ADDDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DISTRIBUTION AND STRUCTURE OF TREELINE SPECIES IN ERICACEOUS VEGETATION OF HARRENA ESCARPMENT, BALE MOUNTAINS

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A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE IN BIOLOGICAL SCIENCE

(*BOTANICAL SCIENCES STREAM*),

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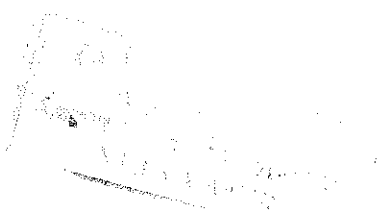

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DEDICATION

Dedicated to my late mother W/ro Birkinesh Awlachew who sacrificed all her resources for the benefit of her children

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Abstract

The Bale mountain range is located between the wet east African mountains (proper) and the dry northeast African mountains, Southeast Ethiopia. This mountain range hosts some of endemic flora and fauna which are endangered of extinction. The most extensive Ericaceous vegetation in the continent is found in Bale Mountains. The southern slope of this mountain range is known for its distinct vegetation zonation of the Afromontane forests. The Ericaceous vegetation between the montane forest and the afroalpine of this slope is relatively little disturbed than other similar Ericaceous vegetation elsewhere in Africa.

Study on the distribution and structure of this vegetation was made on the southern slope, Harrena escarpment. The vegetation north of Rira village, between 3000m and 4200m was sampled after selecting continuous homogenous sites systematically along the altitudinal gradient. Cover abundance of the species for vascular plants, frequency, height and DBH for woody treeline species were taken in 110 quadrats. The environmental parameters along the altitudinal gradient including soil pH, texture, total nitrogen, and soil moisture were measured. Altitude, slope, and aspect were measured for all qudrats. All the environmental and vegetation data were analyzed with Syntax, Canoco, Minitab and Sigma plot.

Thirteen community types were described and their distribution showed a clear pattern at different parts of the Ericaceous vegetation. However some of the community types which were restricted to the Afroalpine belt were found in the Ericaceous vegetation. This might be a possible indication of the expansion of the afroalpine belt to lower altitude, even below 3400 m (Erica dominated Hagenia-Hypericum zone).

The analysis of distribution of seven tree and shrub species showed that Schefflera volkensii was restricted to the lower part of the Ericaceous *vegetation (*Erica *dominated Hagenia-Hypericum zone)* and *H. revolutum, R. melanophloes and D. penninervium occur both at lower and central parts of the* Ericaceous *vegetation. E. trimera and E. arborea occur in all the three parts of the Ericaceous vegetation. The density of trees (proper) was higher at lower parts of the Ericaceous vegetation than the central part.*

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The height of the tree and shrub species has shown a decreasing tendency with increase in altitude. This trend was very gradual for E. trimera. The species occurs for about 1.2 km altitudinal range showing difference in height and habit along altitudinal gradient. The regression analysis (r^2=0.58) has shown a consistent decrease in height along altitude. No abrupt transition was documented in the systematically selected continuous Ericaceous vegetation.

Among the environmental parameters taken altitude was the strongest explanatory variable. Soil pH, and texture have shown stronger correlation with altitude. While percent total nitrogen was showing more significant ($p<0.01$) correlation with microsite factors.

E. trimera, as major constituent the vegetation under question showed a gradual transition in height and life-form.

1. INTRODUCTION

Scope of the Problem

Mountain ecosystems are known for their importance as a water source for the lowlands and source of biodiversity. They are characterized by their environmental extremities that are manifested by temperature, light and atmospheric pressure of which temperature stress is the most influential one. Accordingly, the organisms living in this fragile ecosystem have developed adaptive mechanism to cope up with these environmental extremities. Their adaptation mainly focuses on avoidance and tolerance of the stress due to the environmental extremities. Man also has adapted to live and exploit this environment. Mountain ecosystem comprises one-fifth of the earth land surface. But the physical and political remoteness of this ecosystem has created difficulty for the stakeholders to understand the balance between competing claims for protection versus sustainable uses. As a result mountain areas are ignored, or regarded as undifferentiated highlands. On the other hand, they are sensitive ecological zones still inhibited by large number of peoples (Barry, 1992). They are also strongly influenced by the surrounding lowland and urban areas with regard to timber production and water shade management.

As a result, the interaction between mountain communities and lower lying regions, cultural aspects of traditional relationships between people, forests, and forest values is becoming the top agenda of UN (Butt and Price, 1999). After the Rio-summit the sustainable use of this fragile ecosystem has drawn a worldwide attention. Agenda 21 (Chapter 13) approaches the problem from two angles. On the one hand, generating and strengthening knowledge about

the ecology and sustainable development for the world ecosystems and on the other hand the integrated watershed management and alternative livelihood opportunities have become global priorities. This challenge is expected to be more entertained in the year 2002 UN-International year of mountain (Butt and Price, 1999).

Most research work on mountain focused on commercial exploitation of timber and other resources. The value of mountains as a source for timber and other commercial products is incomparable to their importance as safe water supply to over half of the world population and biodiversity resource. This is true both in economic terms and conservation (Chapin & Whiteman, 1998). Nevertheless, the distinct patterns of vegetation of mountains had attracted the attention of many scholars for a century (Hedberg, 1964; Lovett, 1996). The change in high mountain is more conspicuous than the lower ones due to their unique environmental setting. High mountains are marked by the existence of treeline. The existence of later is the basis for using the term "high mountain" (Troll, 1973). It is the most striking vegetation boundary wherever the mountain rises to a sufficient height (Hermes 1950 cited in Korner, 1999). Since many facts are unproved and hypothetical, the opinions about tree/timberline are different. Moreover, the natural barriers of forests are expressed in different forms, despite their general similar trend.

Wardle (1971) defines timberline as the upper limit of forest (trees or shrubs about 2m height) on mountain. While Troll (1973) puts an altitudinal range between few meter above sea level (e.g. 1,600m North Scandinavia) to 4,500m in equatorial Cordilla of South America for using the above term "treeline". The altitude could also be as law as 420m in Finland (Tikkanen and

Heikkinen, 1995). A treeline is a labile combat zone, ecotone (*kampfzone*) where the protective forest encounters an open wind landscape and often used as indication of boundary. It is a discontinuity, between extreme harsh conditions and more moderate ones (Heikkinen *et al.*, 1995). But this definition is too narrow and restricted to the temperate climate. Autio (1995) and Korner (1999) have stressed on ambiguity and the vagueness of the terms that are used to express these boundaries. The former stress on the need for more expressive and clear term, while the later took treeline as middle term between timberline and tree species limit. Korner (1999) had suggested treeline as more appropriate term for the forest line. Similarly, Autio (1995) has attempted to explain the differences between treeline, forestline, timberline, and tree species limit schematically. According to Korner (1999) treeline marks a line connecting the highest patches of forest and the opening of the canopy and the decline of it gradually. It is a thermal stress transition in life-form dominance beyond which massive single stems and tall crowns either can not be developed, unaffordable or disadvantageous.

There are two wings of argument on this line. The first group argues that the forest may reach its upper limit as closed stand and ceases abruptly as sharp line against a tree-less alpine zone. It may also however, gradually dissolve from dense high stand to isolated tree and finally to stunted individuals (Wardle, 1971; Tranquillini, 1979). The gradual opening of the forest results from the worsening of the factor for the growth and survival with increase in altitude. So, isolated trees receive more heat and light ensuring a greater productivity than the closed stand. These isolated trees that are exposed to cold damage will show a stunted growth. Therefore, broad transition is a natural and primary condition (Tranquillini, 1979).

The other group argues if edaphic condition and topography allow, the forest continues as closed stand up to its final upper limit and form a sharp boundary. There is a clear contrast in microclimate between closed forest and the region outside the limit where trees are eliminated. The proponents of this theory take the broad transition as a secondary phenomenon (due to fire, grazing, cutting). The treelines that we have now are at lower site than have to be potentially (Mayer, 1976 cited in Tranquillini, 1979; Ellenberg, 1968 cited in Mattson, 1995). If the broad transition left undisturbed, the forest would began re-invading the upper part that will be accompanied by severe damage to the young trees due to cold. Eventually this secondary transition would be transformed to abrupt boundary.

Despite the two opposing views, all parties agree that trees are struggling to survive the extremities of the climate and microclimate in the zone with their different physiological and morphological adaptation. In both views the treeline depends on unfavorable heat balance with rising elevation. According to Gates (1980) temperature is an extremely important environmental variable to all life-forms. Because it is the measure of the energy status determined by energy exchange with environment. Consequently, it affects all life processes (Raven, 1986). The decrease in temperature with altitude is common to both temperate and tropical climate (Lovett, 1993). In the former, where seasonal variation of temperature dominates, growth is restricted to the vegetative period. In tropics growth inhibited by night frost. In addition the fluctuation of the temperature on diurnal basis which has a higher amplitude plays a crucial role (Daubenmire, 1957).

The possible explanation how this overriding factor affects the performance of the plants is hitherto unresolved issue. This could be due to lack of long term ecophysiological studies (Tranquillini, 1979) and remoteness of the mountain from metreological station from most alpine region (Grace & Russel, 1982; Barry, 1992; Barry & Chorley, 1992; Jones, 1993). Moreover, the meteorological stations do not reflect the microenvironment which is more important to plants. This observation was pioneered by Grieg, who had added a new dimension on high mountain research with his book, published in 1927,*"the climate near the ground"* (Grieg, 1959). The other reason is due to complex nature of temperature on life-forms. Temperature has a direct influence on numerous physiological processes such as germination, growth, photosynthesis, respiration and water transport (Daubenmire, 1957; Tranquillini, 1979; Larcher, 1980). Plants in both region are subjected to temperature stress (Levitt, 1972).

A July temperature of 10 °C is taken as a forest limit in most literature (Daubenmire, 1957; Heikkinnen *et al.,* 1995; Autio, 1995; Grace, 1990). Ohsawa (1990) took the temperature of the warmest month as in indicative of treeline. But, following global analysis on the secondary data Korner (1998), found the warmest temperature was less indicative of the treeline. Rather it overestimates the actual temperature during growing season. The warmest month temperature hypothesis was also criticized by Miehe & Miehe (1994) and Goldstein *et al.* (1994). Both authors have indicated that the treeline occurs at a temperature lower than 10 °C. Korner (1998) proposed the temperature of 5.5 - 7.5 ° C which is close to 7 °C soil temperature. In fact a soil temperature of 7 °C as a more reliable indicator of treeline has been hypothesized earlier (Walter & Medina 1969, cited in Walter, 1973). Soil temperature is more

important for plant growth (Skiba, 1995) by affecting the soil physical and chemical weathering (Smith, 1983), microbial activity (Gonzalez *et al.,* 2001), water movement (Ishikawa & Bledsoe, 2000)

The diurnal variation of temperature in tropical climate is found to be greater than the seasonal temperature which contrasted markedly with higher latitudes. Hedberg (1951) put a corner stone on the study of tropico-alpine ecology with his universally accepted and widely quoted expression of this environment: *" summer everyday and winter every night"*. A soil temperature of 5.9 - 7.3 °C was found to coincide to the treeline (Rundel, 1994; Miehe & Miehe, 1994) which is in agreement to 7 °C mean soil temperature (Walter and Medina, 1969 cited in Walter, 1973). But this data lacks long term micro-metreological information from tropical regions especially from tropical African mountains that are some times called "The Galapagos Island of Africa" (Kingdon, 1997).

Nevertheless, the functional explanation has been investigated both at higher and low latitudes (Gates, 1980; Larcher, 1980; Schulze, 1985; Grace, 1990; Goldstein *et al.*, 1994, Beck, 1994; Meinzer, *et al., 1994;* Rada *et al.*, 1996; Masresha Fetene *et al.*, 1997 & 1998). Korner (1999) hypothesized the growth limitation in relation with microclimate. Although he accepts the adaptation of carbon assimilating machinery to low temperature from his own investigation (Korner, *et al.* 1988), he criticize overlooking leaf photosynthesis. The trade-offs between potential carbon gain and allocation to un productive tissue to ensure mechanical support has earlier been discussed by Givinich (1986) and Raven (1986). Korner (1999) argues that tree life-form is limited at treeline altitudes by the possibilities for the investment

rather than by production of assimilates. In his strong critics on carbon assimilation he stated that "Dry matter production is generally poorly documented for treeline than leaf photosynthetic rate as fascination with electronic machinery than spades but, lacks any rationale". Because there is tremendous discrepancy between altitudinal trends in growth and the potential for photosynthesis.

Korner's functional approach and closer look in to the microclimate is widely accepted by many scholars. The functional explanation is based mainly on water relation and photosynthesis (Beck, 1994; Meinzer *et al.,* 1994; Masresha Fetene *et al.,* 1997 & 1998; Field & Brodribb, 2001; Rada *et al.,* 1996). But the argument lies in explaining this functional adaptation. There is a sharp contrast on the interpretation of the adaptation of life-forms to microclimate. Korner (1999) argues that tree life-form is disadvantageous on high mountains because the degree of stress is more sever in the free air than near the ground. However, ecophysiological investigation of the giant rosette tree-like life-form *Lobelia rhynchopetalum* in Bale mountains has shown that the plant escape the harsh diurnal fluctuation of environmental stress near the ground by having arborescent habit (Masresha Fetene, *et al.,* 1998). A similar observation has been made on Mt. Elgon (Wesche, 2000). In fact, Hedberg (1964) has made such an observation earlier. He had expressed the harsh environmental condition in the ground by asking " why a person need to have more blanket in the ground than above when camping in afroalpine environment".

