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VEGETATION DYNAMICS OF THE GRASSLAND-FOREST ECOSYSTEM IN THE WESTERN GHATS OF KERALA

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CONTENTS

		Page	File
	Abstract	I	r.154.2
1	Introduction	1	r.154.3
2	The Grasslands of Kerala	7	r.154.4
3	The Area of Study	10	r.154.5
4	Vegetal Mosaic Continua	22	r.154.6
5	Vegetal Succession	56	r.154.7
6	The Soil Profile	91	r.154.8
7	The Climate	140	r.154.9
8	Synthesis	151	r.154.10
8	References	158	r.154.11

ABSTRACT

Indian literature on the ecological status of the high elevational grasslands of south Indian hill stations is compartmented. One school holds that the grasslands, like the shola forests, are climatic climaxes. The other school holds that they are biotic climax formations. Of late, this controversy has generated problems in the afforestation of grasslands and the study was undertaken to resolve the controversy through empirical studies and meta-analysis of available information.

The study involved two approaches: (1). reconnaissance studies in a number of locations, for understanding the pattern of vegetal succession and the variability of vegetal mosaics, and (2). location centered investigations on vegetal dynamics, soil and climate. The location centered studies were conducted at the Silent Valley National Park (Medium Elevational Zone) and the Eravikulam National Park (High Elevational Zone).

The study comprised investigations on three segments of the vegetation: (1) soils of the grassland-forest ecosystem, (2) studies on vegetal mosaics of grassland-forest ecosystem, and (3) climate of the grassland-forest ecosystem! Particulars of soil investigation embraced the soil particulates, iron exchange ability, organic carbon and the macronutrients N, K, C, and the micro-nutrient, Mg. Studies on the vegetation comprised seed invasion, germination trials, regeneration monitoring, grassland vegetal mosaics and their significance in succession. The climate component involved measurement of weather parameters, temperature and humidity, in the forest, ecotone and grassland, and the general precipitation, rain.

Community studies of the grasslands at both the elevations proved that they are not as uniform as we see fiom a distance? They are actually a conglomeration of several distinct communities differing in species composition, soil moisture regimes and compositional or disturbance regimes, as is also met with in the forest communities. On closer examination different vegetal mosaics could be identified in the shrublands too. These vegetal mosaics, because of their niche specificity represent a successional continuum, which in turn suggest that the grasslands certainly are in progressive succession towards an arborescent vegetation, and not climax by themselves.

The slow pace of succession of grasslands to wooded communities is found to be due to the paucity of invasion of diaspore populations of the right kind of species into the grasslands. Diaspore invasion into the grassland takes place mainly through wind and birds. Seed germination and seedling establishment do not seem to be oppressed by the grassy vegetation than by the more or less dry moisture regime, fire and frost. Nevertheless, the emergence of new recruits of tree species in the grasslands are very few. The forest ecotones represent the growing perimeter of the forest as evidenced by the higher tree biodiversity and high densities of established seedlings.

Soils of the two elevational zones were found to be uncomparable on grounds of elevational difference and the high-deposition of organic carbon and macro- and micro-nutrients at the high elevational zone. Irrespective of the zones, all macronutrients showed a decreasing trend with increasing depth. For other parameters either there was no trend with depth or the trends differed across the two elevational zones. Within the range of parameters of study, pedology failed to distinguish the different vegetal mosaics without overlap of

characteristics, except in very few instances. This probably implies that, soil features are important only second to the chance invasion of diaspores of arborescent species, without which succession cannot begin.

Examination of trends in soil chemical properties across the vegetal continuum, grasslands -> shrublands -> forestlands, showed differing trends in the two elevational zones and thus proving of no value for generalization: At the same time beyond the chemical specifics, the soil in the grasslands and the shrublands invariably had high accumulation of larger gravels and other boulder stones in the 20-40 cm layer, and the parent rock was situated rather shallowly, while in climax forests the soil was generally over one meter deep and the parent rock situated fbrther deep. This trend was found true for both the elevational zones. This observation suggests that, for growth of pioneer trees the chemical composition, the total volume of soil (excluding the boulder stones) available on the parent rock surface is also important. The poorly developed soil horizon in the grasslands does not suggest that the grassy landscapes are climaxes. On the other hand they represent an edaphic climax, limited by soil moisture.

Climatologically, the mid elevational zone does not exhibit very extreme cold temperature while at high elevation, the temperature readings during the cold season go down to the minus scale indicating frost or physiological drought. Definitely hostile climate is one of the hurdles in active succession of the high elevational grasslands. The shola forest patches sprinkled within the vast expanse of the grasslands are active centers of forest invasion and therefore climate alone cannot be considered solely responsible for the slow pace of tree invasion in the grassland. It is true that the microclimate of the grasslands and the forests are different but it should be remembered that the climax concept is linked with the macroclimate. If both the grasslands and the forests, the two vegetal types representing the two microclimates at the two elevational zones are considered climax then probably the shrublands which are intermediate between them also need to be considered a climax, which then defeats the very concept of climax.

.The climax concept itself has been criticised since the formulation of it by Clements in 1916. The general criteria by which a climax community is identified are: (1) the apex vegetation, (2) the stability of the vegetation indicated by long persistence, (3) the low degree of changes happening in the vegetation, and (4) the successfull regeneration of the composed species. On closer examination none of these criteria were found to hold true for a climax vegetation. Thus the concept of "climax" has been redefined as 'the vegetation(s) holding maximum biomass per unit area in living stands'. As the term climax always gives a faulty notion to the end point of vegetal succession, a new term, 'optimum vegetation' has been suggested.

The grassland vegetation always holds living biomass much lower than wooded vegetations in the same locations and they have a primitive soil structure with poorly developed horizons. So also, all vegetal types of all microclimates cannot be considered climax (or optimum). On these grounds, the grassland vegetation along the South Indian hill stations have been suggested not to represent any 'climatic climax', but are edaphic climax. Yet, they are no way originated as a result of anthropic or other biogenic means and therefore are primary vegetation. The whole issue of the climatic climax concept of the grasslands seems to have stemmed up following the general practice of considering undisturbed primary vegetations as climatic climax communities, which of course need not be the case always.

As is the case with Tamilnadu, considerable extent of grasslands have been converted to eucalypt and wattle plantations in Kerala too. Plantation activities in grasslands involve the risk of (1) failure of plantations, (2). impoverishment of soil fertility, (3) loss of specific segments of biodiversity preserved in the grasslands, and (4), inefficient atmospheric carbon dioxide fixing patterns Proper evaluation of risks involved needs to be made before taking policy decisions on planting activities in the grasslands.

Immediate research needs are: (1). evaluation of grassland resources, (2). evaluation of risks involved in practicing plantation activities in the grasslands, (3). effect of plantations on grassland soils, and (4). methods to detrench the ill effects of plantations on grassland soil, and (5). the possibility of converting the plantations raised in grasslands to shola forests.

CHAPTER 1. INTRODUCTION

1.1 A deficit balance sheet

ApproximateIy a century has passed since the origin of the conservation movement which started off in the United States (Dasmann, 1974) and today conservation is a pivotal theme for education, research and in developmental planning. The extinction of organisms and landscapes of sentimental, aesthetic and environmental values have been the driving force in the development of ecosystem conservation. Viewed from a broader perspective, the causal force of ecosystem conservation turns out to be a specific case of resource crunch where the resources, unlike in other instances, are non-renewable.

Diversification ofresources by switching over to less used ones and enrichment by new resource bases have been the strategy in approaching the problem of resource crunch. Increasingly vast expanses of wild lands practically untouched by humans in the past have been put to intense use during the Iast several decades. Because of the continuously building population of humans, the resource scenario is unlikely to make a reversed balance sheet in the near future and there is every need for making an environmentaIIy audited prospective revaluation of developmental plans on ecosystem resource use (Basha *et al.;* 1993).

1.2 Grasslands as multiple resources

The grasslands. variously called as the prairies, the steppes. savannas. savanna woodlands, etc (Beard, 1953, Bourliere and Hadley, 1970. Barnad. 1964, Bremeyer and Van Dyne, 1980. Coupland. 1979. French. 1971. GiIIison. 1983, Gillison and Walker, 1981, Ramia, 1968, Skerman and Riveros. 1990, Walker and Gillison. 1982) in different places and continents have had an equal amount of scientific interest comparable to that of forest formations This interest is reflected in the quantum of scientific literature accumulated (Bourliere, 1983) The food value of cereal grasses as staple food for humans. the fodder value of several grass species, and grassy landscapes like the prairies and the medicinal value of many grasses like lemon grass (Barnard and Frankel, 1964. Bews. 1929, Bor, 1960) have maintained and brought significant areas under grassy cover either as man made landscapes or as man-managed landscapes The economic importance of these Iandscapes are indeed inexplicable (Skerman and Riveros, 1990)

1.3 Environmental value of grasslands

Not until recently the importance of the grasslands as sinks of large volumes of atmospheric gases such as carbon dioxide was realized (Solbrig, 1990). The ecological importance of grasslands as food sources for the wildlife, and as reserves of many poorly documented herbaceous plant forms (Shetty and Vivekananthan, 1968, 1970, 1971, 1972, 1973a, 1973b, 1973c, 1991) and their definitive role in ecological succession throws the subject of 'grasslands' again to the forefront of current environmental importance (Puri *et al.*, 1989). Starting from 4,000 year back history of agriculture, the history of grasses and grasslands is thus well knit with the history of human civilisations both as a resource for diet of the top consumers of the ecological pyramid, also as a sanctimonious environmental and resource permitting human life to survive.

1.4 Grasses and grasslands as moulds for human culture

Discovery of the use of fire for cooking, the evolution of grazing herbivores (Hills, 1965; Tivy, 1982) which made domestication of animals possible, nomadic pastoral prehistory, historic Aryan invasion of the tropics due to the advancement of glaciers into the temperate grasslands, cereal cultivation and settled agriculture and lately agroforestry, fodder grass farming, rangeland management, all have something to do with the grasslands. In other words, in each of these stages of human developments, grasses and grasslands have played a key role in moulding human culture, each time adding upon newer dimensions.

1.5 Information base on grasslands

Looking at the World scenario, the information base on grasslands includes several monographs, special volumes (proceedings of symposia), chapters in books and innumerable articles in science serials. Some of the important monographs and review papers are listed in Table 1.1. These literature are scattered on topics like grassland typology, productivity, soil and nutrient cycling, rangeland management, grassland fire, ecosystem modelling, grass systematics, bamboo resources, and the agriculture and agroforestry counterparts on cereal agronomy, breeding and genetic engineering. Literature concerning the origin, perpetuation, stability and ecological status of grasslands are also scattered in these publications.

A bibliographic scan shows that the literature base on Indian grasses and grasslands is also not very prolific (Puri *et al.*, 1969). Most of the earlier studies on Indian grasslands pertain to the typology and classification. Excellent studies on the structure and dynamics. productivity, management are also available from recent times. Selected regionwise references on Indian grasslands are given in Table 1.2.

1.6 The problem

According to an estimate by Clements and Shelford (1939), approximately 40% of the globe's total land cover was under some kind of natural grassy vegetation, before the history of civilized man. The current figure of land area under grasslands is around 24% (Sanchez, 1954) and this diminution is largely attributed to transformation of the natural grasslands as: (1) rangelands with the onset of animal husbandry, and (2). arable lands as a result of agriculture.

In the past, in many parts of India, many good natural forest areas were cleared for agricultural purposes and establishment of cash crops and forest plantations. The identification of the fact that natural forest landscapes are seldom artificially regenerated, and that the health and survival of mankind are intimately linked with the forest wealth, throughout the world, there has been a surge for the suppression of forest denudation activity.

Table 1.1 Important books and other cardinal papers on grassland ecology.

No	Books	Review articles\ Other important papers
1	Bourliere, 1983	Bell, 1971
2	Burms. 1923	Chrostowski and Denevan. 1970
3	Coupland, 1979	Daubenmire, 1968
4	Crisp, 1964	De Vos, 1969
5	Davies, 1960	De Rham, 1970
6	Duffey *et al.*, 1974	Dix and Beidleman, 1969
7	French 1971, 1979	Hanson, 1950
8	Huber, 1974	Hills, 1969
9	Huntley and Walker, 1982	Hills and Randall, 1968
10	Innis, 1978	Hopkins, 1965
11	McLlory, 1964	Old, 1969
12	Moore, 1966, 1973	Sims *et al.*, 1978
13	Pratt and Gwynne, 1977	Steiger, 1930
14	Snaydon, 1987	Van Donselkar, 1965
15	Sprague, 1959	Van Donselkar and Huinink, 1966
16	Walter, 1971	Veasy-Fitzgerald, 1963
17	Whyte, 1974	Weaver, 1958
18	Young and Solbrig, 1993	Weins. 1973

India has an estimated coverage of 13,813 km^2 of grassy vegetation (40% of the land cover; Singh, 1995) and the Kerala State has its share of 130 km^2 (1.35 of the total forest land of the State: Kerala Forest Department, 1995). As a corollary to give up plantation activities by clear felling naturally wooded vegetation, now foresters look around for finding alternate land resources, for growing plantations to meet the peoples demand for wood. This peep up of possibilities extend to natural grasslands (Balagopalan *et al.*, 1998): which perhaps do not come under the most conventional definition of forest as a "landscape dominated by arborescent vegetation". Moreover, if forest planting operations are to be conducted in these grasslands, no destruction of tree vegetation is required.

In this context, the question: Where do the grasslands, as landscapes dominated by grassy species, find their position in the evolutionary history of vegetal formations is very important. The grass, from a conventional plant taxonomist's point of view stands at the apex of the evolutionary ladder. Do the grasslands also have a comparable position in the story of vegetal succession'?In other words, are they climax formations or early- or mid- successional?

Throughout the Western Ghats, all extensive grasslands lie adjacent to the evergreen forest formations, assuming a forest- grassland continuum. Therefore, the question can be refi-arned: Do both the forest and grassland communities represent stable, climax formations? If the grassland communities also represent climax formations, landscape modification of the ecosystems need added care.

Table 1.2 Selected region\ State wise studies on Indian grasslands

Region\State, References	Region\State, References	Region\State, References
India (whole) Bor. 1960 Champion, 1936 Champion & Seth. 1968 Dabadghao & Shankara-narayan, 1973 Misra R 1983 Pun *et al.* I989 Singh. 1995 Whyte. 1957 **Western Himalaya** Gupta & Nanda. 1970 **Western Ghats** Agrawal *et al*. 1961 Bharucha & Shankara-naravan. 1958a. 1958b Blasco. 1971 Fischer, 1921 Ranganathan. 1938 **Eastern Ghats** Paliwal & Gnanam, 1985 **Himachal Pradesh** Mohan. 1955 **Assam** Bor, 1940 **Nepal** Numata, 1966	**Meghalaya** Tripathi & Pandey, 1991 **Punjab** Singh & Yadava, 1974 **Rajasthan** Bhimaya *et al.* 1966 Gupta & Prakash. 1978 Gupta & Saxena, 1972 Sathyanarayana & Sarkaranarayan. 1964 **Uttar Pradesh** Sankaranarayan. 1970 Seth. 1954 Singh. 1967, 1972 **Gujarat** Jadav *et al.*, 1993 Kanodia & Nanda. 1966 Kapadia, 1949,1951 **Maharashtra** Bharucha & Deve, 1952 Puri & Mahajan. 1957 Puri & Vasavada, 1958	**Madhya Pradesh** Jain. 1971 Mall *et al*. 3973 Misra, 1955. 1973 Naik. 1973 Pandeva, 1951-1952. 1955. 1961. 1964 Tiwari. D K. 1953-1954 Tiwari S D N. 1954 **Orissa** Misra & Misra. 1991 **Andhra Pradesh** Chinnamani 1970 **Karnataka** Chinnamani. 1968 **Tamilnadu** Agrawal *et al*. 196 Blasco. 1971 Fischer. 1921 Gupta *et al.* 1967 Ranganathan. 1938 **Kerala** Chandrasekharan. 1962a. 1962b. 1962c, 1962d Karunakaran *et al*. 1997 Shetty & Viveka-nanthan. 1972. 1973c 1991 Sreekumar & Nair. 1991

1.7 Two views on the climax status of grasslands

Studies on the ecological status of the grasslands from within the Kerala part of the country are not available. However, the subject has been alive in ecological literature since Champion (1936) and Ranganathan (1938). The whole gamut of interpretations available and the arguments when examined through, one can find two strong lincs: one group holding the view that the grasslands along the south Indian hill stations are climatic climaxes and the other group considering it as successional of serial in status

Champion in his Forest types of India (1936) considered grasslands as secondary formations, presumably because grasses in general are colonisers and grasslands occupy both edaphically and bioclimatically stressed and disturbed habitats. Ranganathan (1938)who studied the grassland-shola ecosystems of the Nilgiris, proposed that the hilltop grasslands of South Indian Hill Stations also represent a climatic climax vegetation, comparable to that of the shola\evergreen forest.

The controversy introduced by Champion (1936) and Ranganathan (1938) apparently seems to have been taken up by the West. Grassland literature in Europe, New World, Africa and Australia was fully sounded by arguments on this controversy (Goodland, 1970; Hills, 1965; Larson, 1940; Old, 1969; Sauer, 1950; Cole, 1960, 1963; Dix, 1964; Wells, 1965; Veasy-Fitzgerald, 1963; Tiver and Crocker, 1951; also refer Tivy, 1982 for a review). In India too, this controversy was continued (Bor, 1938; Sankaranarayan, 1958; Gupta, 1960, 1971; Gupta and Sankaranarayan, 1962; Chandrasekharan, 1962a, 1962b, 1962c, 1962d; Vishnu-Mitre and Gupta, 1971; Meher-Homji, 1965, 1967, 1969; Puri *et al.*, 1989).

Ranganathan, the original proponent of the bioclimax theory argued that the grassland shows a high degree of stability, as the ability of grasses to survive frost and fire damage is fairly high compared to tree seedlings of sholas and the latter fail to progress into the grassland to any appreciable extend. Evidences for the occurrence of both shola forests and grasslands in the Nilgiris plateaus since around 30,000 years BP (Before Present) have been provided by palaeopalynological investigations (Vishnu- Mitre and Gupta 1971; Vasanthy, 1988) (Fig. 8.1). These evidences could even be suggested supportive of Ranganathan's biclimax hypothesis.

Footing on an altogether different logic, Meher-Homji (1965, 1967, 1969) reiterated the view that the high altitude grasslands together with their ligneous vegetation, the shrub savanna, represents a climax vegetation. He conceived that the ligneous vegetation of tropical hill stations (like Nilgiris and Eravikulam) as a conglomeration of a tropical type (the native shola forest) and a temperate type (the shrub savanna containing ligneous elements like Rhododendron). The shrub savanna has a wider ecological amplitude and is able to survive exposure to sun and cold alike, while the shola forest tree species which are of tropical origin fail to do so and therefore are unable to invade the grasslands. Palaeopalynological studies of Vasanthy *et al* (1980) have shown that the shrub savanna has a history running back to 6000 years B.P. and following Meher-Homji (1965), Puri *et al*, (1989) draw this finding as proof of the stability of the shrub savanna, and consequently of the grasslands.

If we follow Meher-Homji's (1965, 1967, 1969) arguments more closely, it is not difficult to see that it sounds: the shrub savanna, 'the temperate equivalent vegetation', is the climax vegetation in the effectively temperate climate' of the tropical hill stations. Therefore the theory is identical to Ranganathan's (1938) hypothesis of the role of frost in the stability of grasslands.

In view of the fact that two ciimax vegetations (shola forests and grasslands) for one at the same geolocation is untenable, Bor (1938) refuted Ranganathan's hypothesis and proposed a biotic subclimax status to the grasslands, largely owing- to fire. Many subsequent investigators, Sankaranarayan (1958), Gupta, (1960, 1971), Gupta and Sankaranarayan (1970) and Chandrasekharan (1962a, 1962b, 1962c, 1962d), and Vishnu-Mitre and Gupta (1971) subscribed to this view.

1.8 Objectives

The fact that the conflicting views on the ecological status of the grasslands of the Western Ghats have emanated management issues. As a matter of fact, the main objective of the project was to conduct vegetation ecological studies and to make a meta-analysis ofthe facts to arrive at a logical conclusion on the ecological status of the grasslands with special reference to Kerala.

The specific objectives ofthe project were:

1. To study the structure and composition of the plant populations in grasslands. ecotones and the forests.
2. To understand the dynamics of plant populations in grasslands and forests. and
3. To understand the relationship of soil properties and climatic parameters of the vegetal types: the grasslands and the forests.

CHAPTER 2. THE GRASSLANDS OF KERALA

2.1 Introduction

The term 'grasslands' always casts an image of a landscape dominated by graminoid plants, or where a significant component of the vegetation is of graminoid plants. As generally understood, the grassy composition should be more than 2 percent of the vegetation (Gillison, 1983; Specht, 1981).

Although the term grassland is of cross-continental usage, grasslands as a vegetation differ very much in their composition, physiognomy, specifics of geomorphology and soil structure, moisture regime, the geocordinates (Iatitude, longitude and altitude) and history. As a matter of fact, different terminologies exist for the grasslands (Table 2.1).

Table 2.1. Terminologies in different approaches to classification of grasslands.

1. **Physiognomic terminologies:** grassland, savanna *(incl.* woodland savanna, tree savanna, bamboo savanna, shrub savanna), steppe, *etc.* (Gillison, 1983; *cf.* Puri *et al.,* 1989; Blasco, 1971).
2. **EIevationaI terminologies:** low elevation, moderate altitudinal, high altitudina1, *etc.* *(cf* Blasco, 1971; Sreekumar and Nair, 1991).
3. **Moisture regemic terminoiogies:** xerophilous, mesophilous, and hygrophilous *(cf.* Puri *et al.,* 1989; Sreekumar and Nair, 1991)
4. **Compositional terminologies:** denoted by grass and ligneous elements making the vegetation (Dabadghao and Sankaranarayan, 1973; Puri *et al.,* 1989)
5. **Successional terminologies:** secondary, climax and degraded (Bhimaya *et al.,* 1966).

Very much in parallel with the typology of forest vegetations, there is no universally accepted hierarchically organized classification for the grasslands too. The classification of Indian grasslands also suffer from this.

2.2 Typology of the grasslands of Kerala

According to the nation-wide classification of the Indian grassland covers by Dabdghao and Shankaranarayan (1973), the peninsular Indian grasslands belong to the Schima-Dicanthium type. Grasslands of Kerala also belong to this broader category. Not all the grass covers found in Kerala however is accomplished within the above compositional cover, especially the high altitude ones (cf Karunakaran *et al.,* 1997).

Coming to the context of Kerala, one of the earliest works available on vegetation types of the State is that of Chandrasekharan (1962a, 1962b, 1962c, 1962d). The proposed classification by and Iarge followed the general scheme of Champion (1936) and accordingly he did not differentiate the different kinds of grasslands by species composition. Chandrasekharan (1962a) recognised the grasslands of Kerala into (1) that occurring elevations < 1200 m asl, and (2) that occurring elevations > 1200 m asl.

Later when he expanded the classification (Chandrasekharan, 1962b), he recognized grasslands as successionally secondary vegetation types in each of the major vegetational groups. Thus the I S_6 Low level grasslands belonged to the Tropical Wet Evergreen forest formation, II S_1 Moist Savanna represented the grassland counterpart of the Tropical moist deciduous forest formation, the 111 S_1 The dry Savannahs were characteristic of the Tropical dry deciduous forest formation, and the V S_I The high level (montane) grasslands of the montane temperate forests.

Blasco (1971) who was the first to make a detailed study of the grasslands of the South Indian states indeed recognized three elevational types within which were the floristic types interwoven. This account includes the grassland types found in Kerala too.

Sreekumar and Nair (1991) who made a taxonomic study of the grasses of the State although recognized only two elevational types, recognized the moisture regemic categories described by Puri *et al.* (1989), and added a few more floristic types, in addition to the floristic communities described by Blasco. When the above types are meshed to make a composite classification for the grasslands of the State, it includes eight different floristic communities inhabiting areas of larger extent (Table 2.2), in which many other successional, ecotonal, or degradation types exist.

Table 2.2. Grassland vegetation types recognized from the Kerala State.

1. LOW LEVEL GRASSLANDS Sreekumar & Nair (1991)

1.1 Hygrophilous Grasslands Puri et al. (1989)
= Wet grasslands Sreekumar & Nair (1991)

1.1.1 Eriochloa-Paspalum-Panicum-Brachiaria comm. Sreekumar & Nair (1991)
<= msl, > 2,200 mm rain yr^{1}. eg.: 1. ALLEPPEY DT.: R-Block and Chithira Martthandam. 2. ALLEPPEY DT.: Low lands reclaimed from Vembanad lake. 3. KOTTAYAM DT.: Low lands reclaimed from Ashtamudi lakes of Kottayam and Kayamkulam area

1.1.2 Zoysia-Cynodon-Paspalum-Sporobolus comm. Sreekumar & Nair (1991)
= msl, > 2,200 mm rain yr^{-1}. eg.: QUILON DT.: Coastal margins of Vhavarn, Needndakara and Munrothuruthu. TRIVANDRUM DT.: Coastal margins of Veli.

1.2 Xerophilous Grasslands Puri et al. (1989)

1.2.1 Cymbopogon flexuosus-Aristida hystrix-A. setacea comm. Blasco (1971)
= Cymbopogon flexuous type Blasco (1971)
< 800 m asl, 500-1,000 mm rain yr^{-1}, mean temperature of the coldest month > 20° C, always with a shrubby or small tree growth of species like: Zizyphus oenoplia, Dichrostachys cineraria, Sapindus emarginatus, Atalantia monophylla.

Table 2.2. Grassland vegetation types recognised from the Kerala State (contd.)

2. MODERATE ALTITUDE GRASSLANDS Blasco (1971)

2.1 Themeda cymbaria-Cymbopogon comm. Blasco (1971)
> 800-1,900 m asl, > 1,000-3,000 mm rain yr^{-1}.

2.1.1 Tree Savanna Blasco (1971)

2.1.1.1 Anogeissus latifolia- Pterocarpus marsupium- Bridelia retusa- Terminalia chebula- Phoenix humilis comm. Blasco (1971)

Diagnosis: Differing from the Pterocarpus marsupium-Phyllanthus emblica-Phoenix humilis-Zizyphus rugosa comm. in the presence of the tree species, Anogeissus latifolia and Terminalia chebula in the savanna.

> 800-1,900 m asl, 1,000-2,500 mm rain yr^{-1}, lowest minimum temperature +9° C. Distr.: Mostly restricted to the eastern slopes of Western ghats. eg. IDUKKI DT.: Upper reaches of Chinnar WLS.2.1.1.2 Pterocarpus marsupium Phyllanthus emblica-Phoenix humilis-Zizyphus rugosa comm., comm. nov.

Diagnosis: Differing from the Anogeissus latifolia-Pterocarpus marsupium-Bridelia retusa-Terminalia chebula-Phoenix humilis comm. Blasco (1971) in that, here the tree species, Anogeissus latifolia and Terminalia chebula are absent in the savanna.
> 800-1,900 m asl; > 2,000-2,500 mm yr^{-1}, grass bunches ±160 per 100 m^2, 1.5-2 m tall, tree stratum 15-20 m tall. Distr.: Mostly restricted to the western slopes of the Western ghats. eg. :PALGHAT DT.: Lower reaches of Silent Valley and Attappady.

2.1.2 Shrub Savanna Blasco (1971)

2.1.2.1 Chqsopognon zeylanicus-Phlebophyllum kunthianum-Viburnum coriaceum-Rhodondendron nilagiricum comm. Blasco (1971)
> 1,400-1,900 asl; > 1,000-1,800 mm yr^{-1} ?,ligneous layer only 3-4 m tall, often coionised by the bracken fern, Pteridium aquilinum the soils, and Phlebophyllum kunthianum on shallow soils; the common shrubs are Hypericum mysorense, Mahonia grahamiana, Viburnum coriaceum, *etc.* eg.: IDUKKI DT.: Foot hills of Mannavan shola

3. HIGH ALTITUDE GRASSLANDS Blasco (1971)

3.1 Chrysopogon zeylanicus-Arundinella vaginata comm. Blasco (1971)
= Chrysopogon zeylanicus-Eulalia phaeothris comm. Sreekumar and Nair (1991)
> 2,000-2,200 m asl, > 2,500 mm rain yr^{-1}, grass layer 90-110 cm tall, lowest minimum temperature -5(-10) ° C. eg.: IDUKKI DT.: Hamilton plateaux of the Eravikulam National Park.

comm. - community.

In depth study of the high altitude grasslands of Eravikulam was made by Karunakaran *et al.* (I 997). These investigators have drawn attention to the typological complexities involved in the classification of the high altitude grasslands. Apparently, different authors who have studied these grasslands offered different species compositional names: (1) *Chrysopogon zeylanicus-Arundinella vaginata* comm. (Blasco, 1971), (2). *Eulalia phaeothrix-S. nervosum* comm. Rice (1 984), (3) *Chrysopogon zeylanicus-Eulalia phaeothrix* comm. (Sreekumar and Nair (1991). These differences seem largely due to the differences in the intensity and extent of the area of study by the investigators, the difference in criteria employed, and reflect the dilemma of vegetation typology as a whole.

Karunakaran *et al.* (1997) have come up with a list of 23 species association but the over all dominance has been shown to be in favour of *Chrysopogon zeylanicus* and *Schima nervosum.* Out of the 23 associations, seven of them contain one or more species of shrubs and are also referable by the physiognomic term shrub savanna, or intermediate between shrub savanna and the grassland. The rest, 16 associations are dominated by grasses and or cyperaceous members. The associations described by them are given in Table 5.20.

2.3 The Wet Grasslands

At least some portions of the swampy, marshy and coastal niche lying below the mean sea level (commonly called the 'cole lands') of Kuttanad and Alleppey perhaps were wet grasslands, reclaimed since early 20th century for rice cultivation. In some areas, the wet grasslands might have been converted for the aquafarming of shrimps and prawns, especially in the near past. Some areas adjacent to townships were also restored for the purpose of settlements and some times for industrial purposes. The wet grasslands are practically untouched by forester's activities and is no concern for the present study.

2.4 The Dry Grasslands

Accountable extent of dry grasslands with sporadic patches of scrubs sprinkled here and there exist along the lateritic rocky hillock plateaux at Thalimparamba, Kasaragod, Bendadukka, Chelanoor and Lower Wynad. At least the major share of these grasslands are joint community properties maintained under the pressure of grazing. These grasslands are also in various stages of degradation.

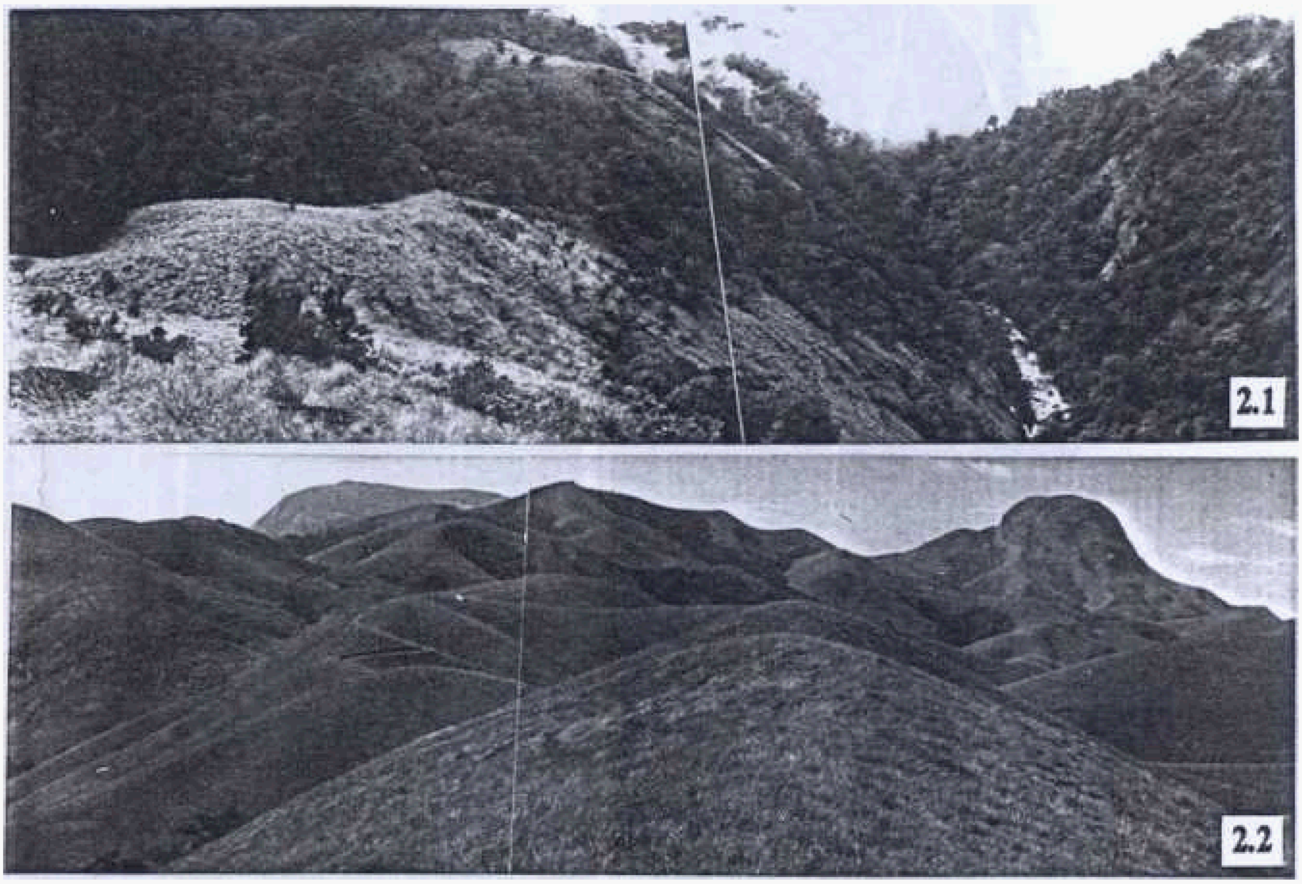
The low elevational dry grasslands of the eastern lee-ward slopes of the Western Ghats are of very limited extent in Kerala, as exemplified by that found in the Chinnar Wildlife Sanctuary. These savannas are more of the nature of sparsely wooded dry deciduous and scrub jungles mutilated by fire and continuous grazing. Because of smaller extent, highly unproductive soil and low precipitation (500-600 mm yr^{-1}), they are less suitable for any silvicultural operation.

2.5 The Moist Grasslands

Excluding the above grassland formations in the State, the potential grasslands that can be thought of for transformation to woodlands of desired species are the medium elevational (Fig. 2.1) and high elevational grasslands (Fig. 2.2); where the edaphic and pluvial conditions might support a plantation activity.

The tree savannas constituting the medium elevational grasslands exist along the eastern slopes of Western ghats in Wynad and Idukki Districts, and along the western slopes in Silent Valley and many other Forest Divisions. Vast expanses of high altitudinal grasslands exist along the upper reaches of the mountain ranges of Idukki and lesser extent in Palghat, to Pathanamthitta and Trivandrum Districts.

The medium elevational grasslands exist largely as smaller enclaves on hill crests and steep slopes as enclaves of a few hectare, within the evergreen forest stretches (Fig. 2.1). In broader sense, the high elevational grasslands like those Eravikulam are also bigger grassy enclaves. These grasslands are restricted to geomorphically elevated plateau complexes (Fig. 2.3) which represent the rocky landmass that resisted weathering. The plateau grasslands are



Figures 2.1-2.2. Grassland landscapes in the Western Ghats. Fig. 2.1. The low elevational grasslands in Silent Valley National Park. Along medium elevations, the grasslands are smaller enclaves distributed within the forest stretches, often restricted to hill mounds and steep slopes. Fig. 2.2. The high elevational grasslands of Eravikulam National Park, with the Anai mudi peak (2,685 m gms1, the highest peak south of Himalayas) in the background. The patchy shola forests are sprinkled here and there, being restricted to the troughs and valleys between the hi1 locks and are mostly associated,withstreamlets and the patches are noway continuaus. The vast expanse of the grasslands at high elevations with the sandwitched little shola forest patches presents a landscape just reverse of the medium elevations (also compare figures 5.38 and 5.39).

2.3

2.4

Figures 2.3 & 2.4. Vegetal landscapes of the high elevational belt. Fig. 2.4. The plateau of the Mukurti National Park (Tamilnadu) with its rolling grasslands. The ridges which support the plateau belong to the New Amarambalam Reserved Forest (Nilambur, Kerala) which are clothed with dense evergreen and subtropical hill forests. In the plateau there is no continuous forest but only patchy sholas. Such plateau grasslands are known Prom Tropical America and Africa, south of the equator, and are suggested to be edaphic climaxes. For details see Chapter 8. Synthesis. Figure 2.4. A picture of the western aspect of the Eravikulam National Park (±2,000 m as1 showing the continuity of the subtropical hill forests and the patchy shola forests. The densely clothed ridge on the foreground of the landscape shows the evergreen forests belonging to the Malayattoor Forest Division. As the arborescent vegetation enters into the high elevational grasslands, they turn out to be in patches and takes the shape of a mosaic ecotone.

surrounded all around by the vast forest stretches; by the moist deciduous, evergreen, subtropical hill forests and shola forests along the windward side (Figs. 2.3 & 2.4) and by dry deciduous forests, moist deciduous forests and the shola forests on the leeward side of the Western Ghats.

Only moist grasslands belonging to medium and high elevations were studied in the present attempt. The focus of study was the general trends of dynamics and succession leading to generation of facts about the ecological status of grasslands as a whole. and therefore not centered around given species compositional types of grasslands.

CHAPTER 3. AREA OF STUDY

3.1 Introduction

The questions concerning the stability and ecological status of the grasslands along the Western Ghats is a complex one. The problem is that, should one consider all the grasslands along the length and breadth of the Western Ghats as identical? In other words, do all these grasslands belong to the same kind? If only they belong to the same kind, could the results be applied universally; else the studies have to be conducted in location specific sites and the results applied accordingly.

The answer to the question posed is not affirmative. There exists considerable variation in grasslands across altitude, latitude and with respect to the windward and leeward aspects of the Western Ghats

The grassland vegetation of Kerala can be recognised into eight floristic types falling in three elevational and three physiognomic types (Table 2.2). Within each of these types, can be recognized various edaphic, moisture regime and other successional stages. Studies on each of these categories although is desirable in answering the ecological question concerning the successional status, is both time consuming and exhaustive. In order to tackle the difficulties, a two fold study was organized: (1) reconnaissance field studies were conducted at several locations preponderant in grassland vegetation so as to gather a general picture of the patterns of succession taking place in the grassland, (2) the reconnaissance studies were reinforced by location specific studies to understand the specifics of vegetation dynamics involved in the successional processes. The locations for these studies were identified based on the observations of the reconnaissance study.

3.2 Areas of reconnaissance study

Reconnaissance field visits were conducted in a number of grassland areas. These visits were also aimed at generating some information on the history of the grassland vegetation. The areas thus visited include the following:

1. The Mukurthi National Park, The Nilgiris Dt., Tamilnadu
2. The Eravikulam National Park, Idukki Dt., Kerala
3. The Silent Valley National Park around Sirandhri and Cheriya Walakkad region, Kerala.
4. The Chinnar Wildlife Sanctuary and Idukki Dt., Kerala, and
5. The Vallakkadavu Grassland Afforestation Division, Kerala

Figure **3.1** is a map of Kerala which shows the location of the study areas.

3.2.1 The Mukurthi National Park

The Park falls within the North Coimbatore Division of the Tamil Nadu State. It is an extension of the Nilgiris Plateau, dominated by high elevational rolling grasslands and patchy shola forests sheltered in vallies and depressions. It lies adjacent

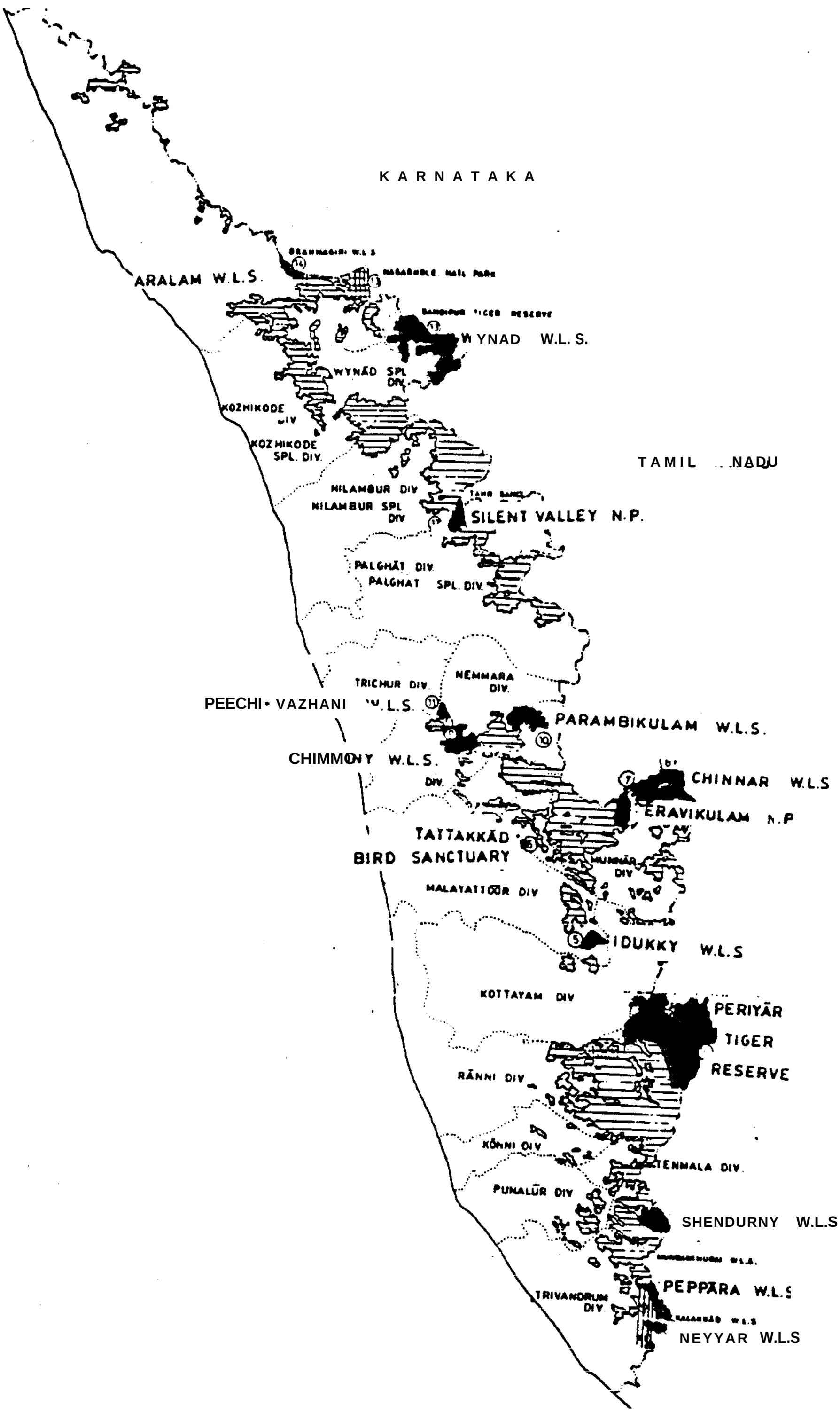


Fig. 3.1. Map of Kerala showing the location of study areas, the Silent Valley National Park, Eravikulam National Park and Chinnar Wildlife Sanctuary. The Mukurti National Park belonging to Tamilnadu is not shown in the map, but its location can be made out easily, being adjacent to the Silent Valley National Park. The Vallakkadavu Grassland Afforestation Division belongs to the Periyar Tiger Reserve and the latter is shown in the map.

to the Silent Valley National Park and the New Amarambalam Reserve Forests of Nilambur. The grassland continuum is comparable to that of the Eravikulam National Park (Kerala State) with resident populations of Nilgiri tahr.

The Mukurthi Nation Park was traversed from Oottacamund via Avalanche, making a cross sectional trek running from Bangitapal to Anchida, a border area between Silent Valley National Park and Mukurthi National Park. Descriptions of some of the shrub ecotones and grassland mosaics are based on observations from Mukurthi National Park, in addition to that of Eravikulam.

3.2.2 The Eravikulam National Park

Supporting Annaimudi,. the highest peak in South India, the Eravikulam National Park (Fig. 3.3) stretches as a plateau of rolling grasslands and shola forests sharing adjacent with the Chinnar Wildlife Sanctuary (Kerala) and the Indira Gandhi Wildlife Sanctuary (Tamil Nadu). Having selected as an area for location specific studies particulars of physiography, climate, vegetation, etc, are given in detail subsequently.

Most of the descriptions of vegetal mosaics of high elevational grasslands are derived from studies in Eravikulam National Park. So also, the results on vegetal dynamics of these grasslands are derived largely from Eravikulam.

3.2.3 The Silent Valley National Park

Of the two National Parks of the State, Silent Valley (Fig. 3.2) is the one that has a historical importance in taking the Indian conservational scenario to the international canvass. On the lower reaches of the sanctuary are many mid-elevational grassland are patches distributed, which were once under the continued influence of forest fire. At Walakkad, the park holds some grasslands of secondary origin, having derived from forestland cleared for tea plantation which did not succeed however. On the northern higher reaches some patches of high elevational grasslands exist, adjoining the Mukurthi National park. Physiographic and other geospatial details are described subsequently.

Most of the studies on vegetation dynamics of the mid- elevational grasslands were conducted in Silent Valley. Accounts of primary succession of midelevational grasslands are based on grasslands of Sirandhri, Pulippara and other areas adjoining the abandoned dam sight. Descriptions of secondary succession of the forests leading to grasslands and back, of the midelevational forests are based on the grasslands of Walakkad.

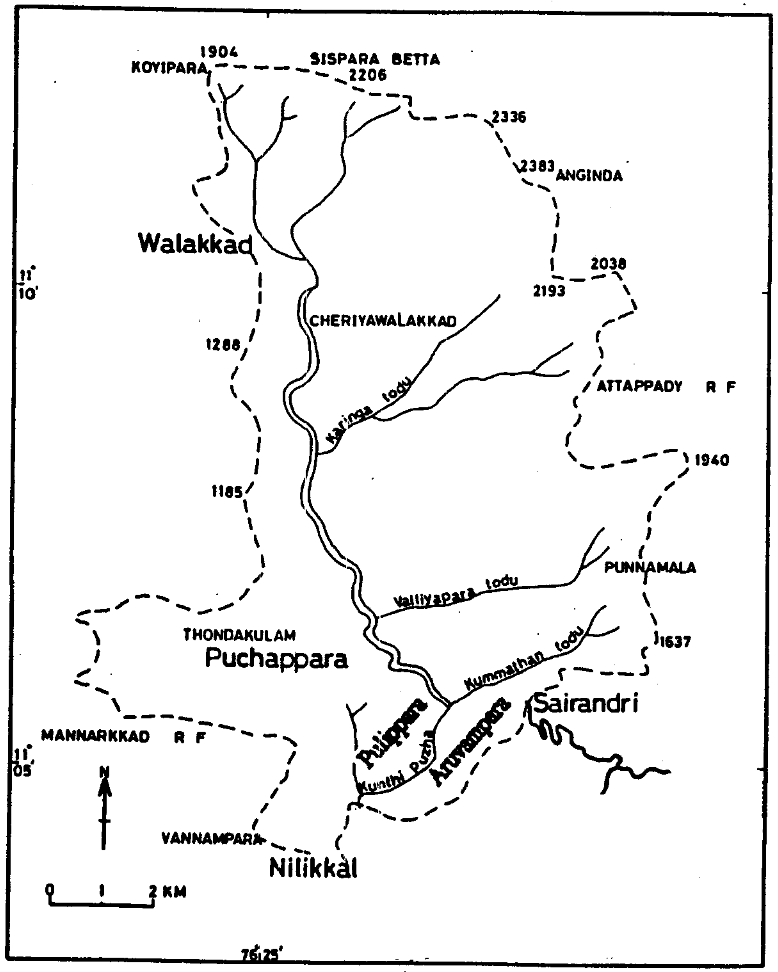


Fig. 3.2. A slightly enlarged map of Silent Valley National Park showing the study sites: Pulippara, Aruvampara, Sirandhri, Walakkad, Anginda, etc.

