e., a northward as well as southward movement. The *Rhododendron* species of the south Indian hill tops and Sri Lanka are quite similar to *R. arboreum* of the Himalaya. Though edaphic and climatological factors are suitable for *Rhododendron* species the absence of species other than *R. arboreum* va. *nilagiricum* from the north east region of India to the peninsular region emphasise a southward migration from Western Himalayas. He further discussed the probable routes of migration to the Mysore plateau. The African elements entered India through north east Africa, Arabia, and Baluchistan during the Miocene. The Mediterranean elements travelled through north-west Himalaya, and from the Himalaya to south India mainly through Vindhyas and Satpuras.

Based on the foregoing discussions, it can be concluded that land connections between Himalayas and WGs in the past were responsible for species migration. But no single theory holds good in explaining the phytogeographical affinities of two distinct areas. The major gaps in all the postulates are (i) though the ecological conditions are adequate for many temperate species, none of the pines have been reported from south, (ii) the absence of obligate frugivorous migratory birds from the Himalaya to the WGs to facilitate zoochory, (iii) the suggested geological period of migration, (iv) the antiquity of the Western Ghats over the Himalaya. Thus considering the young age of Himalaya, the WGs might have been the species donor rather than the receiver.

5.5 Summary

Floral inventories in the grasslands resulted in the collection of 308 species, adding 106 new species to the earlier list, emphasizing the importance of this survey. Fifty one species were found to be endemic to the montane grasslands of the WGs, proclaiming its uniqueness. Twenty nine were listed as rare and endangered species, indicating the increasing destruction of this habitat. The phytogeographical affinities with different biogeographic zones such as Eastern Ghats, Patanas of Sri Lanka, Western Himalaya and Naga and Khasi hills, throws light on the migration of species or their independent origin, that has to be studied separately. The high species richness in the ecotones (*shola*-grassland edges) compared to other areas indicated the availability of conducive microclimates. The generally dry nature of the grasslands were explained by the greater number of therophytes over chaemophytes and hemicryptophytes.

Chapter 6

COMMUNITY STRUCTURE AND COMPOSITION

6.1 Introduction

Plant community is the composition of spatially and temporally integrated species that retain their individuality in an area (Misra, 1968; Mueller-Dombois & Ellenberg, 1974). The varying quality and quantity of the community is referred to as structure (Misra, 1968). Plant communities and associations characterize the 'habitats' in which transformation, accumulation and flow of energy are involved. There are two views regarding the concept of community: (a) the organismic concept of Clements (1928) states that the whole vegetation can be divided into formations and each formation is further divided into associations. (b) Gleason's (1926) view states that populations independently respond to environmental variables. Plant community is the level at which populations and individuals of a plant species can be identified (Kent & Coker, 1992). It is at this level that humans can make best sense of nature and variation. This chapter describes the vegetation structure, phenology and the relation between vegetation and environmental variables in ENP.

6.2 Methodology

6.2.1 Field method:

Identification of relevé and data collection: In each landscape unit, similar patches of vegetation (relevé) were identified and circular plots of 5 m radius were laid. Species inventory, sociability, cover and phenological expressions were recorded by standing in the middle of the plot.

Phenological observations on 150 species were made along a transect (*ca.* 3 km) on altitudinal gradient of 1600m to 2700 m. Three Individuals of each species were tagged and every month phenophases were recorded for a period of one year.

In order to study the *shola*-grassland dynamism on long term basis, five exclosures (Iron chain links and anklers) of 11m x 11m (effective area 10m x 10m) were erected, four in grasslands and one on the *shola* edge. In the grassland, six 1m x 1m quadrats were marked and cover of each species were noted for studying the dynamism. The exclosure erected on the *shola* edge was divided into 4 strips (2x10m). One strip was completely in the open grassland and another in shola forest. The other two were in *shola*-grassland edges. In each strip, all species were enumerated, and a few of them (dicots) were tagged for studying the growth. Except in the shola strip, five 1m x 1m quadrats were laid for vegetation cover. All these control plots had comparable uncontrolled sites.

6.2.2 Analytical methods:

<u>Similarity index</u>: Similarity index between releve's was calculated according to Sorenson's (Mueller-Dombois & Ellenberg, 1974) formula Ss=2c/(A+B), where, Ss= Sorrenson's index, c=common species, A=number of species in releve A, B=number of species in releve B.

<u>Diversity index</u>: The relation between diversity and stability of ecosystems is well known. Diversity measures of a stand indicate the structure of the plant community in an area (Magurran, 1988). It can be expressed qualitatively as species richness and quantitatively by different indices. One of the most commonly used is Shannon-Weiner's index (H'). The diversity in this respect is a measure of evenness. It does not account for

the dominance value of the individual species as in the case of Simpson's index. However, this index makes two assumptions, that individuals are randomly sampled from an infinitely large population, and that all the species from a community are included in the sample (Magurran, 1988; Kent & Coker, 1992).

$H' = -\Sigma$ pi lnpi,

where, p_i = proportion of individuals or abundance of the *i*th species expressed as proportion of the total cover

ln = log $base_n$.

The same index (H') can be expressed in the form of species number (hypothetical) by another index called N_1 (McArthur, 1965).

$N_1 = e^{H'}$,

where N_1=equally dominant species, H'=Shannon-Weiner's index calculated with base e (n), and e (n)=2.71828 (Ludwig & Reynolds; 1988 Krebs, 1989).

Species richness was calculated using the Menhinick index (Magurran, 1988)

$R = S/\sqrt{N}$,

where, R = species richness, S = number of species in a community, N = number of individuals of all species in a community.

Evenness of the stand (species with equal or virtually equal distribution/abundance) was calculated through index J (Magurran, 1988),

$J = H'/\log S$,

where, J = evenness index, S = total number of species in a community.

Species Associations

Plant associations were derived manually using Table Transfer Method (Mueller-Dombois & Ellenberg, 1974, Westhoff & Maarel, 1978) as well as using the computer programme TWINSPAN-Two Way Indicator Species Analysis (Hill, 1979).

a. Table transfer (sorting) method

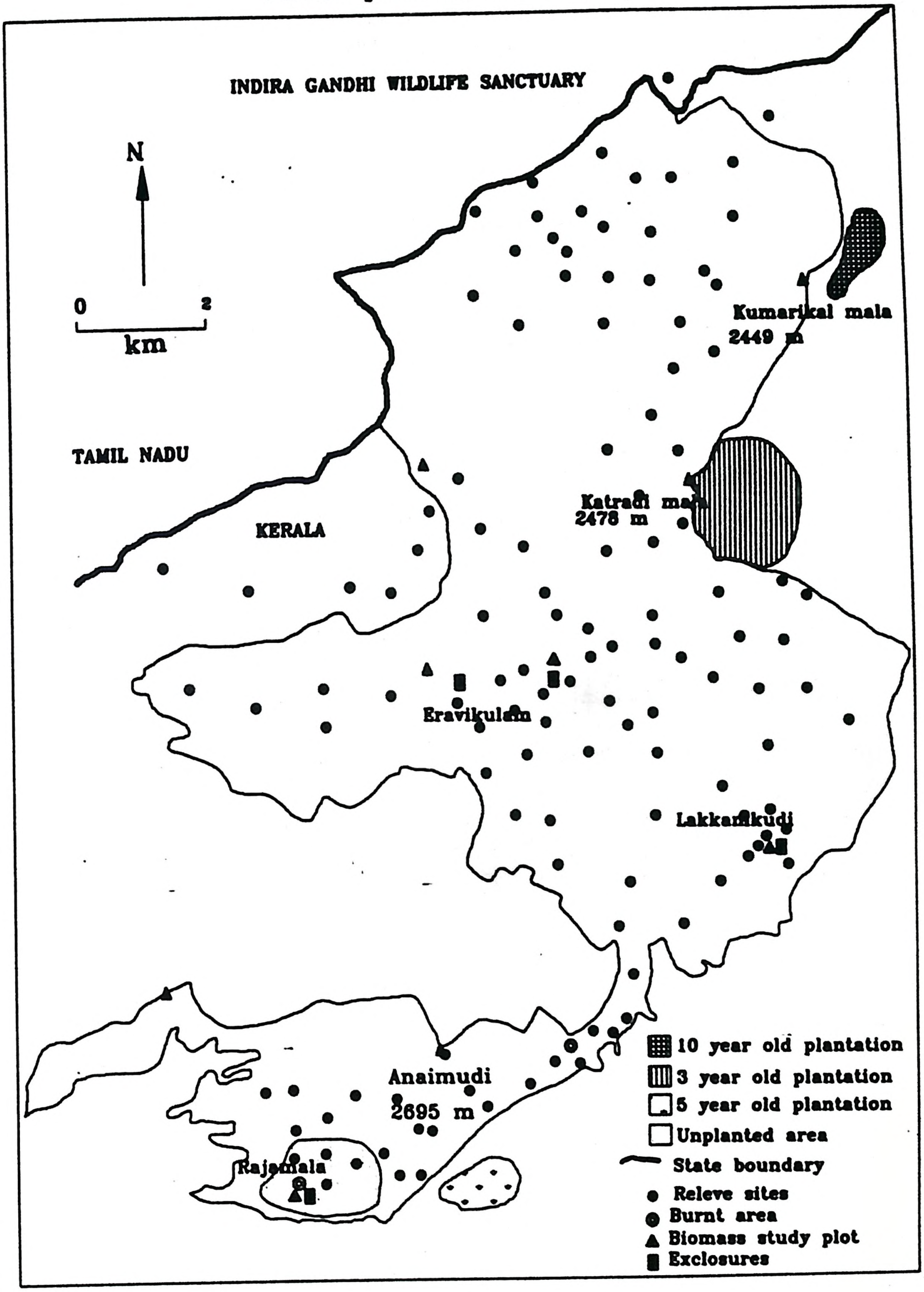
Sorting involved the following stages: (i) the compilation of *raw data table* according to similarity index between relevés, (ii) calculation of *constancy* (≈ frequency) of each species, (iii) identification of *differential species* on the basis of constancy. Differential species are those which tend to occur together in a series of quadrats and thus can be used to characterise the group. (iv) a *partial ordered table* was made with the help of differential species, (v) sorting of species was first done within the partial table with *companion species* (dominant species), and differential species. This particular table is called as *differentiated table*. Each of these group then represent an association (Shimwell, 1971; Mueller-Dombois & Ellenberg, 1974; Westhoff & Maarel, 1978; and Kent & Coker, 1992).

Altogether, 123 relevés were laid throughout the park (Figure 6.1) in various landscape units. These were arranged according to similarity indices. Based on the constancy of each species, character species, differential species and companion species were sorted to form associaitons.

b. Two Way Indicator Species Analysis- TWINSPAN:

All the relevé data were pooled together to run the TWINSPAN programme. Since the output through default did not match with the field observations, the options for pseudospecies cut level and weightage for species to be included in the final table were changed. Seven psudospecies cut levels were given according to the frequency of cover (abundance) scale. They are 0.1, 0.5, 3, 10, 20, 38, >63, with % frequencies 18.7, 47.3, 17.0, 8.5, 4.5, 2.8, and 1.1 respectively.

Figure 6.1: Map showing various experimental and wattle plantation study sites



The plant communities were classified and named based on the association concept (Mueller-Dombois & Ellenberg, 1974). This involved formation of groups of definite floristic composition, physiognomy and uniform habitat based on the definition given by International Botanical Congress, Brussels, in 1910 (Mueller-Dombois & Ellenberg 1974). In the present analysis uniform habitat condition was not taken into consideration. Associations were named after less frequent to frequent and abundant species.

Canonical correspondence analysis-CANOCO (ter Braak, 1987-92) was used to determine the relationship between environmental factors with vegetation association and species. It is a multivariate method of integrated (direct) ordination of species, together with associated environmental variables that results in the correlation of environmental data as well as species variability. It uses multiple regression to select the linear combination of environmental variables that explain species abundance and distribution. Monte Carlo permutation tests were used to determine whether the canonical axes were significantly related to environmental variables.

Of the 123 relevés, environmental variables (edaphic) of only 52 relevés were used for CANOCO analysis. Each relevé is represented by 16 environmental variables. Relevés were selected in such a way that they constituted all associations that resulted from TWINSPAN.

6.3 Results

6.3.1 Phenology:

The analysis of phenological data showed a preponderance of sprouting (10 %) and vegetative phase (78%) in the month of June, flowering (54%) in October, fruiting

(25%) in March, and dryness or senescence (53%) in April (Table 6.1). During September, October and November, none of the species were sprouting. Likewise July, August, September and October being the monsoon senescence was not noticed. Humidity was found to be positively correlated with all the phenophases ($r=0.264$, $p<0.001$). Mean maximum temperature showed negative correlation ($r=-0.098$, $p<0.001$) and mean minimum temperature and rainfall were positively correlated but not significantly ($r=0.18$ and 0.17, $p<0.001$).

Table 6.1. Phenology of the grassland species in ENP (n=150 species)

MONTH	PHENOPHASE in %				
	Sprouting	Vegetative	Flowering	Fruiting	Dried
January	2	24	18	24	33
February	2.7	20	19	23	36
March	4	17	9	25	47
April	2.7	24	10	12	53
May	9	49	10	7	27
June	10	78	7	3	2
July	7	67	23	4	-
August	3	72	25	1	-
September	-	63	36	0.6	-
October	-	43	54	5	-
November	-	37	49	14	0.6
December	2	29	27	23	20

6.3.2 Long term monitoring:

The data collected for 18 months (at 6 month intervals) did not show any significant change in dynamics of grassland. The only difference noticed was the cover value of *Phlebophyllum kunthianum* in the *Chrysopogon zeylanicus* community. In the case of *Cymbopogon flexuosus*, community the vigour (height) of *Heteropogon contortus* increased when compared to outside the exclosure. *Sehima nervosum* community did not register any observable changes. The data from *shola*-grassland edge recorded an increase in the following native species like *Leucas helianthemifolia*, *Rapanea wightiana*, *Plectranthus wightii*, *Brachyocorythis wightii*, *Ischaemum indicum* and *Chrysopogon zeylanicus*, whereas colonisers such as *Ageratina adenophora* and *Pteridium aquilinum* showed a decrease in number inside the exclosure. In all the data sets only, one seedling of *Syzygium arnotianum* of 5 cm was noticed. The height of species such as *Chrysopogon zeylanicus* and *Rapanea wightiana* also increased.

The ten most frequent species found in the grasslands of ENP in descending order were *Eulalia phaeothrix*, *Ischaemum indicum*, *Chrysopogon zeylanicus*, *Arundinella purpurea*, *Sehima nervosum*, *Tripogon bromoides*, *Anaphalis lawii*, *Andropogon lividus*, *Drosera peltata* and *Polygala japonica* (Table 6.2).

Table 6.2. The ten most frequent species found in the grasslands of ENP.

SL.NO	Name of the species	Frequency	% frequency
1	*Eulalia phaeothrix*	110	3.6
2	*Ischaemum indicum*	107	3.5
3	*Chrysopogon zeylanicus*	98	3.2
4	*Arundinella purpurea*	96	3.2
5	*Sehima nervosum*	95	3.1
6	*Tripogon bromoides*	95	3.1
7	*Anaphalis lawii*	85	2.8
8	*Andropogon lividus*	77	2.5
9	*Drosera peltata*	70	2.3
10	*Polygala japonica*	67	2.2

6.3.3 Communities based on Table Transfer method

The table transfer on the basis of cover abundance and sociability following Braun-the Blanquet approach of vegetation classification identified communities with two predominant species: *Chrysopogon zeylanicus* and *Sehima nervosum*. They were found all through the park in different combinations. However, small landscape units such as bogs (BG) were dominated by *Eriocaulon robustum*, grazed area (CG) by *Heteropogon contortus* and scraped area (SC) by *Ischaemum indicum*.

The diverse nature of the shola-grassland interface was evident from the distinct associations, viz. *Ischaemum indicum-Tripogon ananthaswamianus-Chrysopogon zeylanicus* towards grassland and *Panicum javanicum-Pouzolzia wightii-Chrysopogon zeylanicus* towards *shola*. The tabular method identified 22 associations.

6.3.3.1 FLAT TOP (FT)

The hill tops were normally with zero aspect and characterised by low soil depth. The vegetation was usually sparse with exposed areas. More gravel was found in these areas. All the three associations were dominated by *Chrysopogon zeylanicus*. The communities are *Sehima nervosum-Apocopis wightii-C. zeylanicus* (SAC), *Cyanotis arachnoides- Phlebophyllum kunthianum-C. zeylanicus* (CPC), and *Eulalia thwaitsii-Habenaria heyneana-C. zeylanicus* (EHC). *P. kunthianum* was found on small mounds on the plateaus, especially towards Eravikulam and Poovar. Some of the common herbs present in this landscape unit were *Anaphalis lawii, Gentiana quadrifaria, G. pedicellata, Curculigo orchioides*, etc.

6.3.3.2 SLOPE WITH ROCKY OUTCROPS (SRO)

Rocky slopes were the most important landscape units present in the park. The

Nilgiri tahr used such areas as escape terrain and for feeding. Many species of this association were eaten by tahr. Although *Crotalaria fysonii* did not contribute much to the vegetation cover, its high constancy made its presence in the association. The most common association of SRO was *Phlebophyllum kunthianum -C. fysonii-C. zeylanicus* (PCC). *Curculigo orchioides-Osbeckia lineolata-C. zeylanicus* (COC) and *Gentiana quadrifaria-Hedyotis swertiodes-C. zeylanicus* (GHC) were the other two associations in this landscape unit. Since *C. orchiodes* is a seasonal plant, this association could be noticed during or towards the end of monsoon. The association GHC was commonly seen in areas which are exposed either by trampling or by erosion. Shrubby species such as *Hypericum mysorense, Ageratina adenophora, Vanasushava pedata* were seen in this association.

6.3.3.3 Slope Without Rocky outcrops (SWR)

This represented the largest landscape unit in the park. Soil depth was considerably higher than SRO. The ground was almost completely covered by vegetation. The carpet like appearance of *Sehima nervosum* was very characteristic of this association. The presence of *P. kunthianum* was prominent in Poovar, Varattakkulam, and Anaimudi slopes. The slopes of the knolls and mounds on the plateau came under this group. The species associations were *Swertia corymbosa-Phlebophyllum kunthianum-S. nervosum* (SPS), *Senecio lavandulaefolius-Helictrotrichon indicum-S. nervosum* (SHS) and *Fimbristylis kinghii - Habenaria heyneana - S. nervosum* (FHS). *H. heyneana* was present throughout the landscpe. The associated species of this landscape were *Eulalia phaeothrix, Arundinella purpurea, Andropogon lividus, Helictotrichon virescens, A. lawii, Drosera peltata*, etc.

6.3.3.4 VALLEY (VL)

The valleys were of two types, wet and dry. Both types had high % of soil moisture and were deep. Sedges were among the associated species. The prominent associations were *Carex phacota-Vanasushava pedata-S. nervosum* (CHS), *Cyperus spp.-Eriocaulon robustum-S. nervosum* (CES) and *Carex filicinae-Emilia sonchifolia-S. nervosum* (CES). Among this CES represented the largest in extension which was characteristic of poorly drained valleys. *S. nervosum* was found in continuous patches. Species such as *Anemone rivularis, Thalictrum javanicum, Pedicularis zeylanica, Commelina clavata* were common in this association.

6.3.3.5 BOG (BG)

There were two kinds of water-logged areas (bogs). One was near the *shola* where streams originate, and the second one was in the deep valleys. Both the areas were characterised by the presence of *Eriocaulon robustum*. The two associations found in this landscape unit, were *Commelina clavata-Chrysopogon zeylanicus-E. robustum* (CCE) and *Smithia blanda-Isachne borneorum-E. robustum* (SIE). The presence of *C. zeylanicus* in the first association indicated that these bogs were close to *shola* patches. Other common species found in this group were *Hedyotis swertioides, H. articularis, Ischaemum indicum, Impatiens pandata, I. campanulata, Hypericum wightianum, Peristylis spiralis* etc.

6.3.3.6 SHOLA GRASSLAND EDGE (SGE)

The predominant associations along *shola*-grassland edges were *Ischaemum indicum -Tripogon ananthaswamianus-C. zeylanicus* (ITC), *Isachne setosa-Pouzolzia wightii-C. zeylanicus* (IPC) and *Andropogon lividus-Anaphalis lawii-C. zeylanicus* (AAC).

Herbaceous species such as *A. lawii, Polygala japonica, Disporum leschenaultianum, Disperis neilgherrensis, Satyrium nepalense, Hydrocotyle javanica, Laurenbergia gracilis, Wahlenbergia marginata*, undershrubs such as *Andrographis neesiana, Osbeckia lineolata, Hedyotis swertiodes, and Pteridium aquilinum* and shrubs such as *Gaultheria fragrantissima, Ageratina adenophora* were found in these associations. The association ITC was found at the true edge, IPC towards *shola* and AAC towards true grasslands.

6.3.3.7 Cattle grazed areas (CG)

The preponderance of unpalatable *Artemisia nilagirica* and *Cymbopogon flexuosus* indicate the grazing pressure at such sites. Due to excessive grazing the dominant species *Heteropogon contortus* had been transformed into a creeping form. Rare orchid species such as *Habenaria rariflora* and *H. crassifolia* were also found in such areas. The three associations found in this landscape unit were *A. nilagirica-C. flexuosus-H. contortus* (ACH), *Arundinella purpurea-Phlebophyllum kunthianum-H. contortus* (APH) and *Tripogon bromoides-C. zeylanicus - H. contortus* (TCH). The association ACH was found near settlements, where grazing pressure is heavy, APH was found on rocky slopes far from settlements, and TCH was found on non-rocky slopes that indicate less grazed vegetation.

6.3.3.8 Scraped areas (SC)

These areas were developed due to scraping for introducing exotic species of grasses, and as part of the fire management practices. The neighbouring vegetation was dominated by *S. nervosum*. So, this can be considered as a seral stage. The two dominant vegetation groups were *H. contortus-Leucas helianthemifolia-I. indicum* (HLI) and

Fimbristylis kinghii-S. nervosum-I. indicum (FSI). Species such as *A. lawii, Laurenbergia gracilis, Drosera peltata* were common in these associations.

6.3.4 Communities based on TWINSPAN

On the basis of abundance and similarity TWINSPAN gives different species associations. Since the output largely depends upon the pseudospecies cut level, the one which is most conducive (cut level 7) to the field condition was selected for description. TWINSPAN also identified *Chrysopogon zeylanicus* and *Sehima nervosum* as dominant species. But it was different from tabular transfer in the case of dominant species in the bog as *Isachne setosa,* in cattle grazed area as *Cymbopogon flexuosus*. Broadly speaking, there were four communities at mean Eigen value 0.30. Of these, most associations were had *Chrysopogon zeylanicus* and *Sehima nervosum*. The diversity index ranged from 1.38 in the cattle grazed area to 2.90 in the *shola*-grassland edge. Since the whole grassland cover was dominated by a few grass species (Table 6.2), each community looked like a homogenous patch in its area. Fifteen plant associations were made by TWINSPAN (Figure 6.2). The diversity indices showed that the association in the cattle grazed area had minimum diversity index (H'=1.38) and shola-grassland edge has maximum diversity (H'=2.90) (Table 6.3) .

(a) ***Smithia blanda - Eriocaulon robustum - Isachne setosa* (SEI)**: This association was found in the bogs of the park, where sheets of rock are present underneath. Even though it was steep and rocky, there would invariably be a small rivulet associated with this vegetation type. *Lycopodium* sp. was charecteristic of this association. There were 31 species present in this association. The diversity index (H') was 2.65, species richness 2.53 ± 0.06, and evenness 0.67. The diversity index (H') indicated that if 14 (N_1) species were equally distributed (evenness), same diversity could be obtained.