The diurnal variation of the temperature and the hygric season was noted in most investigation of this environment (Smith, 1980; Goldstein *et al.,* 1994; Hedberg, 1964; Rundel, 1994).

However, this need to be further investigated parallel with the measurement of the thermal deficit, impact on the life processes in relation with the changing environment. Unfortunately, this ecophysiological approach in the investigation of treeline is very young (Tranquillini, 1979). Therefore, much is expected from such investigation in the tropical alpine region to resolve the treeline saga (Miehe pers.com.). Investigation of the structure and distribution of this vegetation in less disturbed (if there is any) tropical alpine environment is prerequisite for the ecophysiological assessment.

On the other hand, the treeline is a heterogeneous boundary both ecologically and taxonomically and thus different tree species constitute the boundary or the ecotone (Tranquillini, 1979). A number of trees or shrubs ascend the tree limit. The treeline species vary from place to place. The family *Pinaceae* is confined to Northern Hemisphere while the *Ericaceous* genera are common in treelines of tropical Africa (Hedberg, 1964; Wardle, 1971).

The treeline in most east Africa is marked by *Ericaceous* vegetation (Miehe & Miehe, 1994). The family *Ericaceae* is distributed throughout the world. The sub-family *Ericoideae* is restricted to Africa, the Mediterranean and northern Europe (Beentje, 1994). Revising works on the family *Ericaceae*, Miehe & Miehe (1994) has pointed the following three differences:

The main natural distribution of *Ericaceous* vegetation in the tropical Africa is altimontane although it is some times found as a secondary scrub. It occupies a broad transition belt beyond the climatic upper limit of the broad-leaved and coniferous montane trees and below alpine vegetation.

Secondly, unlike the extratropical heathlands, the *Ericaceous* vegetation occupies climatic rather than edaphic ecological niche. Since the soils of most east African mountains are young and volcanic, soil nutrients are not a limiting factor.

Third, the dominant *Ericaceous* species of tropical Africa are tall trees (up to 15 meter high) that could survive as old as 100 years, whereas it is low to medium sized shrubs with limited life span in Europe. A good example is *Calluna vulgaris.*

The most extensive type of this vegetation is found in Ethiopia. Ethiopia accounts for the fifty-five percent of the highlands of tropical Africa that cover 99.5 million hectare of land (FAO, 1978 cited in Daniel Gemechu, 1988). In fact, 3% of the land of the country is above 3000 m (Yalden, 1983) among which Arsi-Bale massive is the most notable one. The highest peaks of this massif are found in Bale mountain range in southeast Ethiopia that host a number of endemic flora and fauna (Mesfin Tadesse, 1991). This mountain range contain the most extensive *Ericaceous* vegetation in east Africa that suffered relatively little from destruction by man made fire (Hedberg, 1986; Miehe & Miehe, 1994).

Botanical expedition in the Bale mountains was reported in 1906 by Neuman & Ellenbeck (cited in Miehe & Miehe, 1994) followed by Smeds (1959), Mooney (1963) and Hedberg (1979). Studies on the florisic composition and physiognomy of the vegetation has been made by Mesfin Tadesse (1986), Friis (1986a & 1986b), Lisanework Negatu (1987), Uhlig

(1988). However, except Hedberg (1986), Friis (1986b), and Miehe & Miehe (1993 & 1994), most of the studies conducted in this mountain are confined to montane forest.

Friis (1986b) recognized the zone between 3200m and 3500m as the upper most forest zone based on its physiognomy. This vegetation zone is relatively little disturbed by human factor (Miehe & Miehe, 1994). The main constituent of this zone, *E. trimera* has a height of up to 15 meter. This vegetation has a considerable physiognomic difference with that of the upper elevation. Friis (1986b) account fire as the primary reason for the physiognomic change, and altitude as a possible factor.

More detailed account of the *Ericaceous* vegetation of Bale was given by Miehe & Miehe (1994) where they compared and contrasted their finding globally and regionally. The *Ericaceous* vegetation of Bale Mountains is about 1,200 km^2, which is 2.5 times the equivalent amount in Kenya. The significance of this figure should be considered in relation with the importance of this vegetation for the endemic mammals living in the Bale mountains. It harbors epiphytic communities that are crucial in hygric buffering between montane and afroalpine vegetation. The cryptograms also serve as bio-indicators of environmental conditions (Grandstien, 1996). This epiphytic moss gradually releases the amount moisture they absorbed. It is known that water as high as, 50, 000 litters was calculated for other east African cloud forest (Pocs, 1976).

According Daniel Gemechu (1988), the Ethiopian mountains can be divided in to north and south based on their relative position to 9 ° latitude. The Bale mountain range being located

at 6 ° N has an intermediate position between the East Africa proper and the drier northeast African mountains (e.g. Semien mountains). This makes the place an important site for making a continent-wide investigation on treeline. The southern mountains are more similar to the mountains of Uganda and Tanzania than Semien. Bale mountains are also a home for endemic and endangered species that include the largest proportion of the 400 remaining Semien foxes in the world (Sillerio-Zuberi & Gotteli, 1992).

Although the *Ericaceous* vegetation of Bale mountain is relatively less disturbed and more extensive than the other *Ericaceous* vegetation in east Africa, it is frequently cleared in search of grazing lands. As a result the afroalpine dwarf-shrub/herbaceous mixed communities have been expanding at the expense of *Ericaceous* population. The growing concern of the destruction of mountain ecosystems in one hand and the importance of this mountain as refuge for the endemic fauna and flora (Brown, 1973) on the other hand, urges conservation and maintenance of the study area.

Accordingly, any plausible conservation or management strategy needs prior ecological investigation of the area. A study on structure and distribution of the *Ericaceous* vegetation is expected to contribute on this line. Moreover, as Hillman (1986) and Miehe & Miehe (1994) emphasized the lack of data for giving possible explanation of the present pattern and potential of the *Ericaceous* vegetation. Many questions could arise in attempt to resolve this problem that include growth and regeneration, impact of fire and performance of the plant. A study on the structure and distribution of this vegetation is crucial in paving the way on this line.

In light of this purpose, the present study aims investigating of the distribution and the altitudinal change of the structure of the *Ericaceous* vegetation in relation to some environmental factors.

2. OBJECTIVES

General objectives

To document pattern of distribution of treeline species and the change in structure of the *Ericaceous* vegetation along the altitudinal gradient.

Specific objectives

- To determine the change in height and DBH of *E. trimera* and other treeline species along the altitudinal gradient,
- To investigate the trend of change in density and frequency of treeline species,
- To document the change in diversity of tree and shrub species along the altitudinal gradient
- To investigate the tendency of environmental factors in relation to the change in height and DBH of *E. trimera* and other treeline species

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study area is located in southern slope of the Bale mountain range, the Harrena Escarpment. In the lower part of this slope the change in altitude (between 1500 and 2800) is gradual and sharp at the upper part (above 2800). The *Ericaceous* vegetation is found stretched in the upper part of this slope. The area is known for its floral and faunal diversity as well as endemicity (Friis, 1986b; Hedberg, 1986; Hillman 1988; Lisanework Negatu and Mesfin Tadesse, 1986; Zerihun Woldu *et al.*, 1989; Minase Gashaw and Masresha, Fetene, 1996), in addition to its socioeconomic importance and value as a genetic reservoir. The present study was conducted north of Rira village 536 km from Addis Ababa which is between 6 ° 45' and & 7 ° N and 39 ° 45'and 39 ° 40' E (see map).

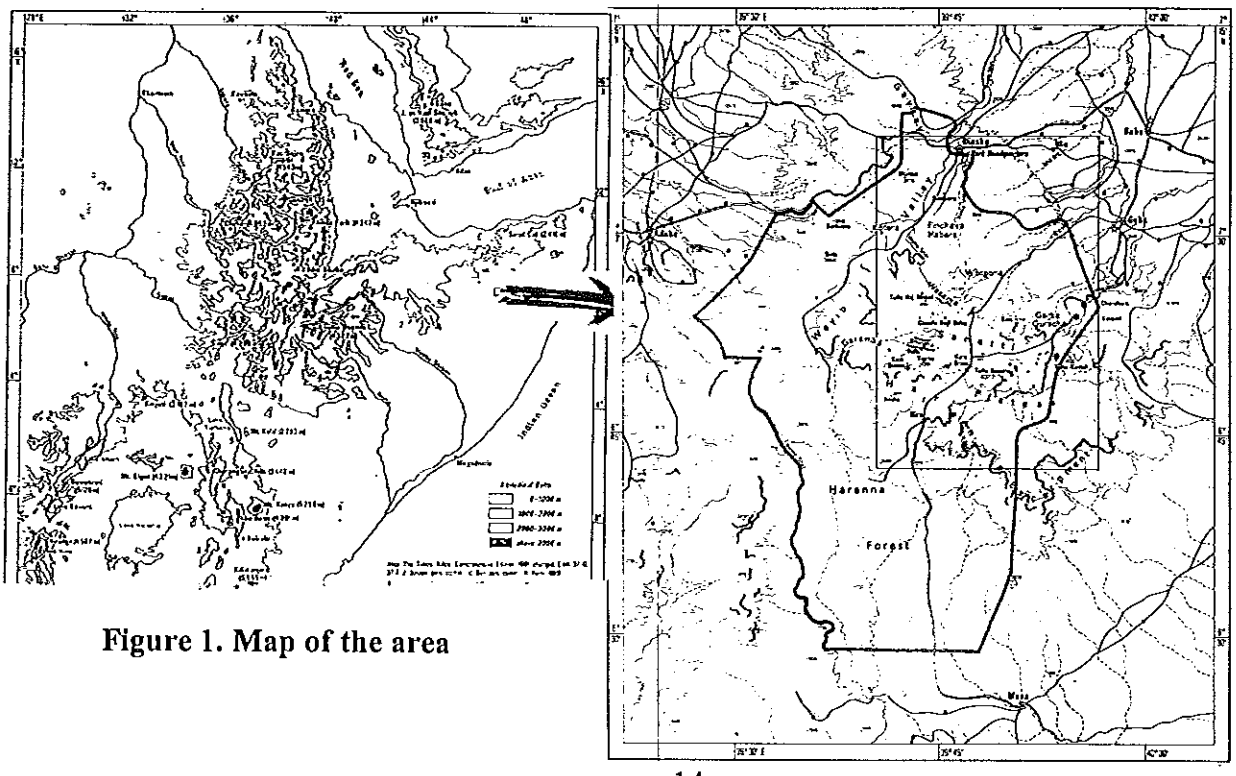


Figure 1. Map of the area

3.1.1. Climate

High mountain ecology largely focused on the interplay of climatic condition and vegetation, the climatic data of this region is still sparse (Hillman, 1986; Liljequest, 1986; Daniel Gemechu, 1988; Barry, 1992; Rundel, 1994; Wesche, 2000). In general the east African climatic domain borders the Congo basin in southwest and the Somalian desert in northeast. The Ethiopian climate is highly influenced by the position of ITCZ (INTER-TROPICAL CNVERGENCE ZONE) that separates the humid tropical air mass to south from the dry northeast. The main wind regimes that govern the climate of Bale mountains include north-easterly, south-easterly and south-east monsoon (Daniel Gemechu, 1977). The general trend is modified by altitude, topography and aspect. Therefore, the Bale mountains experience similar climatic conditions to the great lake region. The result of the interaction of these winds results a bi-modal rainfall (small and big rains).

The seasonality of the rainfall depends on the relative position of ITCZ. From December to February the ITCZ is located south of Ethiopia and northeast trade wind predominates in most of the country. In April the ITCZ moves towards the north and moist southeasterly wind prevail over eastern Ethiopia. This brings the small rains mainly to the southeastern and the eastern Ethiopian highlands. When ITCZ gained its north most position the moist southwest monsoon reaches the western part of the country and brings the long rains. Regions that are windward side to the moist southwest (e.g. some part of the Bale mountains) have a rainfall that strongly reflects the advection of the humidified air. Those areas that are sheltered from the southwest receive low rainfall. Dolo Mena is the extreme

example of rain shadowed station while Dinsho is the highest precipitation side. Therefore the small rains are actually big for some of the stations. The long rain stops abruptly as soon as the ITCZ crossed the Ethiopian highlands.

3.1.1.1. Rainfall

Eventhough the rainfall data in Bale mountain range in general and in the southern slope in particular is suffering from missing data, the available data indicate this mountain range belong to the highest rainfall regime. The area receives an average rainfall of 600-1500mm of rainfall per annum. But, there is 40% variability of the mean. The annual mean rainfall for Rira for the year 1987/88/89/90 as summarized by Miehe & Miehe (1994) was 848mm (Figure 2). Rira basin with exposed steep slope to advective winds and daily rise of convective clouds has unexpectedly low rainfall (less than 1000mm). Therefore, the amount mentioned under estimate the humid condition (Miehe & Miehe, 1994).

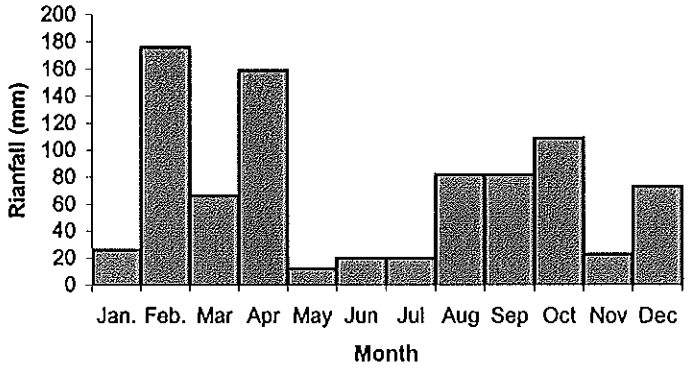


Figure 2. Annual mean precipitation of Rira for the year 1987/88/89/90 as presented by Miehe & Miehe (1994).