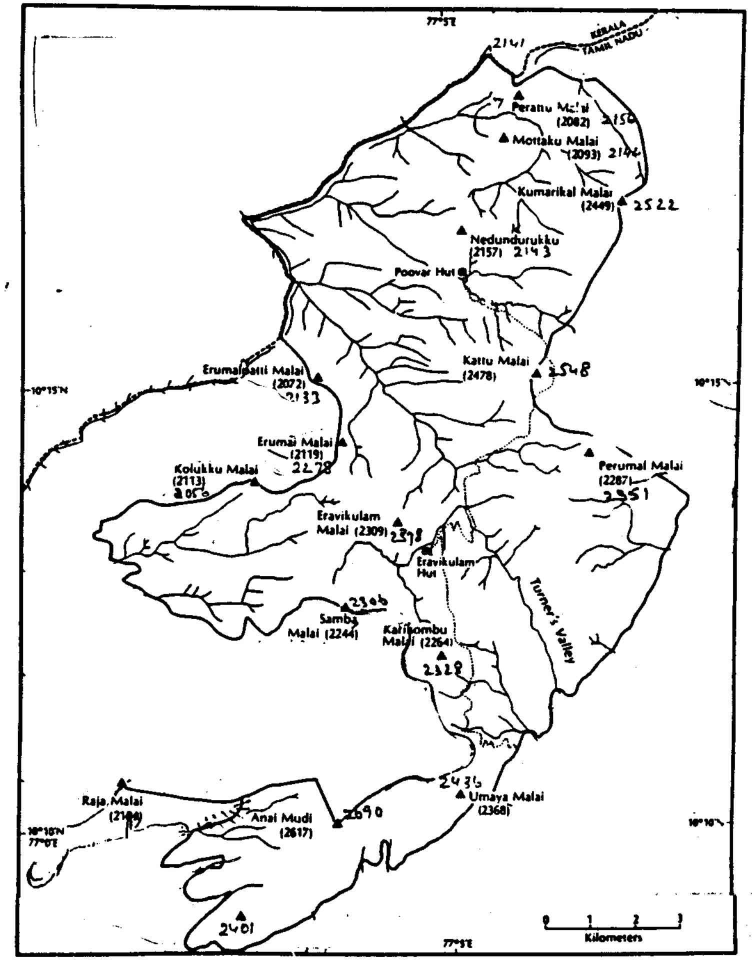


Fig. 3.3. A slightly enlarged map of Eravikulam National Park showing the study sites which are largely clustered around Umayamalai and the Eravikulam hut.

3.2.4 The Chinnar Wildlife Sanctuary

The Chinnar Wildlife Sanctuary (Idukki Dt.) is located adjacent to the Eravikulam National Park on the leeward rainshadow side of the Western Ghats. The natural grasslands are subject to fire and composed of Themeda-Cymbopogon community at medium elevations, mostly in the form of savannas, *ie*, sparsely interspersed with trees. Cymbopogon citratus (lemon grass) is cultivated throughout the sanctuary except at low elevations, almost in the pattern of shifting cultivation.

Some selected observations on successional patterns are derived from reconnaissance studies conducted here.

3.2.5 The Vallakkadavu Grassland Afforestation Division

Along the Ponnam- balamedu of Sabarigiri (Idukki Dt.) and the Vallakkadavu Grassland Afforestation Division, grasslands are tall growing to a height of 3-3.5 m, and composed mainly of Themeda-Cymbopogon community. There has been attempts to afforest the grasslands with Eucalyptus grandis.

3.3 The areas of location specific study

The vegetation dynamics of the successional processes were studied at two specific locations, the Silent Valley National Park and the Eravikulam National Park. Details pertaining to the locations are described below.

3.3.1 The Silent Valley National Park

Physiography

The Silent Valley National Park, is one of the remaining pristine wilderness habitats of high woods and rare zoological and botanical curiosities in the State. Situated in the Palghat District, Kerala, between latitudes 11°05' and 11°25' N and longitudes 76°21' and 76°33' E, the entire stretch of the Park an area of ca. 90 km^2 (89.52 km^2). The Park occupies is composed of a number of ridges rising from the general elevation of the main stream of a river (which later forms the Kunthipuzha) at about 1,000 m asl to a height well over 2000 m asl. The tallest peak, the Anginda, bordering the North, tower to an elevation of 2,383 m asl and is continuous with the plateau of the Nilgiris. Along the northwest, the Nilambur Forest Division, in the east the Attappady Reserved Forests, along the South, border the Park and the vested forests of Nilambur and Palghat Forest Divisions. The water from the forest tract drains into Kunthipuzha (a tributary of Bharathapuzha) and waters the plains of the Mannarghat Valley (Fig. 3.2).

Geology and Soil

The rocks have been traced to the Archean complex, belonging to foliated gneisses or grantoid gneisses and granites (cf Manilal, 1988). The forest soils are of loam and strongly acidic with a mean pH value ranging between 5.1-5.4, the mean organic carbon (OC) range between 20.64 and 23.42 g/kg, and total N between 1.08-1.47g/kg (Balagopalan, 1990).

Climate

The annual pluvial average is over 5,000 mm (Singh *et al.*, 1984a) and is contributed both by southwest and northeast monsoons. Over 80% of the rain is received during the southwest monsoon (June to September), 12% is contributed by northeast monsoon (October to December), 6% through pre-monsoon thunder showers (during May) and the rest (2%) is received during the dry season (Kerala Forest Research Institute, 1990).

The diurnal thermometer records show an amplitude of 22º C, with the following variations. Highest maximum: 30º C; Lowest minimum: 8º C; Mean annual temp: 20.2º C. The dry season extends between February and May, the hottest months being April and May, and the cooler months, December to February. Atmospheric humidity for most part of the year remains well over 95%.

The vegetation

The vegetation is a confluence of tall West Coast tropical evergreen forests, subtropical broad leaved hill forests, the stunted montane wet temperate forests (shola forests) and the mid elevational and high elevational grasslands. Typologically the different forests from a sylvan continuum across the elevational gradients with the low elevational grasslands often forming graminoid landscapes around rocky formations, steep slopes, etc, and the high elevational grasslands inhabiting the cooler hillocks.

Reiated Studies

A detailed account of the flora of the Park is available through the pioneering study of Manila1 (1988). aspects of vegetation and ecology were studied by Aiyar (1935). Basha (1987); plant population structure by Balasubramanyan (1990) and Singh *et al.*, (1984b) and animals by Vijayan & Baiakrishnan (1977), Ramachandran, (1990)and Jayson, (1990)andMathew, (1990).

Present studies

In the Silent Valley National Park, the studies were restricted to the moist, mid elevational grassland- wet evergreen forest continuum, as the high elevational forest-grassland system are located at remote and less accessible regions.

3.3.2 Eravikulam National Park

The Eravikulam National Park is situated in the Idukki District at an average elevation of 2,100 m asl, between the longitudes 10º5' N and 10º20' S, and 77º E and 77'10' E latitudes. Peaked by Anamudi (2,695 m), the highest peak in south India, the Eravikulam National Park can be considered the literal roof of the Western Ghats.

On the north, it is bordered by the Anamalai Sanctuary (Tamilnadu) and south by the the Tata Tea Estates and the west by the Malayatur Forest Division and East by the Chinnar Wildlife Sanctuary and the Munnar Forest Division (Fig. 3.3).

Geology and soil

The rock formations in the region have been dated to the Archean igneous series consisting of gneiss (Koshy, 1970), with minerals like silica, feldspars, nuscovite, biotite etc. (cf Karunakaran *et al.*, 1997). The soils are basically loamy, acidic and with high content of organic carbon (often in the form of peat in grasslands) and nitrogen.

The Climate

The rainfall is over 5,200 mm per annum. As in the Silent Valley National Park, this pluvial quantum is contributed by SW and NE monsoons but remains unimodal in a graphic representation (Jose *et al.*, 1994). The high rainfall swathed with fog and chilly winds make the rainy season very hostile. The elevated position of the Park (average 2,000 m) has a remarkable influence on the atmospheric temperature, the thermometer readings being pushed down to a cooler climate compared to the valleys and downs.

The absolute diurnal temperature oscillates between -3 to 27^{o} C. The mean maximum temperature is found to be 15.3^{o} C, and the mean minimum -3°C (Rice, 1984). January is the coolest month and May the warmest.

The Vegetation

The Park is a refugium of various plant and animal lifescapes of higher elevations in the peninsula. In addition, the park also subtends smaller extents of subtropical hill forests in some portions of the foot hills where the elevation is low. The grasslands also refuge scrublands dominated by Phlepophyllum kunthianum, the massive population of which displays the hillocks as a magnificent floral carpet appearance when it flowers gregariously in an approximate cycle of 12 years. A vegetation map of the park is also available (Menon, 1997).

Animals

The area is renowned for the largest population of surviving Nilgiri tahrs (Hemitragus hylocrius). A few studies on their wildlife biology also exist (Rice, 1984; Easa, 1996).

CHAPTER 4. THE VEGETAL MOSAIC CONTINUA

4.1 Introduction

A vegetation according to Whittaker (1951) is not a discrete unit. It is a mosaic of different tonal variations of distribution of different species in accordance with: (1). the mosaics of edaphic and climatic patterns of the environment, and (2). the extent of adaptability, tolerance and inhibition of the species, and (3). the pattern of availability of species in the local segment of the biosphere (ie, geography). The mosaics of vegetation in an area when arranged sequentially in accordance with the available disturbance regimes often enable one to frame a pathway, a model of vegetal succession in operation. Such successional models have been suggested for many vegetation types (Puri *et al.,* 1989). These models are important in the sense that they can throw light on the relative successional status of vegetations.

4.2 Methods

Two methods are generally followed in studying the vegetal succession pathways: (1). by creating disturbed sites artificially, and (2). by observing naturally occurring environmental mosaics which of course include the disturbed habitats. The latter method is adopted here to trace the pathways of succession in the grassland-forest continuum. As the present studies embrace only the medium elevational and high elevational grasslands, pathways have been traced separately for each of these types.

The vegetation types, especially of the grasslands mentioned in this chapter actually represent different seral stages and do not hold the typological status as vegetation types. Except for a few, they do not occupy vast expanses to be reckoned as a vegetal type. Although referred to by the term 'vegetal type' they are more appropriately called 'vegetal mosaics'.

4.3 Results

4.3.1 The general model of grassland succession

When the successional pathways of the medium-elevational and high elevational grasslands have been compared it becomes clear that both follow the same basic pattern and therefore the general model is illustrated in Figure 4.1 and described subsequently

4.3.1.1 Vegetal mosaics on shallow soils

The rocky exposures, where primary succession is in operation, still persist along the mountain tracts. Lichens, mosses, some small orchids capable of inhabiting serpentine rocks and a few grass species grow as primary colonizers and as they weather the rock surface, depending up on the extent of organic debris accumulated, single species associations (consociations) of grasses appear, often in a relay. These early successional grasses gradually give way to typical grasslands where the species composition of course are different, but where the soil is moderately thick. An alternative pathway leading to the grasslands through intermediary herbaceous stage is also likely.

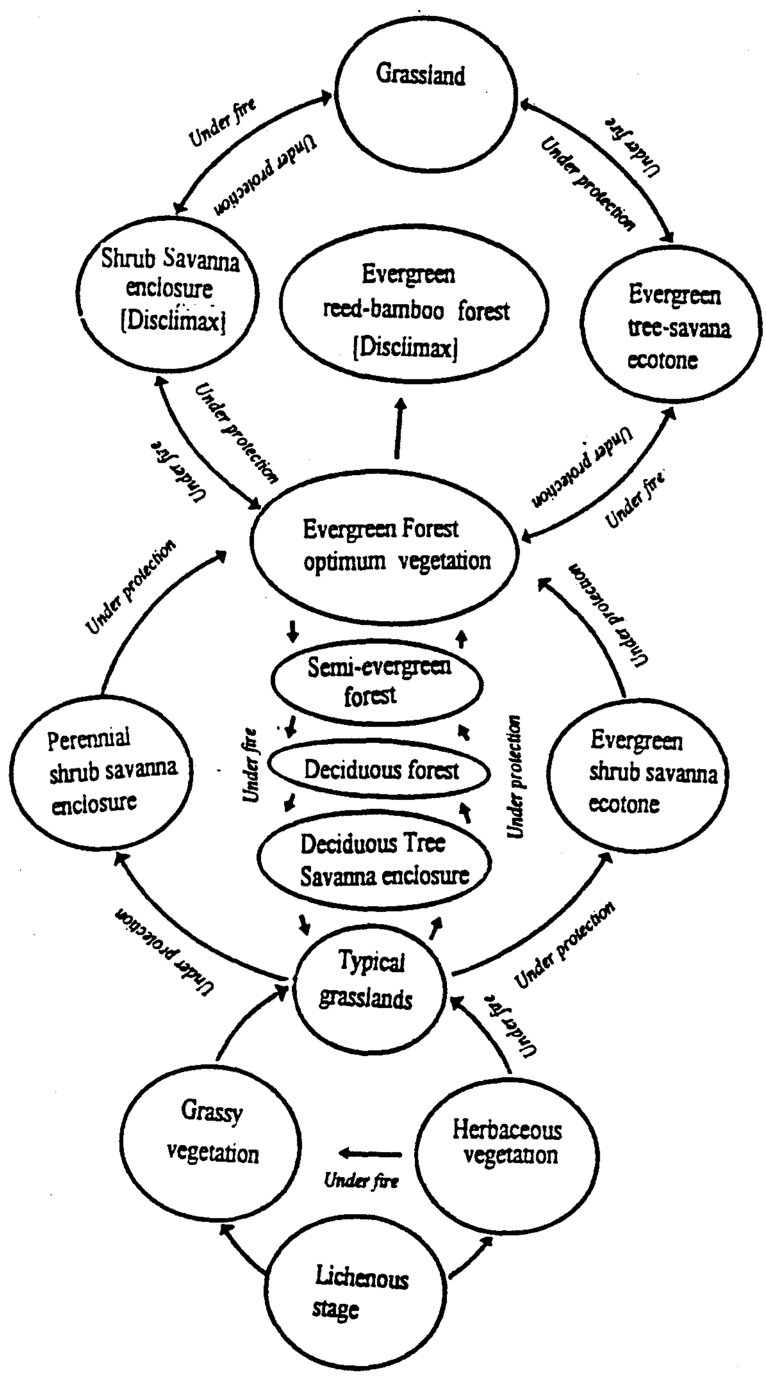


Figure 4.1 Seral sequences in mid elevational and high elevational grasslands of Kerala. The flow chart includes three large circles, the first representing the formation of grassland, the second representing the formation of evergreen forest formation and the third representing the degradation of evergreen forest to disclimax. The essential differences of the flow chart from other forms is that, the ecotonal shrub savanna and tree savanna are distinguished from the shrub savanna and tree savanna enclosures within the grasslands. In ultimate reality, the processes in grassland invasion are one and the same in enclosures as well as ecotones; yet the two are different in species composition and the physiology of the component species. As a matter of fact, the right and the left halves of the chart are not exactly identical. The disclimax circle could have been accommodated within the circle detailing the formation of evergreen forests, but has been depicted as a distinct circle just to amplify the fact that, many of our shola forests are in a disclimax state. The term *evergreen forest* as mentioned in the chart denotes only the phenology and therefore, includes the shola forest too.

4.3.1.2 The apex vegetation

The highest order of vegetation met along both the climatic zones is an evergreen forest holding the highest quantum of living biomass compared to other vegetal mosaics in the area. These sylvan communities also abode high biodiversity both in species and density. Conventional graphic stand structure compositions display an inverse J-shape characteristic of a self perpetuating system through stable regeneration strategies and are certainly referable to the climax in the Clementsian sense.

4.3.1.3 Sera1 stages

Between the grasslands and the evergreen forest two physiognomic types of sylvan development are observable: the shrub savannas and the tree savannas.

4.3.1.4 The shrub savannas (Shrublands)

The shrub savannas are grassy landscapes occupied mostly by evergreen perennial shrubby species. Depending upon their location they may be one of the two types as given below.

1. The shrub savanna enclaves (enclosures) developed within the grasslands.
2. The evergreen shrub savanna ecotones bordering grasslands and the forests.

The shrub savanna of the first category is found within the grasslands either as extensive patches or as enclosures of smaller extent. The shrub savanna ecotone on the other hand is the interface between the grassland and the forest and is the moving front of the forest. Quite often, tree invasion into this ecotone from the preceding evergreen forest is observable. The extensive shrub savanna enclosures are composed of perennial acanthaceous species having seasonal shoot.

Across the shrub savanna mosaics the species composition differs and within each type several compositional types can be identified, each differing in historical, edaphic or microclimatic details. While it is true that compositional differences exist, it is also interesting that remarkable degree of congruence exist in the physiological make up of the species constituting the shrub savanna mosaics across the elevational belts. Some of these enclosures, especially the evergreen ones are capable of furthering succession to an arborescent grove, which ultimately can result in an evergreen forest.

4.3.1.5 The tree savannas

Like the shrub savannas, the tree savannas are also of two locational types: 1. The deciduous tree savanna enclosures developed within the grassland, and 2. the evergreen tree savanna ecotones bordering the forests.

Examination of a large number of these deciduous tree savanna enclosures evince that, apart from the the wide variety of compositional differences, they also vary in density of the arborescent elements, depending upon the age of the tree savanna.

Compared to the shrub savanna and tree savanna ecotones shrub savanna and tree savanna enclosures have a higher potential in advancing the grassland to a forest, as large number of shrub savanna groves can be formed in several loci far and wide within the grassland. However, the exact potential of the enclave mosaics will be determined by the ability of diaspores to reach the prospective loci, in sufficient number.

4.3.1.6 Wooded groves

In isolated locations small deciduous forest groves are also met with. Once the deciduous forest is developed by the growth and coalition of individual deciduous forest groves, the progress towards the evergreen forest climax is possible, through a semievergreen intermediate phase.

The optimal (climax) vegetation, the evergreen forest, is also amenable to retrogression, subject to disturbances like fire, The result is an evergreen tree savanna ecotone if the fire is restricted to the ecotone. If fire embraces the whole tree groves, depending up on the intensity and frequency of fire and chance colonizations, a grassland or a reed-bamboo forest results. The evergreen reed-bamboo forest remains a disclimax, and its further progress into a mixed climax forest is doubtful, as the bamboo growth scarcely allow the arborescent species to expand their population. The evergreen forest on complete burning may result in a shrub savanna or a grassland itself.

As already mentioned in a previous location, the specifics of the general successional model vary and the compositions of the communities also differ along different elevational belts and perhaps across latitudinal and phytogeographic regions. Below are given the observed pathways at moderate elevation (900-1,400 m asl) in the Silent Valley National Park and at the High- elevations (1700-2,100 m asl) in the Eravikulam National Park.

4.3.2 Successional communities in the medium elevation zone (Silent Valley: 900-1,400 m asl; Figures 4.2-4.1 1)

4.3.2.1 Grassy vegetal mosaics on shallow soils

The primeval shallow soil as described above is invaded by a series of grass communities in a relay; these communities are often observed in a centripetal sequence. In their sequence from the center of the rock the communities are:

1. The *Arthraxon* community

This community is made of gregarious growth of a 6-12 cm tall annual grass belonging to the genus Arthraxon (Fig. 4.2). Here the soil is no more than 1-2 cm thick and is made of moss mats and mineral dust.

2. Themeda triandra **community**

This is also a single species community. The grass grows to a height of 30-60 cm tall, is erect growing and the soil is only 5-8 cm thick with the underlying rock (the foreground grass in Fig. 4.3).

4.3.2.2 Grassy vegetal mosaics on moderately thick soils

1. *Eragrostis* community

In troughs between hillocks, where water logging is experienced during the rainy season mosaics of smaller extent, composed largely of a species of *Eragrostis* is met with (Fig. 4.4).

2. Themeda-Cymbopogon-Chrysopogon **community**

.The community generally grows on 30-60 cm thick soils in the depressions, deltas or valleys between hill shoulders (Fig. 4.5). Because of the enhanced soil depth, during the dry seasons, the soil moisture regime here. is slightly better. *Themeda cymbaria, T. sabarimallayana, Cymbopogon flexuosus,* and *Chrysopogon orientale* are the dominant clump forming grasses growing to a height of 1- 1.5 m. The proportion of *T. cymbaria* increases with increasing moisture content and along the grassland ecotones. The trailing grasses are *Ischaemum* sp. and *Themeda tremula.* The dominant herbs include a species of *Crotalaria,* some species *of Blumea, Alysicarpus, etc. This* is the typical grassland along moderate altitudes.

4.3.2.3 Shrub savanna enclosures

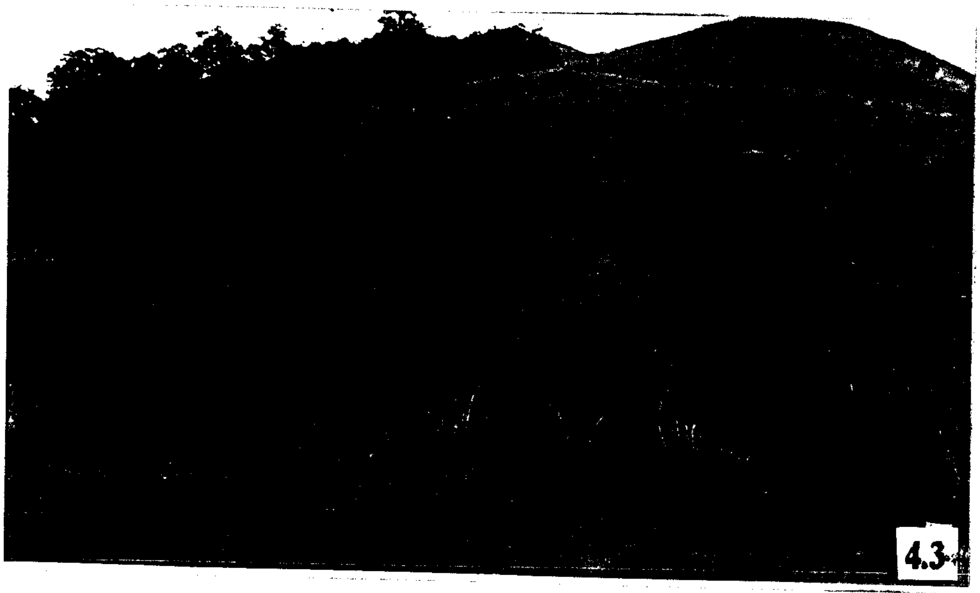
Three communities of different compositions are met with in the grassland as smaller enclosures.

1. The *Pleurocaulis* shrub savanna enclosures

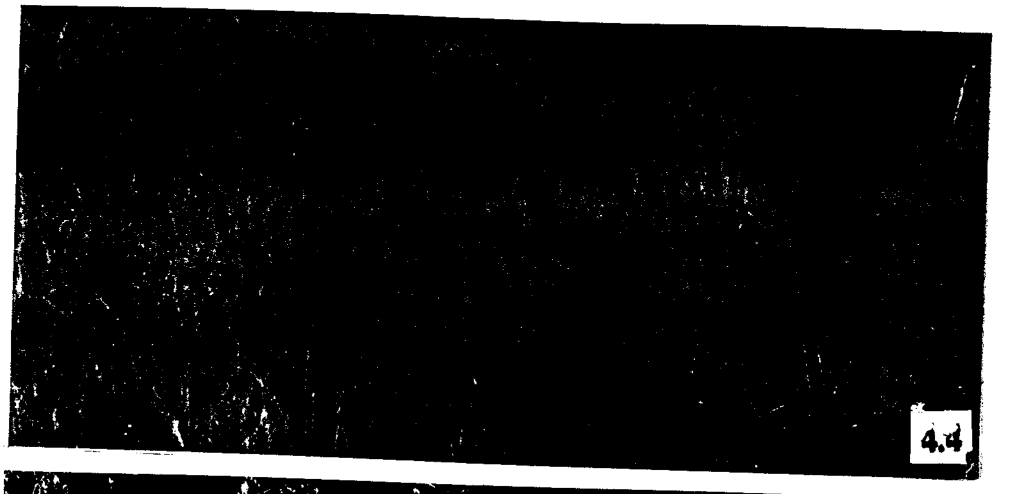
Along the hill shouiders and hill slopes where the soil depth and soil moisture are less compared to the delta and valleys between the hillocks this community finds its place. *Pleurocaulis sessilis.* a caespitose clump forming perennial acanth is mixed with the grasses in equal proportions. This shrub perennates through its horny root stocks, that regenerate every year and flowers very rarely. As many as 350 horny root stocks have been counted in a clump.

2. The *Pteridium* shrub savanna enclaves

Where soil moisture is slightly better, the fern *Pteridium aquilinum* grows in gregarious patches. Because of the creeping underground rhizome, the fern can perennate fire, and because of the poikilohydric nature it can resist drought also effectively. The gregarious



Figures 4.2 & 4.3. Two grassland mosaics of the medium elevational grassland (Silent Valley NP). The *Arthraxon* grassland mosaic. This community grows on primary rock surfaces upon the lichenous and moss crests. Apparently there is very little soil beneath the stands, formed by the decaying organic matter contributed by the lichens and mosses and the disintegrating rock. The stand is only 6-10 cm tall and is an annual. Fig. 4.3. The *Themeda triandra* grassland mosaic (immediately beneath the green patch and on the foreground). The stands grow to a height of 40-60 cm tall and is largely a single species association. The soil is very thin and the parent rock occupies a subsurface position. The green patch represents the typical medium elevational grassland along the windward side of the Western Ghats, the *Themeda-Cymbopogon* association. Here this patch grows on a slightly moist site and therefore keeps green when grasses in all other locations have dried up.



Figures 4.4 & 4.5. Grassland mosaics of medium elevation in the Silent Valley National Park. Fig. 4.4. *Eragrostis* association (on the midground of the photograph in light colour). The site is a location between two hillocks where slight water logging is experienced during the rainy season, where wild animals like gaur come and make mud baths in the water logged clay soil. This vegetal mosaic is also of smaller extent and the soil is with full of pebbles and larger gravels in the subsurface layer, while the surface layer is made of fine silt and clay. The grassy stands surrounding the *Eragrostis* association is *Themeda triandra* association as seen in figures 4.3 and 4.4. Typical *Themeda-Cymbopogon* grassland stand at Valakkad, Silent Valley. The grass stand at flowering is 1-1.5 m tall. Most of the grass panicles seen in the figure are of *Themeda cymbaria*.

nature of the shrub is largely because of the branching subterranean rhizome. Very often the grass *Imperata cylindrica* is also found associated with the fern.

3. The *Maesa* shrub savanna enclaves

Maesa perrottitiana is said to be a fire tolerant shrub, generally found growing along forest ecotones. Occasionally the shrub is found as small gregarious patchy enclaves distinct from the ecotone, but still closer to the ecotone. In these enclaves, the canopy closes and the ground is free of clump forming grasses and regeneration of evergreen tree species take shelter and colonize such enclaves.

4.3.2.4 Shrub savanna ecotones

These communities differ from the shrub savanna enclaves in that they occupy the ecotones which are slightly better than the grasslands in their soil moisture regimes. Two different communities are found.

1. The *Nilgirianthus* shrub savanna ecotone

Here species of shrubby *Nilgirianthus* (acanth) grows gregariously along the ecotone, often growing in strips of 1-2 m wide between the forest and the grassland. There are two variants of this shrub savanna, differing in the species of *Nilgirianthus*. One species is with hispid hairy leaves and growing hardly over 1 m in height, the other is glabrescent but with squarrose and larger leaves and growing to a height of 2 m.

2. The *Maesa-Clerodendron-Leea* shrub savanna ecotone

Here the main shrub component is *Maesa perrottitiana*, growing to a height of 2-2.5 m, in many locations being formed of this single species in a gregarious make up. Occasionally it grows in fair mixture with species of *Leea* and *Clerodendrum viscosum*. The width of the ecotone varies from 1-3 m, reflecting the historical extent of protection available from disturbances.

4.3.2.5 Tree savanna enclosures

Some tree savanna enciosures perhaps do not have an intemediary shrub savanna stage. The tree species of these savannas are mostly of moist deciduous specks, or species that can survive water scarcity. Five different compositional communities have been observed.

1. *Phyllanthus* tree savanna enclosures

This tree species *(P. emblica)* can survive on thin soil bed deposited on rock crevices. The trees unlike in moist deciduous forests are stunted, 3-5 m tall but the tree density is very sparse. The berries perhaps are dispersed by birds and animals, but the hard pyrenes can survive fire. This type of community is met in and around Pulippara in Silent Valley.

2. *Pterocarpus* tree savanna enclosure

Pterocarpus marsupium, a leguminous deciduous tree is found to colonize steep slopes of grassy hillocks where the soil is not deep (Fig. 4.6). The samaras of this species are dispersed by wind. In Silent Valley National Park, there are no moist deciduous forests, yet the Pterocarpus savanna is seen on the western embarkments of the Kunthipuzaha at Sirandhri; the seeds were perhaps transported with the monsoonal winds coming up through the river channel form the moist deciduous forests east of it.

3. The *Phoenix* tree savanna enclosures

Phoenix humilis is an unbranched palm of 10-12 cm thick and growing to a height of 3-4 m. The density of trees although less than that of *Pterocarpus,* are plenty along the Pulippara grasslands especially dong the western banks of Kunthipuzha at Sirandhtri and at Aruvampara (Fig. 4.7). The trees grow on rock crevices, and most of them proxy the history of past fire on the tree trunk. The tree is largely restricted to grasslands closer to the river banks. The same species is represented by a different variety along the river and stream banks in Deccan, a drier belt, compared to Silent Valley. Because of the slightly sweet pericarp, the fruits are eaten and seeds dispersed by elephants. *Phoenix* is believed to be a fire indicator and the hard pyrenes substantiate this.

4. The *Zizyphus-Glochidion* tree savanna enclosures

The tree elements here are *Zizyphus rugosa,* a thorny liana, and *Glochidion neilgherrense,* a short tree. The trees grow to a height of up to 3 m or so. The grassland immediately on the back of the Silent Valley Campsheds 'are typical representatives of this type. Both trees are fairly intermixed and in a 100 m^2 area, there are at least 4 or 5 of them. *Zizyphus* produces white berries and the seeds (pyrenes) are dispersed by means of birds. Occasionally the stands are also mixed with some trees of *Phyllanthus emblica* and *Careya arborea.*

5. The *Syzygium* tree savanna enclosures

Syzygium arnottianum is a moisture loving myrtaceous tree of the evergreen forests. The pulpy pericarp of the berry is eaten both by birds, monkeys and other arboreal animals and are apparently dispersed by them. Trees are large, 60-150 cm in diameter, and 30-35 m tall, and in the grassland they occupy as smaller groups of trees along the sides of streamlets, or as isolated trees where the moisture regime is fairly high. Never the trees form, extensive savanna woodlands. The seeds are dispersed by birds.

4.3.2.6 Forest enclosures

Two physiognomic types are observed: 1. The moist deciduous forest, and 2. Evergreen forest enclosures.

1. The Moist deciduous forest enclosure

The Pterocarpus shrub savanna at Sirandhtri has actually grown into a Pterocarpus moist deciduous forest. In the Chembotty grasslands, near the Bheeman Oda, there is a small mixed moist deciduous forest stand composed of *Dalbergia sissoides* and other moist deciduous species.

A perambulation of tree regeneration in several places shows frequent seedlings or whiplings of *Dalbergia sissoides* and occasional seedlings of *Phyllanthus emblica*, as in the case of the hillocks of Pulippara. An instance of a seedling of Terminalia paniculata, and another instance of a seedling of *Lagerstroemia microcarpa* were also observed in the grasslands of Pulippara. With the inclusion of these, the list of tree species in the tree savanna and woodland enclosure of the moderate elevational grassland at Silent Valley National Park embrace 9 species: *Pterocarpus marsupium, Dalbergia sissoides, Terminalia paniculata, Lagerstroemia microcarpa, Phyllathus emblica, Zizyphus rugosa, Phoenix humilis, Careya arborea,* and *Syzygium arnottianum.*

Eight out of nine species listed above are all moist deciduous species and this evinces that the type of forest that is developing within the grassland as forest enclaves is largely of deciduous trees. If continuous protection exists, several individual forest enclosures may develop as independent patches and may coalesce towards an extended moist deciduous forest in due course of time, where different species associations can be expected depending up on the vagaries in soil and moisture regime.

2. The Evergreen forest enclosures

Although rare, the *Syzygium* tree savanna and the *Maesa* shrub savanna are found to support establish isolated seedlings of evergreen species and might be appropriate to be considered as nuclear to evergreen forest enclosures.

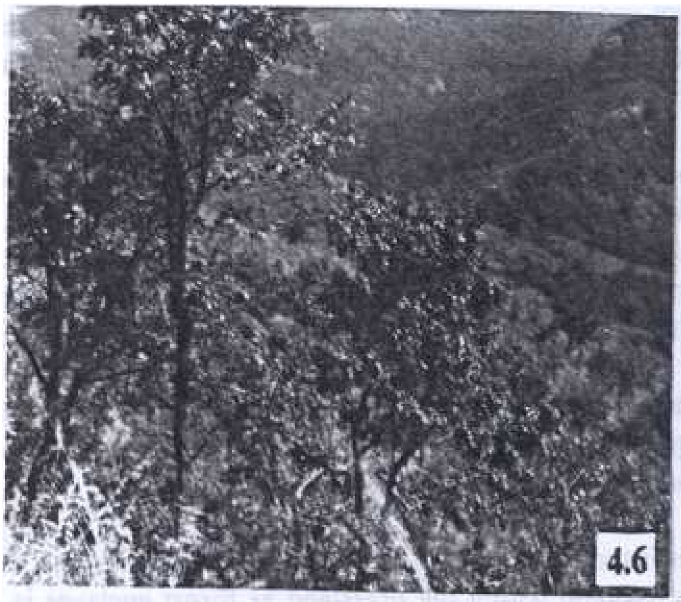
4.3.2.7 Evergreen tree ecotones

Along the margin of the forests, bordering the grassland the ecotone is often composed of evergreen trees of low stature like: *Acronychia laurifolia, Bischofia javanica, Symplocos laurina* and *Clerodendron viscosum.* The compositional specificity of the tree ecotones is less predictable, as the shrub savanna ecotonal front precedes forest advancement.

4.3.2.8 Secondary succession

1. Secondary tree savanna enclaves

At Walakkad, in the secondary grasslands at the failed tea plantation sites, invasion of trees is observed. Where the terrain is flat and soil moisture is high, *Glochidion* tree savanna and along hillocks *Wendlandia* savanna have developed (Fig. 4.8). Other occasional species include *Pterocarpus marsupium, Bridelia squamosa* and *Phyllanthus emblica.*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Figures 4.6-4.8. Different kinds of tree savanna enclosures in the medium elevational grasslands (Silent Valley National Park). Fig. 4.6. *Pterocarpus* tree enclosure in the Pulippara grassland sloping into the abandoned Silent Valley hydroelectric Project site. Moist deciduous forests are practically absent in the Silent Valley National Park. The seed stock of the *Pterocarps* groves in the Park might have come from the Attappady Forests. Fig. 4.7. A Phoenix tree enclave within the grasslands of Silent Val ley (Pulippara). *Phoenix humilis,* the palm is quite frequent in certain locations in Silent Valley especially in the grasslands flanking the two banks of the river at Sirandhri. *Phoenix* is said to be a fire indicator. Along the interior regions of the river the species is scarcely met with. The species is of general occurrence in the grasslands in the eastern slopes of the Western Ghats in Chinnar Wildlife Sanctuary, but is generally absent on the Western Slopes of the Western Ghats. Another variety of the same species is found along the streamlets in Deccan and its phytogeogrraphic and ecological significance as indicator of a drier habitat is evident. Fig. 4.8. A *Wedlandia* tree enclosure at Walakkad, Silent Valley, where the grassland **is** secondary. The evergreen forest was cleared for raising tea plantations. On failure of the tea plantation grasses invaded the land and formed grasslands. *Wendlandia* is a pioneer tree, generally regarded as an indicator of fire.

2. Gulley forest enclaves

Along gullies, which drip off narrow water outlets, species of *Syzygium, Meliosma*, *Symplocos* and some lauraceous members have already formed forest enclaves, and such enclaves in certain sites have advanced fairly to clothe the hillock completely (Figs. 4.9-4.11).

3. The reed-bamboo forests

These are perhaps areas once affected by fire in the distant or near past. Reed-Poeciloneuron forest association at Chembotty and other places are perhaps examples, and might perhaps be a disclimax.

4.3.3 Successional communities in the high elevational zone (Eravikulam; 2,000-2500 m asl: Figures 4.12-4.44)

4.3.3.1 Grassy mosaics on shallow soils

On primary rocky substratum, lichens and mosses are the pioneer colonizers (Fig. 4.12). Moist crests are later colonized by grasses (Figs. 4.13-4.15). Species of *Jansanella* and other grass species inhabit rocky exposures with shallow soils.

4.3.3.2 Grassy mosaics on moderately thick soils

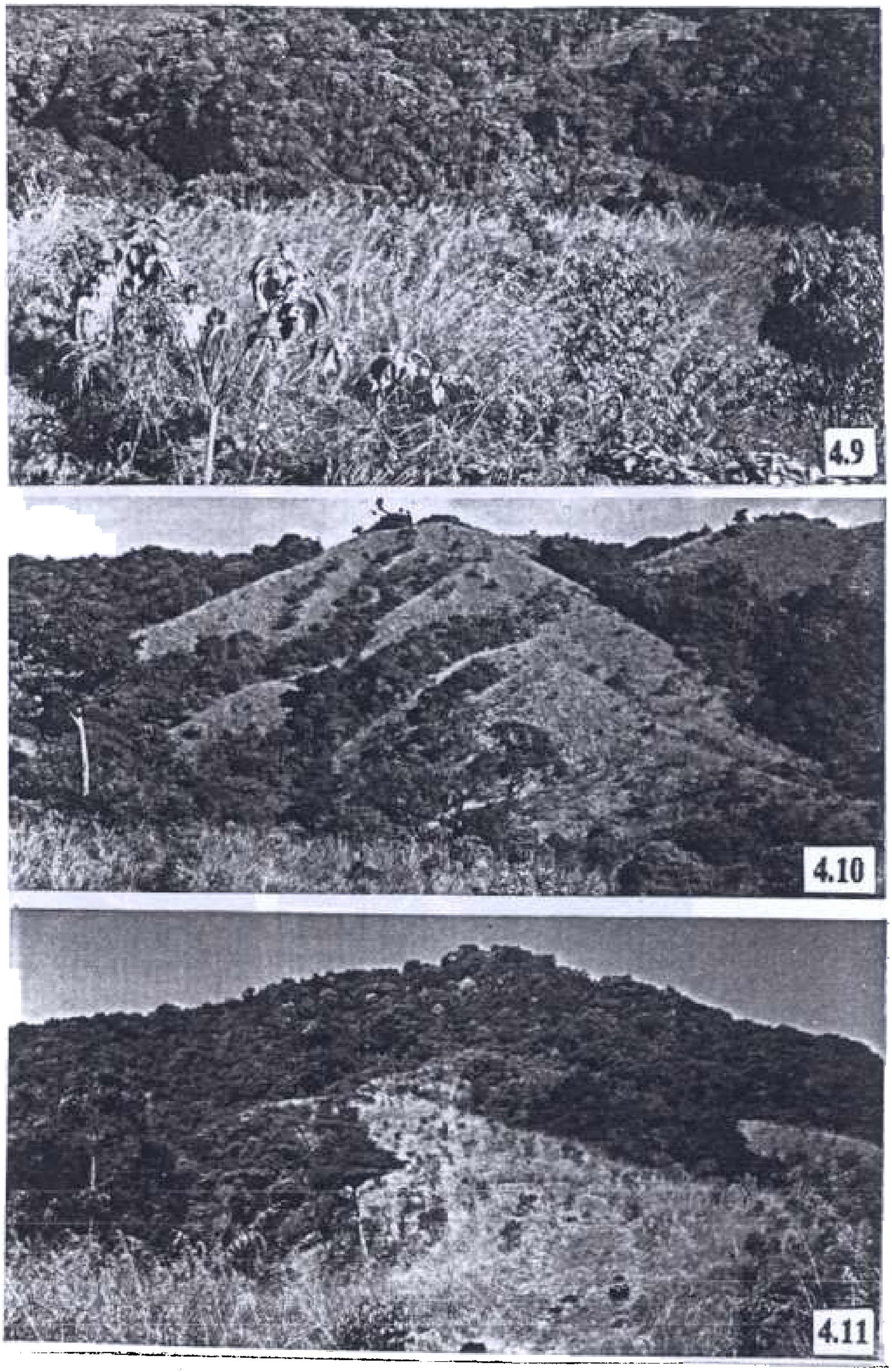
Karunakaran *et al*. (1997) identified 22 species associations in the grasslands of Eravikulam (Fig. 1), some of which according to Meher-Homji (1967) are shrublands. Compatible with the grassland (per se) communities identified by Karunakaran *et al*. (1997), eight macroscopically distinguished species dominations of grassland mosaics were distinguished.

1. The *Eriocaulon robustum-Garnotia tectorum* grassland mosaic

This community characte-ristically grows along troughs between hillocks or slightly flattened troughs where water logging is experienced through a greater part of a year owing to the presence of flowing streamlets (Figs. 4.16 & 4.17). *Eriocaulon robustum* is a non-Poacean clump forming tesseiiate monocot growing to a height of 30-50 cm. *Garnotia tectorum* is a stout grass growing to a height of 1 m or more at flowering with graceful elongate panicles.

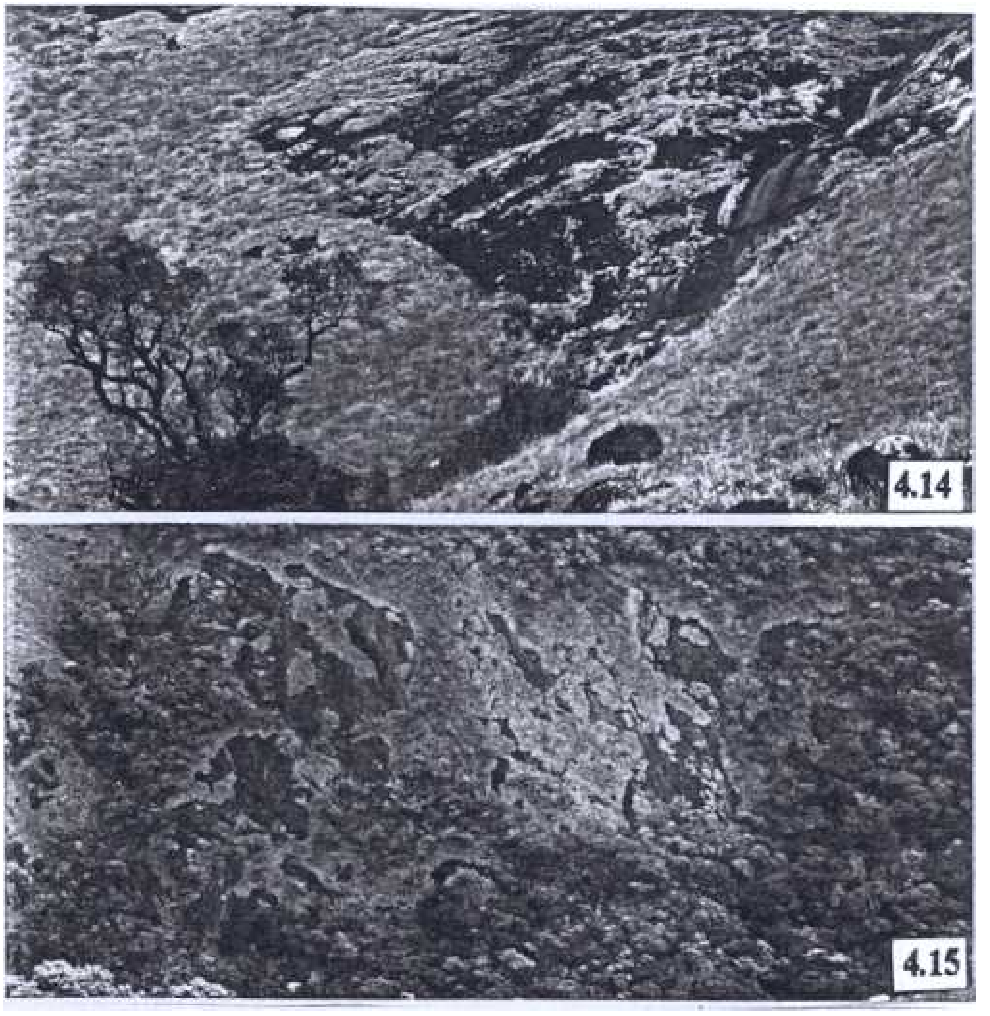
***2. Garnotia tectorum* dominant grassland mosaics**

This vegetal mosaic is also a flood plain grassland mosaic as *Eriocaulon- Garnotia type,* but where the dominance is by *Garnotia.* Generally, this type is met along smaller streamlets.



Figures 4.9–4.11. Succession in secondary grasslands at Walakkad, Silent Valley NP (medium elevation) cleared for the the abandoned tea plantations. The grasslands have been subsequently colonized by *Glochidion neilgherrense*. The woodlands in the grasslands are found largely along the gullies and streamlets (Fig. 4. 10) and they gradually extend to the hill mounds between the gullies (Fig. 4.11).

Figures 4.12 & 4.13. Primary succession on rock surfaces in the high elevational zone (upper reaches of Silent Valley National Park adjoining the Mukurti National Park, Tamilnadu). Fig. 4.12 illustrates rock surface colonized by crusts of xerophytic mosses, up on which pioneer grasses have started growing. Later, the whole organic mound of the moss crusts are colonized by grasses (Fig. 4.13).



Figures 4.14 & 4.15. Advanced phases of primary rock surface colonization by grasses in the high elevational zone (Upper reaches of Silent Valley National Park at Anjinda, adjoining the boundary of Mukurti National Park, Tamilnadu). Both these pictures illustrate that the grasses are pioneers and have important roles in soil formation. In figure 4.15, it is explicit that arborescent vegetation has colonized all areas where soil is deep enough to support, leaving areas with little or scant soil as grassy blanks in the forest land.

Figures 4.16 & 4.17. **Swampy grassland mosaics in the high** elevational zone (Eravikulam National Park). Both the pictures illustrate the general morphology of the *Eriocaulon-Garnotia* grassland mosaic. These mosaics grow on flood plains between hillocks. In figure 4.17, the white flowering heads of *Eriocaulon robustum* are visible. Pedologically, absence of gravels and pebbles in the soil in subsurface layers, very high content of organic carbon and nitrogen distinguish the vegetal type.

3. *Eriocaulon-Pleiocraterium* dominant grassland mosaic

North of the Palghat gap, the *Eriocaulon-Gamotia* grassland mosaic is substituted by *Eriocaulon-Pleiocraterium* mosaic (Figs. 4.18 & 4.19). The habitat is exactly the same as that of *Eriocaulon- Garnotia* grassland mosaic. *Pleiocraterium verticillare* is a rosette forming, almost acaulescent rubiaceous herb, absenting south of the Palghat gap and hence the absence of this vegetal mosaic at Eravikulam.

4, *Jansanella- Tripogon bromoides* dominant grassland mosaics

Along hill mounds where there is much of rocky outcrops, the soil is very thin, where a species of *Jansanella* and *Tripogon bromoides* dominate along with species of *Arundinella.* This grassland mosaic therefore represents a xeric type.

5. *Arundinella fuscata* dominant grassland mosaics

In between the interhill troughs and hill mounds where soil is slightly thicker than at the hill crests and where soil moisture is limiting, several variance of xeric grassland mosaics are observed of which *Arundinella fuscata* dominant grassland mosaic is one.

6. *Arundinella ciliata* dominant grassland mosaic

The grassland mosaics dominated by *Arundinella ciliata* is a variant of the former one and the habitat is also the same.

7. *Eulalia phaeothrix* dominant grassland mosaics

This community is also occupies hill mounds and shoulders. The clumps of *Eulalia phaeothrix* are very small, compared to that of the common tuft grass, *Chrysopogon zeylanicus* (Fig. 4.20).

8. *Chrysopogon zeylanicus* dominant grassland mosaics

Between the hill mounds and the troughs along slopes the grassland is dominated by the common tuft grass, *Chrysopogon zeylanicus.* Especially smaller hill folds as in Fig. 4.21 are colonized by this species. C. *zeylanicus* generally occupies slight moist sites.

4.3.3.3 Shrub savanna enclosures

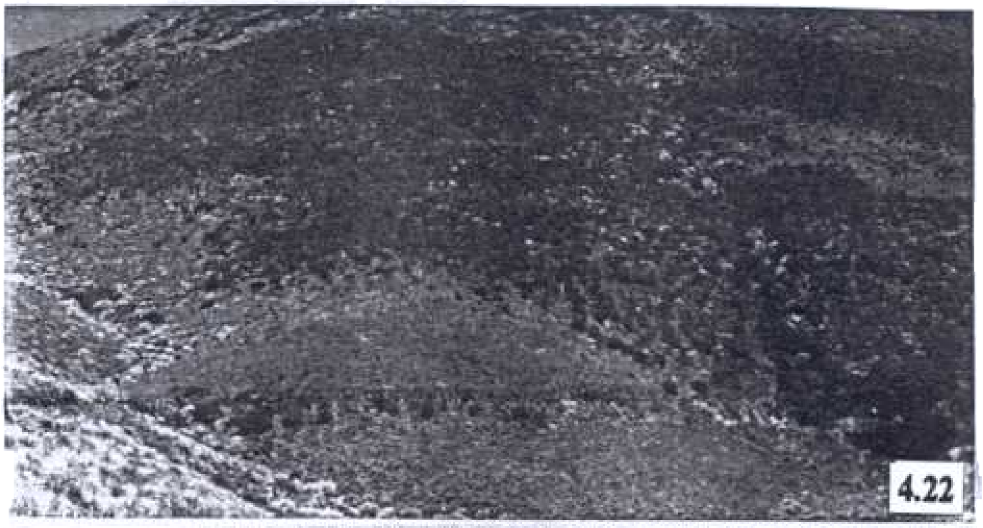
Three shrub savanna communities are met with.