(b) ***Arundinella vaginata-Sehima nervosum-Chrysopogon zeylanicus*** **(ASC)**: This association was found mainly on the gentle slopes, especially on *shola*-grassland edges. Since rockiness was low and soil depth high, both *Chrysopogon* and *Sehima* grew vigorously. *Arundinella vaginata*, a rare species throughout, was seen on such areas due to higher moisture. The diversity index (H') was 2.24, species richness 3.42 ± 0.26 and evenness is 0.55. Thirty six species were present in this association. Species diversity demonstrated that equal distribution of 9 species (N_1) would give the same diversity.

(c) ***Agrostis peninsularis-Eulalia phaeothrix-Chrysopogon zeylanicus*** **(AEC)**: This association was also found along *shola* edges especially on rocky slopes with a past history of frequent burning. *Pteridium aquilinum* was one of the common indicators of such frequently burnt, moist sites. The diversity index (H') was 2.90, species richness is 2.67 ± 0.90 and evenness 0.70. There were 28 species in this association. N_1 indicated that the number of equally dominant species required for this index was 18.

(d) ***Gaultheria fragrantissima-Sehima nervosum-Chrysopogon zeylanicus*** **(GSC)**: This association mostly characterised the moist/rocky part of *shola* edges. The variety of ecotones seen in the park was established by the presence of different associations. The diversity index (H') of the association was 2.63 species richness 3.03 ± 0.28 and evenness 0.68. Thirty six species were present in this community. Number of evenly distributed species required for this diversity index was 14.

Figure 6.2: Dendrogram showing plant species associations in the grasslands of ENP (Number of plots showing associations are given on the top, eigen values are given between two associations).

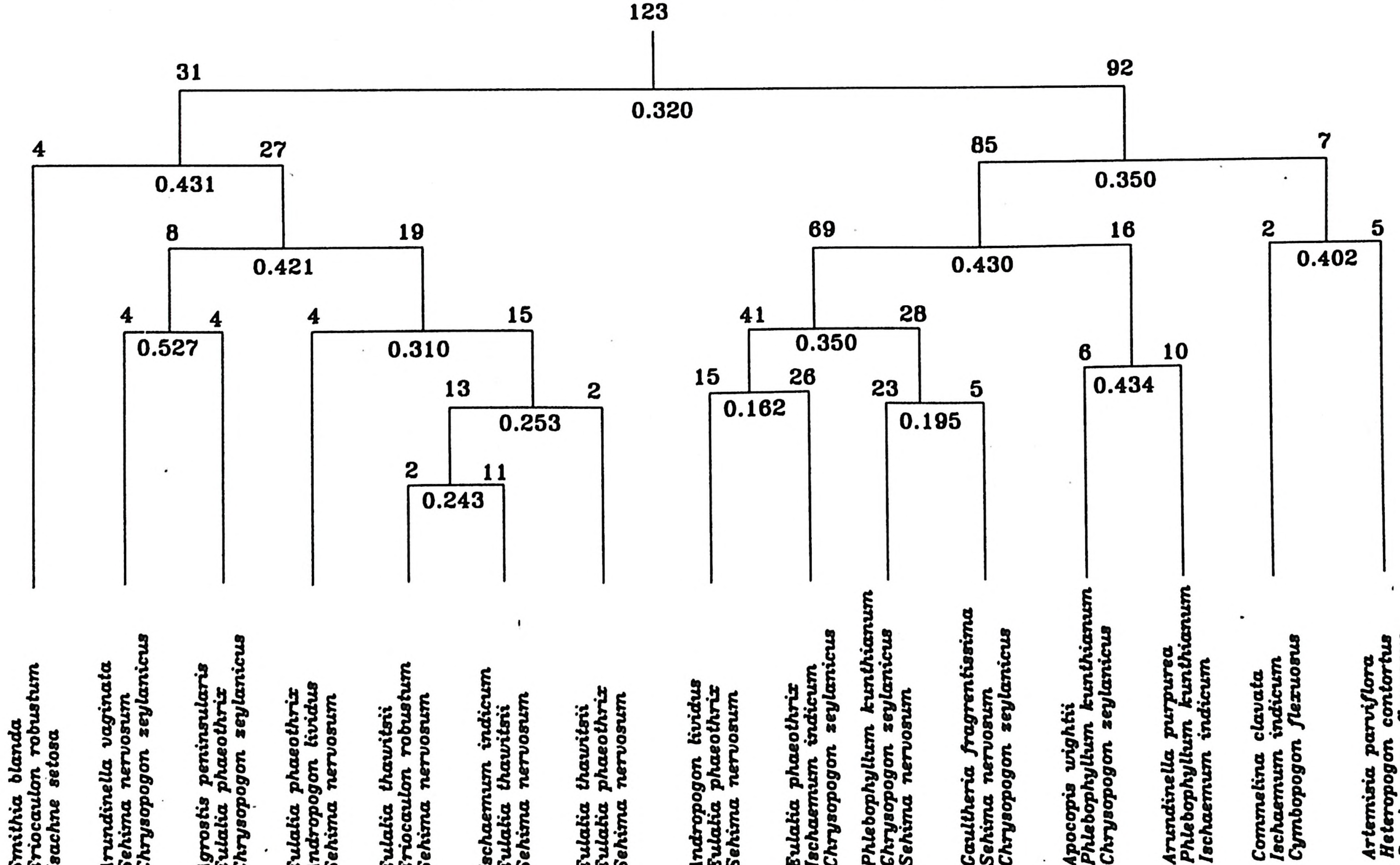


Table 6.3. Diversity, Richness and Evenness of 15 vegetation associations derived by TWINSPAN.

Associations	Diversity (H') Index	Richness Index	Evenness Index	$N_1 = e^{H'}$
SEI	2.65	2.53	.67	14
ASC	2.24	3.42	.55	9
AEC	2.90	2.67	.70	18
AES	1.66	2.21	.46	6
IES	2.64	2.20	.66	14
EErS	2.52	1.86	.68	12
EEuS	2.50	2.52	.68	12
AAC	1.93	2.07	.61	7
EIC	2.48	2.45	.58	12
PCS	2.48	2.64	.66	12
GSC	2.63	3.03	.68	14
APC	2.49	2.71	.50	12
API	1.95	2.32	.55	7
CIC	1.82	1.95	.35	7
AHC	1.38	2.80	.35	4

(e) ***Apocopis wightii-Phlebophyllum kunthianum-Chrysopogon zeylanicus* (APC)**: This association was found on the slopes which had *Phlebophyllum kunthianum*. Although boulders and rocky patches were not common, soil depth was very low (30-45 cm). The annual *Apocopis wightii* could be noticed during the growing season. The diversity index (H') was 2.49, species richness 2.71 ± 0.00 and evenness 0.50. Twelve species were found to be sufficent for obtaining the same diversity if they were equally distributed. The total number of species found in this association was 36.

(f) ***Eulalia thwaitesii-Eriocaulon robustum-Sehima nervosum*** **(EErS)**: The physical similarity of valleys with bog was reflected in the species association also. One of the important representatives of this association was *Eriocaulon robustum*, which thrived best in water logged areas. The nature of association in this landscape indicated that it might change into a bog. Although there were a few tussocks of *Chrysopogon* in these areas the dominant species was *Sehima nervosum*. *C. zeylanicus* normally occupied the meeting point of the slope and flat bottom. The area was wet and soil depth was also considerably high (ca 80 cm). Diversity index (H') of this association is 2.52, species richness 1.86 ± 0.56 and evenness 0.68. Of the 24 species present in this association, 12 were adequate enough to attain this diversity if they were equally distributed.

(g) ***Ischaemum indicum-Eulalia thwaitesii-Sehima nervosum*** **(IES)**: This was the second most dominant association of valleys, largely constituted of grasses. Perhaps, this formed the most extensive cover in the valley vegetation. Diversity index (H') of this association was 2.64, species richness 2.20 ± 0.39 and evenness 0.66. This assocition was represented by 24 species. Fourteen species of equal abundance were needed for attaining this diversity.

(h) ***Andropogon lividus-Eulalia phaeothrix-Sehima nervosum*** **(AES):** This association was fairly large in extent throughout the park and mainly occupied the gentle slopes of the plateau. The habitat features included exposed soil (without rocks) and sparse vegetation. Diversity index (H') was 1.66, species richness 2.21 ± 0.48 and evenness 0.46. The low diversity value indicated that only 6 species were needed (23 were present in this association) to attain this diversity level, provided they were distributed equally.

(i) ***Eulalia phaeothrix-Ischaemum indicum-Chrysopogon zeylanicus*** **(EIC)**: This association was the second largest in the park. The landscape units like flat mounds, rocky and non-rocky slopes were represented in this association. The association was an important habitat for Nilgiri tahr (Karunakaran *et al.*, 1994). All the three representatives of this association were eaten by tahr and other ungulates. Though *Phlebophyllum kunthianum* (Neelakurinji) was present in this association, its abundance was low. In the northern half of the park (e.g., Poovar, Kumarikkal), Neelakurinji was in close association with *S. nervosum*, while in the southern half it was associated with *C. zeylanicus* patches. The diversity index (H') of this association was 2.48, species richness 2.45 ± 0.54 and evenness 0.58. Thirty species were present in this association. But same diversity could be attained with 12 species if they were equally dominant.

(j) ***Phlebophyllum kunthianum-Chrysopogon zeylanicus-Sehima nervosum*** **(PCS)**: This formed the most extensive plant association in the park covering nearly 30% of the grassland area. It occupied both the non rocky undulating and rocky and bouldery slopes of the park. The mat like appearance of the unpalatable *S. nervosum* made such areas less used by animals. The diversity index (H') of this association was 2.48, species richness 2.64 ± 0.94 and evenness 0.66. This association of rocky outcrops, had 23 species. It was found that 12 equally dominant species could contribute the same diversity.

(k) ***Arundinella purpurea-Phlebophyllum kunthianum-Ischaemum indicum*** **(API)**: This association was found in areas where scraping was in 1982-'84 for introducing Kongo signal (*Brachiaria ruziziensis*) grass. Of the four sites surveyed, three had this vegetation composition. The fourth site (near Bheemanoda lake) was totally different from the rest in species composition due to less soil depth (ca. 10 cm). In all the sites, there were more herbaceous elements than grasses. Soil had more gravel than other sites. The annually scraped (fire lines) areas also showed similar composition. The diversity index (H') of this vegetation association was comparatively low (1.95). Species richness was 2.32 ± 0.45 and evenness 0.55. Twenty two species were present in this association. It was found that 7 species were enough to reach this diversity level.

(l) ***Commelina clavata-Ischaemum indicum-Cymbopogon flexuosus*** **(CIC)**: This particular association was found in areas which were highly grazed in the past and presently under moderate grazing (ca. 50 cattle heads/day/10 km^2). The dominant unpalatable tall grass, *C. flexuosus* grew in association with *Habenaria crassifolia, H. rariflora, Commelina clavata, Sopubia trifida, Artemisia parviflora*, etc. The low diversity index (1.82) revealed selective grazing and dominance of unpalatable species. Species richness was 1.95 ± 0.43 and evenness 0.35. This associaiton had 22 species. Low diversity indicated that only 7 species were needed to reach the diversity.

(m) ***Artemisia nilagirica-Heteropogon contortus-Cymbopogon flexuosus*** **(AHC)**: This characteristic association of grazed area was found near settlements, where unpalatable species such as *A. nilagirica* and *C. flexuosus* dominated. The extensive grazing in the past changed the morphology of erect *H. contortus* into a prostrate form. Among the grazed, areas most, fell into this category. The low diversity index (1.38) indicated heavy grazing and dominance of unpalatable species. Species richness was 2.80 ± 0.50 and evenness 0.35. It was noticed that 4 species were enough (total species in this associaiton was 22) to attain this diversity if they were evenly distributed.

(n) ***Eulalia phaeothrix-Eulalia thwaitesii-Sehima nervosum*** **(EEuS)**: This association was found in water-logged areas, especially near Eravikulam Ar on the way to Sambamala. *S. nervosum* was almost uniformly distributed in this area along with *Rananculus reniformis, Hypericum wightianum, Satyrium nepalensis* etc. Along the small gullies in this bog species such as *Garnotia exaristata* was dominated. Diversity index (H') was 2.5 and evenness 0.68. Species richness wass 2.52 ± 0.93. Thirty one species were present in this associaiton. N_1 indicated that if 12 species were distributed evenly the same diversity could be attained.

(o) ***Anaphalis bourneorum-Andropogon lividus-Chrysopogon zeylanicus*** **(AAC)**: This association was found on the summit of Anamudi. Both *Chrysopogon* and *Andropogon* tussocks were not as vigourous as on the lower slopes. Apart from these species, *Gentiana quadrifaria, Eriocaulon collinum, Arundinaria densifolia, Cyanotis arachnoides*, etc were also quite common in this association. The diversity index was 1.93, evenness 0.61 and species richness 2.07 ± 0.44. There were 23 species present in this association. It was found that 7 species would give the same diversity if they were distributed evenly.

6.3.5 Vegetation ordination

The distribution of species is related to the percentage variance of the species with respect to each environmental variable (ter Braak, 1987). The CANOCO results showed that the first axis had 40% of the variation (Figure 6.3) (Eigen value axis 1=0.40) indicating little identity in species composition of many vegetation associations. Among the environmental variables silt, clay and cation exchange capacity had the most significant positive correlations ($p<0.01$) on the first axis. The most significant negative correlations on the first axis were with soil depth, moisture, organic carbon and nitrogen. On the second axis, the variables that were significantly positively correlated, were soil depth, pH and sand. Negatively correlated variables were silt, cation exchange capacity, slope and rockiness. Many samples and thus species were clustered near the centre. Distinct groups were formed by the species of cattle grazed areas and bogs, with environmentally variable clay and soil depth respectively. So, the associations made by *A. nilagirica, H. contortus, C. flexuosus, Commelina clavata,* and *Ischaemum indicum,* were affected by clay. The variable clay is closely related with the first axis (correlation matrix=0.920), and sand and pH is highly correlated with the second axis which is explained by the correlation matrix 0.922. A test for significance with an unrestricted Monte Carlo permutation test (150 permutations) found that F-ratio for the axis one (Eigen value 0.40), and the trace statistic was significant enough ($p < 0.01$) to explain the variation (McDonald *et al*., 1996). Figure 6.4 indicates that the abundance of species such as *C. flexuosus, Themeda cymbaria, Imperata cylindrica, A. parviflora, Blumea alata, Lilium wallichianum, Mariscus cyperrianus, Sonchus wightiana* (second quadrant) were affected by clay and dominance of *T. tremula, Isachne bourneorum, Impatiens chinense, Arthraxon villosum, Lobelia leschnaultii, Eriocaulon robustum* (first quadrant) were affected by sand and pH. The abundance of *Jansenella griffithiana, and Lucas helianthemifolia* were affected by silt and cation exchange capacity of the soil. Variables like nitrogen and organic carbon mostly affected the distribution and abundance of *Juncus bufonius, Osmunda regalis, Carex phacota* in the valleys and along stream. Figure 6.5 & 6.6 clearly show the influence of each environmental variable on species diversity, species richness and evenness. It was found that the plots which related with clay had least evenness and diversity.

Figure 6.3 Orientation of major species along environmental and canonical axis

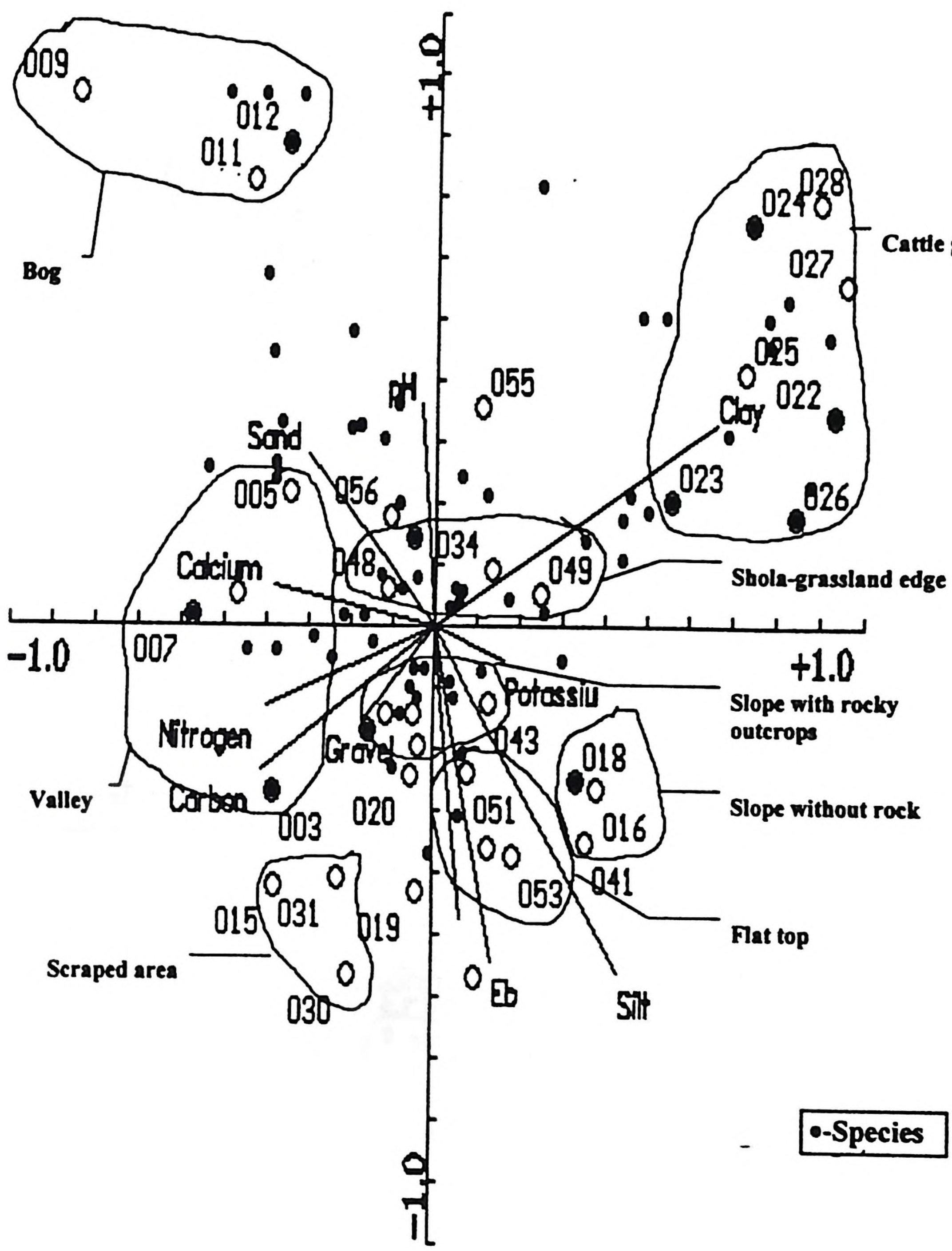


Figure 6.4 Scatter plot showing grassland species distribution with canonical axis