Unlike the temperate regions where rainfall increase in a predictable manner with elevation, precipitation in tropical African mountains reaches its peak in the middle and decrease steadily toward the peak (Rundel, 1994). Generally, annual rainfall in Bale mountain range increases with altitude up to certain altitude (Hillman 1986; Miehe & Miehe, 1994). For the northern slope the maximum rainfall is recorded at 3,850m. Though, EWCO (Ethiopian Wildlife conservation organization) has described the altitudinal gradient in northern slope, it is unfortunate that the altitudinal variation in Rira side is not well documented and the only rainfall stations are in Rira and Dolo Mena. The Harrena forest which is influenced by oceanic messoclimate and supporting Bamboo forest (Bamboo forest is found to occur in more humid areas with rainfall at least more than 1000mm) other luxuriant epiphytes and lianas could not be described with rainfall data from Mena (monomodal). The altitudinal variation in precipitation is shown in Figure 3.

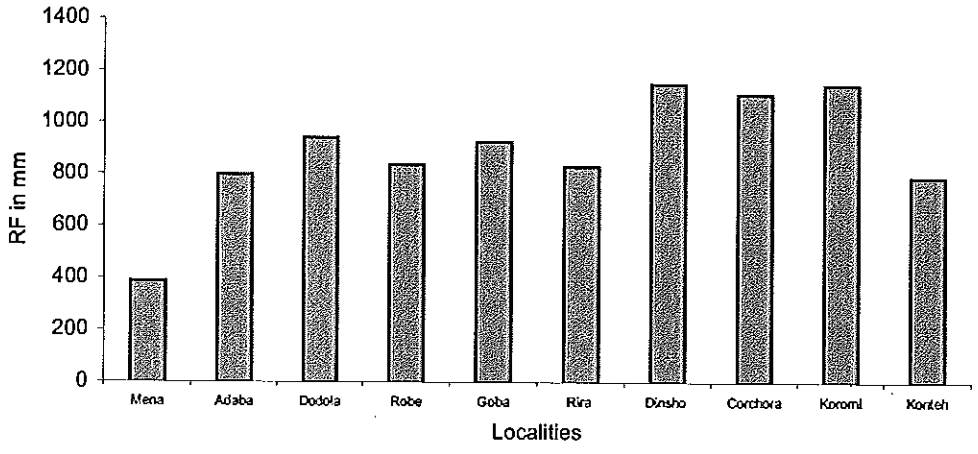


Figure 3. Altitudinal variation in precipitation (mm) for different meteorological station in Bale mountains. Source Hillman (1986).

As it is indicated in Figure 3, the lowest rainfall was recorded at the foot of southern slope, Dolo Mena and the highest at Dinsho at 3170. The rainfall increases with altitude up to 3000m and decreases gradually above 3100m. The rainfall above 3170m shows a gradual decrease between Dinsho and Koromi followed by a sharp drop between Koromi and Konteh. But, the only metreological stations that represent the southern slope are Dolo Mena and Rira.

3.1.1.2.Temperature:

As it is in all tropical mountains, the air temperature shows a higher diurnal variability than seasonal variation. The seasonal amplitude for the southern Ethiopia is found to be 2 °C (Liljequist, 1986). Most pronounced effect of this diurnal temperature variation occurs in dry seasons (mainly from November to February) (Miehe & Miehe, 1994). As it is mentioned in Hillman (1986) the season with low rainfall, low humidity exhibit high diurnal temperature variation. Because maximum temperatures are more strongly depressed during cloudy day than the minimum. This explains the smaller thermic amplitude during wet seasons. The seasonal contrast of thermic amplitude increases with altitude which is mainly due to more strong wind. Hillman (1986) has recorded a minimum temperature of -15°C in Weyib valley (3850m), while Miehe and Miehe (1994) has found nocturnal mimimum temperature of -3°c in the sparsely vegetated area.

This sub-zero temperature results in formation of frost. Frost in Rira has been reported by Mooney (Mooney, 1963). Hillman (1986) and Miehe & Miehe (1994) have also observed

needle ice formation in the sparsely vegetated places in the same area. Frost is expected to occur during clear nights of the year in open places of the *Ericaceous* belt. This implies solifluction (freezing and thawing of the soil) which is common in the afroalpine area is also observed in the upper parts of the *Ericaceous* vegetation. Frost in the open places of the *Ericaceous* belt is expected during all clear nights of year. So frost-induced substrate movement is seasonal phenomenon in the *Ericaceous* belt. It is highly pronounced during the first part of the long dry season where raw materials, low temperature and water are available (October-December). Because in the later season the soil become too dry and low temperature alone could not result in formation of needle ice. However, low temperature occurs only on the top part of the soil. A soil temperature of -12°c has been recorded at surface while it was -7° at 5 cm depth and it was only 0 °c at 15 cm (Miehe & Miehe, 1994).

Like the rainfall the temperature data for the *Ericaceous* vegetation is sparse. The only long-term data available is from Goba and Dinsho. The average temperature for Goba is 13.1 ° C whereas it is 11.8 ° C for Dinsho (see Figure 3). Temperature generally decreases with altitude linearly in the southern mountains. But the mean minimum temperature values are highly variable due to local microclimatic factors. The rate for this decrease in temperature is about 0.4 °C/100m (Daniel Gemechu, 1988). Miehe & Miehe (1994) has found this rate to be 0.63 ° C/100 between Goba (2800m) and Dinsho (3170m).

As it can be seen from the Figure the amplitude of the temperature is higher in dry season (December and January) and lower in wet season (April).

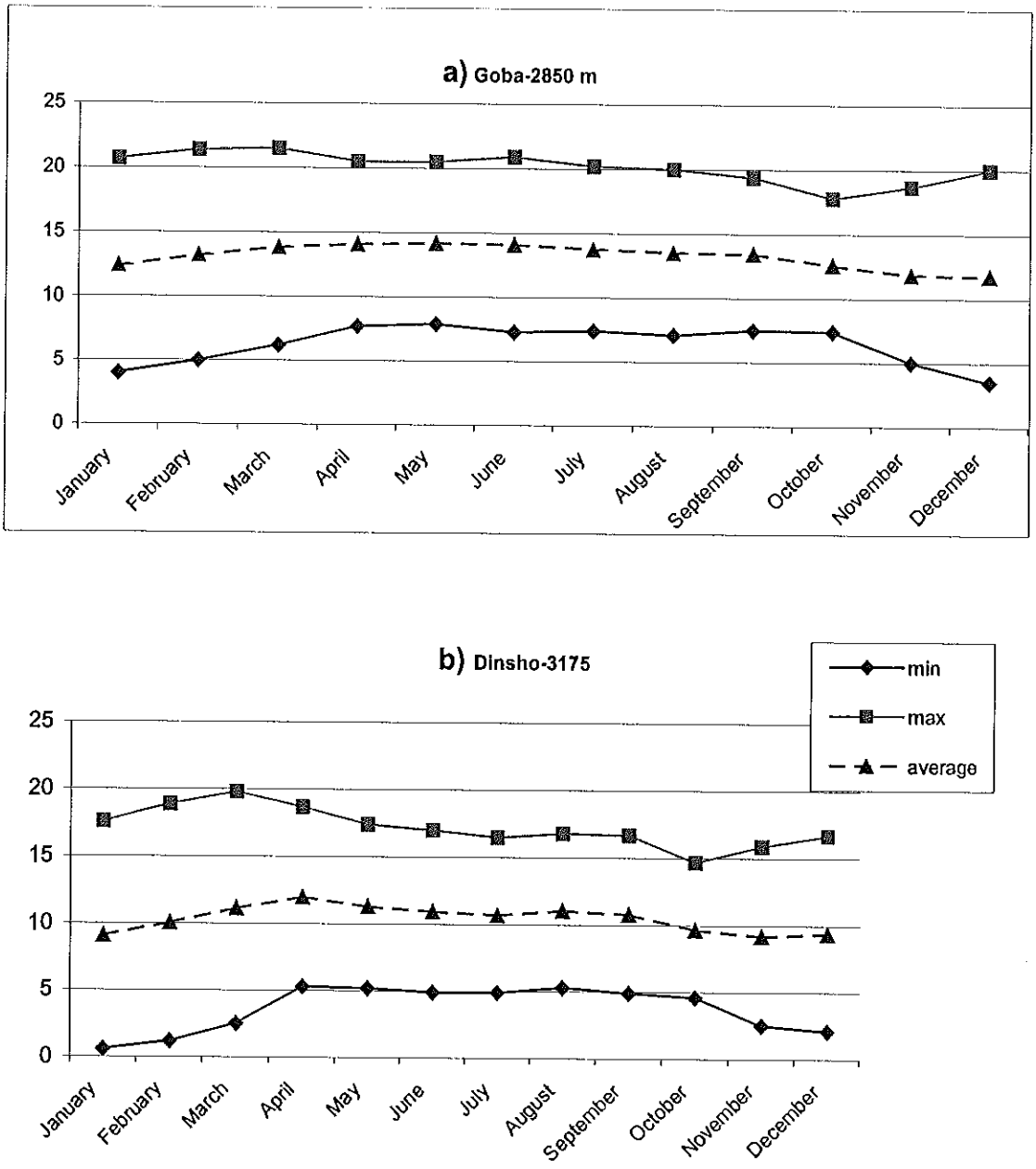


Figure 4 a, b. Altitudinal variation in minimum, maximum and average monthly temperature at Goba (a) and Dinsho (b) in Bale mountaius (modified from Hillman, 1986).

3.1.1.3. Humidity:

The southern slope of the mountain exposed to frequent mist and fog. This could be observed from luxuriant epiphytic mosses in the *Ericaceous* vegetation near Rira. The contrast in the humidity between the northern and southern slope two slopes is also reflected by the dominance of *Juniperus procera* a differential species of the drier forest which is absent in the southern slope. Relative humidity (RH) also shows diurnal variability like temperature. The minimum RH occurs around noon depending on the cloudiness of the sky and the maximum at dusk and down. It is higher in wet season and lower in dry seasons.

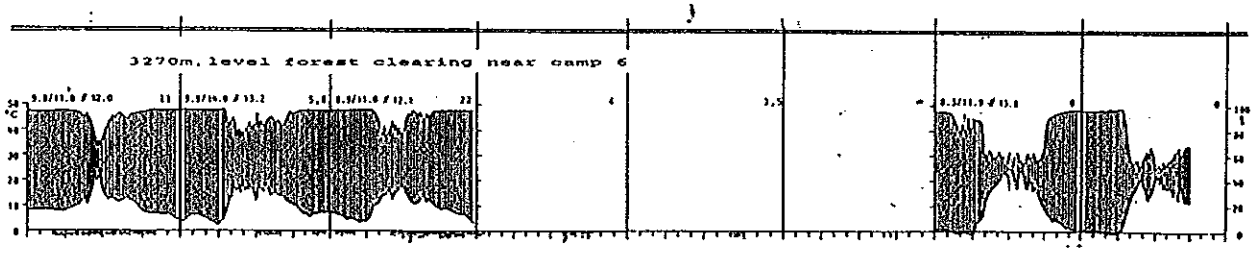


Figure 5. Diurnal variability of RH and temperature in Rira. Taken from (Miehe & Miehe, 1994).

3.1.2. Soil

The soil of Bale mountains has been described as young volcanic soils with no pronounced limitation of nutrients (Weinert and Mazurek, 1984).

3.1.3. Vegetation

The southern slope of Bale mountain range show a very distinct vegetation zonation due to its exposure to the oceanic southwest wind. The shelter from the dry northeast trade wind that affects the northern declivity, the connvective cloud coupled with significant variability of topography and altitude contribute to this end. This has made the place a natural laboratory for studying the vegetation zonation. The vegetation includes the montane and the afroalpine vegetation separated by the *Ericaceous* belt (*sensu* Hedberg, 1951). The montane forest is part of the Afromontane vegetation of Africa that occurs on isolated highlands and mountains stretching from Mt Cameroon in the west to the Ethiopian highlands in the east and to the highlands of South Africa to the south.

The montane forest of southern slope which is part of this vegetation lies between 1450 and 3200m was described by several authors including (Mooney, 1963; Mesfin Tadesse, 1986; Friis, 1986b; Lissanewerk, 1987; Uhlig, 1988; Zerihun *et al.,* 1989; Bussmann, 1997). These authors have described the altitudinal variation of vegetation in different ways.

The lower montane forest

At the bottom of Harrena escarpment (1,450m) the forest is composed of open *Combretum-Terminalia* woodland which is graded into lowest zone of the montane forest belt. The

high forest trees like *Aningeria adolfi-friederci* occur between the altitudinal range of 1650 to 1860m. Other trees like *Podocarpus falcatus* and *Olea capense* have a height of 32-36 (40) m. The stratification of this zone is reflected by its understorey shrubs like *Ocotea kenyensis, Mimusops kummel, Trema orientalis, Celtis africana, Diospyros abyssinica, Polysacias fulva* and *Croton macrostachyus.*

The wettest vegetation zone in the whole slope is found between 1850-2160m. This is reflected by the higher abundance of climbers and epiphytes. The height of the canopy attained here rich 38-40m. It is dominated by *Syzygium guineese.* The other emergent trees are *Podocarpus falcatus* and *Aningeria adolfi-friedericii.* The middle strata is occupied by *Ocotea kenyensis, Alophyllus abyssinica, Teclea nobilis, Vepris dainellii, Bersama abyssinica* and *Galineria saxifraga*

The upper montane

The upper montane forest zone that range between 2160-2700m is differentiated from the lower montane forest by its more openness that support more herbaceous vegetation. The dominant trees in this part include *Schefflera abyssinica,* and *Hagenia abyssinica, Dombeya torida, Prunus African* and *Erythrina abyssinica are also common.* A narrow belt of Bamboo is also found in this zone.