1. The *Phlebophyllum* shrub savanna enclosures

Phlebophyllum kunthianum, a pleistesial acanth, grows gregariously in shrubby tufts intermixed with grasses in extensive areas (Figs. 4.22). It flowers only once in approximately about 12 years, when the hillocks take a pinkish carpet look (Figs. 4.23 & 4.24). The shrub

Figures 4.18 & 4.19. Swampy grassland mosaics in the high elevational zone (Mukurti National Park). Fig. 4.18. the *Eriocaulon–Pleiocraterium* grassland mosaic, which follows the courses of streamlets. *Pleiocraterium verticillare*, a component of the vegetal mosaic is a rosette forming almost stemless herb belonging to the family Rubiaceae. This vegetal type is the counter part of the *Eriocaulon–Garnotia* mosaic in Eravikulam. South of the Palghat gap, *Pleiocraterium verticillare* is absent and hence the absence of the community in Eravikulam.

Figures 4.20 & 4.21. Grassland vegetal mosaics in the high elevational zone (Eravikulam National Park). Fig. 4.20. *Eulalia phaeothrix* community with brown spikes. This community generally occupies drier habitats. Fig. 4.21. The rolling grasslands showing the ***Chrysopogon zeylanicus*** community along the saddles and hill folds (foreground of the picture). *Chrysopogon zeylanicus* is a tuft grass forming large clumps and characteristically prefer moist regimes of soil. The soil under this community is also fairly thick with much peat deposits and the community generally occupies closer to the shola forests. The *Pteridium* shrub community and the shola forests generally invade into the *Chrysopogon* grasslands.



Figures 4.22 & 4.23. Two aspects of the *Phlebophyllum kunthianum* shrub enclosures at high elevations. Fig. 4.22. The *Phlebophyllum* shrubland landscape from Mukurti National Park (Tamilnadu) in its vegetative phase. The shrubs are naturally distributed along areas with shallow soils and rocky outcrops (deep green mosaics from center to the background of the picture). Fig. 4.23. *Phlebophyllum* shrubland during flowering (Eravikulam 1994; photograph courtesy to Suresh Elaman). *Phlebophyllum* is a pleistesial shrub flowering gregariously once in a period of approximately 10-12 years when the shrublands cast an image of a pinkish carpet upon the rolling hillocks.

grows to a height of about 50-80 cm (Fig. 4.25) and with its caespitose growth (Fig. 4.26) can invade even crevices and splits in rocks (Fig. 4.27). .

2. The *Hypericum-Rhododendron* shrub savanna

Along certain hillocks about 1,800 m asl, along hill tops and shola margins, and often closer to the ecotones, shrub savanna enclosures are met with. In certain locations *Hypericum mysorense*, a shrub grows to a height of 60-70 cm and with beautiful bright yellow flowers dominate the grasslands. Regeneration of *Rhododendron arboreum* is intermixed with Hypericum. At some locations a species of *Osbeckia* dominates while at other locations, *Rhodomyrtus tomentosus* and some rubiaceous shrubs dominate.

3. The *Pteridium* shrub savanna enclaves

The gracious *Pteridium* shrub savanna exists in small patches either as enclaves or occasionally along the ecotones (Fig. 4.28). Both *Pteridium* shrub savanna and *Hypericum-Osbeckia* shrub savanna are scarcely found beyond 2,000 m.

4.3.3.4 The shrub savanna ecotones

Three types of communities are met with in this category too.

1. The *Rhododendron* shrub savanna ecotone

Regeneration of *Rhododendron arboreum* spread along the shola forest ecotones forming a shrub savanna.

2. The *Ageratina* ecotone

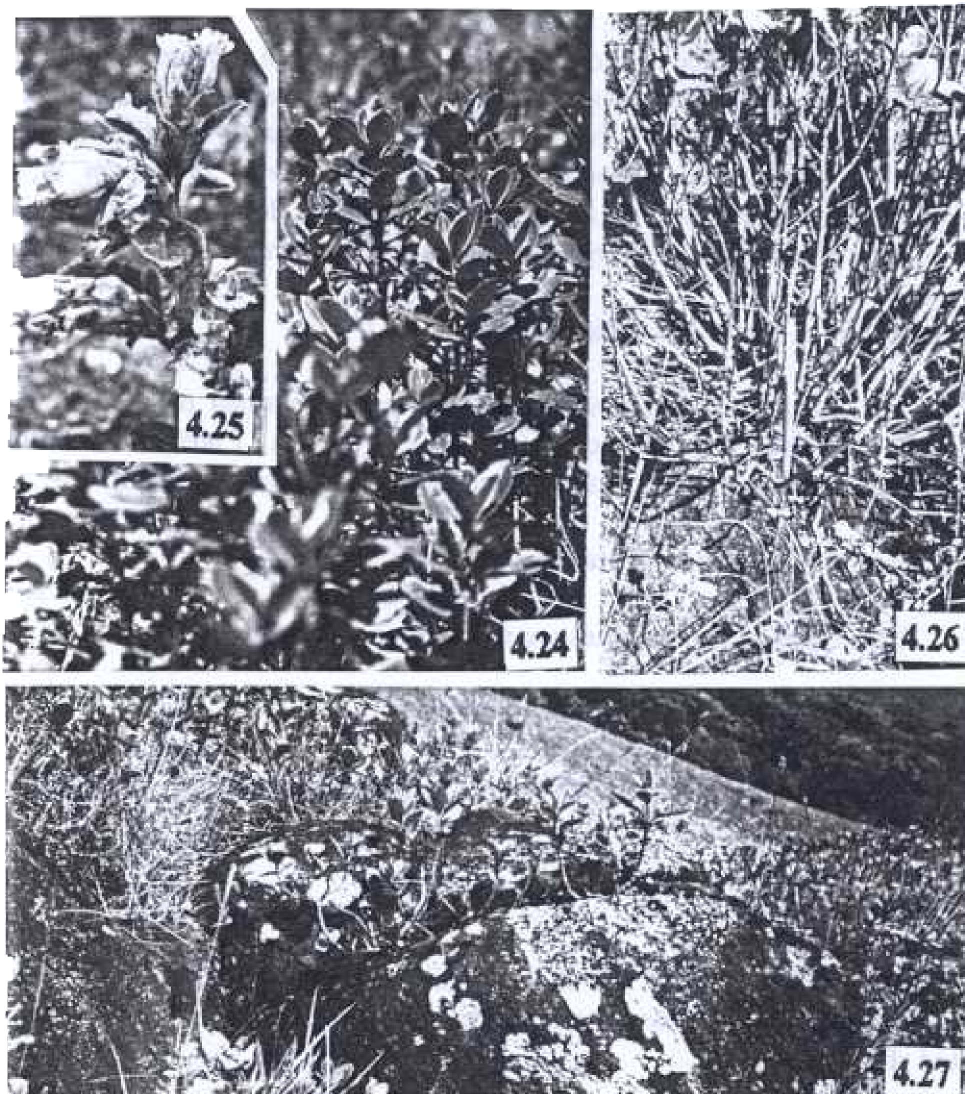
Along the margin of the shola forests, especially about 2,000 m asl, the composit *Ageratina adenophora* grows as a shrub stratum (Fig. 4.32). This is particularly true of fire affected shola forests.

***3. Nilgirianthus* sp. shrub ecotone**

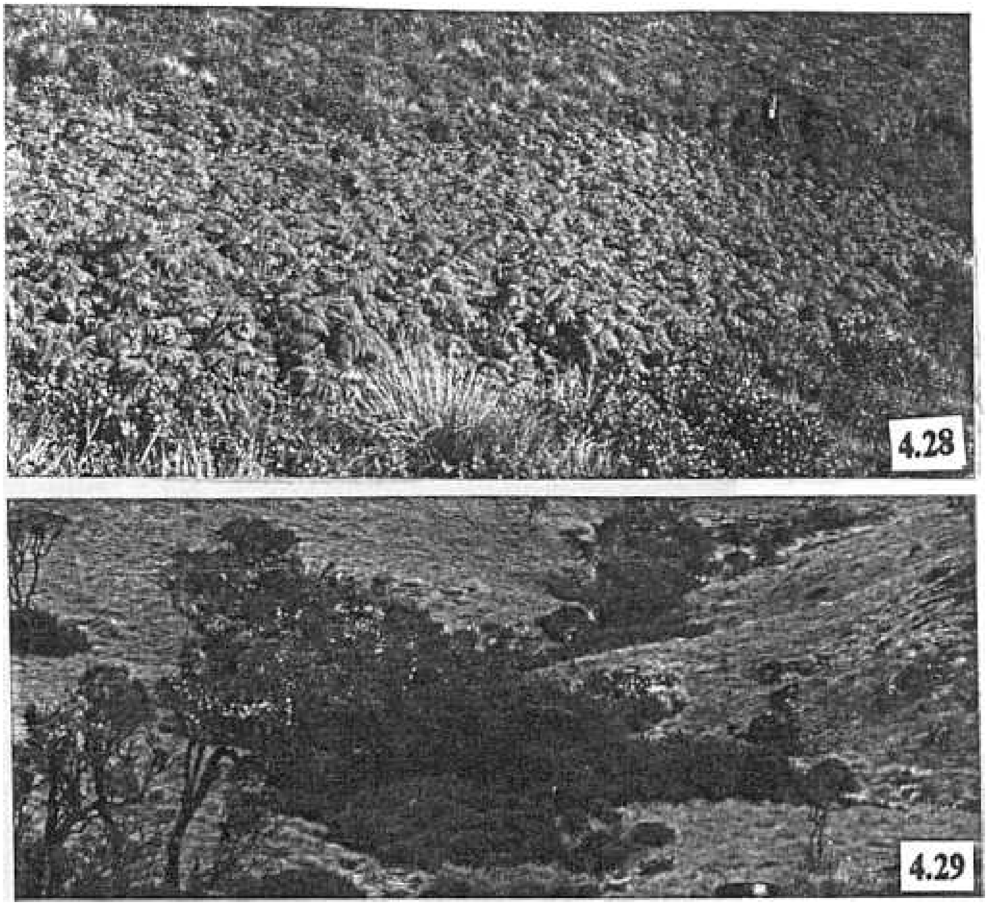
Along the lower limit of high elevational grasslands, two shrubby species of *Nilgirianthus* are found to occupy the ecotone, sometimes to a width of 2 or 3 m (Fig. 4.29).

***4. Gaultheria* shrub ecotone\ enciosure**

The Ericaceous shrub, *Gaultheria fragrantissima* often grows as shrubby enciosures in patches within the grassland (Figs. 4.30 & 4.31). Occasionally they are also found along the ecotones.



Figures 4.24–4.27. ***Phlebophyllum kunthianum.*** A close up of a vegetative stand showing gregarious growth. Fig. 4.25. A flowering branch. Fig. 4.26. A close up of the basal portion of a clump showing the caespitose nature and vegetatively regenerating ability. Fig. 4.27 shows the colonizing ability of *Phlebophyllum*. The shrub can inhabit even cracks and crevices in rocks where there is very little soil. The ***Phlebophyllum*** shrublands were found to have thin soil profiles with full of pebbles and gravel in the subsurface layer.



Figures 4.28 & 4.29. Some high elevational shrublands. Fig. 4.28. A *Pteridium* shrubland enclave (central focus) surrounded by *Phlebophyllum*. *Pteridium*, also called as bracken fern, is characteristically gregarious in having a stoloniferous underground stem, shooting up the compound leaves at regular intervals. The rhizomes hidden in the soil help the plants to perendurate fire. Fig. 4.29. A *Nilagirianthus* sp. shrub ecotone around a shola forest patch at high elevations in the Mukurti National Park (Tamilnadu) adjoining the Silent Valley National Park.

Figures 4.30 & 4.31. Two views of *Gaultheria* shrubland enclave at high elevations in the Mukurti National Park (Tamilnadu). *Gaultheria fragrantissima* is a temperate bushy shrub with aromatic leaves. Because of this property the plant is used in the preparation of tooth powder and paste and therefore extracted in large quantities from the High Ranges. It forms smaller enclaves within the grasslands and occasionally also forms a component of the shrubby ecotones.

5. Gulley shrub ecotone

Along the upper reaches of the shola forests covering streamlets and gully depressions, shrub savanna composed of stunted whipling regeneration of primary shola trees such as *Syzygium* and other genera are found. These are actually expanding sholas.

4.3.3.5 Tree savanna ecotones

Along the shola forest margins, *Rhododendron arboreum* (Fig. 4.33) with its elegant brisk red flowers (Figs. 4.36 & 4.37) and *Mahonia leschenaultiana* are quite frequent, although the species composition is not ***so*** predictable. *Rhododendron* is said to be fire and frost hardy, and is capable of colonising grasslands adjoining the sholas (Figs. 4.33-4.35).

4.3.3.6 Forest enclosures

Little shola forest enclaves in the vast expanse of the grasslands above 2,000 m asl are numerous. They are small woods of varying sizes. Their size decreases as elevation goes up, indicating that they are actually expanding.

4.3.3.7 Secondary succession

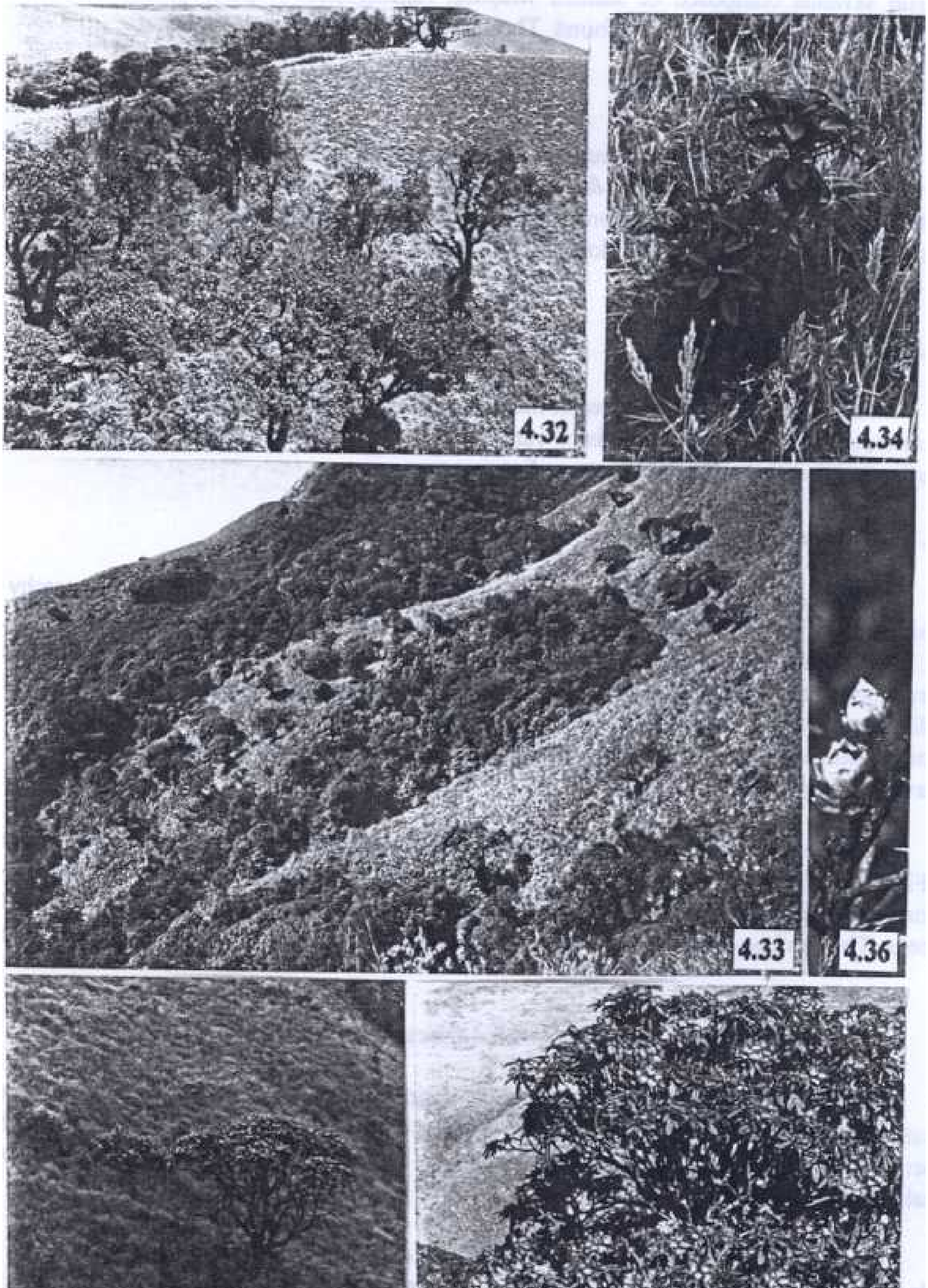
The- climax community along the high elevational belt certainly is the patchy shola forests pot porried within the grassland within the grassland panorama (Figs. 4.38 & 4.39)retaining the optimum biomass in living woods. As a management practice, the grasslands at Eravikulam receive a 2-3 year fire frequency in order to sustain the game, the Nilgiri tahr (Figs. 4.40-4.42). Occasional escapes of fire from these grasslands burn shola forest patches too. The affected forest grassland interface is occupied by Ageratina shrub savanna (Fig. 4.32).

Most of the shola forest enclaves contain a bamboo, *Chimonobambusa densifolia* (Figs. 4.43 & 4.44). The height of the bamboo varies from 3-4 m. In certain other areas, clump forming reed-bamboos growing to a height of over 15 m are also found interspersed with trees. The bamboo-mixed shola forests are perhaps disclimaxes formed owing to past fires.

4.3.4 Discussion

Along both the elevational zones the basic pathway of succession remains one and the same, ***ze,*** throughout the relay: pioneer stage --> grassland --> climax forest, which further proceeds to a bamboo mixed forest disclimax on disturbance. However, the communities taking part are different.

At lower elevations the tree savanna enclosures are composed mostly of moist deciduous tree species. Even along the Himalayas, at high elevations (1,700-2,700 to 3,000 m asl) comparable to that of the shola forests in the South, pioneers like Oak, conifers or deciduous birch (like *Betula utilis* and *B. alnoides)* are met with (Puri *et al.*, 1989). Neither a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Figures 4.32-4.37. Response of shola forests to fire and the role of *Rhododendron* in succession in grasslands. Fig. 4.32. The *Ageratina adenophora* shrub ecotone. *Ageratina* generally colonizes burnt shola forest margins and the picture shows such an affected shola forest patch with emergent trees and copious undergrowth of *Ageratina* (especially on the foreground of the photograph towards the right. Fig. 4.33. *Rhododendron* shrubland mosaic. *Rhododendron arboreum* is an amphitolerant species capable of withstanding frost and fire. *Rhododendrons* generally inhabit the periphery of the shola forests. The picture shows how the species have invaded grassland area between the two shola forest patches. Fig. 4.34. Seedlings of *Rhododendron* that have established in the grassland. The seedlings are 10-25 cm tall. When the seedlings were pulled out, they proved to be no recruitment of the current year. They were regeneration from root, stocks of pre-existent whiplings, indicating the past work of fire. Fig. 4.35 indicates an established tree of *Rhododendron* in the grassland. Such random establishments result in the *Rhododendron* shrubland mosaic as seen in Fig. 4.33. Figs. 4.36 and 4.37 illustrate the attractive scarlet red flowers of *Rhododendron arboreum.*

Figures 4.38 & 4.39. The general panorama of vegetal landscapes in the high elevational zone. Fig. 4.38. The grassland-shola forest continuum at Eravikulam (Near Eravikulam hut). The general landscape here is of the vast grasslands in which the little shola forest patches exist as enclaves. This landscape is just the reverse of that generally met at mid elevation where the forestland is the general landscape, within which the grasslands are relatively smaller patches. The reversal of the vegetal landscapes across elevation can easily be understood in the more familiar artwork as depicted in Fig. 4.39.

high elevational conifer, nor a deciduous pioneer tree species is met along the high elevational zone in Peninsular India.

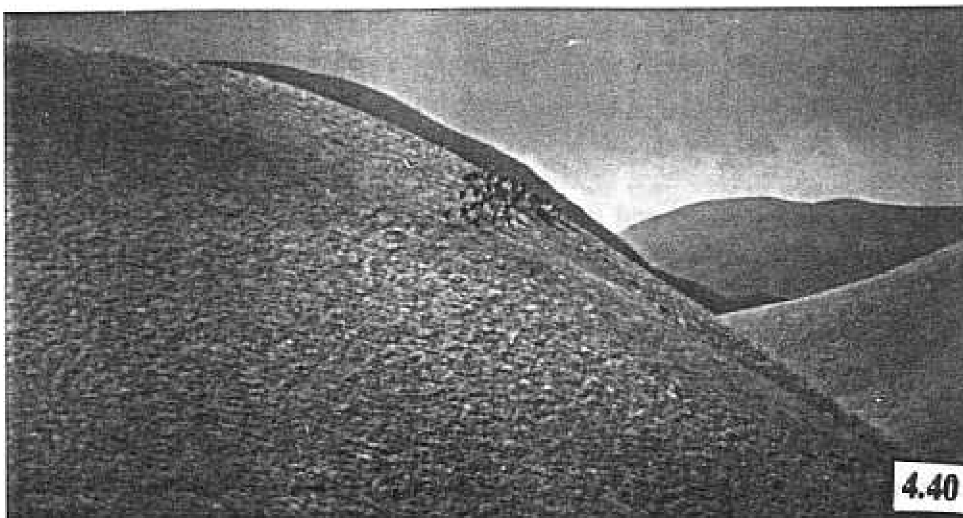
When a statistics of patch size of the shola forests and their elevational preferences were compiled, it was found that most of the smaller sized shola forests were found restricted to the upper elevations and the larger ones were found largely restricted along lower regions (Babu, 1997). The age and area hypothesis (Willis, 1922; also Good, 1974) indicate that the age of the smaller sized ones is less, *ie,* they are in their building phase. Because of the hostile climates of the higher elevations and the higher latitudes, biologists generally believe that the modern angiospermic (broad-leaved) forests originated at lower altitudes and lower latitudes and this process was relatively late along higher altitudes and latitudes. This fact also supports the view that the shola forest patches are in their building phase, in an evolutionary sense. In this sense, although they are no pioneer tree communities and no way deciduous in physiognomy, they are loci of forest building and spreading and are indeed comparable to the tree savannas and wooded tree enclosures of the grassland at lower elevations. In both the climatic situations, it seems that the forest invades into the grassland, except for the fact that this process is obliterated from direct observation by activity of biotic disturbances like fire, grazing, plantation activities, etc.

The bamboo-mixed forests (Fig. 4.44) resulting from repeated fires are also met with at both the climatic regimes, with regional difference in bamboo species. These bamboos being endowed with perennial subterranean rhizomatous systems with many offset buds which are slightly succulent can survive fire, better than any other species, and their total elimination from the ecosystem is unlikely. The bamboo-mixed forests have apparently stabilized and taken the status of a disclimax.

Viewed from the above perspectives, the low elevational and high elevational grassland-forest continua, although appear to differ very much in their specifics it is not much difficultto perceive that they reflect one and the same successional model.

From the point of view of evolution, a vast stretch of forest would not have come to existence as a single unit and simultaneously at one particular point of time. There is every reason to believe that such stretches were results of coalition of several smaller patches originated at different points of space and time. In other words, the patch dynamics model of forest structure holds true even in the juvenile phases of development of larger forest stretches extending over vast areas. Just as there are two war strategies, invading directly in to the enemy's defense front as a single unit, and the other, invading into the enemy's colony at several smaller loci as chance permits, the natural process of forest building in pioneer landscapes is also a two way process: one by advancing the perimeter of the forest junk in which the grassland lies, and the other by establishing **and** expanding the several patchy loci within the grassland.

Presence of many shrubland and tree mosaics in the grasslands in both the elevational zones suggest that the grassland is not a static system but dynamic, moving towards the forest optimum, although the successional process is very slow, scarcely observable and often arrested by other biotic pressures.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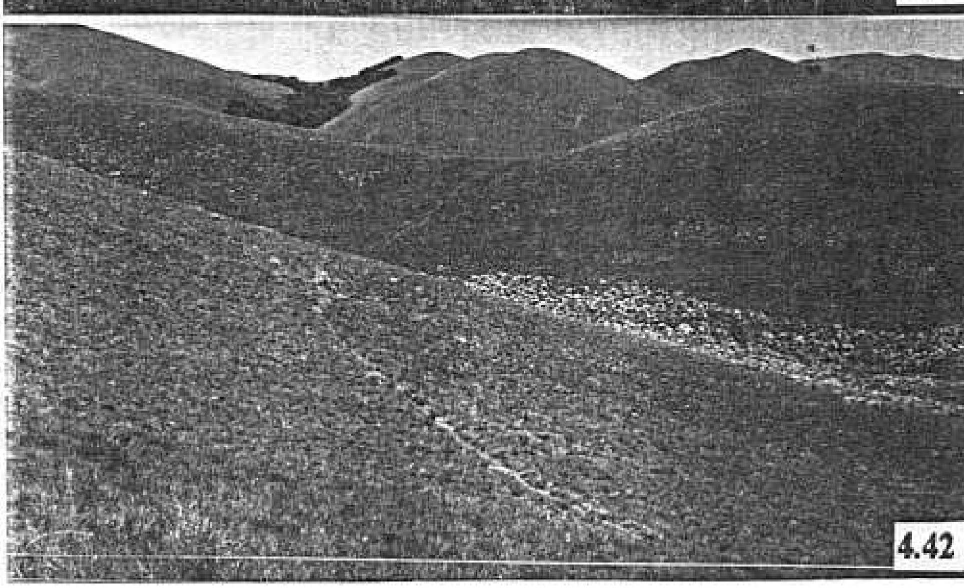

4.42

Figures 4.40-4.42. Fire as a management tool in high elevational grasslands. Fig. 4.40. A view of the grasslands in Eravikulam with a herd of Nilgiri tahr (in central focus). Fig. 4.41. Grazing tahrs in a closer view. Nilgiri tahr is the main attraction of Eravikulam National Park. In the past when the Park area was under the Kannan Devan Hill Produce Company, the interest, was the game animals which mainly composed of **Nilgiri** tahr. Today, after constituting the Park, the interest again pertains to the Nilgiri tahr, but of its protection and sustenance. In the past, burning of grasslands was implemented as a management tool to attract and sustain the tahr populations within in the Park area, and this strategy is continued to date. The burning is conducted in such a way that any given area within the grasslands receives burning at a frequency of approximately once in two years or so. Burning grasslands produces fresh growth of grass which is much more nutritious and palatable to the game. Fig. 4.42 shows a grassland area that has been burnt during the summer. The hillock sloping to the right with velvet green is the burnt area where new growth has come while the unburnt area still remains dry without any fresh growth.

Figures 4.43 & 4.44. The high elevational shola forests. Fig. 4.43. A closer view of an undisturbed shola forest stand, with stunted and gnarled boles (Upper reaches of Silent Valley near Anjinda). The shola forests represent the climax physiognomic vegetal type of the high elevations. Fig. 4.44. An inside view of a shola forest with heavy colonization of a bamboo (Eravikulam National Park). Bamboo mixed shola forests are considered to be a result of secondary succession, the bamboo component being the result of fire. The bamboo seen in the picture is a species of *Chimonobambusa*.

4.3.5 Conclusions

1. Each of the two physiognomic vegetation types, viz, the grasslands and the evergreen forest, is composed of a variety of vegetal mosaics.
2. The grassland mosaics, shrub savanna enclosures, shrub savanna ecotones, tree savanna enclosures, tree\ forest ecotones, patchy forest enclaves in the grassland an the forests represent a vegetal mosaic continuum.
3. Presence of shrub and tree dominated vegetal mosaics in the grassland suggests that it is not a static system. Arborescent elements do invade and establish into the grasslands, but the speed of colonization is very low.

CHAPTER 5. VEGETAL SUCCESSlON

5.1 Introduction

Location centered studies were conducted in the grasslands in the Silent Valley National Park around the proposed dam-site, and 2. the Eravikulam National Park, mainly to address specific issues relating to the vegetation dynamics.

The grasslands although represent the gaminoid vegetation, its successional status of the grassland is determined not by the it alone. The adjacent forest vegetations along with their ecotones are in edaphic, floristic and microclimatic continuum with the grasslands. The migration of ligneous arborescent floristic elements into the grassland takes place. As a matter of fact, the term vegetation, as used here in the present study denotes the grassland-forest continuum, unless specifically denoted.

The concept of climax implies that the composition of' the grasslands perpetuates over long spans of time without much change (Kimmins, 1987). This equilibrium state can be for several reasons:

1. That the grassland component in the system does not deplete significantly over years or that it is too slow to be observed in short spans of time.
2. The arborescent vegetation does not invade into the grasslands or that the rate of invasion isvery slow to be observed in shorter spans of time, or that there are no adjacent tree vegetation that can invade into the grassland ecosystem.
3. The seed diaspore dispersal patterns of' the adjacent arborescent vegetation to the grasslands is such that they are unable to reach far into the grasslands.
4. The grassy vegetation does not permit seeds of the arborescent species to germinate.
5. The arborescent species of the forest vegetation lying adjacent to the grasslands are unable to establish in the grasslands.
6. The animal population in the grassland\ grassland-forest ecotone does not permit the tree seedlings to establish in the grassland.

Towards testing the validity of each of the above hypotheses, a series of experiments were conducted.

5.2 Methods

To make a general picture of the composition of the grassland-forest vegetation some perambulation survey of he respective vegetations and their ecotones were made. On the basis of this, stratification of the vegetation was done and community ecological studies were conducted to characterise the vegetations. Vegetations were sampled quantitatively so as to gather differences between the different vegetations.

In the Silent Valley National Park, the studies of quantitative ecology and vegetation dynamics were conducted mostly at the hillocks of Pulippara and Aruvampara, and in the Eravikulam National Park at places, Nilagiri Teri and Umayamalai. Ten strips of 100 m length were marked cutting the grassland and the forest such that 50 m of the strip lies in the forest and 50 m in the grassland. These strips were marked by means of iron pegs and segmented into 100 m^2 quadrats so that there are 5 quadrats of grassland vegetation and 5 quadrats of forest vegetation in each strip. In the forest quadrats, alll trees >= 10 cm dbh were enumerated girth measured, identified and recorded in data sheets. In a similar fashion all shrubs > 50 cm tall were enumerated and heights measured in all the grassland quadrats. In the grassland plots. all grasses and herbs were also enumerated. The grasses and shrubs were sampled only in a *2* m wide strip running the full length of the 10 m wide strip. Many of the grass species like *Themeda cymbaria. Cymbopogon flexuosus, etc* are clump forming. In enumerating such grasses, the number of individuals in each clump was counted and the height of the tallest shoot in the clump was measured. The enumerated data were pooled variously to generate quantitative details of the vegetations.

Quantitative assessment of tree seedling in the grasslands were conducted in fifty 2.5^2 quadrats so as to knowthe regeneration status.

Twenty four litter traps of 1 m^2 were placed in the field to know the influx of diaspores of tree species in the grassland and the grassland part of the grassland-forest ecotone in Silent Valley. The traps were installed at an escapement of 10 m such that, there were three replicates for each treatment and they extended up to a distance of 50 m in the grassland and 30 m in to the forest from the forest-grassland interface. Seeds falling in these traps were collected monthly for a period of eight months and recorded in data sheets so that the hypothesis that the grasslands do not receive enough seeds of the arborescent species could be tested. The study could not be duplicated at Eravikulam.

In order to take stock of the new recruits of the tree species emerging, new emergencies of tree seedlings in the grassland were monitored in fifty 10 x 0.5 m permanent quadrats starting from the ecotone, to a distance of 50 m at Pulippara in Silent Valley.

It is suspected that the thick grass growth in the grasslands offer some constraints for the tree seeds to germinate. This needed to be verified; for this purpose, seeds of selected tree species which are either colonizers in the grasslands or occupying the forest ecotone or pioneer moist deciduous tree species were collected in sufficient quantity and the seeds sown in the gassland at Sirandhri, Silent Valley. Four treatments were used in sowing the seeds (Table 5.1). The list of tree species tried are also given in Table *5.2*. The germination of the seeds and the estabiishment of tne seediings were monitored for a period of one year.

To test the hypothesis that, there exist significant difference in the tree species inhabiting the forest and forest ecotone, plant species in a 200 m distance of forest-grassland ecotone were collected, identified and categorised into different groups based on habitat types. These studies were conducted both at Silent Valley and Eravikulam. The width of the strip sampled was approximately 20 m, 10 m representing the forest half and 10 m representing the grassland half.

Table 5.1 Different treatments of seed sowing and the species tried.

SEED SOWING TREATMENTS		
1 Undisturbed grassland site		
2 Sites where the above ground grass growth was cut with a knife		
3 Sites where the above ground grass was burnt		
4 Sites where the grassy growth was removed		
TREE SPECIES TRIED		
L Moist Deciduous Trees	**II. Grassland Trees**	**III. Ecotone Trees**
I Terminalia paniculata	*4 Phoenix humilis*	6 *Symplocos laurina*
2 Pterocarpus marsupium	*5 Syzygium arnottianum*	*7 Olea dioica*
3 Terminalia bellirica		*8 Clerodendron viscosum*

In order to test the hypothesis that, there exist significant difference in: (1). the tree species inhabiting, (2). density of tree regeneration, and (3). density of trees in the forest and forest ecotone, enumeration of tree species were conducted in fifteen 100 m^2 quadrats along the ecotone and an equal number of quadrats, twenty meter away from the ecotone, inside the forest. The sampling was done at three separate sites both at Silent Valley and two sites in Eravikulam National Park.

Approximately 300 m length of the grassland-forest boundary was marked by survey stones and outline mapped so as to permit to physically verify vegetation transgression if any in the interface between the grassland and the forest, after a long time span.

5.3 Results and discussion

5.3.1 Patterns and processes in the medium elevational grassland-forest continuum (Silent Valley)

5.3.1.1 The evergreen forest at Pulippara

For most part, the forests of the Silent Valley National Park belongs to the Mid elevational evergreen forests of the *Mesua-Palaquium* association. Eight different compositional types have been identified within this broader category by Aiyar (1900) and the stands at Pulippara, the study site belonged to *Mesua-Cullenia-Palaqium* association. The stand structure of the forests is described below in Table 5.2.

Only 13 tree species with >= 10 cm dbh were encountered in a 1800 sample of the forest area. The 5 most abundant species with RIVI >= 5% were: *Cullenia exarillata, Myistica dactyloides, Drypetes elata, Palaquium ellipticum* and a species of *Aglaia.* These five top dominant species with RIVI >= 5% together made up nearly 81 percent of the importance value. There were 372 trees (>= 10 cm dbh) in a hectare of the forest, which contributed a basal area of 50.3975 m2. In terms of relative fiequency, *Myristica dactyloides* and *Drypetes elata* shared higher values. Other important tree species in the area were: *Syzygium* sp., *Antidesma* sp., *Fahrenheitia zeylanica, Turpinia nepalensis, Garcinia morella, Elaeocarpus tu berculatus, Nephelium longan* and *Aphanamyxis polystachya.*

Table 5.2 Composition and structure of the evergreen forests at Pulippara, Silent Valley NP*.

Species	D\ha	BA\ha	D@	RF@	RBA@	RIVI@	CRIVI@
5 species with RIVI >=5%	***289***	***46.3225***	**7.6**	**73.1**	**91.9**	**80.9**	..
8 species with RIVI < 5%	**83**	**4.0750**	**22.4**	***26.9***	**8.1**	**19.1**	
Cullenia exarillata	72	18.6673	19.4	17.3	37	24.6	24.6
Myristica dactyloides	94	10.5145	25.4	19.2	20.9	21.8	46.4
Drypetes elata	56	6.3975	14.9	19.2	12.7	15.6	62
Palaquium ellipticum	39	6.2207	10.5	7.7	12.3	10.1	72.2
Aglaia sp.	28	4.5225	7.5	9.6	9	8.7	80.9
Syzygium sp.	22	0.3213	6	7.7	0.6	4.8	85.6
Antidesma sp.	17	0.1565	4.5	3.9	0.3	2.9	88.5
Fahrenheitia zeylanica	11	0.4124	3	3.9	0.8	2.6	91.1
Turpinia nepalensis	6	1.9489	1.5	1.9	3.9	2.4	93.5
Garcinia morella	11	0.1224	3	3.9	0.2	2.4	95.9
Elaeocarpus tuberculatus	6	0.8416	1.5	1.9	1.7	1.7	97.5
Nephelium longan	6	0.2013	1.5	1.9	0.4	1.3	98.8
Aphanamyxis polystachya	6	0.0707	1.5	1.9	0.1	1.2	100
Total:	372	50.3975	100	100	100	100	100

* Tree size >= 10 cm dbh (~30 cm gbh). @ Figures rounded off to one decimal place.
BA: Basal arrea CRIVI: Cumulative RIVI. D: Density; RBA. Relative; Basal Area; RD: Relative density; RF: Relative frequency; RIVI: Relative Importance Value (=

5.3.1.2 The mid-elevational grassland at Pulippara

Vast expanses of grasslands are generally absent in the Silent Valley National Park. Within the Park, for most part grasslands exist as areas of smaller extent of a few hectares distributed within the general landscape of the forests or along steep slopes or in association with rock formations. They are basically tail grasslands. i h e structure of the typical grassland is described in Table 5.3.

Although the grassland is typologically referred to as *Themeda-Cymbopogon* type, as evidenced from sampling, it is dominated by *Chrysopogon orientale* with as many as 4,94,100 individual upright shoots. *Themeda triandra* and *Themeda cymbaria* are two closely resembling species difficult to be distinguished between, and perhaps were documented under the former in most earlier literature. These species jointly constituted a stocking of 1,36,500 shoots\ha thus ranking next to *Chrysopogon orientale*. *Cymbopogon flexuosum* is the next dominant with as many as 1,04,000 shoots per hectare. Among these tall grasses, patchy populations of *Imperata cylindrica* are also met with.

Table 5.3 Structure and dominance pattern in the typical grasslands of Pulippara, Silent Valley NP@.

Tall grasses	Density\ha	Short grasses	Density\ha*
Chrysopogon orientale	4,94.1	*Arundo* sp.	1,08.4
Themeda triandra	80.5	*Ischaemum* sp.	87.4
Themeda cymbaria	56	*Themeda tremula*	53.9
Cymbopogon flexuosum	1,04	*Eulalia trispicata*	52.5
Imperata cylindrica	50.2		

• n = 20 replicates of 5 m^2 samples. @ All figures of density x 10^3.

Intermingled with the tall grasses and occupying space between them some short grasses also exist in fair densities. Arundo sp. and *Eulalia trispicata* are two erect growing grasses belonging to this category. *Themeda tremula* and *Ischaemum* sp. are two fairly common trailing grasses and the former also become erect occasionally.

5.3.1.3 The forest-grassland continuum

The grassland and the forests are two physiognomic entities, one where the stand height does not go beyond 2.5 m whereas in the other, it goes up to 45 m or so. But, with regard to availability of moisture and shade, the forest-grassland vegetation is a continuum. Along the inner core, away from the edges, the forests are with deeper soil profile and hence with more storage water. The edges on the other hand receive high radiant heat and the diurnal temperature flux is also high, while the soil depth is less. Nevertheless, because of the forest stand, depending up on the aspect, the edge is not affected by the morning or evening sun. Consequently, the edge is an environment intermediate between the forest and the grassland. The grassland and the ecotone, have shallow soils and is subject to the highest influx of diurnal temperature.·Corresponding to the physiological environment and the physiognomy of stands across the gradient, species compositional changes are also observed across these vegetal mosaics.

The grasslands which appear to be more or less uniform to an untrained eye, is not uniform with respect to available niches. Hill shoulders where rain water rains out quickly, the relatively level inter-hill valleys where moisture retention is higher, the ecotonal grasslands, and the seasonally water-logged sites in valleys or closer to rocky sites all represent niches varying in depth of soil and moisture distribution. This is reflected in the composition of the grass species and their stocking in different sites.

Density distribution of grasses in different grassland mosaics at Pulippara, Silent Valley, is given in Table 5.4. The total stocking of grasses is highest in the wet stands (20,56.6 x10^3\ha),with moist (17,75.6 x 10^3\ha)and water-logged (16,18 x 10^3\ha) stands having densities closer to it. From the table values (Table 5.4), the grassland ecotone appears to have a stocking (15,12 x 10^3\ha) closer to that of the moist, wet and water logged stands and differs fiom the dry (hill shoulder) stands (10,98.9 x 10^3\ha) significantly.

Grassland mosaic types	**Habitat**	**Stocking\ ha (x 10^3)**	**Sample size**	**Replicates**
Wet stand	Rall valleys betweenhillocks	20,56.6	5 m^2	10
Moist stand	Lower slopes of ralls between hillocks	17,75.6	5 m^2	9
Water loggedstand	With shallowly placedrocks	16,18	5 m^2	1
Grassland ecotone	Grassland-forest boundary	15,12	5 m^2	5
Dry stands	Hill shoulders and upper slopes of hills	10,98.9	5 m^2	20

Table 5.5 describes the grass species compositional differences across different niches at Pulippara (Silent Valley). *Chrysopogon orientale* and *Arundo donax* are more or less uniformly distributed in all the grassland habitat types and may be considered representative of the grassland type.

In the wet and moist grassland mosaics, Ischaemum sp., Themeda triandra and Chrysopogon orientale were the top dominant species, with slight variations in their relative ranking. In the water-logged mosaic with shallowly placed rock substratum, *Ischaemum* has practically disappeared fiom the top ranking species and has been replaced by Themeda tremula, another trailing grass.

The ecotone being another mosaic of fairly good moisture regime, *Ischaemum* ranks top here. But here, *Arundinella* has found a place in the top ranking three species, presumably because of a slightly drier moisture regime, compared to the other moist and wet sites. Again *Arundo* sp. exhibits a similar status in the dominance ranking of the dry grassland mosaic, indicating its ability to inhabit drier habitats.

Some grass species are represented in all the grassland mosaic types, while others are not. *Eulalia trispicata* is practically absent from the wet site, sparingly represented in the moist site, but moderately represented in the dry, ecotone and water-logged rocky mosaics. *Themeda triandra* is a colonizer of the wet, moist and water logged sites; in the ecotonal as well as the dry mosaics, it is however pushed down in ranking.

The genus *Themeda* is represented by three species in the grasslands (Table 5.6). Both *Themeda triandra* and *T. tremula* are represented in all mosaic types, while *T. cymbaria* is absenting fiom the water-logged mosaics and poorly represented in dry and ecotone mosaics.

Table 5.5 Distribution of different grass species across different grassland mosaics at Pulippara, Silent Valley*.

Grass species	Density (per hectare) of grass shoots in Grassland mosaics				
	Wet	Moist	Water-loggd	Ecotone	Dry
Top dominant grass species					
Chrysopogon orientale	3,76.6	7,48.4	5,18	2,29.2	4,94.1
Themeda triandra	4,47	2,96.9	6,06	1,14	80.5
Ischaemum sp.	6,17.2	2,62.5	84	7,14.8	99.3
Species of medium rank					
Cymbopogon flexuosum	1,13.8	1,34.2	20	68.4	1,46.9
Imperata cylindrica	1,09.2	1,19.6	1,10	39.2	50.2
Arundo donax	89.4	1,21.8	1,08	1,88	1,08.4
Species absent in some of the mosaic types					
Themeda tremula	49.8	12.4	1,22	93.2	53.9
Themeda cymbaria	2,53.6	70.7	..	34.4	13.1
Eulalia trispicata	..	9.1	50	30.8	52.5

@ All figures of density x 10^3.

Table 5.6 Density distribution patterns of different species of *Themeda* in different grassland mosaics at Pulippara, Silent Valley*

Grass species	Density (per hectare) of shoots in Grassland mosaics				
	Wet	**Moist**	**Water-logged**	**Ecoton e**	**Dry**
Themeda triandra	4,47	2,96.9	6,06	1,14	80.5
Ihemeda tremula	49.8	12.4	1,22	93.2	53.9
Themeda cymbaria	2,53.6	70.7	..	34.4	13.1

From the observed dominance pattern of grass species across the different vegetal mosaics, it appears that the grassland actually is a complex of environmentally varied mosaic of habitats and is seldom uniform. Dry grassland mosaic is definitely a stressed and hostile niche; iikewise, the water- logged mosaic also represents a hostile niche, the excess water limiting physiological activities. As with the total stocking of grass, the ecotonal habitat represents an intermediary habitat with respect to species composition too. It also shows that the grassland ecotone, from the point of view of moisture regime, is intermediate between the forest and the grassland.

The structure and composition of the forest half of the grassland-forest ecotone also differs from that of the typical forests. The grassland-forest boundaries (ecotones) are not sharply demarcated. At places short woods comprising pioneer species, the tree-savanna ecotones appear. Apart from the shrub and tree savanna ecotones, little patches of shrub and tree savanna enclosures are also met within the grasslands which form a continuum with the grassland on one side and the forest on the other. Along the boundaries, for most part, shrubby forms are found to colonize, forming shrub-savanna ecotones (Table 5.7). The shrub and tree ecotones and enclosuresin the grasslands display a grassland-forest continuum than two water tight vegetations.

Table 5.7 Shrub and tree savanna ecotones and enclosures at Silent Valley (100 m asl).

Shrub savanna ecotones	**Tree savanna enclosures**
Nilagirianthes shrub savanna ecotone	*Phyllathus* tree savanna enclosures
Maesa-Cleroderdron-Leea shrub savanna ecotone	*Pterocarpus* tree savanna enclosure
	Phoenix tree savanna enclosures
Shrub savanna enclosures	*Zizyphus-Glochidion* tree savanna encl.
	Syzygium tree savanna enclosures
Pleurocaulis shrub savanna enclosures	
Pteridium shrub savanna enclosures	
Maesa shrub savanna enclosures	

5.3.1.4 Invasion of tree seeds to the grassland

Details of seed catch in the litter traps are given in Table 5.8.

Table 5.8 Seed fall in litter traps at Silent Valley*.

Tree species	**Seeds\ha**		
	Forest	**Ecotone**	**Grassland**
Cassine kedarnathii	400	33	..
Mesua nagassarium	..	134	..
Pygeum gardneri	33	..	..
Glochidion sp.? (Unidentified)	350	..	..
Total tree seeds\ha	783	167	..

Tree seeds were recorded in the litter traps only during the months from June to September 1996, ie, post-monsoon. Fruits of most rain forest trees mature by June and seeds fall during the monsoon. Thus the findings match well with the observations of earlier workers. Diaspores of only four tree species could be encountered in the traps, viz, *Cassine kedarnathii, Mesua nagassarium, Pygeum gardneri* and an unidentified species. The total number of tree seeds computed for the forest habitat was 783 against 167 in the ecotone. And, in the grasslands, despite the higher number of litter traps installed, they recorded no tree seeds at all.

The fruits in the case of most of the evergreen trees are heavy and in many cases the seeds seldom escape out from the fruit. The seeds are also heavy and are not adapted to wind dispersal.

5.3.1.5 Tree seed germination and establishment

The results of germination trials conducted in the grasslands with seeds of tree species are given in table 5.9.

Table 5.9 Result of seed germination studies in the grassland@.

	seeds sown	**Pest# incidence**	**Sowing treatments**				**Com ments**
Tree species	(n*)		Control	Grass cut	Grass burnt	Grass removed	
Pterocarpus marsupium	70		23 (32.9)	14 (19.9)	14 (19.9)	24 (34.3)	GNH
Syzygium arnottianum	150		85 (56.7)	39 (26.0)	80 (53.3)	**35** (23.3)	GNH
Terminalia bellirica	50		6 (12)	8 (16)	15 (30)	7 (14)	NI
Symplocos laurina	400	30%	7 (1.8)	3 (0.8)	5 (1.3)	I (0.3)	..
Clerodendron viscosum	300		2 (0.7)	7 (2.3)	.. (..)	1 (0.3)	NI
Olea dioica	300	> 80%	4 (1.3)	1 (0.3)	(..)	.. ..	..
Phoenix humilis	140	70%	1 (0.7)	.. (..)	.. (..)	..	..

In Table 5.9, the results of germination of *Terminalia paniculata* is not given, as only one seedling emerged out of the 1000 seeds sown. In the case of three species rodent pests were found affecting the survival of seeds. Over 70% of the seeds of *Olea dioica* and *Phoenix humilis* sown were thus lost, while the extent of damage in the case of ***Symplocos laurina*** was less (3 0%). For *Clerodendrum viscosum, Symplocos laurina* and *Olea dioica,* the germination percentage for all the treatments remained less than 2.5 and the comparability of the treatment results was less feasible. In the case of *Phoenix humilis,* out of the 30% seeds survived (170: total for all the 4 treatments) escaping the rodents, only one seedling emerged.

