PLANT COMMUNITY STUDIES AND ECOLOGICAL INVESTIGATION ON THE AFROALPINE VEGETATION OF SANETTIE PLATEAU OF THE BALE MOUNTAINS, ETHIOPIA

A Thesis Presented to the School of
Graduate Studies

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In Partial Fulfilment of the Requirements of the Degree

of Master of Science in Biology

By
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June, 1994

THIS THESIS IS DEDICATED
TO MY LATE BROTHER
DEGEGE GASHAW

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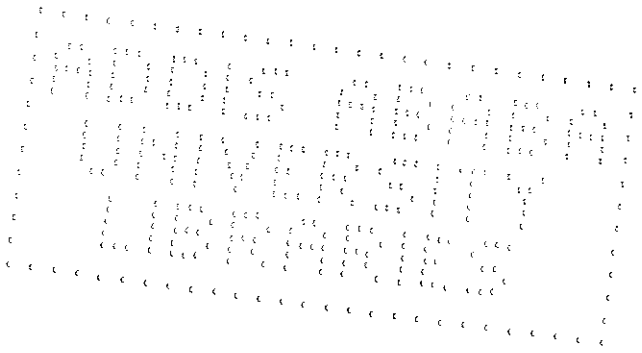


TABLE OF CONTENTS.

ACKNOWLEDGEMENT. i

LIST OF TABLES. vii

LIST OF FIGURES. viii

LIST OF APPENDICES x

ABSTRACT xi

1 INTRODUCTION. 1

2 OBJECTIVE OF THE STUDY. 8

3 DESCRIPTION OF THE STUDY AREA. 9

3.1 GEOLOGY AND GEOMORPHOLOGY. 9

3.2 Vegetation 11

3.3 CLIMATE. 17

3.3.1 RAINFALL. 17

3.3.2 TEMPERATURE. 18

3.3.3 RELATIVE HUMIDITY. 21

3.3.4 ATMOSPHERIC PRESSURE. 23

3.3.5 INSOLATION AND (OUTWARD) LONG WAVE RADIATION 24

3.4 SOLIFLUCTION 25

3.5 HUMAN SETTLEMENT. 26

4.0 MATERIAL AND METHODS. 28

4.1 Location of the study area. 28

4.2 Vegetation sampling. 28

4.3 Community Analysis. 31

4.4 Human Interference. 32

4.5 Environmental data. 32

4.5.1 Soil analysis. 32

4.5.2 Hydrometer methods of mechanical analysis. 33

4.5.3 Soil pH 34

4.5.4 Conductometric method of determining soluble salts. 34

4.5.5 Organic Carbon. 35

4.5.6 Determination of available phosphorus in soil. 36

4.5.7 Determination of total nitrogen. 36

4.5.8 Soil Moisture Content. 38

4.5.9 Analysis of exchangeable bases for soluble sodium and potassium. 38

5 RESULTS AND DISCUSSION. 40

5.1. Vegetation. 40

5.1.1 General: 40

5.1.2 Plant communities 42

5.1.3 Number of Species per group, Vegetation Cover and Species diversity. 52

5.2 COMPARISON OF PLANT GROUPS (CLUSTERS) WITH ENVIRONMENTAL FACTORS. 58

5.2.1 Texture. 58

5.2.2 Soil pH. 59

5.2.3 Soil conductivity. 60

5.2.4 Organic Carbon. 61

5.2.5 Available Phosphorus. 63

5.2.6 Total Nitrogen. 63

5.2.7. Soil Moisture Content. 65

5.2.8 Exchangeable Bases (K^+ and Na^+). 65

6 Summary and Recommendation 68

8 REFERENCES. 71

APPENDIX 76

LIST OF TABLES.

Table 1. Bale Mountains National Park vegetation types and subdivisions 15

Table 2. Altitude (m) and mean relative humidity (1988 - 1989 22

Table 3. The Domin scale. 30

Table 4. Number of species obtained from each cluster. 53

Table 5. Relationship between per cent plant cover and altitude 55

LIST OF FIGURES.

1. Fig. 1 - Map of Ethiopia showing highlands (above) 2,000 m) each side of the Rift Valley. Grey areas indicated land above 3,000. 2

2. Fig. 2 - Water catchment areas 5

3. Fig. 3 - Diagrammatic drawings of the five most important phanerogamic life-forms of the afroalpine belt 13

4. Fig. 4 - Vegetation map of the BMNP 16

5. Fig. 5 - Relationships between rainfall and altitude 20

6. Fig. 6 - Mean monthly rainfall averaged for three locations on the Sanettie plateau 20

7. Fig. 7 (a - b) - Mean monthly maximum and minimum temperatures on the Sanettie plateau and the upper Web valley 20

8. Fig. 8 - Settlement in the Bale Mountains National Park 27

9. Fig. 9 - Location of the study area 29

10. Fig. 10 - Major plant groups at Sanettie plateau 43

11. Fig. 11 - Species diversity versus altitude 57

12. Fig. 12 - Comparison between mean pH and plant groups at Sanettie plateau in the Bale mountains 62

13. Fig. 13 - Comparison between soil organic carbon and plant

groups 62

14. Fig. 14 - Comparison between available phosphorus and plant groups 64

15. Fig. 15 - Comparison between total nitrogen and plant groups 64

16. Fig. 16 - Comparison between soil moisture content and plant groups 67

17. Fig. 17 - Comparison between exchangeable potassium and plant groups 67

LIST OF APPENDICES

Appendix 1 - List of plant species collected from Sanettie 76

Appendix 2 - Values of Diversity Index ratio for all the stands 79

Appendix 3 - Results on Textural analysis 81

ABSTRACT

The vegetation of the afroalpine and subafroalpine regions of Bale Mountains at Sanettie were studied to describe major plant groups and relationships between vegetation and edaphic, climatic and topographic factors. Vegetation composition was studied along an altitudinal gradient extending from 3400 m up to 4300 m above sea level. Vegetation was sampled from 20 m by 20 m quadrats. Frequency and cover of 65 species from a total of 77 quadrats were recorded, human interference was scaled 0 - 5, where 0 stands for insignificant or no interference and 5 for high interference. Soil samples were collected from each quadrat and analyzed for texture, pH, conductivity, organic matter, available phosphorus, total nitrogen, soil moisture content and exchangeable bases (K^+ and Na^+).

Association analysis was performed on the vegetation data using NCLAS: Agglomerative clustering by distance optimization. Seven major plant groups, namely *Kniphofia - Euphorbia - Alchemilla scrub*, *Erica - Philippi belt*, *Helichrysum citrispinum - Alchemilla abyssinica*, *Alchemilla haumanii meadow*, *Festuca - Carex monostachya swamps*, *Helichrysum splendidum - Lobelia - Festuca - Euryops* and *Lobelia - Festuca - Helichrysum gofens* plant groups are described.

The relative mean annual precipitation and daily fluctuations in temperature were found to be the most important factors determining plant group structure. The gradual changes in altitude associated with changes in atmospheric pressure, moisture, and temperature influenced the distribution of vegetation. Vegetation cover and species diversity decreased with an increase in altitude. Plant cover and diversity decreased with an increase in an

estimated degree of human interference. Implications of the findings are discussed and recommendations are given towards the conservation of the biodiversity and the rational utilization of afroalpine ecosystems.

1 INTRODUCTION.

The term afroalpine refers to areas within Africa above 3400 m altitude above sea level (a.s.l.). These regions are found above what are known as sub-afroalpine regions (3000 - 3400 m) and found immediately above the tree line (i.e above 3400 m altitude). The term "Afroalpine" was first proposed by Hauman (1933) for the high altitude flora of the East African mountains (Weinert, 1981).

In Africa, scattered along the two rims of the Great Rift Valley lie a number of isolated high mountains, mostly of volcanic origin (Coe, 1967). Some of these mountains reach altitudes between 3800 m and 6000 m. Virunga volcanoes, Mt. Ruwenzori, Mt. Elgon, Aberdare, Mt. Kenya, Mt. Kilimanjaro, Mt. Meru and the high mountains of Simien and Bale in Ethiopia are some examples (Hedberg, 1964).

Ethiopia has the largest extent of afroalpine habitats in Africa; it is distinguished from all other African countries by the extent of its high ground. Approximately 15 % of Ethiopia lies above 2000 m a.s.l., and 2 % is above 3000 m (Yalden, 1983). About 371,400 Km^2 or 80 % of the land in Africa above 3000 m altitude is found in Ethiopia (Yalden, 1983) (Fig. 1).

The highlands of Ethiopia were formed between 40 to 25 million years from the present by lava outpouring of the trappian series in the Miocene and Oligocene geologic periods (Mohr, 1963). The mountains dominantly overlie precambrian basaltic and trachytic bedrocks.

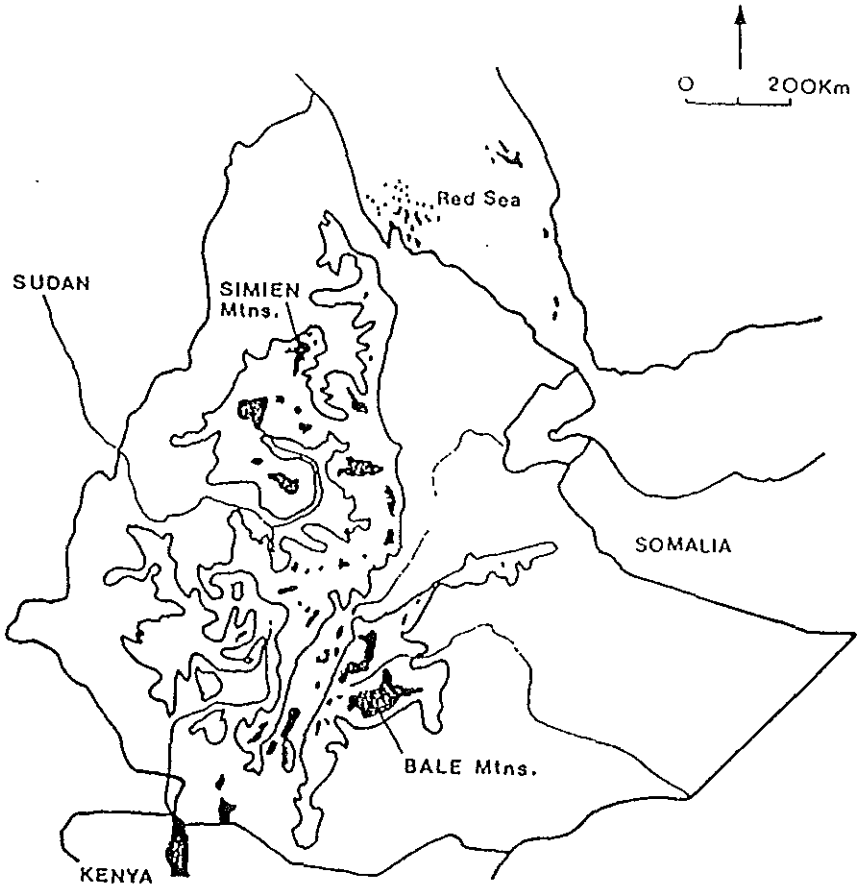


Figure 1. Map of Ethiopia showing highlands (above 2,000m) each side of the Rift Valley. Grey areas indicate land above 3,000m.

The extremes of these mountains constitute sub-afroalpine regions (between 3000-3400 m a.s.l.) and afroalpine regions above 3450 m altitude. Fifteen thousand years ago during the Pleistocene almost all the highlands of Ethiopia were widely covered with afroalpine moorland and grasslands (Sillerio-zubri, and Gotteli, 1990). Today examples of these ecosystems in more or less their original state are found restricted to only a few areas in the Simien mountains (Northern Ethiopia) and the Bale mountains (South eastern Ethiopia).

The Bale massifs belong to the southeastern Ethiopian highlands. Together, these massifs make the largest extent of afroalpine and subafroalpine areas in Ethiopia. The surface layer of afroalpine regions in Bale have been more recently (20 - 12,000 years B.P.) modified by glaciation (Sillero-Zubiri and Gottelli, 1990). The upper soil surfaces have been removed and small lakes and moraines left behind (Smeds, 1959; Messerli, et al., 1877 in Sillero-Zubiri, and Gottelli, 1990). The floral and faunal composition of these regions are unique with a high level of endemicity.

The afroalpine environment of Bale mountains is generally characterized by intense solar radiation, frequent frost heaving on grounds, strong wind current, low air pressure, hailstorms and occasional snow fall. These mountain ranges are of significant importance as they are natural habitats for the country's rare and unique wildlife resources.

The high mountains of Simien, Arsi and Bale provide a refuge for some of Ethiopia's endemic mammals like the Walya Ibex (*Walia capra)*, the Ethiopian wolf (*Canis simensis)*, Gelada baboon(*Theropiticus gelada)*, Mountain Nyala (*Traglaphus buxtoni)*, Menelik's Bush Buck (*Traglaphus scriptus* Meneliki) and Giant mole rat (*Tachyorystis*

macrocephalus), the Abyssinian hare (*Lepus starki*) and a number of endemic rodent species like, *Crocidura spp.* are also found in this ecosystems (Hillman, 1986). About 75 % of the total endemic mammals of Ethiopia are found in afroalpine and subafroalpine regions. Similarly a large portion of the rare and endemic species of birds (about thirteen) and amphibians (about seven) are found in the afroalpine and subafroalpine regions (Yalden and Largen, 1992). Apart from the importance of these regions as the natural habitat of endangered species and as reservoirs of genetic diversity, afroalpine regions are also water-sheds and upper water catchment areas for many of the big rivers like Wabeshebele, Web, Dumal and Welmel in Bale (Fig.2).