At about 2800 to 3200m altitude the treeline species *Hypericum revolutum, E. trimera* and *Erica arborea* dominate the vegetation. The complexity of the physiognomy, structure and the species richness is different at different vegetation belts. The vegetation transition is distinct.

Unlike the other east African mountains the transition to the *Ericaceous* belt in Harrena escarpment is gradual (Miehe & Miehe, 1994). *E. trimera* starts to appear in *Hagenia-Hypericum* zone between 2800 and 3200m. *Hagenia abyssinica* is an emergent tree in this zone. The lower limit of this zone is marked by the appearance of *Hypericum revolutum, Rapanea melanophloes and Pittosperum viridiflorum.*

Zonation scheme of the *Ericaceous* and the afroalpine vegetation is based on the vertical distribution of plant communities alone (Hedberg, 1951). Although Tewolde Berhan G.E. (1988) has classified the mountain vegetation in to montane and afroalpine, there is a third vegetation belt in between the two, the *Ericaceous* belt (Hedberg, 1964). The transition from the *Ericaceous* belt to afroalpine zone is gradual.

The *Ericaceous* belt can be divide into three zones. *Erica* dominated *Hagenia-Hypericum* zone where *E. trimera* occurs as tree with height of 10-15m. this zone lies between the altitudinal range of 3000-3400m. It is taken as sub-zone in the upper montane zone (Wesche, 2000) or a subalpine forest (Schmitt, 1991).

The next part of the *Ericaceous* vegetation is referred as transitional community. This community type reach up to 3600m. This part of the *Ericaceous* belt is poor in number of tree/shrub species. The only common associate of *E. trimera* in this part is *Discopodium peninervum.*

The central and the upper part of *Ericaceous* vegetation are noted for the dominance of monotonous secondary scrub. This vegetation become more patchy and could continue upto 4000m. The later dwarf secondary scrub, sometimes is mixed with afroalpine communities.

The afroalpine zone

This zone is found above continuous *Ericaceous* belt. After 4000m the *Ericaceous* vegetation gradually disintegrate in to 1.5 to 0.5m low solitary scrub. This lower limit is depressed in areas where human interference is higher. The afroalpine zone is open and richer in grass forming community. *Helichrysum* dwarf shrub is a dominant formation in the afroalpine zone. The giant rosette is also a commonly found. *H. citrispinum* replaces *H. splendidum* in a more drier and cooler sites. All the 5 life-forms of Hedberg (1951) giant rosettes, tussock grass, acaulescent rosette, cushion plant and sclerophyllous shrubs are common.

3.1.4. Fauna

The habitat diversity in Bale mountain range allows the area to host a large number of animals. According to Hillman (1986) there are at least 50 mammals, 180 birds and 14 amphibian species among which more than 20% of mammals and 8% birds and 78% of amphibians are endemic to the country. But later Hillman (1993) found that the number to be higher, 66 mammals and 262 bird species (30.4% of 861 species in Ethiopia). A systematized altitudinal zoological expedition to the southern slope has started lately (Afework Bekele, 1988). The Bale mountains serve both as a center of diversity and as hot spot of genetic diversity. According to Yalden (1983) 52.4% of mammals 60% of birds and 35 5% of frogs that are endemic to the country are found in Bale mountains. This accounts 23.85 of 277 mammal species recorded in Ethiopia (Hillman, 1993).

The closed *Ericaceous* vegetation provides a shelter for wild animals in addition to its preference for grazing by some wild animals such as Mountain Nyala. But the real density of the wild animals in the *Ericaceous* belt which is necessary for the analysis of habitat preference is lacking. Distribution of major large mammals in the *Ericaceous* vegetation is indicated in Table1.

Table 1. Larger herbivorous mammals in the Ericaceous zone of BMNP (Bale Mountains National Park).

English name	Occurrence (altitudinal range m)	Total Nº of estimates after Hillman (1986)
Mountain Nyala	3000-4200	1200-1400
Menlik's bush buck	2100-3410	c.340
Bohr Reedbuck	3000-3750	c.400
Grey duckier	3000-3750	c.230
Klipspringer	3450-4300	c.435
Olive baboon	3060-3900	c.400
Rock hyrax	2800-4300	several thousand
Stack'sHare	3100-4300	several thousand

3.1.4. Human Settlement:

The southern Ethiopia was found to be more drier 22,000-12,000 BP (before present) and become more humid after 10,000 BP (Mohammed *et al*, 1992). The earliest evidence of man in Bale was found in the Godeb plain in the upper Wabi-Sheble (Williams *et al.*,

few quaternary pollen analysis show no major vegetation change up to 1850 BP (Bonnefille, 1993; Bonnefille & Hamilton, 1986). Evidence from Mt. Bada indicates for the existence of agro-pastorialism 7000 years BP. But this has not been found in the *Ericaceous* zone. All the above evidences lead to the conclusion that strong clearance (if any) occurred after 1000 BP. The present settlers of Bale were animistic cattle breeders who were *Islamized* during the last few centuries. Pastoralism and honey gathering constitute the main traditional economy of this population (Mooney, 1963).

The *Ericaceous* and afroalpine areas are utilized by pastorals in search of pasture for their animals, and springs (Hora) in this area (plate 1). The highlands of Bale mountains are less densely populated than Semien. For example Barley was cultivated 600-800m lower than Simen. This is also due to the nomadic way of living.

The *Ericaceous* and the afroalpine areas serve as an important source of pasture especially when the herbaceous vegetation is dried up, mineral spring, *Hora* and a good ground for hunting Mountain Nyalas and small antelopes. These activities induce bush fire as an important weapon for hunting, clearing (for cattle track and grazing), and improvement of pasture and simulation of growing fresh grass. The extent to which the composition and dynamics of the *Ericaceous* vegetation is affected is not known. The effect of grazing is complex which is not only limited on biomass removal. It is related with soil water availability and light absorption efficiency (Leriche *et al.*, 2001).

3.2. Methods

3.2.1. Vegetation Data

The vegetation in the *Ericaceous* belt of the Bale Mountains was studied along altitudinal gradient ranging from 3000 to 4200m. Three transects were established systematically at different places. Along the three transect homogenous vegetation and a homogenous site was chosen based on the releve method of Braun-Blanquet (Mueller-Dombois & Ellenberg, 1974).

A total of 110 sample plots with size of 15m x 15m ($125m^2$) were sampled at every 20m distance between the quadrats. The effective qudrat size for the *Ericaceous* vegetation is found to be less than 100 m^2. It was even lower for non *Ericaceous* vegetation in the subalpine zone of Aberdere, Kenya (Schmitt, 1991). For each qudrat a sub-plot of 2m x 2m was made for the herbaceous vegetation. All vascular plant in each quadrats were identified and recorded. For all species the cover abundance was taken following the cover abundance scale of Braun Blanquet modified by Van der Maarel (Van der Maarel, 1979). According to this method the cover abundance value converted into 0-9 scale. The Plant materials that were difficult to identify in the field were collected for identification at the National Herbarium, Addis Ababa University (ETH). They were identified following flora books and comparison with herbarium specimen.

The height of trees and shrub species in all quadrats were registered. DBH, diameter at breast height for all treeline species (tree and shrubs) was also taken whenever it was applicable (When it possible to measure DBH at 1.3 m). For *E. trimera,* the diameter of the

main stem at one-meter height from the ground was taken when measurement of DBH was not applicable. This method have been utilized in Aberdere (Schmitt, 1991) Bale mountains, (Miehe & Miehe, 1994) and Mount Kenya (pers.com.). Frequency and density of all tree and shrub species was calculated for the three parts of *Ericaceous* vegetation.

3.2.2. Environmental Data

3.2.2.1.Climate and Microclimate

Diurnal course of RH and temperature was taken at two sites using Testo kit (microclimate measuring kit). One at the Erica dominated *Hagenia–Hypericum* zone (at 3400m near Toyu campsite) and the other at the upper most part of the *Ericaceous* vegetation at 3800m (Senattie plateau).

The rainfall data at Rira meteorological station was compiled together. In addition secondary data was taken from Hillman (1986) and Miehe & Miehe (1994). During the time of the fieldwork microclimate data for Senatie plateau was taken from Ethio-German field training group (March, 2000). Secondary data on climate and microclimate were also taken.

For each plot altitude was measured using Thomenen altimeter, slope measured using clinometer and aspect using compass. Aspect was codified using Lo Bue scale as mentioned in Zerihun *et al.* (1989) North=0, East=2.5, South=4.4, West=2.5. This scale is based on the total solar energy.

3.2.2.2. Soil

Soil samples were taken from each quadrat both from upper and lower layer (at depth of 30 cm from the surface). The samples were labeled and tagged and then transported for laboratory analysis to Ecology laboratory, Department of Biology, Addis Ababa University. The soil samples were used for analysis of soil moisture, texture, and pH and total nitrogen.

3.2.2.2. Soil moisture

To calculate percent moisture content, soil samples were weighed in the field at the time of collection. The samples then brought to the laboratory and air-dried in the greenhouse at temperature of 28 °C and RH of less than 30%. The soil samples were protected from UV rays with non-transparent plastic sheet.

Gravimetric method was used for moisture analysis. This method involves drying the soil until a constant weight is obtained (Jackson, 1973). Since the wet samples were measured in the field the dried weight was measured after a constant weight was obtained. The water content is obtained by dividing the difference between wet and dry mass by wet mass and multiplying this value by 100 gives percent soil moisture.

Mathematically,

$$\% \text{ Soil moisture} = \frac{\text{Field weight} - \text{Dried weight}}{\text{Field weight}} \times 100\%$$

3.2.2.3. Soil pH

Soil pH was determined following Juo (1978). A 1:1 soil suspension in water was made by dissolving 20g of soil that has passed through 20mm sieve with 20ml of distilled water. The suspension was stirred with glass rode and allowed to settle for 30minutes. The pH was measured using Beckman Chemmate pH meter.

3.2.2.4. Total Nitrogen

Total Nitrogen was determined using the macrokjeldahl method. The analysis of soil nitrogen requires a complete break down of the organic nitrogen (digestion), followed by distillation and titration. In the process of digestion organic nitrogen was converted into ammonium nitrogen. Nitrogen was estimated then from the amount of ammonia liberated by distillation of the digest with alkali.

The whole reaction can be summarized as follows:

Digestion: Organic Nitrogen + H_2SO_4 $\underset{CuSO_4}{K_2SO_4}$ $\rightarrow$ $(NH_4)_{2SO4}$ $+H_2O$

Distillation: $2(NH_4)_2SO_4 + 4NaOH \rightarrow 2NaSO_4 + 4NH_3 + 4H_2O$

$NH_3 + H_3BO_3 \rightarrow NH_4\,H_2BO_3$

Titration: $NH_4H_2BO_3 + HCl \rightarrow NH_4\,Cl + H_3BO_3$

The procedure starts by taking one gram of air-dried soil that has passed through 0.5mm sieve. It was placed in a dry 500ml kjeldahl flask, mixed with 7 g of potassium sulfate and

0.8g copper sulfate to catalyze the reaction and 12ml of concentrated sulfuric acid was added to it. The digestion flasks were then put to the digestion system which was preheated (420°c). Samples were allowed to be digested for about one hour until all the samples become clear with green color. After the racks of the tubes were cooled for 15 minutes, 75ml of distilled water was added into the tube. In a conical flask 25ml of receiver solution was added and the flask placed into the distillation unit. In the distillation unit 50ml of 40% sodium hydroxide was dispensed and distillation allowed to go for about 4 minutes until the receiver solution in the distillate flask become green in color indicating the presence of an alkali ammonia. The distillate was then titirated with standardized 0.1N HCl until the blue gray end point was reached. A blank titration was carried out with the same procedures.

The percentage of total nitrogen was then calculated as follows:

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

Where T = titration volume for sample

B= titration volume for blank

N= normality of acid

3.2.2.5. Hydrometer Method of Mechanical Analysis

As a more stable unit constituting the soil solid, soil particle is little affected by cultivation or any other practices. One method of analyzing these particles is mechanical analysis of the

soil texture. Knowledge of this attribute helps to characterize the structural condition, water retention and transmission, erodability and workability of the soil. In addition it also used in estimation of the ion adsorption behavior of the soil (Anderson and Ingerman, 1993).

The most common and the cheapest method of mechanical analysis is hydrometer method. The whole process involves dispersing the soil mechanically and chemically and then allowing it to settle. The method employ principle's of Stock's law for determination of particle size. It state that in homogenized soil the velocity of the particle to the bottom of container is directly proportional to particle size and the characteristics of the suspending medium (Chopra & Kanwar, 1982; Jou, 1978).