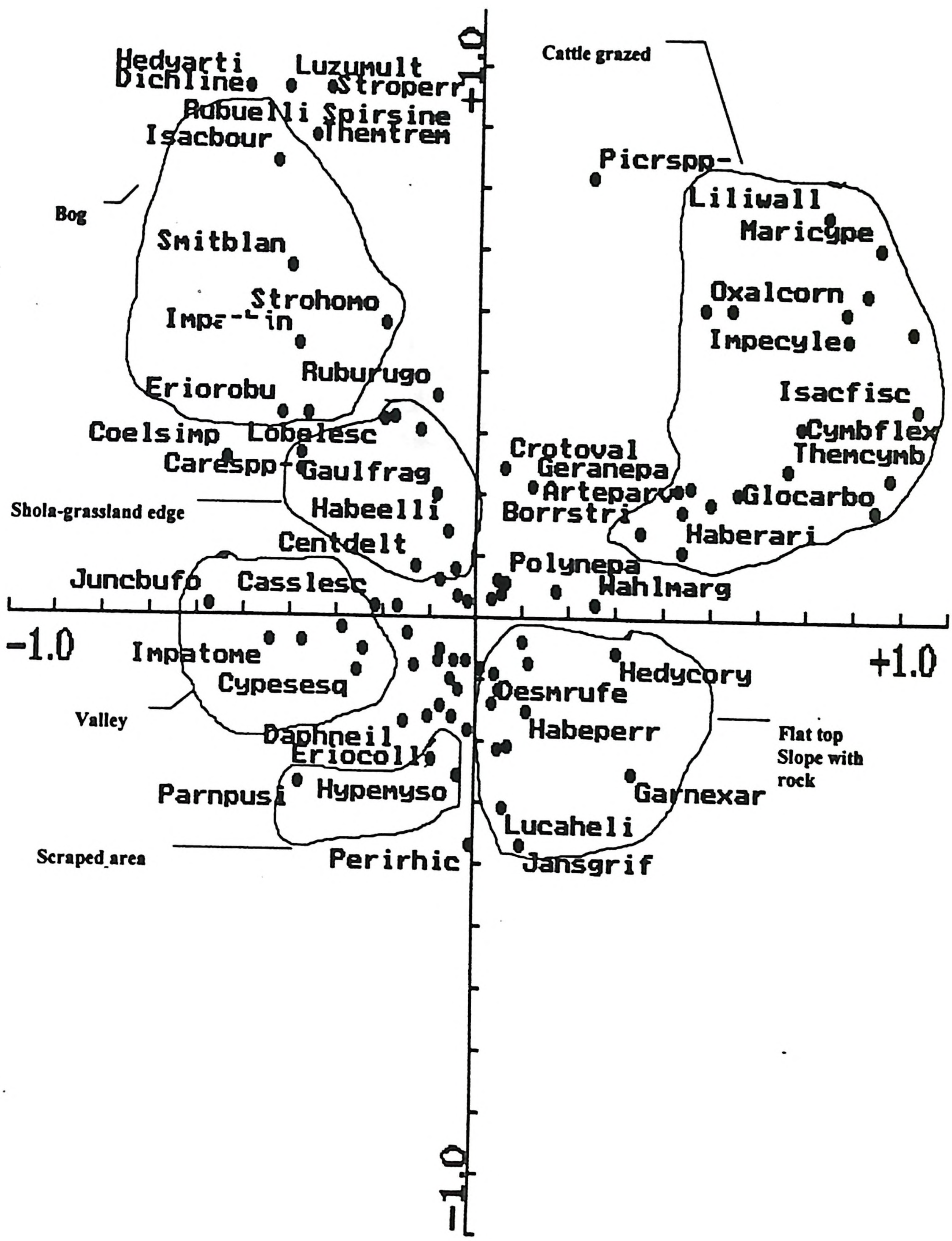


Figure 6.5 Diversity indices (H') of different ordination plots

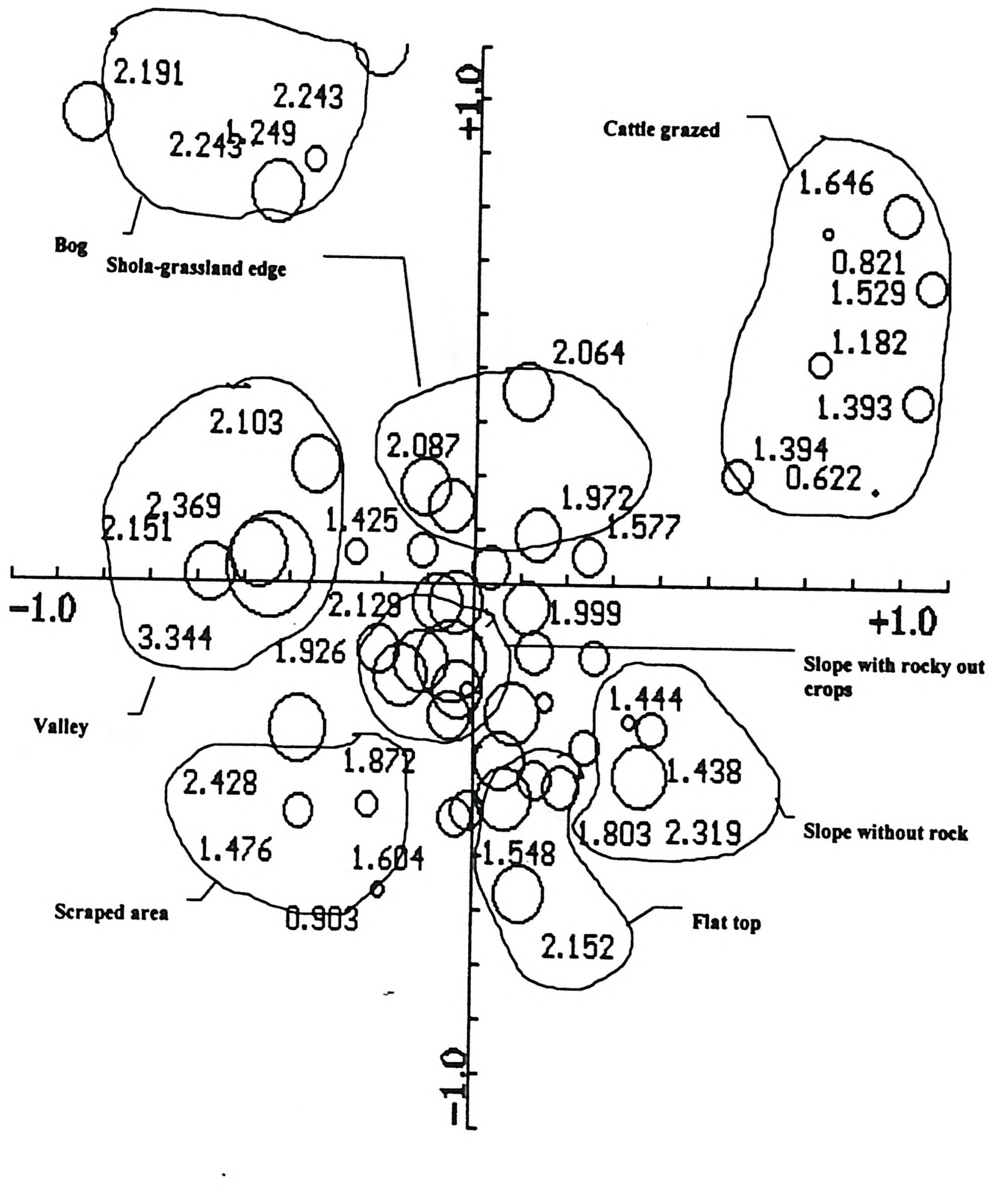
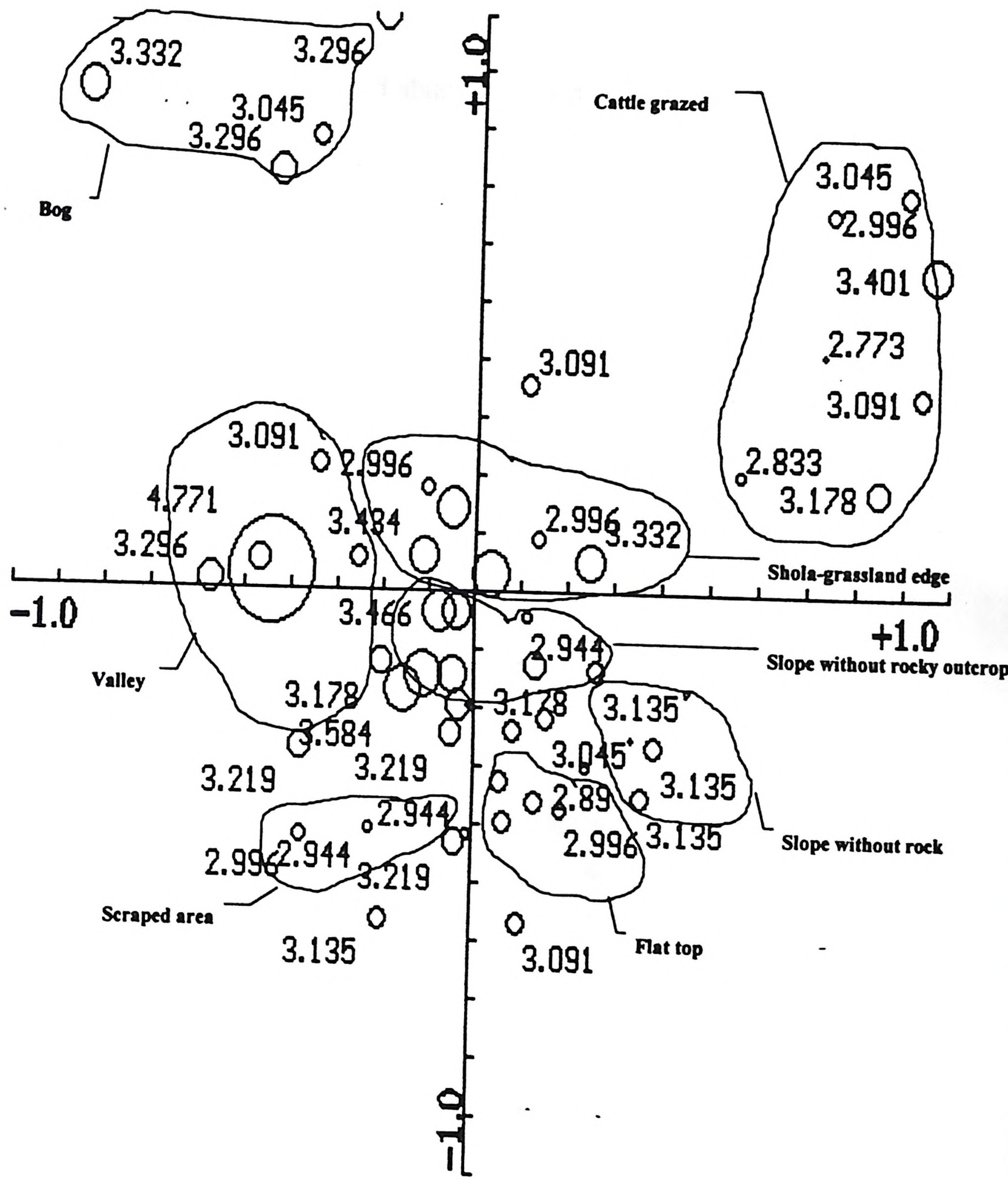


Figure 6.6 Species richness of different ordination plots



At the same time, the plots that were segregated on soil depth, sand and pH axis had high species evenness and diversity. These plots were from bogs and valleys. The plots from non-rocky and rocky slopes were not distinctly separated based on the executed environmental variables. In other words, it shows that the collected variables were inefficient to determine the distribution and abundance of more common species like *C. zeylanicus and S. nervosum.* Flat tops and scraped areas showed more affinity towards silt and cation exchange capacity of the soil.

Environmental variable such as clay, silt and cation exchange capacity had greater influence on species abundance and distribution, represented by long lines (ter Braak, 1986). Species such as *C. flexuosus, Isachne fischeri, Eragrostis uniloides, Imperata cylindrica, Crotalaria leschnaultii, Lilium wallichianum, Smithia blanda, Themeda tremula, Strobilanthes homotropus* and *Eriocaulon robustum* were found beyond the environmental axis since they had high weighted average scores.

6.4 Discussion

6.4.1 Phenology

Phenology is the response of each species towards heat, moisture and light (Lavrenko & Karamysheva, 1993). The phenological diversity in an area is influenced by seasonality (Singh & Krishnamurthy, 1981). A majority of grass and herb species in monsoon grasslands flower, fruit and produce seeds during the rainy season (Misra, 1983). Singh & Gupta (1993) reported the preponderance of annuals in Indian grasslands, with the vegetative phase dominating in the rainy season. The dominance of green leafy stage during June, July, and August, and yellow or brown leaves in March and April indicate strong seasonality in the grasslands of ENP. An intermittent change in climate again make this even more diverse (Lavrenko & Karamysheva, 1993). The second peak of monsoon, and subsequent flushing of herbs and grasses in ENP indicate this phenomenon. Lavrenko & Karamysheva (1993) reported a strong relationship between phenophase and moisture. In temperate semi-natural grasslands, 72% of the species came into flower during May-June (Rychnovska, 1993), whereas in ENP, most of the species were in vegetative phase in these months. The phenological nature of *pampas* showed that with a community, individuals of the same species show different phenophases at the same time (Soriano, 1993), which was comparable to the grasslands of ENP.

6.4.2 Long term monitoring

Problems like successional patterns of vegetation, population dynamics of fauna and flora, impact of mega-projects on local environment and people's health, and impact of certain management activities in the area, cannot be interpreted based on short-term studies (Goldsmith, 1991). The low vegetation cover of Neelakurinji, *P. kunthianum*, in *Chrysopogon* community is because of the mass flowering and drying of the species in 1994. The regeneration of shola species (*Syzygium arnotianum*) on the edges confirmed the role of ecotone vegetation in the advancing the *shola* vegetation towards open areas. This indicates a positive trend towards succession.

6.4.3 Diversity and evenness

High evenness occurs when species are equal or virtually equal in abundance, which is conventionally equated with high diversity (Magurran, 1988). In the grasslands of ENP, we found a highly significant correlation ($r=0.970$, $p<0.001$) between evenness and diversity indices. It was found that associations of the bog, *shola* edge and valley had high evenness, thus high diversity. This may be due to the edge effect (partial protection or complete protection from wind, frost, sun) and edaphic characters of the area. High evenness combined with richness indicates a good number of species, uniformly distributed. The diversity indices of different associations of the grassland of ENP was comparable with other grasslands. It was higher than that of alpine meadows (Ram *et al.*, 1989; Negi & Rikhari, 1994; and Kala *et al.*, 1997). Compared to mediterranean grasslands (H'=3.5 to 5.4) (Montalvo *et al.*, 1993) species diversity was low.

6.4.4 Vegetation Classification and Ordination

Dabadghao & Sankaranarayan (1973) considered the south Indian grasslands as *Sehima-Dichanthium* mesophilous type. But it appears to be a broad classification and does not represent the montane region specifically. A more comprehensive classification of south Indian grasslands is found in Chinnamani (1981) who described the grasslands occurring above 1800 m as temperate grasslands of *Andropogon polyptychus-Eulalia phaeothrix* type. Ranganathan (1938), Sankaranarayan (1958), and Blasco (1971) briefly described the structure of the montane grasslands.

Blasco (1970) considered the high altitude grasslands of the WGs as *Chrysopogon zeylanicus-Arundinella* type (Nilgiris) and *Heteropogon contortus-Arundinella mesophylla* and *E. phaeothrix-Arundinellă fuscata* type for Palnis. According to him, *E. phaeothrix, Themeda triandra, Andropogon lividus* and *Iscahemum aristatum* were rare in the Nilgiris. He considered *E. phaeothrix-A. fuscata* type as more stable and *H. contortus-A. mesophylla* type as more dynamic because the latter was found in the sheep grazed areas such as Mannavannur of Palnis. He further described that grasslands in the high rainfall (>5000 mm annually) areas as dominated by *T. triandra-Isachne kunthiana*, apart from the small patches of *A. lividus* in Sispara area of the Nilgiris. Although these species were found in ENP none of these associations could be separated using TWINSPAN. Ranganathan (1938) identified the dominance of *Andropogon pertusus, Ischaemum pilosum, Themeda inermis, Cymbopogon polyneuros* and *Eragrostis nigra* in Wenlock downs of Nilgiri plateau. Sankaranarayan (1958) named the grasslands of Nilgiris as *Themeda cymbaria* and *Cymbopogon polyneuros*. He found *Ischaemum ciliare, Bothriochloa pertusa* and *E. nigra* as associated species.

A brief classification of community and structure of the grasslands of ENP was attempted by Shetty & Vivekanandan (1971), Rice (1984), Sreekumar & Nair (1991) and Jose *et al.* (1994). The description of communities given by these authors were comparable with this study. Shetty & Vivekanandan (1971) found the grasslands of ENP dominated by *Dichanthium polyptychum var. polyptychum* and *E. phaeothrix*. Although *E. phaeothrix* had maximum frequency (3.6%) in the grasslands of ENP, its association with *S. nervosum* and *C. zeylanicus* suppressed it from being a dominant species by cover. Shetty & Vivekanandan (1971) further said that *Agrostis peninsularis, A. lividus, Arundinella purpurea, A. vaginata, C. zeylanicus, Isachne bourneorum, Ischaemum indicum* and *Tripogon bromoides* occur as companion species. Rice (1984) described this grassland as *E. phaeothrix* and *S. nervosum* type and mentioned that *E. phaeothrix* grasslands were more diverse than *S. nervosum* grasslands. The extensive patches of grasslands at Rajamalai, Anaimudi, Umayamala slopes, Turner's valley, Poovar, Kattumala and Kumarickal areas were dominated by *C. zeylanicus*. However, *S. nervosum* was found to be dominant on the knolls and mounds of the plateau. The widespread occurrence and gregarious flowering of *E. phaeothrix* often gives an impression that this species is the dominant grass in ENP. Sreekumar & Nair (1991) described grasslands of ENP as *E. phaeothrix-C. zeylanicus* especially in the Anaimudi-

Umayamalai slopes. He further expressed that *Dichanthium polyptychum* represents the climax stage of this grassland. But the frequency of *D. polyptychum* species was very low (0.2%). Among the dominant species (*D. polyptychum, Arundinella purpurea, A. vaginata, Andropogon lividus, Helictrotrichon virescens, Agrostis pilosula* and *T. bromoides*) reported by Sreekumar & Nair (1991) all species except *T. bromoides, A. purpurea and A. lividus*, were found to be site specific in this study. Jose *et al.* (1994) described only four species of grasses from the Rajamala side viz., *Arundinella vaginata, A. mesophylla, Digitaria wallichiana* and *Andropogon lividus*. *D. wallichiana* was largely seen along the road side. Compared to other parts of the park, frequency and abundance of *A. lividus* was very low at Rajamala. The tussock grass, *C. zeylanicus*, that provides shade to the emerging seedling of shola species, was as tall as 0.75-1 m in these areas.

Meher-Homji (1967) classified this vegetation into scrubland because of the presence of *P. kunthianum*. *Tripogon bromoides* which was frequent throughout the park did not figure at the association level through computer analysis, due to its low cover value. The diversity and evenness of *C. flexuosus* and *I. indicum* community, which represent cattle grazed and scraped areas were very low. Moreover herbaceous dicots were more frequent than grass species in scraped area.

A comparison of vegetation classification through TWINSPAN and table transfer (Table 6.4) gave some important indications regarding the methodology. The subjectiveness of the analysis was obvious in both the cases. In the table transfer method it lay largely with identification of relevés and stratification of vegetation on the basis of topography within an area of similar climate. In TWINSPAN it was evident from the congregation of plots from non-rocky slopes, rocky slopes, and flat tops. The advantage of manual analysis was that it gave an idea of derivation and segregation of vegetation associations which were easily identifiable in the field. In TWINSPAN even small

Table 6.4. A comparison of species associations in the grasslands of ENP using two methods, Table transfer & TWINSPAN.

Landscape units	Species associations	
	Table transfer	TWINSPAN
Flat top	1.*Sehima nervosum-Apocopis wightii-Chrysopogon zeylanicus.* 2.*Cyanotis arachnoides-Phlebophyllum kunthianum-Chrysopogon zeylanicus.* 3.*Eulalia thwaitesii-Habenaria heyneana-Chrysopogon zeylanicus.*	1.*Anaphalis bourneorum-Andropogon lividus-Chrysopogon zeylanicus.*
Slope with rocky outcrops	1.*Phlebophyllum kunthianum-Crotalaria fysonii-Chrysopogon zeylanicus.* 2.*Curculigo orchioides-Osbeckia lineolata-Chrysopogon zeylanicus.* 3.*Gentiana quadrifaria-Hedyotis swertiodes-Chrysopogon zeylanicus.*	-
Slope without rocky outcrops	1.*Swertia corymbosa-Phlebophyllum kunthianum-Sehima nervosum.* 2.*Senecio lavandulaefolia-Helictrotrichon indicum-Sehima nervosum.* 3.*Fimbristylis kinghii-Habenaria heyneana-Sehima nervosum.*	1.*Andropogon lividus-Eulalia phaeothrix-Sehima nervosum.*
Valley	1.*Carex phacota-Vanasushava pedata-Sehima nervosum.* 2.*Cyperus sp.-Eriocaulon robustum-Sehima nervosum.* 3.*Carex filicinae-Emilia sonchifolia-Sehima nervosum.*	1.*Eulalia thwaitesii-Eriocaulon robustum-Sehima nervosum.* 2.*Ischaemum indicum-Eulalia thwaitsii-Sehima nervosum.*

Shola-grassland edge	1.*Ischaemum indicum-Tripogon ananthaswamianus-Chrysopogon zeylanicus* 2.*Isachne setosa-Pouzolzia wightii-Chrysopogon zeylanicus.* 3.*Andropogon lividus-Anaphalis lawii-Chrysopogon zeylanicus.*	1.*Arundinella vaginata-Sehima nervosum-Chrysopogon zeylanicus.* 2.*Agrostis peninsularis-Eulalia phaeothrix-Chrysopogon zeylanicus.* 3.*Gaultheria fragrantissima-Sehima nervosum-Chrysopogon zeylanicus.* 4.*Apocopis wightii-Phlebophyllum kunthianum-Chrysopogon zeylanicus.*
Cattle grazed areas	1.*Artemisia nilagirica-Cymbapogon flexuosus-Heteropogon contortus.* 2.*Arundinella purpurea-Phlebophyllum kunthianum-Heteropogon contortus.* 3.*Tripogon bromoides-Chrysopogon zeylanicus-Heteropogon contortus.*	1.*Commelina clavata-Ischaemum indicum-Cymbopogon flexuosus.* 2.*Artemisia nilagirica-Heteropogn contortus-Cymbopogon flexuosus.*
Scraped areas	1.*Heteropogon contortus-Leucas helianthemifolia-Ischaemum indicum.* 2.*Fimbristylis kinghii-Sehima nervosum-Ischaemum indicum.*	1.*Arundinella purpurea-Phlebophyllum kunthianum-Ischaemum indicum.*
Bog	1.*Commelina clavata-Chrysopogon zeylanicus-Eriocaulon robustum.* 2.*Smithia blanda-Isachne bourneorum-Eriocaulon robustum.*	1.*Eulalia thawitsii-Eulalia phaeothrix-Sehima nervosum.* 2.*Smithia blanda-Eriocaulon robustum-Isachne setosa.*
Slope without rock, flat top and slope with rock	-	1.*Eulalia phaeothrix-Ischaemum indicum-Chrysopogon zeylanicus.*
Slope with rock, and slope without rock	-	1. *Phlebophyllum kunthianum-Chrysopogon zeylanicus-Sehima nervosum.*

variations in psuedospecies cut level and weightage given to each species make considerable change in the classification (Hill, 1979; and Kent & Coker, 1992). Thus both the methods are not adequate in themselves. The segregation of associations in the table transfer method was with the help of similarity indices between plots, and frequency and abundance of each species. But in TWINSPAN the whole process of dividing a community into different associations depends upon the psudospecies cut level. Proper weightage should also be given to that are rare (low in cover or abundance scale). A common feature which emerged using both the methods was that all the predominant associations were represented by members of Poaceae. Another important feature noticed in TWINSPAN output was the clumping of samples from different landscape units such as slope with rocky outcrops, slope without rocky outcrops, and flat top, indicated thating mere differences in landscape features would not affect species abundance and distribution. To conclude, it is proper to stratify an area on the basis of dominant species rather than topographical features, and then find out the associations on the basis of tabular transfer rather than selecting a 'subjective' computer package for the description of herbaceous communities.

Multivariate techniques can be useful in providing information on the relationships between distribution and abundance of species and environmental variables that were not available through traditional ways of analysis (Kindscher & Wells, 1995). This is the first study on the montane grasslands of the WGs to use such techniques, supported by statistical tests and ordination of species. The role of soil parameter in determining the community distribution and species diversity have been well documented (ter Braak, 1987; McDonald *et al.* 1996). The ordination results of Patanas of Sri Lanka with soil parameters, showed that dominant species such as *C. zeylanicus, E. phaeothrix* have low load on Axis 1 (Premadasa & Mueller-Dombois, 1979), which is comparable to the results that we obtained. Of the 118 species used for ordination, 84 were plotted on different axes. CANOCO proved that diversity of any community was largely influenced by edaphic factors. Grazing and trampling results in reducing soil depth, and especially in the loss of topsoil (Livingstone, 1991). Thus, less fertile soil would be dominated by unpalatable species such as *C. flexuosus* and *A. nilagirica.* The low mean evenness (0.35) and low mean diversity index (H'=1.32) showed by these plots indicate the adverse effect of grazing (Risser, 1991; Pettit *et al.* 1995). Contrary to this, the plots segregated along the sand axis showed high mean evenness (0.72) and high mean diversity (H'=2.50) indices. Due to continuous scraping, the soil became more gravelly, reflected by the ordination of plots in the fourth quadrant, which showed low mean evenness (0.50). The reason for the central occupation of species from *shola*-grassland edges, flat tops and rocky slopes with low mean evenness (0.40) is not apparent. This indicates that environmental variables measured were not sufficient enough to segregate the associations. Although the relationship between all species and environmental varibles could not be established in this analysis, it indicated the adverse effect of scraping and grazing. Future research should focus on the effect of other abiotic variables on the distribution of dominant species such as *C. zeylanicus* and *S. nervosum.*

6.5 Summary:

Although the Table Transfer method and TWINSPAN identified varying number of vegetation associations (22 and 15 respectively), both the analyses were in agreement that *Chrysopogon zeylanicus* and *Sehima nervosum* were the two most dominant species. From both the analyses, it was learnt that stratification of the area should be done based on dominant species rather than landscape features, because the evolutionary aspect of the landscape plays a major role in species composition. The low diversity (H'), evenness and richness of the cattle grazed area over other landscape units indicated the role of grazing on vegetation structure and composition. Species ordination i.e., Canonical Correspondence Ordination (CANOCO) with environmental variables did not clearly indicate different associations and their corresponding variables. This lack of clarity may be due to the relative uniformity in variables or the inadequacy of samples. The phenological observations showed that there is an apparent seasonality exhibited in the region, and the phenological expressions are in accordance with it.

Chapter 7

BIOMASS PRODUCTION

7.1 Introduction

Understanding the structure and functioning of an ecosystem is the fundamental objective of ecological research. One of the first steps in evaluating the functioning of a community is to quantify the solar energy fixation, i.e., primary productivity (Redmann, 1992), which is related to the structure and species abundance (McNaughton, 1967) of a given community. This helps in the prediction of sustainable yield of products, and other benefits to humankind. The growing human population in the past few decades has greatly increased the demand for more plant resources as food for humans and livestock, and has necessitated the exploration of new approaches for management and utilization of various ecological systems. Gadgil & Meher-Homji (1985) stressed the need to enhance the productivity of the savannas as a source of fuel and fodder. The IBP (International Biological Programme) is concerned with productivity and human welfare, and envisages a world-wide study on organic matter production on land, fresh water and sea (Singh & Yadava, 1974). Research on Indian grasslands have been undertaken mostly on the northern and northwestern parts (Pandeya, 1974; Singh & Yadava, 1974; Singh & Ambasht, 1975; Sankar & Velayudan, 1979; Ram *et al.,* 1989; Bawa, 1995), and little work has been done in the eastern and southern parts, except that of Karunaichamy & Paliwal (1989), Yadava & Kakati (1993), Devidas & Puravid (1995). The results of biomass production and intake by cattle and wild animals in Eravikulam National Park are presented and discussed in this chapter.