However, afroalpine ecosystems are seriously affected by human interference. Although these areas are mostly unfavourable and inhospitable for habitation, human encroachment is still very common. As a result man has become a major threat to the natural resources of these mountains. The original ecosystems presumably contained high level of genetic pools which have become eroded since (Hillman, 1986). There is some agricultural practice especially at the subafroalpine zone, such as barely cultivation and livestock grazing (Tewldebrehan, 1986). Prolonged improper land use regimes have resulted in severely degraded, exhausted

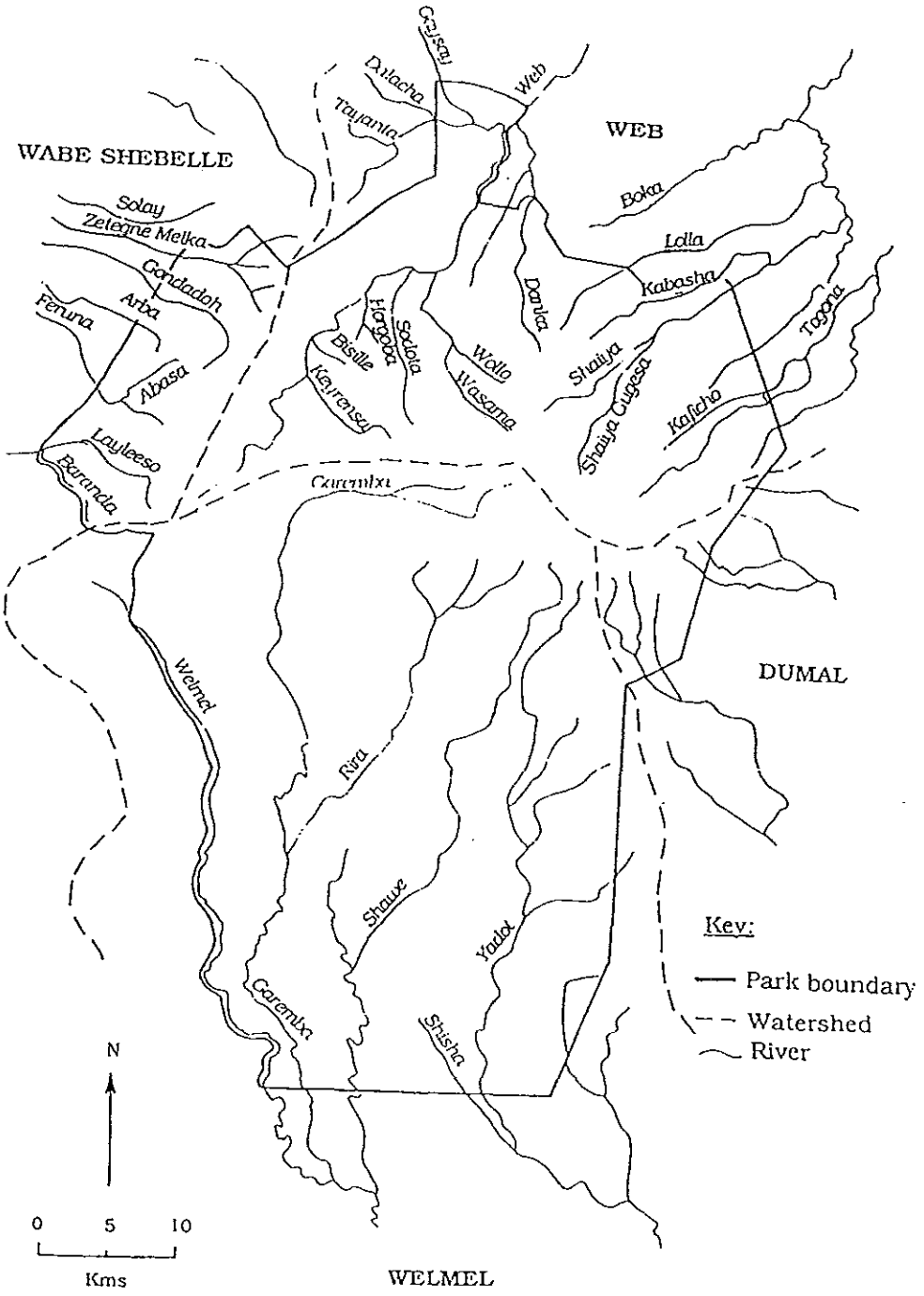


Figure 2 : River Catchment Areas of the Bale Mountains National Park.

and unproductive ecosystems (Hurni, 1986). Harvesting the vegetation as fuel wood and severe heather burning include among the causes for the accelerated disappearance of these ecosystems.

The Ethiopian highlands have been an attraction to a number of geographers, botanists and ecologists for more than a century. Bottego (1892-1893) made the first orographical exploration in some parts of the Bale mountain massif (Weinert, 1981). He travelled along the Dechuba, Welemel up to the upper Genale Gudda, in the southern parts of the mountain. In 1899-1901, Erlanger, Ellenbeck and Holtermuller travelled along Ghinir through the Mena valley to Genale Dschuba and they reached the northern edge of the Goba massif. A more extensive expedition was made along the river Wabishebele in 1928-1929. Some floral surveys were made and geological maps were prepared in different scales during these periods (Weinert, 1981).

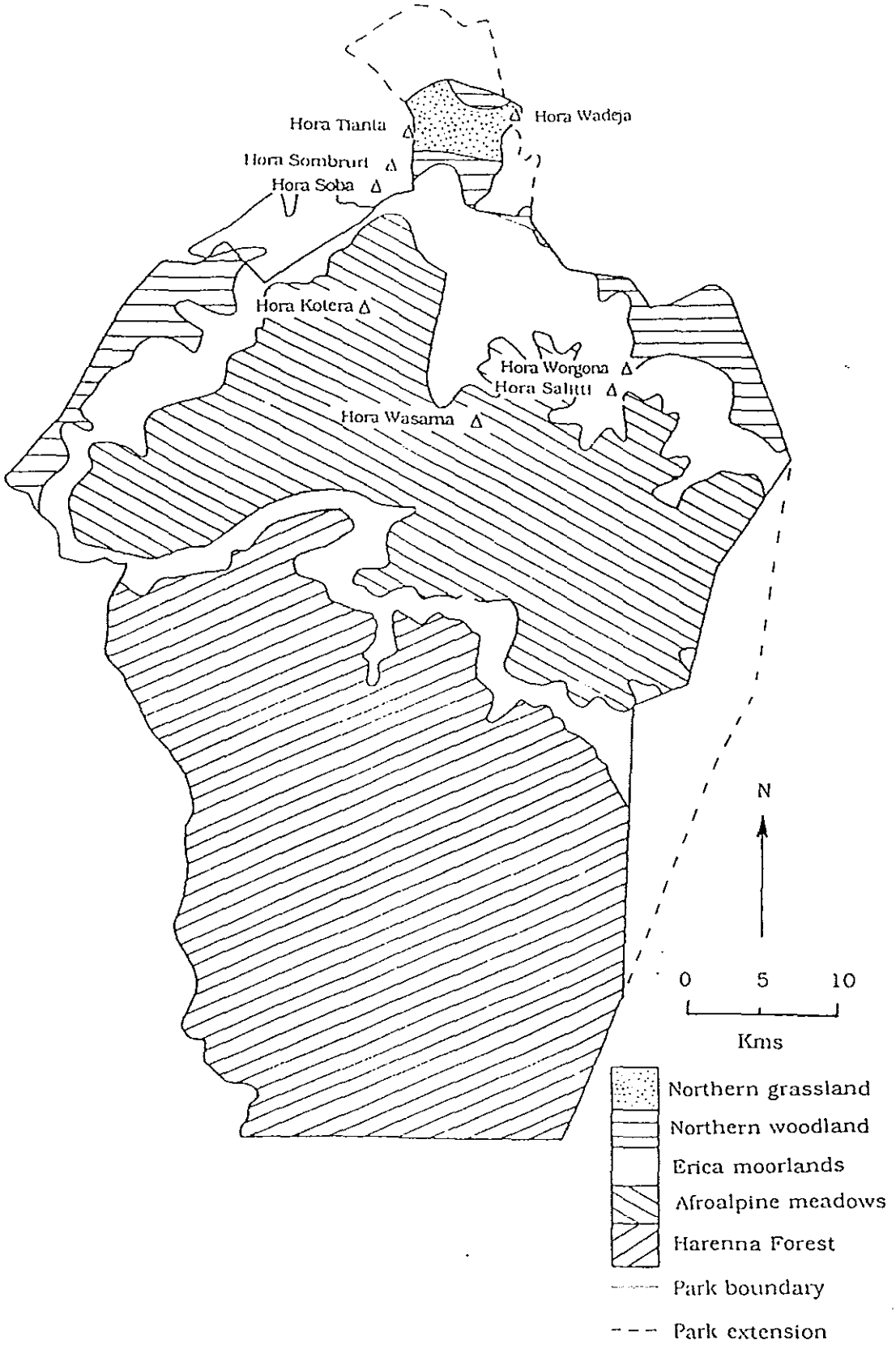
The Goba massif had been crossed and explored in respect to the flora and vegetation cover during the Italian occupation (1936-1941). The plant collections were deposited in Royal Botanic Gardens, Kew, and in the Herbarium of the University of Florence. Work on these collections have been published in a series of papers of the Adumabratio Florae Aethiopieae since 1953 (Weinert, 1981). The British botanist H.F. Mooney was among the first to collect plants in the Bale mountains. Mooney collected some plants in the mountains west of Goba between 1959 and 1960. He was later followed by other collectors such as Hedberg (1975), Mesfin (1980), and Weinert (1981). The first general account on the vertical distribution of certain significant plant species of the vegetation zones was given by the German geographer Werdecker in 1953 and 1958-1959 (Weinert,

Each of these life-forms is characterized by the use of a set of distinctive traits to adapt in an environment with "Summer every day and winter every night" (Hedberg, 1964). According to Hedberg (1975) the Ethiopian afroalpine vegetation displays the same life-form pattern and adaptive trends like tropical east African afroalpine flora. Life-form categorization of the afroalpine vegetation is more complex and difficult as compared with the other altitudinal zones (Hedberg, 1964). One of the main reasons is that the afroalpine climate is so peculiar and unique that there is no thermal season in which the dry and wet (rainy) seasons are clearly differentiated as in the case of montane forest and lowland areas. Besides one can not be absolutely sure whether a given afroalpine plant is a shrub, a tree or a herb specially when the plant is at younger or growing stage. It is, therefore, hardly practical to classify all the afroalpine vascular plants to definite life-forms (Hedberg, 1964).

Afroalpine and subafroalpine vegetation begin immediately following the natural tree boarder line. The lower altitudinal limit of afroalpine and subafroalpine vegetation is thus dependent on the upper limit of the tree-line. In Bale mountains, the altitude of tree boarder line can be located between 3400 and 3500 m. However this is strongly influenced by orographic, climatic and edaphic conditions (Hedberg, 1975). Some of the dominant trees occurring at the tree boarder are: *Hagenia abyssinica*, *Hypericum revolutum*, *Gnidia glauca*, *Discopodium penninervum*, *Erica arborea*, etc. Hillman (1986) divided the area of Bale Mountains National Park into different zones based on soil types, drainage, slope, aspect and vegetation. The sub-divisions based on vegetation were made on the basis of the visually dominant species as is indicated in (Table 1). Preliminary mapping of the vegetation worked by Hillman (1986) for the whole park has been achieved, based on ground survey and from data on aerial photographs (Fig. 4).

Table 1 : B.M.N.P. Vegetation Types and Subdivisions.

Park Section	Vegetation Zone	Size Km2	Size %	Altitude Range (m.a.s.l)	Vegetation Subdivisions
1. Northern area	I. Northern grasslands	16	0.7	3000-3100	a. open grassland b. swamp grassland c. Artemesia/Helichrysum bush
	II. Northern woodlands	86	3.9	3000-3100	d. Hagenia/Juniperus woodland e. Hypericum bush f. Montane grassland g. Hypericum woodland
2. Central plateau and peaks	III. Erica moorlands	340	15.5	3100-3800	h. Erica/Philippia moorland i. Erica/Philippia forest
	IV. Afroalpine meadows	695	31.6	>3900	j. alpine grass meadow k. Alchemilla meadow l. Helichrysum meadow m. high altitude swamp
3. Southern area	V. Hagenia Forest	1062	48.3	1500-3100	o. mixed forest p. bamboo (Arundinaria) forest q. Podocarpus forest



(Adapted from Hillman, 1986)

Figure 4 - Vegetation Map of the Bale Mountains National Park.

3.3 CLIMATE.

The nature of afroalpine climate is basically governed by two geographical circumstances: the vicinity to the equator, and the high altitude above sea level (Hedberg, 1964). There is a considerable variation in climate as a result of the great variation in altitude and by the very bulk of the mountain massifs themselves which attract orographic rain (Hillman, 1986).

Most of the climatological information for these mountainous regions come from lowland areas where there are meteorological stations. Unfortunately meteorological data for the plateau are very scant. Three high altitude raingauges were installed at Sanettie (at different altitudinal levels in the study site) and data on rainfall, temperature and relative humidity have been collected for the last fifteen years as described below:

3.3.1 RAINFALL.

Precipitation at the Bale mountains falls largely as rain, occasionally as snow or mist. The rainfall is characterized by an eight month rainy season from March to October, followed by a four month dry season from November to February, with the rainfall well-distributed throughout the wet season ranging between 1000 - 1400 mm. annual rain (Daniael, 1977). The rains come from two different sources at various times of the wet season, the equatorial westerlies and the Indian ocean monsoons.

The relationship between rainfall and altitude at Sanettie are shown in Figure 5. Rainfall appears to increase with altitude up until 3850 m, then after this level it begins to fall again (Hillman, 1986). The highest amount of rainfall recorded so far from this high altitude is during April to May and also with a relatively lower peak in September and October (Fig. 6). Hailstorms and occasionally a snow fall have been observed staying on the ground for a few days. There is also frequent frost heaving on ground and on vegetation (Hillman, 1986).