Fifty-one grams of 2mm sieved dried sample was added to 50ml of 5% sodium hexametaphosphate along with 100ml distilled water. The suspension was stirred for mixing with glass rode and then allowed to stand for 30 minutes. The soil suspension was stirred using a mutlti-mix machine for 15 minutes, then transferred into a one liter glass cylinder. The suspension was diluted with distilled water up to a one-liter mark. The soil suspension was mixed by covering the mouth of cylinder, by hand and inverting several times. Hydrometer and temperature readings were taken at the 40 seconds and after 3 hours. The different soil fractions were calculated as follows:

1. % SAND = 100 [H_1 - 0.2 (T_1 - 68)-]2

2. % CLAY = H_2– [0.2 (T_2 - 68) -2]2

3. % SILT = 100 - (%SAND + % CLAY)

Where H_1 is the first hydrometer reading after 40 seconds

T_1= the temperature reading after 40 seconds

H_2= the hydrometer reading after 3 hours and

T_2 =the temperature reading after 3 hours

3.2.2.5. Additional Information

The importance of fire as limiting factor in the alpine and subalpine zone is discussed by several authors (e.g. Hedberg, 1964; Friis, 1992; Wesche, 2000). Observation was made for the presence or absence of *Bryum argentinum,* charcoal, remnant of burnt twigs/lignotubers in all quadrats. And the following remarks were made: 0= Total absence, 1 = the presence of one, 2=for presence of two, 3=for the presence of three of the indicators. The purpose is to observe the presence of fire evidence. However, this doesn't indicate the intensity and history of fire.

3.2.2.6. Data Analysis

Vegetation data were subjected to SYN-Tax programme NCLAS- Hierarchical clustering by distance optimization (Podani 1988). Cover abundance values were used to classify vegetation data. In classifying the community types the subjects group average, product moment correlation and squared distance/dissimilarities were used to depict the degree of dissimilarities among the different quadrats. The classifications begins with whole stands and then sub-divided to end up with ultimate classes. Different clusters then were arranged

hierarchically. Sigma plot version 4.1 and Minitab Statistical Software also used in analysis of environmental variables.

Both the vegetation data and the environmental variables were also treated using Canonical Correspondence Analysis (CCA) using the program CANOCO (ter Braak, 1995) to get the ordination of vegetation data, and environmental variables.

Species richness and relative abundance were measured using the Shannon-Wiener index of diversity (Magurran, 1991).

$$H' = -\sum_{i=1}^{k} Pi \ln Pi$$

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

pi= the proportional abundance of the i^{th} species = (ni/N)

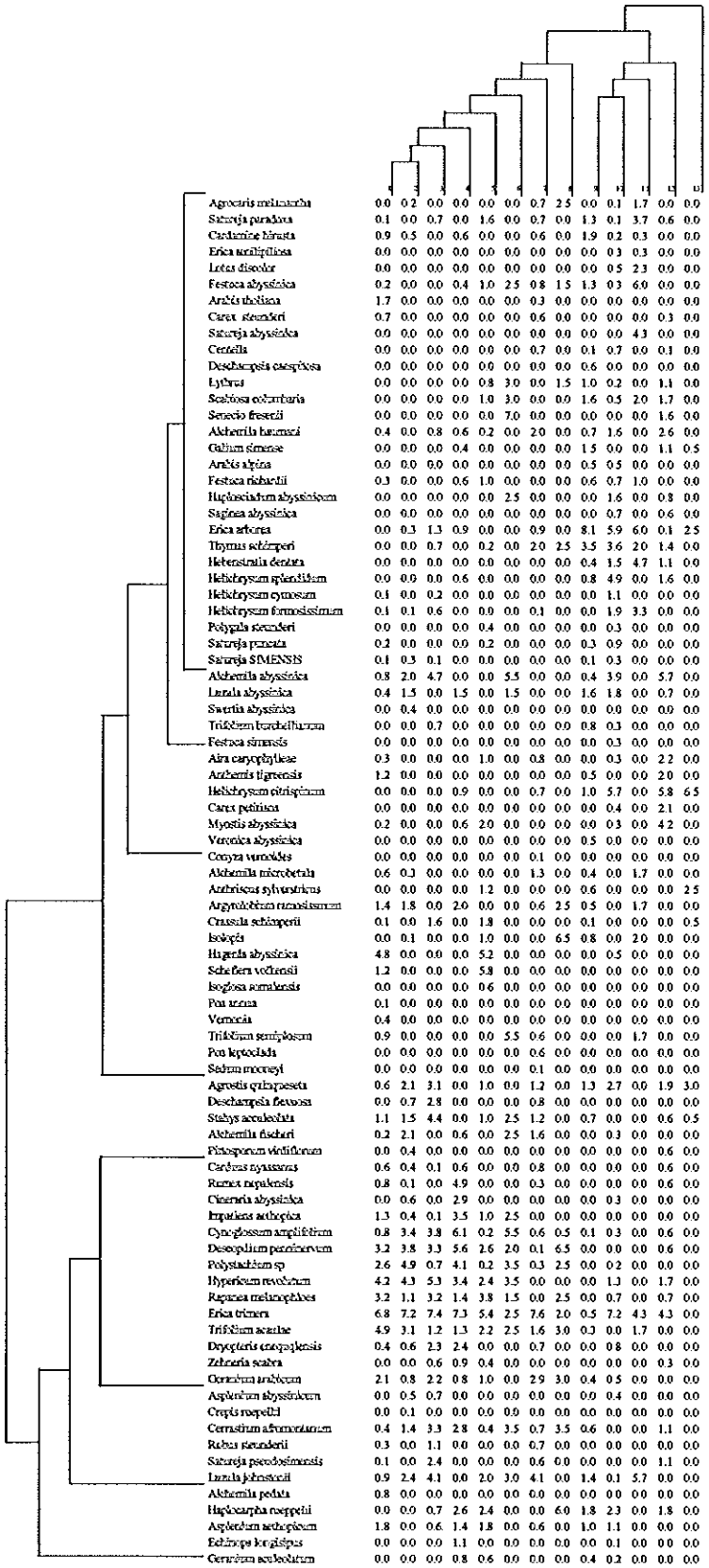
4. RESULT

In the 110 quadrats a total of 84 vascular plants were identified. Out of the 84 species that were found between 3000 and 4200m a.s.l. eight were tree and shrubs and the rest were herbs. Complete lists of the plants are shown on Appendix 1. The result is discussed by dividing the *Ericaceous* vegetation into three altitudinal category. The lower part, which lies between 3000-3400m, the central which lies between 3400-3600 m, and the upper part between 3600-4200m. This altitudinal categories agree with previous works. For example the lower part is often referred as *Erica* dominated *Hagenia-Hypericum* zone (Hedberg, 1964; Miehe & Miehe, 1994). Whenever upper, lower and central parts mentioned in the following parts, it refers the above altitudinal categories.

4.1. Description of Plant Community Types

A total of 13 community types were identified from the analysis of clustered stands at a dissimilarity level range of 0.3 to 0.7 which was based on cover / abundance value of the 84 species. The classification scheme and the complete list of the community types are indicated in synoptic Table (Table 3) and their altitudinal distribution of the community types the *Ericaceous* vegetation are summarized in Table 2. Naming of the community types was done based on the characteristic species that has the highest cover abundance value.

Table 3 Synoptic table for the 13 plant communities.



	1	2	3	4	5	6	7	8	9	10	11	12	13
Agrocaris melanantha	0.0	0.2	0.0	0.0	0.0	0.0	0.7	2.5	0.0	0.1	1.7	0.9	0.0
Satureja paradoxa	0.1	0.0	0.7	0.0	1.6	0.0	0.7	0.0	1.3	0.1	3.7	0.6	0.0
Cardamine hirsuta	0.9	0.5	0.0	0.6	0.0	0.0	0.6	0.0	1.9	0.2	0.3	0.0	0.0
Erica arnbiflilosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0
Lotus discolor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.3	0.0	0.0
Festuca abyssinica	0.2	0.0	0.0	0.4	1.0	2.5	0.8	1.5	1.3	0.3	6.0	0.0	0.0
Arabis thaliana	1.7	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Carex stenodori	0.7	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.3	0.0
Satureja abyssinica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0
Centella	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.1	0.7	0.0	0.1	0.0
Deschampsia caespitosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
Lythrus	0.0	0.0	0.0	0.0	0.8	3.0	0.0	1.5	1.0	0.2	0.0	1.1	0.0
Scabiosa columbaria	0.0	0.0	0.0	0.0	1.0	3.0	0.0	0.0	1.6	0.5	2.0	1.7	0.0
Senecio fresenii	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0
Alchemilla haumei	0.4	0.0	0.8	0.6	0.2	0.0	2.0	0.0	0.7	1.6	0.0	2.6	0.0
Galium simense	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	1.5	0.0	0.0	1.1	0.5
Arabis alpina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0
Festuca richardii	0.3	0.0	0.0	0.6	1.0	0.0	0.0	0.0	0.6	0.7	1.0	0.0	0.0
Hupleurum abyssinicum	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	1.6	0.0	0.8	0.0
Sagina abyssinica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.6	0.0
Erica arborea	0.0	0.3	1.3	0.9	0.0	0.0	0.9	0.0	8.1	5.9	6.0	0.1	2.5
Thymus schimperi	0.0	0.0	0.7	0.0	0.2	0.0	2.0	2.5	3.5	3.6	2.0	1.4	0.0
Hebenstreitia dentata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.5	4.7	1.1	0.0
Helichrysum splendidum	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.8	4.9	0.0	1.6	0.0
Helichrysum cymosum	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Helichrysum formosissimum	0.1	0.1	0.6	0.0	0.0	0.0	0.1	0.0	0.0	1.9	3.3	0.0	0.0
Polygala stenodori	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Satureja punctata	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.9	0.0	0.0	0.0
Satureja SIMENSIS	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0
Alchemilla abyssinica	0.8	2.0	4.7	0.0	0.0	5.5	0.0	0.0	0.4	3.9	0.0	5.7	0.0
Lamala abyssinica	0.4	1.5	0.0	1.5	0.0	1.5	0.0	0.0	1.6	1.8	0.0	0.7	0.0
Swertia abyssinica	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trifolium burchellianum	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.0	0.0	0.0
Festuca simensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Aira caryophyllea	0.3	0.0	0.0	0.0	1.0	0.0	0.8	0.0	0.0	0.3	0.0	2.2	0.0
Anthemis tigreensis	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	2.0	0.0
Helichrysum citrispicum	0.0	0.0	0.0	0.9	0.0	0.0	0.7	0.0	1.0	5.7	0.0	5.8	6.5
Carex petitiana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.1	0.0
Myosotis abyssinica	0.2	0.0	0.0	0.6	2.0	0.0	0.0	0.0	0.0	0.3	0.0	4.2	0.0
Veronica abyssinica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Conyza variolata	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Alchemilla microbetala	0.6	0.1	0.0	0.0	0.0	0.0	1.3	0.0	0.4	0.0	1.7	0.0	0.0
Anthriscus sylvestrinus	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.6	0.0	0.0	0.0	2.5
Argyrobolium rueppelianum	1.4	1.8	0.0	2.0	0.0	0.0	0.6	2.5	0.5	0.0	1.7	0.0	0.0
Crassula schimperii	0.1	0.0	1.6	0.0	1.8	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.5
Isoloma	0.0	0.1	0.0	0.0	1.0	0.0	0.0	6.5	0.8	0.0	2.0	0.0	0.0
Hagenia abyssinica	4.8	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Schefflera volkensii	1.2	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isoglossa somalensis	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poa annua	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vernonia	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trifolium semipilosum	0.9	0.0	0.0	0.0	0.0	5.5	0.6	0.0	0.0	0.0	1.7	0.0	0.0
Poa leptoclada	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Sedum mooneyi	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Agrostis quinqueseta	0.6	2.1	3.1	0.0	1.0	0.0	1.2	0.0	1.3	2.7	0.0	1.9	3.0
Deschampsia flexuosa	0.0	0.7	2.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Stelys acuelolata	1.1	1.5	4.4	0.0	1.0	2.5	1.2	0.0	0.7	0.0	0.0	0.6	0.5
Alchemilla fischeri	0.2	2.1	0.0	0.6	0.0	2.5	1.6	0.0	0.0	0.3	0.0	0.0	0.0
Pittosporum viridiflorum	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Carduus nyassanus	0.6	0.4	0.1	0.6	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.6	0.0
Rumex nepalensis	0.8	0.1	0.0	4.9	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.6	0.0
Cineraria abyssinica	0.0	0.6	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Impatiens aethopica	1.3	0.4	0.1	3.5	1.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cynoglossum amplifolium	0.8	3.4	3.8	6.1	0.2	5.5	0.6	0.5	0.1	0.3	0.0	0.6	0.0
Desmodium pernicervum	3.2	3.8	3.3	5.6	2.6	2.0	0.1	6.5	0.0	0.0	0.0	0.6	0.0
Polystachium sp	2.6	4.9	0.7	4.1	0.2	3.5	0.3	2.5	0.0	0.2	0.0	0.0	0.0
Hypericum revolutum	4.2	4.3	5.3	3.4	2.4	3.5	0.0	0.0	0.0	1.3	0.0	1.7	0.0
Rapanea melanophloes	3.2	1.1	3.2	1.4	3.8	1.5	0.0	2.5	0.0	0.7	0.0	0.7	0.0
Erica trimera	6.8	7.2	7.4	7.3	5.4	2.5	7.6	2.0	0.5	7.2	4.3	4.3	0.0
Trifolium acaule	4.9	3.1	1.2	1.3	2.2	2.5	1.6	3.0	0.3	0.0	1.7	0.0	0.0
Dryopteris cinropajensis	0.4	0.6	2.3	2.4	0.0	0.0	0.7	0.0	0.0	0.8	0.0	0.0	0.0
Zehneria scabra	0.0	0.0	0.6	0.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Cornicina arabicum	2.1	0.8	2.2	0.8	1.0	0.0	2.9	3.0	0.4	0.5	0.0	0.0	0.0
Asplenium abyssinicum	0.0	0.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Crepis rueppellii	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cerastium afromontanum	0.4	1.4	3.3	2.8	0.4	3.5	0.7	3.5	0.6	0.0	0.0	1.1	0.0
Rubus stenodorii	0.3	0.0	1.1	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Satureja pseudosimensis	0.1	0.0	2.4	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	1.1	0.0
Lamala johnstonii	0.9	2.4	4.1	0.0	2.0	3.0	4.1	0.0	1.4	0.1	5.7	0.0	0.0
Alchemilla pedata	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haplocarpha rueppelii	0.0	0.0	0.7	2.6	2.4	0.0	0.0	6.0	1.8	2.3	0.0	1.8	0.0
Asplenium aethiopicum	1.8	0.0	0.6	1.4	1.8	0.0	0.6	0.0	1.0	1.1	0.0	0.0	0.0
Echinops longisepus	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Cerastium scaberulum	0.0	0.0	0.0	0.8	0.6	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.0

Table 3 The distribution of community types at the lower, central and upper part of the *Ericaceous* vegetation . (+ indicate presence and – absence.)