Two species, *Pterocarpus marsupium* and *Syzygium arnottianum* showed appreciable germination. For *Pterocarpus marsupium* 32.9% and 34.3% germination were recorded for control and 'grass- removed' treatments, and with 19.9% each for 'grass-cut' and 'grass-burnt' treatments. The high germination percentage in the control treatment here indicates that the grass growth does not affect seed germination. The results obtained for *Syzygium arnottianum* also parallel closely. 56.7% and 53.3% germination were observed for the control and 'grass-burnt' treatments respectively and 26% and 23.3% for the 'grass-cut' and 'grass-removed' treatments.

In the case of *Terminalia bellirica,* burnt grasslands had a significantly high percentage of germination (30%), while in all other treatments, including the control, the percentage ranged between 12 and 14.

From the results obtained, the following are apparent: (1). In the grasslands all tree species do not have the same germination behaviour. (2). The species in which sufficient data of germination for comparison across different treatments were available, it was evident that the grass growth does not offer much a constraint for tree seed germination, although this statement cannot be extended for all the species. In the case of *Terminalia bellirica,* 'burnt-grassland' treatment showed better germination. (3). Apart from the few tree species included in the current study, experimental germination trials of a large number of tree species in different locations would be required to know the intricacies of slow tree invasion in grasslands. (4). The fauna, especially the rodents in the grassland\ ecotone could be a determining factor in keeping the grassland as grassland, at least along low elevations.

5.3.1.6 New recruits emerging in the grasslands

Only five instances of emergence of new recruits of tree species were encountered from the 0.25 ha sample area monitored for a year, which is equivalent to 200 recruits\ha. The recruits encountered belonged to *Phyllanthus emblica* and *Zizyphus rugosa.* Although the annual natality rates of tree seedlings is low as evidenced by the paucity of tree recruits in the grassland, the little tree- savanna enclosures of *Pterocarpus marsupium, Phyllanthus emblica,* etc, found embedded within the grasslands suggests that the history of the site and the seed invasion in to the grassland are also important aspects determining the permanence of the grassland vegetation.

5.3.1.7 Established tree regeneration population in the grasslands

The per hectare stocking of established seedlings (50-200 cm height) of tree species encountered was 32, which indeed is very inadequate. The individuals belonged to *Clerodendrum viscosum, Phoenix humilis and Elaeocarpus tuberculatus.* The new recruits and the persisting seedlings were almost exclusively of deciduous trees or other pioneer shrubs.

The above findings infer that seeds which arrive the grasslands are largely of deciduous trees with diaspores transported by wind and again some species are distributed by birds *(Phyllanthus emblica* and *Zizyphus rugosa)* or animals *(Phoenix humilis).* Even the shrubs which colonize the grasslands are either wind dispersed (Pteridium aquilinum) or bird dispersed *(Maesa perrottetiana, Leea* sp.), or with vegetatively regenerating seasonal shoots *(Pleurocaulis sessilis).* The diaspores of the evergreen trees even if they reach the grasslands have only short longevity and fail to germinate and establish.

Experimental germination studies suggest that. even a good percentage of the deciduous tree diaspores reaching the grasslands are devoured by rodents and some percentage of the germinated seedlings destroyed by insect or other pests. Although the grassland soil does not offer much obstruction to germination and establishment of seedlings, the seedling bank which finally survives is that which withstand: (1) the harsh highly seasonal physical environment, (2) the low and compact soil environment and, (3) the harsh biotic environment involving pests, cattle, and fire. By and large these properties are owned by pioneer shrubs and deciduous trees, and thus the shrub mosaics and deciduous tree enclosures are the mid successional communities in grassland succession.

5.3.1.8 Differences in tree species in forest and forest ecotone

Details of enumeration of plant species along 200 m length of forest-grassland boundary at Pulippara, Silent Valley, are summarized in Table 5.10.

Table 5.10 Species differences in forest and forest ecotone.

Habitat	**All species**	**Tree species**
Forest alone	47	15
Forest ecotone alone	13	8
Forest + forest ecotone	34	19
Forest + Forest ecotone + Grassland ecotone	5	1
Grassland alone (Wood savanna enclosures or sporadic trees found in the grasslands)	18*	6*
Grassland ecotone alone	17	1
Grassland + Grassland ecotone	15	1

The total number of species inhabiting the forest and the forest ecotone together is fewer than the total number of species inhabiting the forest alone. Although the above holds true, if we look into the distribution of tree species across the different habitat types, the total number of tree species inhabiting forest and forest ecotone together is greater than the number of tree species restricted to the forest alone.

For all spp: S Forest + forest ecotone] < S [forest alone] .. (I)
For tree spp: S Forest + forest ecotone] >S Forest alone] ..(2)

This means that the number of tree species capable of inhabiting the forest ecotone is higher than the number of species that inhabit the forest environment itself. Similar results were also obtained from the quantitative comparison of ecotonal forest stands and stands 20 m inside the forest (see below).

Results of analysis of enumeration of trees and saplings in fifteen 100 m^2 plots in the ecotone and comparison to that from an equal sample area from the interior forest are given below (Table 5.11).

Table 5.11 Species richness (S) of trees\ arborescent species (>=l0 cm gbh: ca **3** cm dbh) in the ecotone and forest samples*.

Category of sample	Size of sample	Replicates	Species no.+ SD
Forest + Forest ecotone	0.90 ha	1	77
Forest ecotone only	0.45 ha	1	74
Forest stand only	0.45 ha	1	64
Forest ecotone only	0.15 ha	3	65+5
Forest stand only	0.15 ha	3	53 +4

From a total of 0.9 ha sample comprising the forest and forest ecotone stands, a total of 77 tree\ arborescent species >= 10 cm dbh were recorded. In each of the 0.45 ha subsamples belonging to the forest ecotone and forest, the species number were respectively 74 and 64, with a difference of 10 species. In subsamples of 0.15 ha, the mean figures of species richness turned out to be 65 + 5 and 53 + 4 respectively (Table 5.11).

Distribution of species richness (S) across different size classes is presented in Table 5.12. In the sapling stage (> 3-10 cm dbh), the mean number of tree species was 52 in the

Table 5.12 Distribution of number of species of trees\ arborescent species (>= **10** cm gbh: *ca*. 3 cm dbh) in the ecotone and forest sample; across different size classes.

Samples	Diameter classes						
	< 10 cm dbh		>= 10 to< 60 cm dbh		>=60cm dbh		Sample size*
	FE	FO	FE	FO	FE	FO	
Sample 1	**51**	**46**	**35**	**34**	**6**	**6**	**0.15** ha
Sample 2	**55**	**41**	**48**	**27**	**9**	**5**	**0.15** ha
Sample 3	**51**	**45**	**43**	**30**	**6**	**7**	**0.15** ha
Mean*: SD*:	**522 2**	**44± 2**	**42±** 5	30± **3**	7± 1	**6** 1	**0.15** ha

forest ecotone samples against 44 species in the forest samples. This difference is also observed in the mature tree class too (>= 10 to < 60 cm dbh), but almost disappears in the older tree class (>= 60 cm dbh).

A further partitioning of the data on tree\ arborescent species obtained from the forest and forest ecotone stands showed that there exists no species exclusively restricted to the ecotonal region. On the other hand, at least 12 species of evergreen tree species were recorded only in the forest samples studied (Table 5.13).

Of these, five (see Table 5.13) were found to be early or mid successional species associated with the patch-dynamics mechanism of the forest stand. Mallotus albus although belongs to the evergreen forests, characteristically occupy tree falls or slightly disturbed habitats. Boehmeria sp. is often found to occupy edges frequently, although in the samples studied the species did not appear in the ecotonal samples. *Glycosmis mauritiana* and *Atalantia wightii* are undershrubs within the stands. Excluding these early- and mid-successional species, there were only seven species found to be truly restricted to the forest samples. Perhaps a larger sampling might prove that some more of the tree species found restricted to forest samples in the present study extend their distribution to the ecotones.

Table 5.13 Arborescent species found only in the forest samples and not in the ecotone samples.

Species	Density'	Species	Density*
Late-successional		**Early- to Mid- successional**	
Neolitsea cassia	280	*Atalantia wightii*	140
Cryptocarya japonica	280	*Boehmeria* sp.	47
Apollonias arnotii	47	*Glycosmis mauritiana*	47
Artocarpus heterophyllus	47	*Mallotus albus*	47
Haldina cordifolia	47		
Palaquium ellipticum	47		
Xanthophyllum flavescens	47		

* Density per hectare

In the light of the fact that there are no tree\arborescent species restricted exclusively to the forest ecotone, and that most tree\arborescent species found in the forest stands are actually capable of occupying the ecotonal belt, it appears that, the ecotone is in a tonal continuum with the forest.

5.3.1.9 Differences in density of arborescent species in forest and forest ecotone

Comparable with the statistic of species richness across the two habitats, density of tree\arborescent species also showed similar results (Table 5.14).

The mean per hectare density of arborescent taxa >= 3 cm dbh, across the forest ecotone and forest samples were 2842 + 356 and 2044 + 87 respectively From Table 5.14 it can be seen that this difference is less evident in the older tree class (>= 60 cm dbh)

Thus, the gross difference in density across the two habitats is contributed by saplings and mature trees of medium diameters. The high density of these size classes in the ecotone shows that the ecotone is an active center of colonization

Table 5.14 Statistic of density of tree\arborescent species (>=l0 cm gbh: ca 3 cm dbh) in the ecotone and forest sample*@.

Samples	**Diameter classes**							
	3-10 cm dbh		>= 10 to <60 cm dbh		>= 60 cm dbh		Total (>= 3 cm dbh)	
	FE	FO	FE	FO	FE	FO	FE	FO
Sample 1	1904	1281	637	651	42	42	2583	1974
Sample2	1918	1309	1218	637	112	70	3248	2016
Sample 3	1722	1435	931	609	42	98	2695	2142
Mean. SD*	: 1848± : 89	1342± 67	929± 237	632± 18	65± 33	70± 23	2842± 356	2044± 87

* Sample size: 0.15 ha comprising fifteen m² quadrates.
@ All figures represent per hectare densities unded off to whole digits.
FE: Forest ecotone; FO: Forest stand 10-20 m interior from the grassland-forest interface

Table 5.15 Arborescent species with high density in forest ecotone and less in forest*.

Species	**Densityba**		**Species**	**Densityba**	
	FE	FO		FE	FO
Mesua nagassarium	2193	*560*	*Saccopetalum* sp.	4014	1775
Cinnamomum zeylanicum	1913	513	*Aglaia anamallayana*	1214	420
Calophyllum austro-indicum	653	140	*Elaeocarpus munronii*	327	47
Elaeocarpus tuberculatus	327	140	*Trichilia connaroides*	327	94
Persea *macrantha*	1167	513			
Pavetta hispida	1260	375	*Acronychia pedunculata*	1960	420
Maesa perrottetiana	6301	47	*Glochidionneilgherrense*	420	94
Olea dioica	1493	93	*Mallotusphilippensis*	514	280
Allophyllus cobbe	700	141			

Forest ecotone: 0.45 ha with fifteen 100 m² quadrates in 3 replicates
Forest stands: 0.45 ha with fifteen 100 m² quadrates in 3 replicates
* Sample size:

Species restricted exclusively to the forest ecotone were not met with, and that those restricted exclusively to the forest were few. Nevertheless, there are a number of species which have shown distinct demographic differences across the two habitats (Tables 5.15 and 5.16).

Sixteen species were found to have significantly higher density in the ecotone samples, compared to their populations in the forest stands (Table 5.15). When the species were grouped according to their habitat and phenology, they segregated into three categories. Five species, viz, Mesua nagassarium, Cinnamomum zeylanicum, Calophyllum austro-indicum, Elaeocarpus tuberculatus and Persea macrantha were emergent evergreen canopy trees and four species, evergreen underwood species. It is likely that the population status of some these species may also vary, if the sample size is increased further. The rest, seven species, were found to be shrubs or small trees which are commonly found in moist deciduous forests too, except one, Acronychia laurifolia. Not much change in relative distribution across the two habitats can be expected of these species.

While there is a preponderance of the shrubby species which actually contribute to the higher density (of arborescent species in the ecotone), some of the canopy trees and a few evergreen shrubs showed high densities in the forest stands (Table 5.16). The canopy trees included: Palaquium ellipticum, Cullenia exarillata, Canarium strictum and Dymocarpus longan. It also included some medium sized trees such as Turpinia malabarica and Meliosma pinnata. The underwood species included a species of Eugenia and Antidesma each, generally restricted to the underwood stratum. Euodia lunu-ankenda, another early successional colonizer which is also found in the moist deciduous forests, also showed a similar distribution across the forest-forest ecotone habitats (Table 5.16).

The actual number of tree species that are restricted purely to the interior stands of forests are not many. The number of species inhabiting the ecotonal stands is significantly higher than that in the interior forest stands. This definitely means that ecotones are sites for active colonization, which perhaps might be due to higher quanta of incident light.

Table 5.16 Species with high density in forest and less in forest ecotone*.

Species	**Density\ha**		**Species**	**Density\ha**	
	FE	**FO**		**FE**	**FO**
Evergreen emergent\small trees			**Evergreen undershrubs**		
Palaquium ellipticum	1913	3220	*Eugenia* sp.	47	467
Cullenia exarillata	1540	2474	***Antidesma menasu***	233	700
Dymocarpus longun	1400	2286			
Canarium strictum	93	233	**Tree found in tree fall gaps; also found in deciduous forests**		
Meliosma pinnata	467	887			
Turpinia malabarica	234	421	***Euodia lunu-ankenda***	280	747

Forest ecotone: 0.45 a with fifteen 10 m^2 quadrats in 3 replicates
Forest stands : 0.45 ha with fifteen 100 m^2 quadrats in 3 replicates:
* Sample size:

5.3.2 Patterns and processes in the high elevational grassland-forest continuum (Eravikulam)

5.3.2.1 Shola forest at Nilagiri Teri, Eravikulam NP

The shoal forests studied belonged to the montane temperate forests as described by Champion and Seth (1968). These are patchy woods or glens sheltered to hill folds and extending to a few hectares or smaller narrow patches recoursing the streamlets along higher elevations along the Western Ghats. Compared to the Wet Evergreen forests, the stands are more or less stunted having a height not exceeding 15-10 m at 2100-2200 m asl. Structure of two 0.25 ha stands, one at 1950 m as1 (Nilagiri Teri) and another at 2,100 m as1 (V-Point), both falling within the Eravikulam National Park, is given in Tables 5.17 and 5.18. Further details on the shola forests in general and of the study sites in particular are to be found in Studies on the Shola Forests of Kerala (Swarupanandan *et al.*, 1998).

The stand structure at Nilagiri Teri (1950 m) had eight tree species with RIVI >= 5%. Approximately 70% of the density, 65% of frequency, more than 77% of the basal area and around 71% of the relative importance value were contributed by these eight species. The dominant species were: *Chionanthes macrocarpa, Mastixia arborea, a Lauraceous taxon, Actinodaphne bourdillonii, Isonandra candolleana, Syzygium densflorum, Gomphandra coriacea* and *Glochidion neilgherrense.*

The actual number of tree species that are restricted purely to the interior stands of forests are not many. The number of species inhabiting the ecotonal stands is significantly higher than that in the interior forest stands. This definitely means that ecotones are sites for active colonization, which perhaps might be due to higher quanta of incident light.

The rest of the species numbering 23, while increased the diversity content contributed only a minor share to the community in terms of phytosociological attributes. The names of the species are to be found in Table 5.17.

At the second sampling site (V-Point, 2,100 m asl), again the high proportion of density, basal area, fiequency, and RIVI were contributed by a few (6) dominant tree species. The species were: *Cinnamomum wightii, Ilex* sp., *Ligustrum perrottettii, Syzygium densiflorum* and *Elaeocarpus recurvatus*. But here the 23 non- dominant tree species constituted approximately 51% of the RIVl and therefore differs from Nilagiri Teri stand (1950 m). The details of the species and their phytosociological attributes are given in Table 5.18.

5.3.2.2 High-elevational grassland of Eravikulam

The grassland of Eravikulam studied in conjecture with the shola forests belong to the moist grasslands of the *Chrysopogon zeylanicus-Arundinella vaginata* community (Blasco, 1971). The dominant grass species in the community were: *Chrysopogon zeylanicus, Eulalia* sp., *Arundinella mesophylla, Arundinella fuscata* and *Eulalia phaeothrix*. Depending upon the site, compositional changes are often met with, but there are no appreciable changes in the constitution of the dominant species. Many of the dominant species are short grasses growing not more than 1 m or so. General stand structure of the grassland vegetation is described in Table 5.19.

Table 5.17 Phytosociological details of shola forests at Nilagiri Teri, Eravikulam (1,950 m)*.

Species	D\ha	BA\ha	RD@	RF@	RBA@	RIVI@	CRIVI@
8 Species with RIVI >=5%	464	34.0203	69.9	65	77.1	70.7	
19 Species with RIVI >= 5%	200	10.1086	30.1	35	22.9	29.3	
Chionanthes macrocarpa	136	7.9992	20.5	13.8	18.1	17.5	17.5
Mastixia arborea	80	3.7585	12	11.4	8.5	10.7	28.1
Lauraceae (Unidentified sp)	72	5.2325	10.8	8.9	11.9	10.6	38.7
Actinodaphne bourdillonii	52	3.2906	7.8	9.8	7.5	8.4	47
Isonandra candolleana	36	3.9279	5.4	5.7	8.9	6.7	53.7
Syzygium densiflorum	12	6.5808	1.8	2.4	14.9	6.4	0.1
Gomphandra coriacea	44	1.2134	6.6	7.3	2.8	5.6	5.7
Glochidion neilgherrense	32	2.0174	4.8	5.7	4.6	5	70.7
Persea macarantha	16	2.5082	2.4	2.4	5.7	3.5	74.2
Pygeum gardneri	20	1.3380	3	4.1	3	3.3	7.6
Cinnamomum wightii	24	0.4297	3.6	4.1	1	2.9	80.5
Scolopia crenata	28	0.4493	4.2	3.3	1	2.8	83.3
Symplocos cochin-chinensis	20	0.4026	3	4.1	0.9	2.7	85.9
Syzygium sp. pilla njaval	4	2.0206	0.6	0.8	4.6	2	87.9
Garcinia cowa	8	1.2555	1.2	1.6	2.9	1.9	89.8
Saprosma foetens	12	0.2173	1.8	2.4	0.5	1.6	91.3
Symplocos sp.	12	0.5006	1.8	1.6	0.9	1.5	92.9
Ternstroemia japonica	8	0,3699	1.2	1.6	0.8	1.2	94.1
Lasianthus acuminatus	8	0.1395	1.2	1.6	0.3	1.1	95.1
Cinnamomum sulphuratum	8	0.0759	1.2	1.6	0.2	1	96.1
Isonandra sp.	8	0.0849	1.2	0.8	0.2	0.7	96.9
Unidentified sp. (konnayandi)	4	0.1303	0.6	0.8	0.3	0.6	97.4
Maesa perrotetiana	4	0.0703	0.6	0.8	0.2	0.5	98
Rubiaceae (Unidentified sp)	4	0.0616	0.6	0.8	0.1	0.5	98.5
Symplocos spicata	4	0.0588	0.6	0.8	0.1	0.5	99
Meliosma pinnata	4	0.0484	0.6	0.8	0.1	0.5	99.5
Litsea sp.	4	0.0459	0.6	0.8	0.1	0.5	100
Total:	664	44.1278	100	100	100	100	100

* Sample size: 0.25 ha; Trees >= 10 cm dbh.; @, Figures ruounded off to one decimal place.
BA: Basal area; CRIVI: Cumulative RIVI. D: Densty; RBA: Relative; Basal Area;
RD: Relative density; RF: Relative frequency; RIVI: Relative Importance Value (=

Table 5.18 Phytosociological details of shola forests at V-Point, Eravikulam (2,100 m)*.

Species	D\ha	BA\ha	RD@	RF@	RBA@	RIVI@	CRIVI@
4 species with RIVI >= 5%	488	9.3098	57.8	39.2	55.5	50.8	
23 species with RIVI < 5%	356	5.4611	42.1	60.8	44.5	49.2	
Cinnamomum wightii	328	2.1079	38.9	15.8	34.8	29.8	29.8
Ilex denticulata	72	4.8187	8.5	8.3	13.9	10.2	40.0
Ligustrum perrottetii	52	2.3795	6.1	9.1	6.8	7.4	47.5
Syzygium densiflorum	44	1.5550	5.2	7.5	4.5	5.7	53.2
Elaeocarpus recurvatus	44	0.8282	5.2	7.5	2.4	5	58.2
Symplocos sp.	40	1.1168	4.7	6.7	3.2	4.9	63.1
Litsea ligustrina	40	0.6744	4.7	5.8	1.9	4.2	67.2
Rhododendron nilagiricum	20	2.6002	2.3	2.5	7.5	4.1	71.4
Pittosporum tetraspermum	28	0.7349	3.3	4.2	2.1	3.2	74.6
Rapanea wightiana	24	0.5854	2.8	4.2	1.6	2.9	77.5
Eurya nitida	24	0.5809	2.8	3.3	1.7	2.6	80.1
Unidentified sp.	4	2.184 1	0.5	0.8	6.3	2.5	82.6
Cryptocarya sp.	16	0.9117	1.9	2.5	2.6	2.3	85.0
Symplocos sp.	4	1.9728	0.5	0.8	5.7	2.3	87.3
Symplocos cochin-chinensie	20	0.3778	2.4	3.3	1.1	2.3	89.6
Psychotria sp.	16	0.1683	1.9	3.3	0.5	1.9	91.5
Actinodaphne bourdillonii	12	0.2674	1.4	2.5	0.8	1.6	93.0
Vaccinium leschenaultii	8	0.1482	1	1.7	0.4	1	94.0
Lauraceae (Unidentified)	8	0.1296	1	1.7	0.4	1	95.0
Mahonia leschenaultiana	8	0.0825	1	1.7	0.2	1	%.0
Ardisia rhomboidea	8	0.0672	1	1.7	0.2	0.9	97.0
Syzygium sp.	4	0.1263	0.5	0.8	0.4	0.6	97.5
Litsea laevis	4	0.1184	0.5	0.8	0.3	0.6	98.0
Eugenia sp.	4	0.0795	0.5	0.8	0.2	0.5	98.5
Lauraceae (Unidentified)	4	0.0703	0.5	0.8	0.2	0.5	99.0
Saprosma foetens	4	0.0436	0.5	0.8	0.1	0.5	99.5
Ixora sp.	4	0.0412	0.5	0.8	0.1	0.5	100.0
Total:	844	4.7709	100	100	100	100	100

Table 5.19 Structure and dominance pattern of grassland stands at Eravikulam*@.

Species	Density\ha	Species	Density\ha
Nilagiri Ten. 1950 m asl		Umavamalai, 2080 m asl	
Chrysopogon zeylanicus	804	*Eulalia* sp.	1850
Eulalia **sp.**	325	*Chrysopogon zeylanicus*	903
Arundinella mesophylla	213	*Eulalia phaeothrix*	117
Arundinella fuscata	85	*Arundinella fuscata*	44
Eulalia phaeothrix	24	*Eulalia trisnicata*	34
Total for all 10 species	1803	Total for all 9 species	2970

* All figures rounded off to thousands; @ Sample size: Twelve 1 m^2 quadrats

Other grass species in the stands include *Tripogon bromoides, Arundinella ciliata, Heteropogon* sp., *Dicanthium oliganthum, Jansanella griffithiana,* etc. (Tables 5.2 1 & 5.22).

5.3.2.3 Shola forest-grassland continuum

The high elevational grassland also is not so uniform in composition across its length and breadth. Twenty two plant associations have been described from the Eravikulam grasslands (Karunakaran *et al.,* 1997) (Table 5.20).

Table 5.20 Species associations described for the high altitude grasslands of Earavikulam (Karunakaran *et al.* 1997).

Associations dominated by grasses and cyperoids
1. *Schima nervosum-Apocopis wightii-Chrysopgon zeylanicus* assoc.
2. *Eulalia thwaitesii-Habenaria heyneana-Schima nervosum* assoc.
3. *Fimbristylis kinghii-Habenaria heyneana-Schima nervosum* assoc.
4. *Carex phacota-Vanasushava-Schima nervosum assoc.*
5. *Cyperus spp.-Emilia sonchifolia-Schima nervosum* assoc.
6. *Ischaemum indicum-Tripogon ananthaswamianus-Chrysopogon zeylanicus* assoc.
7. *Isachne setosa-Pouzolzia wightii-Chrysopogon zeylanicus assoc.*
8. *Andropogon lividus-Amphalis lawii-Chrysopogon zeylanicus* assoc.
9. *Arundinella purpurea-Phlebophyllum kunthianum-Heteropogon contortus* assoc.
10. *Tripgon ananthaswamianus-Chrysopogon zeylanicus-Heteropogon contortus* assoc.
I I. *Heteropogon contortus-leucas helianthemifoliap Ischaemum indicum* assoc.
12. *Fimbristylis kingii-Schima nervosum-Ischamum indicum* assoc.
13. *Commelina clavata-Chrysopgon zeylanicus-Eriocaulon robustum* assoc.
14. *Smithia blanda-Isachne setosa-Eriocaulon robustum* assoc.
Associations with one or more shrubby components (shrub savannas)
15. *Cyanotis arachnoides-Phlebophyllum kunthianum-Chrysopogon zeylanicus* assoc.
16. *Phlebophyllum kunthianum-Crotalaria fisonii-Chrysopogon zeylanicus* assoc.
I7. *Curculigo orcheoidks-Osbeckia lineoloata-Chrysopogon zeylanicus* assoc.
18. *Garnotia qudrifaria-Hedyotis swertioides-Chrysopgon zeylanicus* assoc.
19. *Swertia corymbosa-Phlebophyllum kunthianum-Schima nervosum* assoc.
20. *Senecio lavandulaefolia-Helictotrichon indicum-Schima nervosum* assoc.
21. *Artemisia nilagirica-Cymbopogon flexuosus-Heteropogon contortus assoc.*

The communities\ vegetal mosaics inhabit diverse niches such as hill top flats, slopes with rocky outcrops, slopes without rocky outcrops, valleys, swampy areas, drainage beds, *etc.* The community differences ultimately assumes to be a matter of micro- environmental differences of the habitats.

Disregarding the above compositional differences of the grassland mosaics, distance dependent relations in the stocking of grasses is also observable. Observed densities of grass shoots computed for every 10 m wide strips starting from the forest- grassland interface to 50 m distance in the grassland are given in Table 5.21.

Table 5.21 Density per hectare of different life forms in the high altitude grasslands with increasing distance from the grassland-forest interface (Nilagiri Teri, 1950 m)*.

Life forms	Locality	Altitude (m)	Density across different distances from grassland-forest interface					
			0-10 m	10-20 m	20-30 m	30-40 m	40-50m	0-50 m
Grasses	NT	1950	1520	1388.3	2080	1960	1645	18.7
	UM	2080	188.3	1594.9	1736.7	714.9	3225	2092
Other	NT	1950	463.3	335	351.7	61.7	123.3	307
Herbs	UM	2080	506.9	260	428.4	176.7	198.7	14.1
Shrubs	NT	1950	423.3	563.3	438.3	288.3	358.3	14.3
	UM	2080	263.5	40.1	54.9	46.7	35.1	8.1

* All figures of density x 10^3. NT: Nilagiri Ten (1950 m asl); UM: Umayamalai (2080 m asl).

The general trend is of increasing density of grass shoots from the vegetal interface to the interior of the grassland, within the 50 m belt. This trend is stronger at Umayamalai (2080 m) than at Nilagiri Ten (1950 m) suggesting an elevational trend too.

Density of different grass species at both of the study sites with differing distances from the vegetal interface is given in Table 5.22 and 5.23. *Arundinella fuscata* shows an almost decreasing trend off density from interface to the interior of the grassland at Nilagiri Teri (1950 m) but shows a patchy distribution with clubbed populations at Umayamalai (1080 m). A species of *Eulalia* showed an ascending trend of density with increasing distance from vegetal interface at Umayamalai (2080 m), but again had a patchy distribution at Nilagiri Teri (1950 m). At Nilagiri Teri (1950 m), *Arundinella mesophylla* showed highest densities between 20-40 m from the vegetal interface and showed lower densities in both directions. The same species however had very low densities at Umayamalai (2080 m). Other grass species also exhibited evidences of patchy distribution in their densities (Tables 5.22, 5.23).

With respect to herbs and shrubs again, exaggregation is generally observed along the ecotonal belts especially within the 0-30 m belt from the interface (Table 5.24). The dominant, most frequent herbs in the high elevational grasslands are in the 0-50 m belt from the vegetal interface (Tables 5.24, 5.25) are: *Curculigo orcheoides, Luctuca hastata, Habenaria* sp., *Xyris* sp. , *Hydrocotyl javanica, Lysimachia deltoidea, Carex mysorense, Crotalaria semperflorens, Ranunculus reniformis, Valeriana hookeriana, Laurenbergia* sp., *Polygala* sp., *Anaphalis* sp., *Cyanotis* sp., *etc.* Some of these species are particularly characteristic of the ecotone: *Curculigo orcheoides, Xyris* sp., *Luctuca hastata, Hydrocotyl javanica* and *Carex mysorense* (Tables 5.24 & 5.25).

Table 5.22 Density per hectare of different grass species in the high altitude grasslands with increasing distance from the grassland-forest interface (Nilagiri Teri, 1950 m)*.

Species	Densitiesacross increasing distaace from grasssland-forest interface					
	0-10 m	10-20 m	20-30 m	30-40 m	40-50 m	0-50 m
Chrysopogonzeylanicus	705	481.7	290	1053.3	555	617
Eulalia sp.	503.3	395	550	300	350	419.7
Arundinella mesophylla	31.7	200	291.7	265	161.7	190
Arundinellafuscata	143.3	175	125	70	101.7	123
Eulaliaphaeothrix	33.3	111.7	100	10	38.3	60
Eulalia trispicata	75	20	90			37
Tripogon bromoides			295	153	41.6	98
Arundinella ciliata	21.7	..	200		40	52.3
Heteropogon sp.	..			130		26
Dicanthium oliganthum	..		105	..		21
Jansnella griffithia			33.3		25	11.7
Themeda sabarimallayana			. .	..	308	61.7
Apluda mutica	._				23.3	4.7
Garnotia tectorum	..	5				1

Table 5.23 Density per hectare of different grass species in the high altitude grasslands with increasing distance from the grassland-forest interface (Umayamalai, 2080 m)*.

Species	Densities acrossincreasing distance from grassland-forest interface					
	0-10m	10-20m	20-30m	30-40m	40-50m	0-50m
Eulalia sp.	266.7	355	698.3	1526.6	2173.3	1004
Chrysopogom zeylanicus	830	1033.2	786.7	1050	754.9	891
Eulaliapheothrix		91.7	125	86.6	146.7	90
Arundinella fuscata		50	38.3	16.7	71.7	35.3
Eulalia trispicata			75	10	58.3	28.7
Apluda	11.7	50	5			13.3
Sporobolus candolleanus	36.6	10	5	1.7		10.7
Garnotia tectorum	43.3		..		6.7	10
Agrostis humilis				23.3	11.7	7
Arundinella mesophylla	..	5	1.7		1.7	1.7
Ischaemum commutatum			I.7			0.3

The commonest shrubs found in the high elevational grassland are: *Stobilanthes kunthianus*, *Ageratina adenophora*, *Hypericum mysorense*, *Pteridium aquilinum* and *Gaultheria fragrantissima*. Along the ecotonal belts, *Ageratina adenophora*, *Pouzolzia bennettittii* and *Pteridium aquilinum* are common (Table 5.26).

Table 5.24 Density per hectare of herb species in the high altitude grasslands with increasing distance from the grassland- forest inter-face (Nilagiri Teri, 1950 m)*.

Species						
	0-10 m	10-20m	20-30m	30-40m	40-50m	0-50m
Curculigo oleoides	173.3	96.7	15	76.7	33.3	79
Lactuca hastata	30	25	133.3	86.7	10	57
Habenaria sp.	1.7	6.7	16.7	15	21.7	57
Crotalaria semperiflorens	10	15	11.7	25	8.3	14
Crotlaria sp.	13.3	21.7	10	16.7	1.7	12.7
Drosera peltata		25	13.3		16.7	11
Anaphalis sp.	3.3	1.7		41.7		9.3
Xyris sp.	176.7	95		..		54.3
Osbeckia sp.	11.7	20				6.3
Justicia sp.	25	..	53.3	..	..	3.3
Andrographis sp.		10	6.7			3.3
15 less freqent species	18.4	18.2	91.3		25	30.7

* All figures of & 10^3

Table 5.25 Density\ha of selected dominant herbs in the high altitude grasslands with increasing distance from the grassland-forest inter-face (Umayamalai, 2080 m)*.

Species	Densities across increasing distance from grasland-forest interface					
	0-10 m	10-20m	20-30m	30-40m	40-50m	0-50 m
Curculigo orcheoides	206.8	20	61.6	96.6	21.8	81.4
Hydrocotyl javanica	90	13.3	15	6.7	11.6	27.3
Lysimachia deltoidea	15	16.7	16.7	1.7	16.7	13.4
Ranunculus reni formis	1.7	3.3	1.7	3.3	1.7	2.3
Valeriana hookeriana		88.4	64.9	5	23.4	36.3
Laurenbergia sp.		6.7	53.3	6.6	13.3	16
Polygala sp.		16.7	13.4	5	23.4	11.7
Anaphalis sp.		8.3	21.7	16.7	8.4	11
Cyanotis axillaris		10	8.4	1.7	26.7	
Calanthe sp.	1.7	11.7		1.7	25	8
Unidentified sp.		5	5	1.7	6.7	3.7
Andrographis sp.	1.7		125	8.3		27
Carex mysorense	90	5	20			23
Lactuca hastata	55				3.3	11.7
Circium sp.	20			5		5
Bupelurum mucronatum				5	13.3	3.7
Apiaceae	3.3	5	5			2.7
16 less frequent species	s 21.7	49.9	16.7	11.7	3.4	20.6

* All figures of density x 10^3.

Local variations exist in the composition of the shrubs of the ecotone and several shrub savanna ecotones have been recognized. Some of the dominant shrubs also form patches of shrub savanna enclosures within the grasslands. Occasionally, some characteristic tree savanna ecotones are also met with (Table 5.27).

Table 5.26 Density per hectare of shrub species in the high altitude grasslands with increasing distance from the grassland- forest interface*.

Species	**Densities across increasing distance from grassland-forestinterface**					
	0-10m	10-20m	20-30m	30-4m	40-5m	0-50m
Nilagiri Ten, 1950 *m* asl						
Strobilanthes kunthianus	361.7	541.7	396.7	275	348	384.2
Ageratina adenophora	50	1.7	6.7	3.3	8.3	14
Hypericum mysorense	8.3		35	10	1.7	11
Gaultheria fragrantissima		20				3.3
Pteridium aquilinum	3.3					0.7
Umayamalai, 2080 **m asl**						
Ageratina adenophora	76.7	21.7	54.9	45	35.1	46.7
Pouzolzia bennettittiana	153.3	11.7		1.7		33.3
Pteridium aquilinum	26.8	1.7				5.7
Rubus niveus	6.7					1.3
Gaultheriafragrantissima	..	5	..			1

Table 5.27 Shrub and tree ecotones and enclosures in the high elevational grasslands at grasslands of Earavikulam.

Shrub ecotones	**Shrub enclosures**
Rhododendron shrub ecotone ***Ageratina*** shrub ecotone ***Nilgirianthus*** shrub ecotone ***Gaultheria*** sbrub ecotone	***Phlebophyllum*** shrub savanna enclosure ***Hypericum-Rhododendron*** shrub savanna enclosure ***Pteridium*** shrub savanna enclosure
Tree ecotone and Tree enclave *Rhododendron-Mahonia leschenaultii* **tree ecotone** **Patchy shola forest enclaved in the grasslands.**	

The patchy montane shola forest enclaves embedded within the grasslands, the tree ecotones, the shrub ecotones and enclosures represent a continuum, than the discrete vegetal units.

5.3.2.4 Invasion of tree seeds to the grassland

Seed invasion in to the high elevational grassland could not be attempted in the present study. However Meher-Homji (1975: cited in *Puri et al.*,1989) has made a classification of the arborescent species of the shola forests according to their dispersal mode. This statistic is further synthesized in Table 5.28.

Tale 5.28 Dispersal modes of arborescent species of the shola forests.

Modes of dispersal	No. of species	Percent
Birds + Bats + Monkeys + Other animals	6	8.8
Birds + Monkeys + Other animals	1	1.5
Birds + other animals	5	7.4
Birds + Bats	2	2.9
Birds alone	48	78.6
Monkeys alone	1	1.5
Birds + Wind	1	1.5
Wind alone	3	4.4
Total:	68	100.0

From Table 5.27 it can be seen that approximately 95.6% of the 68 arborescent species are zoochoric. The animals involved in dispersing the seeds include birds, bats, monkeys and other larger animals, but birds alone is the largest among. In 78.6% of the species dispersal is effected through birds alone. Only 4-6% of the species are capable of dispersing their seeds through wind. Whatever be the population of dispersing animals in the shola forests, the efficacy of zoochory is less compared to that of anemochory and therefore, the density of seeds reaching unit area of the grasslands would be very low. As a matter of fact, the low elevational grasslands and the high elevational grasslands hold the same status, with respect to the invasion of seeds of arborescent species.

5.3.2.5 Tree seed germination and establishment

Seedling emergence of tree species in the grasslands could not be monitored in the high elevational grassland. However, the poor stocking of tree regenerations in the typical grassland areas suggest that establishment of tree seedlings is very poor. Meher- Homji is of the opinion that establishment of tree seedlings in the grasslands are subject to double risk, being affected both by frost during winter and fires during the summer.

5.3.2.6 Differences in tree species in forest and forest ecotone

Table 5.29 is a summary of species richness across forest and forest ecotone stands studied.

Table 5.29 Statistic of species richness of trees/ arborescent species (>=l0 cm gbh:ca. 3 cm dbh) in the ecotone and forest sample;

Category of sample	Size of sample	Replicates	Species no.
Forest + Forestecotone	0.40 ha	1	52
Forest ecotone only	0.20 ha	1	36
Forest stand only	0.20 ha	1	39
Forest ecotone only	0.10 ha	2	26
Forest stand only	0.10 ha	2	24.5

A total of 52 arborescent\ tree species >= 3 cm dbh were encountered in a total of 0.4 ha sample (including both forest ecotone and interior forest samples. Mean figures of 26 species and 24.5 species were recorded from the forest ecotone and forest stands respectively assuming not much of difference in species niches across the two habitats (Table 5.29).

On partitioning the above results for different size classes at Nilagiri Teri (1950 m), there were more number of species in the ecotone stand both for the sapling (3-10 cm dbh class) and mature tree life stages. However, not much appreciable difference is observed at Umayamalai (1080 m). This probably also reflects the reduction in the number of tree species along the ecotones, compared to that at lower elevations (Table 5.30). In other words, the number of pioneer arborescent species capable of invading the grasslands are very less, as elevation goes up.

Table 5.30 Distribution of number of trees\ arborescent species (>= 10 cm gbh:) in the ecotone and forest samples* across different size classes (Eravikulam)

Samples	**Diameter classes**						
	< 10 cm dbh		>= 10 to < 60 cm dbh		>= 60 cm dbh		Sample size*
	FE	FO	FE	FO	FE	FO	
Sample 1	27	24	33	21	4	4	0.10 ha
Sample 2	15	18	19	19	2	9	0.10 ha

* Each sample comprised of ten 100 m^2 quadrats; FE: Forest ecotone; FO: Forest.

5.3.2.7 Differences in tree density in forest and forest ecotone

Distribution of density of arborescent\ tree species across different size classes shows that, in the mature tree phase (10- 60 cm dbh class) and in the older tree phase (>= 60 cm dbh class), density of arborescent species is always higher in the ecotone than in the forest. The trend of density distribution in the sapling phase however is not predictable (Table 5.3.1).

Table 5.31 Density distribution in different size classes in forest and forest ecotone stands in the high elevational belt.

Sample	**Densities in different diameter classes**							
	3-10cm		10-60 cm		> 60 cm		Total	
	FO	FE	FO	FE	FO	FE	FO	FE
1	2470	1500	450	1000	40	60	2960	2560
2	2810	2950	980	1750	10	100	3800	4800

Apart from the gross differences in stand structure between the ecotonal and forest stands, differences in the distribution of individual tree species across these two habitats are also observed. Thirteen species were recorded only from the ecotone samples (Table most of which are probably pioneers. The habitat specificity of the six species recorded only from forest sample is less certain.

Fifteen arborescent species were found to have higher densities in the forest ecotone samples, compared to that in the forest samples (Table 5.33). This included three shrubs: *Maesa perrottetiana, Chasalia curvflora* and *Rapanea wightiana.* In close parallel, two species Cinnamomum wightii and Mastixia arborea were found preferring the forest habitat. Two underwood shrubs, *Lasianthus coffeoides* and *Ardisia rhomboidea* also prefer the forest environment, as evidenced from the density distribution patterns (Table 5.34).

Table 5.32 Species represented only in one of the habitats in the high elevational zone @.

Species	Density\ha	Species	Density\ha
Species found in ecotone only		**Species found only in forest**	
Rhododendron nilagiricum	50	***Symplocos capitatum***	50
Rhodomyrtus tomentosa	20	***Gomphandra coriacea***	40
Ternstroemia japonica	20 .	***Scolopia crenata***	15
Viburnum coriaceum	20	***Excoecaria sp.***	10
Aporusa lindleyana	10	**Shrubs**	
Ligustrum perrottettii	10	***Strobilanthes homotropa***	760
Meliosma simplicifolia	10	***Saprosma foetens***	20

* Density per hectare. @ Sample size: 0.2 hectare comprising of twenty 100 m^2 quadrats.

Table 5.33 Species with high density in forest ecotones samples and sparingly represented in forest stands at the high elevational zone *@.

Species	FO	FE	Species	FO	FE
Microtropis ramiflora	**215**	*505*	*Cryptocarya sp.*	5	40
Litsea wightiana	215	325	*Elaeocarps recurvatus*	5	40
Syzygium densiflorum	*65*	285	*Actinodaphne bourdillonii*	15	35
Neolitsea zeylanica	15	I**15**	*Ilex denticulata*	5	55
Symplocos sp. 2	10	105	Shrubs		
Vaccinium leschenaultii	*5*	105	*Maesa perrottetiana*	5	230
Chionanihes macrocarpa	30	*75*	*Chasalia curviflora*	180	355
Mahonia leschenaultii	10	*75*	*Rapanea wightiana*	30	175

* Density per hectare. @ Sample size: 0.2 hectare comprising of twenty 100 m^2 quadrats.
FE: Forest ecotone; FO: Forest

Table 5.34 Species with high density in forest samples but sparingly represented in forest stands at the high elevational zone*@.

Species	FO	FE	Species	FO	FE
Trees			**Sbrubs**		
Cinnamomum wightii	325	265	*Lasianthus coffeoides*	305	225
Mastixia arborea	150	55	*Ardisia rhomboidea*	665	170

* Density per hectare, @ Sample size: 0.2 ha comprising of twenty 100 m^2 quadrates.

FE: ecotone; FO: Forest stand.

5.4 Discussion

5.4.1 Structure of vegetation

Both at Silent Valley (medium elevational) as well as at Eravikulam (high elevational), the grasslands seem to be a complex of grassy vegetal mosaics. These vegetal mosaics are distributed according to their niche priority. The nonuniformity of these grasslands therefore suggest a dynamic vegetation, than a static one.

The forest stands likewise showed differences in composition along the ecotones and the interior forests. There were species restricted to the ecotones and several species had differing densities along the ecotone and the interior forest again amplifying their habitat specificity. Compared to interior forests, the ecotonal forests had higher species richness, higher density and assumed a 'moving front' of the forest.

Active colonization of the grassland ecotone with shrubs and herbs other than the grasses is quite evident by their density. Colonization of the interior grasslands with ligneous species is also evidenced by the presence of shrub and tree enclosures within the grasslands. Compositional differences exist within the shrub and tree ecotones and shrub and tree savanna enclosures. The different grassy vegetal mosaics, the shrub and tree enclosures and ecotones, the forest ecotones and the interior forest represent a continuum of vegetal mosaics, rather than two water tight vegetal units, the grassland and the forest.

5.4.2 Insufficient seed and seedling banks

Studies on the successional dynamics at the mid-elevational zone showed that the process of tree diaspore invasion into the grasslands is very slow and their germination and establishment is very much strained.

Most of the evergreen forest tree diaspores are heavy. Hardly any seeds of evergreen tree species cross the ecotonal zone and reaches the grasslands except for a few like *Syzygium arnottianum*, were the berries are dispersed by birds, Seeds which arrive the grasslands in slightly larger quantities are of deciduous trees with diaspores transported by wind, birds (*Phyllanthus emblica* and *Zizyphus rugosa*) or animals (*Phoenix humilis*). Even in the case of shrubs which colonize the grasslands are either wind dispersed *(Pteridium aquilinum)* or bird dispersed *(Maesa perrottetiana, Leea* sp.), or with vegetatively regenerating seasonal shoots *(Pleurocaulis sessilis).*

The diaspores of the evergreen trees even if they reach the grasslands have only a short longevity and fail to germinate and establish. Experimental germination studies suggest that even a good percentage of the deciduous tree diaspores reaching the grasslands are devoured by rodents and some percentage of the germinated seedlings destroyed by insect or other pests. Although the grassland soil does not offer much obstruction to germination and establishment of seedlings, the seedling bank which finally survives is that which withstand: (1) the harsh highly seasonal physical environment, (2) the compact soil environment and, (3) the harsh biotic environment involving pests, cattle, and fire. By and large these properties are owned by pioneer shrubs and deciduous trees, and thus the shrub mosaics and deciduous tree enclosures are the mid successional communities in grassland succession.

In the high elevational zone again, the tropical trees of the shola forests also have heavy diaspores although in comparison to the diaspores of the wet evergreen forests they are smaller and lighter, and are not adapted to wind dispersal. A good percentage of the diaspores of arborescent species are baccate (berries) and the prevalent active dispersal mechanism perhaps is bird dispersal. The quantum of seeds that can be dispersed by birds definitely should be lesser than by anemochory and‘the quantum of seeds of arborescent species immigrating into the grassland could be very low as is the case with the mid elevational zone too. The ligneous species which are successful in colonizing the high elevational grassland are anemochorous. Rhododendron, a pioneer colonizer in the high elevational zone, has a fundamentally different morphology for its fruit, a capsule, and the seeds are extremely small and therefore spread by wind. Shrubs colonizing the ecotones and shrubby enclaves like *Pteridium aquilinum* (the bracken fern), *Ageratina adenophora* have minute spores or comose seeds and are therefore dispersed by wind. The shrub, *Phlebophyllum kunthianum*, the counterpart of *Pleurocaulis sessilis* in the mid-elevational zone, has exactly the same regeneration strategy of the latter, ie, by vegetative means. It suffices to conclude that the paucity of invading diaspore populations and seedling banks of arborescent\ ligneous species in the grasslands in both the elevational zones is experienced very much.

Very little is known on the fate of seeds reaching the grasslands and the establishment of the seedlings of arborescent species except that the scorching winter cold (and frost), summer dryness and fire slacken the tree seedling banks in the grasslands. From the germination experiments conducted in this study it is known that at least in the mid elevational zone, rodents and other animal pests affect survival of seeds and seedlings of arborescent species. Perhaps similar biological controls operate in the high elevational zone too.

5.4.3 Paucity of pioneer arborescent species capable of invading the high elevational grasslands

Throughout Kerala, the annual pluvial precipitation is well over 2,500 mm (except at certain leeward slopes like Marayur, Chinnar, etc). Thus, according to the climatic regime the whole area falling within the geographic limits of the Kerala State can potentially evergreen forests. However, substantial area on the windward side of the Western Ghats in Kerala holds natural moist deciduous forests. The occurrence of moist deciduous forests comprising mostly of hard wood species in the so called potentially evergreen areas is generally considered to be due to recurring fire (Pascal, 1988) and consequently the moist deciduous forests in Kerala are considered fire climaxes (Seth and Kaul, 1978; Champion, 1936; Champion and Seth, 1968).

If the area now occupied by the grasslands were under recurring fire continuously for a number of years, grassland is not the kind of climax vegetation to be expected. In areas receiving >= 1,500 mm of rain per annum we can expect the development of a fire-climax vegetation, such as a moist deciduous forest, where the living biomass of the vegetation is fairly higher than that of the grassland. The average annual precipitation at Eravikulam and Nilgiris is sufficiently higher than 1,500 mm and the formation of a moist deciduous forest would be justified. Indeed along moderate elevations (ca. 900-1,400 m asl), in places like Idukki, the grasslands have been found to be colonized by moist deciduous tree species like Phyllanthus emblica, Careya arborea, Terminalia crenulata etc. where the characteristic forest vegetation in the same topography is evergreen\ subtropical hill forests which are to be expected to colonize the grasslands. However, moist deciduous forests are absenting in their sera1 some what advanced stage in the grasslands of higher elevations, say >= 2,000 m gasl.