3.3.2 TEMPERATURE.

Temperature records from high mountains indicate that the wet seasons are comparatively warm and the dry seasons are extremely cold at nights and warm during the days. On the highest plateau of Bale at Sanettie the lowest recorded temperature was -12.5 °C. and the maximum was 24 °C. Data on temperature for the high altitude of Sanettie plateau were only measured during field trips. In Dinsho (3000 - 3200 m) mean monthly maximum temperature was found to be 17^{0}C, whereas at higher elevations for Chorchora (3500 m); Koromi (3850 m); and Tullu Demtu (4300 m) mean monthly temperature were recorded as 15^{0}c., 12^{0}c., and 8^{0}c. respectively. Mean monthly temperature were found to be decreased with altitude. The annual variations in temperature are considered to be very small as compared to daily fluctuations in temperature. A dry season daily temperature range of 40 °C. (25 °C. day time and -15 °C night time temperatures) have been recorded (Hillman, 1986). This suggests a pronounced diurnal temperature fluctuations (Fig. 7a and b) as compared to seasonal variations, fitting well to Hedberg's (1964) description of such

areas "SUMMER EVERY DAY AND WINTER EVERY NIGHT". In this region wet periods with high rainfall and cloud cover results in moderate diurnal changes, whereas dry periods with cloudless skies show large daily variations (Weinert, 1981). Aerial and soil temperature measurements have also shown a considerable variation. Hurni (1986) stated that at the afroalpine region of the Simien Mountains the average temperature at 2 m height from the ground is much higher than at the soil surface. He further noted that soil temperature at 20 to 50 cm ground depth was close to the annual average air temperature. Such distinctness in the microclimates at the same altitudes have considerable impact on

the type of vegetation and their physiognomy (Hedberg, 1964).

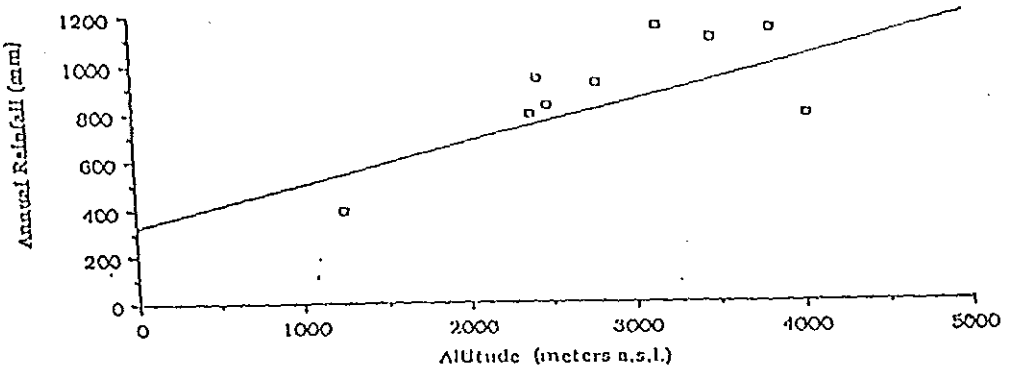


Fig. 5 - Relationships between Rainfall and Altitude (1985-1990)

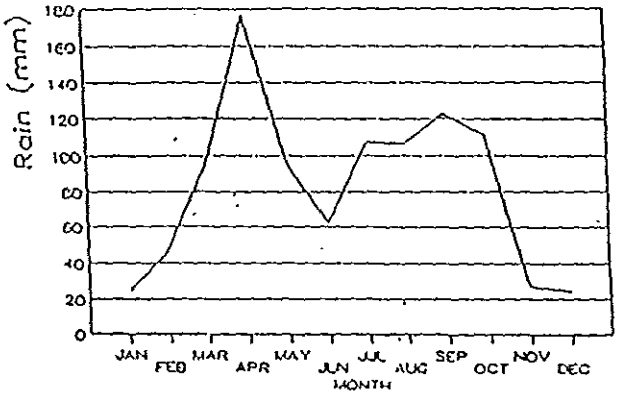


Fig. 6 - Mean Monthly Rainfall Averaged for three locations on Sanetti Plateau (June 1985 - March 1990)

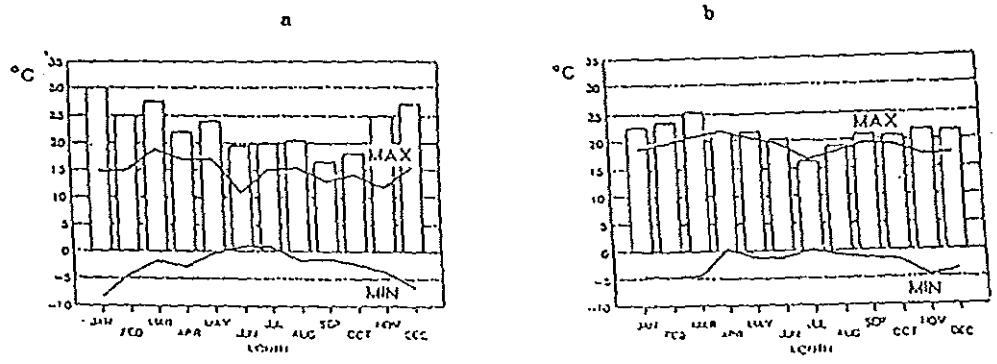


Fig. 7 (a-b)- Mean Monthly maximum and minimum tempretures on the Sanetti Plateau (a) and the upper web valley (b).

3.3.3 RELATIVE HUMIDITY.

Thermohygrograph measurements on relative humidity from the Bale mountains showed that values were highest in the wet season and lowest in the dry season. A 100 % humidity was obtained for the highest range and 17 % humidity value was the lowest recorded during the dry period (Table 2).

Table 2. Altitude (m) and mean relative humidity (1988 - 1989) from Sanettie plateau.

Altitude (m)	Relative humidity (%)	
	maximum	minimum
3200	76.5	57.0
3300	91.5	44.0
3400	100	44.0
3500	75.0	35.0
3600	96.5	45.0
3700	96.0	38.0
3800	98.8	17.0
3900	98.0	28.5
4000	95.7	36.0
4100	96.7	21.7
4200	95.0	54.0

It is likely that dry season values up in the Sanettie plateau and Web valleys (above 4000 m) would be lower than at the lower altitudes (below 3200 m) (Hillman, 1986). This author noted that at the very dry time of the year (February 1984), plants in the upper Web valley were crushed to powder under foot, having been totally dehydrated by the sun and by frost sublimation at night. He noticed the absence of frost formation at the very low temperature of -15 °C., but thick ice formation on water pools indicating that the air at this high elevation was very dry with a relatively much lower value in relative humidity.

3.3.4 ATMOSPHERIC PRESSURE.

Atmospheric pressure obviously becomes lower with an increase in altitude. There is no data on atmospheric pressure taken from the high mountains of Bale. However, in a similar study on the ecology of afroalpine vegetation of the East African high mountains, 600 mb. or 60 % of the value at sea level has been recorded at an altitude of 4400 m and about 500 mb. or 50 % was recorded at 5900 m (Hedberg, 1964). The accompanying decrease in the partial pressure of carbon dioxide presumably results in slow growth rate of most afroalpine vascular plants (Hedberg, 1964). The thin or rarefied air at high level is much more transparent for radiation than that at sea level and has a smaller heat capacity (Hedberg, 1964) which may have much effect on the vegetation of the surrounding area.

3.3.5 INSOLATION AND (OUTWARD) LONG WAVE RADIATION

No records of solar radiation are available for the afroalpine zones on the Bale mountains as well as for the east African high mountains. However, Hedberg (1964) noted that because of the rarefied and clean atmosphere at high level less of the incoming radiation is absorbed above the ground, so that under a clear sky the intensity of sunshine is greater than in the lowlands. Similarly the relative amount of ultraviolet radiation is considerably higher at high altitudes than at sea level. The intensity of ultraviolet radiation becomes much higher with an increase in altitude and this has deleterious effect on some vulnerable parts of afroalpine plants (Hedberg, 1986).

In the Ethiopian highlands total radiation increases with rise in elevation from about above 2500 m in the southeast, while it decreases in the northwest and northeast (Daniael, 1988). Hence, total radiation is slightly higher in the southeastern mountains than in the northwest and northeast mountains. Hedberg (1964) has also mentioned that during total cloud and mist cover on the upper parts of the mountains the intensity of insolation will be much reduced. However part of the incoming radiation penetrates the clouds as diffuse light and infrared rays. Part of the incoming radiation reaching the ground is reflected, but a considerable portion of it is absorbed by the ground and the vegetation (Weinert, 1981). The plant and ground cover also emit radiation, mainly in the form of infrared rays (Geiger, 1950 in Hedberg, 1964). This long wave radiation is of little importance during the day time, being much smaller in amount than the incident short wave radiation, but at night the outward radiation is by far more important and may lead to a pronounced cooling

of the soil surface (Hedberg, 1964). This long wave radiation from the ground is counteracted by reradiation from the atmosphere. But the intensity of reradiation decreases with increasing altitude, and hence the effective long-wave radiation from the ground increases (Geiger, 1950 in Hedberg, 1964). Therefore on every clear nights in the afroalpine belt of the high mountains there is a strong long wave outward radiation, resulting most often in night frost (Hedberg, 1964).

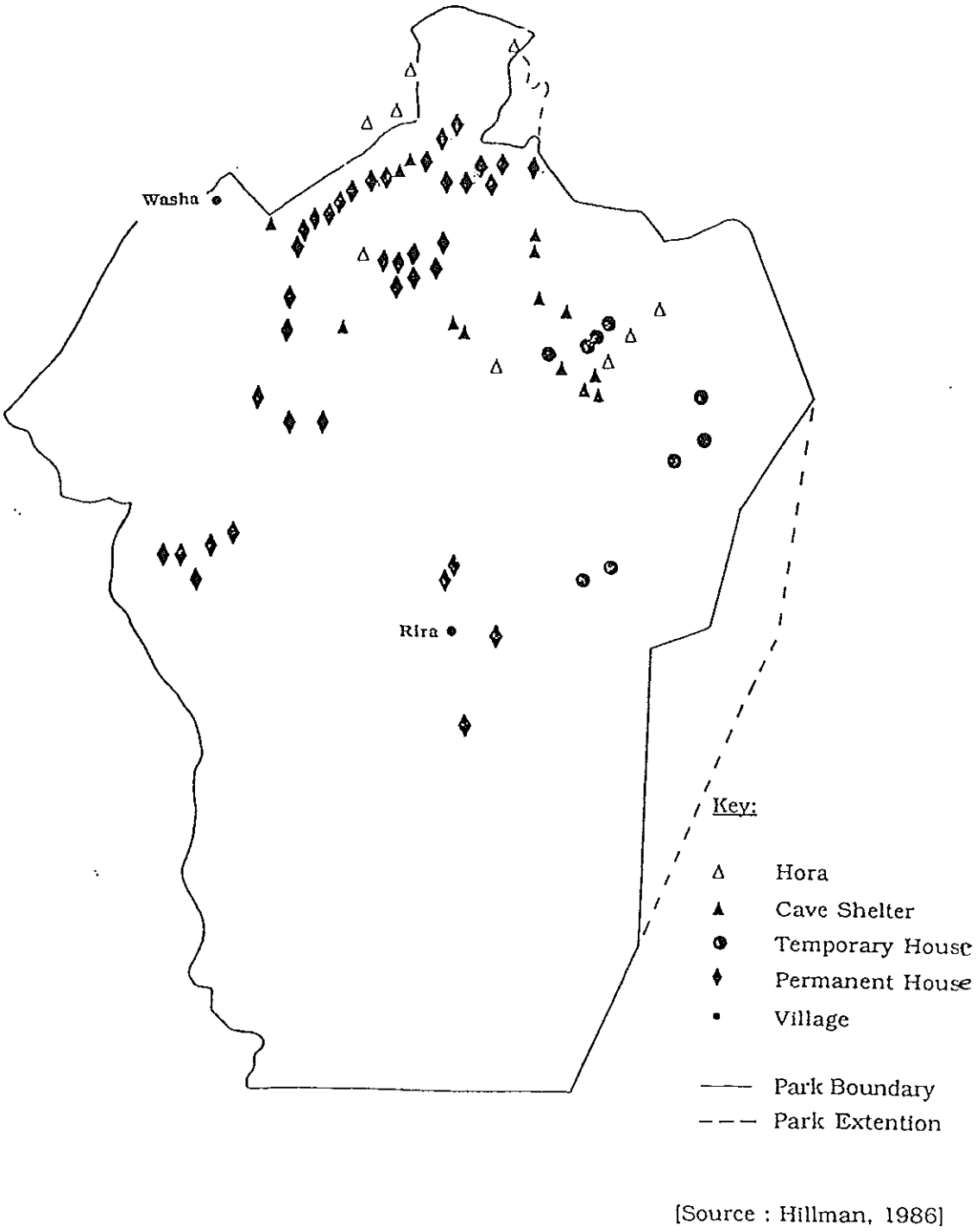
3.4 SOLIFLUCTION

Solifluction, the diurnal freezing and thawing of moist soil, is a frequent phenomenon which mostly occurs at very high altitudes in afroalpine zones. During a frosty night the surface of bare soil layer with enough moisture content will be frozen, sink to a few centimetre depth, and then melts back again next day. This alternation between freezing and thawing causes various types of movements in the soil such as the formation of needle-ice at the surface, accompanied by heaving of stones, roots etc (Hedberg, 1964). Solifluction thus has a detrimental effect on the growth and seedling establishment of plants (Young and Smith, 1987). Seedlings of many species could be eliminated by frost heaving despite the fact that there are large surfaces of open soil. A very large area in the Bale high mountains, specially the site at Tullu Demtu is left as bare soil or frost desert as a result of severe solifluction (Hillman, 1986).

3.5 HUMAN SETTLEMENT.

Previously there was very little settlement in the higher parts of the Bale mountains; however some records have shown that the number of settlement areas has alarmingly increased within the last 25 years (Hillman, 1986). The distribution of settlement in the Bale Mountains National Park is shown on (Fig. 8). The settlement areas have been divided into permanent settlement, and periodic (nomadic) use of the mountain area (Hillman, 1986).

Permanent settlement in the afroalpine regions are obviously very few. The harsh or inhospitable climate of afroalpine areas has restricted heavy human encroachment. Nevertheless, there have been observed a number of permanent settlement in the upper Web valley, at the edge of the southern side of Tullu Demtu (4300 m.) and around the Aboul Kassim Sanettie area, Chorchora and Angeso. The people living in the high mountains of Bale are entirely Oromos. In areas below 3500 m altitude livestock is combined with cultivation. The living conditions of the people is very poor and is only concerned with livestock keeping. Based on the number of houses recorded on the ground and from aerial photographs, and from an aerial survey carried out in December 1984, the number of permanent settlement in the park accounted for approximately 2500 people living in the park (that is in the northern woodland, Afroalpine and southern Harenna forest) (Hillman, 1986). But the number has now presumably increased. There are considerable temporary settlements in the afroalpine regions. Herdsmen travel regularly to the springs with their livestock, since the horas (mineral spring) provide an essential source of minerals needed to supplement the diet of their animals (Mc-Carthy, 1990).