N^0	COMMUNITY TYPE	LOWER 3000-3400 m	CENTRAL 3400-3600 m	UPPER 3900-4200 m
1	*Erica trimera-Hagenia abyssinica-Hypericum revolutum*	+	+	-
2	*Erica trimera -Polystichum fuscopalaceum.-Hypericum revolutum*	+	+	-
3	*Erica trimera-Hypericum revolutum -Alchemilla abyssinica*	+	+	-
4	*Erica trimera-Cynoglossum amplifolium-Discopodium penninervium*	-	+	-
5	*Schefflera volkensii -Erica trimera-Hagenia abyssinica*	+	-	-
6	*Senecio fresenii-Alchemilla abyssinica-Trifolium semipilosum*	+	+	-
7	*Erica trimera -Luzula johnstonii-Geranium arabicum*	+	+	-
8	*Discopodium penninervium.- Isoelpis setaceae- Haplocarpha rueppelli*	+	-	-
9	*Erica arborea-Thymus schimperi-Cardamine hirusta*	+	+	+
10	*Erica trimera -Erica arborea-Helichrysum citrispinum*	+	+	+
11	*Festuca abyssinica –Hebenstretia dentata-Satureja abyssinica*	-	+	+
12	*Helichrysum citrispinum –Alchemilla abyssinica-Erica trimera*	-	+	-
13	*Helichrysum citrispinum –Agrostis quinqueseta-Erica arborea*	-	-	+

Table 3 The distribution of community types at the lower, central and upper part of the *Ericaceous* vegetation .(+ indicate presence and – absence.).

N^0	COMMUNITY TYPE	LOWER 3000-3400 m	CENTRAL 3400-3600 m	UPPER 3900-4200 m
1	*Erica trimera-Hagenia abyssinica-Hypericum revolutum*	+	+	-
2	*Erica trimera -Polystichum fuscopalaceum.-Hypericum revolutum*	+	+	-
3	*Erica trimera-Hypericum revolutum -Alchemilla abyssinica*	+	+	-
4	*Erica trimera-Cynoglossum amplifolium-Discopodium penninervium*	-	+	-
5	*Schefflera volkensii -Erica trimera-Hagenia abyssinica*	+	-	-
6	*Senecio fresenii-Alchemilla abyssinica-Trifolium semipilosum*	+	+	-
7	*Erica trimera -Luzula johnstonii-Geranium arabicum*	+	+	-
8	*Discopodium penninervium.- Isoelpis setaceae- Haplocarpha rueppelli*	+	-	-
9	*Erica arborea-Thymus schimperi-Cardamine hirusta*	+	+	+
10	*Erica trimera -Erica arborea-Helichrysum citrispinum*	+	+	+
11	*Festuca abyssinica –Hebenstretia dentata-Satureja abyssinica*	-	+	+
12	*Helichrysum citrispinum –Alchemilla abyssinica-Erica trimera*	-	+	-
13	*Helichrysum citrispinum –Agrostis quinqueseta-Erica arborea*	-	-	+

1. *Erica trimera.- Hagenia abyssinica - Hypericum revolutum* type

This community type is found between 3000m and 3400m except two stands at 3740, which are found near boulder rocks. This community type occurs in moderate environmental conditions. The relatively high percent total nitrogen could be due to the large broad-leaved species that contribute to the organic form of nitrogen. The characteristic species for this community type are *Erica trimera, Hagenia abyssinica, Hypericum revolutum, Trifolium acaulae,* and *Discopodium penninervium.* At lower altitude, between 3000 and 3200m this community type form a sub-community which is characterized by the association of *H. abyssinica* and *H. revolutum.* This community type is the most stratified and diversified. The species richness is higher both in terms of tree and herbaceous species with Shannon-Wiener 3.23.

2. *Erica trimera -Polystichum fuscopalaceum.-Hypericum revolutum* type

Although this community type occurs between 3200m and 3500m, it is most common in the lower part of the *Ericaceous* vegetation, especially between 3300m and 3400m. It occurs in a moderate soil condition. The characteristic species include *Erica trimera,* the co-dominant tree *Hypericum revolutum,* the most common herbaceous species *Polystichum fuscopalaceum Discopodium penninervium,* and *Cynoglossum amplifolium* Shannon-Wiener diversity index was 3.1.

3. *Erica trimera - Hypericum revolutum -Alchemilla abyssinica* -type

This community type is found more frequently at the central part of the *Ericaceous* vegetation although it occurs also at the lower part of the *Ericaceous* vegetation. The altitudinal range is between 3380-3490m. This community type is found in a more steeper slope. The characteristic species include *Erica trimera, H. revolutum, Alchemilla abyssinica, Stachys acauleolata,* and *Luzula johnstonii.* The dominance of *E trimera* is conspicuous in the upper layer of the canopy. Shannon-Wiener diversity index was 3.1.

4. *Erica trimera-Cynoglossum amplifolium- Discopodium penninervium* type

It is more common in the central part of the *Ericaceous* vegetation. The altitudinal range is from 3350-3450m. This could be due to the hygric buffering of the cryptogamic species which are found both on the ground and on the branch and stems of *E. trimera. E. trimera, Cynoglossum amplifolium, Discopodium penninervium, Rumex natalensis* and *Polystichum fuscopalaceum* are characteristic species. Monotonous *E. trimera* dominates the tree layer. The shrub which is more frequently associated with *E. trimera* is *Discopodium penninervium.* The more crooked and twisted habit of this tree coupled with more humid condition make this community type more hospitable to mosses. The diversity index is 3.1

5. *Schefflera volkensii -Erica trimera-Hagenia abyssinica* type

This community type is confined to the lower part of the *Ericaceous* vegetation. It has a limited occurrence between 3100 and 3300m. The characteristic species are *Schefflera volkensii; Erica trimera Hagenia abyssinica, Rapnea melanophloes,* and *Discopodium penninervium* are the characteristic species. The emergent tree in this community type is *Schefflera volkensii* has more erect appearance than any of its companions. *Schefflera*

volkensii has a very limited distribution next to *Pittosporum viridiflorum* which is the rarest in all stands. In fact *P. viridiflorum* was found only in one spot. Shannon-Wiener diversity index was 3.2.

6. *Senecio fresenii-Alchemilla abyssinica-Trifolium semipilosum* type

It is found both in the lower and central part of the *Ericaceous* vegetation between 3100 and 3450m. This community type is characterized by *Senecio fresenii, Alchemilla abyssinica, Cynoglossum amplifolium, Trifolium semipilosum* and *Cerrastium afromontanum* are the characteristic species. The diversity index, Shannon was 2.9.

7. *Erica trimera -Luzula johnstonii- Geranium arabicum* type

The altitudinal range for this community type is between 3310 to 3560m. *Erica trimera, Luzula johnstonii, Geranium arabicum, Alchemilla haumanni,* and *Thymus schimperi* are the characteristic species. It is dominated by *Luzula johnstonii.* This species sometimes form a small patches exclusively dominated by *Luzula johnstonii* under the shade of *E. trimera*. Shannon-Wiener diversity index was 3.1.

8. *Discopodium penninervium-Isoelpis setaceae- Haplocarpha rueppelli* type

This community type is represented only by two stands (at 3300 and 3320 m). It occurs in an almost level ground. The characteristic species include *Discopodium penninervium, Isoelpis setaceae, Haplocarpha rueppelli, Cerrastium afromontanum* and *Trifolium acaulae.* Shannon-Wiener diversity index was 2.6.

9. ***Erica arborea-Thymus schimperi-Cardamine hirusta*** **type**

This community type occurs in a wide altitudinal range, from 3300m to 3900m. The percent soil moisture also varies accordingly. *Erica arborea, Thymus schimperi, Cardamine hirusta, Haplocarpha rueppelli* and *Scabiosa culumbaria* are the characteristic species. *Haplocarpha rueppelli,* member of the acaulescent rosette plant, has a special adaptation. The lower part of the leaf is covered by a dense whitish indumentum. Shannon-Wiener diversity index was 3.1.

10. ***Erica trimera -Erica arborea –Helichrysum citrispinum*** **type**

It occurs almost in all part of the *Ericaceous* vegetation. At the upper part of the *Ericaceous* vegetation, it forms a patch of vegetation near the rock boulders. It is also common in fire affected area. The characteristic species are *Erica trimera, Erica arborea, Helichrysum citrispinum, Helichrysum splendidum* and *Alchemilla abyssinica.* Shannon was 3.3.

11. ***Festuca abyssinica–Hebenstretia dentata-Satureja abyssinica*** **type**

This community type occurs in the central part of *Ericaceous* vegetation. It occurs on steepy slope including rock boulders. *Festuca abyssinica, Hebenstretia dentata, Satureja abyssinica* and *Saginea abyssinica* are the characteristic species. Shannon-Wiener diversity index was 2.8.

12. ***Helichrysum citrispinum –Alchemilla abyssinica-Erica trimera*** **type**

This community type occurs in altitudinal range of 3350-3480m near a severely grazed land forming patches. The characteristic species are *Helichrysum citrispinum, Alchemilla abyssinica, Erica trimera, Myosotis abyssinica* and *Alchemilla haumanni.* Shannon-Wiener was 3.6.

13. *Helichrysum citrispinum –Agrostis quinqueseta-Erica arborea* type

This is alpine community type which is also found at the upper part of *Ericaceous* vegetation. The soil is extremely dry and this can be attributed to the lower vegetation cover of this community type. In addition it has a higher value of aspect which indicate maximum insolation. Consequently, the lowest average percent moisture occurs here. *Helichrysum citrispinum, Agrostis quinqueseta, Erica arborea, Anthriscus sylvestris,* and *Galium simense* are characteristic species. This community type has the lowest diversity index, 1.6.

4.2 Comparison of Plant Community Types with the Environmental Factors

The distributions of the plant community types are found to be related with altitude. The lowest diversity was found in community type 13 with Shannon-Wiener 1.9. Only community type 6 has shown lower diversity at lower part of the *Ericaceous* vegetation. The diversity at lower parts of the *Ericaceous* vegetation is highest both in woody and herbaceous vegetation. Although a higher diversity was also recorded in some of the community types at the upper part *Ericaceous* vegetation, it is only in terms of herbaceous species. The number of tree and shrub species is extremely lower. It is about 7 on the lower

part while it is only 2 in the upper part of the *Ericaceous* vegetation, mainly *E. trimera* and *E. arborea.*

Table 4. Species richness and diversity in the 13 plant community types

COMMUNITY TYPES	SPECIES RICHNESS	H'	N
1	45	3.8	17
2	33	3.5	17
3	32	3.5	9
4	31	3.4	8
5	34	3.5	5
6	20	3.0	2
7	37	3.6	9
8	15	2.7	2
9	39	3.7	12
10	48	3.9	15
11	20	3.0	3
12	35	3.6	9
13	7	1.9	2

ANNOVA among the 13 plant community types for the environmental variables is summarized in Appendix 4. Percent total nitrogen, and pH has shown a significant difference with P value of less than 0.05. The variability for the other environmental parameters are higher among them selves (within the community type) than the variability between community types. The average value for the environmental variables is shown in Appendix 2.

The highest percent total nitrogen was found in community type 3 and the lowest in community type 8 which were 1.68 and 0.03, respectively (Figure 6). The highest percent

soil moisture was found in community type 4 which was 35.4% and lowest 9.9% (Figure 7).

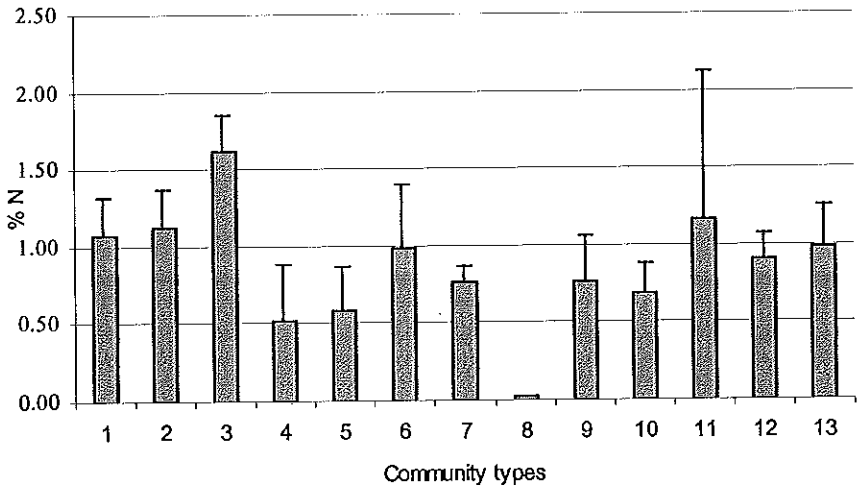


Figure 6. Variability in % total Nitrogen among the 13 plant community types. The whiskers indicate the standard error.