7.2 Materials and methods

Above ground plant biomass was quantified within 1m x 1m sample plots. Since ENP receives rains from June to November, and the rest of the year is relatively dry, there is a period of active growth and seed production. Clipping was restricted to two seasons, one after monsoon (December) and one before monsoon (May). Three sites were selected, based on land use (treatment) and community composition: (i) located in the tourism zone of Eravikulam National Park (Rajamala), where large numbers of Nilgiri tahr graze, and where the dominant species was *Chrysopogon zeylanicus*. (ii) in the core area of Eravikulam National Park where grazing pressure is low, and *Sehima nervosum* dominates the grassland vegetation. (iii) near Lakkamkudi, the tribal settlement area where tahr as well as livestock graze regularly, and *Cymbopogon flexuosus* is the dominant species. In each site one exclosure (control plot) of 11m x 11m x 2m (effective area 10m x 10m) were erected in March 1994, to check the effect of grazing. Three plots each were clipped inside and outside the exclosure. Clipping was done with sharp scissors, and species were clipped as low as possible. Litter was collected from each plot after harvesting. The clipped vegetation with standing dead was packed into perforated polythene bags and brought to the base camp, where it was separated by species. Sedges and herbaceous dicots were put together because they were lower in quantity. Shrubs and ferns were collected separately. These materials were then cut into appropriate lengths, dried and weighed separately. All the drying was done using an oven at 80°C until constant weight was obtained.

Below-ground biomass was estimated by taking a monolith of 25 x 25 x 30 cm in the centre of 1m x 1m plot. 30 cm monolith was selected because during the collection of soil samples we found that the roots of most species were found at this level. These monoliths were collected, and roots were separated by washing in running water with the help of a 0.2 mm mesh screen. This material was also oven dried at 80°C until constant weight was obtained.

Above-ground biomass production was determined by summation of positive increment in the standing crop without litter (trough peak analysis) over time at the end of both the seasons (Singh & Yadava, 1974, Singh *et al.*, 1975).

7.3 Results

The net primary production (NPP) in all three sites varied with species composition and treatment. The plots inside the exclosures in all the three sites showed almost equal NPP (1901-1937 g m^{-2}), although they varied in below-ground net primary production (BNP) and above-ground net primary production (ANP) at one site (Table 7.1). Outside the exclosure NPP is nearly equal at Rajamala and Eravikulam, (1460 g m^{-2}, 1595 g m^{-2} respectively), but it is only 849 g m^{-2} at Lakkamkudi, the village grazing site. At Rajamala and Eravikulam NPP within and outside the exclosures were not significantly different (t=1.5 p=0.2; t=2.25 p=0.1 respectively) but Lakkamkudi area showed significant (t=4.33, p=0.05) difference in NPP between inside and outside the exclosures (Table 7.1).

Inside the exclosures ANP was maximum at Eravikulam (1158 g m^{-2}) and minimum at Rajamala (835 g m^{-2}). ANP outside the exclosures was maximum at Eravikulam (902 g m^{-2}) and minimum at Lakkamkudi (316 g m^{-2}) as shown in Table 7.1.

BNP inside the exclosures at Rajamala was greatest (1066 g m^{-2}), whereas at Eravikulam it was least (746 g m^{-2}). But outside the exclosures, Lakkamkudi reported lower BNP (533 g m^{-2}), and at Rajamala it was the highest (820 g m^{-2}) (Table 7.1).

The contribution of BNP and ANP to NPP inside and outside the exclosure at Rajamala were 43 and 57% respectively (Table 7.1). At Lakkamkudi inside the exclosure both ANP and BNP contributed equally to NPP, but outside the exclosure BNP contributed 63% and ANP only 37%. The contribution of ANP and BNP to NPP of Eravikulam was almost equal inside and outside the exclosure(Table 7.1).

The ANP was not significantly different ($t=2.95$, $p=0.1$) at Rajamala and Eravikulam between inside and outside the exclosures. But Lakkamkudi showed significant difference ($t=4.3$, $p=0.05$) in ANP inside and outside exclosures. ANP and BNP, inside the exclosure were significantly different ($t=2.95$, $p=0.02$)only at Eravikulam.

Seasonal ANP was higher in all the communities and treatments for after monsoon clipping, compared to before monsoon. Inside the exclosures maximum values for after monsoon was obtained at Eravikulam (992 g m^{-2}) and it was least at Lakkamkudi (555 g m^{-2}) and for Rajamala (720 g m^{-2}) (Table 7.2). Outside the exclosures highest biomass was in Eravikulam (684 g m^{-2}) and lowest in Lakkamkudi (184 g m^{-2}) for after monsoon clipping. In the before monsoon clipping, inside the exclosures, maximum ANP was found at Lakkamkudi (416 g m^{-2}) and minimum at Rajamala (115 g m^{-2}). Outside the exclosures, ANP was highest before monsoon in Eravikulam (218 g m^{-2}) and lowest in Rajamala (50 g m^{-2}). Referring to table 7.2, for both inside and outside the exclosures, ANP was significantly different for after and before monsoon at Rajamala (inside: $t=10.72$, $p=0.01$; outside: $t=6$, $p=0.02$), and Eravikulam (inside: $t=11.17$, $p=0.02$; outside: $t=3.82$, $p=0.03$). But at Lakkamkudi, only outside the exclosures, they were significantly ($t=9.2$, $p=0.03$) different.

The rate of ANP was found to be highest at Eravikulam inside the exclosures (4.6 g m^{-2} day^{-1}) and lowest at Lakkamkudi outside the exclosures (0.8 g m^{-2} day^{-1}) for after monsoon (Table 7.3). But in the before monsoon clipping, rate of ANP was highest inside the exclosures at Lakkamkudi (2.8 g m^{-2} day^{-1}) while it was least at Eravikulam, outside the exclosures (0.3 g m^{-2} day^{-1}). The rate of annual net primary production was highest inside the exclosures at Eravikulam (3.1 g m^{-2} day^{-1}) and lowest (0.8 g $m^{-2}day^{-1}$) outside the exclosures at Lakkamkudi.

In all the three communities studied, grasses and sedges contributed most to the NPP (Table 7.4). The contribution of monocots to NPP was greatest in Eravikulam inside the exclosure (1133 g m^{-2}), and least in Lakkamkudi outside the exclosure (298 g m^{-2}). The biomass of dicots was greatest inside the exclosures at Rajamala (259 g m^{-2}), and least outside the exclosures at Lakkamkudi (18 g m^{-2}). The bracken, *Pteridium aquilinum*, contributed 103 g m^{-2} (ca. 10%) to the ANP inside the exclosure at Lakkamkudi. The contribution of monocots to ANP was maximum (98%) inside the exclosures at Eravikulam, and minimum (59%) outside the exclosure at Rajamala (Table 7.4).

Fifty two species contributed to biomass in this study. The following species contributed maximum biomass at Rajamala: *C. zeylanicus* and *Phlebophyllum kunthianum* (inside exclosure), and *Ischaemum indicum* and *P. kunthianum* (outside exclosure); at Eravikulam: *Sehima nervosum* and *Eulalia phaeothrix* (both inside & outside exclosure), and at Lakkamkudi: *Heteropogon contortus* and *Cymbopogon flexuosus* (both inside and outside the exclosure) (Table 7.5). Of the three dominant grasses, *S. nervosum* contributed 67% to the ANP of Eravikulam inside the exclosures, and 57% to outside the exclosures. It was 42% for *H. contortus* inside the exclosures at Lakkamkudi and 44% for *C. zeylanicus* inside the exclosures at Rajamala. The contribution of the dominant shrub species *P. kunthianum* at Rajamala was 22 & 32% inside enclosed and outside the exclosure respectively. Compared to *H. contortus*, the contribution of *C. flexuosus* to ANP was found to be lower inside the exclosure (14.2%) and almost equal outside the exclosure (33.5%) at Lakkamkudi.

Table 7.1. Total above and below ground biomass (g m^{-2}) recorded at three sites of ENP.

Site		Biomass ± S.D (gm^{-2})		
		Above-ground	Below-ground	Total (NPP)
Rajamala	Inside Exclosure	835 (43) ± 35.8	1066 (57) ± 81	1901
	Outside Exclosure	640 (43) ± 23.8	820 (57) ± 59	1460
Eravikulam	Inside Exclosure	^{a}1158 (60) ± 64.4	^{a}746 (40) ± 30	1904
	Outside Exclosure	902 (56) ± 40.3	693 (44) ± 81	1595
Lakkamkudi	Inside Exclosure	^{b}971 (50) ± 30.3	966 (50) ± 111	1937^{c}
	Outside Exclosure	^{b}316 (37) ± 12.2	533 (63) ± 55	849^{c}

a,b,& c indicate significantly different (p=0.05) pairs
percentages are in paranthesis

Table 7.2. Seasonal above ground biomass (g m^{-2}) recorded in three sites of ENP.

Site		Biomass ± S.D.	
		After monsoon	Before monsoon
Rajamala	Inside exclosure	720 ± 43.1[a]	115 ± 7.2[a]
	Outside exclosure	590 ± 24.2[b]	50 ± 2.8[b]
Eravikulam	Inside exclosure	992 ± 58.6[c]	166 ± 9.1[c]
	Outside exclosure	684 ± 43.3[d]	218 ± 16.6[d]
Lakkamkudi	Inside exclosure	555 ± 35	416 ± 24.4
	Outside exclosure	184 ± 15.7[e]	132 ± 5.3[e]

a, b, c, d, & c indicate significanly different ($p=<0.05$) pairs

Table 7.3. Rate of above ground biomass production (g m^{-2} day-^{1}) in three sites of ENP.

Site	ANP (g $m^{-2}day^{-1}$) After monsoon	Before monsoon	Annual
Rajamala inside Exclosure	3.4	0.8	2.2
Rajamala outside Exclosure	2.8	0.3	1.7
Eravikulam inside Exclosure	4.6	1.1	3.1
Eravikulam outside Exclosure	3.1	1.4	2.4
Lakkamkudi inside Exclosure	2.6	2.8	2.6
Lakkamkudi outside Exclosure	0.8	0.9	0.8

Table 7.4. Contribution of monocots, dicots and ferns to above ground biomass at three sites in ENP.

Site	Above ground biomass (gm^{-2})		
	Monocots (%)	Dicots (%)	Ferns (%)
Rajamala inside Exclosure	626 (75)	194 (23)	15 (2)
Rajamala outside Exclosure	381 (59)	259 (41)	-
Eravikulam inside Exclosure	1133 (98)	25 (2)	-
Eravikulam outside Exclosure	878 (97)	24 (3)	-
Lakkamkudi inside Exclosure	720 (74)	148 (15)	103 (11)
Lakkamakudi outside Exclosure	298 (94)	18 (6)	-

7.4 Discussion

Peak biomass in all grasslands occurred in the monsoon, as observed in other tropical grasslands of India (Yadava & Singh, 1986; Bawa, 1995). The average annual rainfall in ENP during the study period was 4991 mm. The NPP of all the communities in ENP were comparable with that of tropical and temperate grasslands (Table 7.6). Singh *et al.* (1985) concluded that the ANP of Indian grasslands ranges from 98 to 3396 g m^{-2} and BNP from 61 to 1972 g m^{-2}. The annual ANP of the three communities inside the exclosures in ENP were higher than reported for alpine grasslands of the Himalaya (Joshi *et al.*, 1988; Ram *et al.*, 1989; Rikhari *et al.* 1992; Shah *et al.* 1994; Kala *et al.* 1997). Misra & Misra (1979) found, for a grassland (tropical) in Berhampur, that annual ANP was 571 g m^{-2} and below ground production was 401 g m^{-2} but for Kurusketra it was 2407 g m^{-2} and 1131 g m^{-2} (Singh & Yadava, 1974). Yadava & Kakati (1993), in a grassland at Imphal, found an annual NPP of 2464 g m^{-2}. Karunaichamy & Paliwal (1989) reported 1522 and 607 g m^{-2} as maximum biomass for the protected and grazed areas respectively at Madurai. The NPP reported by trough-peak analysis for a grazed savanna in Bandipur National Park (1816 gm^{-2}) (Devidas & Puyravd, 1995) and that of ENP were comparable. In a similar grassland of Grass Hills in the Anamalais, Paulsamy *et al.* (1997), in an unburnt *Chrysopogon zeylanicus* community, found that the total net production was 3155 g m^{-2}/year for 1988-'89 and 2856 g m^{-2}/year for 1989-'90. The rate of above ground production at ENP (0.8-3.1 g m^{-2} day^{-1}) was higher than temperate (Himalayan) grasslands (Bawa, 1995), and lower than tropical grasslands of Kurukshetra (Singh & Yadava, 1974). The prolonged growth period and strong seasonality in which all species attain peak biomass at the same time (Weigert & Evans, 1964) is usually due to heavy rainfall, congenial temperature and edaphic conditions. In ENP conditions were suitable for vigorous growth during the north-east and south-west monsoons. The NPP values indicate that these grasslands are neither truly tropical nor temperate but intermediate i.e., tropical montane (Meher-Homji, 1970). The significant difference among above ground biomass production across the season in all three communities indicated that there was a second (pre monsoon) peak of biomass production due to the robust growth of dominant perennial species due to summer rains (452 mm for the year 1994) coupled with rise in temperature, increasing photosynthetic activity (Caldwell, 1975). All the dominant grasses are of C_4 (Appendix III) nature, which also increase the productivity through maximum net rate of photosynthesis (Caldwell, 1975). The significant variation in ANP of Lakkamkudi across the controlled and uncontrolled area indicated heavy grazing by cattle. However, the grazing pressure by wild animals was not enough to bring out differences in herbage removal and production at Eravikulam and Rajamala. Like alpine meadows (Ram *et al.*, 1989), grasses and sedges contributed most to the annual net above ground production of ENP. But the composition of ligneous Species were more (3-41%) than that described for Indian grasslands (3-10%) by Misra (1983).

Table 7.5. Dominant species contributing to the above-ground biomass in three communities of ENP

Location	Community	Treatment	Species	Biomass ± SD
		Inside Exclosure	*C. zeylanicus*	371 ± 43
Rajamala				
	Chrysopogon zeylanicus			
			Phlebophyllum kunthianum	189 ± 34.6
		Outside Exclosure	*P. kunthianum*	207 ± 21.6
			Ischaemum indicum	137 ± 13.8
		Inside Exclosure	*S. nervosum*	783 ± 109
Eravikulam				
	Sehima nervosum			
			Eulalia phaeothrix	145 ± 36
		Outside Exclosure	*S. nervosum*	520 ± 93.6
			E. phaeothrix	151 ± 19.6
		Inside Exclosure	*Heteropogon contortus*	408 ± 88
Lakkamkudi	*Cymbopogon flexuosus*			
			C. flexuosus	138 ± 12.5
		Outside Exclosure	*C. flexuosus*	106 ± 0
			H. contortus	103 ± 18.3

Table 7.6. A comparison of NPP between different communities of grassland in India.

Site	Rainfall (mm)	Dominant species	ANP	BNP	NPP
Jodhpur	311	*Cenchrus ciliaris* *Dactyloctenium indicum*	164	570	734
Khirasara (plains, grazed)	325	*Sehima nervosum* *Cymbopogon martinii*	201	155	356
Khirasara (plains, grazed)	325	*Aristidia adscencionis* *Fagonia cretica*	98	247	345
Pilani	391	*Cenchrus ciliaris* *Cynodon dactylon*	217	61	278
Udaipur	603	*Apluda mutica* *Aristidia adscencionis*	211	227	438
Kurukshetra	790	*Panicum miliare* *Alhagi camelorum*	2407	1131	3538
Delhi	800	*Heteropogon contortus*	798	-	-
Kurukshetra	803	*Dichanthium-Cenchrus-Bothriochloa*	618	785	1463

Kurukshetra	803	*Eragrostis nutans*	862	1592	2454
Kurukshetra	803	*Desmostachya bipinnata*	2143	998	3141
Varanasi (low land)	843	*Sehima-Heteropogon*	3396	1161	4557
Varanasi (Up land)	843	*Dichanthium annulatum*	2218	1377	3595
Jhansi	936	*Cynodon dactylon*	1019	497	1516
Ujjain	1030	*S. nervosum*	520	464	984
Berhampur	1040	Mixed grass	571	1361	1932
Ratlam	1257	*Heteropogon-Apluda-Cymbopogon*	433	399	832
Ambikapur	1359	*Andropogon muricatus Saccharum spontaneum*	436	-	-
Sagar	1410	*Heteropogon-Apluda-Cymbopogon*	914	937	1851
Sambalpur	2053	*Andropogon muricatus Saccharum sponteneum*	458	1972	2574
Imphal	1323	*Bothriochloa intermedia Imperata cylindrica*	1569	895	2464

Tehri Garhwal hills, grazed	1975	*Carex nubigena*	233	374	607
Central Himalaya	1577	*Danthonia cachemyriana*	114-407	59-250	173-657
Rajamala-ENP* controlled	4991	*Chrysopogon zeylanicus* *Phlebophyllum kunthianum*	835	1066	1901
Rajamala-ENP* uncontrolled	4991	*Ischaemum indicum* *P. kunthianum*	640	820	1460
Eravikulam-ENP controlled*	4860	*S. nervosum* *Eulalia phaeothrix*	1158	746	1904
Eravikulam-ENP uncontrolled*	4860	*S. nervosum* *Eulalia phaeothrix*	902	693	1595
Lakkamkudi-ENP controlled*	4430	*Cymbopogon zeylanicus* *Heteropogon contortus*	971	906	1937
Lakkamkudi-ENP uncontrolled*	4430	*Cymbopogon flexuosus* *H. contortus*	316	533	849

* Present study

Source: Singh & Gupta (1993)

In grazed *Cymbopogon-Heteropogon* community biomass accumulation was maximum the below ground (63%). The above-ground parts of palatable species such as *H. contortus,* adapted more towards the horizontal physiognomy (Sankar & Velayudhan, 1979; Milchunas & Lauenroth, 1989). According to the intermediate disturbance hypothesis, an increase in species diversity (Chapter 6) is common in plant communities with a short grazing history, whereas the opposite was true with long-term and high intensity of grazing, as was seen at Lakkamkudi (Rath & Misra, 1980; Milchunas & Lauenroth, 1989). The contribution of above- and below-ground biomass to the net primary productivity of *Iselima laxum* grassland reported by Sankar & Velayudhan (1979) was comparable to the *S. nervosum* community of Eravikulam. The low removal of herbage by wild ungulates might explain the situation of accumulation of greatest above-ground biomass. High humidity favours perennials, (Singh & Gupta, 1993) which increase below-ground production more than above-ground production, especially in an area of grazing. This was found to be true in the case of Rajamala and Lakkamkudi, where moderate and heavy grazing occurred respectively. The tall unpalatable *C. flexuosus* contributed more to the above-ground biomass of the control plot at Lakkamkudi. The equal contribution of above- and below-ground biomass to NPP across the controlled and uncontrolled situation of Rajamala might be due to more above ground investment of *P. kunthianum,* which was less prone to grazing. The preponderance of grass species *Ischaemum indicum* in the *C. zeylanicus* community at Rajamala may be due to sampling bias which should be checked in a future study. McNaughton (1979), observed that structural and organisational properties of communities in the Serengeti grasslands changed with protection (exclosure). The increase in above ground biomass of control plot over uncontrolled plot might lead towards this. The seasonal ANP did not show any significant relation with environmental variables such as rainfall, humidity and temperature.

The presence of species such as *Pteridium aquilinum, Eulalia phaeothrix, Arundinella tuberculata, Ageratina adenophora, Eriocaulon sp., Blumea neilgherrensis, Cyanotis arachnoides* and *Conyza stricta* only inside the exclosure and not outside, at Lakkamakudi, indicated the effect of grazing on species composition. Species richness was also high in the exclosed area compare to the open area although these differences were not significant. This structural and compositional variation in vegetation explains the adverse effect of high intensity grazing in this system.

7.5 Summary

The net primary productivity (NPP) values in all the three dominant comunities showed that these grasslands are between tropical and temperate grasslands in terms of biomass production. The lower NPP outside the exclosures at Lakkamkudi compared to the other two sites indicated heavy grazing pressure. Inside the exclosures, all the three sites recorded equal amount of NPP, indicating their functional similarity. The adverse effect of grazing was noticed on species composition also. In all the communities, graminaceous species contributed more to the above ground productivity (ANP), which ascertains the nature of vegetation as true grasslands.

Chapter 8

EFECT OF FIRE AND BLACK WATTLE (*Acacia mearnsii*) PLANTATION ON GRASSLAND VEGETATION

Among different factors affecting the stability and composition of the montane *shola*-grassland vegetation, fire and monoculture plantations of black wattle are the most important. The pressure of grazing, fuel wood collection, and other minor illegal activities such as collection of *Drosera peltata*, and other flowers, canes, etc, are not profound at present. The grassland burning and plantation issues based on field observations are discussed in this chapter.

8.1 Fire

Fire is one of the most wide-spread and ancient fundamental ecological factors maintaining many grasslands of the world (Daubenmire, 1968). Annual burning, either accidental or intentional, can regulate the structure and composition of grassland vegetation (Rodgers, 1986). In the past, deciduous and coniferous forests were influenced by natural as well as man made fires. The latter increased when the number of people using the forest increased. Today, almost all incidents of forest fires are caused by man.

In India, fire studies have been undertaken mainly on wet grasslands (Laurie, 1978; Rodgers, 1986). Very little information is available on fire in dry grasslands (Ranganathan, 1938; Pandey, 1974; Singh & Yadava, 1977; Prasad, 1985). These studies were mostly short-term, with little discussion on the structure and composition of grassland following fire, and the consequent herbivory. Most of the studies dealt with the effect of burning on biomass production (Pandey, 1974; Yadava & Singh, 1977; Paulsamy *et al.*, 1997). Since the inception of Wildlife (Protection) Act 1972, forest fires have been prevented in many areas, as fire was supposed to endanger the ecosystem of a protected area. Complete prevention of fire in an area which is prone to fire, can increase fire hazards in case of accidental fires, due to increase in fuel loads (accumulated dry biomass). The outlook towards fire from the management point of view has been that, if it did not result in any timber (monetary) loss, it was not considered as disastrous, and would not be recorded. Lack of fire records from ENP may be due to such a view point and the notion that all grasslands are seral in nature and they are unproductive (Champion & Seth, 1968; Kunhikrishnan, 1991). The occurrence of fire, and thus the history of vegetation, is usually related to human intervention.

History of fire in Eravikula National Park:

Historical accounts reveal that the day local human populations (Muthuvns) of today, invaded this area in the 14th century (Singh, 1994). The nearest place where evidence of prehistoric man was found, is at Marayoor not far from the boundary of the National Park. This small population practesed a stone age lifestyle till 500 ~~B.C.~~ A.D., which is unlikely to have caused ecosystem degradation (Rajan Gurukkal *pers. comm*). The lack of continuity between the low-lying and montane grasslands might bring one to the conclusion that the activities of early man were restricted to the valleys. However, it is difficult to believe that, in preference to all the conducive areas, they selected the grassland formation of the most wet mountain tops.

The forest records of ENP do not talk about the occurrence or frequency of fire in the past. The only fire incident recorded, was that of 1991, in which some *shola* patches were partially or completely burnt. The chances of natural fire from lightning is very remote (information from the local people). ENP has fire threat from the peripheral tea estates, tribal agriculture fields, and tourists.

Although the role of fire in maintaining the physiognomy of montane vegetation of Western Ghats has been recognised for several decades (Bor, 1938; Ranganathan, 1938; Champion & Seth, 1968; Meher-Homji, 1969; Blasco, 1970), detailed ecological studies on the effects of fire in these grasslands are lacking.

8.2 Black wattle plantation

The commercial forestry operations by private entrepreneurs, Social Forestry Programmes, and activities of the Kerala Forest Development Corporation (KFDC) persistently threatened the *shola*-grassland complex of the High Ranges (Nair, 1994). The establishment of monoculture plantations in the High Ranges started in the beginning of this century. In the last 50-60 years 50% forest cover has been replaced by plantation of which 82% is contributed by teak, wattle and eucalyptus (Basha, 1990). The attention of governments on forestry programmes yielding short-term financial gains, diverted national resources away from both forest management and conservation (Sayer & Anadu, 1989). Since it was built on an economic basis, without looking into the ecological consequences, plantations of *Eucalyptus globulus, E. terticornis, Acacia mearnsii, A. auriculiformis, A. dealbata* etc., were raised in all grasslands, except ENP which was inhabited by tahr. The growing population and thus demand on forest produce (fuel wood, pulp) enhanced fast degradation of these fragile ecosystems. Thus both agro and industrial forestry flourished by replacing natural vegetation with plantation, completely ignoring conservation forestry.