[Source : Hillman, 1986]

Figure 8. Settlement in the Bale Mountains National Park.

4.0 MATERIAL AND METHODS.

4.1 Location of the study area.

The study was conducted in the Bale Mountains National Park, south east of Ethiopia, 500 kms. from Addis Abeba. Sanettie plateau, was chosen as the specific study site (Fig. 9).

4.2 Vegetation sampling.

The afroalpine vegetation of Bale mountains was studied along an altitudinal transect ranging from the subafroalpine Erica - Philippia belt at 3400 m. upto the summit of Tullu Demtu (4300 m.) at Sanettie plateau. A total of seventy seven quadrat (20 x 20 m.) were systematically selected. All species in each quadrat were registered and samples of species collected. Tentative identification were conducted in the field and unknown species were dried and brought to the National Herbarium at Addis Abeba University for further identification. Each quadrat was investigated for species cover - abundance value. Slope and aspect of the quadrat were also recorded. The Domin - Krajina cover - Abundance method of estimating or rating plant cover (Causton, 1988) was used as shown in (Table 3).

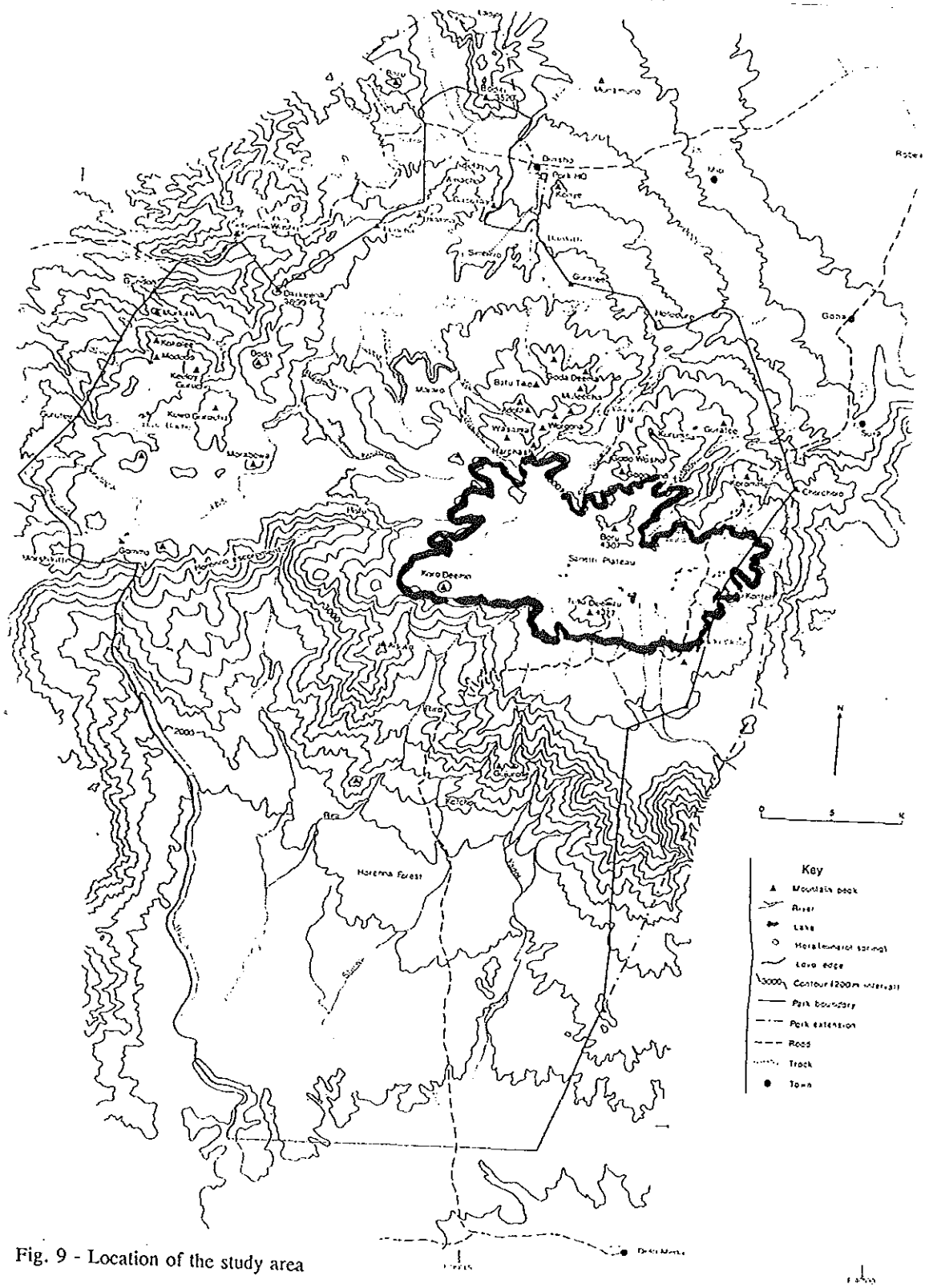


Fig. 9 - Location of the study area

Table 3. The Domin scale.

Rating	Description
+	isolated; cover small
1	scarce; cover about 10%
2	very scattered; cover 20%
3	scattered; cover 21 - 30%
4	abundant; cover 31 - 40%
5	abundant; cover 41 - 50%
6	cover 51 - 60%
7	cover 61 - 70%
8	cover 71 - 80%
9	cover 81 - 90%
10	cover 91 - 100%

4.3 Community Analysis.

Data on vegetation were analyzed according to Gauch (1982) and Jongman et al. (1987) based on species abundances in a two - way samples - by - species data matrix. Cover - abundance values were used as class labels or entities to classify vegetation data. The computer programme used in classifying vegetation data was SYN - TAX PROGRAMME NCLAS - HIERARCHICAL CLUSTERING BY DISTANCE OPTIMIZATION (Gauch, 1982). In classifying the objects group average, product moment correlation and squared distance or dissimilarities were used to depict the degree of dissimilarities among the different quadrats. The different clusters then were arranged hierarchically.

Species richness and relative abundance or dominance were measured using the Shannon - Weaver index of diversity function (Moore and Chapman, 1976; Muller-Dombois and Ellenberg, 1974). Values of plant cover were used to calculate Diversity Index of all stands as follows (Kerbs, 1972 in Moore and Chapman, 1986).

$$H = - \sum_{i=1}^{S} (p_i) \ (\log_2 p_i)$$

Where H = index of species diversity derived from the information statistic,

S = Number of species

P_i = proportion of total sample belonging to the i^{th} species.

4.4 Human Interference.

Degree of human interferences were estimated for all quadrats by giving an arbitrary scale from 0 to 5, where 0 denotes total absence of human interference at a specific site, and 5 stands for heavy human pressure or impact.

4.5 Environmental data.

For every quadrat selected a number of environmental parameters were measured. Altitude was determined using a simple altimeter, slope and aspect were determined with visual estimation and a prismatic compass, respectively.

4.5.1 Soil analysis.

Soil samples were taken from each quadrat from the surface (0 - 5 cm depth) and from 20 to 30 cm depth at 50 meter interval starting from 3450 m altitude upto the highest peak (4300 m). The samples from each stand were then air-dried in the laboratory, passed through a 2 mm sieve and the following analysis conducted as described below.

1981). In recent time, Georg and Sabina Miehe (1989) made a phyto-socio-geographical survey on some of the high mountains of Bale. Shimeles (1985) studied the ecology of giant mole rat (*Tachyorystes macrocephalus)* on Sanettie plateau.

Between 1982 and 1987, with the objective of writing a management plan for Bale Mountains National Park, Chris Hillman made a number of surveys and ecological studies (Hillman, 1986). Although his studies principally dealt with the fauna of the region, he also made collections of some of the plants of the region and made detailed descriptions of the area. Mc-Carthy (1990) while studing the use of natural mineral springs (horas) within and around Bale Mountains National Park, made a general description of the vegetation of the surrounding areas.

At lower altitudes Lisanework and Mesfin (1989) made an ecological investigation in the Harenna forest. They studied the vegetation in the Harenna forest along an altitudinal gradient. However his studies did not include the afroalpine region. Thus the corresponding work in the sub-afroalpine and afroalpine regions has always been lacking. In addition, very little combined ecological, physiognomic and phytosociological studies have been carried out in these ecosystems, although integrated ecological and physiological studies are known to be prerequisites for the maintenance and systematic utilization of any ecosystem. With this in mind the present work aimed at an ecological study of the sub-afroalpine and afroalpine regions of the Bale mountains in order to contribute towards the conservation and sustainable utilization of the ecosystems.

2 OBJECTIVE OF THE STUDY.

The study had the following major objectives:

* To characterize the nature of afroalpine environment of the Bale Mountains.
* To describe vegetation associations and plant life forms of the area.
* To study the influence of topographic, climatic and edaphic factors on the vegetation of the area.

3 DESCRIPTION OF THE STUDY AREA.

The study was conducted in the Bale Mountains National Park (BMNP) at Sanettie plateau. The BMNP occupies an area of 2400 Km^2 and is located in south-eastern Ethiopia, 400 km. by road from Addis Ababa. The Bale mountains form the south-eastern limit of the eastern Ethiopian highlands, along the eastern edge of the Rift Valley. The eastern highlands extend in a horse shoe-shaped ridge, west from Gara-muleta near the city of Harer, in the north through the Ahmar mountains of Harerge region, then south through the Arsi mountains in Arsi region and, finally, east through the Bale mountains (Mc-Carthy, 1992).

The study area includes the major part of the mountain massif in the form of a high altitude plateau of an altitude extending from 3400 m upto 4300 m. The park lies entirely within the Bale Administrative region and is encompassed by the following coordinates:

N 6° 29^1 - N 7° 10^1 ; E 39° 28^1 - E 39° 57^1

3.1 GEOLOGY AND GEOMORPHOLOGY.

The Ethiopian highlands consist at their base of intensively folded and faulted procambium rocks which are overlain by subhorizontal Mesozoic marine strata and Tertiary basalt traps (Mohr, 1963). In the upper Eocene these layers have been uplifted and rifting that followed gave rise to the rift system (Mohr, 1963). The great height of the Ethiopian plateau is therefore a result of an intrusion of lava in Tertiary times, so that a thick layer of basalt up to 3000 m deep, was deposited on the underlying marine Cretaceous rocks

Hedberg (1964) has classified the afroalpine flora into five main life-form categories (Fig. 3): Giant rosette plants, tussock grasses, Caulescent rosette plants, Cushion plants and Sclerophyllous shrubs.

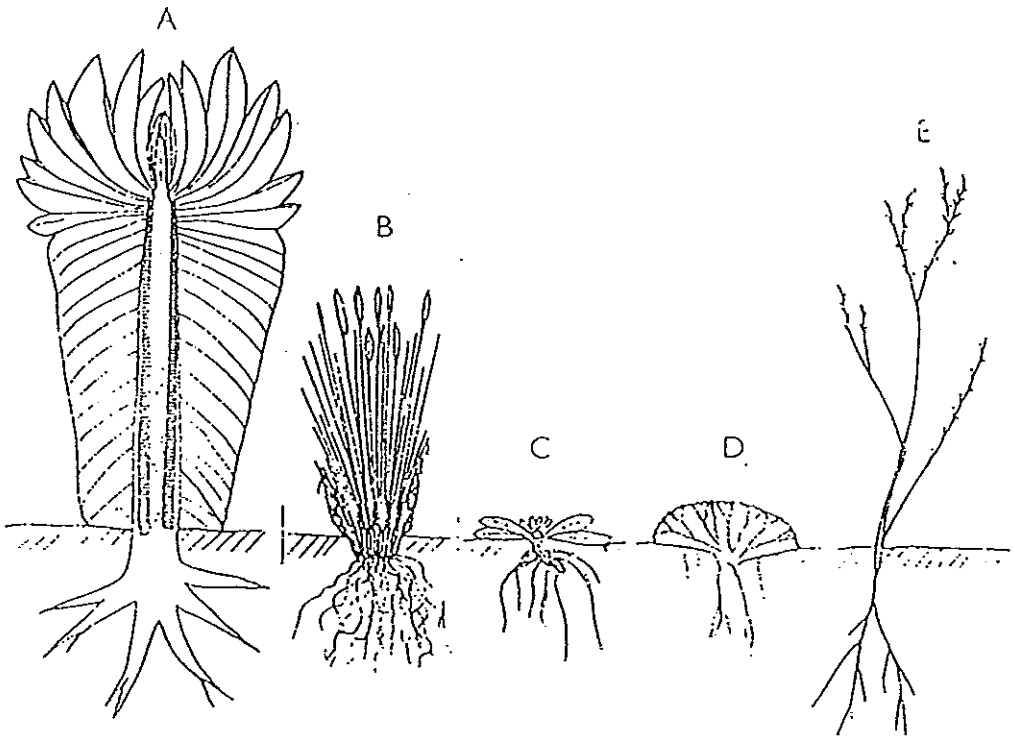


Fig. 3 - Diagrammatic drawings of the five most important phanerogamic life-forms of the afroalpine belt. A, giant-rosette plant; B, tussock grass; C, acaulescent rosette plant; D, cushion plant; E, sclerophyllous shrub. (From Hedberg, 1964b.)