The pronounced absence of moist deciduous forests at these elevations are for two reasons. As elevation goes up, the diurnal temperature goes down and the mean temperature at Eravikulam and Nilgiris is around 15°C. Most of our hard wood species occupy habitats with a higher diurnal temperature flux which in turn harden their wood tissue and are presumably not capable of inhabiting cooler climates. In other words, should a drought climax or fire climax arborescent vegetation develop along higher elevations affected by fire, the species have to be of fire hardy temperate elements. Not only that these species have to be fire hardy, but they should also be capable of withstanding the extreme cold during the winter, which often might go as low as -9°C (Legris and Blasco, 1969). In other words, the fire hardy tree species should be winter hardy too.

A typical example of a tree species which is both fire hardy and winter hardy is Rhododendron nilagiricum. Not many other species of this physiological ability are known form higher elevations of South India. On the other hand Rhododenron trees are found colonized along the shola forest margins (Fig. 4.33), along with trees of Mahonia leschenaultii and species of Rapanea. Seedlings of Rhododendron are also capable of colonizing grasslands adjacent to the shola forest patches (Fig. 4.33 & 4.35).

Unlike most other shola forest species (which have berries) Rhododendron has a capsule that breaks open when the atmospheric humidity lowers (as it happens during a fire incidence) and the seeds are very tiny to be carried away by wind. Examination of a large number of seedlings of R. nilagiricum, 10-15 cm tall has shown that they are no recruits of the current year(4.34). They all had stout root stocks, inferring their age to a few years and the effect of previous year's attack of fire on the seedling. This regeneration strategy is identical to that of a number of moist deciduous and dry deciduous tree species such as Terminalia paniculata, T. crenulata, T. bellirica, Xylia xylocarpa, Pterocarpus marsupium, Hymenodictyon excelsum and Commiphora caudata which inhabit fire fi-equent habitats.

But, unlike the fire hardy moist deciduous forest trees, *Rhododendron* does not form a vast forest stand. For, as soon as the Rhododendrons establish a fire hardy belt, the temperate and tropical arborescent elements which are not capable of resisting fire find shelter within the *Rhododendron* woods and establish there, pushing the successive generations of *Rhodendrons* to the periphery and eliminating the *Rhododendrons* from the center. Thus this amphitolerant tree species, unlike the woody moist deciduous forest species, do not form an extensive vegetation; but together with other tropical and subtropical tree species inhabiting higher elevations, they form a mixed centripetally staratified vegetation, where the fire hardy belt occupying the periphery of shola forests. Paucity of amphitolerant tree species might be offering some amount of stability to the grasslands. However, during the last 30,000 year history of grasslands (Vasanthy, 1988) regular fire had a history of only less than 1,000 years (Ranganathan, 1938) in the current millenium. The amphitolerant pioneer arborescent vegetal mosaic only needed to be drought tolerant rather than fire tolerant, the fire tolerance requirement being relatively recent.

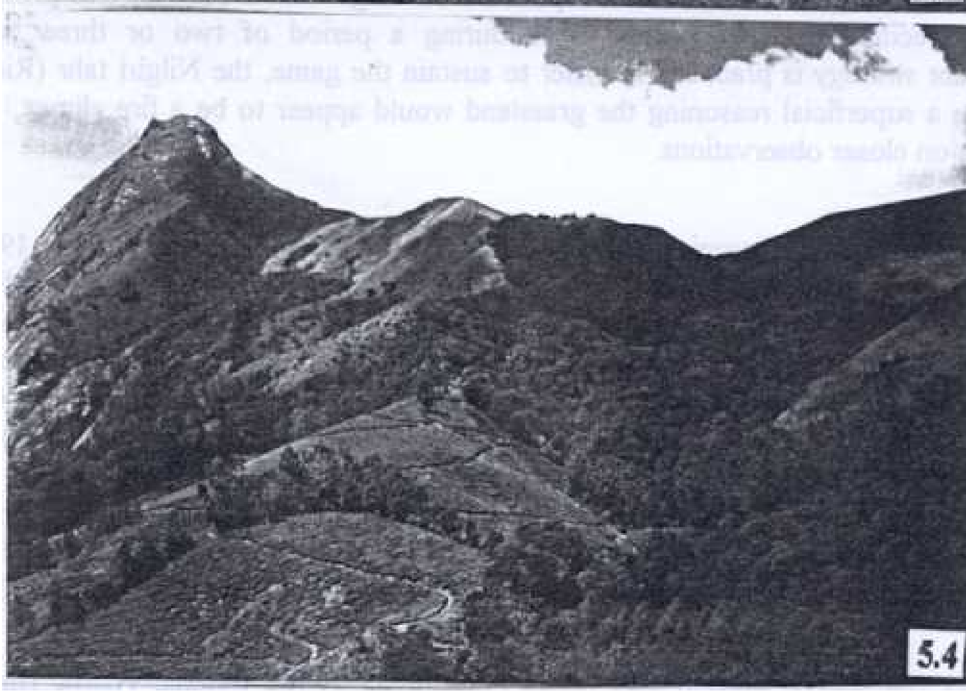
At elevations >= 1,500 m gas1 plantations of eucalypt and black wattle have been raised along the high altitude grasslands of Munnar, Eravikulam, Devikulam, Vallakkadavu, Sabarigiri and other places (Figs. 5.1 & 5.2). Eucalypts although cannot be considered fire hardy, fire tolerant or fire loving, black wattle is definitely fire loving. Copious regeneration is obtained for black wattle on burning the stands. It also invades into burned grassland areas rather quickly as has happened in the Eravikulam National Park (Karunakaran *et al.*, 1997). The success of eucalypt and wattle in mountain grasslands is indicative of the fact that there is paucity of the right kind of arborescent species capable of colonizing the landscapes.

5.4.4 The status of the shola forests

One of the reasons why the grasslands have been considered climax is because of the reluctance of the shola forest patches in actively expanding into the grasslands. In the medium elevational grasslands, a number of mid-successional tree savanna enclosures have been observed, as described in a previous section. These sylvan patches represent loci of forest building which proceed onto an evergreen forest. In the high elevational grasslands, there is no mid - successional deciduous tree savanna counterparts. However, it must be remembered that here the grassland is the general vegetation in which the shola forest patches are distributed as smaller sylvan patches and the latter are therefore comparable to the tree savanna enclosures in medium elevational grasslands. There are reasons to believe that the shola patches are in their expanding phase (5.3 & 5.4) as evinced from the patterns of differential distribution of shola patches of differing sues. The larger shola patches occupy a lower elevation and the smaller ones the upper elevation (Babu, 1997).

The shola forests although represent the climax vegetation also contains pioneers like Rhododendrons along their periphery. The last 100 year history of exorbitant human population build up, the plantation activities in the shola forest areas (Fig. **5.3)** and increased grassland fire that spread into the shola forests are other reasons why the shola forests do not spread actively. On these grounds, the grassland does not seem to represent a climax.

Figures 5.1. & 5.2. Afforested grasslands at Vallakkadavu in the Grassland Afforestation Division, Peermedu. Fig. 5.1. A young eucalypt plantation. Fig. 5.2. An approximately 2-year old plantation.



Figures 5.3 & 5.4. Two facets of the shola forests. The patchy shola forests are said to be diminishing in extent. However, the nuclear shola patches like the one in figure 5.3, at the top hills in their folds tell us more of a developing shola forest patch than of a dwindling one. Reduction in the area under shola forests mainly result from human activities such as plantation work (Fig. 5.4.), fire, etc. Otherwise, sholas are actually invading into the grasslands, from the nuclear loci situated in the folds and troughs between the rolling hillocks (Fig. 5.4).

Paucity of seeds of arborescent species invading the grasslands and the corresponding slow pace of tree invasion into the grasslands, paucity of pioneer tree species invading the high elevational grasslands and the long history of grasslands extending into geological time scales might suggest the grassland a climax vegetation.

5.5 Grassland a fire/biotic climax

Approximately one half of the investigators who have conducted studies on grasslands have opined that fire has been a major cause for the stability and spread of grasslands (Champion, 1936; Bor, 1938). Even today, it is not infrequent that occasionally shola forests are subject to burning, due to accidental spread of fire from the grasslands. In such cases grasses are found to colonize the burnt shola forest patches and some times a dense short bamboo, which again is a grass (belonging to Poaceae) scientifically. Thus much of the boundaries between the grasslands and the shola forests might have undergone rearrangements because of the recurring fire that pervaded the highlands during the past.

Taking Eravikulam as a case study, pres erved management records stands proof that the area had been under the practice of periodic burning. Annual burning was practiced such that any specific area gets burned once during a period of two or three years. This management strategy is practiced in order to sustain the game, the Nilgiri tahr (Rice, 1984). Thus from a superficial reasoning the grassland would appear to be a fire climax, but which obliterates on closer observations.

Vegetal fire along tropical latitudes is almost entirely anthropogenic (Fox, 1976). As is on today, the present population at Eravikulam including its nuclear townships (Munnar and Devikolam) and the distributed settlements, is not much. All historical and present settlements are far away from the elevated plateau of Eravikulam, both in terms of distance and the hostile environment. The earliest known human settlement was located at Marayoor, where the megalithic prehistoric man lived until 500 BC. the Muthuvans, the tribals at Lakkam colony (situated on the border of the Park), which count to ca. 200 in number today should have been much fewer in the past. Their invasion to the area from Tamilnadu is associated with the story of Karnaki and dates back to 1,400 AD (Singh, 1994; Karunakaran *et al.*, 1997). It is highly improbable that the park area had been under pronounced influence of fire before 1900.

The Eravikulam plateau was under the control of the Kannan Devan Hill Produce Company (KADHPC) until 1970 and was managed by an NGO, the High Range Game Preservation Association (HRGPA) since 1928. Membered chiefly by the plantation managers, the HRGPA utilized the plateau as a game land. The regulatory management strategy for the grasslands originated with them, as burning provided fresh grassland growth to attract the game animals, which mainly comprised the Nilgiri tahr but included other animals too. The burning regime seems to have been carried over even after the constitution of the Eravikulam Wildlife Sanctuary in 1975 and its subsequent agggradation to National Park in 1978 (Rice, 1984).

The above discussions allow to presume a regular burning history of the grasslands at Eravikulam not earlier than 1930s. History of the Nilgiri plateaux also provides a compatible picture. Before the history of recent immigrations during the British period, the Todas, Badagas and Kotas were the original communities in the land. Of these, only the Badagas practiced (shifting) agriculture and both Badagas and Todas practiced pastoral activities while the Kotas were purely artisans. Badagas are immigrants from Karnataka and seems t o have arrived the land somewhere between 1,200-1,400 AD. The Todas claim to be the original inhabitants of the land and the earliest literary record available of them dates back to 1,100 AD or so. Burning the grassland was a custom with the Todas and the Badagas who cleared vast areas for shifting cultivation. Generalization from the reminiscent histories, the burning of grasslands in the Nilgiris could not have had a history running back beyond 1,000 AD, or at best not beyond 500 AD.

Palaeontological evidences suggest the presumption that the tropical high altitude grassland communities existed approximately 30,000 years BP (Vasanthy, 1988) ie, much before man began using fire as a tool in managing the vegetations. Therefore on the basis of existing knowledge of regional palaeontology, anthropology and history, the 'pyrogenic origin of grasslands' proves to be non-axiomatic and Shetty and Vivekananthan (1971) were right in holding that anthropic attribution of the origin of natural grasslands along the Western Ghats do not hold true. They are actually remnants of the once more extensive natural grasslands (cf also Tivy, 1982). However, their their stability in the recent past (in the current millenium) has been largely due to anthropic intervention and fire. Many shola forest patches have been partially or completely burned and invaded by grasses preferring habitats disturbed and matches the 'man-fire-grazing symbiosis' origin (Tivy, 1982) of many grasslands in the temperate latitudes (Sauer, 1950; Wells, 1945). Presence of fire hardy tree elements in savannas, invasion of trees to grasslands under protection also substantiate this (Tivy, 1982). Here, of course the fire\ biotic climax concept also holds true.

5.5 Conclusions

1. Within the grass lifeform, there are species preferring different niches, and so are the different kinds of trees in the forest, indicating the presence of many different niches in both the ecosystems.

2. Most large sized grasslands along the Western Ghats fall in the climatic zone of the Wet evergreen and shola forests. The fruits and seeds of the trees in these ecosystems are generally heavy, and therefore scarcely cross the elevational belt, and reach the grasslands.

3. Most of the arborescent species that find their way to colonization into the grassland are moist deciduous trees in the medium elevational zone, and fire and frost tolerant trees in the high elevational zone. Microclimatic and disturbance factors are evidently involved in the slow colonization of grasslands by tree species.

4. The thick grass growth probably does not affect germination of arborescent species in the grasslands but their survival is affected. Perhaps animal pests such as rodents are also important in affecting survival of seeds and seedlings in the grasslands. affected by rodent and other pests.

5. Density of annual tree recruits getting established in the grassland is very low, being only a portion of the small seed lot arriving there.

6. Apart from the fact that grasslands are invaded by trees at a slow pace, the forest ecotones are proved to be active centers of colonization, both in species richness and stocking. The grassland ecotones lying adjacent to the forest ecotones are also active centers of colonization by shrubby species, and therefore represent the moving front of the forest edge.

7. Unavailability of the right kind of arborescent species capable of invading the grasslands is experienced in both the medium elevational and high elevational grasslands.

8. Considering the slow rate of invasion of arborescent species and taking into consideration the biotic disturbances, it is quite likely that the grasslands would keep its physiognomy at least for another few hundread years. That is, the grassland is a stable vegetation if the period of colonisation is only a few hundread years fom now.

9. Absence of the right kind of species to change the vegetal strucutre and the relative stability are indications of climax vegetations. However, it should be remembered that the observations leading to these conclusions stem from short term studies. But if we interpret the vegetal structure, which is produced as a result of long term processes, the grassland is dynamic. The dual picture owes to the descriptive nature of the 'climax concept' than a desirable definitive definition.

10. History of human population development and history of widespread and recurring vegetal fires along the Western Ghats have only a short history of less than 1,000 years. In the 30,000 years of history of grasslands in this geographic region, grasslands have acquired a fire climax status too, in the recent past.

CHAPTER 6. THE SOIL PROFILE

6.1 Introduction

Soil is the substratum in which, the geotropic half of the vegetation is embedded and which yields necessary macro- and micro- nutrients. More than the nutrients, soil also provides the para-gravitational orientation to plants. Most of the moisture required for the build up and perendurance of biological matter is also obtained from the soil. Yet more than the chemical composition (the mineral composition), the morphological (physical) properties of the soil such as profile (depth or thickness), texture, porosity, moisture holding capacity, etc also affect the vegetation and the biological spectrum.

The present studies were conducted mainly to understand whether the grassland and the forest vegetations differin soil characteristics. In other words, the pedological studies were aimed at understanding the probable edaphic reasons if any, of distribution of grasslands and forests, by restricting the studies to selected locations.

6.2 Materials and methods

6.2.1 Sample areas

Soils studied included two elevational zones, viz, the mid elevational zone represented by the Silent Valley National Park (1,000 to 1,300 m asl) and the high elevational zone represented by the Eravikulam National Park (1,900-2,200 m asl). Throughout this chapter, the term mid elevational zone (MEZ) and Silent Valley have been used interchangeably; in a similar manner, the term high elevational zone (HEZ) and Eravikulam have been used reciprocally.

Altogether, 93 soil pits were sampled, of which 35 pits belonged to the Silent Valley National Park, ie, mid-elevational grassland-evergreen forest continuum (MEZ)] and 58 pits belonged to the Eravikulam National Park, representing the high elevational grassland-shola forest continuum (HEZ). The locational address of the sample pits are given in the Tables 6.1 and 6.2.

6.2.2 Vegetal types

In each of the elevational zones, the study vegetations included three or four physiognomic vegetal types: the grasslands, the shrublands, tree enclosures and forestlands. The shrublands included both shrub enclosures within the grasslands and shrub ecotones. The tree enclosures are wooded patches within the grasslands. The forestlands are wooded formations quite distinct from the grasslands. In the high elevational zones, both tree enclosures and forestlands coincide, as forests are fiagmented groves within the vast expanse of the grasslands.

Table 6.1. Description of soil pit sites at Silent Valley

No	Locality	Veg. type	Vegetal mosaic	Habitat	Altitude	n*
1	Pulippara	GL	*Arthraxon sp.*		870	2
2	Pulippara	GL	*Eragrostis sp.*		870	2
3	Pulippara	GL	*Themeda triandra*		870	2
4	Pulippara	GL	*Themeda-Cymbopogon*	Moist	875	3
5	Pulippara	GL	*Themeda-Cymbopogon*	Lower	875	1
6	Pulippara	GL	*Themeda-Cymbopogon*	Middle	875	1
7	Pulippara	GL	*Themeda-Cymbopogon*	Top	875	1
8	Pulippara	GL	*Themeda-C'ymbopogon*		900	1
9	Chembotty	GL	*Themeda-Cymbopogon*	Lower	840	1
10	Chembotty	GL	*Themeda-Cymbopogon*	Middle	850	1
11	Chembotty	GL	*Themeda-Cymbopogon*	Top	900	1
12	Aruvampara	GL	*Themeda-Cymbopogon*	Top	900	1
13	Pulippara	SEn	*Pteridium aquilinum*		870	1
14	Aruvampara	SEn	*Pteridium aquilinum*		950	1
15	Pulippara	SEc	*Maesa perrottetiana*		900	1
16	Aruvampara	SEc	*Maesa perrottetiana*		900	2
17	Aruvampara	SEc	*Nilgirianthus sp.*		850	1
18	Aruvampara	SEc	*Nilgrianthus sp.*		900	2
19	Pulippara	SEc			900	1
20	Pulippara	TE	*Pterocarpus marsupium*		870	3
21	Aruvampara	TE	*Phoenix humilis*		900	1
22	Pulippara	TE	*Phoenix humilis*		900	1
23	Kunthipuzha	TE	*Phoenix humilis*		900	1
24	Pulippara	EGF		Not burnt	850	1
25	Pulippara	EGF		Burnt	800	1
26	Chembotty	EGF		Burnt	850	1

Table 6.2 Description of soil pit sites at Eravikulam.

NO.	Locality	Veg.	Vegetal mosaic	Habitat	Altitude
1	V-point	GL	*Jansanella-Tripogon*	Rocky	2150
2	V-point	GL	*Tripogon-Arundinella*	Rocky	2170
3	Mampallam	GL		Burnt	1970
4	Mampallam	GL		Burnt	1990
5	Mampallam	GL		Burnt	2000
6	Anaimudi	GL	*Eriocaulon-Garnotia*		2060
7	Anaimudi	GL	*Eriocaulon-Gamotia*		2060
8	Anaimudi	GL	*Gamotia tectorum*		2020
9	Anaimudi	GL	*Garnotia tectorum*		2060
10	Anaimudi	GL	*Eulalia phaeothrix*		2040
11	Anaimudi	GL	*Eulalia phaeothrix*		2060
12	Anaimudi	GL	*Eulalia phaeothrix*		2070
13	Vattasathampu	GL	*Eulalia phaeothrix*		2150
14	Vattasathampu	GL	*Eulalia phaeothrix*		2170
15	Vattasathampu	GL	*Eulalia phaeothrix*		2190
16	Amarachola	GL	*Chrysopogon zeylanicus*		2060
17	Amarachola	GL	*Chrysopogon zeylanicus*		2080

Gl: Grassland; EGP: Evergreen forest; TE: Tree enclosure; SEC: Shrub ecotone;
SEn: Shrub enclosure; SF: Shola forest Veg: Vegetation; FE: Forest ecotone. (.. table contd.)

Table 6.2 Description of soil pit sites at Eravikulam (contd.).

No.	Locality	Veg.	Vegetal mosaic	Habitat	Altitude
18	Amarachola	SEn	***Gaultheria fragrantissima***		2060
19	Amarachola	SEn	***Gaultheriafragrantissima***		2075
20	Amarachola	SEn	***Gaultheria fragrantissima***		2090
21	Mestrikettu	GL	***Arundinellafuscata***		2100
22	Mestrikettu	GL	***Arundinellafuscata***		2130
25		GL	***Arundinellafuscata***		2070
23	Anaimudi	GL	***Arundinella ciliata***		2060
24	Anaimudi	GL	***Arundinella ciliata***		2060
26	Vattasathampu	GL	***Tripogon bromoides***		2160
27	Vattasathampu	GL	***Tripogon bromoides***		2180
28	Vattasathampu	GL	***Tripogon bromoides***		2200
29	v-point	SEc	***Strobilanthes sp.***		2070
30	V-pint	SEc	***Strobilanthes sp.***		2100
31	V-point	SEc	***Strobilanthes sp.***		2150
32	Mestrikettu	SEc	***Strobilanthes homotropa***		2130
33	Mestrikettu	SEc	***Strobilanthes homotropa***		2160
34	Amarachola	SEn	***Hypericum-Rhodoendron***		1940
35	Amarachola	SEn	***Hypericum-Rhodoendron***		1960
36	Amarachola	SEn	***Hypericum-Rhodoendron***		1970
37	Amarachoia	SEc	***Pteridrum aquilinum***		1890
38	Amarachoia	SEc	***Pteridium aquilinum***		1910
39	Amarachola	SEc	***Pteridrum aquilinum***		1920
40	Amarachoia	GL	***Chrysopogonzeylanicus***		1890
41	Amarachola	GL	***Chrysopogonzeylanicus***		2060
42	Amarachoia	GL	***Chrysopogonzeylanicus***		2080
43	Ushikan	SEc	***Ageratina adenophora***		2120
44	Ushikan	SEc	***Ageratina adenophora***		2145
45	Ushikan	SEc	***Ageratina adenophora***		2160
46	Amarachola	FE			1900
47	Amarachola	FE			1920
48	Amarachola	FE			1970
49	Nilagiri Teri	SF			1880
50	Nilagiri Teri	SF			1910
51	Nilagiri Teri	SF			1940
52	v-point	SF			2135
53	V-point	SF			2140
54	v-point	SF			2150
55	V-point	SF	***Chimonobambusasp.***		2135
56	V-point	SF	***Chimonobambusa sp.***		2140
57	V-point	SF	***Chimonobambusa sp.***		2150

GL : Grassland; EGF: Evergreen forest; TE: Tree enclosure; SEC: Shrub ecotone; SEn: Shrub t, enciosure; SF: Shola forest; Veg: Vegetation; FE: Forest ecotone.

Each of these physiognomic vegetations is represented by a variety of compositional, moisture regemic, disturbance or elevational variants. Such variant stands are often of local existence or often of smaller extents except a few of them and are therefore termed 'vegetal mosaics'. These vegetal mosaics are important from the point of view of succession, and in each elevational zone, they differ in composition and other details. Throughout this study, for the ease of discussions, the terms 'vegetal mosaic' and 'vegetal type' are used more or less synonymously, although from the point of vegetal taxonomy, most of these mosaics do not qualify addressing by the term vegetal type.

The vegetations studied are therefore recognized in two levels: (1). the physiognomic leve1,and (2). the species compositional or mosaic level. The latter are interwoven within the physiognomic vegetation types. The physiognomic and mosaic vegetal types falling within, of which soil samples were collected for analysis are given in Table 6.3. Altogether, from both the elevational zones, 33 vegetal mosaics were represented. Details of the vegetal mosaics are given in Chapter 4.

Table 6.3 Vegetation mosaics studied for soil characteristics

I. Grasslands	**II. Shrub ecotones/ enclosures**
1 .1 Mid elevational Grassland mosaics 1 ***Arthraxon*** consociation **(grassland)** **2** ***Eragrostis*** conlsociation **(grassland)** **3** ***Themeda triandra*** association **(grassland)** **4** ***Themeda-Cymbopogon*** **dominant grassland** (Moist site) *5* ***Themeda-Cymbopogon*** **dominantgrassland** (Mesic site)	**2.1 Mid levational Shrub ecotones/ enclosure mosaics** **16** ***Pteridium aquilinum*** shrub ecotone **17** ***Maesa perrottetiana*** shrub ecotone, encl. 18 ***Nilgirianthus sp.*** shrub ecotone 19 ***Pleurocaulis sessilis*** shrub enclosure
1.2 High elevational Grassland mosaics **6** ***Jansanella-Tripogon*** dominant grassland *7* ***Tripogon-Arundinella ciliata*** dominant **grassland(rocky)** 8 Burnt grasslands 9 ***Eriocaulon-Garnotia*** dominant grassland 10 ***Garnotia tectorum*** dominant grassland 11 ***Eulalia phaeothrix*** dominant grassland **12** ***Chrysopogon zeylanicus*** dominant grassland **13** ***Arundinellafuscata*** dominant grassland 14 ***Arundinella ciliata*** dominant grassland 15 ***Tripogon bromoides*** dominant grassland	**2.2** High **elevational Shrub ecotones/ enclosure mosaics** 20 ***Gaulthena fragrantissima*** shrub encl. 21 ***Strobilanthes sp.*** shrub ecotone 22 ***Strobilanthes homotropa*** shrub ecotone **23** ***Hypericum-Rhododendron*** shrub ecotone **24** ***Pteridium aquilinum*** shrub ecotone/encl. **25** ***Ageratina adenophora*** shrub ecotone **26** ***Phlebophyllum kunthianum*** shrub encl. **III. Tree enclosures/ Forest ecotones** **3.1 Mid elevational Tree enclosure/Forest ecotone mosaics** **27** ***Pterocarpus marsupium*** tree enclosure **28** ***Phoenix humilis*** tree enclosure **3.2 High elevational Tree ecotone mosaics** 29 Shola forest ecotone
4.1 Mid elevational Forest mosaics 30 Wet evergreen forest (unburnt) 31 Wet evergreen forest (burnt)	**4.2 High elevational Forest mosaic** 32 Shola forest (unburnt) 33 Shola forest with ***Chimonobambusa*** **sp.**

6.2.3 Soil sampling and analyses

The soils were taken from 1 m x 1 m x 0.6 m pits from representative areas of the vegetations and samples were collected from three layers: 0-20, 20-40, 40-60 cm. The soil samples were air dried, passed through 2 mm sieve and particles > 2 mm (gravel) were determined. Analyses were carried out for particle-size separates, pH, exchangeable bases (EB), organic carbon (OC), total N and available K, Ca, and Mg as per standard procedures in ASA (1965) and Jackson (1958). Descriptions of the soil pits are deposited in the databank in the Library of the Kerala Forest Research Institute.

6.2.4 Pooling of data

The soil properties of the different layers of pits were pooled so that meaningful comparisons at various levels could be done. Properties of the three layers (0-20, 20-40, 40-60 cm) of the pits were pooled to obtain the pit means. These means were again pooled to obtain mean values for each species compositional vegetal type. These in turn were pooled to obtain mean values representing different physiognomic vegetation types (grasslands, shrub enclosures/ ecotones, tree enclosures/ forests), and further to obtain means for the two elevational zones.

Following the pooling of the pedometric data, soils were compared at various levels as given below:

1 Values of 0-60 cm layer
- 1.1 Across the two elevational zones
- 1.2 Across different physiognomic vegetal types
- 1.3 Across different species compositional vegetal mosaics

6.3 Observations and Results

Pooled mean values in the 0-60 cm layers in different species compositional vegetal types of Silent Valley are depicted in Figure 6.1 and that of Eravikulam in Figure 6.2.

Throughout this section, the soil properties are described and discussed in the two elevational zones and sequence of comparison in each of these elevational zones conforms to the sequence starting from grassland, shrub enclosure! ecotone, tree enclosure and to forest stands. In each physiognomic vegetal type of the two elevational zones, species compositional types or other variant types with minimal and higher values are also described.

Confounded mean values for each of the soil properties in the 0-60 cm soil pits of the different species compositional vegetal types as well as the physiognomic vegetal types are given in Figs. 6.3 A-D and Tables 6.4 and 6.5.

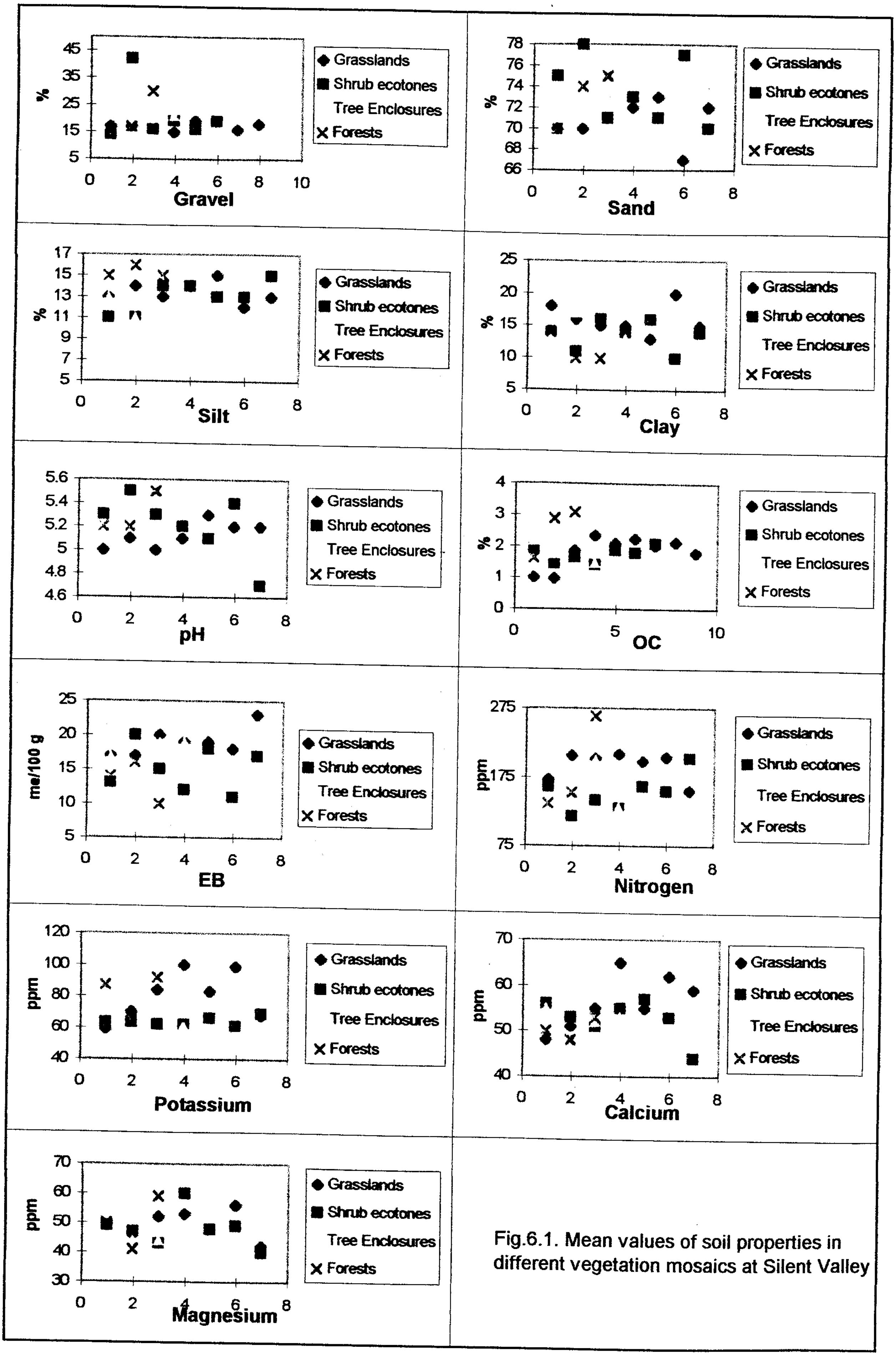


Fig.6.1. Mean values of soil properties in different vegetation mosaics at Silent Valley

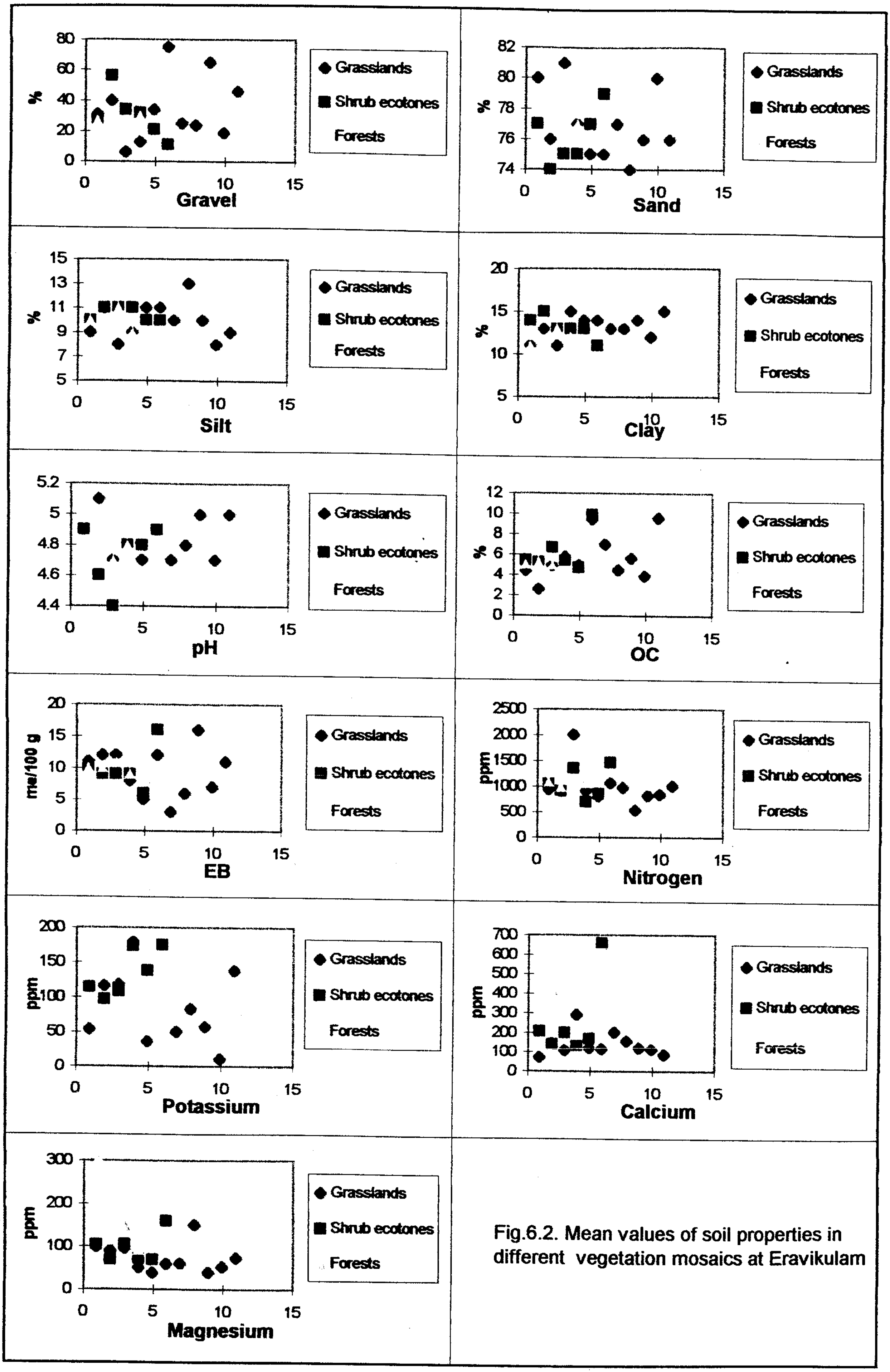


Fig.6.2. Mean values of soil properties in different vegetation mosaics at Eravikulam

Fig.6.3A Mean values of soil properties in different vegetal types

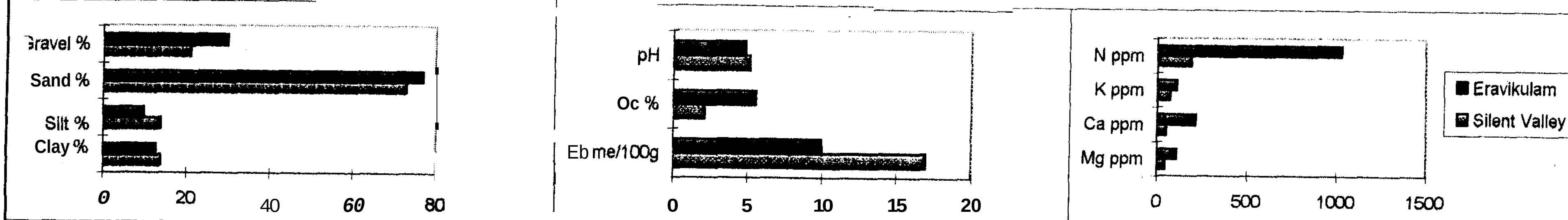


Fig.6.3B.Mean values of soil properties in the Grassland

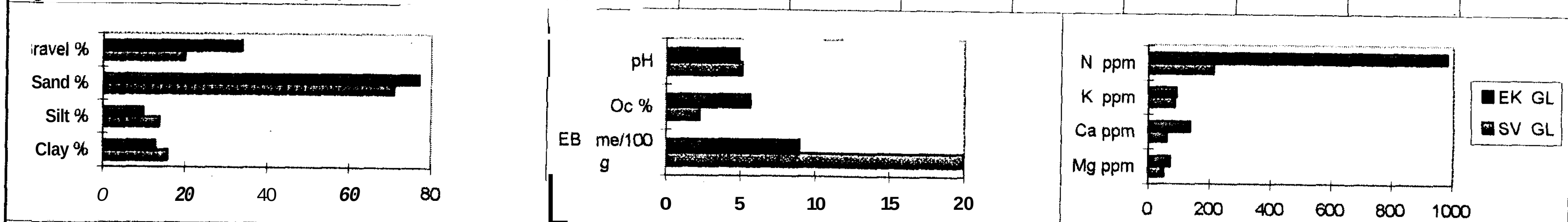


Fig.6.3C. Mean values of soil properties in the Shrub enclosure

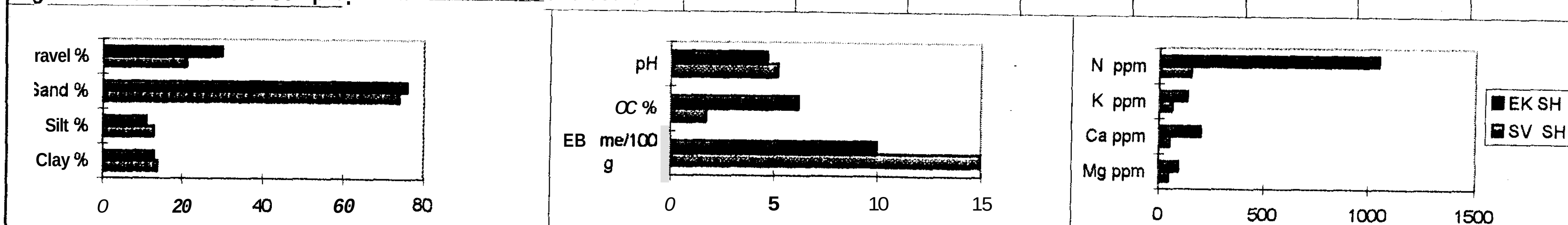
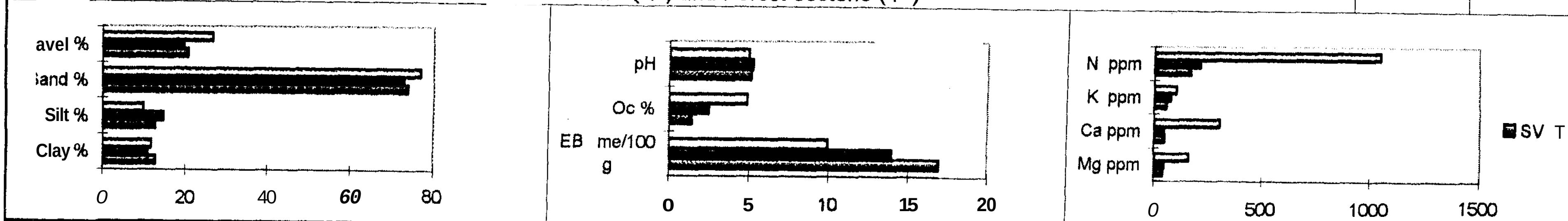


Fig.6.3D. Mean values of soil properties in the Tree enclosure (T) and Forest ecotone (F)



6.3.1 Parent rocks, large gravels and boulder stones

6.3.1.1 Medium Elevational Zone (Silent Valley)

Of the medium elevational grasslands, Arthraxon association characteristically grows on a rocky substratum, upon the organic debris formed by xerophytic clump forming mosses. Thus hard material above the parent rock is placed at 1-2 cm below the vegetation. In Themeda triandra association again, the hard material above the parent rock is shallowly placed such that no other grass species is successful in establishing a dense population there.

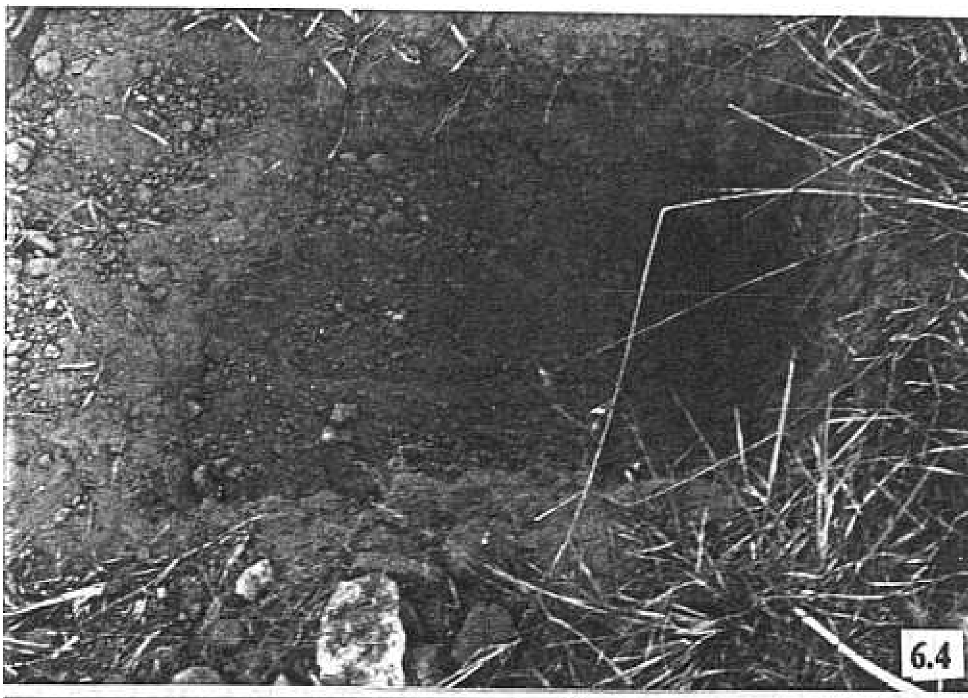
In the *Themeda-Cymbopogon* grasslands, generally the parent rock is slightly weathered than in Arthraxon and Themeda associations and are brittle to hard and placed at about 30-50 cm below the soil (Figs. 6.4 -6.13) and are provided with plenty of gravels and pebbles (Figs. 6.4 & 6.10).

In the case of *Eragrostis* grassland mosaic and other grassland mosaics of valleys, the soil is very rich in large gravels especially of the size 3-5 mm or larger (Fig. 6.4).

Table 6.4 Pedometric properties of vegetation types of the mid elevational grassland-forest continuum (Silent Valley).

Alt.	n*	Veg type	Compositional type	Gravel	Sand	Silt	Clay	pH	EB
				%	%	%	%		me/100g
870	2	GL	***Arthraxon* sp.**	27	71	16	14	5.0	22
870	2	GL	***Eragrostis* sp.**	30	70	16	15	5.0	23
870	3	GL	***Themeda triandra***	17	70	13	18	5.0	17
875	1	GL	***Themeda-Cymbopogon***	17	70	14	16	5.1	17
875	3	GL	***Tkemeda-Cymbopogon***	18	71	13	15	5.0	20
875	2	GL	***Themeda-Cymbopogon***	15	72	14	15	5.1	19
900	1	GL	***Themeda-Cymbopogon***	19	73	15	13	5.3	19
850	3	GL	***Themeda-Cymbopogon***	19	67	12	20	5.2	18
900	1	GL	***Themeda-Cymbopogon***	16	72	13	15	5.2	23
870	1	SEncl.	***Pteridium aquilinum***	14	75	11	14	5.3	13
950	1	SEncl.	***Pteridium aquilinum***	42	78	11	11	5.5	20
900	1	SEct.	***Maesa perrottetiana***	16	71	14	16	5.3	15
900	2	SEct.	***Maesa perrottetiana***	19	73	14	14	5.2	12
850	1	SEct.	***Nilgirianthus* sp.**	16	71	13	16	5.1	18
900	2	SEncl.	***Nilgirianthus* sp.**	19	77	13	10	5.4	11
900	1	SEct	***Shrub*** ecotone	18	70	15	14	4.7	17
870	3	TEncl	***Pterocarpus marsupium***	21	74	13	13	4.9	17
900	1	TEncl.	***Phoenix humilis***	20	72	11	17	5.0	13
900	1	TEncl.	***Phoenix humilis***	20	75	16	9	5.5	19
900	1	TEncl.	***Phoenix humilis***	21	75	12	13	5.5	19
850	1	EGF	***Burnt EGF***	14	70	15	14	5.2	16
800	1	EGF	***Unburnt Evergreen for.***	17	74	16	10	5.2	16
850	1	EGF	***Unburnt Evergreen for.***	30	75	15	10	5.5	10

EGF: Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: **Shrub** enclosure; TEncl.: Tree enclosure; * n = no. of pits studied (.. tsble



Figures 6.4 & 6.5. Pictures of soil pits in grassland vegetations. Fig. 6.4. Soil pit of *Themeda triandra* association (Mid elevational grassland at Silent Valley). The soil is rich in slightly larger gravel often intermixed with pebbles and stones. Fig. 6.5. A soil profile underneath a *Themeda ecotonal* association fringing the forestland, exposed through the action of erosion. The shallow placement of the rock substratum is very much evident here.

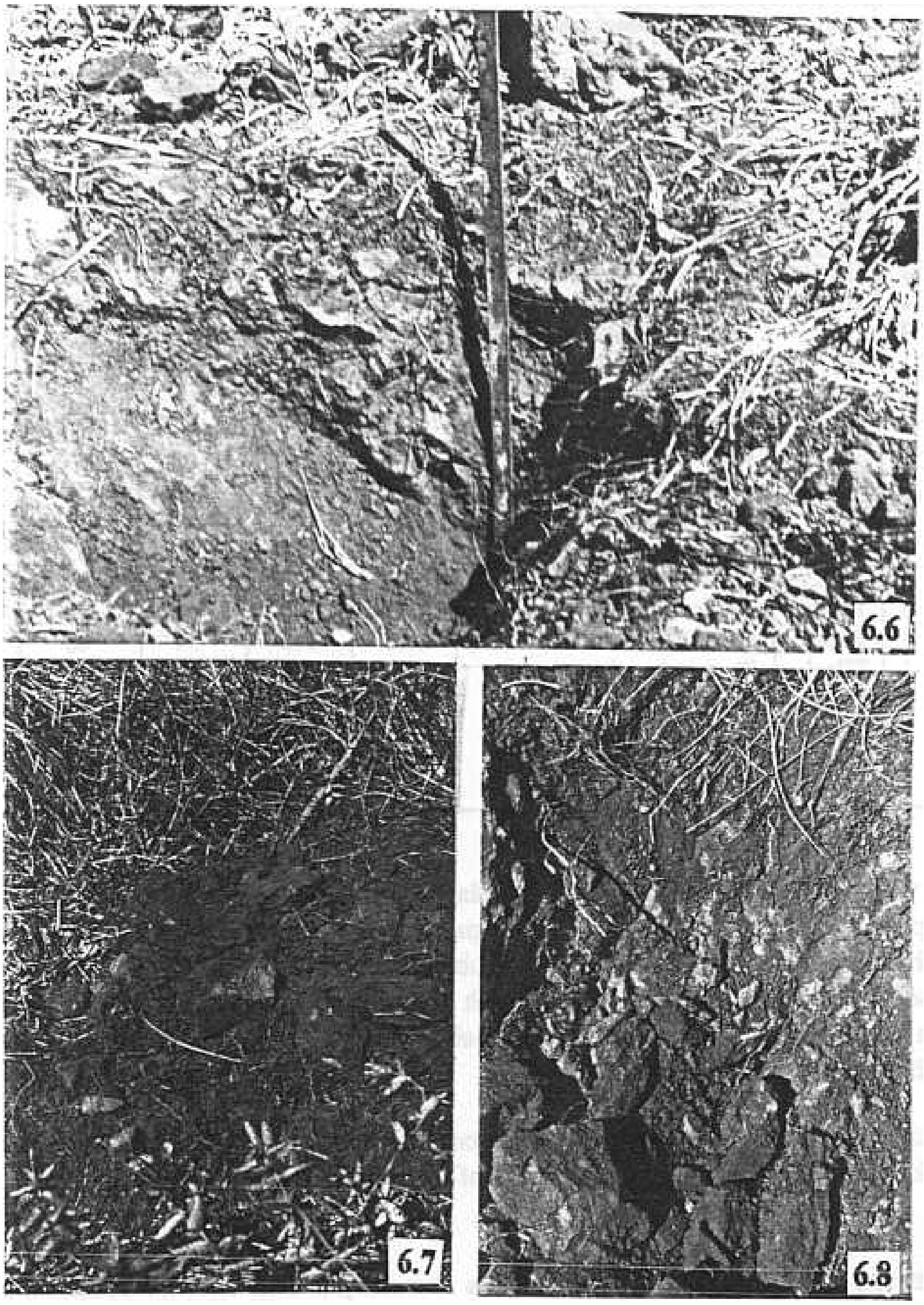
Table 6.4 Pedometric properties in different vegetation types of the mid elevational grassland-forest continuum (Silent Valley) (table contd.).