Black wattle was being planted for the tannin, which is used for leather tanning and also for pulp and paper industries. An important feature of black wattle is that it spreads very quickly in burnt areas (Chengappa K. N. *pers. comm.*). The effects of shift in land use (afforestation) on natural vegetation and associated species were not a concern till the recent past, and the forestry sector focussed its attention on fast-growing species and high productivity. But when the natural vegetation started depleting, and the habitat of many native plants and animals became threatened, the situation of unavoidable man-wildlife conflict arose. As part of ecological study on the grasslands of ENP, an attempt was made to study the effect of black wattle plantation on species composition and diversity of montane grasslands. The results, and a brief discussion follow.

8.3. Materials and methods

8.3.1 Fire Study:

Two grassland communities viz., *Chrysopogon zeylanicus* and *Sehima nervosum* were selected for analysis of effects of burning, and subsequent study at Rajamala and Anamudi slopes respectively. For each community, two sites were selected, and at each site one plot of 10 m radius was marked for early and late burning experiment. The area for burning was demarcated by cutting the grass along the boundary of the plot. Burning was carried out in the months of December (early, cool or winter burning) and April (late, warm or summer burning) in the evening after 1800 hours. Each site was divided into eight segments in eight directions (to avoid sampling bias due to aspect and slope), and one plot of $1m^2$ was marked in each segment for regular observations for 18 months. Burnt and unburnt plots were adjacent to each other.

The effect of burning on regeneration of Neelakurinji *(Phlebophyllum kunthianum)* was also studied. Three 100 m^2 plots containing almost equal abundance of Neelakurinji were identified in similar topography. Five 1 m x 1 m quadrats were marked in this (four in the corners and one in the diagonal centre). One of the plots was burnt in December, another in April and third was left unburnt. Seedlings were counted in each $(1\ m)^2$ quadrat in July (one month after the beginning of monsoon). Soil samples were collected from the burnt and unburnt areas only once and analyzed for physical and chemical properties.

8.3.2 Wattle plantation:

Four areas were selected for studying the effect of wattle plantation (Figure 6.1) on grassland vegetation:

i. Rajamala (control) area where, Nilgiri tahr is present and there is no wattle plantation.

ii. Eastern side of Kattumala, representing three-year old wattle plantation, located just outside the park.

iii. Koyyamala area, representing five-year-old plantation, located about 1 km away from the park.

iv. Eastern side of Kumarikkal (Koodakkadu Reserved Forests) representing 10-year-old plantation. It is nearly 0.5 km away from the park boundary.

In each area 10 circular plots of 5 m radius were laid, and data on species, their abundance, sociability and animal evidences were collected. All locations are almost in the same topography and altitude.

8.4 Analytical Methods

(i) The data on vegetation composition in the burning experiment, were analyzed for species diversity (Shannon-Weiner's index), richness and evenness (Magurran, 1988). Non parametric (Kruskal-Wallis One way ANOVA) test was carried out to find out whether vegetation attributes (diversity, richness, evenness, and cover) varied significantly between the treatments, and months (winter and summer burning).

(ii) The data from wattle plantations were analyzed for species composition and structure. Plant species associations were ordinated with the help of TWINSPAN (Hill 1979). Six pseudospecies cut levels (0.50, 1.00, 3.00, 15.00, 38.00 and 63.00) were executed for species ordination. Species diversity (Shannon-Weiners's Diversity index), evenness, and richness, were calculated for each association (Magurran, 1988). Number of endemic plants, weeds, and palatable species for Nilgiri tahr were sorted out with the help of available literature.

8.5 Results

8.5.1. Effects of Fire

The immediate effects of both early and late fire is the creation of small barren areas between tussocks in both the communities. The perennial tussock species such as *Ischaemum indicum*, *C. zeylanicus*, *Heteropogon contortus*, *S. nervosum*, and *Eulalia phaeothrix* were burnt partially. Shrub species like *P. kunthianum, Pteridium aquilinum, Ageratina adenophora, Leucas helianthemifolia* were also burnt incompletely. Other observations were,

i. Burning induced flowering of *S. nervosum* and *Andropogon lividus*. ii. Nilgiri tahr used burnt areas intensively soon after burning. *Chrysopogon* community was preferred more than *Sehima* community.

iii. Sprouting of perennial species was very fast. We recorded 6 cm fresh leaf blades in *C. zeylanicus*, 13 cm in *S. nervosum*, 8 cm in *P. aquilinum*, 5 cm in *A. lividus*, 5 cm in *H. contortus*, 4 cm in *I. indicum*, 5 cm in *Arundinella purpurea* in a fortnight after burning. After this it was difficult to assess the growth because of grazing.

The chemical and physical properties of soil changed with fire treatment. Sand showed an increase with early and late burning, but silt showed a decreasing trend (Table 8.1). At Rajamala, gravel percent decreased where as at Anamudi there was a marginal increase of silt in burnt area. The pH value decreased after burning at Rajamala. The %

of organic Carbon at both the places increased with both treatments, whereas N declined in the same situation. The amount of K showed an increase at Rajamala where as at Anamudi it decreased slightly. Electrical conductivity of the soil which is the net result of chemical composition was found to decrease with early and late burning.

The effect of fire on grassland diversity, richness and evenness was not significant between treatments. The changes that occurred were non-directional (Table 8.2). The diversity index (H') of early burnt plot at Rajamala showed slight increase after 12 months but it declined at 18 months. At Anamudi it was very low (1.25) after 18 months compared to 6 months (2.61). We did not notice any major change in community composition between different treatments at both sites. A few species such as *Hypoxis aurea, Osbeckia cupularis, Habenaria longicorniculata, Brachyocorythis wightii*, and *Centrantherum reticulatum* were noticed at Rajamala after burning.

Likewise at Anamudi, *Crotalaria ovalifolia, Polygala sibirica, Ranunculus reniformis, Hypericum mysorense* and *Commelina clavata* were present. All these species are not unique to burnt areas, but at the time of burning they were not present in the plot. The cumulative number of species before burning was 32 and after early and late burning it was 28 and 26 respectively at Rajamala. It was 33, 30 and 28 corresponding to pre, early and late burning at Anamudi.

Regarding the structure of the vegetation, the cover value of dicots (shrub and herb) was significantly different (Kruskal-Wallis One Way ANOVA- X^2=4.1, p=0.04) between unburnt and early burnt and unburnt and late burnt areas at Rajamala (Table 8.3).

Table 8.1. Comparison of soil parameters between unburnt, early and late burnt areas of ENP.

Parameters	Treatment	Rajamala	Anamudi
Sand (%)	Unburnt	85.86	85.14
	Early burnt	86.00	89.00
	Late burnt	88.83	87.83
Silt (%)	Unburnt	10.00	8.00
	Early burnt	9.83	6.83
	Late burnt	6.67	7.17
Clay (%)	Unburnt	4.14	3.57
	Early burnt	4.17	4.17
	Late burnt	4.50	4.50
Gravel (%)	Unburnt	21.00	10.14
	Early burnt	9.33	14.33
	Late burnt	13.83	11.83
pH	Unburnt	4.99	4.69
	Early burnt	4.72	4.70
	Late burnt	4.67	4.70
Organic Carbon(%)	Unburnt	3.94	4.94
	Early burnt	4.28	5.13
	Late burnt	4.63	7.60
Nitrogen (ppm)	Unburnt	4684.57	4807.14
	Early burnt	3158.83	3490.67
	late burnt	3435.17	4188.83
Potassium (ppm)	Unburnt	52.14	251.43
	Early burnt	105.67	180.67
	Late burnt	127.50	207.83
Calcium	Unburnt	0.01	0.00
	Early burnt	0.02	0.04
	Late burnt	0.01	0.01
Electrical Conductivity	Unburnt	17	21
	Early burnt	19	18
	Late burnt	13	18

Table 8.2. A comparison of species diversity, richness and evenness between unburnt, early, and late burnt vegetation in ENP.

Treatment	Time	Attributes	Rajamala	Anamudi
Un-burnt	6 months	Diversity (H')	1.66	1.16
		Richness	0.94	0.69
		Evenness	0.75	0.61
	12 months	Diversity (H')	1.72	1.23
		Richness	0.98	0.71
		Evenness	0.74	0.62
	18 months	Diversity (H')	1.68	1.21
		Richness	0.96	0.70
		Evenness	0.73	0.61
Early burnt	6 months	Diversity (H')	1.14	2.61
		Richness	0.76	1.03
		Evenness	0.70	0.98
	12 months	Diversity (H')	1.87	2.50
		Richness	0.97	1.21
		Evenness	0.83	0.92
	18 months	Diversity (H')	1.75	1.25
		Richness	0.96	0.76
		Evenness	0.77	0.62
Late burnt	6 months	Diversity (H')	1.62	1.28
		Richness	0.87	0.76
		Evenness	0.76	0.63
	12 months	Diversity (H')	1.64	1.60
		Richness	0.76	0.90
		Evenness	0.81	0.73
	18 months	Diversity (H')	1.74	1.71
		Richness	0.94	1.12
		Evenness	0.80	0.70

Table 8.3. A comparison of vegetation and ground cover between the treatments at different time intervals after burning of ENP.

Treatment	Time after burning	% Ground Cover		
		Group	Rajamala	Anamudi
Un-burnt	6 months	Graminaceous	66.5	93.5
		Shrubs & Herbs	27.5	6.5
		Bare Ground	6	0.0
	12 months	Graminaceous	65	92
		Shrubs & Herbs	31	8
		Bare Ground	4	0.0
	18 months	Graminaceous	68.5	93
		Shrubs & Herbs	23.5	7
		Bare Ground	8	0.0
Early burnt	6 months*	Graminaceous	31.5	53.5
		Shrubs & Herbs	15	5
		Bare Ground	52.5	41.5
	12 months*	Graminaceous	56.5	80
		Shrubs & Herbs	19	11
		Bare Ground	24.5	9
	18 months*	Graminaceous	77	92.5
		Shrubs & Herbs	9	5
		Bare Ground	14	2.5
Late burnt	6 months*	Graminaceous	48	69
		Shrubs & Herbs	12	7
		Bare Ground	39	24
	12 months*	Graminaceous	54.5	78.5
		Shrubs & Herbs	15	11.5
		Bare Ground	30.5	10
	18 months*	Graminaceous	70	87.5
		Shrubs & Herbs	7	8
		Bare Ground	23	4.5

* significant

Table 8.4. A comparison of cover of *Pteridium aquilinum* in different treatment areas in ENP.

Location	Plot	Treatment	Cover (%)		
			6 months	12 months	18 months
		Unburnt	0.6	1.1	2
	1	Early burnt	1.2	2	4
		Late burnt	1.5	0.7	3
Rajamala		Unburnt	0.0	0.0	0.0
	2	Early burnt	0.5	1	1.1
		Late burnt	0.6	1.1	1.1
		Unburnt	0.4	1.0	1.0
	1	Early burnt	0.0	0.0	1.5
		Late burnt	0.4	1	1.5
Anamudi		Unburnt	5	3.8	4
	2	Early burnt	4	6	4
		Late burnt	8	8.1	8.1

The cover values of graminoids, dicots and exposed area did not vary significantly between early and late burnt sites after 18 months of burning. But between 6 and 18 (X^2=5.33, p=0.02; X^2=4.1, p=0.03) and 12 and 18 (X^2=6.7, p=0.03) months, graminoides, dicots and exposed area showed a significant change in percentage cover in both areas. In both areas, there was more exposed ground in the first 6 months, which decreased gradually. In *S. nervosum* community (Anamudi), the % vegetation cover increased to 97.5 and 95.5% in 18 months, in the early and late burnt areas respectively.

On the other hand, in *C. zeylanicus* community, % of vegetation cover after 18 months, increased 86 and 77% in cool and warm season burning respectively.

At Anamudi, the % of exposed area between unburnt and early burnt, and unburnt and late burnt, was found to be significantly different (X^2=4, p=0.04). Cover values of graminoids showed significant difference between 12 and 18 months (X^2=5.3, p=0.02).

The cover of the fire resistant fern, *Pteridium aquilinum*, was found to increase in all the plots with different treatments (Table 8.4). Though the cover value was not significantly different (Kruskal-Wallis One way ANOVA) between the burnt and unburnt areas, their presence was noteworthy (Nykvist *et al* 1994). It was found that the regeneration of Neelakurinji (*Phlebophyllum kunthianum*) was affected by both early and late burning. In the early burnt area, there were only 2 (± 2) seedlings m^{-2}, but in the late burnt area, it was 43 (± 22) m^{-2} as against 130 (± 36) m^{-2} in the unburnt. There was a significant difference in seedlings between unburnt and early burnt (X^2=6.81, p=0.009), unburnt and late burnt (X^2=12.5, p=0.001), and early and late burnt (X^2=6.81, p=0.009).

8.5.2 Effects of black wattle plantation:

It was found that five-year-old plantations had the maximum number of species (34), and the least (23) was in three- and ten-year old plantations (Table 8.5). The number of endemic species was highest in unplanted area (14) and it reduced with age of plantation, reaching the lowest (3) in ten-year-old plantation (Figure 8.1). The same trend was found in the case of food species of tahr (Rice, 1984). But weeds and other unpalatable species were more (22) in the ten-year-old plantation and less (2) in unplanted area. Regarding animal signs, evidences of tahr were noticed at unplanted and three-year-old plantations. But at five-and ten-year-old plantations lack any of these evidences. It was found that the diversity index (r=0.75, p=0.01) and evenness (r=0.65, p=0.01) were positively correlated with age of plantation. Ten-year-old plantations had four associations and the other three treatments had two associations each (Figure 8.2). In the ten-year-old plantation (black wattle) was the dominant species. Only one association in the ten-year-old plantation had grasses in the association level. The others were represented by herbs and shrubs. In all other plantations, grasses are the dominant species. The nomenclature of the plant associations have been described in Chapter 6. The diversity index (Table 8.6) was highest in the ten-year-old plantation, and minimum in the three-year-old plantation. The same trend was seen in the case of evenness also (Figure 8.3).

Unplanted area

The grasslands free from wattle plantaiton (e.g., Rajamala) had two associations viz., ***Arundinella tuberculata-Heteropogon contortus-Chrysopogon zeylanicus*** **(AHC) and** ***Phlebophyllum kunthianum-A. tuberculata-C. zeylanicus*** **(PAC)**. *Fimbristylis kinghii, Drosera peltata*, and *Hypericum mysorense* were common in these associations. Nilgiri tahr uses this area intensively and there were evidences in all the sample plots. The first association had a lower diversity index (H'=1.94), than the second (H'=2.02). Total number of species in both associations was 24. The diversity index 1.94 indicated that if seven species (N_1) were equally abundant the same diversity could be attained. In the case of the second association, it was found to be eight. Species richness was 2.29 ± 0.24 in AHC, whereas it was 2.13 ± 0.21 in PAC. But evenness was more in PAC (0.64), indicating uniform distribution of species compared to AHC (0.61).

Three-year-old plantation

The two main associations in three-year-old plantation sites were ***Acacia mearnsii-Tripogon bromoides-Anthestiria ciliata* (ATA) and *Anaphalis pulneynsis-A. mearnsii-A. ciliata* (AAA)**. The species *A. mearnsii* had reached a height of about 2-3m in this plantation. In some places branching was profuse from the base, thus contributing more cover. Even though grasses grew luxuriantly, tahr did not use this area. *Leucas helianthemifolia*, *Viola patrinii*, *Blumea nilgherrense*, *Crotalaria ovalifolia* and *Habenaria perrottettiana* were also present in these plots. Seedlings of wattle were planted with mosses, lichens and herbs (to retain moisture)and weeds such as *Ageratina adenophora* are well represented at the base of each sapling. The diversity index for ATA and AAA were 1.99 and 1.86 respectively. Both the associations had low diversity indices and the number of equally dominant species needed for reaching the same diversity is 7. But the total number of species found in the ATA association was 22, whereas it was 25 for AAA association. Richness in ATA association is 1.72 ± 0.14, and in AAA it was 2.03 ± 0.24. The comparatively high evenness of ATA (0.64) indicated more uniformity in species distribution over AAA (0.58).

Figure 8.1. Charecteristics of vegetation in different ages of black wattle plantation.

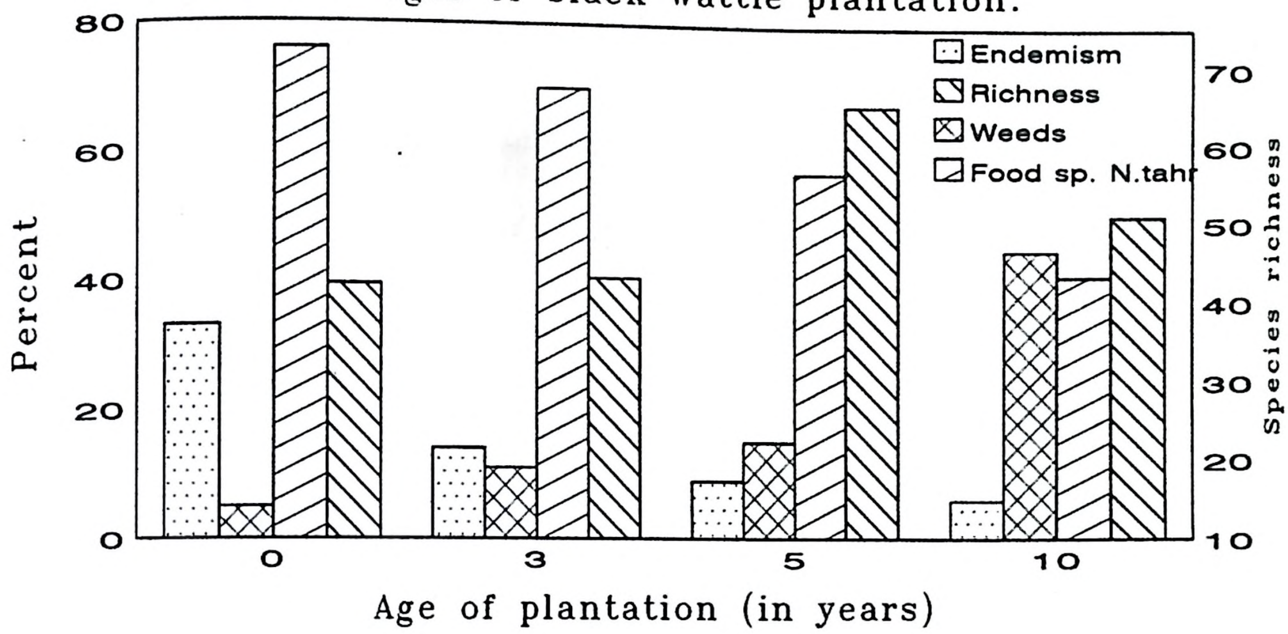
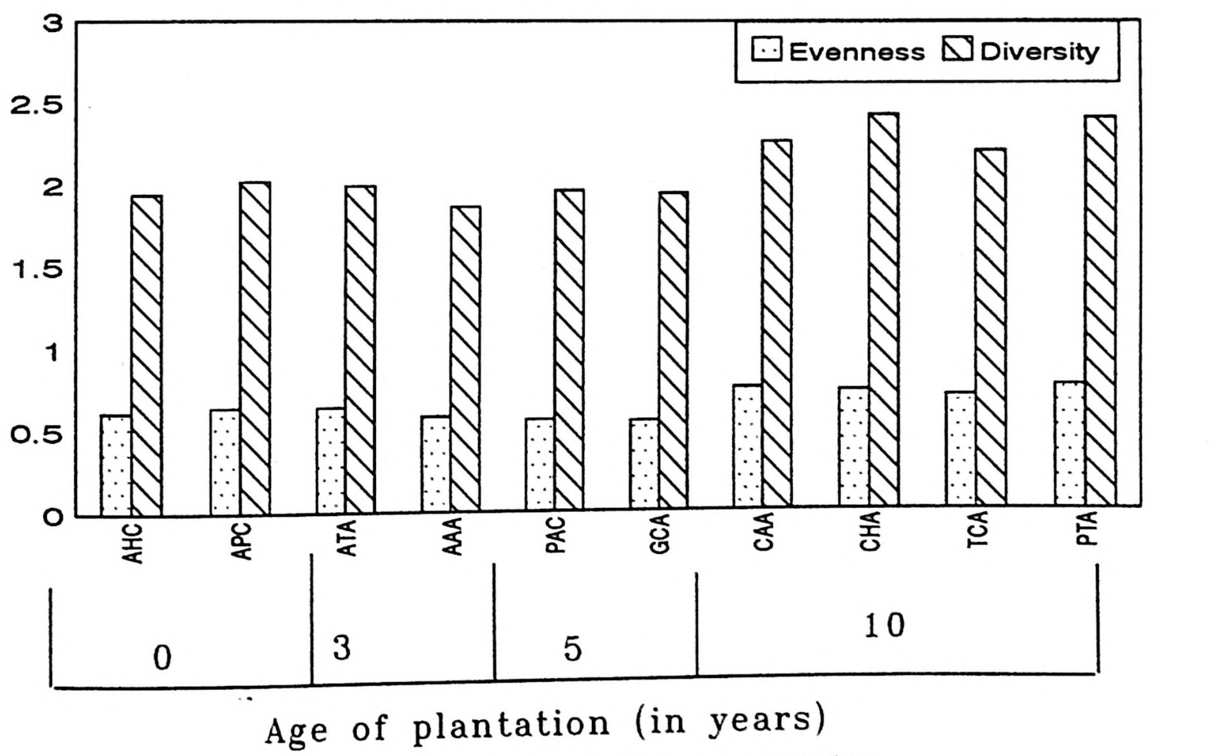


Figure 8.2. Species diversity, and evenness of different plant associations in black wattle plantation



AHC-Arundinella tuberculata-Heteropogon contortus-Chrysopogon zeylanicus
APC-A.tuberculata-Phlebophyllum kunthianum-C.zeyalnicus
ATA-Acacia mearnsii-Tripogon bromoides-Anthestira ciliata
AAA-Anaphalis pulneynsis-A. mearnsii-A. ciliata
PAC-Pouzolzia wightii-A. mearnsii-C. zeyalnicus
GCA-Gentiana quadrifaria-C. zeylanicus-A. mearnsii
CAA-Carex filicinae-Ageratina adenophora-A. mearnsii
CHA-Conyza bonarensis-Hedyotis corymbosa-A. mearnsii
TCA-Themeda cymbaria-Cymbopogon flexuosus-A. mearnsii
PTA-Psychotria congesta-Triumfeta rhomboidea- A. mearnsii

Five year old plantation

In five year old plantation, *A. mearnsii* had reached a height of 5-8 m, and there was good canopy cover (50-60%) at some places. Thus there were more herbs and shrubs growing in this area than in three-year-old plantations. The two associations were ***Pouzolzia wightii-A. mearnsii-C. zeylanicus* (PAC) and *Gentiana quadrifaria-C. zeylanicus-A. mearnsii* (GCA)**. The first association (PAC) was more dominant than the second one (GCA). The blades of *C. zeylanicus* in this plantation reached a length of 1m when compared to the 50-60 cm in the unplanted area. Guar dungs were frequent in this area. Hoof marks of sambar and gaur were noticed. The species that are very common in the association are *Valeriana hookeriana, Micromeria biflora, Ageratina adenophora* etc. Though both the associations had a larger number of species (33 for PAC and 35 for GCA) than any other association, the diversity indices were 1.96 and 1.94 respectively. It was found that in both the associaitons only seven equally abundant species were needed for attaining the above diversity indices. Richness and evenness in both associations were similar (Table 8.6).

Ten year old plantation

Here *A. mearnsii* was fully grown, with a mean GBH of 60 cm, and with very good (70-80 %) canopy cover. Thus the growth of grasses were reduced very much and except one association all others were formed of herbs and shrubs.