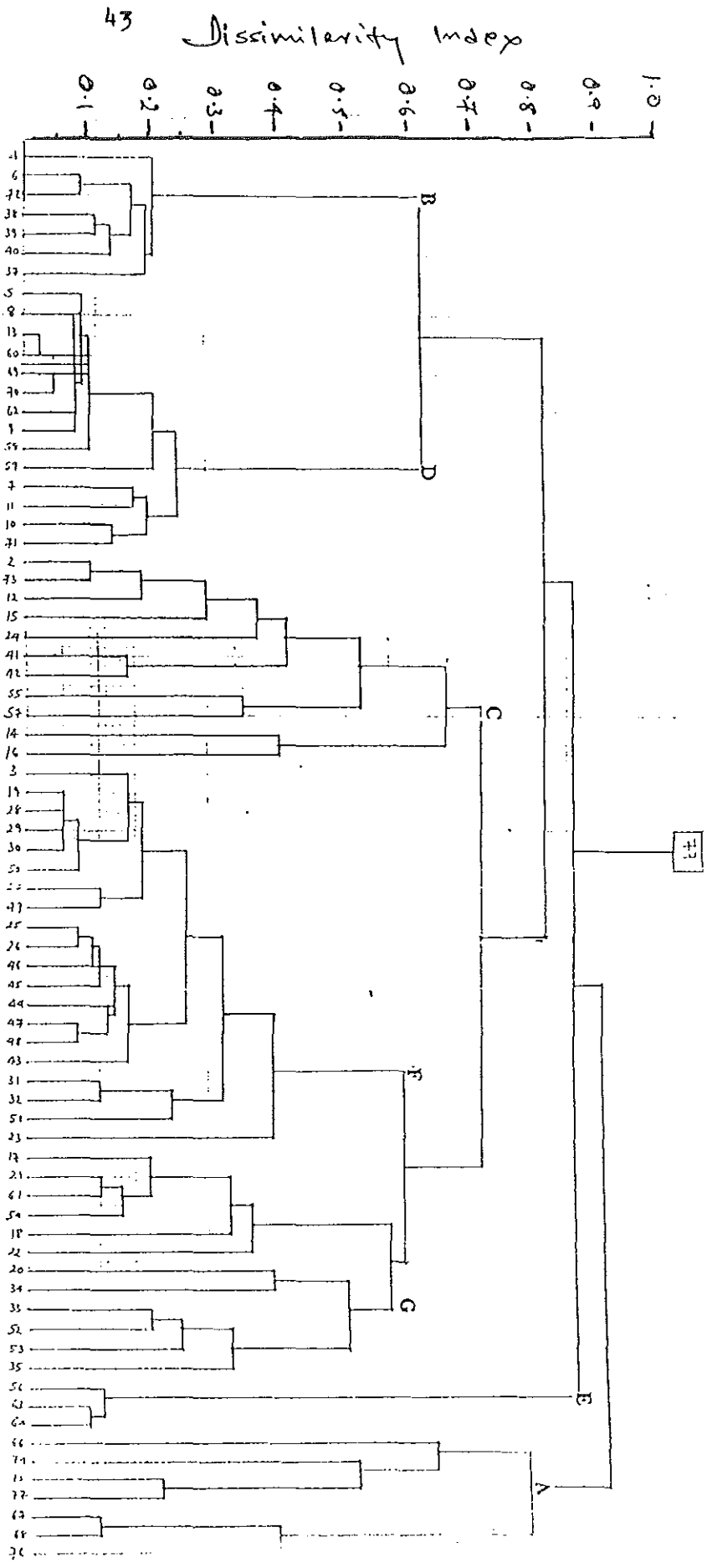


Fig. 10 - Major plant groups at Sanetlie plateau

Since this altitude is the lowermost portion of Sanettie plateau with a relatively much better climatic and edaphic factors, i.e. high precipitation, and temperature, the soil is rich in organic matter, nitrogen, phosphorus and potassium, thus plant growth is vigorous and maximum plant size is seen at this level. Due to the favourable climate human interference is very large and the area is highly disturbed.

B. Erica - Philippia type (3500 - 3700 m.)

Immediately above the tree-line *Erica - Phillippia* complexes dominate a large portion of afroalpine and subafroalpine regions in the Sanettie plateau. The ericaceous plants form the most extensive vegetation types in both subafroalpine and afroalpine zones. According to Hedberg (1975) the upper limit of the ericaceous belt in Ethiopia is often higher than in East Africa. Potentially these two species can be found in all habitat types reaching an altitude of 4200 m on very warm slopes, sheltered from northerly winds. Up to 4000 m Erica - Phillippia complexes form dense stands of trees attaining heights of between 4 and 5 m. However, at the uppermost altitudinal range, the species grow to a height of 30 to 50 cm., adopting the life form of a dwarf shrub, growing mostly in association with Helichrysum heath. Below the treeline *Erica arborea* can reach to tree sizes about 10 to 15 meters. In the subafroalpine region woody plants like *Hypericum revolutum*, *Gnidia glauca* and *Rapanea simensis* grow in association with the ericaceous plants. Very few understorey vegetation are observed in association with Erica and Philippia bushes: *Alchemilla haumanii*, *Alchemilla rothii*, *Alchemilla abyssinica*, *Thymus serrulatus*, *Hebenstreitia dentata*, *Cineraria abyssinica*, and *Galium aparinoides* are the major ones.

The Heather belt is highly susceptible to fire burning. Quantitative data on fire occurrence and its effect on soil nutrients and hydrology are absent. But in a similar study of the effects of heather burning on seed germination and vegetation regeneration by Malik and Gimingham (1985), fire controls community composition either by the elimination of fire-sensitive species, and by selection in favour of plants capable of rapid post-fire regeneration, especially by vegetative means. All the species investigated regenerate vegetatively at least to some extent, by one means or another, after burning at any temperature within the range of 400 to 800 °C (Malik and Gimingham, 1985). Their capacity to participate in a community subjected to recurrent disturbance by fire derives to a large extent from a small number of morphological and anatomical features. Some species produce copious new shoots from the stem base at or near ground level, others from buds on creeping stems or protected within tillers or leaf rosettes. A further set regenerate rapidly from perennating organs below the surface. Species whose surface soil and humus, and in which germination is rapid after the passage of fire, will also be at an advantage (Malik and Gimingham, 1985).

C. Helichrysum citrispinum - Alchemilla abyssinica type (3700 - 3800 m.).

Just above the Ericaceous belt cushion forms of *Helichrysum citrispinum* and *Alchemilla abyssinica* become prominent at an altitude between 3700 and 3800 m. Lower down in the heather moorland *Helichrysum citrispinum* is also much common and covers a wide range of the burnt site of Erica moorland. There is also a slight human interference at this level. *Alchemilla haumanii*, *Salvia merjamie*, *Alchemilla rothii*, *Anthemis tigrensis*, *Festuca abyssinica*, *Cineraria abyssinica*, *Helichrysum splendidum*, *Haplocarpha rueppellii*, *Erigeron afroalpina*, *Trifolium burchellianum*, *Erica arborea*, *Lobelia rhynchopetalum*,

Senecio schultzii, *Hebenstreitia dentata*, *Swertia volkensii* and some other species are also found together in association with the characteristic species.

The cushion form of *Helichrysum spp.* are the dominant species occurring at Sanettie plateau. The branched stem nature of these species is an adaptation for a highly soliflucted ground(soil). Reduction in the length of internodes is also a remarkable adaptation against low or freezing temperature (Meinzer and Goldstein, 1986). In most of the *Helichrysum spp.* the stems are well protected and insulated below the surface of the compact cushions. The spaces between the branches of the stem are filled with leaf litters and soil. The surface of the cushions thus loses less heat by outward radiation at night, as a result the stems inside appear to be well protected against freezing (Hedberg, 1964). The shiny involucral bracts in *Helichrysum splendidum*, *Helichrysum formosissimum*, *Helichrysum gofense* and *Helichrysum citrispinum* have a good capacity for light reflection (Hedberg, 1964). The plants therefore are perhaps equipped to control their transpiration rate and shield from overheating and damage by ultraviolet radiation.

D. Alchemilla haumanii type (3800 - 3900 m.).

At this elevation *Alchemilla haumanii* is widely spread along the mountain ridges, valley bottoms and edge of cliffs. Several of these plants tend to grow in dense mats or bushes which presumably create ameliorated microclimates of their own, in which some other less hardy species may gain foothold (Hedberg, 1964). The mat like growth pattern of the stem obviously decreases outward radiation at night and reduces frost formation besides protecting the plant from frequent solifluction.

In most cases, *Alchemilla haumanii* grows in close association with *Erica arborea* or as the dominant colonizing species in areas where *Erica - Phillippia* cover has been removed by fire. Some other plants found together with *Alchemilla haumanii* include: *Helichrysum citrispinum*, *Alchemilla abyssinica*, *Alchemilla rothii*, *Anthemis tigrensis*, *Festuca abyssinica*, *Helichrysum splendidum*, *Haplocarpha rueppellii*, *Erigeron alpina*, and *Lobelia rhynchopetalum.*

E. Haplocarpha - Festuca - Carex monostachya type (3900 - 4000 m.).

The high altitude swamps and boggy areas are dominantly covered by the three characteristic species: *Haplocarpha rueppellii*, *Festuca abyssinica*, and *Carex monostachya.* The three species are mostly found together while in fewer places one or two of the three species may totally cover a large swampy or boggy area. Not so frequently other species like *Helichrysum citrispinum*, *Anthemis tigrensis*, *Lobelia rhynchopetalum, Dianthoseris schimperi*, *Ranunculus spp.* are found together with these characteristic species. Very little human disturbances is observed at this level. Water logged, boggy and swampy areas in the afroalpine community are characterized by poorly drained and aired soils. Although not investigated in the present study another possible adaption of plants of swampy areas might be the development of specialized pneumatophore like roots which enable these plants to inhabit water - soaked and therefore poorly aired soils (Beck, et al. 1981).

Haplocarpha rueppellii is the dominant species in the swampy or boggy areas at Sanettie Plateau. The lower side of the leaves of this species is covered by a dense and whitish (light-colored) indumentum, which make the leaf rosettes quite conspicuous at long distance. This indumentum must certainly help to protect not only the outward radiation

Some of these species have shiny leaves to reflect intense solar radiation. *Euryops prostratus* for instance has developed net - like or prostrate resting stems. This helps the plant to resist the effects of mole rat burrowing and solifluction. *Helichrysum splendidum* form cushion type of growth pattern to create a favourable microclimate. A number of species like *Helichrysum citrispinum*, *Alchemilla haumanii*, *Alchemilla abyssinica*, *Trifolium acaule*, *Anthemis tigrensis*, *Haplocarpha rueppellii*, *Erigeron afroalpina*, *Cerastium afromontanum*, *Senecio schultzii*, *Aira caryophylla* have been observed growing in association with the characteristic species.

G. Festuca - Lobelia - Helichrysum gofense type (4200 - 4300 m.),

This is the highest peak of Sanettie plateau where the characteristic species *Festuca abyssinica*, *Lobelia rhynchopetalum* and *Helichrysum gofense* become prominent. The growth of many of these species is highly constrained by severe climate (low temperature and moisture content, frost formation and intense ultraviolet radiation). *Lobelia rhynchopetalum* is the dominant species at this elevation. *Lobelia rhynchopetalum* (Giant Lobelia) is an endemic plant of the Ethiopian high mountains, the only representative of the genus with the giant rosette life form found in Sanettie plateau.

Lobelia rhynchopetalum is a perennial plant characterized by thick and unbranched woody or herbaceous stems, usually covered with a dense mantle of marcescent dry leaves. The leaf rosette is huge and holds a large number of leaves which in due times terminate by producing an immense inflorescence. The leaves of giant Lobelias during the freezing night curl inwards towards the centre of the leaf rosette with their margins strongly reflexed protecting the young leaves and the unexpanded leaves in the apical bud from freezing (Young, 1984). In the afroalpine giant rosette plants the leaves are concentrated or crowded into one or a few large rosettes. These rosette leaves form a parabolic geometrical structure improving capture and retention of long and short wave solar radiation, consequently increasing tissue temperature (Young and Smith, 1987). In giant Lobelia the marcescent leaves prevent night time stem temperatures from falling below 0° C. even when environmental temperatures are several degrees below zero (Meinzer and Goldstein, 1986).

The interior rosette of Lobelias are filled with watery liquid or mucilaginous fluid (secreted by the plant itself), enclosed by the imbricate leaf bases which may have a function of depressing the freezing point of the water bathing the whole plant (Fitter and Hay, 1989). Water has a higher heat capacity than air, thus the fluid of giant rosette plants may act as an effective heat storage mechanism (Young and Smith, 1987). Young and Smith (1987) noted that removal of the fluid from *Lobelia keniensis* rosettes resulted in subfreezing night time temperatures in the apical bud, but buds in control plants did not experience freezing temperatures. The presence of thick leathery leaves in *L. rhynchopetalum* reduces transpirational water loss.

4.5.2 Hydrometer methods of mechanical analysis.

The Bouyocos hydrometer method given by Jou (1978) and Chopera and Kanwar (1976) was used to determine the sand, silt and clay fractions of the soil samples. Fifty one grams of 2 mm sieved air-dried soil sample was added to 50 ml. of 5 % sodium hexametaphosphate along with 100 ml distilled water. The suspension was stirred for mixing and then allowed to stand for 30 minutes. Using a multimix machine the soil suspension was stirred for 15 minutes, then transferred into a one liter glass cylinder. The suspension was diluted with distilled water upto a one liter mark. The cylinder, with its mouth covered by hand, was inverted several times until all soil was in suspension. The cylinder was placed on a table and the time noted immediately. Hydrometer and temperature readings were taken at the end of 40 seconds and 3 hours. The different soil fractionation were calculated as follows:

a) $\%\ SAND = 100 - [H_1 + 0.2\ (T_1 - 68) - 2\ ]\ 2$

b) $\%\ CLAY = H_2 + [0.2\ (T_2 - 68) - 2\ ]2$

c) $\%\ SILT = 100 - (\%SAND + \%\ CLAY)$

where; H_1 is the first hydrometer reading after 40 seconds;

T_1 is the temperature reading at 40 seconds;

H_2 is the hydrometer reading at 3 hours and;

T_2 is the temperature reading at 3 hours;

The part, 0.2(T - 68), was used as a correction factor which was added to the hydrometer reading. The reading at 40 seconds measured the percentage of silt and clay in the suspension. This amount subtracted from 100 gave the content of sand particles. The second reading at 3 hours gave the percentage of clay in suspension. The percentage of silt was obtained by subtracting the combined percentages of clay and sand from one hundred.