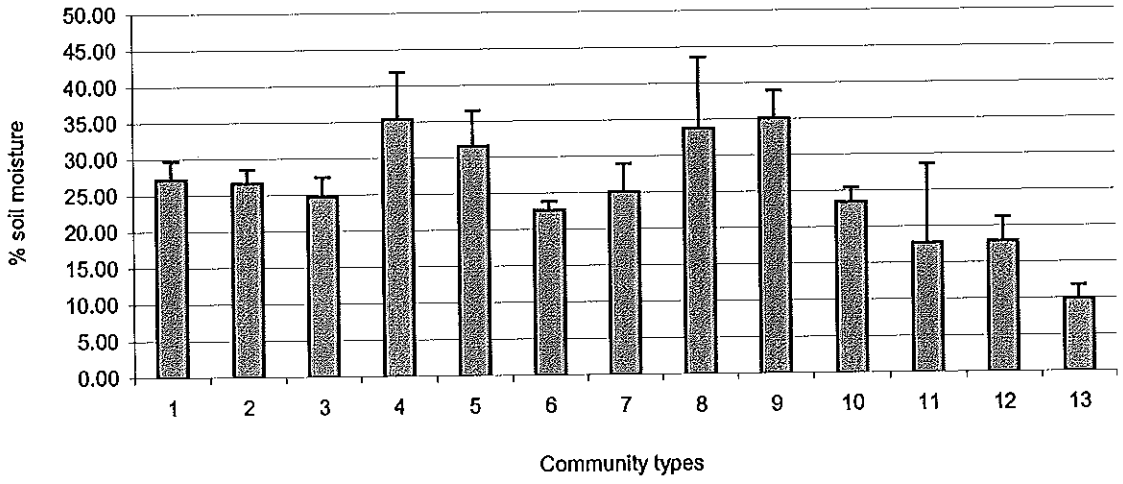


Figure 7. Percent soil moisture and their variability among the thirteen plant community types. The whiskers indicate the standard error.

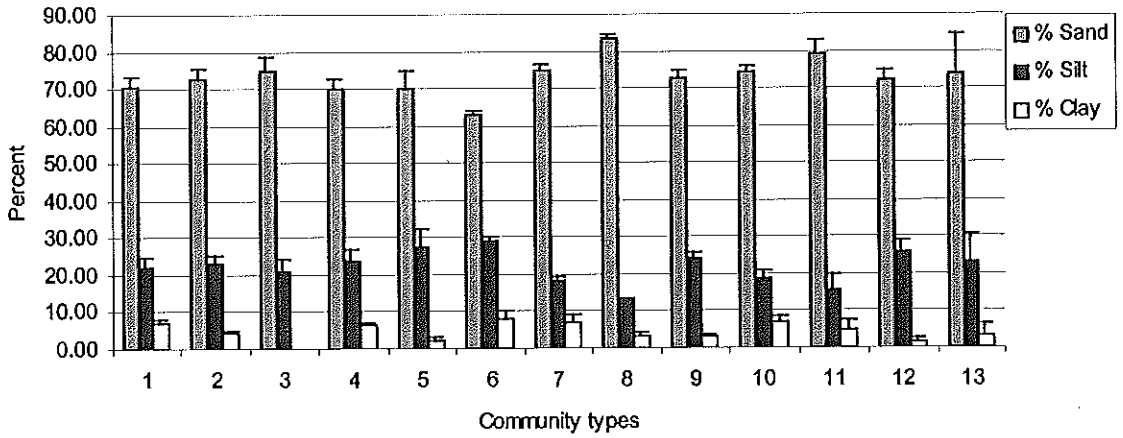


Figure 8. Percent sand, silt and clay among the thirteen-plant community types and their variability. The whiskers indicate the standard error.

4.3. Altitudinal Gradients

4.3.1. Density and Frequency

In all the 110 quadrats a total of 8 tree and shrubs were recorded. *E. trimera* was found in almost all the stands. The frequency of the 7 tree/shrub species shows variation with altitude. The eighth species, *Pittosporum viridiflorum* was recorded only in a single stand. *E. trimera* and *Hypericum revolutum* show similarity in the trend of change in frequency (Figure 9) but *H. revolutum* was absent in upper part of the *Ericaceous* vegetation. At the lower part of the *Ericaceous* vegetation, the frequency of *E. trimera* is lower due to the dominance of the monatne species. But when one observes at the general trend, it was found to be distributed all over the three parts of the *Ericaceous* vegetation. No other species has shown such distribution including species of the same genera *(E. arborea)*.

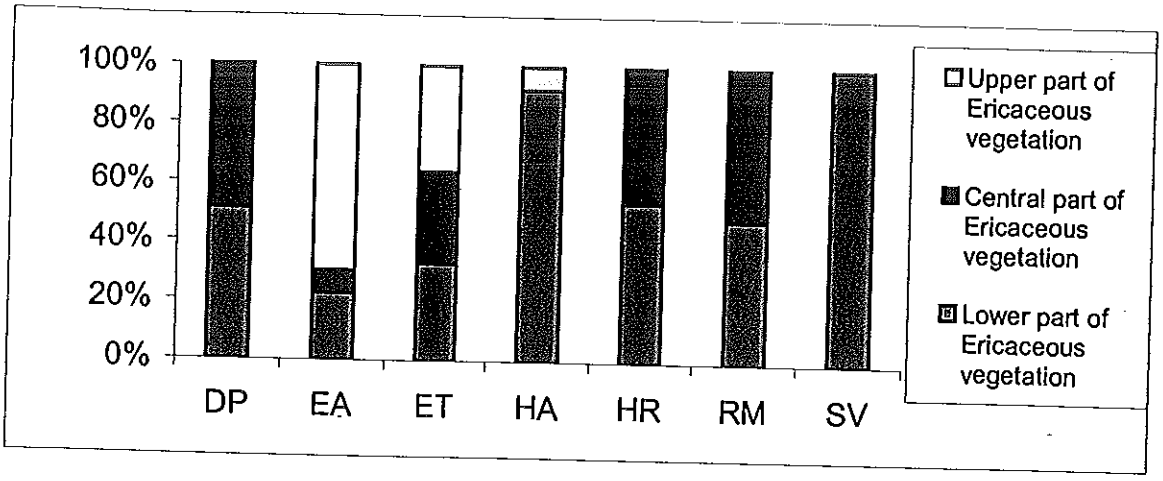


Figure 9. Frequency of the 7 treeline species *D. penninervium* (DP), *Erica arborea* (EA), *E. trimera* (ET), *H. abyssinica* (HA), *H. revolutum* (HR) *S. volkensii* and *R. melanophloes (RM)* at upper, central, and lower part of the *Ericaceous* vegetation.

Table 5. Average percent cover of the 7 treeline species *D. penninervium* (DP), *Erica arborea* (EA), *E. trimera* (ET), *H. abyssinica* (HA), *H. revolutum* (HR) *S. volkensii* (SV) and *R. melanophloes* (RM) at lower 1, central 2, and upper part of the *Ericaceous* vegetation

	DP	EA	ET	HA	HR	RM	SV
Lower part of Ericaceous vegetation	5±2.5	30±10	50±15.49	30±15.49	20±6.12	15±8.86	20
Central part of Ericaceous vegetation	10±10.66	45±29.91	55.69±30	-	10±6	10±6.91	-
Upper part of Ericaceous vegetation	-	34.92±30	30±20	15.27±12	-	-	-

The distribution of *Schefflera volkensii* is restricted to the lower part. *Rapnea melanophloes, Hypericum revolutum* and *Discopodium penninervium* are found both in lower and central part (Figure 9, 10, and Table 5).

As it is shown in Table 4, the percent cover of *E. trimera* at upper, lower and central parts of the *Ericaceous* vegetation was 50, 55, and 30, respectively. *H. abyssinica* has an average cover of 30% at lower part, absent at the central and 15% at the upper part. *H. revolutum* and *R. melanophloes* show a similar trend. Their distribution is limited to the lower and the central part. The cover for the former is 20% at the lower and 15% at the central part of the *Ericaceous* vegetation, while the later has 15% and 10% at the lower and the central part of the *Ericaceous* vegetation, respectively. In contrast to these two monatne trees, *D. penninervium* has lower percent cover, (5%) than the central part of the *Ericaceous* vegetation which is 10%.

The density (N^{o}/ha) of trees shows three different patterns. The first pattern was decrease in density with increase altitude. This was observed in *H. revolutum,* and *R. melanophloes.* Both of which have higher density at lower part than the central part. Their density at the lower part was 44 and 56/ha for the former and the later, respectively. At the central part of the *Ericaceous* vegetation the density of the former is 30/ha and the later 34/ha, respectively. *H. abyssinica* has shown the second pattern i.e. the highest density at lower part, 22/ha absent at the central part and 19/ha at the upper part of the Ericaceous vegetation. The third pattern was observed in *S. volkensii* which is confined to the lower part and the density is 19/ha (Figure 10).

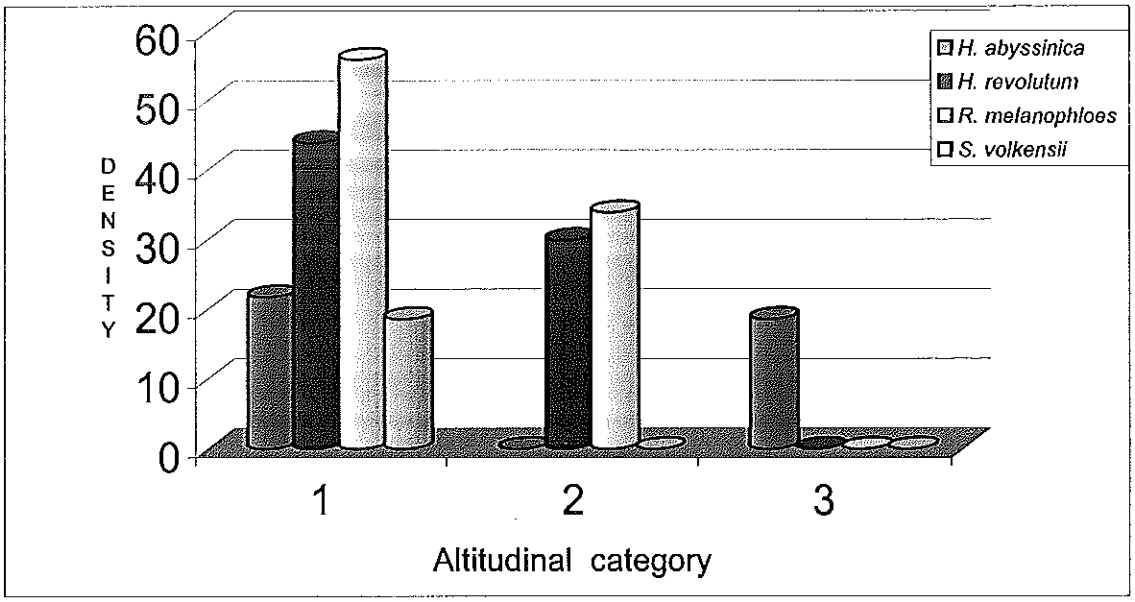


Figure 10 Density/ ha for 4 tree species at lower (1), central (2) and upper (3) part of the *Ericaceous* vegetation.

4.2.2. Height and DBH

Height and DBH of the 7 treeline tree and shrubs was found to decrease with increase in altitude (Table 6) This pattern was different between *E. trimera* and the other species. The regression analysis (Figure 11) of height and against altitude has shown a consistent decrease in height ($r^2 = 0.56$). The maximum height for *E. trimera* (16m) was recorded at the lower part of the *Ericaceous* vegetation. The decrease in height was coupled with appearance of more shruby habit. It was observed that the change in height was gradual no sudden drop was observed. Although with a lesser degree the DBH has also a similar trend. This gradual change in height and life-form is in contrast to *Hagenia abyssinica.* The height and DBH of all the treeline species is summarized in Table 6.