Figure 8.3: Dendrogram showing plant species associations in the black wattle planted and unplanted areas (Number of plots representing associations and eigen values are shown on the top and below the clusters respectively).

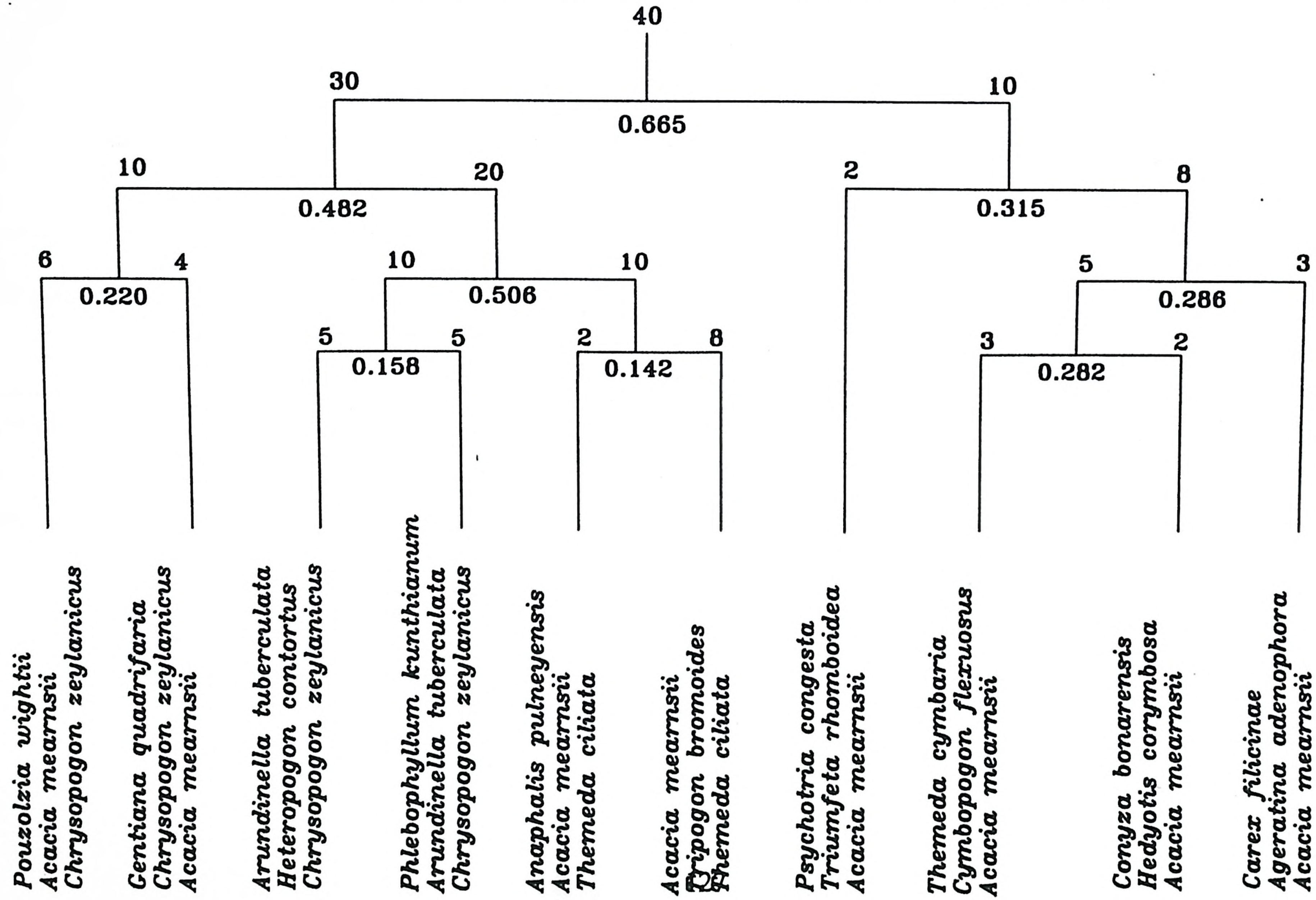


Table 8.5. Vegetation characteristics of different aged wattle plantations.

Age of plantation	No. of Endemic Species (%)	No. of Food species of N.tahr (%)	No. of Weed species (%)	Species richness± S.D.	Diversity(H')	Richness±SD	Evenness
Unplanted	14 (33)	32 (76)	2 (5)	24 ± 4	1.98	2.21±0.22	0.62
3 years	6 (14)	30 (70)	5 (11)	23 ± 5	1.87	1.87±0.19	0.61
5 years	6 (9)	37 (57)	10 (15)	34 ± 2	1.95	2.67±0.26	0.55
10 years	3 (6)	20 (41)	22 (45)	23 ± 4	2.64	2.22±0.65	0.73

S.D.-Standard deviation of mean; values in parentheses show percentages.

Table 8.6. Diversity, Richness and Evenness of different vegetation associations.

Association	Diversity(H')	Richness±SD	Evenness	N_1=eH'
Arundinella tuberculata-H. contortus-C. zeylanicus	1.94	2.29 ± 0.24	0.61	7
A.tuberculata-Phlebophyllum kunthianum-C.zeylanicus	2.02	2.13 ± 0.21	0.64	8
Acacia mearnsii-Tripogon bromoides-Themeda ciliata	1.99	1.72 ± 0.14	0.64	7
Anaphalis pulneyensis-A.mearnsii-A.ciliata	1.86	2.03 ± 0.24	0.58	6
Pouzolzia wightii-A.mearnsii-C.zeylanicus	1.96	2.65 ± 0.16	0.56	7
Gentiana quadrifaria-C.zeylanicus-A.mearnsii	1.94	2.67 ± 0.36	0.55	7
Carex filicinea-Ageratina adenophora-A.mearnsii	2.26	1.97 ± 0.77	0.75	9
Conyza bonarensis-Hedyotis corymbosa-A.mearnsii	2.42	2.86 ± 0.88	0.73	11
Themeda cymbaria-Cymbopogon flexuosus-A.mearnsii	2.20	2.04 ± 0.36	0.70	9
Psychotria congesta-Triumfeta rhomboidea-A.mearnsii	2.40	2.01 ± 0.38	0.76	11

SD-Standard Deviation

The unpalatable species were more in this case. The ground was almost covered with litter of *A. mearnsii*. The four associations were ***Carex filicinae-Ageratina adenophora-A. mearnsii*** **(CAA),** ***Conyza bonariensis-Hedyotis corymbosa-A. mearnsii*** **(CHA),** ***Themeda cymbaria-Cymbopogon flexuosus-A. mearnsii*** **(TCA) and** ***Psychotria congesta-Triumfeta rhomboidea-A. mearnsii*** **(PTA).** The first association was found in moist areas. The second association was represented in well-shaded areas of the plantation where disturbances are less. The association TCA was restricted to the edge of the plantation. Presence of *P. congesta* indicates a trend towards the development of natural vegetation. How far this species will withstand disturbance, depends upon the period of felling. The important species found in this vegetation are *Maesa indica*, *Smilax wightii, Sida cordifolia*, *Hedyotis corymbosa*, *Themeda tremula*, *Wendlandia thyrsoides*, *Phyllanthus rheedii* and *Chromalena odorata*. The diversity index was highest in CHA (H'=2.42), and lowest in TCA (H'=2.20). The diversity indices of associations CAA and TCA indicated that 9 evenly distributed species would be sufficient for the same diversity. But for the associations CHA and PTA it was 11 species. Total number of species in each associations was 21 in CAA, 27 in CHA, 23 in TCA, and 20 in PTA. Among the four associations, species richness was highest in CHA (2.86 ± 0.86), and lowest in CAA (1.97 ± 0.77). Generally, evenness, which is related to diversity, was high among the associations. Species association PTA showed more uniformity in species distribution (Evenness=0.76).

8.6 Discussion

8.6.1 Fire:

Biotic communities adapt themselves to fire, as they do to temperature or other factors (Odum, 1971). Burning results in destruction of surface litter, killing of many microbes and other invertebrates, partial sterilization, and associated nutrient cycling (Daubenmire, 1968). The effect of fire in small areas like ENP are two-fold viz., (i) direct effect in the form of run-off, soil erosion, species invasion, and, (ii) indirect effect through trampling and over-grazing by ungulates. Changes in vegetation composition are often slow in fire-adapted climax communities. The effects of burning on the grasslands of ENP are likely to be different from those of wet grasslands and savannas due to inherent climatic differences (Daubenmire, 1968).

In ENP, significant change in the exposed area after burning (between the tussocks) might lead to the creation of sterile soil through accelerated erosion. In the first year after burning, since there is less vegetation, infiltration of water will be less, and soil erosion in the subsequent years will depend upon the intensity of grazing and rainfall (Shaw, 1957; Banks, 1964; Lloyd, 1968; Duffey, 1974; Slott, 1988). Though many authors (Cook, 1939; Garren, 1943; Moore, 1960; Misra *et al.*, 1989; Naidu & Srivasuki, 1994; Korhola *et al.*, 1996) report an increase in pH after burning, there was no significant change in the case of ENP. This may be due to less litter compared to other areas as also observed by Blaisdell (1953), and Reynolds & Bohming (1956) in the steppes of southeastern Arizona. Nitrogen content in the soil was reduced because of its volatile nature (Cook, 1939; Blaisdell, 1953; Daubenmire, 1968). The change in physical properties of soil may be due to erosion after burning. The cation and anion exchange capacity (electrical conductivity) of soil was reduced, which could be due to low humus content (Edwards 1942). The slight increase in organic carbon was due to the increased decomposition rates with increase in soil temperature (Chandler *et al.*, 1983). The decrease in nitrogen and slight increase of organic carbon indicates that C/N ratio changes after burning (Moore, 1960). In mild fire (early burning) volatilisation of hydrophobic substances would be less due to low temperature generated, compared to late burning. This results in more moist soil, thus less infiltration and more run off. But in late burn, volatilisation is high, thus more infiltration and less run-off. The loss of cations from the burnt sites are mainly on account of surface erosion (Edwards, 1942). Dilution of ion concentration by increased run off and losses of ion by volatilisation are the other factors responsible for their decrease in the soil (Naidu & Srivasuki, 1994). Burnt soils become less compact with low infiltration rate and become more subject to erosion in comparison to unburnt soils. Since ENP receives rain throughout the year in varying degrees which, combined with the grazing intensity after fire, suppresses the active growth of vegetation (Trollope, 1982) resulting in greater run-off.

The preponderance of therophytes in ENP grasslands indicates a low water retaining capacity of the soil (Cook, 1939) that may have resulted from periodic burning. This trend towards annual species may later change the species composition (Gibson, 1988). Significant relations between ash production and flowering of *Andropogon gerardii* in the prairies, and dominance of C_4 species in annually burnt grasslands were reported by Gibson (1988). Even though litter was not very high, burning induced flowering of *S. nervosum* and *A. lividus*, both C_4 grasses.

Both early and late burning were found to be hazardous to the shrub species. The low number of seedlings of Neelakurinji in the early burnt area could be due to the temperature bite on the immature seeds, as observed in shrubs like *Rubus alleghensis, Rosa multiflora*, and *Prunus serotiana* by Abrams (1988), Hartent (1991), and Hruska & Ebinger (1995). But in the case of summer burning, the dispersed seeds were burnt due to the high temperature. This may also result a change in species composition if fire repeatedly occurred in the flowering year of Neelakurinji.

Johnsingh (1986) reported congregation of ungulates in the burnt areas due to availability of tender grasses. Burning may stimulate the activity of roots, which in turn would increase the uptake of nutrients and thus growth, and attract more ungulates (Mes, 1958). The significant difference in vegetation cover of graminoids between different months in the *C. zeylanicus* community may be due to this. However, the increased palatability of new grass blades may result in close cropping of the photosynthetic tissue, which might not allow the plants to recover if the burnt area is small and ungulate density is high (Mes, 1958). Thus it is very important to consider the time (season) of burning and the extent of area to be burnt. Spring burning of standing dead and litter would result in excess N_2 volatilisation, and eventually cause a reduction in productivity (Gibson & Hulbert, 1987). The cover of shrub and grasses was reduced at Rajamala because of heavy grazing by tahr.

The insignificant change in soil properties and total vegetation composition after early and late burning may be due to the healing activity of the system, which may be fast in the early years of disturbance. Subsequent fire may change the situation in edaphic factors, and thus result in a visible change in the total vegetation. So it may not be possible to observe a distinct change in any level of the community in the first few years. Thus, from the vegetation point of view, both early and late burning may have different effects on the system. When we consider the habitat improvement for endangered animals like Nilgiri tahr, early burning in patches can be practised with strict vigilance, in prescribed area at predetermined times under the supervision of a skilled manager. This burning and its changes on vegetation and soil should be monitored regularly on long term basis.

8.6.2 Black wattle plantation

The naturally regenerated early growth forest is ecologically more beneficial for the earth than a plantation of monospecies of the same age (Li *et al.*, 1991). Vast areas of montane grassland-*shola* ecosystem of the Nilgiris, have been converted into black wattle plantations along with the commencement of hectic plantation activities in the late 1890s (Muthiah, 1993). The wattle has an enormous capacity to regenerate from root suckers and it produces seeds profusely. It has virtually taken over the *shola* and grasslands in many parts of the Nilgiris (Von Lungerke & Blasco, 1989; Samaraj, 1993). In the last 150 years, almost 26,000 ha of grasslands in the Nilgiris have been replaced by cultivation. Among this, wattle was planted in 9775 ha and *Eucalyptus* in 5150 ha (Sukumar, 1993). The grasslands are an integral part of the natural vegetation of the Nilgiris. Paleoecological studies of the vegetation show the presence of grasslands over 20,000 years ago (Sukumar *et al.*, 1993) showing that they are also a climatic climax of the area. The species richness, diversity index, and evenness indicate that, for a certain period these attributes will increase and when the monoculture gets stabilised they will start declining (Wallace *et al.*, 1992). The common pioneer species such as *Ageratina adenophora*, *Pteridium aquilinum*, and *Chromalena odorata* found in the 10-year-old plantations, indicate that there will not be any identity for the vegetation after the plantation stabilises. The encroachment of weeds in plantations were reported by Rajvanshi *et al* . (1983). Boettcher *et al.* (1995) reported that the diversity of shrubs in afforested rangelands is indicative of a presettlement composition in the future. The spreading of alien species, decrease in endemic species and food species of tahr, indicate a radical change in the community. The high amount of tannin present in the bark and leaf of this species will retard mineralization of litter, thus making insufficient improvement of the soil (Noble, 1967) for the regeneration of native species. This will, in turn invite 'unwanted' species like *Chromalina odorata*, *Wendlandia thyrsoides,* etc. The high species richness in five-year-old plantation might be due to the partial cover provided by *A. mearnsii*, in which grasses, herbs and shrubs thrive well (Boettcher *et al.*, 1995). Khan (1978) reported remarkably low bird diversity in the *Eucalyptus* and black wattle plantations of Nilgiris when compared to *shola*-grassland vegetation. Though we have not done any soil studies in plantations, Balagopalan & Jose (1995), and Osman *et al.* (1995) reported that depletion of soil in the plantation could affect productivity of successive rotation. Agarwal *et al.* (1961), Chinnamani *et al.* (1965), and Samaraj *et al.* (1977) reported that more run-off and soil erosion were found in black wattle and eucalyptus plantations than in natural grasslands.

The actual extent of habitat alteration in the High Ranges due to wattle plantation is not known. Roughly 90 km^2 area of eucalyptus and wattle plantation is owned by M/s Tata Tea Ltd (Anon., 1991) in the High Ranges. Apart from this, past forestry operation by Kerala Forest Department has also altered some *shola*-grassland complex. Such a loss has now been recognised and it is high time that we develop better land use and conservation plans following the principles of conservation forestry, to meet both demand and supply.

8.7 Summary

Burning (early and late) in *S. nervosum* and *C. zeylanicus* communities showed that, in both early and late burnt areas, there were no significant changes in species diversity, richness, and evenness. This may be either due to inadequacy of data or due to the stability of vegetaiton. The significant difference in vegetation cover of dicots at varying times after burning was due to the slow rate of growth compared to monocots.

The overall changes in species composition and structure in the black wattle planted area of different ages showed that, with the increase in age of plantation, the grassland is looses its identity and species diversity rapidly transforming in to a monoculture wood land.

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

The overall aim of management of ENP is the long-term conservation of the *shola*-grassland ecosystem and a viable population of tahr. A few ecological studies (Rice, 1984; Madhusudan, 1995; Easa, 1996) have identified some of the problems and suggested conservation strategies for ENP. A sound management practice respects the properties of the system and aims at the maintenance of objectives set forth. Results of this study indicate a need for strong management practices for the maintenance of sustainable population of tahr and its habitat. Wildlife census data in Mukuruti National Park by the Nilgiri Wildlife & Environment Association in 1996, reported a sharp decline in the tahr population, from 334 reported by Davidar (1978) to 117. In this context, any management plan to be implemented in ENP should be strong enough to support the present population of tahr, since ENP is one of the last strongholds of this species in the world. Based on the findings of this study, the following suggestions were made for the better management of ENP.

9.2 Vegetation

The *shola*-grassland vegetation types are complementary to each other for the sustenance of montane ecosystem. Since the physiognomy of these two biomes are different, separate management strategies should be adopted for each. Various strategies that can be employed for the grasslands are discussed below.

9.2.1 Grasslands

A distinct community structure, composition and floristics were described for this grassland, which is different from the earlier classification. Though dominant species were found throughout the park, the species with more conservation values (Appendix-I i.e., rare, endemic, endangered, and those that are limited in distribution, need to be monitored with the help of trained field staffs. The experimental introduction of Congo signal grass, *(Brachiaria ruziziensis)* as part of pasture development (Rice, 1984) in early 1990s proved to be a failure, because it failed to regenerate. The annual trek path and fire line maintenance by scraping the existing vegetation should be refrained from, because of the change in community composition in these areas. The best way of maintaining a trekking path is by cutting the vegetation along the trail once in a year. For fire lines, it will be proper to burn a 5-10m wide strip of vegetation along strategic lines at the end of December, rather than removing the vegetation by scraping in the month of February or March. Spreading of an exotic species (*Ageratina adenophora*) was noticed along the *shola*-grassland edges and trek paths. This can be controlled by cutting or uprooting the species before flowering. The collection of *Drosera peltata*, lichens and different *Anaphalis* spp. by people of the nearby estates should be checked effectively, by patrolling, and with the help of enforcement staff from the neighbouring forest divisions.

9.3 Fire

The burning experiment conducted in the grasslands revealed that the impact of fire on soil and vegetation could not be visualised in a small time period. The changes that were noticed in the initial years may enhance or heal up in due course with the repeated occurrence of fire. It needs to be established that whether the preponderance of therophytes in these grasslands resulted from periodic burning or due to soil characteristics. The negative impact of burning on regeneration of shrub species was noticed in the case of Neelakurinji. If prescribed (early) burning is not followed, a single incidence of fire would burn the accumulated biomass in *shola* edges with high intensity, resulting in the opening of the canopy of the *shola* and gradually giving way to pioneer species including grasses (Plate 8). The presence of *Pteridium aquilinum, Ageratina adenophora, Euphorbia rothiana, Chrysopogon zeylanicus, Rubus moluccanus, Lobelia leschnaultii* and *Maesa indica* in the *shola*-grassland interphase indicated the frequent occurrence of fire and change in vegetation composition, i.e., retrogression of shola. The unburnt edges are dominated by *Strobilanthes* spp. and *Gaultheria fragrantissima* (Shetty & Vivekanandan, 1971). The intensity of impact on lower plants (algae, fungi, bryophytes and lichens), amphibians, birds and reptiles are not known. Thus, the strategies include the protection of *sholas* from intense summer fire, and following of early (cool) burning experimentally, to manage the *shola*-grassland system.

Grassland burning should be practised in the following way,:

i. burning should be done before January.

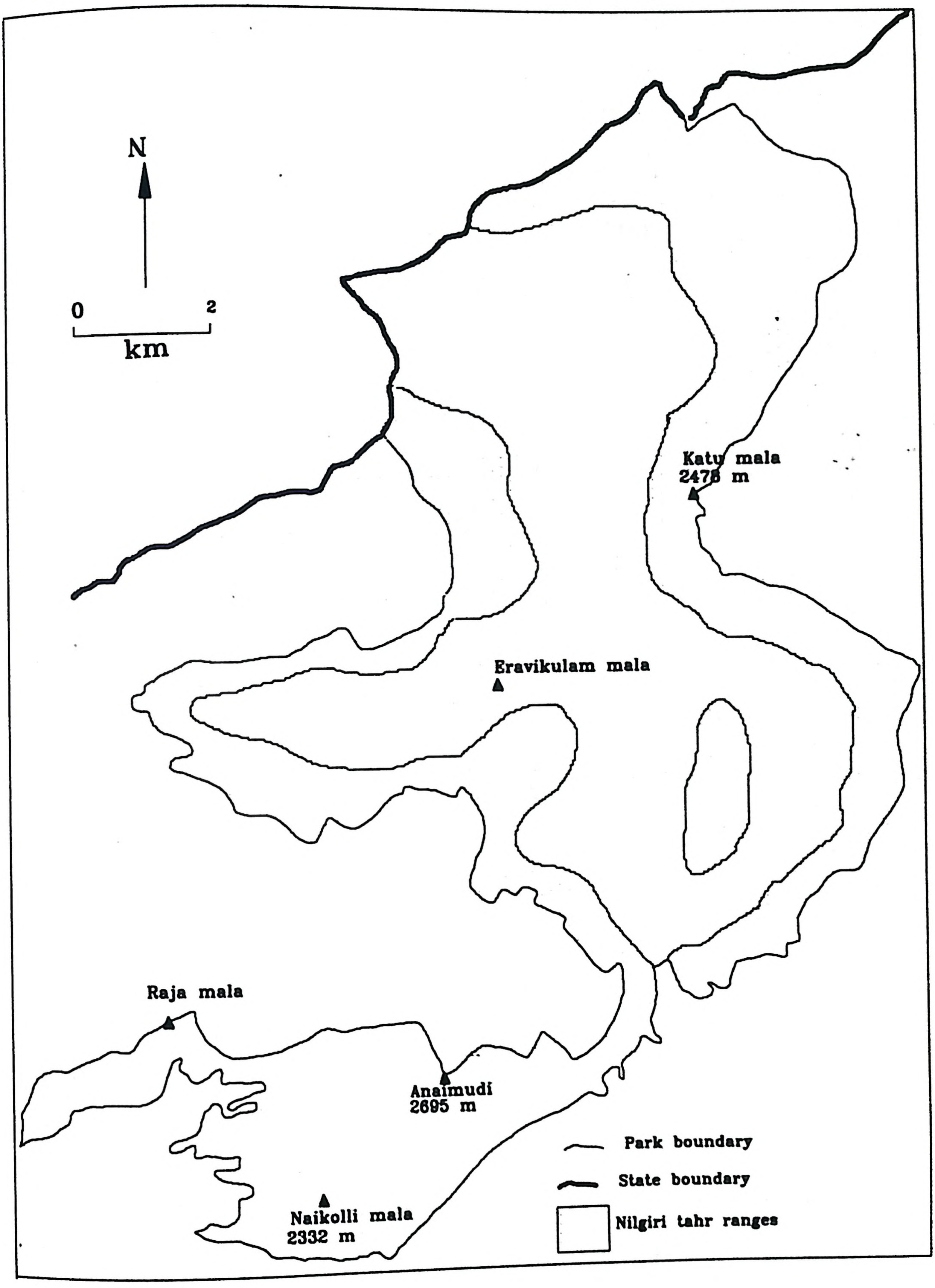
ii. the grassland communities used by tahr frequently or continuously should be selected for frequent burning (Figure 9.1).

iii. since grazing pressure is higher in the burnt areas, the extent of grassland to be burnt should be large enough to sustain the grazing pressure.

iv. Priority should be given to fire prone areas like the boundaries of tea estates, settlements, road sides, etc.

v. Burning should not be done in the year when Neelakurinji (*Phlebophyllum kunthianum* is in bloom.