4.5.3 Soil pH

The pH of soil samples were determined following the procedure given by Juo (1978). A 1:1 soil suspension in water was first made by dissolving 20 g of soil with 20 ml of distilled water. The suspension was allowed to stand for 30 minutes, with occasional stirring. The pH was then determined using a Beckman Chemmate pH meter.

4.5.4 Conductometric method of determining soluble salts.

Soil conductivity was determined following Jou (1978) and Chopera and Kanwar (1976). A 1:2 saturated soil paste was prepared by adding 50 g of air-dried soil sample passed through a 2 mm sieve into 100 ml distilled water. The soil water mixture was consolidated from time to time to glisten during the stirring process. The soil paste was then left on a mechanical shaker for 16 hours or overnight. After the soil suspension was filtered through a Buchner funnel conductivity was measured using a conductivity meter (cell).

4.5.5 Organic Carbon.

Determination of organic carbon was according to the Walkey - Black method given by Jou (1978). Soil organic matter content was estimated from the determination of carbon, which is made by oxidation under standardized conditions with potassium dichromate in sulfuric acid medium. An air-dried soil sample weighing 0.2 g passed through 0.5 mm sieve was treated with 10 ml of potassium dichromate in excess in the presence of 20 ml of sulfuric acid. The soil suspension was then swirled gently to disperse the soil in the solution. Concentrated phosphoric acid (10 ml) was added in order to complex the Fe^{3+} ions. After 30 minutes, 1 ml diphenyl amine indicator, which develops a deep blue black color, was then added. The excess potassium dichromate was titrated with a ferrous solution (0.5 N $FeSO_4$). As soon as ferrous ions were added in excess, the indicator turned from blue black to a brilliant green color. Blank titrations were also carried out to standardize the dichromate solution. The percentage of organic carbon was then calculated according to the following formula given by Chopera and Kanwar (1976).

$$per\ cent\ carbon = \frac{(ml.\ K_2Cr_2O_7 - ml.FeSO_4)\ x\ 0.003\ x\ 100}{W(gm)}$$

where W = weight of air dry soil.

4.5.6 Determination of available phosphorus in soil.

Bray No. 1 method was followed to determine phosphorus in the different soil samples as used by Jou (1978). An extracting solution was prepared by adding 15 ml. of 1 N ammonium fluoride and 25 ml of HCl into 460 ml distilled water. One gram of air-dried soil, passed through 2 mm sieve, was then treated with 7 ml of the extracting solution. The solution was shaken for 1 minute in a mechanical shaker and centrifuged for 15 minutes to get a clear supernatant. From the clear supernatant 2 ml was placed in a 20 ml test tube, then added 5 ml distilled water, 2 ml ammonium molybdate and 1 ml stanneous chloride dilute solution. After the solution was mixed properly and left for 5 minutes, percent absorbance was read using a spectrophotometer (Spectronic 1001). Content of extractable phosphorus in the soil solution was then determined by using standard curves obtained with standard phosphate solutions.

4.5.7 Determination of total nitrogen.

Nitrogen was determined using the microKjeldahl method. The method involves two processes: digestion and distillation. During digestion organic - nitrogen is converted into ammonium - nitrogen. Nitrogen is then estimated from the amount of ammonia liberated by distillation of the digest with alkali. One gram air-dried soil sample (passed through 0.5 mm sieve) was placed in a dry 500 ml Kjeldahl flask, mixed with 7 gm of potassium sulphate and 0.8 gm copper sulphate dilute solution to which 12 ml of concentrated sulfuric acid was added. The digestion flasks were then put to the digestion system which was preheated (420 $^{\circ}$C). Samples were digested for about one hour until all the samples

become clear with a blue / green solution. The rack of tubes were then cooled for 10 to 20 minutes. Deionized water, 75 ml was added into the tubes. In a conical flask 25 ml. of receiver solution (Boric acid indicator) was added and the flask placed into the distillation unit. In the distillation unit 50 ml. of 40 % Sodium hydroxide was dispensed and distillation allowed to go for about 4 minutes until the receiver solution in the distillate flask became green in color indicating the presence of an alkali - ammonia. The distillate was then titrated with standardized 0.1 N HCl until the blue / grey end point was reached. Similarly blank titration were also carried out.

The percentage of total nitrogen was then calculated as follows:

$$\%N = \frac{(T-B) \times N \times 14.007 \times 100}{Weight of sample (mg)}$$

where T = Titration volume for sample.

B = Titration volume for blank.

N = Normality of acid.

leached with 5 or 10 ml of ammonium acetate solution (distilled water). Then the filtrate was transferred into an Erlenmeyer flask and adjusted to a volume of 250 ml with ammonium acetate solution (distilled water). Exchangeable K and Na were measured by flame photometer directly from the leachate using K and Na filter, respectively. After determining transmittance the content of Na and K was calculated with the following formula given by Yerima (1992):

Exch. K meq./100 g.soil = ppm. x 250/5 x 100/1000 x 1/39.1 x M

= ppm. x 0.128 x M

Exch.Na meq./100 g.soil= ppm.x 250/5 x 100/1000 x 1/22.9 x M

= ppm. x 0.217 x M

In which: ppm = Reading from calibrated graph.

M = moisture correction factor.

5 RESULTS AND DISCUSSION.

5.1. Vegetation.

5.1.1 General:

The vegetation of Bale mountains at Sanettie can generally be classified into two major vegetation zones or regions, subafroalpine and afroalpine regions. The subafroalpine region extends in altitude between 3000 to 3400 m. The areas between 3000 and 3400 m are largely dominated by three woodland trees: *Hagenia abyssinica, Juniperus procera* and *Hypericum revolutum.* On the northeastern side of Sanettie plateau these three dominant trees form a clear vegetation stratification. The area from 3000 upto 3100 m. is mainly covered by *Juniperus woodland*, from 3100 to 3200 m. *Hagenia* trees become dominant, then above this point *Hypericum woodland* covers a considerable area of subafroalpine regions upto the tree-line. Some other trees like: *Discopodium penninervum*, *Maytenus ovatus*, *Rapanea simensis*, *Schefflera volkensii*, and *Allophylus abyssinicus* occur in association with these characteristic tree species of the subafroalpine regions. *Erica - Philippia* complexes are the most distinctive features of subafroalpine ecosystems. Together the two species cover a considerable area of Sanettie plateau from 3200 to 3400 m making the wide and extended heather moorland. Herbaceous and shrubby species at this level are very diverse and thick plant cover is much common.

The afroalpine zone (3450 - 4300 m) at Sanettie gradually replaces the sub-afroalpine vegetation zone. It contains a number of plant forms with distinctive features.

5.1.2 Plant communities

Sixty five species were recorded from all quadrats (Appendix 1) at Sanettie plateau. Seven major plant groupings (i.e clusters) designated as A, B, C, D, E, F, G, were identified (Fig. 10) and the number of species found in each plant group is presented in Table 4. Each of these plant groups has a characteristic species of their own and the similarity in each group is based on species cover and abundance. The different plant groups were named by the dominant species which occur in each cluster i.e., species with the highest value of plant cover. The following description of plant grouping was based upon the results of association analysis (classification) as described in the Material and Methods. The different groups were arranged systematically based upon their differences in altitude.

A. Kniphofia - Euphorbia - Alchemilla abyssinica type (3400 - 3500).

Kniphofia foliosa, Euphorbia dumalis and *Alchemilla abyssinica* were the characteristic species at this level. This plant group occurs at the lower level of the subafroalpine regions at Sanettie. Few meters below this point (3400 m.) the characteristic species are found in association with some highland trees like *Hypericum revolutum, Maytenus ovatus, Hagenia abyssinica, Juniperus procera,* and with some herbaceous and shrubby species like *Argemone mexicana, Rubus spp., Conyza spp., Cirsium spp., Urtica simensis, Cynoglossum lanceolatum* and *Cynoglossum geometricum, Geranium arabicum, Satureia spp., Thymus serrulatus, Hypoxis spp., Ranunculus oreophytus, Galium aparinoides* and with some other species.

A remarkable structural modification observed in the giant rosette plant, *Lobelia rhynchopetalum* is that at immature stages plant leaves are more pubescent (a morphological adaptation against ground frost) but when the plant increases in height the leaves tend to be more glabrous (a protection against the strong radiation and insolation). Lobelias have special water storage tissues that enable them to maintain the water balance (Hedberg, 1964). Stems of giant rosette plants have a central parenchymatous pith surrounded by a cylinder of well-developed secondary xylem (Meinzer and Goldstein, 1986). Hedberg (1964) noted that the pith of the caulescent giant rosettes may act as a water reservoir and with the relatively good hydraulic connections between the pith and xylem, this special structure may serve as a source of water specially during cold temperatures and during scarcity of water.

Unlike other afroalpine plants, giant Lobelia (*Lobelia rhynchopetalum*) tends to increase in height with increasing elevation. Greater plant height can be related to fire resistance, or longevity and to escape from herbivores (Young and Smith, 1987). Young and Smith (1987) further explained that the production of a tall aerial stem may protect the meristematic leaf and reproductive tissues from the effects of diurnal temperature fluctuations. Measurements on temperature in the northern Andes and on Mt. Kenya have shown that night-time minimum temperatures are lower and day time maximum temperatures are higher at ground level than at one meter above the ground (Young and Smith, 1987).

The characteristic species *Lobelia rhynchopetalum*, *Festuca abyssinica* and *Helichrysum gofense* grow in association with the following plants: *Alchemilla abyssinica*, *Alchemilla rothii*, *Anthemis tigrensis*, *Helichrysum splendidum*, *Erigeron alpina*, *Trifolium*

burchellianum, *Veronica abyssinica*, *Senecio schultzii*, *Viola abyssinica*, *Aira caryophylla*, *Silene burchellii*, *Pennisetum humile*. Human interference is absent at this level.

5.1.3 Number of Species per group, Vegetation Cover and Species diversity.

The total number of species per community as obtained by hierarchichal clustering is given in Table 4. As indicated in Table 4, group A has more species than the other groups. This may be attributed to the favourable climate prevailing at this lower level (3400 m.). With an increase in altitude from A to G, human interferences tend to decrease because, the environment is getting harsh and inhospitable.

Data on environmental factors have shown that mean monthly values of temperature, rainfall, moisture content, and relative humidity decreases with an increase in altitude. The effects of these conditions in Sanettie plateau have resulted in an overall decrease in species richness, vegetation cover and growth forms of herbaceous and shrubby species.

Table 4. Number of species obtained from each cluster.

Cluster	Number of species	Human interference
A	30	5
B	21	3
C	28	2
D	24	1
E	22	1
F	29	1
G	25	0

Differences in vegetation cover between quadrats in an altitudinal gradient was compared by taking the sum total of the cover of individual species in a quadrat (see Table 5). Vegetation cover ranged between 20 % at 4300 m altitude and 151.6 % at 3400 m altitude. There was a striking reduction in vegetation cover with an increase in altitude. At the top of Tullu Demtu (4300 m) most of the places look like desert and are covered by rocks and soliflucted grounds. There are places totally devoid of vegetation. The reduction in vegetation cover with altitude (especially above 4000 m) was mainly attributed to the decrease in % soil moisture content, soil organic carbon and total nitrogen. Mean monthly temperature and precipitation decrease with altitude result in frequent frost formation and in most of the time snow can stay three or four days. This may have a detrimental effect on vegetation and presumably affects the vegetation cover of the area. Other factors like: strong wind, solifluction and mole rat burrowing become severe with an increase in altitude which accounts for low plant cover.

The result on Diversity index has come in agreement with that of vegetation cover values. It was clearly indicated that species abundance and richness decline with an increase in altitude (Fig. 11). Values of species diversity index (H) for each stand are given in (Appendix 2).

Table 5. Relationship between per cent plant cover and altitude

(SD = standard deviation)

Altitude	Mean	SD
3450	151.6	± 46.6
3500	131.3	± 43.8
3550	90.0	± 5.0
3600	92.0	± 10.4
3650	97.5	± 2.5
3700	76.0	± 21.0
3750	93.5	± 2.5
3800	97.0	± 7.1
3850	89.7	± 9.4
3900	82.0	± 15.3
3950	70.0	± 8.5
4000	88.5	± 15.8
4050	74.4	± 18.0

Table 5. Continued.