Alt,	n*	Veg type	Compositional type	OC	N	K	Ca	Mg
				%	ppm	ppm	ppm	ppm
870	2	GL	***Arthraxon sp.***	3.04	291	103	67	49
870	2	GL	***Eragrostis sp.***	2.95	278	123	83	78
870	3	GL	***Themeda triandra***	1.86	171	59	48	49
875	1	GL	***Themeda-Cymbopogon***	2.32	206	70.	51	46
875	3	GL	***Themda-Cymbopogon***	2.20	202	84	55	52
875	2	GL	***Themeda-Cymbopogon***	2.24	208	100	65	53
900	1	GL	***Themeda-Cymbopogon***	2.04	198	83	55	48
850	3	GL	***Themeda-Cymbopogon***	2.14	204	99	62	56
900	1	GL	***Themeda-Cymbopogon***	1.80	156	68	59	42
870	1	SEncl.	***Pteridium aquilinum***	1.9	161	63	56	49
950	1	SEncl.	***Pteridium aquilinum***	1.45	118	63	53	47
900	1	SEct.	***Maesa perrottetiana***	1.65	142	62	51	43
900	2	SEct.	***Maesaperrottetiana***	1.41	130	62	55	60
850	1	SEct	***Nilgirianthus sp.***	1.86	162	66	57	48
900	2	SEncl.	***Nilgirianthus sp.***	1.80	155	61	**53**	49
900	1	SEct.	***Shrub ecotone***	2.14	203	69	44	40
870	3	TEncl.	***Pterocarpus marsupium***	2.17	200	81	55	45
900	1	TEncl.	***Phoenix humilis***	1.75	145	54	48	44
900	1	TEncl	***Phoenix humilis***	2.5	209	49	52	44
900	1	TEncl.	***Phoenix humilis***	1.48	131	61	53	49
850	1	EGF	***Burnt Evergreen for.***	1.63	137	87	50	50
800	1	EGF	***Unburnt Evergreen for.***	2.88	253	65	48	41
850	1	EGF	***Unburnt Evergreen for.***	3.08	264	92	53	59

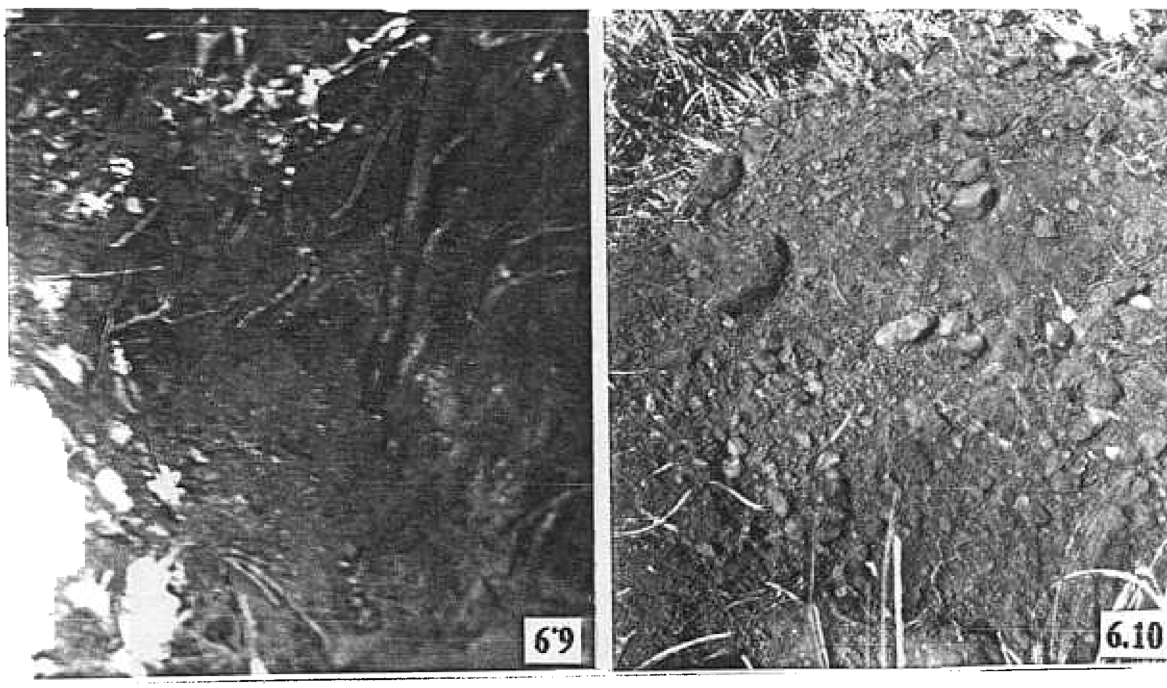
A variety of *Themeda triandra* grassland mosaic which inhabits the ecotones has shallowly placed parent rocks (Fig. 6.5). Compared to the grasslands on slopes, those at the hill crests have very shallowly located rocky substratum (Figs. 6.7 & 6.8). A few metre deep profile of soil in a hill shoulder of grassland with Pleurocaulis and some isolated tree growth is depicted in Figure 6.11. Copious presence of pebbles and disintegrating parent rock materials were seen beneath the rather thin soil layer.

In the case of *Nilgirianthus* sp. (shrub ecotones of the medium elevation), although the parent rock is slightly deeper, a distinct layer of larger pebbles of 8-15 mm is found beneath the soil.

Both the mid elevational tree enclosures *Pterocarpus* and *Phoenix* dominant ones are distributed along the sharp escarpments of the banks of Kunthipuzha river, and where the soil is underlined with a shallowly placed granitic or slightly weathered rocks. In the case of the medium elevational evergreen forests, the parent rock is deep seated with the soil layer often measuring 2-2.5 m or more.



Figures 6.6–6.8. Soil profiles in grasslands and shrubland enclosures in the grassland at mid elevations. Fig. 6.6. A soil profile of the *Plurocaulis* shrubland enclosure (Pulippara, Silent Valley National Park). The soil here is very thin with parent rock located in the subsurface layer. Fig. 6.7. Beginning of a soil pit digging in a *Pleurocaulis* shrubland enclosure (Aruvampara, Silent Valley NP). The stones in the picture are brocken from the parent rock lying a few centimeters beneath the soil. Fig. 6.8. A soil pit showing the profile in a hill shoulder grassland. Here again the thin soil layer and the shallowly placed parent rocks are visible.



Figures 6.9. & 6.10. Soil profiles in grassland ecotones and savanna (woodland) enclaves within the grasslands at medium elevations. Fig. 6.9. Soil profile and the forest-grassland interface (Pulippara, Silent Valley NP), showing a slightly deeper soil layer than the grasslands. The rock layer is still visible beneath the soil, located not much deep. Fig. 6.10. A soil pit of a savanna woodland enclave within the grassland colonized by *Glochidion neilgherrense* and *Wendlandia notoniana*, etc. Note the profuse presence of larger gravel and pebbles in the soil.

Figure 6.11. A cross section of the soil horizon in the mid elevational wooded savanna enclave at Silent Valley (near the weather station). The grassland here is colonized by shrubs and small trees like *Phyllanthus emblica, Zizyphus rugosa* and *Glochidion neilgherrense.* The depth of the soil layer is slightly better than that of the shrubland enclosures as seen in the previous photographs. However, the weathering parent rock is still visible beneath the soil layer located not so deep.

Table 6.5 Pedometric properties in different vegetation types (Eravikulam).

Alt.	n*	Veg type	Compositional type	Gravel	Sand	Silt	Clay	pH	EB
				%	Ye	%	%		me/100gL
2160	2	GL	*Rocky grassland*	31	80	9	11	4.9	11
1985	3	GL	*Burnt grassland*	40	76	11	13	5.1	12
2060	2	GL	*Eriocaulon-Garnotia*	6	81	8	11	4.7	12
2040	2	GL	*Garnotia tectorum*	13	77	9	15	4.8	8
2055	3	GL	*Eulaiiaphaeothrix*	34	75	11	14	4.7	5
2170	3	GL	*Eulaliaphaeothrix*	75	75	11	14	4.9	12
2070	2	GL	*Chrysopogonzeylanicus*	25	77	10	13	4.7	3
1950	3	GL	*Chrysopogonzeylanicus*	24	74	13	13	4.8	6
2100	3	GL	*Arundinellafuscata*	65	76	10	14	5	16
2060	2	GL	*Arundinella ciliata*	19	80	8	12	4.7	7
2180	3	GL	*Tripogonbromoides*	46	76	9	15	5	11
2075	3	SEncl.	*Gaultheriafragrantissima*	27	77	10	14	4.9	10
2100	3	SEnCl.	*Strobilanthes sp.*	56	74	11	15	4.6	9
2145	2	SEct.	*Strobilantheshomotropa*	34	75	11	13	4.4	9
1955	3	SEct.	*Hypricum-Rhodoendron*	32	75	11	13	4.8	9
1905	3	SEct.	*Pteridium aquilinum*	21	77	10	13	4.8	6
2140	3	SEct.	*Ageratina adenophora*	11	79	10	11	4.9	16
1930	3	SF	*Sholaforest ecotone*	27	79	10	11	4.8	10
1910	3	SF	*Sholaforest*	30	75	9	10	4.7	10
2140	3	SF	*Sholaforest*	20	76	11	13	4.7	11
2140	3	SF	*Chimonobambusa sp.*	30	79	9	12	4.8	9

Table 6.5 Pedometric properties in different vegetation types (Eravikulam) (table contd.).

Alt,	n*	Veg type	Compositional type	OC	N	K	Ca	Mg
				%	ppm	ppm	ppm	ppm
2160	2	GL	*Rocky grassland*	4.40	933	53	73	98
1985	3	GL	*Burnt grassland*	2.57	908	116	144	90
2060	2	GL	*Eriocaulon-Garnotia*	4.91	2009	118	107	95
2040	2	GL	*Garnotia tectorum*	5.77	910	179	290	50
2055	3	GL	*Eulaliaphaeothrix*	4.96	812	36	120	38
2170	3	GL	*Eulaliaphaeothrix*	9.45	1062	175	116	59
2070	2	GL	*Chrysopogon zeylanicus*	7.00	974	50	202	60
1950	3	GL	*Chrysopogonzeylanicus*	4.50	532	83	155	151
2100	3	GL	*Arundinellafuscata*	5.63	815	57	120	39
2060	2	GL	*Arundinellaciliata*	3.91	843	11	113	52
2180	3	GL	*Tripogon bromoides*	9.60	1013	138	86	73
2075	3	SEncl.	*Gaultheriafragrantissima*	5.37	1044	114	207	104
2100	3	SEncl.	*Strobilanthes sp.*	5.22	908	%	138	69
2145	2	SEct.	*Strobilantheshomotropa*	6.68	1353	108	200	105
1955	3	SEct.	*Hypericum-Rhodoendron*	5.38	701	173	133	71
1905	3	SEct.	*Pteridium aquilinum*	4.72	853	138	169	69
2140	3	SEct.	*Ageratina adenophora*	9.90	1463	175	660	159
1930	3	SF	*Sholaforest ecotone*	5.00	1055	97	284	304
1910	3	SF	*Sholaforest*	5.22	986	57	417	113
2140	3	SF	*Shola forest*	4.99	1153	154	335	147
2140	2	SE	*Chimonobambusa sp.*	4.56	1167	107	187	91

FEcot.:Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEnc
SF:Shola forest; * n = no.of pits.

On digging a trench cutting the grassland ecotone and the forest ecotone at the mid elevational zone, it was found that like the grasslands, the parent rock is shallowly placed in the ecotone and continues with a sudden fault at the summit of the two vegetations so that the rock is at a lower level in the forest. Thus, in many places along the grassland ecotone, the ground contour is led into a sudden depression while reaching the forest, in congruity with the contour of the underlying parent rock shelf. These rock shelves are in a way comparable to the continental shelves occurring at the summit of land and sea.

6.3.1.2 High elevational zone (Eravikulam)

Grasslands with rocky outcrops colonized by Janzanella sp. have the hard material abouve the parent rocks located within the 0-20 cm layer of the soil. Eulalia phaeothrix grassland mosaics are found to have, copious small gravels, actively weathering or not weathering boulder stones in the 40-60 cm depth. Sheet rocks were also found located within the same depth. Actively weathering lateritic or otherwise boulders were met within the 40-60 cm depth in the case of Arundinella ciliata and Tripogon bromoides grasslands.

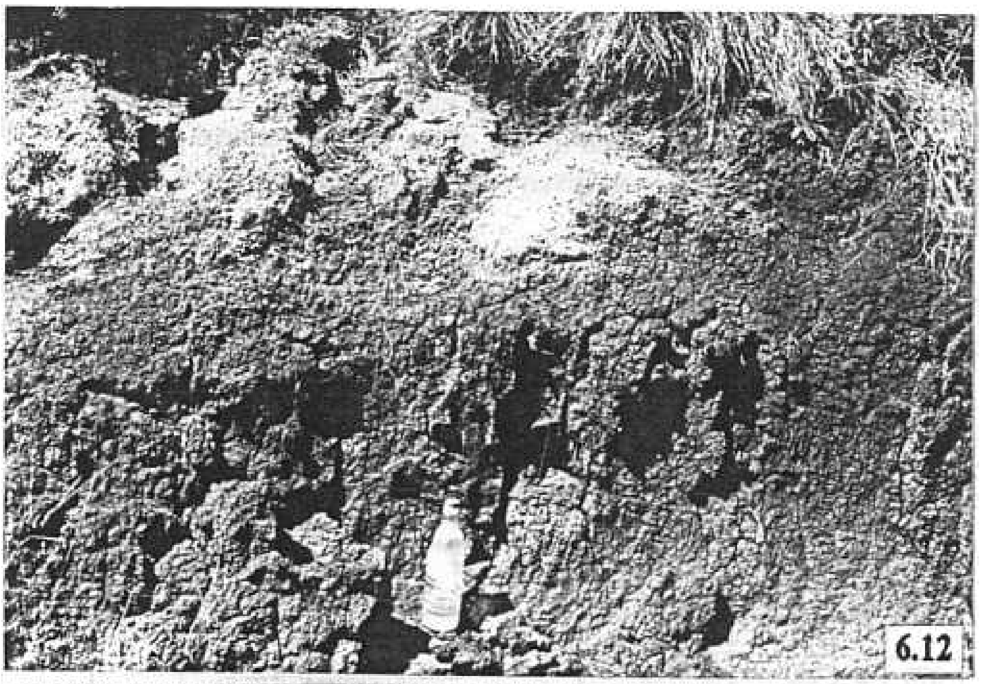
A general trend of increasing soil and decreasing gravel and boulder stones associated with a lowering of the placement of parent material was found across the high elevational grassland mosaics in the following sequence: *Jansanella* mosaic -> *Tripogon bromoides* mosaic --> *Arundinella cilita* mosaic --> *Eulalia phaeothrix* mosaic --> *Chrysopogon zeylanicus* mosaic. *Chrysopogon zeylanicus* mosaics generally occupied locations along slopes or on sides of the hills and generally absent from hill mounts and shoulders and as a consequence, were slightly better in moisture regime. They were often located along the immediate neighbourhood of shola forest patches. The soil profiles of these mosaics were fairly thick, with a depth of 1 m or more, and the upper layer was dark with rich organic carbon content, the peat (Figs. 6.12 & 6.13). Thus in soil depth, the community stood close to that of the shola forest and these were the areas to which the shola forests spread throughout the arnphitolerant species like *Rhododendron.*

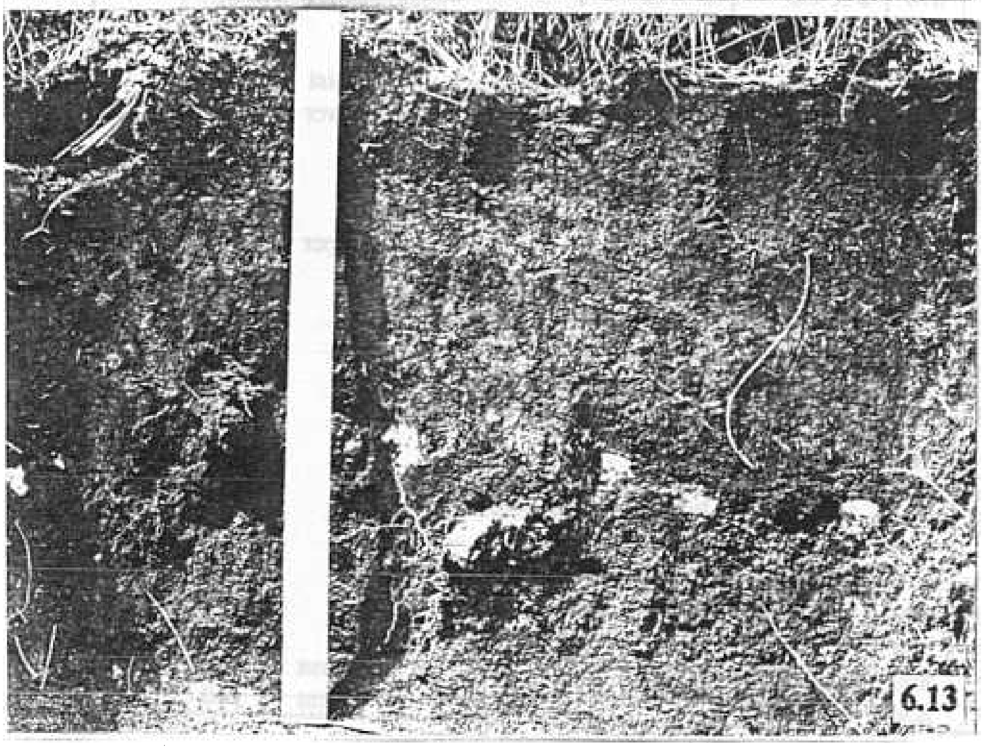
Stones of medium to large sized (5-10 cm diam) and of yellowish and orange yellow colour, were found in plenty in the case of *Pteridium* shrub enclosures (Fig. 4.28) and *Strobilanthes* sp. shrub ecotone soils in the surface (Fig. 4.29). Weathering lateritic or other boulders are encountered in plenty in the same horizon in the case of *Strobilanthes homotropa* and *Rhododendron- Hypericum* shrub ecotones. The lower layers in all these cases are invariably provided with larger gravels and bouiders and in many instances the parent rock is located there. Extensive *Phlebophyllum kunthianum* shrub enclosure (Figs. 4.22 & 4.23) was found to inhabit grasslands with rocky outcrops where the soil was shallow.

In contrast to the grasslands and shrublands, the soil profile was very deep in the case of shola forests. In two instances, parent rock was met with at a depth of 1.5 and 1.8 m.

6.3.2 Gravel

Different vegetal mosaics displayed gravel percent ranging between 6-75% in the 0-60 cm layer. The net range of variability of gravel content across the vegetal mosaics therefore is very high (Figs. 6.1 & 6.2).





Figures 6.12 & 6.13.— Soil profiles in *Chrysopogon* dominated grassland mosaics at Eravikulam National Park, the High Elevational Zone (±2000 m gmsl). In sharp contrast to the thin soil layers of most grassland mosaics, *Chrysopogon* grasslands have a rather thick soil layer comparable in depth to that of the shola forests. The blackish upper soil is peaty. *Chrysopogon zeylanicus* generally prefers moist slopes (saddles) of the hills, quite often adjacent to the shola forests and are the areas to which the shola forests advance in due course.

The two elevational zones showed mean values in the 0-60 cm layer that differed slightly: mid elevational zone with a mean of 21% and the high elevational zone with **30%,** perhaps indicating higher rates of weathering at mid elevations. The high elevational range of variability (69) was too high compared to that of the mid elevational range of variability (28). The mid elevational maximum for any given vegetal type was 42% and for the high elevational zone, it was 75%.

At mid elevations, across the different physiognomic vegetal types, there was not much difference in the mean values of gravel. Irrespective of the vegetation types, most values showed a tendency to cling towards the modal value of around 20% (Fig. 6.1 and Table 6.6).

Table 6.6 Gravel in different vegetation groups (Silent Valley).

Sl no.	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	10-60	0-60
1	870	2	GL	*Arthraxon sp.*		27			
2	870	2	GL	*Eragrostis sp.*		30			
3	870	2	GL	*Themeda triandra*		20	17	15	17
4	875	1	GL	*Thenteda-Cymbopogon*	**Moist**	24	15	13	17
5	875	3	GL	*Themeda-Cymbopogon*	**Lower**	25	17	12	18
6	875	2	GL	*Themeda-Cymbopogon*		21	13	11	15
7	900	1	GL	*Themeda-Cymbopogon*		26	18	14	19
8	850	3	GL	*Themeda-Cymbopogon*		27	18	11	19
9	900	1	GL	*Themeda-Cymbopogon*	**Upper**	20	14	14	16
10	870	1	SEncl.	*Pteridium aquilinum*		18	14	10	14
11	950	1	SEncl.	*Pteridium aquilinum*		47	43	37	42
12	900	1	SEct.	*Maesa perrottetiana*		22	15	11	16
13	900	2	SEct.	*Maesa perrottetiana*		24	17	15	19
14	850	1	SEct.	*Nilgirianthus sp.*		21	15	10	16
15	900	2	SEncl.	*Nilgirianthus sp.*		26	18	12	19
16	900	1	SEct.			24	16	13	18
17	870	3	TEncl.	*Pterocarpus marsupium*		23	24	16	21
18	900	1	TEncl.	*Phoenix humilis*		28	21	12	20
19	900	1	TEncl.	*Phoenix humiiis*		29	18	12	20
20	900	1	TEncl.	*Phoenix humilis*		33	19	12	21
21	850	1	EGF			20	13	9	14
22	800	I	EGF		**Burnt**	28	12	11	17
23	850	1	EGF		**Burnt**	40	31	19	30

EGF: Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; TEncl.: Tree enclosure. * n= no. of pits studied.

At mid elevations, the gravel content exhibited minimal quantities by some of the subsets of *Themeda-Cymbopogon* grassland (15%), *Pteridium* shrub enclosure (14%) and the evergreen forest (14%). The higher range of gravel content was exhibited by some subsets *Pteridium* shrub enclosure (42%) and the burnt evergreen forest (30%; Table 6.6).

Table *6.7* Gravel in different vegetation groups (Eravikulam)

No	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm) 0-20	20-40	40-60	0-60
1	2160	2	GL		Rocky	32	19	42	31
2	1985	3	GL		Burnt	47	38	34	40
3	2060	2	GL	*Eriocaulon - arnotia*		2	10	5	6
4	2040	2	GL	*Garnotia tectorum*		7	22	11	13
5	2055	3	GL	*Eulalia phaeothrix*		6	48	47	34
6	2170	3	GL	*Eulalia phaeothrix*		67	81	78	75
7	2070	2	GL	*Chrysopgon zeylanicus*		2	25	49	25
8	1950	3	GL	*Chrysopgon zeylanicus*		27	20	26	24
9	2100	3	GL	*Arundinella fuscata*		63	57	75	65
10	2060	2	GL	*Arundinella ciliata*		2	24	31	19
11	2180	3	GL	*Tripogon bromoides*		28	48	61	46
12	2075	3	SEncl.	*Gaultheria fragrantissima*		18	33	31	27
13	2100	3	SEct.	*Strobilanthes sp.*		58	55	56	56
14	2145	2	SECt.	*Strobilanthes homotropa*		18	32	51	34
15	1955	3	SECt.	*Hypricum-Rhodoendron*		32	33	30	32
16	1905	3	SECt.	*Pteridium aquilinum*		27	20	15	21
17	2140	3	SECt.	*Ageratina adenophora*		15	12	5	11
18	1930	3	FEcot.			30	26	26	27
19	1910	3	SF			30	29	30	30
20	2140	3	SF			18	20	21	20
21	2140	3	SF	*Chimonobambusa sp.*		26	31	32	30

FE#cot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure;
SF: Shola forest; * n = no. of pits studied.

In contrast to the mid elevational zone, the high elevational zone showed a gradually decreasing trend of gravel percent from grassland (mean = 34%) to the forestland (mean = 27%) with intermediate value for the shrub enclosures/ ecotones (mean = 30%). The range of variability also showed a similar trend with high value for the grassland and low value for the forest (Fig. 6.3).

At high elevations, the lowest values 6 and 13% gravel were found for two grassland types, Eriocaulon-Garnotia association and Garnotia tectorum dominant grassland respectively, both colonizing either swampy grasslands along shallow valleys between hillocks or along ralls, where the soil is almost always wet (Table 6.7). The *Ageratina* shrub ecotone (11%) also had low values. The highest maximum value of 75% gravel was observed for some subsets of the *Eulalia phaeothrix* dominant grasslands. However, this was not universal for the compositional type, the value being around 34% for another sample set of the same compositional type. Other vegetal types of high gravel content were subsets of *Arundinella fuscata* grassland (65%), *Strobilanthes* sp. ecotone (56%), *Tripogon bromoides* grassland (46%) and *Eulalia phaeothrix* grassland (34%) (Table 6.7).

6.3.3 Sand

Sand per cent varied between 67 and 78 in the mid elevation while it was 74 to 81% in the high elevational zone. The difference between the mean values for sand percent of the mid elevational and high elevational zones differed very little (Fig. 6.3a).

Most mean values of different vegetal types clustered within the range of 71-77% and there was no trend of difference between the physiognomic vegetation types (Figs. 6.1 and 6.2).

The vegetal types with low sand content at the mid elevational zone were selected subsets of *Themeda-Cymbopogon* grassland (67%), *Eragrostis* grassland (70%), *Themeda triandra* grassland (70%), *Themeda-Cymbopogon* grassland (70%) and the evergreen forest (70%). Those with high sand contents were: *Pteridium* shrub enclosure (78%), *Nilgirianthus* sp. shrub ecotone (77%) and burnt evergreen forest (75%) (Fig. 6.11 and Table 6.8).

At the high elevational zone, the lowest values were expressed by some subsets of *Chrysopogon zeylanicus* grassland (74%), *Strobilanthes* sp. shrub ecotone (74%) and high values were shown by *Eriocaulon-Garnotia* grassland (81%), *Arundinella ciliata* grassland (80%), *Ageratina* ecotone (79%) and shrub ecotone (77%) (Table 6.9).

Table 6.8 Sand in different vegetation groups (Silent Valley).

Sl no	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	***Arthraxon sp.***		71			
2	870	2	GL	***Eragrostis sp.***		70			
3	870	2	GL	***Themeda triandra***		70	69	70	70
4	875	1	GL	***Themeda-Cymbopogon***	Moist	70	70	71	70
5	875	3	GL	***Themeda-Cymbopogon***	Lower	72	71	71	71
6	875	2	GL	***Themeda-Cymbopogon***		72	72	71	72
7	900	1	GL	***Themeda-Cymbopogon***		74	73	72	73
8	850	3	GL	***Themeda-Cymbopogon***		68	67	67	67
9	900	1	GL	***Themeda-Cymbopogon***	upper	73	72	72	72
10	870	1	SEncl.	***Pteridium aquiinum***		77	75	74	75
11	950	1	SEncl.	***Pteridium aquiinum***		80	78	76	78
12	900	1	SEct.	***Maesa perroitetiana***		71	71	71	71
13	900	2	SEct	***Maesa perrottetiana***		74	72	72	73
14	850	1	SEct.	***Nilgirianthus sp.***		72	71	71	71
15	900	2	SEct.	***Nilgirianthus sp.***		78	77	77	77
16	900	1	SEct			71	70	70	70
17	870	3	TEncl.	***Pterocarpus marsupium***		75	74	73	74
18	900	1	TEncl.	***Phoenix humilis***		74	71	70	72
19	900	1	TEncl.	***Phoenix humilis***		75	76	74	75
20	900	1	TEncl.	***Phoenix humilis***		75	76	75	75
21	850	1	EGF			69	71	71	70
22	800	1	EGF		Burnt	74	75	74	74
23	850	1	EGF		Burnt	76	75	75	75

IGF: Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; TEncl.: Tree enclosure. * n = no. of pits studied

Table 6.9 Sand in different vegetation groups (Eravikulam).

No	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-30	40-60	0-60
1	2160	2	GL		Rocky	80	79	80	80
2	1985	3	GL		Burnt	77	75	75	76
3	2060	2	GL	*Eriocaulon - Garnotia*		81	81	81	81
4	2040	2	GL	*Garnotia tectorum*		77	77	77	77
5	2055	3	GL	*Eulalia phaeothrix*		76	75	75	75
6	2170	3	GL	*Eulalia phaeothrix*		76	75	73	75
7	2070	2	GL	*Chrysopogon zeylanicus*		76	78	78	77
8	1950	3	GL	*Chrysopogon zeylanicus*		78	75	69	74
9	2100	3	GL	*Arundnella fuscata*		76	76	76	76
10	2060	2	GL	*Arundinella ciliata*		81	80	80	80
11	2180	3	GL	*Tripogon bromoides*		75	76	76	76
12	2075	3	SEncl.	*Gauitheria fragrantissima*		78	77	75	77
13	2100	3	SEct.	*Strobilanthes sp.*		76	74	72	74
14	2145	2	SEct	*Strobiianthes homotropa*		77	73	76	75
15	1955	3	SEct.	*Hypericum-Rhodoendron*		76	77	73	75
16	1905	3	SEct.	*Pteridium aquilinum*		77	79	76	77
17	2140	3	SEct.	*Ageratina adenophora*		80	79	78	79
18	1930	3	FEcot.			79	79	79	79
19	1910	3	SF			62	81	81	75
20	2140	3	SF			79	77	73	76
21	2140	3	SF	*Chimonobambusa sp.*		79	80	78	79

6.3.4 Silt

With a range of 8% variability, the mean values of silt content was found distributed between 8 and 16%. The mean values were 14% and 10% respectively for the mid and the high elevational zones (Fig. 6.3). A scan through the minimal and maximal values exhibited by the vegetal mosaics of the two elevational zones showed that scarcely did the maximum silt content of the high elevational zone transgressed into the minimal values of the mid elevational belt. This indicated that the mean values did not differ appreciably (Tables 6.10 & 6.1 1).

At both the elevational zones, the values being closer no trend of silt content variability could be made out between the physiognomic vegetation types. No distinction of vegetation types is possible on the basis of silt content. However, the high elevational shrub ecotones/ enclosures and shola forests were more uniform in silt content with low variability range (Tables 6.10 & 6.11).

At the mid elevational zone, low values of silt content were observed for some of the subsets of *Pteridium* shrub ecotone, Phoenix tree enclosure, both with 11% silt. Comparatively high values were observed for some subsets of *Phoenix* tree enclosure and a stand of burnt evergreen forest, all with 16% silt content. Also, all the evergreen forest samples showed higher values of silt content within the range of 15 and 16% (Table 6.10).

Table 6.10 Silt in different vegetation mosaics (Silent Valley).

sl no	Alti tnde	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	*Arthrmon sp.*		16			
2	870	2	GL	*Eragrostis sp.*		16			
3	870	2	GL	*Themeda triandra*		13	14	3	13
4	875	1	GL	*Themeda-Cymbopogon*	**Moist**	13	14	14	14
5	875	3	GL	*Themeda-Cymbopogon*	**Lower**	13	13	14	13
6	875	2	GL	*Themeda-Cymbopogon*		16	14	12	14
7	900	1	GL	*Themeda-Cymbopogon*		17	14	13	15
8	850	3	GL	*Themeda-Cymbopogon*		11	14	12	12
9	900	1	GL	*Themeda-Cymbopogon*	Upper	14	12	12	13
10	870	1	SEncl.	*Pteridium aquilinum*		10	11	11	11
11	950	1	SEncl.	*Pteridium aquilinum*		12	11	10	11
12	900	1	SECt.	*Maesa perrottetiana*		15	13	14	14
13	900	2	SECt.	*Maesa perrottetiana*		15	14	12	14
14	850	1	SECt.	*Nilgirianthus sp*		13	13	13	13
15	900	2	SEncl.	*Nilgirianthus sp.*		12	13	14	13
16	900	1	SECt.			15	15	16	15
17	870	3	TEncl.	*Pterocarpus marsupium*		14	13	13	13
18	900	1	TEncl.	*Phoenix humilis*		12	11	10	11
19	900	1	TEncl.	*Phoenix humilis*		18	14	16	16
20	900	1	TEncl.	*Phoenix humilis*		10	12	13	12
21	850	1	EGF			16	15	15	15
22	800	1	EGF		Burnt	15	16	16	16
23	850	1	EGF		Burnt	14	15	15	15

Table 6.11 Silt in different vegetation groups (Eravikulam).

No	Alti tude	n*	Veg type	Composition	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	2160	2	GL		Rocky	10	9	8	9
2	1985	3	GL		Burnt	11	11	11	11
3	2060	2	GL	*Eriocaulon-Garnotia*		9	8	7	8
4	2040	2	GL	*Garnotia tectorum*		10	9	9	9
5	2055	3	GL	*Eulalia phaeothrix*		11	12	11	11
6	2170	3	GL	*Eulalia phaeothrix*		10	12	12	11
7	2070	2	GL	*Chrysopogon zeylanicus*		11	9	9	10
8	1950	3	GL	*Chrysopogon zeylanicus*		11	12	15	13
9	2100	3	GL	*Arundinella fuscata*		11	10	10	10
10	2060	2	GL	*Arundinella ciliata*		9	8	8	8
11	2180	3	GL	*Tripogon bromoides*		10	9	8	9
12	2075	3	SEncl	*Gaultheria fragrantissima*		10	10	10	10
13	2100	3	SEct.	*Strobilanthes sp.*		10	11	12	11
14	2145	2	SEct.	*Strobilanthes homotropa*		11	12	11	11
15	1955	3	SEct.	*Hypericum-Rhodoendron*		11	11	12	11
16	1905	3	SEct.	*Pteridium aquilinum*		10	9	10	10
17	2140	3	SEct.	*Ageratina adenophora*		10	10	9	10
18	1930	3	FEcot			10	11	10	10
19	1910	3	SF			10	10	8	9
20	2140	3	SF			10	10	12	11
21	2140	3	SF	*Chimonobambusa sp.*		9	8	9	9

At high elevation, a minimum of 8 and 9% silt content was exhibited by some subsets of *Eriocaulon-Gamotia* grassland (8%), *Arundinella ciliata* grassland, rocky high elevational grassland, *Tripogon bromoides* grassland, shola forest and *Chimonobambusa* sp. shola (9%). The higher extremes were represented by: burnt grassland, both the subsets of *Eulalia phaeothrix* grassland, *Strobilanthes.* sp., *S. homotropa, Hypericum-Rhododendron* shrub enclosures/ecotones and a subset of shola forest, all with 11% gravel content (Table 6.11). The highest was recorded in *Chrysopogon zeylanicus* grassland (13%).

6.3.5 Clay

Clay content ranged between 9 and 20% with the mean figures for mid elevational and high elevational zones being 14% and 13%, respectively. The maximum variability recorded for the mid elevational zone therefore was 11% and 5% for the high elevational zone (Fig. 6.3).

Even within the smaller ranges of variability of clay content, a definite trend of declining clay content from grasslands to forest through the intermediary of shrub enclosures was evident. This trend was visible at both the elevational zones.

Table 6.12 Clay in different vegetation mosaics (Silent Valley).

Sl no	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	Arthraxon sp.		14			
2	870	2	GL	Eragrostis sp.		15			
3	870	2	GL	Themeda triandra		18	18	18	18
4	875	1	GL	Themeda-Cymbopogon	Moist	17	16	15	16
5	875	3	GL	Themeda-Cymbopogon	Lower	15	15	15	15
6	875	2	GL	Themeda-Cymbopogon		12	15	17	15
7	900	1	GL	Themeda-Cymbopogon		10	14	16	13
8	850	3	GL	Themeda-Cymbopogon		21	19	21	20
9	900	1	GL	Themeda-Cymbopogon	Upper	13	16	16	15
10	870	1	SEncl	Pteridium aquilinum		13	14	15	14
11	950	1	SEncl	Pteridium aquilinum		8	11	14	11
12	900	1	SEct.	Maesa perrottetiana		15	17	16	16
13	900	2	SEct.	Maesa perrottetiana		11	14	16	14
14	850	1	SEct.	Nilagirianthus sp.		16	17	17	16
15	900	2	SEncl	Nilagirianthus sp.		10	10	9	10
16	900	1	SEct.			14	15	14	14
17	870	3	TEncl	Pterocarpus marsupium		11	13	14	13
18	900	1	TEncl	Phoenix humilis		14	18	20	17
19	900	1	TEncl	Phoenix humilis		7	10	10	9
20	900	1	TEncl	Phoenix humilis		15	12	12	13
21	850	1	EGF			15	14	14	14
22	800	1	EGF		Burnt	11	9	10	10
23	850	1	EGF		Burnt	10	10	10	10

EGF Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; TEncl.: Tree enclosure. * n = no. of soil pits studied

At mid elevation, the lower values were represented by both of the two subsets of burnt forest soil samples (10%), one of the two subsets of shrub enclosure, Nilagirianthus sp.,and one of the three subsets Phoenix tree enclosures (9%). The low clay content in burnt forests can be the effect of burning. Phoenix is considered to be an indicator of fire and the low value here also might account for fire. The higher values of clay content were shown by selected subsets of Themeda-Cymbopogon grassland (16%),Phoenix tree enclosure (17%) and Themeda triandra grassland (18%) (Table 6.12).

At high elevation, examples of low clay content were rocky grassland, *Garnotia tectrorum* grassland, *Ageratina* shrub ecotone, and forest ecotone (11%). The counter parts with high clay content were: *Garnotia tectorum* grassland, *Tripogon bromoides* grassland and *Strobilanthes* sp. shrub ecotone (Table 6.13).

Table 6.13 Clay in different vegetation groups (Eravikulam).

No	Altitude	n*	Veg type	Composition	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	2160	2	GL		Rocky	10	12	12	11
2	1985	3	GL		Burnt	12	14	14	13
3	2060	2	GL	***Eriocaulon-Garnotia***		11	11	12	11
4	2040	2	GL	***Garnotia tectorum***		14	15	15	15
5	2055	3	GL	***Eulalia phaeothrix***		13	13	15	14
6	2170	3	GL	***Eulalia phaeothrix***		14	13	1s	14
7	2070	2	GL	***Chrysopogon zeylanicus***		13	12	13	13
8	1950	3	GL	***Chrysopogon zeylanicus***		11	13	16	13
9	2100	3	GL	***Arundinella fuscata***		14	14	15	14
10	2060	2	GL	***Arundinella ciliata***		10	12	13	12
11	2180	3	GL	***Tripogon bromoides***		15	15	16	15
12	2075	3	SEncl.	***Gaultheria fragrantissima***		13	13	15	14
13	2100	3	SEct.	***Strobilanthes sp.***		13	15	16	15
14	2145	2	SEct.	***Slrobilanthes homotropa***		12	15	13	13
15	1955	3	SEct.	***Hvpricum-Rhodoendron***		13	12	14	13
16	1905	3	SEct.	***Pteridum aquilinum***		13	12	15	13
17	2140	3	SEct.	***Ageratina adenophora***		10	11	13	11
18	1930	3	FEcot.			11	11	12	11
19	1910	3	SF			11	9	11	10
20	2140	3	SF			12	13	15	13
21	2140	3	SF	***Chimonobambusa sp.***		12	12	13	12

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; SF: Shola forest. * n = no. of soil pits studied.

6.3.6 Acidity (pH)

The mean pH values were found dispersed between the extremes 4.4 and 5.5, showing that the acidity ranged from very strongly acid to strongly acid. The mid elevational zone showed the highest maximum pH (5.5). The observed range of pH variability within each of the elevational belts also matched to almost the same value (Fig. 6.3).

Apparently there is not much difference in the pH of evergreen forests, tree enclosures and shrub ecotones/ enclosures in both the elevational zones. Within vegetation type variability was highest in mid elevational shrub enclosures and mid elevational tree enclosures (0.6 units). In all other cases, the within vegetation type variability was rather low. In the case of grasslands however, the values never crossed **5.3,** indicating a lower acidity level (Tables 6.14 and 6.15).

At mid elevation, the lowest value was recorded for a subset of shrub ecotone (4.7) and the highest values were recorded for Pteridium shrub ecotone, two subsets of Phoenix tree enclosures and a burnt evergreen forest sample, all with a value equalling 5.5 (Table 6.14). At the high elevational zone, the minimal value of 4.4 and 4.6 were obtained for subsets of ecotone and *Strobilanthes* sp. ecotone, respectively (Table 6.15).

Irrespective of the vegetal types, a trend of slight decrease of pH values by 0.1 or 0.2 is observed with depth.

Table 6.14 Soil pH in different vegetation mosaics (Silent Valley).

Sl no	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	***Arthraxon sp.***		5.0			
2	870	2	GL	***Eragrostis sp..***		5.0			
3	870	2	GL	***Themeda triandra***		5.1	5.1	4.9	5.0
4	875	1	GL	***Themeda-Cymbopogon***	Moist	5.1	5.1	5.0	5.1
5	875	3	GL	***Themeda-Cymbopogon***	Lower	5.0	5.0	4.9	5.0
6	875	2	GL	***Themeda-Cymbopogon***		5.1	5.1	5.0	5.1
7	900	1	GL	***Themeda-Cymbopogon***		5.5	5.3	5.1	5.3
8	850	3	GL	***Themeda-Cymbopogon***		5.3	5.1	5.1	5.2
9	900	1	GL	***Themeda-Cymbopogon***	Upper	**5.3**	5.1	5.1	5.2
10	870	1	SEncl.	***Pteridium aquilinum***		5.5	5.3	5.2	5.3
11	950	1	SEncl	***Pteridium aquilinum***		5.7	5.4	5.4	5.5
12	900	1	SEct.	***Maesa perrottetiana***		5.4	5.2	5.2	5.3
13	900	2	SEct.	***Maesa perrottetiana***		5.3	5.2	5.2	5.2
14	850	1	SEct.	***Nilgirianthus sp.***		5.1	5.1	5.1	5.1
15	900	2	SEncl.	***Nilgirianthus sp.***		5.5	5.4	5.4	5.4
16	900	1	*SEct.*			4.8	4.8	4.8	4.7
17	870	3	TEncl.	***Pterocarpus marsupium***		5.O	4.9	4.8	4.9
18	900	1	TEncl.	***Phoenix humilis***		4.8	5.0	5.1	5.0
19	900	1	TEncl.	***Phoenix humilis***		5.5	5.4	5.5	5.5
20	900	1	TEncl.	***Phoenix humilis***		5.5	5.5	5.5	5.5
21	850	1	EGF			5.2	5.4	5.1	5.2
22	800	1	EGF		Burnt	5.3	5.2	5.2	5.2
23	850	1	EGF		Burnt	5.6	5.5	5.5	5.5

EGF: Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; TEncl.: Tree enclosure. * n = no. of soil pits studied.

Table 6.15 Soil pH in different vegetation groups (Eravikulam).

No	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth(cm)			
						0-20	20-40	40-60	0-60
I	2160	2	GL		Rocky Burnt	4.8	5.0	**5.0**	4.9
2	1985	3	GL			5.1	52	**5.2**	5.1
3	2060	2	GL	*Eriocaulon - Garnotia*		4.9	4.5	4.7	4.7
4	2040	2	GL	*Garnotia tectorum*		4.8	4.7	4.9	4.8
5	2055	3	GL	*Eulalia phaeothrix*		4.7	4.8	4.7	4.7
6	2170	3	GL	*Eulalia phaeothrix*		4.9	4.8	4.9	4.9
7	2070	2	GL	*Chrysopogon zeylanicus*		4.7	4.7	4.8	4.7
8	1950	3	GL	*Chrysopogon zeylanicus*		4.9	4.8	4.7	4.8
9	2100	3	GL	*Arundinella fuscata*		5.1	4.9	4.9	5
10	2060	2	GL	*Arundinella ciliata*		4.8	4.6	4.8	4.7
11	2180	3	GL	*Trpogon bromoides*		5	5	5	5
12	2075	3	SEncl.	*Gaultheria fragrantissima*		5.1	4.8	4.9	4.9
13	2100	3	SEct.	*Strobilanthes sp.*		4.6	4.6	4.6	4.6
14	2145	2	SEct.	*Strobilanthes homotropa*		4.5	4.3	4.3	4.4
15	1955	3	SEct.	*Hypericum-Rhodoendron*		5	4.8	4.7	4.8
16	1905	3	SEct.	*Pteridium aquilinum*		5	4.8	4.6	4.8
17	2140	3	SEct.	*Ageratina adenophora*		**5.3**	4.9	4.6	4.9
18	1930	3	FEcot.			5	4.7	4.6	4.8
19	1910	3	SF			4.8	4.6	4.7	4.7
20	2140	3	SF			4.7	4.7	4.7	4.7
21	2140	3	SF	*Chimonobambusa* sp.		4.8	4.8	4.8	4.8

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrubecotone; SEncl.: Shrub enclosure; SF: Shola forest. * n = no. of soil pits studied

6.3.7 Organic carbon (OC)

From a low value of 1.41% to as much as *9.9%,* the organic carbon (OC) in soils varied. The mean values for mid elevational and high elevational zones were 2.14% and 5.62%, respectively, indicating significant inter-zonal differences. Compared to the lower quanta in the soils of mid elevational vegetal types, in the high elevational zone, the OC percentage ranged between 3.91 and 9.90%. The higher percentages OC with increase in elevation is already documented in pedological literature and the observations correspondedvery well. However, the range of variability in the mid elevational zone was of 1.67% while it was 4.43% in the high elevational zone showing that the vegetal types in the high elevational zone was much more variable (Fig. 6.3).

The grasslands of mid elevational and high elevational zones expressed significant differences in mean values of organic carbon. Similar differences were found between the shrub enclosures and the forest stands of the two elevational zones too. In all these cases the physiognomic vegetation types of the high elevational zone displayed quantities of OC content by double that of the mid elevational counterpart or still higher values.

The pattern of OC variations across different physiognomic vegetal types did not show' the same pattern in both the elevational zones; the patterns displayed mutually opposite trends. At the mid elevational zone, the OC content was high in both the grassland and the evergreen forest stands with lower mean values for the shrub enclosures/ ecotones and the tree enclosure (Table 6.16).

Table 6.16 Organic carbon in different vegetation groups (Silent Valley).

Sl no	Altitude		type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	***Arthraxon sp.***		3.04			
2	870	2	GL	***Eragrostis sp.***		2.95			
3	870	2	GL	***Themeda triandra***		2.66	1.78	1.14	1.86
4	875	1	GL	***Themeda-Cymbopogon***	Moist	3.38	2.31	1.36	2.32
5	875	3	GL	***Themeda-Cymbopogon***	Lower	3.05	2.10	1.44	2.20
6	875	2	GL	***Themeda-Cymbopogon***		3.34	2.06	1.31	2.24
7	900	1	GL	***Themeda-Cymbopogon***		3.05	2.01	1.07	2.04
8	850	3	GL	***Themeda-Cymbopogon***		3.17	2.08	1.17	2.14
9	900	1	GL	***Themeda-Cymbopogon***	upper	2.66	1.72	1.02	1.80
10	870	1	SEncl.	***Pteridium aquilinum***		2.76	1.93	1.0	1.9
11	950	1	SEncl.	***Pteridium aquilinum***		1.82	1.51	1.01	1.45
12	900	1	SEct	***Maesa perrottetiana***		2.57	1.43	0.94	1.65
13	900	2	SEct.	***Maesa perrottetiana***		1.82	1.41	1.01	1.41
14	850	1	SEct.	***Nilgirianthus sp.***		2.88	1.66	1.03	1.86
15	900	2	SEncl.	***Nilgirianthus sp.***		2.51	1.87	1.02	1.80
16	900	1	SEct.			3.01	2.10	1.31	2.14
17	870	3	TEncl.	***Pterocarpus marsupium***		3.12	2.15	1.20	2.17
18	900	1	TEncl.	***Phoenix humilis***		2.82	1.41	1.00	1.75
19	900	1	TEncl.	***Phoenix humilis***		3.47	2.6	1.43	2.5
20	900	1	TEncl.	***Phoenix humilis***		2.15	1.41	0.89	1.48
21	850	1	EGF			1.83	1.62	1.43	1.63
22	800	1	EGF	***Burnt***		3.49	3.12	2.02	2.88
23	850	1	EGF	***Burnt***		3.83	3.01	2.4	3.08

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; SF: Shola forest. * n = no. of soil pits studied.