Figure 9.1: Map showing distribution of Nilgiri tahr in ENP



The early burning practise for protecting shola patches has been explained in Figure 9.2. To protect *sholas* from further degradation, and to assist regeneration it is always ideal not to burn the tall grasses found (same species of the open areas, which attained greater height due to microclimatic variation) on the edges (*ca* 10 m) of the *shola* since they might provide the required micro-environment for *shola* regeneration which was observed in exclosure erected at Eravikulam. Outside this, a belt (based on the size ofthe *shola* patch) of 10-15 m can be marked in all fire-prone sides and those areas burnt in alternate years. Second-year burning should be further outside this strip at the same time and can be practised alternately. If a small patch of grassland is interspersed between two *sholas*, this patch should not be burnt because succession may bring back *sholas* at such sites.

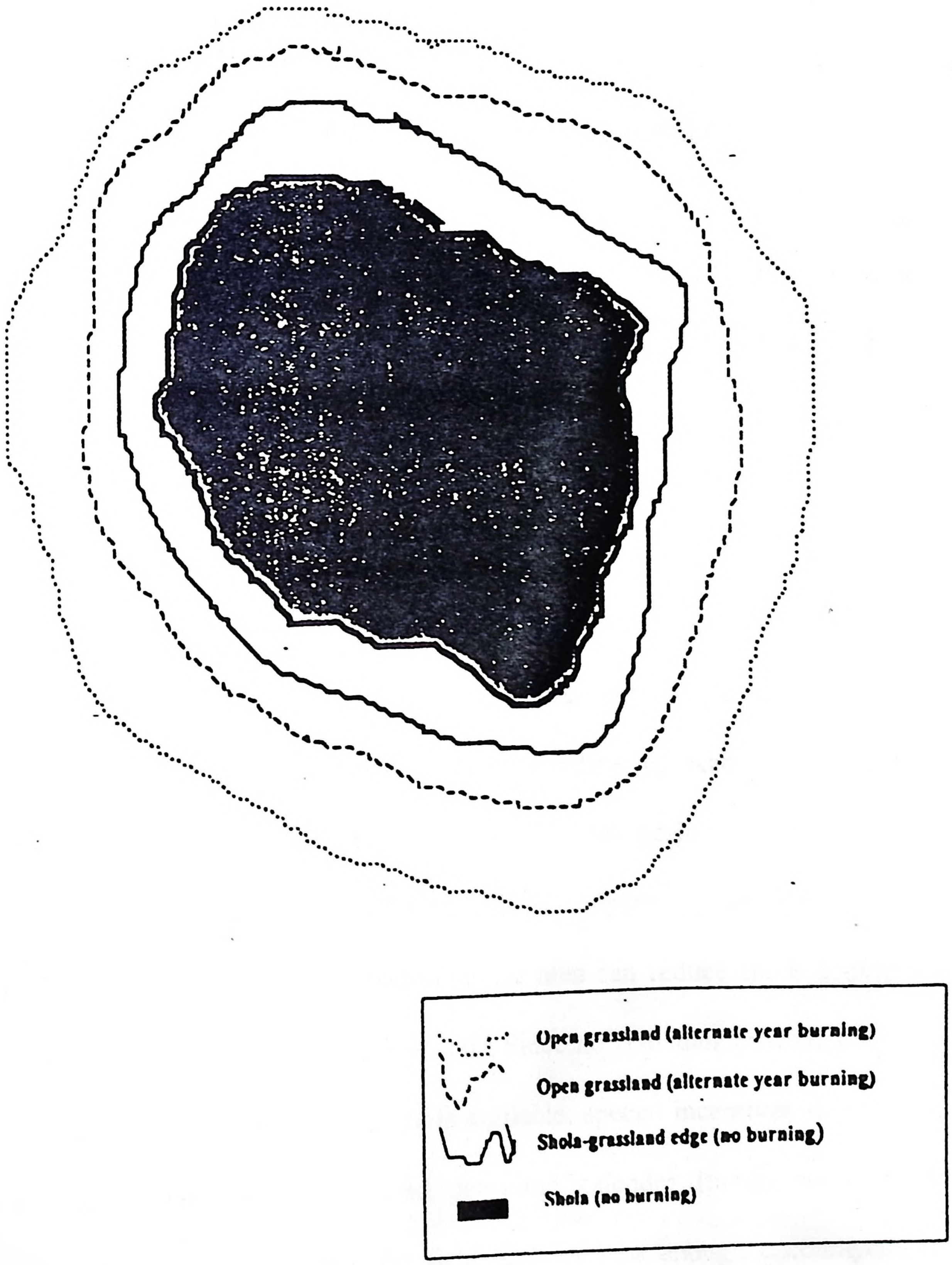
9.4 Administration and Establishment

Based on certain observations during the field study it was felt that the administrative and logistics of ENP should be strengthened for effective management. They are,

9.4.1. Park boundaries:

For strong protection and management, the area under jurisdiction should be defined and demarcated properly. The boundary, according to the Kerala Government notification, is marked only where it coincides with the inter-state or Tea estate boundaries. In some areas, distinction between National Park, Reserve Forest, and tea estate, is not clear. For instance at Rajamala, the demarcation between Kadalar estate and the Park is not clear. Similarly the demarcation between Chattamaunnar estate and Perumal Mala along the eastern boundary.

Figure 9.2 Schematic representation of burning to be practiced around shola forests,ENP



Therefore, a survey along the boundary is urgent to detect encroachment (e.g. at Chattamunnar), and to prepare an authentic boundary map.

9.4.2 Addition of the areas:

There are quite a few ecologically important forest and grassland patches adjacent to the National Park, on the western side of Anamudi, Rajamala and Erumapetti. Apart from Nilgiri tahr, large mammals such as gaur, elephant, sambar, tiger, and leopard, are found in these areas (*Pers. observ.*). Since these areas belong to the Munnar Forest Division, where authorities are busy with many other responsibilities, wild animals do not get adequate protection. Therefore, for the effective conservation of a large array of species, it is recommended to include these area (*ca.* 40 km^2) in the park, and with the help of suitable management strategies, it should be brought under extended the range of tahr.

9.4.3 Staff and Patrolling:

People from neighbouring estates and villages enter the National Park for the collection of *Drosera peltata*, flowers of *Anaphalis* spp., *Helichrysum buddleoides*, lichens, etc. The snaring of tahr along the boundary of Kadalar, Vaguvara, and Chattamunnar estates were also noticed. During the study period, a gun-shot was heard only once at Perumal Mala. It would be difficult to completely stop all the disturbances in the park, but a better system of patrolling the area can reduce these activities. This requires fire arms and the enforcement of staff. Since no vehicular movement is possible inside the park and only one camping site is available, special incentives should be given to the patrolling staff. A well planned patrolling calender (programme) should be implemented in ENP, ensuring that the field staff are gets enough encouragement and leisure. Shift in patrol duties with administrative duties can be tried experimentally. It would be desirable to construct wireless stations at Poovar and Eravikulam hut. These can be run on solar energy. Since adjoining areas of ENP (Grass Hills of Indira Gandhi NP in Tamil Nadu) tahr habitat, both the Tamil Nadu and Kerala Governments should come forward for joint management and patrolling strategies for the protection of this area. The curtailment of collecting plants and flowers is possible only with the help of neighbouring (territorial) forest officers, because they issue permits for collection and transportation of these plants from their area of jurisdiction.

9.4.4 Tourism:

Because of the serenity and beauty of High Ranges, ENP has got an important position on the tourism map of India. A large number of Indian as well as foreign tourists visit ENP every year. During the study period (1992-'93, 1993-'94, and 1994-'95) 25,000, 45,000 and nearly 1,00,000 lakh people visited this area respectively (Source: Record of Kerala Forest Department). The sharp rise in number during 1994-95 was due to the mass blooming of Neelakurinji. Tourists are allowed to spend the day in the tourism zone (Rajamala) by paying a nominal fee (Rs.10/ for Indians and Rs 50/ for the foreigners). The main attraction of this area is the almost assured sighting of tahr at touchable distance. But very little has been done to inform or educate tourists on this animal or its threatened status, except for constructing an information centre at Rajamala inside the park. Since this centre is being used only for taking classes for nature camps, a well equipped tourist information centre should be developed at Munnar. The existing dormitory at Munnar can be used for this purpose. This centre should have displays of vegetation, rare, endemic and exquisite flowers, butterflies, amphibians, birds, and animals of ENP and the "Do's" and "Don'ts" inside the park. Audio-visual facilities proclaiming the rich fauna and flora of ENP, Western Ghats, and India will be of much use. Tourist passes can be issued at this station, and people can make best use of the displays. The practice of distributing brochures to the visitors should be resumed. The park management should utilise the growing awareness of Indian population about their wilderness, in order to get their support in conserving the species and habitats in the years to come.

9.4.5 Eco-development

The tribal settlement in the national park is more than a century old. They are basically agrarians and the habitat around their settlement is degraded (Chapter 6). A fairly large number of tahr were found in this area, which needs intensive management (KFRI, 1993). It may be very difficult to translocate this tribal village in a state like Kerala, because of non-availability of suitable alternate land. It would be better to implement certain ecodevelopment activities that would reduce pressure on tahr and its habitat. The following activities are suggested on an experimental basis:

i. More employment opportunities such as as protection and fire watching should be given to the tribal people,

ii. growing of local fodder grasses i.e., *Chrysopogon zeylanicus, Ischaemum indicum, Heteropogon contortus, Cynodon dactylon, Themeda tremula* etc., near the settlements. Such areas should not be accessible to the tahr as this may result into conflict, and the spread of epidemic diseases. The appropriate location where it can be cultivated is the eastern side of the *Kudi*.

iii. The same area can be used for growing some native fuel wood species. Presently the fuel wood demand is met from estates and nearby forests. If eucalyptus, *Ulnus* spp., silver oak, and *Macaranga peltata* can be cultivated near the boundary adjoining estates, it will be sufficient enough to meet the fuel wood requirement of this settlement. The extent of area for this plantation should be decided in such a way that there will not be any further expansion in the coming years. The felling should be selective and rotational with proper soil conservation measures. Whenever there is felling the gap should be filled immediately with seedlings.

All State Departments and other agencies involved in the tribal development program should work in consultation with the Forest Department or the Forest Department should coordinate all these activities.

9.5 Black wattle plantation areas

The phytosociological study in the plantation area of black wattle showed that the natural ecosystem is altered substantially by plantation activities. The impact was significant on species composition and structure. The concern over the spread of these exotics in tahr habitat was expressed by earlier studies (Schaller, 1970; Davidar, 1978; Khan, 1978; Rice 1984; Blasco & Von Lengerke, 1989; Sukumar, 1993; Nair, 1994; Madhusudan, 1995 Mishra & Jhonsingh, 1995). Montane grasslands in their its natural state, exist only in Mukurti NP (Nilgiris), Indira Gandhi WLS & NP, and ENP (Anamalai Hills). Of these, ENP is the only Protected Area without black wattle plantation inside the park. However, there are signs of the spread of this species along the southern and north-eastern boundaries. Cutting (not allowing to flower), and removal of seedlings may be practical to eradicate all existing trees and saplings in the park, within a few years. Measures should be taken to remove seedlings of black wattle growing in front of Eravikulam hut on the way to Turner's valley.

9.6 Cattle grazing

The effect of livestock grazing on productivity and structure of vegetation composition in grasslands of ENP (Lakkamkudi) has been discussed in Chapter 6 and 7. There is a strong need for management activities that cater to both, the interests of local people and wild ungulates. Rotational grazing may not be possible in ENP, since the area under cattle grazing is limited. As such, livestock grazing is limited, and it may not be considered as threat to wild ungulates in the form of resource competition, but it may become a problem if communicable diseases like foot-and-mouth start spreading. All cattle in the tribal settlements should be vaccinated against transmissible diseases. The cattle of other people should not be allowed to graze inside the park, and the estate people should develop their own pasture land within the estate. Stall-feeding by estate people can be done by cutting fodder from the same area.

9.7 Long term monitoring of vegetation

The results of exclosure studies indicated that without a long-term study, factors like succession can not be studied. In this regard, the park management should undertake a long-term monitoring of the *shola*-grassland interphase using the exclosures erected during this study. It can be done with the help of local institutions such as Kerala Forest Research Institute (KFRI) and Tropical Botanic Garden and Research Institute (TBGRI), in collaboration of Wildlife Institute of India (WII). The number of exclosures should be increased to cover more habitat types and areas.

9.8 People's participation

The conservation and management of any protected area is practical only when there is cooperation and help from local people. It is known that the present day ENP was controlled by the NGO, High Range Game Association (now known as High Range Wildlife and Environmental Preservation Association (HRWEPA), financially assisted by M/s Tata Tea Company (P) Ltd.) till 1970. Even after declaring Eravikulam as NP, this NGO has been extending all possible help in management of the area. Since majority of the local populations are estate employeres the role of HRWEPA is very important in conserving ENP in the long run.

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*-original not seen.

Appendix-I

List of plants collected from the grasslands of ENP.

RANUNCULACEAE

**Anemone rivularis* Ham.	H	
Rananculus reniformis Wall.	H	
Thalictrum javanicum Bl.	H	
MENISPERMACEAE		
**Cyclea peltata* Hook.f.&Thoms.	C	
BERBERIDACEAE		
Berberis tinctoria Lesch.	S	
Mahonia leschenaultii Tak.	S	
BRASSICACEAE		
**Cardamine hirsuta* L.	H	
**Cardamine africana* Linn.	H	
Cardamine trifoliolata Hook.f.&Thoms. *(C.trichocarpa)*	H	
VIOLACEAE		
Viola patrinii DC.	H	
Viola retusa	H	
Viola distans	H	
POLYGALACEAE		
Polygala japonica Houtt.	H	
(Polygala sibirica Sensu Bennet)	H	
CARYOPHYLLACEAE		
Drymaria cordata Willd.	H	
HYPERICACEAE		
#*Hypericum mysorense* Heyne.	S	Endemic
**Hypericum japonicum* Thunb.	H	
**Hypericum wightianum* Wall.	H	

MALVACEAE

**Urena lobata* L.	S	

TILIACEAE

**Triumfetta pilosa* Roth.	S	

LINACEAE

**Linum mysorense* Heyne.	H	

GERANIACEAE

Geranium nepalense Sweet.	H	

BALSAMINACEAE

**Impatiens pusilla* Benth.	H	
#*Impatiens tomentosa* Heyne.	H	Endemic
Impatiens modesta W.	H	Endemic
**Impatiens maculata* W.	H	Endemic
**Impatiens campanulata* W.	H	
Impatiens pandata Barnes.	H	Endemic
#**Impatiens chinensis* L.	H	Endemic
**Impatiens goughii* W.	H	Endemic

OXALIDACEAE

**Oxalis richardiana* Babu.	H	
#**Oxalis corniculata* L.	H	

SAPINDACEAE

Dodonaea viscosa L.	Small tree	

FABACEAE

**Crotalaria leschenaultii* DC.	H	
**Crotalaria formosa* Grah.	H	Endemic
Crotalaria fysonii Dunn.	H	Endemic
**Crotalaria tomentosa* Rottl.	H	Endemic
Crotalaria walkeri Arn.	H	Endemic
#**Crotalaria ovalifoia* Wall.	H	Endemic
**Desmodium triquetrum* DC.	H	
#*Uraria rufescense* (DC.)Schindl. (*Desmodium rufescense* DC.)	H	
**Flemingia nilgheriensis* (Baker)W.ex Cooke	H	Endemic
**Flemingia strobilifera* R.Br.	H	

(F.bractata (Roxb.)W.)		
Parochetus communis Hamm.	H	
**Smithia gracilis* Benth.	H	Endemic
#Smithia blanda Wall.	H	

CAESALPINACEAE

*#*Cassia leschenaultiana* DC.	H	

MIMOSACEAE

**Acacia mearnsii* De Willd.	T	

ROSACEAE

*#*Rubus rugosus* Sm.	S	
#Rubus ellipticus Sm.	S	
**Rubus racemosus* Roxb.	S	

PARNASSIACEAE

*#*Parnassia pusilla* Wall.ex A.		
(P.mysorense)		
Parnassia wightiana Wall.		

CRASSULACEAE

Kalanchoe grandiflora W.&.A.	S	Endemic

DROSERACEAE

**Drosera burmanni* Vahl.	H	Endemic
Drosera peltata Sm.	H	

HOLARAGIACEAE

Laurembergia coccinea (Blume) Kanitz (Serpicula hirsuta)	H	

MELASTOMACEAE

Osbeckia cupularis Don.	H	
**Osbeckia gracilis* Bedd. *(O.lineolata* Gamble*)*	S	
**Osbeckia aspera var.wightiana* (Benth.ex W.&A.)Trimen (Osbeckia wightiana Benth.ex W.&A.)	S	
Osbeckia leschenaultiana DC.	S	Endemic
**Sonerila pulneyensis* Gamb.	H	

Sonerila rotundifolia Bedd.	H	

APIACEAE

Bupleurum distichophyllum W.&.A	H	Endemic
Centella asiatica Urb.	H	
**Hydrcotyle javanica* Thumb.	H	
Pimpinella candolleana W.& A.	H	
Vanasushava pedata (W.)Mukh.& Const. (Heracleum pedatum W.).	S	Endemic

RUBIACEAE

#**Borreria stricta* K. Sch.	H	
Hedyotis stylosa Br.	S	Endemic
Hedyotis swertiodes Hk.f.	H	Endemic
#*Hedyotis articularis* Br.	H	Endemic
Hedyotis santapui Shetty & Vivek.	H	
#**Hedyotis corymbosa* (L.)Lamk.	S	Endemic
**Hedyotis buxifolia* Bedd	S	Endemic
**Knoxia mollis* R.Br. (*K.corymbosa)*	H	
Mussaenda hirsutissima(Hk.f.)Hutch ex Gamble	S	
**Neanotis wightiana (W.&A.)Lewis* (*Anotis wightiana,*B.& Hk f)		
**Neanotis indica (DC.)Lewis* (*Anotis leschenaultiana* B.&H.K.f)		
Neonatis foetida (Hook.f) Lewis (*H.foetida* Dalz.*)*	H	
Ophiorrhiza leschnaultii	H	

VALERIANACEAE

Valeriana beddomei Cl.	H	Endemic
**Valeriana leschenaultii* DC.	H	Endemic
**Valeriana hookeriana* W. & A.		

ASTERACEAE

**Ageratina adenophora* (Spreng) King & Robinsion.	S	
**Anaphalis pulneyensis*	H	
Anaphalis bournei Fyson.	H	Endemic
**Anaphalis leptophylla* DC.	H	
Anaphalis travancorica Sm.	H	Endemic
Anaphalis marcescense Cl.	H	
Anaphalis spp.	H	
**Anaphalis lawii* Gamb.	H	
Anaphalis wightiana DC.	H	
Anaphalis meeboldii W. W. Sm.	H	Endemic
#**Artemisia japonica Thunb.*	S	

(*A. parviflora* Roxb.)		
Artemisia nilagirica Pamp.	S	
**Bidens pilosa* L.	S	
**Blumea mollis (D.Don.)Merrill.*	S	
(*B.neilgherrensis* Hk f.)		
**Blumea alata* (D.Don)DC.	S	
(Laggera alata)		
Blumea vulgaris	S	
#**Centratherum deltoides*		
Cicerbita cyanea (D.Don)Beauv.		
(Lactuca hastata DC.*)*		
Cirsium wallichii DC.		
(Cnicus wallichii)	S	
**Conyza bonariensis* (L) Cronq.	S	
(C.ambigua DC.)		
**Conyza stricta* Willd.	S	
Dichrocephala chrysanthemifolia DC.	S	
Emilia zeylanica Cl.	S	
**Emilia sonchifolia* DC.	S	
Erigeron karvinskianus DC.		
(Erigeron mucronatus) DC.	H	
Galinsoga quadriradiata Ruiz.& Pavon	H	
(G.parviflora var. *quadriradiata* Ruiz.& Pavon		
Helichrysum buddleoides DC.	H	
Phyllocephalum indicum (Less.) Kirkman		
(Centrantherum reticulatum)	H	
Senecio wightii (W.)Benth.	H	
Senecio lavandulaefolius Wight	H	Endemic
Senecio zeylanicus DC.	H	
**Sonchus wightianus* DC.	H	
(S.arvensis)		
Spilanthes clava DC.	H	
(S.acmella)		
Vernonia anamudica Shetty & Vivek.	S	Endemic

CAMPANULACEAE

**Campanula fulgens* Wall.	H	
Campanula alphonsii Wall.	H	Endemic
Lobelia nicotianaefolia Heyne	S	
#*Lobelia leschenaultiana* (Presl) Skottsb.	S	
(L.excelsa Lesch.ex Roxb.)		
Lobelia trijuga		
#*Wahlenbergia marginata* (Thunb.)DC.	H	
(W.gracilis DC.)		

VACCINIACEAE

Vaccinium leschenaultii W.	T	

ERICACEAE

#*Gaultheria fragrantissima* Wall.	S	
Rhododendron arboreum Sm. ssp. *nilagiricum* (Zenk) Tagg.	T	Endemic

PRIMULACEAE

Lysimachia leschenaultii Duby.	H	Endemic
Lysimachia deltoides W.		

MYRSINACEAE

Maesa indica (Roxb.)A.DC. (*M. indica* var. *perrottetiana* Cl.)	S	

OLEACEAE

Ligustrum perrottetii A.Dc.	T	

GENTIANACEAE

Exacum wightianum Arn.	H	Endemic
**Exacum atropurpureum* Bedd.	H	
Gentiana quadrifaria Bl.	H	
**Gentiana pedicellata* Wall.	H	
Swertia corymbosa W.	H	Endemic

SCROPHULARIACEAE

**Calceolaria mexicana* Benth	H	
**Lindernia* spp	H	
Pedicularis zeylanica Benth.	H	
**Pedicularis perrottetii* Benth	H	
Sopubia trifida Ham.	H	
Torenia bicolor Dalz.	H	

LENTIBULARIACEAE

Utricularia scandens Benj. var. *scandens* (*U.wallichiana* W.)	H	
Utricularia caerulea L.	H	Endemic
Utricularia graminifolia Vahl.	H	

GESNERIACEAE

**Didymocarpus tomentosa*Barnes	H	

ACANTHACEAE

Andrographis neesiana W.	H	Endemic
Justicia japonica Thunb.		
(J.simplex D.Don)		
Phlebophyllum kunthianum Nees.	S	Endemic
**Strobilanthes foliosus* T.And.	S	Endemic
#**Strobilanthes perrottetianus* Nees.		
#**Strobilanthus homotropus* Nees.	S	Endemic

LAMIACEAE

**Anisomeles indica* O.Kze.	H	
**Brunella vulgaris* L.	S	
Clinopodium umbrosum (Bieb.)Koch.	H	
(*Calamintha umbrosa* Benth.)		
**Coleus barbatus* Benth.	S	
Leucas vestita var. *devikolemensis* Shetty &Vivek	H	Endemic
**Leucas hirta* Spr.	H	
#**Leucas helianthemifolia* Desf.	H	
Leucas lancaeofolia Desf.	H	
Micromeria biflora Benth.	H	
Plectranthus wightii Benth.	H	
Pogostemon speciosus Benth.	S	
Pogostemon pubescens Benth	S	
Scutellaria barbata D.Don.	H	
Scutellaria spp	H	

PLANTAGINACEAE

Plantago erosa Wall.	H	
(P.major auct non L.)		