4100	87	± 2.9
4150	89.3	± 3.9
4200	78.0	± 11.3
4250	43.7	± 16.0
4300	20.0	± 8.6

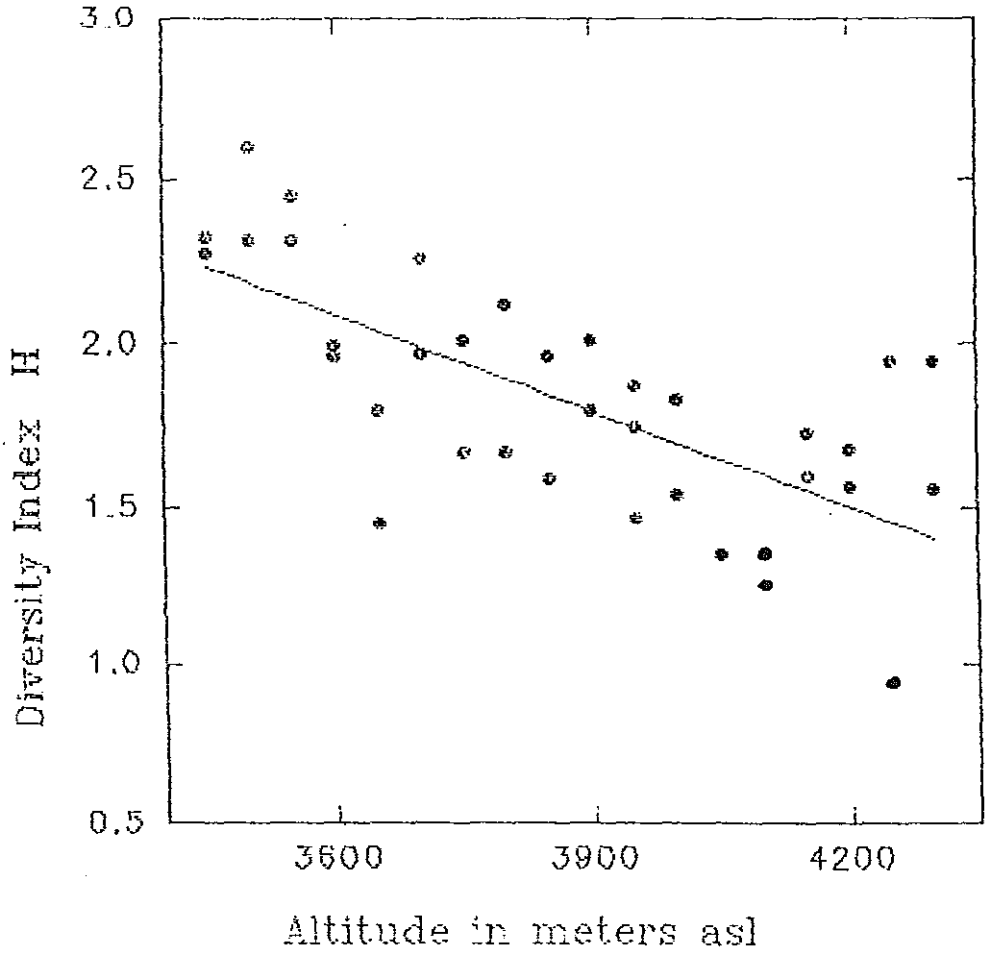


Fig. 11 - Species diversity versus altitude

5.2 COMPARISON OF PLANT GROUPS (CLUSTERS) WITH ENVIRONMENTAL FACTORS.

The various environmental fractors measured were averaged for each of the final 7 plant groups identified by cluster analysis. Each pair of the groups were then compared using the t-test for every environmental factor measured. A probability of 0.05 was considered as signigicant, and each of the averaged environmental factors were plotted against the different plant groups (clusters). The results of the comparison are found to be as follows:

5.2.1 Texture.

The amounts of sand, clay and silt of the analyzed soil from Sanettie plateau are given in (Appendix 3). Differences in texture amongst the groups were not very significant. However some differences were obtained from the different soil samples collected from the various altitude. The upper stratum contains a relatively high fraction of sandy particles but at lower altitude there is a sharp decline in percent grains of sand. The granites of the crystalline basement wither to sandy soils and the sandstones are the base material for the shallow and poor sandy soils (Last, 1962; in Weinert, 1981). Very low percent clay was recorded from all sites. But a relatively high amount of clay fractions have been obtained from the southern side of Tullu Demtu towards Harenna escarpment. This perhaps reflects the effect of chemical weathering due to the high amount of relative humidity and plant cover prevailing in the southern aspect of the plateau. The silt fraction predominates at lower level, however at the uppermost part of Sanettie plateau values are considerably low. The structural elements of silty loams of red or black color are mainly weathered from the

basic rocks or volcanic origin (basalt and trachyte). A part of the silt fraction could originate from some volcanic ashes too (Weinert, 1984).

Overall sand accounts for more than 50 percent of the soil composition. Silt fractions are relatively high throughout the plateau, but especially predominate at lower altitudes. The content of clay particles on the other hand is considerably lower. This shows that chemical weathering is slow in these regions perhaps due to the low annual temperatures and moisture (Smith, 1983).

5.2.2 Soil pH.

Soil pH ranged from 5.82 to 7.68 and comparisons of mean pH for all plant groups (clusters) are shown in figure 12. The averaged soil pH values of groups A, B, C, and D, were found to be medium acidic whereas groups E, F, and G were mildly alkaline. A certain acidity of the soils obtained from groups A, B, C, and D might be caused by a more intensive break - down of organic matter. There is also considerable leaching of the soils as these areas have more than 1000 mm annual rainfall and the temperature range is at a relative low annual average of less than 14 °C (Daniael, 1977). Samples taken from the northern and southern areas of Sanettie plateau and from the different soil depths also showed the same trend.

5.2.3 Soil conductivity.

The electrical conductivity of a soil is the specific conductivity at 25 °C of a water extract obtained form a soil and water mixture of a definite ratio (Donahne, 1990). The soils of Sanettie Plateau contain comparatively low level of soluble salts. As a result values of electrical conductivity ranged between 0.00 and 0.20 millisiemens meter^{-1}. The different plant groups (clusters) didnot show a significant differences in electrical conductivity. Nevertheless, results have shown that electrical conductance was higher at lower altitudes and there was a sudden drop in conductivity at higher altitudes. Low soluble salt concentration and consequently low electrical conductance with increasing altitude and slope may be accounted for the low precipitation or moisture content of the soil. Since the conductivity values obtained are within the range of 0.00 - 0.8 millisiemens meter^{-1} (where approximate salt concentration is below 0.05 %) (Moore and Chapman, 1976), this range is assumed to be normal for most plant growth (Chopra and Kanwar, 1976).

5.2.4 Organic Carbon.

A reasonably high organic carbon content was obtained for soils from the Sanettie plateau. The lowest value obtained was 1.2 % and the highest was 13.4 %. Groups A and B had relatively higher amount of organic carbon as compared to groups C, D, E, F, and G, particularly groups F and G contained very low organic carbon (Fig. 13). The high amount of organic carbon for groups A and B could be attributed to the low mean temperature combined with high rainfall (Foth and Turk, 1972). Foth (1972) suggested that the mineralization of humus decreases with a lowering of the mean temperature and with increasing precipitation. Moreover, low soil temperature and pH reduce microbial activity, thus retarding decomposition of organic matter.

Soil organic matter is a very important fraction of the soil because of its high cation exchange capacity (Yerima, 1992). In addition it retains nutrients against leaching losses, and supplies many nutrients particularly N, P, and some of the micro - nutrients. Organic matter in soil imparts favourable structure to the soil and is mainly responsible for the soil's microbial activity (Russell, 1973).

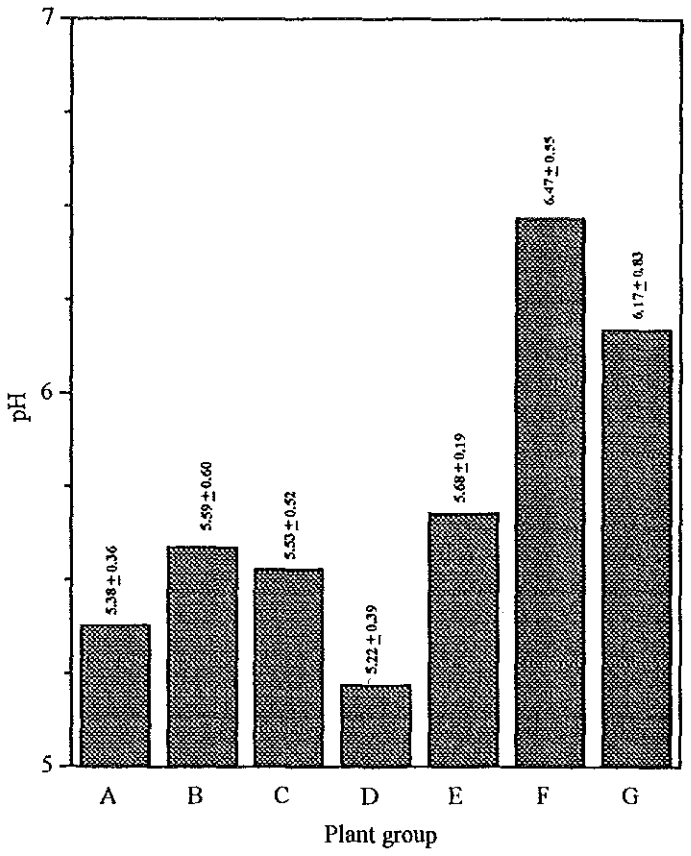


Fig. 12. Comparison between mean pH and plant groups.

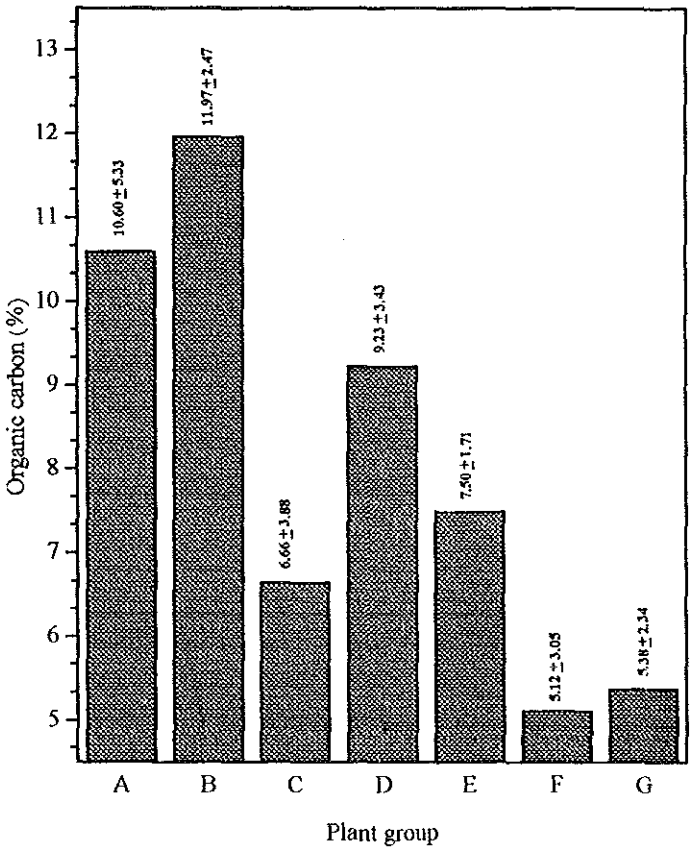


Fig. 13. Comparison between mean per cent organic carbon and plant groups.

5.2.5 Available Phosphorus.

The amount of phosphorus in the soil samples at Sanettie ranged between 0.5 and 4.5 ppm. This is a relatively high level (Weinert, 1984). However, this high level may not correspond to higher plant growth as the uptake of phosphorus by plant is influenced by soil temperature (Russel, 1973). The high amount of phosphorus at Sanettie plateau may be attributed to the high alkalinity of the soil. The averaged values of soil phosphorus obtained from all the 7 plant groups (clusters) were more or less similar (Fig. 14).

5.2.6 Total Nitrogen.

In the Sanettie plateau the amount of soil nitrogen ranged between 0.00 and 1.12 %. There was a slight differences in the content of percent nitrogen between each plant groups (Fig. 15). Very low level of percent nitrogen were obtained for most of the plant groups (B, C, D, E, F, G), this could be attributed to the low soil temperature which mostly goes down below 0° c. Russell (1973) suggested that nitrification only proceeds rapidly in warm soils, and goes on very slowly when the soil temperature is below 4 or 5 °C. Mineralization of soil nitrogen in the afroalpine regions may thus be influenced by soil temperature. The amount of ammonium or nitrate, the principal forms of nitrogen uptake by plants may thus become very low accounting for the stunted and slow growth of most plants of afroalpine regions.

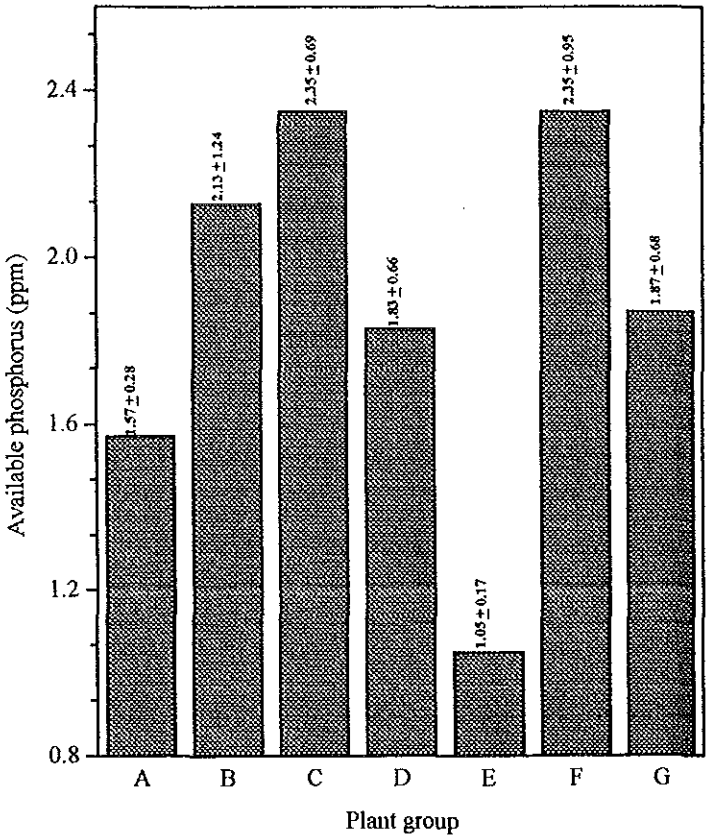


Fig. 14. Comparison between mean available phosphorus and plant groups.

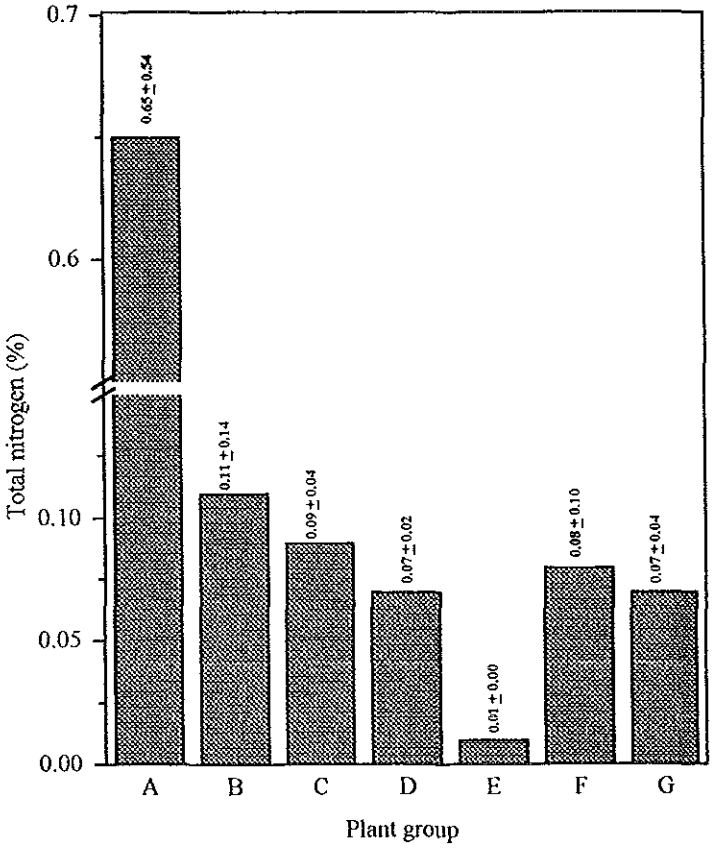


Fig. 15. Comparison between mean total nitrogen and plant groups.