At the high elevational zone, however, the picture of OC distribution across the vegetal types was unimodal with the highest quantity/unit area located in the shrub enclosure (6.21%). The grasslands (mean: 5.7%) and the shola forests (mean: 4.94%) displayed comparatively lower values of organic carbon. The high values of organic carbon recorded along the shrub enclosures/ecotones is highly surprising and needs to be investigated (Table 6.16).

At mid elevation, the lower values of OC were recorded for subsets of the following vegetal types: *Maesa* shrub ecotone (1.41%), *Pteridium* shrub ecotone (1.45%), *Phoenix* tree ecotone (1.48% and l.75%), *Themeda-Cymbopogon* grassland (1.80%), *Themeda triandra* grassland (1.86%) and *Nilgirianthus* sp. ecotone (1.80%, 1.86%). The higher values were recorded for selected subsets of the following compositional vegetal type: burnt evergreen forest (2.88% and 3.08%) (Table 6.16).

At higher elevation, the lower values were recorded by some subsets of burnt grassland (2.57%) and *Arundinella ciliata* grassland (3.91%). The higher values were recorded for some subsets of *Ageratina* shrub ecotone (9.9%), *Tripogon bromoides* grassland (9.6%), *Eulalia phaeothrix* grassland (9.45%) and *Chrysopogon zeylanicus* grassland (7%) and *Strobilanthes homotropa* shrub ecotone (6.68%) (Table 6.17).

Table 6.17 Organic carbon in different vegetation groups (Eravikulam).

No	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	2160	2	GL		Rocky	6.13	3.90	3.17	4.4
2	1985	3	GL		Burnt	5.21	1.59	0.91	2.57
3	2060	2	GL	***Eriocaulon - Garnotia***		2.65	6.50	5.59	4.91
4	2040	2	GL	***Garnotia tectorum***		6.8	4.42	6.07	5.77
5	2055	3	GL	***Eulalia phaeothrix***		6.7	5.1	3.1	4.96
6	2170	3	GL	***Eulalia phaeothrix***		12.51	8.66	7.18	9.45
7	2070	2	GL	***Chrysopogon zeylanicus***		8.2	7.25	5.55	7.00
8	1950	3	GL	***Chrysopogon zeylanicus***		6.02	4.66	2.83	4.5
9	2100	3	GL	***Arundinella fuscata***		8.25	6.1	2.55	5.63
10	2060	2	GL	***Arundinella ciliata***		3.19	2.84	5.69	3.91
11	2180	3	GL	***Tripogon bromoides***		12.42	8.42	7.95	9.60
12	2075	3	SEncl.	***Gaultheria fragrantissima***		7.89	4.14	4.19	5.37
13	2100	3	SEct.	***Strobilanthes sp.***		7.89	4.60	3.17	5.22
14	2145	2	SEct.	***Strobilanthes homotropa***		7.25	6.61	6.18	6.68
15	1955	3	SEct.	***Hypericum-Rhodoendron***		8.18	4.91	3.07	5.38
16	1905	3	SEct.	***Pteridium aquilinum***		5.7	5	3.48	4.72
17	2140	3	SEct.	***Ageratina adenophora***		0.24	11.59	7.88	9.90
18	1930	3	FEcot.			6.36	4.91	3.72	5.00
19	1910	3	SF			6.3	4.92	4.45	5.22
20	2140	3	SF			5.73	6.25	3	4.99
21	2140	3	SF	***Chimonobambusa** sp.*		5.40	5.02	3.27	1.56

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure;
SF: Shola forest. * n = no. of soil pits studied.

6.3.8 Exchangeable bases (me/100 gm soil)

The observed quantities of exchangeable bases (EB) in different vegetal mosaics ranged between 3 and and 23 me/100 g soil and the mean values were between 10 and 17. The range of variability in each of the elevational zone was found to be the same (13%). The high elevational vegetal types are much more variable than the low elevational ones.

At both the elevational zones, range limits of variability did not help to circumscribe the physiognomic vegetation types. In mid elevational zone, a linear descent of exchangeable bases fiom grassland to forests is observed. The grasslands invariably had high values of EB and markedly differed from other physiognomic vegetal types, although some subsets of shrub ecotones and tree enclosures shared lowest minimal values of EB in grasslands. At any rate, the grassland with the mean value of 20 me/100 g soil is definitely different from the evergreen forest stands with the mean of 14 me/100 g soil. The distribution of EB as depicted by the mean values in the high elevational zone was not clear. Although the mean values depicted a pattern just the reverse of the mid elevational zone, the table of observed values across the vegetal mosaics did not support this (Fig. 6.3).

At mid elevation, the lower values of 10 and 11 me/100 g soil as observed were shared by some subsets of the vegetal mosaics: *Nilgrianthus* sp. shrub ecotone (11 ppm) and a subset of the burnt evergreen forest (10 me/100 g soil). The higher values of 20-23 me/100 g soil were almost exclusively restricted to the grasslands: two subsets of *Themeda-Chrysopogon* grassland (20 and 23 me/100 g soil) (Table 6.18).

Table 6.18 Exchangeable bases in different vegetation group (Silent Valley).

Sl no	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	***Arthraxon* sp.**		22			
2	870	2	GL	***Eragostis* sp.**		23			
3	870	2	GL	***Themeda triandra***		22	19	11	17
4	875	1	GL	***Themeda-Cymbopogon***	**Moist**	21	17	13	17
5	875	3	GL	***Themeda-Cymbopogon***	**Lower**	24	20	15	20
6	875	2	GL	***Themeda-Cymbopogon***		25	18	15	19
7	900	1	GL	***Themeda-Cymbopogon***		27	17	13	19
8	850	3	GL	***Themeda-Cymbopogon***		25	17	12	18
9	900	1	GL	***Themeda-Cymbopogon***	**Upper**	31	20	17	23
10	870	1	SEncl.	***Pteridium aquilinum***		12	14	14	13
11	950	1	SEncl.	***Pteridium aquilinum***		25	18	17	20
12	900	1	SEct.	***Maesa perrottetiana***		20	13	10	15
13	900	2	SEct.	***Maesa perrottetiana***		15	12	10	12
14	850	1	SEct.	***Nilgirianthus sp.***		25	18	12	18
15	900	2	SEncl.	***Nilgirianthus sp.***		14	12	8	11
16	900	1	SEct.			23	17	11	17
17	870	3	TEncl.	***Pterocarpus marsupium***		22	16	14	17
18	900	1	TEncl.	***Phoenix humilis***		18	12	9	13
19	900	1	TEncl.	***Phoenix humilis***		32	13	11	19
20	900	1	TEncl.	***Phoenix humilis***		28	15	13	19
21	850	1	EGF			17	16	14	16
22	800	1	EGF	***Burnt***		18	16	15	16
23	850	1	EGF	***Burnt***		14	10	6	10

ECF: Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; TEncl.: Tree enclosure; * n = no. of soil pits studied.

At higher elevation, the lower values (3-8 me/l00 g soil) were observed in the case of some subsets of *Chrysopogon zeylanicus* grassland (3 me/100 g soil and 6 me/100 g soil), a subset of *Eulaliaphaeothrix* grassland (5 me/100 g soil), *Pteridium* shrub ecotone (6 me/100 g soil), *Arundinella ciliata* grassland (7 me/100 g soil) and *Garnotia tectorum* grassland (8 me/l00 g soil) were again shared by subsets of grassland communities: *Arundinella fuscata* grassland (16me/100 g soil), *Ageratina* shrub ecotone (16 me/100 g soil) and burnt grassland (12 me/100 g soil), *Eriocaulon- Garnotia* grassland (12 me/100 g soil) and a subset of *Chrysopogon zeylanicus* grassland all had 12 me/100 g soil. Except for the *Ageratina* shrub ecotone, all other shrub ecotones and the shola forest types showed moderate values within the range of 9-11 me/100 g soil (Table 6.19).soil), most of which were indeed grassland vegetal mosaics.

Table 6.19 Exchangeable base in different vegetation groups (Eravikulam).

Sl no	Alti tude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	26-40	40-60	0-60
1	2160	2	GL		Rocky	6	11	17	11
2	1985	3	GL		Burnt	14	12	10	12
3	2060	2	GL	***Eriocaulon - Gamotia***		13	10	14	12
4	2040	2	GL	***Gamotia tectorum***		16	4	3	8
5	2055	3	GL	***Eulalia phaeothrix*** .		5	6	3	5
6	2170	3	GL	***Eulalia phaeothrix***		11	11	14	12
7	2070	2	GL	***Chrysopogonzeylanicus***		4	4	2	3
8	1950	3	GL	***Chysopogonzeylanicus***		18	5	5	6
9	2100	3	GL	***Arundinellafuscata***		14	17	16	16
10	2060	2	GL	***Arundinella ciliata***		7	6	9	7
11	2180	3	GL	***Tripogon bromoides***		12	10	10	11
12	2075	3	SEncl.	***Gaultheriafragrantissima***		13	9	8	10
13	2100	3	SEct.	***Strobilanthes* sp.**		10	10	6	9
14	2145	2	SEct.	***Strobilanthes homotropa***		12	8	6	9
15	1955	3	SEct.	***Hypericum-Rhodoendron***		11	7	8	9
16	1905	3	SEct.	***Pteria'ium aquilinum***		9	5	5	6
17	2140	3	SEct.	***Ageratina adenophora***		24	15	9	16
18	1930	3	FEcot.			15	8	7	10
19	1910	3	SF			14	7	10	10
20	2140	3	SF			14	10	8	11
21	2140	3	SF	***Chimonohambusa* sp.**		13	8	7	9

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; SF: Shola forest. * n = no. of soil pits studied.

6.3.9 Total Nitrogen (pprn)

Distribution of nitrogen in soils ranged between 118 ppm and 2,009 ppm. Tabular data across the vegetal mosaics proved distinctness of the two elevational belts. In the mid elevational zone the value ranges from 118 ppm upto 291 ppm only whereas the value range for the high elevational zone was 532-2009. That is, without any overlap of values across the elevational zones (Fig. 6.3).

Compared to the high elevational zone, the mid elevational zone is poor in nitrogen; the values observed at mid elevational zone is approximately only one fifth of that generally found at higher elevations (Tables 6.20 and 6.21).

Table 6.20 Nitrogen in different vegetation mosaics (Silent Valley).

Sl no	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	*Arthraxon sp.*		291			
2	870	2	GL	*Eragrostis sp.*		278			
3	870	2	GL	*Themeda triandra*		253	156	105	171
4	875	1	GL	*Themeda-Cymbopogon*	Moist	301	196	119	206
5	875	3	GL	*Themeda-Cymbopogon*	Lower	283	192	129	202
6	875	2	GL	*Themeda-Cymbopogon*		303	197	124	208
7	900	1	GL	*Themeda-Cymbopogon*		292	197	103	198
8	850	3	GL	*Themeda-Cymbopogon*		301	202	108	204
9	900	1	GL	*Themeda-Cymbopgon*	Upper	240	139	89	156
10	870	1	SEncl.	*Pteridium aquilinum*		231	162	90	161
11	950	1	SEncl.	*Pteridium aquilinum*		147	115	92	118
12	900	1	SEct.	*Maesa perrottetiana*		233	118	76	142
13	900	2	SEct.	*Maesa perrottetiana*		169	128	94	130
14	850	1	SEct.	*Nilgirianthus* sp.		258	138	91	162
15	900	2	SEncl.	*Nilgirianthus* sp.		214	162	90	155
16	900	1	SEct.			293	199	116	203
17	870	3	TEncl.	*Pterocarpus marsupium*		276	200	121	200
18	900	1	TEncl.	*Phoenix humilis*		237	112	87	145
19	900	1	TEncl.	*Phoenix humilis*		299	117	112	209
20	900	1	TEncl.	*Phoenix humilis*		197	120	75	131
21	850	1	EGF			163	141	108	137
22	800	1	EGF		Burnt	312	278	169	253
23	850	1	EGF		Burnt	312	279	201	264

EGF: Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; TEncl.: Tree enclosure. * n = no. of soil pits studied

At the mid elevational zone, a general quadratic trend of distribution of nitrogen with lower values in the shrub and tree enclosures and higher values in both grasslands and forest stands was observed. This pattern matched exactly the pattern of distribution of organic carbon across the vegetal mosaics of mid elevational zone. Nitrogen is a macronutrient involved in the building up of biomass. The non-linear pattern of N distribution across the physiognomic vegetal types perhaps accounted for the fact that N was highly utilized by the pioneer shrub and tree species of the grassland where the shrub/ tree enclosures were found. The shrub enclosures/ ecotones and tree enclosures were locations where active biomass build up was taking place at a rate much higher than in the grassland and the forest (Table 6.20).

At the high elevational zone, the trend of distribution of nitrogen in soils was less discernible. The mean values of physiognomic vegetal types followed one of a linear trend with minimum for the grassland and with higher values for shrub enclosure and forest stands. Such a trend was also observed in the distribution of minimal values of the vegetal types while the maxima followed a liner trend in the reverse order, ie, with maximal value for the grassland and the lower values with the shrub enclosure and the forest stand (Table 6.21).

Table 6.21 Nitrogen in different vegetation groups (Eravikulam).

No	Alti tude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	2160	2	GL		Rocky	952	840	1008	933
2	1985	3	GL		Burnt	1026	8%	803	908
3	2060	2	GL	***Eriocaulon - Garnotia***		2264	2087	1676	2009
4	2040	2	GL	***Garnotia tectorum***		1078	756	896	910
5	2055	3	GL	***Eulaliaphaeothrix***		961	887	588	812
6	2170	3	GL	***Eulalia phaeothrix***		1198	1082	905	1062
7	2070	2	GL	***Chrysopogonzeylanicus***		1088	l000	833	974
8	1950	3	GL	***Chrysopogon zeylanicus***		663	532	401	532
9	2100	3	GL	***Arundinellafuscata***		979	905	560	815
10	2060	2	GL	***Arundinella ciliata***		1000	882	647	843
11	2180	3	GL	***Tripogon bromoides***		1117	980	941	1013
12	2075	3	SEct.	***Gaultheria fragrantissima***		1045	1323	765	1044
13	2100	3	SEct,	***Strobilanthes sp.***		1307	709	709	908
14	2145	2	SEct	***Strobilantheshomotropa***		1676	1294	1088	1353
15	1955	3	SEct.	***Hypericum-Rhodoendron***		782	656	666	701
16	1905	3	SEct.	***Pteridium aquilinum***		1049	774	725	853
17	2140	3	SEct.	***Ageratina adenophora***		1736	1512	1141	1463
18	1930	3	FEcot.			1421	950	794	1055
19	1910	3	SF			1292	725	941	986
20	2140	3	SF			1139	1388	933	1153
21	2140	3	SF	***Chimonobambusa sp.***		1176	1101	924	1067

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure;
SF: Shola forest. * n= no. of soil pits studied.

In the mid elevational zone, out of the 7 subsets of grassland vegetal mosaics, 5 showed values closer to 200 ppm or higher than that, while in the shrublands, out of the 7 subsamples, all 6 had values below 200 ppm except one which was just above 200 ppm. In the case of unburnt evergreen forests, the values were greater than 250 ppm while in the burnt evergreen forests, it was below 150 ppm. The tree enclosures showed values ranging between 131 ppm to ca. 200 ppm. At the high elevational zone, such patterns were less apparent (Table 6.20).

In the mid elevational zone, the species compositional vegetal mosaics with lower values for nitrogen were some subsets of Pteridium shrub ecotone (118ppm), Maesa shrub ecotone (130 ppm) and a subset of Phoenix tree enclosure (131 ppm; Table 6.20).

At the high elevational zone, the lowest value of 532 ppm was observed for Chrysopogon zeylanicus dominant grassland and 70I pprn for Hypericum-Rhododendron shrub ecotone. The highest value of 2,009 ppm was observed for Eriocaulon-Garnotia grassland community. All other figures for most communities of all physiognomic vegetal types were closer to a modal range of 1000- 1,500 ppm (Table 6.21).

6.3.10 Potassium (ppm)

Potassium available in the soil ranged within the bounds of 11 ppm and 175 ppm. The lower and upper bounds of the values obtained for the mid elevational zone was found to be a subset of the set of the figures for high elevational zone and thus, the variability of the soils of the former is low (Fig. 6.3).

The patterns of distribution of potassium in both the elevational zones followed the same as for nitrogen, except that the figures were different. Thus, the pattern for the mid elevational zone was quadratic and for the high elevational zone, it was liner with all complexities as mentioned for nitrogen.

At the mid elevational zone, most mean values for each of the subsets of grasslands turned out to be closer to or greater than 70 ppm. In contrast, all except one subset of the total 7 shrub ecotones had values within the range of 62+1-2. The values of the tree enclosures and the evergreen forests were more or less continuous without any scope for categorical distinction (Table 6.22).

Table 6.22 Potassium in different vegetation mosaics (Silent Valley).

Sl no	**Altitude**	**n***	**Veg type**	**Compositional type**	**Habitat**	**Soil depth (cm)**			
						0-20	**20-40**	**40-60**	**0-60**
1	870	2	GL	***Arthraxon sp.***		103			
2	870	2	GL	***Eragrostis sp.***		123			
3	870	2	GL	***Themeda triandra***		73	66	38	59
4	875	1	GL	***Themeda-Cymbopogon***	Moist	99	69	43	70
5	875	3	GL	***Themeda-Cymbopogon***	Lower	117	78	57	84
6	875	2	GL	***Themeda-Cymbopogon***		162	75	63	100
7	900	1	GL	***Themeda-Cymbopogon***		128	76	45	83
8	850	3	GL	***Themeda-Cymbopogon***		162	73	61	99
9	900	1	GL	***Themeda-Cymbopogon***	Upper	80	75	48	68
10	870	1	SEncl.	***Pteridium aquilinum***		91	60	37	63
11	950	1	SEncl.	***Pteridium aquilinum***		88	62	39	63
12	900	1	SEct	***Maesa perrottetiana***		92	60	34	62
13	900	2	SEct.	***Maesa perrottetiana***		83	61	42	62
14	850	1	SEct.	***Nilgirianthus*** *sp.*		110	51	36	66
15	900	2	SEncl.	***Nilgirianthus sp.***		90	62	31	61
16	900	1	SEct.			108	59	41	69
17	870	3	TEncl.	***Pterocarpus marsupium***		117	76	47	81
18	900	1	TEncl.	***Phoenix humilis***		60	58	53	54
19	900	1	TEncl.	***Phoenix humilis***		73	44	31	49
20	900	1	TEncl.	***Phoenix humilis***		80	67	35	61
21	850	1	EGF			112	87	61	87
22	800	1	EGF		Burnt	80	73	43	65
23	850	1	EGF		Burnt	149	72	54	92

EGF: Evergreen forest; FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; TEncl.: Tree enclosure. * n = no. of soil pits studied

At the mid elevational zone, low figures (60 ppm and below) were exhibited by several vegetal subsets: *Themeda triandra* grassland (59 pprn), most shrub ecotones (61-66 ppm) and all subsets of the *Phoenix* tree enclosure (49-61 ppm). The counter- parts with upper values were restricted to some of the species compositional vegetal mosaics of the grassland formations: two subsets of the *Themeda-Cymbopogon* community (100 pprn and 99 ppm; Table 6.22).

At the high elevational zone, low levels of potassium were observed in some of the subsets of grassland communities: *Arundinella ciliata* community (11 pprn), a subset of *Eulalia phaeothrix* community (36 ppm) and a subset of *Chrysopogon zeylanicus* dominant community (50 ppm). The higher counterparts were again some of the grassland communities: *Garnotia tectorum* community (179 ppm), a subset of *Eulalia phaeothrix* community (175 ppm) and two shrub ecotones: *Ageratina* shrub ecotone (175 ppm) and *Hypericum-Rhododendron* community (173 ppm) (Table 6.23).

Table 6.23 Potassium in different vegetation groups (Eravikulam).

No	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	2160	2	GL		Rocky	45	61	53	53
2	1985	3	GL		Burnt	201	78	68	116
3	2060	2	GL	***Eriocaulon - Garnotia***		120	141	93	118
4	2040	2	GL	***Garnotia tectorum***		264	139	133	179
5	2055	3	GL	***Eulalia phaeothrix***		54	32	21	36
6	2170	3	GL	***Eulalia phaeothrix***		269	164	93	175
7	2070	2	GL	***Chrysopogonzeylanicus***		66	42	45	50
8	1950	3	GL	***Chrysopogonzeylanicus***		152	63	35	83
9	2100	3	GL	***Arundinellafuscata***		105	38	28	57
10	2060	2	GL	***Arundinella ciliata***		16	9	8	11
11	2180	3	GL	***Tripogon bromoides***		210	122	83	138
12	2075	3	SEct.	***Gaultheria fragrantissima***		205	85	53	114
13	2100	3	SEct.	***Strobilanthes sp.***		168	76	45	96
14	2145	2	SEct.	***Strobilantheshomotropa***		150	98	75	108
15	1955	3	SEct.	***Hypericum-Rhodoendron***		259	135	125	173
16	1905	3	SEct.	***Pteridium aquilinum***		209	133	71	138
17	2140	3	SEct.	***Ageratina adenophora***		295	144	86	175
18	1930	3	FEcot.			117	81	62	97
19	1910	3	S F			94	43	33	57
20	2140	3	S F			257	135	70	154
21	2140	3	S F	***Chimonobambusa sp.***		135	102	84	107

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; SF: Shola forest. * n = no. of soil pits studied.

6.3.11 Calcium (ppm)

The variability of calcium available in the soil samples was between 44 and 660 ppm. At the mid elevational zone the range was 44-83 ppm and that at the high elevational zone was 73-660 with very little overlap between the two elevational zones. The range of variability for the low elevational zone was negligible (21 ppm) compared to a difference of 587 ppm for the high elevational zone (Fig. 6.3).

The mid elevational zone showed a descending linear trend of calcium distribution across the physiognomic vegetal types, grassland, shrub ecotones, tree enclosures and forest stands. The pattern of range variability also followed a descending linear trend corresponding to the mean values. The pattern of the high elevation zone was less determinable. The mean values showed an ascending linear trend across the same sequence of vegetal units as did the minimal values too. However, the maximal values followed a unimodal pattern with the highest value recorded for shrub ecotones/ enclosures. Here, the range of variability of quantities was very high, compared to that of the mid elevational zone by 5-10 folds or more in specific instances (Fig. 6.3).

At the mid elevational zone, the minimum calcium content in the soil was shown by: a subset of shrub ecotone (44 ppm), *Themeda triandra* grassland (48 ppm), a subset of Phoenix tree enclosure (48 ppm) and a subset of burnt evergreen forest (48 ppm). Maximum values were shown mostly by subsets of grasslands: some subsets of *Themeda-Cymbopogon* grassland (65-62 ppm) (Table 6.24).

Table 6.24 Calcium in different vegetation mosaics (Silent Valley).

Sl no	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	***Arthraxon sp***		67			
2	870	2	GL	***Eragrostis sp.***		83			
3	870	2	GL	***Themeda triandra***		60	48	35	48
4	875	1	GL	***Themeda-Cymbopogon***	Moist	71	45	36	51
5	875	3	GL	***Themeda-Cymbopogon***	Lower	86	50	40	55
6	875	2	GL	***Themeda-Cymbopogon***		85	64	46	65
7	900	1	GL	***Themeda-Cymbopogon***		76	53	36	55
8	850	3	GL	***Themeda-Cymbopogon***		87	60	39	62
9	900	1	GL	***Themeda-Cymbopogon***	Upper	77	63	38	59
10	870	1	SEncl.	***Pteridium aquilinum***		86	51	30	56
11	950	1	SEncl.	***Pteridium aquilinum***		74	50	35	53
12	900	1	SEct.	***Maesa perrottetiana***		75	53	26	51
13	900	2	SEct.	***Maesa perrottetiana***		83	43	40	55
14	850	1	SEct.	***Nilgirianthus sp.***		79	57	34	57
15	900	2	SEncl.	***Nilgirianthus sp.***		75	53	30	53
16	900	1	SEct.			61	42	29	44
17	870	3	TEncl.	***Pterocarpus marsupium***		79	51	34	55
18	900	1	TEncl.	***Phoenix humilis***		58	47	39	48
19	900	1	TEncl.	***Phoenix humilis***		68	47	40	52
20	900	1	TEncl.	***Phoenix humilis***		74	59	27	53
21	850	1	EGF			79	44	26	50
22	800	1	EGF		Burnt	63	42	38	48
23	850	1	EGF		Burnt	78	51	29	53

At higher elevations, the lowest minimum values were represented by subsets of vegetal types: grassland with rocky outcrops (73 ppm) and *Tripogon* grassland (86 ppm) and the highest maxima were represented by *Ageratina* shrub ecotone (660 ppm). Both the subsets of shola forest samples showed high values (335 ppm and 417 ppm) and the forest ecotone showed a value closer to these values (284 ppm). The only value higher than that of the shola forests was that of *Ageratina* shrub ecotone mentioned above, The shola forests with profuse bamboo growth showed a lower (187 ppm) than that of the shola forests without bamboo and the forest ecotone. In none of the shola forest and shrub ecotones mosaics the amount of calcium was lower than 100 ppm while such situations were also observed with some types of grasslands (Table 6.25).

Table 6.25 Calcium in different vegetation groups (Eravikulam).

No	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	2160	2	GL		Rocky	100	60	60	73
2	1985	3	GL		Burnt	233	100	100	144
3	2060	2	GL	***Eriocaulon - Garnotia***		140	100	80	107
4	2040	2	GL	***Garnotia tectorum***		280	120	470	290
5	2055	3	GL	***Eulalia phaeothrix***		133	133	93	120
6	2170	3	GL	***Eulalia phaeothrix***		133	107	107	116
7	2070	2	GL	***Chrysopgon zeylanicus***		167	253	187	202
8	1950	3	GL	***Chrysopogon zeylanicus***		133	200	133	155
9	2100	3	GL	***Arundinella fuscata***		147	100	113	120
10	2060	2	GL	***Arundinella ciliata***		130	80	130	113
11	2180	3	GL	***Tripogon bromoides***		95	90	73	86
12	2075	3	SEncl.	***Gaultheria fragrantissima***		433	100	87	207
13	2100	3	SEct.	***Strobilanthes sp.***		227	87	100	138
14	2145	2	SEct.	***Strobilanthes homotropa***		370	160	70	200
15	1955	3	SEct.	***Hypericum-Rhodoendron***		193	113	93	133
16	1905	3	SEct.	***Pteridium aquilinum***		200	147	160	169
17	2140	3	SEct.	***Ageratina adenophora***		1680	180	120	660
18	1930	3	FEcot.			333	293	227	284
19	1910	3	SF			773	220	250	417
20	2140	3	SF			680	233	93	335
21	2140	3	SF	***Chimonobambusa sp.***		380	267	153	187

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure;
SF: Shoia forest. * n = no. of soil pits studied.

6.3.12 Magnesium (ppm)

The total range of magnesium in the soil was found to vary between 39 and 304 ppm. The mean values of the two elevational zones differed considerably, although many lower values of the high elevational zone was found to be in the range of the upper limits of vegetal mosaics of the mid elevational zone.

At the high elevational zone, an ascending linear trend starting with the grasslands ending with the shola forests was noticed. However, a definite trend was not observed for the mid elevational zone; here all mean values clustered in the range of 48 and 53 ppm (Fig. 6.3).

At the mid elevational zone, the lower values of Mg contents in the soils were shown by selected subsets of a shrub ecotone (40 ppm), a subset of the burnt evergreen forest stand (41 ppm), a subset of Themeda-cymbopogon grassland (42 ppm) and the Maesa shrub ecotone

(43 ppm). Higher values were represented by: a subset of Maesa shrub ecotone (60 ppm) and a subset of a burnt evergreen forest (59 ppm) (Table 6.26).

Table 6.26 Magnesium in different vegetation mosaics (Silent Valley).

Sl no	Alti tude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
1	870	2	GL	***Arthraxon sp.***		49			
2	870	2	GL	***Eragrostis sp.***		78			
3	870	2	GL	***Themeda triandra***		54	42	50	49
4	675	1	GL	***Themeda-Cymbopogon***	Moist	67	41	31	46
5	875	3	GL	***Themeda-Cymbopogon***	Lower	82	47	27	52
6	875	2	GL	***Themeda-Cymbopogon***		71	52	37	53
7	900	1	GL	***Themeda-Cymbopogon***		69	43	32	48
8	850	3	GL	***Themeda-Cymbopogon***		75	54	40	56
9	900	1	GL	***Themeda-Cymbopogon***	Upper	51	40	36	42
10	870	1	SEncl.	***Pteridium aquilinum***		73	49	26	49
11	950	1	SEncl.	***Pteridium aquilinum***		69	44	29	47
12	900	1	SEct.	***Maesa perrottetiana***		63	41	25	43
13	900	2	SEct.	***Maesa perrottetiana***		78	62	39	60
14	850	1	SEct.	***Nilgirianthus sp.***		72	46	26	48
15	900	2	SEncl.	***Nilgirianthus sp.***		71	47	28	49
16	900	1	SEct.			60	38	21	40
17	870	3	TEncl.	***Pterocarpus marsupium***		64	41	29	45
18	900	1	TEncl.	***Phoenix humilis***		49	38	46	44
19	900	1	TEncl.	***Phoenix humilis***		66	39	27	44
20	900	1	TEncl.	***Phoenix humilis***		70	45	31	49
21	850	1	EGF			72	49	28	50
22	800	1	EGF		Burnt	58	39	27	41
23	850	1	EGF		Burnt	84	60	34	59

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone; SEncl.: Shrub enclosure; SF: Shola forest. * n = no. of soil pits studied.

At the high elevational zone, the lower values exhibited by *Eulalia phaeothrix* grassland (38 ppm) and *Arundinella fuscata* grassland (39 ppm). The higher values were represented by: the shola forest ecotone (304 ppm), *Ageratina* shrub ecotone (159 ppm), a subset of *Chrysopogon zeylanicus* grassland (151 ppm) and a subset of shola forest sample (147 ppm) (Table 6.27).

Table 6.27 Magnesium in different vegetation groups (Eravikulam).

No	Altitude	n*	Veg type	Compositional type	Habitat	Soil depth (cm)			
						0-20	20-40	40-60	0-60
	2160	2	GL		Rocky	85	90	120	98
2	1985	3	GL		Bumt	100	97	73	90
3	2060	2	GL	*Eriocaulon - Gamotia*		75	135	75	95
4	2040	2	GL	*Gamotia tectorum*		55	30	65	50
5	2055	3	GL	*Eulaliaphaeoihrix*		50	37	27	38
6	2170	3	GL	*Eulalia phaeothrix*		60	63	53	59
7	2070	2	GL	*Chrysopogonzeylanicus*		70	53	57	60
8	1950	3	GL	*Chrysopogon zeylanicus*		307	83	63	151
9	2100	3	GL	*Arundinellafuscata*		43	37	37	39
10	2060	2	GL	*Arundinella ciliata*		35	75	45	52
11	2180	3	GL	*Tripogon bromoides*		80	70	70	73
12	2075	3	SEncl.	*Gaultheriafragrantssima*		143	93	77	104
13	2100	3	SEct.	*Strobilanthes sp.*		100	47	60	69
14	2145	2	SEct.	*Strobilantheshomotropa*		150	80	85	105
15	1955	3	SEct	*Hypericum-Rhodoendron*		103	47	63	71
16	1905	3	SEct.	*Pteridium aquilinum*		110	53	43	69
17	2140	3	SEct.	*Ageratina adenophora*		253	147	77	159
18	1930	3	FEcot.			540	120	253	304
19	1910	3	SF			143	110	87	113
20	2140	3	SF			213	127	100	147
21	2140	3	SF	*Chimonobambusa sp.*		90	110	73	91

FEcot.: Forest ecotone; GL: Grassland; SEct.: Shrub ecotone, SEncl.: Shrub enclosure;
SF: Shola forest. * n = no. of soil pits studied

6.4 Discussion

6.4.1 Comparison of soil properties of the elevational continuum (Silent Valley and Eavikulam)

The mean values of soil properties in the two elevational zones, Silent Valley (MEZ) and Eravikulam (HEZ), are given in Figure 6.3 and Tables 6.28 to 6.29.

6.4.1.1 Trends with depth across different elevational zones

The mean values of soil properties (for the 0-60 cm layer) at Silent Valley (MEZ) showed that in general, gravel, EB, OC, N, K, Ca and Mg contents decreased with depth while silt, clay and pH increased or did not show any appreciable trend. At Eravikulam (HEZ) too, the parameters mentioned above displayed similar trends except that for gravel which did not show any particular trend, compared to the descending trend at Silent Valley (MEZ). Infiltration of clay and silt into the deeper layers was evident at both the elevational zones (Tables 6.30 and 6.31).

6.4.1.2 Trends in mean values of soil properties in the 0-60 cm layer across elevational zones

Soil particle-size separates

At Silent Valley (MEZ), the gravel content variation range was considerably low (28%) compared to that of Eravikulam (HEZ) (69%). At the same time, the mean values of the two zones were not that different (21% vs. 27%). Both mean values as well as the ranges of variability of sand and silt did not show much difference in the two zones, except for slightly higher sand content which otherwise was found compensated by the slightly lower silt content. Mean figures for clay content again displayed a similar trend across the two elevational zones without much appreciable difference in percentage (Table 6.28).

Stat	Grav (%)		Sand (%)		Silt (%)		Clay (%)		pH		EB*	
	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ
Minima	14	6	67	74	11	8	9	10	4.7	4.4	10	3
Maxima	42	75	78	81	16	11	20	15	5.5	5.1	23	16
Range(s)	28	69	11	7	5	3	11	5	0.8	0.7	13	13
Mean(s)	21	27	73	77	14	10	14	12	5.2	5	17	10

Stat	OC (%)		N (ppm)		K (ppm)		Ca (ppm)		Mg (ppm)	
	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ
Minima	1.41	2.57	118	532	49	11	44	73	40	39
Maxima	3.08	7	264	2009	100	175	65	660	60	304
Range(s)	1.67	4.43	146	1477	51	164	21	587	20	265
Mean(s)	2.14	4.94	189	1065	74	104	54	306	49	164

Soil pH and exchangeable bases (EB)

The observed values of hydrogen ion concentration (pH) at Silent Valley (MEZ) ranged between 4.7 to 5.5 indicating that the soils ranged from very strongly acid to strongly acid. The mean pH value of 5.0 at Eravikulam (HEZ) showed that soils of Eravikulam (HEZ) was much more acidic than Silent Valley (MEZ). Corresponding with the figures for pH, the zones displayed compatible figures for exchangeable bases (EB). The mean values for EB were 17 and 10 milliequivalent/l00 g soil, respectively for Silent Valley (MEZ) and Eravikulam (HEZ), the dispersion of values having had the same magnitude (13 me/ 100 g) at both the zones (Table 6.28).

Organic carbon

Organic carbon (OC), the carbon contained in dead and decaying organic matter, not directly absorbed by plants. It serves as a buffer and a storehouse of nutrients and radicals of organic acids, aldehydes and alcohols, which are released into the soil and are used by the plants. There was pronounced difference in the OC content between the zones. The mean value for Silent Valley, 2.14% was found to be dispersed within the range of variability of 1.67%. The mean value for Eravikulam (HEZ) was found to be 4.94% which was more than double of that for Silent Valley (MEZ). Likewise, the range of variability for Eravikulam (HEZ) was 4.43%, which is 2.65 times that of Silent Valley (MEZ) (Table 6.28).

Pedological literature has already documented the increasing organic carbon content of soils with increasing elevation and increasing latitudes. The activities of microbes on dead and decaying materials are slow and lethargic under conditions of high acidity prevailing under high altitude/ latitude situations (Firosova, 1967; Primavesi, 1968). The high altitude and the associated cooler climate, and the highly acidic soils of the area, low activities of microorganisms and the low decay rate of organic debris are links of one and the same orthogonal cause- effect ladder. The high organic carbon content and high acidity of the soils at Eravikulam (HEZ) therefore accounts for the high altitude.

Nutrients

Following the pattern of OC, mean values of the three nutrients, N, K and Ca were found to differ considerably between the two zones, all having higher values for Eravikulam (HEZ). The values for N at Silent Valley (MEZ) and Eravikulam (HEZ) were 189 ppm and 1,065 ppm, respectively and their ranges of variability were 146 and 1,477 ppm, respectively. The value obtained for Eravikulam (HEZ) was 5.6 times that of Silent Valley (MEZ) and the range, more than 10 times. There was no overlap of values of N for the two zones too. The highest maximum recorded for any vegetal mosaic at Silent Valley (MEZ) was 264 ppm and the lowest minimum recorded for Eravikulam (HEZ) was 532 ppm. Considering the important role of nitrogen (N) in the build up of living material (amino acids and proteins), more than a macro nutrient, it is a meganutrient. Yet the high amounts of N in the soils at high altitudes is scarcely available to the plants, owing to the low bacterial activities (Table 6.28).

The mean values and the range of variability of potassium at Eravikulam (HEZ) was 1.24 and 3.2 times, respectively of that observed for Silent Valley (MEZ). Calcium contents in the soils of Eravikulam (HEZ) outweighed that of Silent Valley (HEZ) and were 5.7 times (mean) and 2.8 times (range) (Table 6.28).

Magnesium, again followed the pattern of other nutrients. The mean value for Mg at Eravikulam (HEZ) (164 ppm) was 3.3 times higher than that of Silent Valley (MEZ) and the range of variability 13 times (Table 6.28).

The elevation of study sites at Eravikulam (HEZ) was in the range of 1,890-2,200 m while that at Silent Valley (MEZ) was in the range of 840-950. Between the study sites in each elevation zone, the variation in elevation was not much. But when Eravikulam (HEZ) and Silent Valley (MEZ) are taken separately, it could be seen that there was a difference of about 1000-1300 m. This altitudinal difference was reflected in the tremendous difference in species composition of the vegetal types and formations of the two zones. It is not difficult to understand the high inter-zonal variation in soil properties of the two elevational zones, Silent Valley (MEZ) and Eravikulam (HEZ). Soils at Eravikulam (HEZ) were very strongly acid and contained high amount of organic carbon whereas those at Silent Valley (MEZ) were strongly acid and had lower organic carbon. In contrast, soils at Silent Valley (MEZ) contained higher amounts of finer particles deeper layers (Table 6.28).

6.4.1.3 Comparison of soils across vegetal continua(grasslands through shrublands to forestlands) in the two elevational zones

In the previous section, it was found that the two elevational zones, Silent Valley (MEZ) and Eravikulam (HEZ) differed drastically in OC and nutrient contents. For this reason, similar vegetal formations of the two zones (for example the grasslands of Silent Valley and Eravikulam) did differ considerably and there is no scope for drawing pedological identity among them. On the other hand, the grassland vegetal mosaics through the shrubland mosaics to the forestlands offered a vegetal continuum, and the trends of soil properties across this gradient in each of the two altitudinal zones provided meaningful comparisons.

Trends across depth

In the previous section, it was found that at the zonal level, sand, silt, clay and pH showed no appreciable trends with depth. However, when the data were further partitioned according to each of the physiognomic vegetation types, some of the properties showed definite trends (Table 6.29).

The trend for gravel did not differ from that obtained for the elevational zones before data partitioning. Sand percent showed a reduction with depth both in grasslands and shrublands of Silent Valley, while the forestlands of Silent Valley and none of the vegetation types at Eravikulam showed any trend. In the case of silt, except for the shola forests, all the other vegetal types belonging to both the elevational zones displayed no trend. A slight increase in clay seemed to be the trend with all the vegetal types of Eravikulam, in contrast to the absence of any trend in any of the vegetation types of Silent Valley. This again points to the higher infiltration of clay to lower layers of soil at Eravikulam.

Exchangeable bases (EB), OC, N, K and Ca continued almost the same trends even after partitioning of data except that Mg failed to show a definite trend in all the three vegetal types at Eravikulam.

Trends in mean values of soil properties in the 0-60 cm layer

Table 6.30 provides an illustrated summary of the observed trends in each of the soil properties, across the grassland-shrubland-forestland continuum in both the altitudinal zones.

Gravel showed a decreasing trend at Eravikulam but had no trend at Silent Valley. Both sand and silt did not display any trend in both the zones. In the case of clay, a faintly decreasing trend was noticed at Eravikulam while at Silent Valley, the values remained same.

Values for pH showed an ascending trend depicting advancement towards less acidity in forestlands in Silent Valley. However, no such trend was observed at the Eravikulam. Likewise EB showed a descending trend across the vegetal continuum at Silent Valley but failed to show any trend at Eravikulam.

Table 6.29 Trends in soil properties with depth in the two elevational zones

Soil prop.	Sile Vallev (MEZ) 0-20 > 20-40 > 40-60 cm			Eravikulam (HEZ) 0-20 > 20-40 > 40-60 cm		
	GL	SL	FL	GL	SL	FL
Gravel	↘	↘	↘	nt	nt	↗
Sand	↘	↘	nt	nt	nt	nt
Silt	nt	nt	nt	nt	nt	nt
Clay	nt	nt	nt	↗	↗	↗
pH	↘	↘	↘	nt	nt	nt
EB	↘	↘	↘	nt	↘	nt
OC	↘	↘	↘	↘	↘	↘
N	↘	↘	↘	↘	↘	↘
K	↘	↘	↘	↘	↘	↘
Ca	↘	↘	↘	nt	↘	↘
Mg	↘	↘	↘	nt	nt	nt

FL: Forestland; *GL*: Grassland; *HEZ*: High elevational zone; *MEZ*: Medium elevational zone; *nt*: no trends (apparely) or both ascending and decending trends observed in differet compositional vegetal mosaics; *SL*: Shrubland.

Ascending arrow : ascending trend of the property with depth

Descending arrow: decending trend of the property with depth

Table 6.30 *Summary of trends in soil properties across the grassland-shrubland-forestland continua in the two elevational zones.*

Soil Properties	Silent Valley (MEZ) GL > SL > FL	Eravikulam (HEZ) GL > SL > FL
Gravel	nt	GL ↘ FL
Sand	nt	nt
Silt	nt	nt
Clay	↘	↘
pH	↗	nt
EB	↘	nt
OC	∪	∩
N	∪	
K	∪	↗
Ca	↘	↗
Mg		↗

FL: Forestland; *GL*: Grassland; *HEZ*: High elevational zone; *MEZ*: Medium elevational zone; *nt*: no trends (apparely) or both ascending and decending trends observed in differet compositional vegetal mosaics; *SL*: Shrubland.

Ascending arrow : decending trend of the property with depth

Descending arrow: ascending trend of the property with depth

Parabola: represents a decrease in the value of the properties in the shrubland with greater values in the grassland and forest.

Hyperbola: representa a unimoda distribution with peak in the shrubland

For Silent Valley (MEZ), organic carbon depicted a trough- like curve with low values in the shrublands and higher values both in the grassland and forest. The curve was found to be reversed with a unimodal pattern for Eravikulam (HEZ) with higher values represented by the shrublands. Going along with OC, both N and K also showed a quadratic trough-like curve at Silent Valley (MEZ) but depicted an ascending trend at Eravikulam (HEZ).

That of calcium was a descending trend at Silent Valley (MEZ) but did not show any clear trend at Eravikulam (HEZ). Magnesium did not show any trend at Silent Valley (MEZ) but showed an ascending trend at Eravikulam HEZ).

Looking at the panorama of trends in soil properties of the two elevational zones, it is interesting to see that they fall in to two categories: (1). same pattern in both elevational zones, as depicted by sand, silt and clay, (2). differing patterns in the two elevational zones, as depicted by gravel, pH, EB, OC, N, K, Ca and Mg.

The patterns of distribution of most of the soil properties across the vegetal continua differed in the two elevational zones. This presumably could be due to the differences in species composition of similar physiognomic formations in the two elevational zones and their differences in the physiology of metabolism. Whatever be the exact causes of these pattern differences, it is clear that similar vegetal formations of the two elevational zones (eg. grassland formations of MEZ and HEZ) are not identical in terms of pedometry.

The shrublands are generally intermediate between the grasslands and the forests in stand biomass. Tables 6.29 and 6.31 and Figure 6.3 provide variability of mean values of soil properties in each of the elevational zones. Here it can be noted that the values of shrublands for clay, pH, EB, and Ca at Silent Valley (MEZ) and those for gravel, N, Ca and Mg at Eravikulam (HEZ) are intermediate between that of the grasslands and forests, confirming the intermediate position of the soils of the shrublands.

Apart from the intermediate position, in many cases, the shrublands held optimal values compared to the grassland and forestland formations, as was with silt, OC, N, K and Mg at Silent Valley (MEZ) and sand and pH at Eravikulam (HEZ). These abnormalities could be due to the peculiar nature of biomass building up strategies which they possess and which differ from that of the grasslands and the forests.

6.4.1.4 Pedometric identity of vegetal types

Table 6.31 provides variability of mean values of soil properties across different vegetal mosaics in the two elevational zones. It is obvious that characterization and identification of individual vegetal mosaics (or species compositional vegetal types) is rather difficult, based on one or a few of the soil properties alone. This is precisely because, neither the depth dependent trends are vegetation specific (either at the species compositional level or at the physiognomic level; cf Tables 6.29 and 6.30) nor the properties remain discrete, without any overlap across the vegetal types in the same elevational zone.

Table 6.31 Mean values of soil properties across vegetal continua in two elevational zones.

Vegetation	Gravel(%)		Sand(%)		Silt (%)		Clay(%)		pH		EB*	
	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ
Grasslands	20	34	71	77	14	10	15	13	5.1	5	20	9
Shrublands	21	30	74	76	13	11	13	13	5.2	4.7	15	10
Forestlands	20	27	73	77	15	10						

Vegetation	OC (%)		N (ppm)		K (ppm)		Ca (ppm)		Mg (ppm)	
			MEZ	HEZ	MEZ	HEZ	MEZ	HEZ	MEZ	HEZ
Grasslands	2.29	5.7	213	983	88	92	61	139	53	73
Shrublands	1.74	6.2	153	1054	64	134	53	176	48	96
Forestlands	2.53	4.94	218	1065	81	104	50	306	50	164

MEZ: Mid elevational zone (Silent Valley); HEZ: High elevational zone (Eravikulam). * me/100 g

The possibility of identification of vegetal types on the associative nature of two or more properties also does not seem to be helpful, at least at the physiognomic vegetation type level. However, at the species compositional level, a few of them were found to stand out clearly (Table 6.32).

Table 6.32 Species compositional vegetal types that showed distinct pedological characters of identity.

Elevational zones, Vegetal mosaics and Soil characteristics
Medium elevational zone:
***Arthraxon* dominant grassland mosaic:** Highest quantities of silt (16%), N (299 ppm) and comparatively high values of K (103 ppm), OC (3.04%) and EB (22 me/ 100 gm) in the mid elevational zone. [Fig. 5.2]
***Eragrostis* dominant grassland mosaic:** Highest quantities of silt (16%), EB (23 me/100 gm), K (923 ppm), Ca (83 ppm) and Mg (78 ppm) and comparatively high quantities of gravel (30%) and OC (2.95%) in the mid elevational zone. [Fig.5.4]
High elevational zone:
***Eriocaulon-Garotia* grassland mosaic:** Highest quantities of N (2009 ppm) and sand (81%), and comparatively lower values ofgravel (6%) and silt (8%) in the high elevational zone.[Figs. 5.16 & 5.17]
***Arundinella ciliata* dominant gassland mosaic:** Lowest quantities of silt (8%) and K (1 1%) and comparatively low values of OC (3.91%) EB (7 me/100 gm), and Mg (52 ppm) and comparatively high values of sand (80%) in the high elevational zone. [Fig. 5.32]
***Ageratina* shrub ecotone mosaic:** Highest quantities of OC (9.9%) and Ca (600 ppm), EB (16 me/100 gm) and comparatively higher values for N (1463 ppm), K (175 ppm), sand (79%) and Mg (159 ppm), and comparatively lower values of gravel (11%) and clay (1 1%) in the high elevational zone.
Shola forest ecotone mosaic: Highest quantities of Mg (304 ppm) and comparatively high quantities of Ca (284 ppm) in the high elevational zone.

The total number of species compositional vegetal mosaics involved in the present study is 28 of which 12 belong to Silent Valley and 16 to Eravikulam (Table 6.3). From Table 6.32, we find that only 6 out of 28 vegetal mosaics could be distinguished to some levels, based on soil properties. If only a high percentage of vegetal mosaics could be distinctly characterized by pedometry, there is scope for looking into the causes of the differences. The pedometric inseparability of majority of the vegetal mosaics on the basis of the properties studied is evident. As differences in the quantitative characteristics of macronutrients across different vegetal type are not disticntive, perhaps micronutrients are important from this point, which needs further study.