CHENOPODIACEAE

**Chenopodium ambrosioides* L.	S	

POLYGONACEAE

#*Polygonum nepalense* Meissn.	H	
(*P.punctatum* Buch-Ham.ex DC.		
**Polygonum chinense* L.	S	

THYMELACEAE

Gnidia glauca (Fresen)Gilg.		
(*Lasiosiphon erioephalus* (Meissn.)Decne.)	T	

EUPHORBIACEAE

Euphorbia laeta Heyne ex Roth.		
(Euphorbia rothiana) Spr.	H	
#**Glochidion arboreum* W.	T	
Phyllanthus rheedii W.	H	
Phyllanthus gardnerianus (W.)Baill	H	

URTICACEAE

**Laportea biflora*	S	
**Pouzolzia accuminata*	H	
Pouzolzia wightii Benn	H	

ORCHIDACEAE

Brachycorythis splendida Summ.	H	Endemic
Brachycorythis wightii Summ.	H	Endemic
**Disperis neilgherrensis* W.	H	
Habenaria heyneana Lindl.	H	
#*Habenaria perrottetiana* A.Rich		
**Habenaria crassifolia* A.Rich.	H	Endemic
#**Habenaria elliptica* W.	H	Endemic
#**Habenaria rariflora* A.Rich.	H	
**Habenaria longicorniculata* Grah.	H	Endemic
**Habenaria barnesii* Summ.	H	
Liparis wightiana Thw.	H	
Malaxis densiflora (A.Rich)O.Kuntz.	H	Endemic
**Malaxis intermedia*(A.Rich.)Seidenf		
**Malaxis rheedii* Sw.	H	
#*Peristylus richardianus* W.	H	
**Peristylus spiralis* A.rich.	H	
Satyrium nepalense Don.	H	
#*Spiranthes sinensis* (Pers.)Ames.	H	
(S.australis Lindl.*)*		

HYPOXIDACEAE

Curculigo orchioides Gaertn.	H	
**Hypoxis aurea* Lour.		

LILIACEAE

Asparagus laevissimus Stued.	C	
Chlorophytum malabaricum Baker	H	
Disporum leschenaultianum D.Don	H	
#**Lilium wallichianum* J.A.&J.H.Sch. var. *neilgherrense.*(W.)Hara	H	

XYRIDACEAE		
Xyris spp	H	
COMMELINACEAE		
**Commelina hirsuta* Cl.	H	Endemic
Commelina clavata Cl.	H	
**Cyanotis arachnoidea* Cl.	H	
**Cyanotis pilosa* Sch.	H	
**Murdania dimorpha* (Dalz.)Bruk.	H	
(*Aneilema dimorphum* Dalz.)	H	
JUNCACEAE		
#**Juncus bufonius* L.	H	
Juncus inflexus L.	H	
(J.glaucus Erh.ex Sibth.)		
#**Luzula multiflora* (Retz.)Lejeune	H	Endemic
(L.campestris auct non DC.)		
PALMACEAE		
**Phoenix humilis* Royle.	T	
ERIOCAULACEAE		
**Eriocaulon geoffreyi* Fyson	H	
#*Eriocaulon collinum* Hk.f.		
#**Eriocaulon robustum* Stued.		
CYPERACEAE		
Carex filicina Nees.	H	
Carex phacota, Spr.	H	
#*Carex* sp.	H	
#**Cyperus cyperinus* (Retz.)Valck.	H	
(*Mariscus cyperinus* Vahl.)		
**Cyperus Kyllingia* Endl.	H	
#**Cyperus sanguinolentus* Vall.	H	
**Cyperus sesquiflorus* (Torr)Mattf.& Kuk.	H	
(K.cylendrica)		
Cyperus brevifolius (Rottb.)Hassk.	H	
(Kyllingia brevifolia Roth.)		
**Eleocharis congesta* D.Don.	H	
Fimbristylis kingii Cl.	H	Endemic.
#**Picris* sp.	H	
Rhynchospora rugosa (Vahl)Gale	H	
Scirpus fluitans Linn.	H	

POACEAE

Agrostis peninsularis Hook.f.	H	Endemic.
Agrostis pilosula Trin.	H	
Andropogon lividus Thw.	H	Endemic.
Andropogon polyptychum var. *polyptychum*	H	
Andropogon polyptychum var. *deccanensis*	H	
Anthistiria ciliata L.f.	H	
Apocopis courtallumensis (Steud)Henr. (*Apocopis wightii* Nees.)	H	
Arthraxon villosus C.E.C.Fischer.	H	
Arthraxon lanlceolatus (Roxb.)Hochst.	H	
Arundinella vaginata Bor.	H	Endemic.
*Arundinella purpurea*Stued.	H	Endemic.
Arundinella mesophylla Nees.	H	
Arundinella ciliata (Roxb)Nees.	H	
Arundinella tuberculata Munro	H	
Bothriochloa parameswaranii Sreekumar et al.	H	Endemic
Bothriochloa foulkesii (Hook.f.)Henr.	H	
Bothriochloa insculpata (A.Rich.) A.Campus.	H	
Brachiaria reptans (Linn.)Gard.&C.E.Hubb.	H	
Capillipedium assimile (Steud)A.Camus		
Chrysopogon zeylanicus (Stued.)Thw.	H	
Chrysopogon tadulingamii Sreekumar et al.	H	Endemic.
#*Coelachne simpliciuscula* (stued.)Benth.	H	
Coelachne perpusilla (Stued.),Thw.	H	
Cyrtococcum deccanense Bor.	H	
#*Cymbopogon flexuosus* (Stued.)Wats.	H	
Cynodon dactylon (Linn.)Pers.	H	
#*Dichanthium oliganthum* (Stued.) Cope. *(D.polyptychum)*	H	
Dichanthium foulkesii (Hook f.)Jain and Despande.		
Digitaria wallichiana (Stued.)Stapf.	H	
Eleusine indica (Linn.) Gaertn.	H	
Eragrostis unioloides (Retz.)Stued.	H	
Eragrostis pilosa (Linn) P.Beauv.	H	
Eragrostis nigra Steud.	H	
Eulalia phaeothrix (Hack)O.Kunz.	H	
Eulalia thwaitesii (Hack)O.Kunz.	H	
Eulalia trispicata (Schult)Henr.	H	
#*Garnotia exaristata* Gould.	H	
Garnotia courtellensis (Arn.& Nees)Thw.	H	
Helictotrichon virescens (Stued)Henr.	H	
Heteropogon contortus (Linn.)Roem & Shultz.	H	
#*Imperata cylindrica* (Linn.)Raeusch.	H	
Isachne setosa C.E.C.Fischer.	H	
#*Isachne fischeri* Bor.	H	Endemic.
#*Isachne bourneorum* C.E.C.Fischer.	H	Endemic.
Ischaemum tadulingamii N.C.Nair et al.	H	

Ischaemum commutatum Hack.	H	
Ischaemum indicum (Houtt.) Merrill.	H	
Ischaemum nilagiricum Hack.	H	
#*Jansenella griffithiana* (C.Muell.)Bor.	H	
Oplismenus compositus (Linn.)P.Beauv.	H	
Panicum gardneri Thw.	H	
Paspalidum punctatum (Burm.)A.Camus.	H	
Poa annua Linn.	H	
Sacciolepis indica (Linn.)A.Chase (Aira indica)		
Sehima nervosum (Rottl.)Stapf.	H	
Setaria pumila (Poir)Roem.& Schutt. (*S. glauca* Sensu Hook f.)	H	
Setaria pallide		
#*Themeda tremula* (Stued.)Hack.	H	
#*Themeda cymbaria* (Roxb)Hack.	H	
Tripogon bromoides Roem & Schult.	H	
Tripogon narayanii P.V.Sreekumar et al.	H	Endemic.
Tripogon anantaswamianus P.V.Sreekumar et al.	H	Endemic.
Zenkeria jainii N.C.Nair et al.	H	Endemic.
Zenkeria elegans Trin.	H	

PTERIDOPHYTES

ASPLENIACEAE

Asplenium unilaterale Lam. H

GLEICHENIACEAE

**Dicranopteris linearis* (Burm. f) Underw
(Gleichenia dichotama Hook.)

LINDSAEACEAE

Lindsea odorata Roxb.
(Lindsea cultrata Sw.)
Sphaenomeris chinensis (Linn.)Maxon.

LYCOPODIACEAE

**Lycopodium cernuum* Linn.
Lycopodium spp

OSMUNDACEAE

Osmunda regalis Linn.

DENNSTAEDTIACEAE

Pteridium aquilinum (L.)Kuhn.

POLYPODIACEAE

Lepisorus nodus (Hook.)Ching

DAVALLIACEAE

**Leucostegia hymenophylloides* Presl.

*** specis reported in the present study**
 # species plotted in the scatter plot (Fig. 6.4)

H- Herb, S- Shrub, T- Tree

Appendix-II

List of C4 and C3 Grasses found in ENP.

C4 Grasses

Andropogon lividus Thw.	Herb.	Endemic.
Andropogon polyptychum var. *polyptychum*	Herb.	
Andropogon polyptychum var. *deccanensis*	Herb.	
Anthistiria ciliata L.f.	Herb.	
Apocopis courtallumensis Steud.)Henr. (*Apocopsis wightii* Nees.)	Herb	
Arthraxon villosus C.E.C.Fischer	Herb.	
Arthraxon lanceolatus (Roxb.)Hochst.	Herb.	
Arundinella vaginata Bor.	Herb.	Endemic.
Arundinella purpurea Stued. Herb. Endemic.		
Arundinella mesophylla nees.	Herb.	
Arundinella ciliata (Roxb)Nees.	Herb.	
Arundinella tuberculata Munro	Herb	
Bothriochloa parameswaranii Sreekumar et al.	Herb.	Endemic
Bothriochloa foulkesii (Hook.f.)Henr.	Herb.	
Bothriochloa insculpata (A.Rich.) A.Campus.	Herb.	
Brachiaria reptans (L.)Gard.&C.E.Hubb.	Herb.	
Capillipedium assimile (Steud)A.Camus		
Chrysopogon zeylanicus (Stued.)Thw.	Herb.	
Chrysopogon tadulingamii Sreekumar et al.	Herb	Endemic.
Cyrtococcum deccanense Bor.	Herb.	
Cymbopogon flexuosus (Stued.)Wats.	Herb.	
Cynodon dactyon (Linn.)Pers.	Herb.	
Dichanthium oliganthum (Stued.) Cope. (*D.polyptychum*)	Herb.	
Dichanthium foulkesii (Hook f.)Jain and Despande.		
Digitaria wallichiana (Stued.)Stapf.	Herb.	
Eleusine indica (Linn.) Gaertn.	Herb.	
Eragrostis unioloides (Retz.)Stued.	Herb.	
Eragrostis pilosa (Linn) P.Beauv.	Herb.	
Eragrostis nigra Steud.	Herb	
Eulalia phaeothrix (Hack)O.Kunz.	Herb.	
Eulalia thwaitesii (Hack)O.Kuntze	Herb.	
Eulalia trispicata (Schult)Henr.	Herb.	
Heteropogon contortus (Linn.)Roem & Shultz.	Herb	
Imperata cylindrica (Linn.)Raeusch.	Herb.	
Ischaemum tadulingamii N.C.Nair et al.	Herb	
Ischaemum commutatum Hack.	Herb.	
Ischaemum indicum (Houtt.) Merrill.	Herb.	
Ischaemum nilagiricum Hack.	Herb	
Sehima nervosum (Rottl.)Stapf.	Herb.	
Setaria pumila (Poir)Roem.&Schlt. (*S. glauca* Sensu Hook f.)	Herb	

Setaria pallide		
Themeda tremula (Stued.)Hack.	Herb.	
Themeda cymbaria (Roxb.)Hack.	Herb.	

C_3 Grasses

Tripogon bromoides Roem & Schult.	Herb.	
Tripogon narayanii Sreekumar et al.	Herb.	Endemic.
Tripogon anantaswamianus Sreekumar et al.	Herb	Endemic.
Zenkeria jainii N.C.Nair et al.	Herb.	Endemic.
Zenkeria elegans Trin.	Herb.	
Agrostis peninsularis Hk.f.	Herb	Eendemic.
Agrostis pilosula Trin.	Herb.	
Jansenella griffithiana (C.Muell.)Bor.	Herb	
Oplismenus compositus (Linn.)P.Beauv.	Herb.	
Panicum gardneri Thw.	Herb.	
Paspalidum punctatum (Burm.)A.Camus.	Herb.	
Poa annua Linn.	Herb.	
Sacciolepis indica (Linn.)A.Chase (Aira indica)		
Isachne setosa C.E.C.Fischer.	Herb.	
Isachne fischeri Bor.	Herb.	Endemic.
Isachne bourneorum C.E.C.Fischer.	Herb.	Endemic.
Garnotia exaristata Gould.	Herb.	
Garnotia courtellensis (Arn.& Nees)Thw.	Herb	
Helictotrichon virescens (Stued)Henr.	Herb	
Coelachne simpliciuscula (stued.)Benth.	Herb.	
Coelachne perpusilla (Stued.),Thw.	Herb.	

Appendix-III

List of rare and threatened species found in the grasslands of ENP.

Poaceae
Anthoxanthum borii, Jain.
Arundinella vaginata Bor.
Isachne fischerii Fischer.
I. setosa, Fischer.
Andrpogon lividus Thawits.
Arthraxon lanceolatus (Roxb.) Hochst

Orchidaceae
Brachyocorythis splendida.
Brachyocorythis wigtii.
Disperis neilgherrensis Wight.
Habenaria perrotettiana A.Rich.
Habenaria barnesii Summerhayes &Fischer
Spiranthes sinensis (Pears) Ames.

Asteraceae
Anaphalis barnesii, Fischer.

Balsaminae
Impatiens chinensis L.
Impatiens coelotropis
Impatiens pandata Barnes

Gesneriaceae
Didymocarpus macrostachya Barnes

Campanulaceae
Campanula alphonsii Wallich

Commelinaceae
Commelina hirsuta (Wight) Clarke.

Juncaceae
Luzula multiflora (Retz.) Lejeune
(L.campestris)

Rubiaceae
Hedyotis buxifolia Bedd.
H.swertiodes

Hypericaceae
Hypericum japonicum, Thumb.

Apiaceae
Pimpinella pulneynsis, Gamb.
Vanasushava pedata, (W) Mukh & Const.

Liliaceae
Chlorophytum malabaricum, Bak.
Lilium wallichianum var. neilgherrense, W.

Fabaceae
Crotalaria fysonii, Dunn.

Srophulariaceae
Pedicularis zeylanica, Benth.

Appendix IV

Grassland flora of ENP and their affinities with other phytogeographic regions.

SL. NO.	Name of genera	Valley of Flowers NP (W.Himalaya)	Khasi hills	Eastern Ghats	Patanas (Sri Lanka)	Pleistocoene Flora.
1	*Artemisia*	+	-	_	+	_
2	*Anaphalis*	+	-	-	-	-
3	*Asplenium*	+	+	-	-	-
4	*Berberis*	+	-	-	+	-
5	*Bupleurum*	+	-	-	-	+
6	*Calamintha*	+	-	+	+	-
7	*Cardamine*	+	-	-	+	-
8	*Carex*	+	-	-	-	-
9	*Chenopodium*	+	-	-	-	-
10	*Erigeron*	+	-	-	-	+
11	*Euphorbia*	+	-	-	-	+
12	*Gentiana*	+	-	-	-	-

13	*Gaultheria*	+	-	-	+	-
14	*Habenaria*	+	-	-	-	-
15	*Heracleum*	+	-	-	-	+
16	*Hypericum*	+	-	-	-	-
17	*Impatiens*	+	-	-	-	-
18	*Lilium*	+	-	-	-	-
19	*Lycopodium*	+	-	-	-	-
20	*Lysimachia*	+	-	-	-	+
21	*Malaxis*	+	-	-	-	-
22	*Parnassia*	+	-	-	-	-
23	*Pedicularis*	+	-	-	-	+
24	*Pimpinella*	+	-	+	+	-
25	*Poa*	+	-	-	-	-
26	*Ranunculus*	+	-	+	-	+
27	*Rubus*	+	-	-	+	-
28	*Scutellaria*	+	-	-	-	-

29	*Senecio*	+	-	+	-	-
30	*Spiranthes*	+	-	-	-	-
31	*Strobilanthes*	+	-	-	-	-
32	*Swertia*	+	-	-	+	+
33	*Thalictrum*	+	-	+	+	-
34	*Valeriana*	+	-	-	-	-
35	*Viola*	+	-	-	+	-
36	*Utricularia*	-	-	-	+	-
37	*Exacum*	-	-	-	+	+
38	*Eriocaulon*	-	+	-	+	-
39	*Geranium*	-	-	-	+	-
40	*Vaccinium*	-	-	-	+	-
41	*Rhododendron*	-	-	-	+	-
42	*Anotis*	-	-	+	-	-
43	*Vernonia*	-	-	-	-	+
44	*Arisaema*	-	-	-	-	+

45	*Osbeckia*	-	-	+	-	-
46	*Andropogon*	-	-	+	-	-
47	*Justicia*	-	-	+	-	-
48	*Flemingia*	-	+	-	-	-
49	*Fimbristylis*	-	+	-	-	-
50	*Dichrocephalus*	-	+	+	-	-
51	*Anemone*	-	-	-	+	-
	Name of the Species					
52	*Agrostis pilosula*	+	-	-	-	-
53	*Anemone rivularis*	+	+	+	-	+
54	*Geranium nepalense*	+	+	-	-	+
55	*Helictrotrichon virescens*	+	-	-	-	-
56	*Juncus bufonius*	+	-	-	-	-
57	*Parochaetus communis*	+	-	-	+	+
58	*Plantago erosa*	+	-	+	-	-
59	*Polygonum nepalense*	+	-	+	-	-

60	*Rhododendron arboreum*	+	+	-	-	-
61	*Satyrium nepalens*	+	-	+	+	-
62	*Anisomeles indica*	+	-	-	-	-
63	*Carex filicina*	+	-	+	-	-
64	*Chenopodium ambrosioides*	+	-	-	-	-
65	*Cyanodon dactylon*	+	+	+	-	-
66	*Cyperus brevifolius*	+	-	-	-	-
67	*Cyperus sanguinolentus*	+	-	-	-	-
68	*Eleusine indica*	+	-	-	-	-
69	*Eragrostis nigra*	+	+	-	-	-
70	*Eragrostis unioloides*	+	-	+	-	-
71	*Gentiana pedicellata*	+	-	-	-	-
72	*Heteropogon contortus*	+	-	+	-	-
73	*Hypoxis aurea*	+	-	-	-	-
74	*Luzula multiflora*	+	-	-	-	-
75	*Micromeria biflora*	+	-	-	-	-

76	*Oplismanus compositus*	+	-	-	-	-
77	*Poa annua*	+	-	+	-	-
78	*Polygonum chinense*	+	-	+	-	-
79	*Phoenix humilis*	+	-	+	-	-
80	*Osbeckia wightiana*	-	-	-	+	-
81	*Maesa indica*	-	+	+	+	-
82	*Andropogon lividus*	-	-	-	+	-
83	*Chrysopogon zeylanicus*	-	-	+	+	-
84	*Cyanotis pilosa*	-	-	+	+	-
85	*Desmodium triquetrum*	-	+	-	+	-
86	*Eulalia phaeothrix*	-	-	-	+	-
87	*Gentiana quadrifaria*	-	-	-	+	-
88	*Imperata cylindrica*	-	+	+	+	-
89	*Ischaemum indicum*	-	-	+	+	-
90	*Osbeckia cupularis*	-	-	+	+	-
91	*Pedicularis zeylanica*	-	-	-	+	-

92	*Phyllanthus gardneriana*	-	-	+	+	-
93	*Pteridium aquilinum*	-	-	-	+	-
94	*Themeda tremula*	-	-	-	+	-
95	*Wahlenbergia marginata*	-	+	-	+	-
96	*Oxalis corniculata*	-	-	-	+	-
97	*Eulalia trispicata*	-	-	+	+	-
98	*Tripogon bromoides*	-	-	+	+	-
99	*Bidens pilosa*	-	+	+	+	-
100	*Blumea alata*	-	-	+	+	-
101	*Galinsoga parviflora*	-	+	+	+	-
102	*Conyza bonariensis*	-	-	+	+	-
103	*Emilia sonchifolia*	-	+	+	+	-
104	*Helichrysum buddleiodes*	-	-	-	+	-
105	*Campanula fulgens*	-	+	-	+	-
106	*Lobelia nicotianifolia*	-	+	-	+	-
107	*Lobelia leschenaultiana*	-	-	-	+	-

108	*Viola patrinii*	-	+	+	-	+
109	*Polygala sibirica*	-	+	-	-	+
110	*Berberis tinctoria*	-	+	+	-	-
111	*Exacum perrottettii*	-	-	+	-	-
112	*Ranunculus reniformis*	-	+	-	-	-
113	*Cirsium wallichii*	-	+	-	-	-
114	*Lysimachia deltoides*	-	+	-	-	-
115	*Exacum atropurpureum*	-	+	-	-	-
116	*Exacum wightianum*	-	+	-	-	-
117	*Thalictrum japonicum*	-	+	-	-	-
118	*Parnassia wightiana*	-	+	-	-	-
119	*Lactuca hastata*	-	+	-	-	-
120	*Gaultheria fragrantissima*	-	+	-	-	-
121	*Polygala japonica*	-	+	-	-	-
122	*Triumfeta pilosa*	-	+	-	-	-
123	*Urena lobata*	-	+	-	-	-

124	*Flemingia strobilifera*	-	+	-	-	-
125	*Smithia blanda*	-	+	+	-	-
126	*Setaria glauca*	-	+	+	-	-
127	*Drosera peltata*	-	+	+	-	-
128	*Artemisia nilagirica*	-	+	-	-	-
129	*Laurenbergia coccinea*	-	-	+	-	-
130	*Pimpinella candolleana*	-	-	+	-	-
131	*Phlebophyllum kunthianum*	-	-	+	-	-
132	*Mussaenda hirsuitissima*	-	-	+	-	-
133	*Malaxis rheedii*	-	-	+	-	-
134	*Linum mysorense*	-	-	+	-	-
135	*Impatiens chinense*	-	-	+	-	-
136	*Laggera alata*	-	-	+	-	-
137	*Lilium neilgherrense*	-	-	+	-	-
138	*Curculigo orchioides*	-	-	+	-	-
140	*Dodonea viscosa*	-	-	+	-	-

141	*Hypericum japonicum*	-	-	+	-	-
142	*Rubus ellipticus*	-	-	+	-	-
143	*Sehima nervosum*	-	-	+	-	-
144	*Crotalaria ovalifolia*	-	-	+	-	-
145	*Cyanotis arachnoides*	-	-	+	-	-
146	*Cyclea peltata*	-	-	+	-	-
147	*Cymbopogon flexuosus*	-	-	+	-	-
148	*Didymocarpus tomentosa*	-	-	+	-	-
149	*Disperis neilgherrense*	-	-	+	-	-
150	*Drosera burmannii*	-	-	+	-	-
151	*Erigeron karvinskianus*	-	+	+	-	-
152	*Eriocaulon robustum*	-	-	+	-	-
153	*Fimbristylis kingii*	-	-	+	-	-
154	*Flemingia strobilifera*	-	-	+	-	-
155	*Galinsoga quadriradiata*	-	-	+	-	-
156	*Habenaria longicorniculata*	-	-	+	-	-

157	*Habenaria heyneana*	-	-	+	-	-
158	*Habenaria rariflora*	-	-	+	-	-
159	*Sonchus wightianus*	-	-	+	-	-
160	*Swertia corymbosa*	-	-	+	-	-
161	*Utricularia graminifolia*	-	-	+	-	-
162	*Zenkeria elegans*	-	-	+	-	-

(+ = common genera, - = no affinity)

Plate-I

Rocky slopes of ENP

Valley, Bog and non rocky slopes

Plate-II

Valley

Eravikulam Ar

Plate-III

Valley, Non-rocky slopes and Shola grassland edges

Shola edge with exclosures

Plate-IV

Early burning of the grassland

Cattle grazing

Plate-V

Point grided frame

Biomass clipping

Plate-VI

Phlebophyllum kunthianum (Neelakurinji)

Brachycorythis wightii

Plate-VIII

Burnt shola

Nilgiri tahr - grazing in the burnt area

Plate IX

Eravikulam Plateau

Nilgiri tahr (Hemitragus hylocrius)