5.2.7. Soil Moisture Content.

The amount of soil water available is an important factor influencing the distribution of plants in afroalpine regions. Soil moisture content at Sanettie plateau ranged between 0 to 40 %. Groups A, B, C, and D which occurred at the lower afroalpine level contained a relatively high amount of moisture, while groups E, F, and G had very low soil moisture (Fig. 16). In the plant groups A, B, C, and D the soils contained more fine - textured material and humus than in the plant groups E, F, and G. Consequently moisture content was higher in groups A, B, C, and D. The low amount of soil water content in groups E, F, and G could be attributed to the high level of the sand fraction of the soil. Therefore in the upper belt of Sanettie plateau where annual rainfall is very low and erratic, lack of soil water could be the principal factor limiting the growth and establishment of plants. A large portion of the upper parts of Tullu Demtu (> 4100 m altitude) are more desert like with dwarf and scant vegetation, but lower down at Chorchora (3400 - 3500 m.) there is an ample amount of soil water therefore patches of closed vegetation are very common.

5.2.8 Exchangeable Bases (K^+ and Na^+).

The investigated soils of all samples from Sanettie plateau were found to be rich in basic exchangeable cations (K^+ and Na^+), of which K^+ was the most abundant. Comparisons of mean values of per cent K for all plant groups are given in Figure 17. The values were ranged from 0.13 to 4.34 % K^+ and most of the soil samples contained 0.8 to 2.0 % K.

The plant groups A and B were mainly occurred at the lower altitudinal levels and contained high amount of potassium as compared to the plant groups C, D, E, F, and G. This might be due to the frequent burning of the ground vegetation that increase the amount of potassium at the lower altitude.

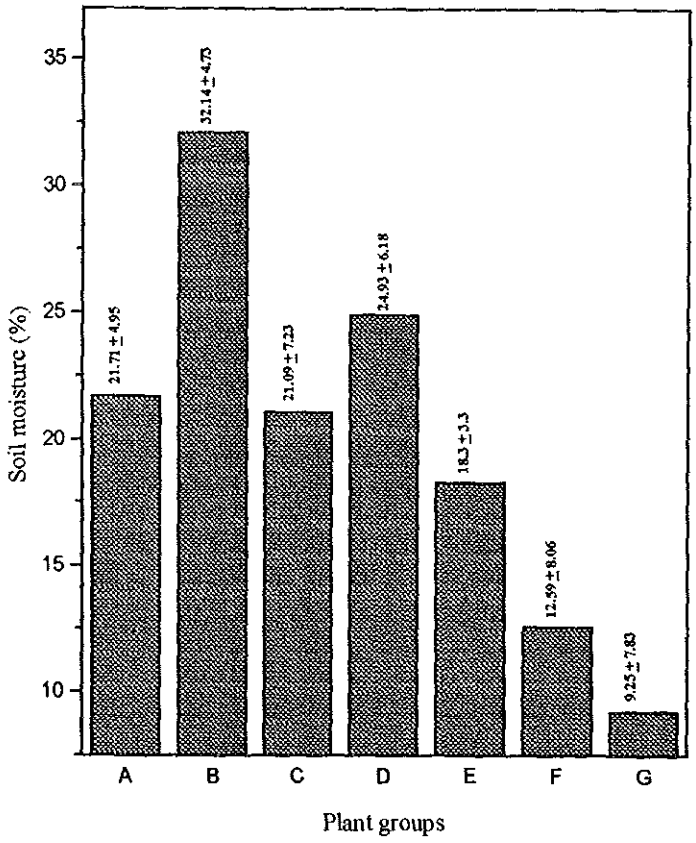


Fig. 16. Comparison between mean soil moisture content and plant groups.

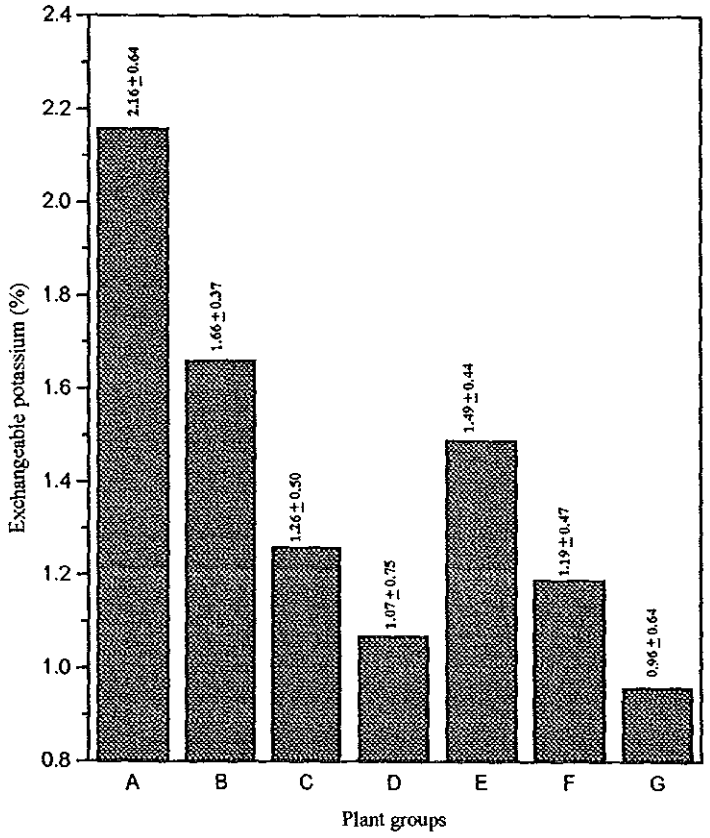


Fig. 17. Comparison between mean exchangeable potassium and plant groups.

6 Summary and Recommendation

The afroalpine vegetation of Bale mountains, in particular the vegetation of Sanettie plateau, was classified into seven vegetation groups. These plant groups occupy distinct altitudinal zones.

Kniphofia - Euphorbia - Alchemilla abyssinica scrub land occupies from 3400 up to 3500 m whereas **Erica - Philippia belt** comes just above the tree - line but predominantly from 3500 to 3700 m. Above the heather moorland the afroalpine belt is first characterized by **Helichrysum citrispinum - Alchemilla abyssinica** from 3700 to 3800 m. Then a considerable wide area of afroalpine meadow and edge of mountain cliffs from 3800 upto 3900 m is covered by **Alchemilla haumanii** meadow. High altitude swamps and boggy areas at 3900 and 4000 m are largely dominated by the **Haplocarpha - Festuca - Carex monostachya plant group.** The upper level of afroalpine vegetation at Sanettie plateau is dominated by **Helichrysum splendidum - Lobelia - Festuca - Euryops plant groups** in an altitudinal range between 4000 to 4200 m. Finally at the summit of Tullu Demtu from 4200 to 4300 m the plant group **Festuca - Lobelia, Helichrysum gofens** becomes dominant.

There are distinct macro and microclimatic differences in the afroalpine and subafroalpine regions. These differences by and large account for the occurrence of different characteristic plant groups at the different altitudinal levels. The relatively high amount of precipitation and diurnal fluctuations in temperature particularly account for the

tracking, and the threat to wild animals are a major problem arising from the movement of people within these ecosystems. The Ethiopian Wildlife Conservation Organization is doing its best to preserve the afroalpine ecosystems of Bale. However, the task of conserving natural resources cannot be achieved by a single organization. Awareness creation program for the local population, unreserved effort and participation from the local people will all be decisive in conserving and rationally utilizing this fragile high plateau ecosystems.

Finally as this study is only a preliminary investigation it is recommended that the area be further investigated for its floral and faunal resources. Intensive ecological and phytosociological studies of the vegetation of Sanettie plateau will be important to conserve and systematically utilize the afroalpine ecosystems.

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APPENDIX - 1

Plants collected from Bale Mountains , Sanettie plateau.

Code No.	Specific epithete
1	Helichrysum citrispinum Del.
2	Alchemilla haumanii Rothm.
3	Alchemilla abyssinica
4	Senecio steudellii Sch. Bip.
5	Rumex abyssinicus Jacq.
6	Salvia merjamie Forsk.
7	Arabis alpina L.
8	Trifolium acaule A. Rich.
9	Alchemilla rothii Oliv.
10	Anthemis tigrensis A. Rich.
11	Festuca abyssinica A. Rich.
12	Cineraria abyssinica Sch. Bip.
13	Galium aparinoides Forssk.
14	Helichrysum splendidum (Thunb.)Less
15	Haplocarpha rueppellii (Sch. Bip.)Beav.
16	Erigeron afroalpinum
17	Trifolium burchellianum ser.
18	Kniphofia foliosa Hochst.

19	Oxalis corniculata L.
20	Erica - Phillippia complex
21	Mentha viridis L.
22	Lobelia rhynchopetalum (Hochst)Hemsl.
23	Thymus serrulatus Hochst. ex Benth.
24	Dianthoseris schimperi
25	Cerastium afromontanum T.C.E.Fr. & Weimark.
26	Satureia biflora (D. Don.)Benth
27	Helichrysum citrispinum var.(hochnelii Schweinf.) Hedb.
28	Veronica abyssinica Fres.
29	Senecio schultzii Hochst. ex A. Rich.
30	Senecio unionis Sch. Bip. ex A. Rich.
31	Helichrysum gofense Cufod.
32	Romulea keniensis Hedb.
33	Swertia volkensii Gilg.
34	Hypoxis villosa L.f.
35	Viola abyssinica Oliv.
36	Carex monostachya A. Rich.
37	Aira caryophylla
38	Euryops prostratus Nordenstam.
39	Ursinia nana Dc.
40	Senecio vulgaris L.
41	Silene burchellii Dc.
42	Agrostis gracilifolia C.E.Hubbard.
43	Sonchus melanolepis

44 Hebenstreitia dentata L.

45 Agrocharis melallntha

46 Hagenia abyssinica (Bruce)J.F. Gmel.

47 Helichrysum cymosum (L) Less.

48 Conyza stricta Willd.

49 Sedum baleensis M. Gilbert

50 Helichrysum formosissimum (Sch. Bip. A. Rich.

51 Conium maculatum L.

52 Dichrocephala alpina R.E. Fries

53 Geranium arabicum Forsk.

54 Umbilicus botryoides A. Rich.

55 Cynoglosum lanceolatum Forsk.

56 Epiphytes

57 Euphorbia dumalis S. Carter

58 Urtica simensis Hochst. ex Steud.

59 Hypericum revolutum Vahl.

60 Argemone mexicana L.

61 Bartsia petitiana (A. Rich.)Hemsl

62 Cynoglossum geometricum Baker & Wright

63 Ranunculus oreophytus Del.

64 Pennisetum humile Hochst. ex A. Rich.

65 Heracleum elgonense (Wolff.) Bullock.

* 53.	5.	6.	1.561	1.609	.970 *
* 54.	9.	14.	1.871	2.197	.852 *
* 55.	10.	14.	2.168	2.303	.942 *
* 56.	7.	14.	1.451	1.946	.746 *
* 57.	7.	11.	1.799	1.946	.924 *
* 58.	6.	13.	1.411	1.792	.787 *
* 59.	2.	10.	.673	.693	.971 *
* 60.	1.	9.	.000	.000	.000 *
* 61.	2.	10.	.325	.693	.469 *
* 62.	5.	12.	1.099	1.609	.683 *
* 63.	1.	9.	.000	.000	.000 *
* 64.	2.	10.	.325	.693	.469 *
* 65.	2.	7.	.410	.693	.592 *
* 66.	1.	8.	.000	.000	.000 *
* 67.	4.	9.	1.003	1.386	.723 *
* 68.	4.	10.	.940	1.386	.678 *
* 69.	1.	9.	.000	.000	.000 *
* 70.	3.	11.	.600	1.099	.546 *
* 71.	3.	10.	.898	1.099	.817 *
* 72.	3.	11.	.860	1.099	.783 *
* 73.	2.	10.	.325	.693	.469 *
* 74.	9.	15.	1.899	2.197	.864 *
* 75.	9.	21.	1.955	2.197	.890 *
* 76.	17.	33.	2.298	2.833	.811 *
* 77.	14.	25.	2.320	2.639	.879 *

Q. No.	% SAND	% Clay	% SILT
44	58.4	10.0	31.6
45	42.4	24.0	33.6
46	42.4	22.0	35.6
47	48.4	12.0	39.6
48	48.4	17.6	33.6
49	54.7	11.6	33.6
50	52.7	20.0	27.3
51	58.7	15.6	25.6
52	52.7	11.6	35.6
53	70.7	1.6	27.6
54	62.4	8.0	29.6
55	44.4	2.0	53.6
56	70.4	6.0	23.6
57	34.4	18.0	47.6
58	68.4	4.0	27.6
59	44.4	4.0	51.6
60	54.4	4.0	41.6
61	44.4	6.0	49.6
62	48.4	6.0	45.6
63	60.4	12.0	27.6
64	70.4	10.0	19.6
65	42.4	16.0	41.6
66	42.4	16.0	41.6
67	44.4	6.0	49.6
68	44.4	6.0	49.6
69	54.0	3.3	42.7
70	54.0	3.3	42.7

Texture - 3

Q. No.	% SAND	% Clay	% SILT
71	54.0	3.3	42.7
72	54.0	3.3	42.7
73	51.3	1.3	47.4
74	73.3	1.6	25.1
75	73.3	1.6	25.1
76	73.3	1.6	25.1
77	73.3	1.6	25.1
Average	4452.5 57.8 %	504.4 6.6 %	2744.3 35.6 %