6.4.1.5 Correspondence of soils to the vegetal continuua

General trends

Regardless of the above observations however, there are affirmative patterns of soil differences across the grassland-shrubland-forestland continuum. The compactness and porosity of soils are also important factors that affect plant distribution. In both the elevational zones, the grasslands and shrublands were found to have a shallowly surface soils above hard rocks, whereas in the case of the forestlands, on an average the soil is 1-2 m deep above the hard material lying over parent rock although, shallow or rocky locations can also be found. These differences of the soils of the physiognomic vegetation types certainly remain valid although the chemistry and other properties did not offer much distinctive properties. Numerous documentations exist describing similar relationships of vegetation structure and composition in accordance with the soil depth, texture and structure (Eiten, 1972; Werger, 1983).

Most plant species are adapted differently to different soil moisture regimes. Soil moisture seems to be an important factor closely related to geomorphology, especially the relief of the underlying rock. The duration of soil flooding and water recharge are different across geomorphic gradients and the grassland- shrubland- forestland- mosaics were distributed very much in tune with. Thus, the gallery forests occupy stream courses where flooding or moisture availability is not deficient throughout the year, marshy grasslands occupy the flood plains between hillocks and grasslands with xeric species along hill crusts and mounds (Cole, 1960; Eiten, 1972; Werger, 1983; Werger and Ellenborek, 1980). Depending upon the hydrological regimes, compositional structure of the grasslands also changes and accordingly watershed grasslands (on the rolling hill mounds), flood plain grasslands, drainage lane grasslands etc, are also distinguished (Werger, 1983).

At medium elevation

The grassland-evergreen forest continuum represents a gradient of soil moisture regemic niches in the medium elevational zone. Here, because of the 40-50 m thick insulation of the arborescent vegetation, the rain water reaches the ground only slowly and causes minimum erosion. Disregarding the randomly scattered isolated sites of shallow soils in the evergreen forests the soil is generally one meter or more deep. The moisture recharge capacity in the forests is therefore high (maximum) than the shrublands and the grasslands and the ability to provide incessant water supply for the vegetation is also high both in terms absolute quantum and duration.

Coming to the grasslands along medium elevations, the swampy floodplain grassy mosaics are practically absent. [However, when the rivers reach the lower plains, the flood plains of the sandy deltas in broader rivers like Bharathapuzha are largely colonized by Saccharam spontaneum, a moisture loving gregarious grass. Again in the plains along countrysides and villages, Saccharam spontaneum occupies the banks of streamlets as drainage line grasslands]. Of the watershed grasslands, the Arthraxon grassland mosaic is a typical xerophytic association exclusively on primary rock surface colonized by lichens and mosses. Here soil is practically nil and the grass is an annual and grows hardly over 10-15 cm in height. The extent of moisture availability is restricted to that which is retained by the cushions of lichens and moss crusts and the scant soil traces formed by the disintegration of the rock. Where the soil is 1-2 cm thick upon the hard material above the parent rock, the characteristic vegetation is a consociation of *Themeda triandra* where again moisture is very much limiting.

Themeda-Cymbopogon community is the typical compositional type of the hill slopes and hill crests, but where dryness increased, the *Pleurocaulis* shrubland mosaic dominated and where the moisture status was slightly better the density of Pleurocaulis decreased. The ecotonal grassland habitats were better in soil moisture status primarily because the forest ecotone shadowed the sun either in the morning or in the evening and hence evapotranspiration was lesser than the hill tops. Here again soil depth was better than the hill tops. As a result, the ecotonal grasslands was found to have abundant representation of a shade/moisture loving species of grass belonging to the genus *Ischaemum*.

At high elevations

The high elevational grassland and forestland (shola) mosaics also conformed to the differences in soil moisture regemic pattern. The shola forests were all found along streamlets. Likewise, the Eriocaulon-Garnotia grassland and the Garnotia tectorum grassland mosaics were restricted to swampy flood plains and streamlet mouths (drainage lines) while all other compositional types of the high elevational grasslands were watershed grasslands.

Within the watershed grasslands, there were observable trends in the distribution of different species compositional grassland mosaics across the soil moisture gradient. *Jasnella-Tripogon* grassland and *Tripagon-Arundinella* grassland rnosaics characteristically occupied the convex mounds of the rolling hillocks, which often have rocky outcrops and where erosion and evapotranspiration were high. Here, soil depth was minimum and hence the duration and quantity of soil moisture supply was also low. Along the slopes of hillocks, the interhillock trough margins were better off in soil accumulation and consequently soil depth and soil moisture. Accordingly the moisture loving *Chrysopogon zeylanicus* grassland mosaic characteristically occupied these habitats. Generally, the hillocks entered into a sudden depression as the relief crossed the ecotone to the shola forest and the ecotones were also better in soil moisture regime and was characteristically occupied by the tuft grass, *Chrysopogon zeylanicus*. Other compositional types of grassland mosaics occupied in between the troughs and crests of the hillocks, showing intermediate moisture requirements.

Role of soil moisture

In short, soil moisture is the pivotal parameter, which is determined by and reflected in soil texture and structure. A physiological analysis of the facts also leads to the same conclusion. In the first place, water is the largest substance present in plant and animal bodies, both by volume and weight and therefore legitimately the largest of all the nutrients. In the second place, water is the medium through which most nutrients enter the plant body and so also translocated within the plant body by evapotranspiration. Role of water in photosynthesis, the process by which atmospheric carbon is converted to organic carbon, is also very dominant. Resource (nutrient) availability, mobilization and storage in vegetation are controlled by water. The chief source of water to plants is through soil and the role of soil moisture in vegetation structure should be very pertinent too.

Soil genesis

Particulars of soil genesis are also involved. Being depressed regions, most finer soil materials reach the streamlets and gutters alongwith rain water. A major portion of the so collected soil leach out to add to the soil beds of the valleys and river mouths; the upstream water-channels, in the presence of plenty of boulder stones, are still able to retain soil to a great extent. Thus, both soil depth and its quality along the streamlets is far better than along the hill shoulders. In other words, the hill shoulders are active sites of weathering of rock and other parent materials (ie, soil formation) and the stream channels are the dump yards and highways for soil transportation. As soil depth is fairly high along the stream channels, moisture retention is also high, compared to the hill shoulders and slopes. As a matter of fact, while the late successional species are capable of colonizing the soil rich stream banks and forests occupy this zone.

Only pioneers (early successional species, largely grasses) are capable of inhabiting the soil poor hill shoulders and slopes. On the whole, a somewhat crude generalization holds true; a mature soil profile is not found beneath the grasslands. The grassy landscapes have a hard impermeable horizon placed shallowly in the subsoil and therefore the depth and duration of available soil moisture is limited and unable to support an arborescent vegetation. The moisture regime is highly affected especially when there is an alternation of soil saturation and desiccation owing to markedly distinct seasonality of the rainfall regime (Warming, 1892; Schimper, 1903). In such a habitat, plant lifeforms with efficient resource management strategies and xerophytic adaptations alone can survive.

Grassland an edaphic climax

Grasses with high species diversity (Tivy, 1982), the herbaceous and generally caespitose or creeping life forms with horny root stocks or underground running stems, the numerous spreading fibrous roots, annually regenerating shoot system, very efficient vegetative reproduction for local colonization, high photosynthetic and carbon fixing abilities, are best suited in these habitats. Considered from this angle, accradition of the grasslands as an edaphic climax bears sense and meaning. High elevational plateaux grasslands (savannas) in south America and Zimbabwe, which are apparently comparable to the plateaux grasslands of Eravikulam and Nilgiris are also regarded as edaphic climaxes on comparable geomorphic edaphic grounds (Cole, 1960,1963).

Inferring from the distribution of the different physiognomic vegetation types and the correlation of the soil moisture and soil depth (volume), it won't be too far fetched to hypothesize that biomass of the natural optimum vegetation that can stand in the soil would be roughly proportionate to the soil volume per unit area (excluding gravel, boulders and stones), except where excess water (water logging) hinders plant growth. This is roughly reflected in the depth at which the parent rock is located.

6.5 Conclusions

1. No physiognomic vegetation type showed distinct pedometric characteristics so as to circumscribe them without any overlap of character states with other types.

2. Soil chemical properties were less distinctive of the different species compositional and physiognomic vegetal types. Out of the 28 vegetal mosaics studied, only six stood distinct in some way.

3. As differences in the quantitative characteristics of macro- nutrients across different vegetal types were not distinctive, perhaps micronutrients were important from this point.

4. Although soil chemistry was less helpful in differentiating the different vegetal types, some gross picture of differentiation was observed. The grasslands and shrub vegetations were devoid of a deep soil profile. They had a shallowly placed hard rocky, boulder or gravelly substratum. The forest was the only vegetation with a deep soil layer.

5. Rather than the chemical properties of the soil, the texture or total soil volume/unit area over the parent rock might be more important with respect to the physiognomic vegetation types. Soil texture basically controls the moisture regime and therefore the differences between the grasslands and forests were one of moisture availability. In this sense, the grasslands appeared to be an edaphic climax vegetation where soil moisture stress was experienced.

CHAPTER 7. THE CLIMATE

7.1 Introduction

By definition, climate is the state of the atmosphere over a longer span of time and a wider spatial unit. Therefore, it describes the energy states of the areal media of the biota. Ever numerous publications exist relating to the physiological adaptations, anatomy and morphology of plant parts and climate. The relationship between plant life forms and climate is also well established and it is also clear that this relationship limits the physiognomy of stands to specific climate regimes (Schimper, 1903).

Atmospheric temperature (determined largely by the infrared rays reaching the earth), precipitation, atmospheric humidity and wind are considered the principal components of climate. Of all the three, temperature alone defines the major climatic regimes on the geoid and the tropical, temperate and polar zones are in accordance. The tropical and temperate vegetations also differ in their features as narrated at length in several monographic volumes.

But why do vegetations differ in their physiognomy and composition in one and same climate'? What are the factors manifesting these differences? If two or more distinct physiognomic vegetation types inhabit one and the same climate can each one of them be considered a climatic climax? These are the questions posed by Ranganathan (1938), when he considered both the grasslands and the shola forests as climax vegetations. Experts like Meher-Homji have argued that climatically the grassland and the forest are different in certain specifics (Meher-Homji, 1965, 1967).

7.2 Methods

As a part of the present study, we made some observations on two of the climatic parameters of the study sites, Silent VaIley and has gathered information from other weather stations, with regard to Eravikulam.

At Silent VaIley, an automatic recorder hygrothermograph each was installed one in the grassland, another in the grassland- forest ecotone, and a third one in the forest. The hygrothermograph were with a rotation cycle of 30 days and operating from power sources derived from two 1.5 volt dry cells. Documented literature indicates that the temperature variations affect the tree seedling germination and establishment in the grasslands. Therefore. all the equipments were installed at the ground level, contrary to the conventional practice of measuring the parameters in the Stevenson screen cage so that the measurements are close to the ground. The equipments were protected from rain and direct sun by keeping in wooden cages provided with ampIe ventilations and were installed inside a 5 m by 5 m fenced enclosure lest the wild animals should destroy the systems. As it is known from the literature that it is the drop in night temperature that matters the establishment of the tree seedlings, weather parameters were monitored for a period of 6 months during the coldest period of the year. DetaiIs of distribution of rain were obtained from the Meteorological Station at Sirandhri, maintained by the Centre for Water Resources Development and Management (CWRDM), Kozhikkode.

The weather data for Eravikulam National Park were obtained from Vaguvarai Tea Estate, Munnar, and partially derived from Rice (1984).

7.3 Results

7.3.1 Climate at Silent Valley (ca. 1,100 m asl)

Recorded data for atmospheric temperature and relative humidity were obtained for 16 months from May 1995 onwards till August 1996. The data are given in tables below.

7.3.1.1 Temperature

The extremes of temperature recorded for the different vegetation types are given in table 7.1. The minimum temperature recorded is almost the same across the vegetation types; the maximum temperature recorded for the forest is the lowest (30" C) while it is higher for the grassland and ecotone (37 and 39 respectively). The amplitude between the lowest maximum and highest maximum proved to be minimum again lowest for the forest (16) while it was 6-9 degrees higher for the grassland and ecotone.

Table 7.1 Annual vagaries in the temperature variables for the different vegetation types at Silent Valley.

Vegetation	**Minimum**	**Maximum**	**Amplitude**
Grassland	13	37	24
Ecotone	12	39	27
Forest	14	30	16

Variations of temperature across the vegetation types are given in table 7.2. There is significant difference in the lower and upper maxima recorded. For the forest and the ecotone the lower maxima recorded center around 20" C while it is much higher for the grassland (27" C). Likewise, against the upper maximum of 30" recorded for the forest it is around 38 for the grassland and ecotone. The amplitude between monthly maxima and monthly minima were worked out. The difference in amplitude across the months ranged between 5 and 10 in the case of the forest while this ranged between 7 and 21 in the case of the ecotone and the grassland (Table 7.2).

Table 7.2 Vagaries in temperature of different vegetation types at Silent Valley.

Vegetation	**Minima**		**Maxima**		**Amplitude**	
	Lower	Upper	Lower	Upper	Lower	Upper
Grassland	13	20	27	37	7	18
Ecotone	12	23	19	39	10	21
Forest	14	19	20	30	5	10

Details of temperature in the different vegetation types during three seasons, *ie,* rainy season, cold season, warm season at Silent valley are given in tables 7.3 to 7.5 below. In all the three seasons, the forest had a less amplitude between monthly minimum and monthly maximum, where as both the grassland and the ecotone have a higher amplitude of this measure.

In earlier studies, it was found that the drop in night temperature during the coldest months in some high elevational grasslands reaches below 0" C (freezing point) causing physiological drought to new recruits and young seedlings (Meher- Homji, 1965). Hence. temperature variations during the colder months November to February are given in table 7.4 below.

None of the vegetations showed a temperature close to or below 0" C. However, the monthly difference between the monthly maximum and minimum temperature had an amplitude ranging between 5-7° C in the case of forest and was much lower compared to the grassland and grassland ecotone where the range were between 10 and 19" C with a mean of 14° C.

Table 7.3 Vagaries in temperature during the rainy season across different vegetation types at Silent Valley during 1995-1996.

Stat	**Grassland**					**Ecotone**					**Forest**				
	Jun 96	J	A	S	**O**	J	J	A	S	O	J	J	A	S	O
Max	33	30	31	30	31	nr	nr	nr	19	26	22	nr	nr	20	nr
Min	17	17	17	15	16	nr	nr	nr	14	13	16	nr	nr	15	nr
Amp1	16	13	14	15	15	nr	nr	nr	5	13	6	nr	nr	5	nr

Table 7.4 Statistics of temperature during the cold months across the different vegetation types.

Stat	**Grassland**				**Ecotone**				**Forest**			
	N	D	Jan96	F	N	D	Jan96	F	N	D	Jan96	F
Max	28	nr	nr	32	22	27	32	34	20	nr	25	27
Min	13	nr	nr	17	12	15	15	15	15	nr	20	20

Table 7.5 Statistics of temperature during the warmer months across the different vegetation types at Silent Valley

Stat	**Grassland**			**Ecotone**			**Forest**		
	M96	A	M	M96	A		M96	A	M
Max	37	nr	nr	39	37	33	30	28	25
Min	19	nr	nr	18	17	23	20	18	19
Diff.	18	nr	nr	21	20	10	10	10	6

A similar marked difference in the amplitude of monthly minimum and maximum temperature also exist between the vegetation types, the forest having a minimal amplitude (around 10°C) and the grassland and the ecotone with a higher value around 20° C.

Thus with temperature oscillations the grassland and the ecotone were more or less similar and drastically different from the forest, with higher extremes of temperature flux.

7.3.1.2 Rain

The data of rainfall presented here are derived from the weather station maintained by the Center for Water Resources Development and Management, Kozhikkode.

Table 7.6 Observed vagaries of rainfall (mm *) at Sirandhri, Silent Valley, during the year 1994-1995.

	Jun	**J**	**A**	**S**	**O**	**N**	**D**	**J95**	**F**	**M**	**A**	**M**
Actual	1318	2204	698	300	676	329	nr	nr	nr	24	88	199

The average annual rainfall for the area is around 4,700 mm\yr (Kerala Forest Research Institute, 1990), the annual quantum of 5,836 mm during 1994-1995 being an exceptional year. The south-west monsoon showers during June to September, the north-east monsoon showering during the months of October and November. A few convectional summer rains and pre-monsoon rains are also received. The proportional contributions by the two monsoons during the year 1994-95 were: south-west monsoon 77.5%, north-east monsoon 17.2% and summer rains 5.3%. Six months from December to May are relatively dry. The months The altitude of the area being in the range of 900-1400 m asl, the rainfall data shows that the area is potentially suitable for the growth of evergreen forests.

7.3.1.3 Humidity

There is not much difference in the annual lowest minimum relative humidity, its observed highest maximum and the amplitude across the different vegetation types (cf Table. 7.7).

Table 7.7 Annual vagaries in the relative humidity variables for the different vegetation types at Silent Valley.

Vegetation	**Minimum**	**Maximum**	**Amplitude**
Grassland	35	100	65
Ecotone	35	99	64
Forest	35	100	65

However, a comparison of the highest minimum value of relative humidity during different months across the vegetation types shows that its upper limit is around 75% in the case of grassland and ecotone while it goes up to 95% in the forest during some months. This is also reflected in the difference between monthly maxima and minima; the lowest range of this difference was between 23% and 27% in grassland\ecotone while it was only 5% in the case of forest (Table 7.8).

Vegetation	Minima		Maxima		Difference	
	Lowest	Highest	Lowest	Highest	Lowest	Highest
Grassland	35	72	98	100	27	43
Ecotone	35	75	95	99	23	64
Forest	35	95	98	100	5	63

The tables evidence that there is appreciable difference in the diurnal flux of temperature and relative humidity across habitats. From forest through the ecotone to the grassland, this is maximum in the grassland and least in the forest. The drop in relative humidity in the grassland down to around 65% in the grassland is almost regular. There exist significant differences between the three habitats, the grassland, the gassland-forest ecotone, and the forest.

Table 7.9 Statistics of relative humidity along the warmer months across different vegetations.

Stat	Grassland					Ecotone					Forest				
	J96	F	M	A	M	J96	F	M	A	M	Jan96	F	M	A	M
Max	100	100	nr	100	nr	99	99	99	98	95	100	100	98	98	98
Min	65	35	nr	62	nr	35	40	35	75	55	70	42	35	67	70
Diff	64	59	64	23	40	30	58	63	31	28	35	35	nr	38	nr

7.3.2 Climate at Eravikulam (1700-2700 m asl)

7.3.2.1 Temperature

Most available climate data of the Eravikulam National Park come from (1). Rajamala, a location in the lower hills of the park at around 1,700 m asl, where the Offices of the Park are located, or (2). The Vaguvarai Tea Estate, located adjacent to the Park. The climatic data for the Eravikulam plateau (2,000 to 2300 m asl), which is a fairly reasonable representation of the rolling grassy landscape of the Park, is scarcely available.

As the available weather data were partially summarised, detailed analysis were not possible. The weather details for Vaguvarai, (representing Eravikulam) is given in Table 7.10.

Table 7.10 Observed vagaries of temperature (° C) at Eravikulam during the year 1994.

Stat	Rainy season					Cold season				Warm season		
	Jun	J	A	S	O	N	D	Jan	F	M	A	M
Min	13	13	13	13	12	12	10	10	14	13	13	13
Max	20	16	18	20	24	22	26	22	22	27	25	25
Amp1	7	3	5	7	1 2	10	16	12	8	14	12	12

The lowest minimum temperature recorded for the year 1994 was 10° C, the highest being 27° C. The highest temperature recorded was during March (27° C) and the warmer months being March to May. Easa (1995) has recorded the highest maximum of 3 1°C and the lowest minimum of 9°C or so for Rajamala, for the year 1993-1994. The lower spectrum of amplitudes between minimum and maximum ranged between 3 and 7° C, observed during July (ie, during rainy season) and the higher spectrum of amplitudes ranged between 10 and 16° C. The higher spectrum of amplitudes embraced both the the warm season (March to May) as well as the cold season (November to February).

Rice (1984) has given temperature records for Eravikulam hut for the period from 1979 to 1981. The highest maximum recorded was 29°C and the lowest maximum 10°C. The highest minimum recorded likewise turned out to be 12°C and the lowest minimum -3°C. All the months, December (0°C), January (-3°C), February (2°C) and March (0°C) recorded minimum temperatures close to 0°C. Although Rice (1984) does not mention whether he measured the temperature inside the shola forest or in the grassland, it is quite unlikely that he measured it in the open grassland close to the ground. The -3°C recorded in January however infers that if temperature measurements are made in open grasslands close to the ground the records would go below -3°C.

Plant physiologists have already observed that a temperature around 27-30° C is ideal for plant growth. The cold season therefore might be offering some constraint to plant growth in all vegetations. Though the lowest temperature recorded at Vaguvarai is only 10°C and at Eravikulam hut is only -3°C, in places like Nilgiris, temperature running to the minus scale of -9°C has been recorded and it is a known fact that such temperatures are deleterious to plant growth owing to physiological drought.

Although the lower night temperature minimum at Silent Valley was around 12° C and as such there is no chance of physiological drought, it is not a good climate for plant growth. Even if there is no appreciable difference in the lowest minimum temperature recorded in the grassland, ecotone and the forest in Silent Valley (mid elevation, ±l,000 m asl), like the warm season, the cold season also shares a high flux (amplitude) of diurnal temperature in the grassland and grassland ecotone, unlike in the forest. Similar trends of temperature are also met in the high elevational grasslands. The difference between monthly mean maximum and mean minimum of the Eravikulam plateau (data derived from Rice, 1984) turned out to be in the range of 9.6°C in December and 13.6°C in May, the moths in between having intermediate values. The months December to May include both the cold season (December to February) and the warmer months (March to Day). When high flux of diurnal temperature is coupled with the physiological drought during the cold months, effect might be very severe offering constraints to regeneration establishment.

7.3.2.2 Rain

The details of rainfall at Vaguvarai are given in Table. 7.ll.

Table 7.11 Observed vagaries of rainfall (mm*) at Rajamala (1994) and Vaguvarai (top,1850 m; 1995) (Eravikulam National Park).

Eravikulam	**Jun**	**J**	**A**	**S**	**O**	**N**	**D**	**Jan**	**F**	**M**	**A**	**M**
	1279	1683	694	365	394	95	11	33	25	3	143	245
Vaguvarai	**Jun 95**	**J**	**A**	**S**	**O**	**N**	**D**	**J95**	**F**	**M**	**A**	**M**
	545	819	779	712	181	140	nr	51	nr	31	160	269

The Rajamala area received 4,970 mm of rain during the year 1994. Approximately 91 percent of this rain was received during south-west monsoon between June and November and ca. 8 percent through pre-monsoon showers. Vaguvarai (ca. 1850 m asl) received but only 3,685 mm of rain during the year 1995. In addition to the high rainfall, the area receives some amount of moisture by way of mist and fog, especially during the cool months and night. The area never falls within the aridic category, as is also evinced by the atmospheric humidity which does not go beyond the lower limit of 65% even during the cold and dry seasons. However, during the cold (winter) months the chilling cold might definitely be affecting both physical growth and population increase of plants by affecting the establishment of tree seedlings.

7.3.2.3 Humidity

Table 7.12 displays average pattern of vagaries at Vaguvarai (Eravikulam NP).

Table 7.12 Observed vagaries of atmospheric humidity (average percent) at Vaguvarai (Eravikulam NP) during 1994.

	Jun	**J**	**A**	**S**	**O**	**N**	**D**	**Jan**	**F**	**M**	**A**	**M**
Mean	82	75	73	80		75	70	65	65	65	67	69

Average humidity does not go heyond 65% during any of the months.

7.4 Discussion

7.4.1 Stability of grassland and climatic settings

Temperature and moisture though are factors affecting the biota independently, they also modulate the state of each other reciprocally. Wind is more an indirect component which ultimately modulates the temperature-moisture regime. Grassland is an open landscape with high visibility and very little shade above the grass, if ever it exists. Energy fluxes in the atmosphere affect the landscape much more forcefully than in other vegetal landscapes.

Both temperature and humidity showed maximum flux in the grassland than in the forest as observed from Silent Valley. Similar observations on the temperature flux have been made in the high altitude grasslands, (Meher-Homji, 1967).

Temperature in its lower extremes caused physiological drought and in its upper extremes causes physical drought. In high altitude zones both kind of dryness are experienced and this is reflected in the amplitude of diurnal and seasonal flux of absolute temperatures. Over geologic time spans, another kind of dryness is experienced, owing to diminished or accelerated solar activity, or due to accrued change in composition of the atmosphere (IPCC, 1992). Along medium elevations the lower temperature hazard does not affect plant populations much, except that the growth rate is diminished. High altitude forest habitats are also partially relieved of the low temperature effect: owing to the thick forest insulation. But the high altitude grasslands definitely suffer much by way of frost in the cold season.

Wind has also been pointed out to be the reason for the restricted distribution of the patchy shola forests to depressions and folds along the South Indian hill stations. The stability of the grasslands along the hill shoulders is therefore partially attributed to wind. However, the hill folds and hill shoulders are not so water tight; the folds in between the hill shoulders also receive some amount of wind.

Temperature has been held responsible for the stability of grasslands along South Indian Hill Stations. As a matter of fact, grassland is considered a climatic climax. Nevertheless, the opposing school of thought that the tropical high altitude grasslands are not climatic climax is also equally strong. So, an objective meta-analysis of the issue should start on identifying a referential climax grassland of which the climatic climax attribute is undebated and to which the grasslands of dubious status could be compared.

7.4.2 Tree lines and climatic climax grasslands

Beyond the tree line along higher latitudes (beyond temperate latitudes) and higher altitudes (along alpine elevations) shrubby and herbaceous landscapes (the moraines) dominate and grassland is one among them. The former is exemplified by the thundras and the latter by the high elevational mountain grasslands of the Himalayas. Although higher latitudes and higher altitudes are not exactly comparable, both share the common feature of drop in temperature as they go up and up. As a matter of fact, the growing season is very much shortened (cf. Puri *et al.*. 1988) beyond the tree linethe speed of atmospheric circulation is very high that no tree growth is possible. Taken form this perspective, the upper Himalayan grasslands beyond the tree line (3,300-3,600 m gmsl; Puri *et al.*, 1989) represent climatically climax grasslands. However, the subalpine as well as temperate grasslands have been considered to be merely subclimaxes, formed primarily due to biotic factors such as clearing of forest, accidental and controlled fire, continuous grazing and other bio-edaphic reasons (Puri *et al.*, 1989).

In contrast to the referential Himalayan grasslands, the general height of the rolling grasslands of Eravikulam and the Nilgiris range between 2,000-2,300 m gmsl (Karunakaran *et al.*, 1997; Sukumar *et al.*, 1995) and are fairly below the tree line limits, as observed along the Himalayas. The highest point of the Western Ghats is located at least by 10 degrees below (south) of the Himalayas (ca. 27^{o}-35^{o} N) and Eravikulam (ca. 10^{o} S) and Nilgiris (ca. 11.5^{o} S) are still far lower in latitude. Therefore, if we are to consider the limit of tree line along these places it should be substantially higher up than 3,300- 3,600 m gmsl, the tree limit along the Himalayas. Of course, the geoid does not present elevations of that height along peninsular India, the highest terrestrial point being 2,695 m gmsl at Anaimudi, falling within the Eravikulam area. Yet the patchy shola forests inhabit all elevations up to 2,500 m gmsl giving every reason to suspect the climatic climax status of the peninsular hill top grasslands.

7.4.3 Microclimate vs. Macroclimate

Climate is the sum total of the atmospheric state which also matters the geoid surface. the soil. All the major climatic regions described are circumscribed by latitudino-altitudinal zones, as climate shows direct relationships with change in latitude and altitude. As the geodesic surface (soil surface) are manifest by gradients of longitude, latitude and altitude, the climate of any large area (macroclimate) is actually an average (idealized) description of climate of a large number of spatial points (microclimate). The microclimate of each of these locations differ from the macroclimate not only with respect to its geodetic position, but is also affected by other features such as proximity to water bodies like sea. lakes and rivers and the kind of vegetation that clothe the soil surface. The grass stand is a thin clothing on the soil surface (ca. 0.5-3.5 m) compared *to* the thick forest profile (10-45 m) and permits all the atmospheric phenomena to affect the soil easily. We have already seen that in the grasslands the amplitude of the diurnal flux in temperature'is very high and the night temperature in high elevational grasslands falls as low as -9°C (Legris and Blasco, 1969). Thus within the high elevational macroclimatic regime (>= 2,000 m gmsl), there are actually two dominant microclimatic regimes, one represented by the grassland and the other by the forest vegetation.

Microclimatic differences are not only spatial phenomena. climate changes in one and the same location over geologic time scales are actually temporal microclimatic shifts. Temporal microclimatic shifts and vegetal records in the South Indian hill top grasslands have been studied with the aid of palaeopalynology (Sukumar *et al.,* 1995; Vasanthy, 1988). **A** confounded pictorial representation of their findings is given in Figure. 7.1.

Sukumar *et al.* (1995) have identified three palaeoclimatic arid phases (1) 20,000-16,000 years B.P., (2) 6,000-3500 years BP and (3) at around 600 year BP These arid phases were dominated by C_4 grasses or their expansion, while the interglacial periods were moist and favoured the expansion of C_3 forests (stunted sholas) and C_3 grasses. In essence, the grassland-forest boundaries oscillated in response to changes in atmospheric composition (Sukumar *et al.,* 1995) and the consequent ocean level changes, the two vegetation types shrinking and expanding in an alternate manner, in mutually opposite directions (Fig 7.I)

Now, if we look at the grasslands of the Western Ghats as a whole, with regard to their origin, they are no more uniform. They represent a conglomeration of basically three different ontogenetic types. Thus, perhaps several grassland segments could be identified.

1. Grassland segments originated 30.000 years BP, and not affected by climatic shifts and fire.
2. Receding and acceding grassland segments (the flux) in tune with palaeoclimatic shifts and lying along the ecotones.
3. Receding and acceding grassland segments (the flux) in tune with fire. which of course arc of recent origin, *ie* not earlier than 1.000 AD (~1,000 years BP).

Various combinations of the above three types also could perhaps be obtained. Of these the grasslands of biotic or fire originated grassland segments definitely are secondary and no climax.

Present (1997 AD)

600 yr BP } Short dry phase
} .... Sholas diminishing; grasslands
3,500 yr BP } expanding
} And phase................ C_4 grasses and forests increase
6,000 yr BP }
}
97000yrBP } Deglaciation period... C_3 forests and C_3 grasses dominate

11,000yrBP }
16,000 yr BP }
} Arid phase .... C_4 grasses dominate

20,000yrBP }

30,000 yr BP }.............................. Earliest record of grasslands

35,000 yr BP } .... Earliest record of shola forests

Figure 8.1. Pictorial representation of microclimatic shifts and records of vegetation types in South Indian hill stations (reconstructed from Vasanthy, 1988 and Sukumar et al., 1995)

The moment when fire deteriorates the forest or when the shola establishes in the grassland, the microclimatic state within the macroclimatic zone undergoes change. Even when the grassland is recently formed through the colonization of a burnt shola forest, the climatic element is still involved. Thus we come to the conclusion that both the grasslands and the shola forests are microclimatically determined. Ranganathan (1938) and Meher-Homji's (1965) proposition that the grasslands and the shoal forests are two climaxes, therefore is the simplest case (a bioclimax) of the polyclimax theory.

According to the polyclimax theory (Tansley, 1920, 1935, 1939, 1941), a sufficiently large area cannot be ecologically uniform, that the compartments may be different topographically, edaphically, or from the point of view of biotic disturbances. The polyclimax concept therefore argues in favour of the occurrence of pyrral (fire), edaphic (soil) and biotic climaxes (eg. due to grazing) in addition to the climatic climax (cf Kimmins, 1987; Larson, 1940).

7.4.4 The microclimate or the macroclimate

If microclimatic change is possible with change in vegetation, the composition of the vegetation will also change subsequently, and this repeated reciprocal modifications run in the direction of a climax vegetation, unless constrained by some other resources required for growth. So, within a macroclimatic regime, microclimatic mosaics are in built. Which of these climates, the macro- or the micro-, is glued to the 'climatic climax'? Definitely it is the macroclimate and not the microclimate, but fails to indicate climax as belonging to vegetation of which microclimate falling within the given macroclimate!

Within the grassland-forest continuum we found three physiognomic vegetal types, the grasslands, the shrublands and the forestlands. Within each of these types several species compositional and edaphic mosaics are also identified as described in Chapter 4. Each one of these vegetal mosaics differ in their microclimate and are indeed optima under existing biotic, edaphic or micro-climatic set up. However, if all microclimatic variations of the vegetation could be considered climax then all these mosaics do qualify the term 'climatic climax'. The greatest advantage of the monoclimax theory (Clements, 1916, 1936) is that it provides an indication of the direction of succession and if all the vegetal mosaics are to be considered climatic climaxes, the argument would become self defeating.

7.5 Conclusions

1. There exists significant microclimatic variations between the grassland and the forestland at both the mid and high elevations. The ecotones generally fall in between the two extremes.

2. Among the three principal climatic parameters, temperature is the one that shows high difference between the grassland and the foretland.

3. Temperature differences between grassland and forestland are manifest in the real values of temperature and in the range of temperature flux.

4. In the grasslands, the drop in night temperature during winter is much below and the rise in day temperature during summer is much higher, with respect to that experienced in forestland. This might definitely be affecting the regeneration of arborescent species in the grasslands.

5. The fact that climate is also involved in slowing down of the invasion of arborescent species into the grassland is. no sound reason to consider the grassland a climatic climax. In fact, climate is only one among the factors contributing to it, others being unavailability of seed source and biotic interference.

6. The concept of climatic climax links the climate factor with climax vegetation. The climate involved here is the macroclimate and not the microclimate. Therefore, Ranganathan's (1938) argument that 'the grassland differing in microclimate from the forestland is also a is quite untenable.

CHAPTER 8. SYNTHESIS

8.1 Two views on status of grasslands

The status of the grasslands of the Western Ghats? This has been a concern of academic interest among ecologists and is a matter of current relevance to managers of natural vegetal resources for making management decisions. Two opposing views exist on the issue, one group hold the view that the grasslands along the south Indian hill stations are climatic climaxes and the other group considering it as successional or sera1 in status.

From the discussions held in Chapter V, we find that the grasslands do not receive ample number of diaspores of arborescent species. The thick grass growth may or may not be offering some amount of hindrance, which of course might differ with species. The right kind of arborescent species capable of invading the grasslands are also found wanting in the proximity of these ecosytsems. These features offer a certain degree of stability to the grassland and is therefore suggestive of the climax status.

An examination of the history of human settlement expansion along the Western Ghats tells us that the chances of recurring widespread fire affecting the vegetations earlier than 1000 AD is rather remote. Of course the stability .of the grasslands have been maintained to a great extend due to the agro-pastoral activities involving fire. Hence, the fire climax\biotic climax status of the grassland also remains true. In addition, seed germination trials conducted in the medium elevational grassland has shown that seedling emergence and perhaps establishment are also affected by pests like rodents. In this sense also, the biotic concept of the grasslands might be true.

An analysis of the edaphic settings of the grassland has shown that both in the medium as well as the high elevational zone, shallow soils, soil moisture deficit and alternate desiccation are also involved in maintaining the grasslands. Thus, an edaphic climax status of the grasslands is also suggestive.

The concept that the grasslands also represent a climatic climax like the evergreen\ shola forests as advocated by Ranganathan (1938) and Meher-Homji (1967) subscribes to the polyclimax concept. As described in Chapter VII, if any one of the microclimatic variations in vegetation can also be considered a climatic climax, on the same grounds, all other microclimatic variations of the vegetation would qualify the 'climatic climax' status, self defeating the very purpose of the concept.

The preponderance of the grassland vegetation along higher elevation implies that grassland is the characteristic vegetation at these altitudes. However, whether the dominant vegetation of an area can be considered the climax vegetation is doubtful. Willis' (1922) age and area hypothesis (also refer Good, 1974), when applied to grassland as a vegetal taxon, the 'dominant vegetation' implies merely an older age. On a broader canvass of planar landscape projection, hill stations like Nilgiris and Eravikulam display simply pictures of larger and discontinuous grassy enclaves within the vast forest stretch configuring roughly the Western Ghats. These high elevational magnificent enclaves conform to geologically uplifted original reminiscent surfaces that resisted erosion because of the presence of hard rocky crests (cf. Cole, 1960, 1963) and the flora of which differ from the surrounding forests of the slopes and lower downs. Such grassy reliefs have been documented from tropical South America

Africa, south of equator and were considered to be ancient and more widespread in the past (Tivy, 1982). Apparently the grasslands of South Indian hill stations also represent persisting higher elevational regions of a once more extensive ancestral vegetal type into which the arborescent vegetation invaded and colonized.

8.2. Towards a synthesis on the climax concept

8.2.1 Hypothetical models of grassland-forest continuum

If the microclimatic contours can change little by little over time, three possibilities can be thought of the grassland-forest continuum, as they stand today.

Model 1: Here the picture is of the progression of the shola forests little by little, by invading the grassland until the whole area occupied by the grassland is occupied by the evergreen\ shola forests. The rate of expansion being low, this happens over a very long time span, ***ie,*** in geological time scales. At high elevations as the time required for complete transformation of the grassland to forest might take a much longer time span than at lower elevations, as the length of growing season decreases with increasing elevation.

***Model* 2:** This model is just the opposite of model 1, where the progression of the grasslands little by little by deteriorating the forest climate until the whole area occupied by the forest is occupied by the grassland. This happens under continued biotic disturbance (fire) or continued drought in geological time scales.

Model 3: In this model, maintenance of the proportionate status of the two vegetations without much change over years is suggested and the model results, when years of protection and years of biotic disturbance mutually balance out, or when years of moist regime and years of dry regime balance out.

In Models 2 and 3, the grassland might mimic a climax, but is not exactly ***so.*** Theoretically Model 1 is possible, although it might not sound ***so*** under the on-going trends of global resource crunch and political instability. Under expectation of Model 1, the evergreen\ shola forest alone would qualify consideration as the climax vegetation, as all grasslands would be progressing towards the evergreen\ shola forest regardless of the fact how long this process may take. This seems to be the best model suiting to explain the ecological status of high elevational grasslands. Looking back in to the geological history, only after the grasses have deposited a certain quantum of organic debris and soil on the primary rock surface could the forest vegetation have been able to establish. Thus, prior to the development of shola forests, most of the Eravikulam plateau were perhaps occupied by grasses, or had a completely grassy lifescape with or without some rocky exposures here and there, where the soil formation had a shorter history.

The reduction of patch size of sholas as elevation goes up (Babu, 1997) is an indication that sholas are only making their foot-hold along the high elevational zone. The poorly developed soil horizons and the shallowly placed impermeable rock crusts indicate that the soil building has not reached its mature phase. In fact, grasses are pioneers and are an important group of plants helping in rock weathering, carbon fixing (cf Solbrig, 1990) and humus build up. Tivy (1982), having examined the various aspects of the issue of the ecological status of tropical savannas comments: The lack of clearly defined and consistent zonation [between grasslands and forests], the persistence of woody shrubs into desert [and grassland] environments, and the existence of treeless savanna in areas sufficiently humid to support a forest vegetation have made the concept of a climatic climax untenable for most, if not all, savanna vegetation. Looking from all these angles it is difficult to conceive that the grasslands of South Indian hill stations represent a climatic climax.

8.2.2 Problems of the climax concept

The whole issue of difference of opinion on the status of the grassland revolves round the varied criteria applied to characterize the climax vegetation by different authors (refer Kimmins, 1987). The three common criteria generally applied are:

1. The climax is considered to inhabit for a long time and hence of high stability.
2. The climax is considered to be the apical stage of development and hence a blind end.
3. There can be no more than one climax vegetation for a climatic regime.

Simply because a given vegetation has been in existence for a long time span, it would be inappropriate to conclude that it is a climax vegetation. A time span of a few thousand years is only a little speck in the evolutionary history of the earth's crust, although it is a long time with respect in the life span of man who investigates. May be it is true that climatic climax does not need to exist for longer time span, compared to the intermediate successional stages. In a continuing successional process as depicted in Figure 8.2, the last phase although has a short history in terms of age, compared to others it remains to be the climax vegetation.

<:-----><:------:><:--------:><:---------:><:-----------:><:--:>

TS_1 TS_2 TS_3 TS_4 TS_5 TS_6

Fig. 8.2. A model of a vegetation succession showing the time span of different seres. The age of the sixth sere (TS_6) in this diagram although is short is the climax.

Suppose that we are at a time when all the hillocks of Eravikulam or Nilgiri or any other comparable south Indian hill stations are covered by grasslands without any trace of sholas. At that point of time, *ie*, during a successionally earlier phase, had we posed the question, Weather the grasslands represent a climax?, the answer would certainly have been a firm affirmative. Yet we know now that this is not true. In other words, we seldom know whether the current vegetation will be succeeded by a different vegetation or not. It should also be remembered that biological succession is an unending process, or at least an unusually extended process and seeking the last community is no pragmatism.

The climax is only one of the stages in the successional process. The concept of climax as the apex vegetation in the successional ladder has also been questioned. In several instances, two supposedly different climaxes have been found to alternate each other and in instances of secondary succession, the so called climax is succeeded by an early successional or mid successional community (Kimmins, 1987).

Successional studies on disturbed sites have yielded different communities in one and the same location leaving room to suspect the predictability of the apex vegetation (Noble and Slatyer, 1977). Further, the concept of vegetal mosaics/ associations as mutually exclusive and discrete units has been criticized (Whittaker, 1951) and were considered as mutually integrating communities within the vegetal continuum (Whittaker, 1953), where the composition of the species is less than absolute reality. Thus, in recent years, in lieu of the climax hypothesis (Clements, 1916), climax pattern hypothesis (Whittaker, 1953) and its applications (ordination) are increasingly used (Whittaker, 1973).

8.2.3 The climatic climax redefined

The climax pattern hypothesis although is less particular about the compositional of the climax community the concept of climax is still in built. All modern species replacement models of succession such as the Markov models (cf Horn, 1976), stand models (including gap models: Reed and Clark, 1976; Ek and Monserud, 1974; Shugart *et al.*, 1981; Shugart and West, 1980) and multiple pathway models (Connell and Slatyer, 1977; Cattelino *et al.*, 1979) comprehend the hypothesis although less explicitly, and is very useful.

If none of the cardinal criteria of the climax, the stability, the apical position, the singularity, etc, cannot satisfactorily describe a climax, what should be a reasonably sound definition of the climax? Although the climax is not the last in the successional queue and where the predictability of percentage composition of species is less, we all recognize that, upon careful observation of the vegetal mosaics of an area, it is possible to identify a vegetation type towards which all other types progress. This vegetation has a definite physiognomic make up, within which a few compositional types can be recognized. Normally such a vegetation can easily be singled out in holding the maximum biomass in living stands than other vegetation types in the area.

The fact that biomass accumulation is the ultimate result of biological activities and all organismic and organizational (social) complexities emerge from this, also support this. Incidentally, back in 1969, the distinguished ecologist Eugene P. Odum, has described this as one of the criteria of the climax communities, along with others such as stability, homeostasis, etc. (see Odum, 1971). In what we differ from Odum (1969) is that the biomass criterion alone holds the unmistakable criterion for climatic climax communities.

Theoretically, all biological processes can be continued indefinitely, provided the limiting factors are released. Yet climate is a megaspatial and megatemporal phenomenon. As a matter of fact all activities of the biosphere and in this sense the climatic concept climax is sensible. The term climax however is a misnomer denoting a blind end; perhaps a 'climatic optimum' is better to convey the meaning. Some people reserve the term 'potential natural vegetation'.

In a previous section we found that expectancies of the distant future cannot be a pragmatic solution in describing the climax. This essentially means that, definitions of the climatic optimum has to rest upon the past and present vegetations alone. Considered in a geological time scale, upon the surface of the globe, the position of the continents (latitude and longitude) are not stable, that they do drift apart or collide, break and unite (Du

1937), and so the orogenic and other relief structure (altitude) also change. Thus most geoid locations have experienced climate change (Meher-Homji, 1965) too and therefore in describing the climatic optimum vegetation, vegetations of the distant geological past also are no candidates. In this sense, vegetal unit of a climatic epoch within which there has not been significant change in the average climate of the geographic area alone qualify candidature for consideration as the climatic optimum.

Taking the above points into consideration, a 'climatic optimum vegetation' or a 'potential natural vegetation' can be redefined 'as a vegetation of a climatic regime, which is described by a definite physiognomy and which retains the maximum biomass per unit area in living stands than other vegetal types of the climatic region, within which a few compositional types may be found'. The term 'climatic regime' applies to the description of the climate by a definite latitudino-longitudino- altitudinal spatial frame and a temporal epochal frame.

8.2.4 Status of grasslands in the light of redefinition of climax

Western literature on grasslands of temperate latitudes have almost given up the controversy of the ecological status of grasslands. The reason has been that most of the temperate grasslands are concluded to be secondary, having developed as a result of fire on arborescent vegetation or being maintained under biotic pressure of grazing and rangeland management (Sauer, 1950; Wells, 1965; Tivy, 1982). Very little natural, unmodified grass1ands exist there.

In the light of the suggested redefinition of the climatic climax, it is not difficult to see that the high elevational grasslands of South Indian hill stations also do not represent the optimum vegetation. The sholas stands retain the highest biomass per unit area in the climatic regime. However, it is only pellucid that the grasslands are no way anthropic in origin and hence are primary formations that existed for thousands of years. Indeed in some locations, fire, grazing and other anthropogenic activities might certainly have been helping in the invasion of grasslands to forest areas. Thus, dryness (soil moisture depletion) has been the pivotal cause determining the balance between grassland and forest landscape whether the dryness was geologically determined (owing to subsurface rock layers), geodesically determined (due to frost and wind; eg. Himalayan high altitude grasslands) or biotically originated (anthropogenic fires). Most of the arguments leading to the climax concept are based on short term observation on the vegetations. The history of vegetation in the longer time spans is depicted in the variety of structural mosaics, especially shrub and tree enclosures found within grassy landscapes. Their histories definitely infer that the grassland was not static, but is dynamic, in which case they cannot be considered a climax.

8.3 Conclusions

1. Grasslands are primary

None of the extensive natural grasslands belonging to the Western Ghats seem to be a secondary vegetation. Some segments of the low- and mid- elevational grasslands fight be secondary, the original arborescent vegetation having recessed by anthropogenic fire or felling activities. In many areas, grasslands centered around rocky formations exist chiefly because of the young developmental history of soil formation. The stability of high elevational grasslands owes largely to fire; yet, their origin can no way be attributed to this cause. Hence these grasslands also do not qualify to be considered secondary.

2. Grasslands along the Western Ghats are biotic climaxes

Paucity of seed source of arborescent species capable of invading the grasslands is experienced. Hindrance to germination and establishment 'of seedlings of arborescent species is experienced at least in some segments of the grasslands. In the 30,000 year history of these grasslands along the Western Ghats, fire seems to have played a role in contributing to the spread and stability of grasslands from about 1,000 years before present. Along the high elevational grasslands, invasion by arborescent species was relatively late in the geological history. Taking into consideration the above facts, the grasslands appear more like a biotic climax.

3. Grasslands of the Western Ghats are edaphic climaxes

Shallowly placed rocky substratum or exuberance of boulder stones and gravel are general edaphic peculiarities of grasslands and shrub savannas. Most of the grasslands along the Western Ghats therefore qualify designation as 'edaphic climax' where soil texture and soil moisture stress affect plant growth during a significant period of the year.

4. Grasslands of the Western Ghats represent no climatic climax

It is a well known fact that than at lower and mid elevations, climate contributes to the stability of grasslands at high elevations. Here again the stability is maintained not merely by climate alone, but contributes to it in conjection with other biotic factors. It is also true that grasslands differ from forestlands in microclimate. But the grassland is no way the potential natural vegetation as the climatic climax is linked with the macroclimate and not to the microclimate. Among the several criteria suggested to identify a climatic climax vegetation, the optimal living biomass per unit area alone is the unmistakable one. From this angle too, the grassland fails to qualify a climatic climax vegetation.

5. Terminological confusion exists

There exists some amount of confusion between the successional terms 'primary' and 'climax'. Very often, quite erroneously, a pristine primary vegetation is also assumed to be a climax vegetation, especially by conservationists. Although the conservationist's motto of preserving as many segments of the vegetation as possible can not be viewed with a suspicious eye, use of the two terms as synonyms is actually out of place from conventional ecological diction.

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6.Grasslands are important for wildlife

Natural grasslands offer the lions share of the food resources to the wildlife in forested areas. As wildlife preservation is one of the important objectives of protected areas, conversion of grasslands to plantations should not be done in protected areas. Conversion of grasslands to plantations might be feasible but could be attempted only after an assessment of the grassland resources such as area under grasslands, their distribution across different slope classes, their biodiversity content, and the extent of use of these resources by wildlife and other environmental impacts. The decision should also be based on an evaluation of the capacity of these ecosystems to provide persistent nutrient supply to the plantations over continued rotations and the extent of soil loss it may cause to the ecosystem, especially when the soil is shallow.

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