Table 6. Mean Height and DBH of the 7 treeline trees and shrubs at lower (1), central (2) and upper part (3) of the *Ericaceous* vegetation

	Altitudinal category	DBH (cm)	SE	Height (m)	SE
D. penninervium	1	-	-	2.23	1.90
	2	-	-	1.75	1.28
	3	-	-	-	-
E. arborea	1	-	-	1.62	1.20
	2	-	-	1.12	0.80
	3	-	-	0.95	-
E. trimera	1	23.34	7.44	10.19	2.20
	2	12.32	12.38	5.30	4.53
	3	8.00	3.20	2.08	1.98
H. abyssinica	1	72.67	24.65	24.47	3.04
	2	-	-	-	-
	3	30	28.45	4.83	1.97
H. revolutum	1	26.75	8.83	13.60	3.37
	2	16.74	10.11	7.37	5.86
	3	-	-	-	-
R. melanophloes	1	25.02	9.49	16.50	6.87
	2	14.34	7.81	8.96	6.60
	3	-	-	-	-
S. volkensii	1	48.09	3.98	19.50	
	2	-	-	-	-
	3	-	-	-	

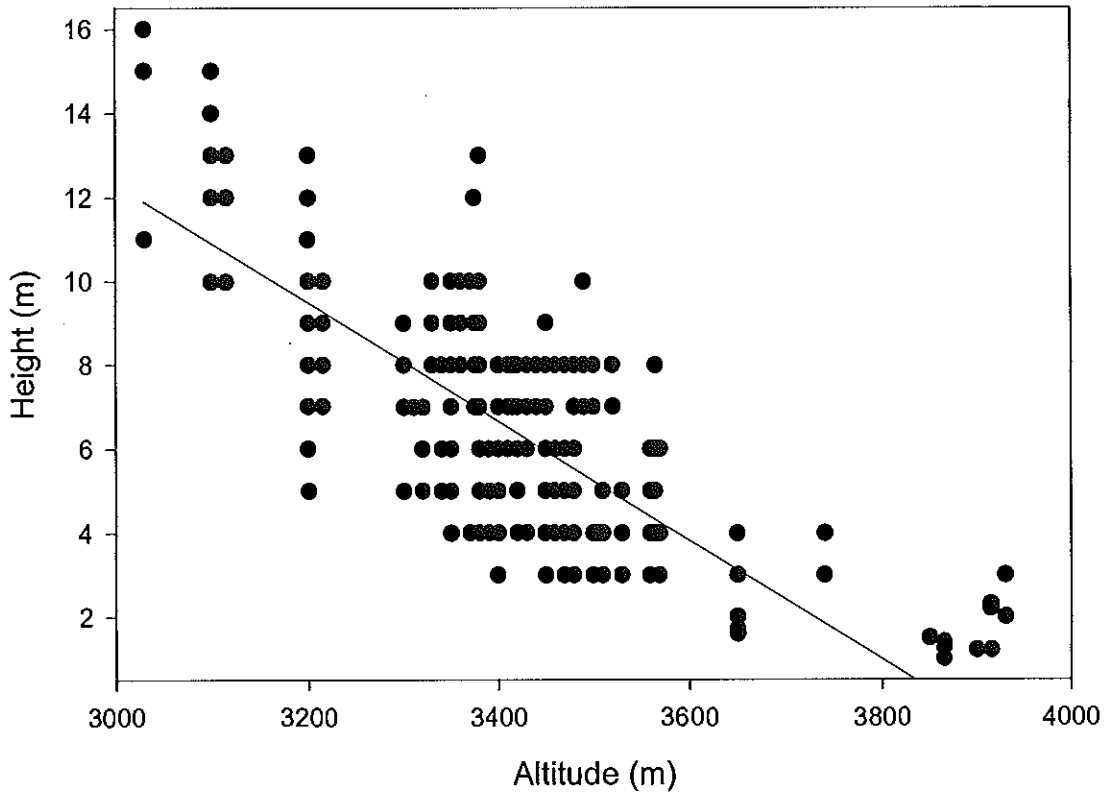


Figure 11 Regression analysis of height (m) against altitude (m) for *E. trimera*

The height of *E. trimera* has shown a significant difference in the three parts of the *Ericaceous* vegetation, ANNOVA $p < 0.01$ (Appendix 3). In the lower part of the *Ericaceous* vegetation *E. trimera* has an average height of 10.2m while it is 5.3m and 2.1m in central and

upper part of the *Ericaceous* vegetation, respectively. The difference in height for *E. trimera* is plotted against the three parts of the *Ericaceous* vegetation (Figure 12).

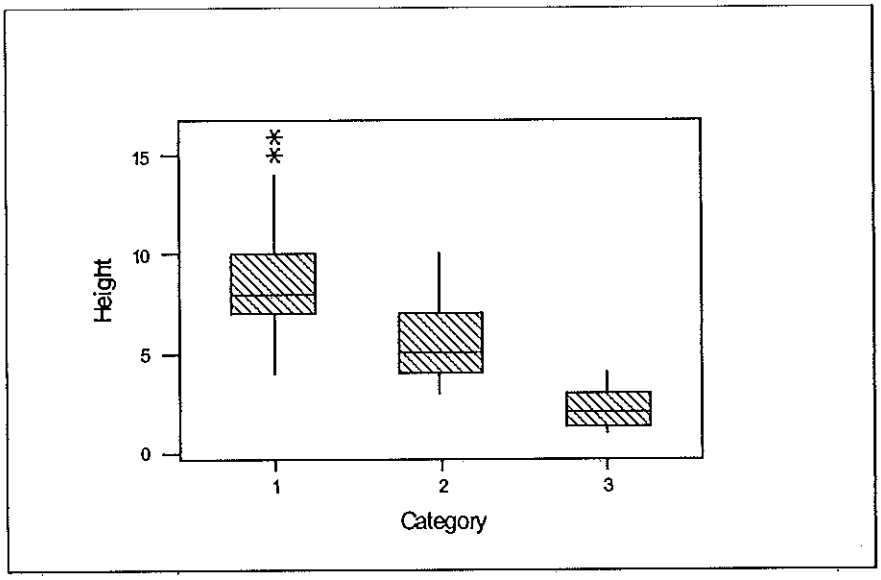


Figure 12. Box plot showing the variability in height in m at lower (1), central (2) and (3) upper part of the *Ericaceous* vegetation. The whiskers of the box plot show inter quartile range.

The DBH has also a similar trend i.e. it shows a decreasing tendency with increase in altitude. The average DBH of *E. trimera* at the lower, central and upper part of the *Ericaceous* vegetation, respectively is 23, 12, and 8 cm, respectively. For all species the DBH was higher at lower part of the *Ericaceous* vegetation than any other part. *H. abyssinica* has the highest average DBH, 72.7cm at the lower part.

4.4. Environmental Factors

4.4.1. Climate and Microclimate

4.4.1.1. Rainfall

Total rainfall for the year 1999 was 497mm which is extremely low. February, November and December are the driest months while October was the wettest month followed by March and April. The precipitation for the three months in mm were 156, 98.1 and 57.9mm respectively (Figure 13). The wet seasons of the year was not typical of the area as we were informed from the villagers. Comparison of rainfall altitudinally was not possible due to lack of data.

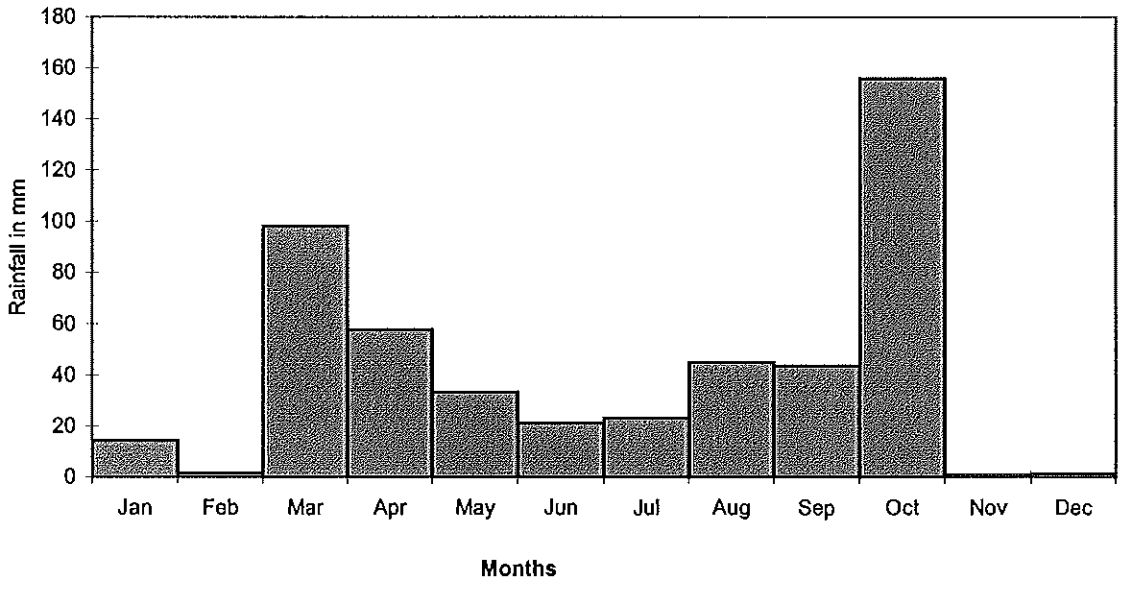


Figure 13 Total monthly rainfall from Rira meteorological station for the year 1999.

4.4.1.2. Temperature

The only available continuous temperature records for Bale mountain range are the northern declivity and some parts of the Senatie plateau. The annual mean temperature for Dinsho (3170m) which is comparable in altitude to Rira (3000m) is 11.8 °C and 13.1 °C at Goba (2800m) station which is a bit lower than Rira.

The measurement of the daily course of the temperature at two sites near Toyu camp (3400) and Senatie camp (3900m) is indicated in Figure 14. In all the sites maximum temperature were measured in early afternoon and the minimum at early morning. The average day temperature (6 °C) at Senatie camp was almost half of the lower one, 12.1°C (Toyu camp). But the variability is higher at Senatie camp. The standard error was 4.3 °C for Senatie and 3.9 °C at Toyu.

4.4.1.3.Humidity

The humidity in montane forest in the southern slope is higher than the northern slope. This indicated by the luxuriant epiphytic communities (Plate 2). The relative humidity measured for three days at two camp sites shows that there is moderate humidity at the lower part of the *Ericaceous* vegetation than the upper one. Eventhough it was not possible to compare the nocturnal relative humidity, the diurnal measurement has revealed the more moderate condition at lower part than at the upper part. The RH ranges between 26% and 92% for Senatie camp and between 40% and 95% for Toyu. The daily average is less than 60% for the former while it is always greater than 75% for the later. Daily course of temperature and relative humidity is shown in (Figure 14).

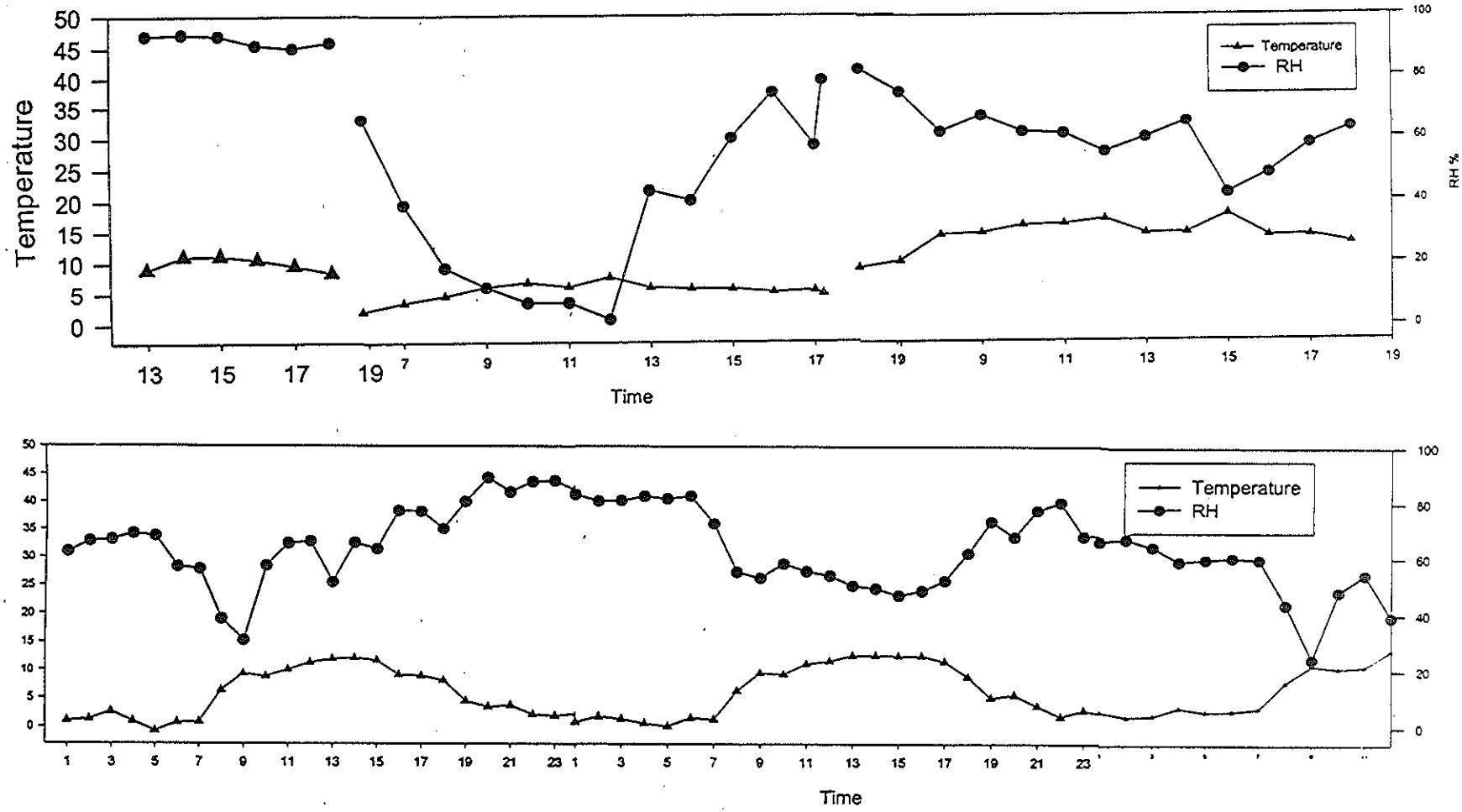


Figure 14 Diumal variation in temperature and RH at the lower (a) and upper part of *Ericaceous* vegetation

4.4.2.1. Texture

Four types of soil textural classes were identified viz loam, loamy sand, sand, and sandyloam. Sand fraction accounted for the highest proportion while clay was the least proportion. The sand fraction dominates in all parts of the *Ericaceous* vegetation. There is a slight trend of increase in % sand along altitude. Percent sand was greater than 50 in all parts of the *Ericaceous* vegetation except one sample at the upper part of the *Ericaceous* vegetation (Figure 15).

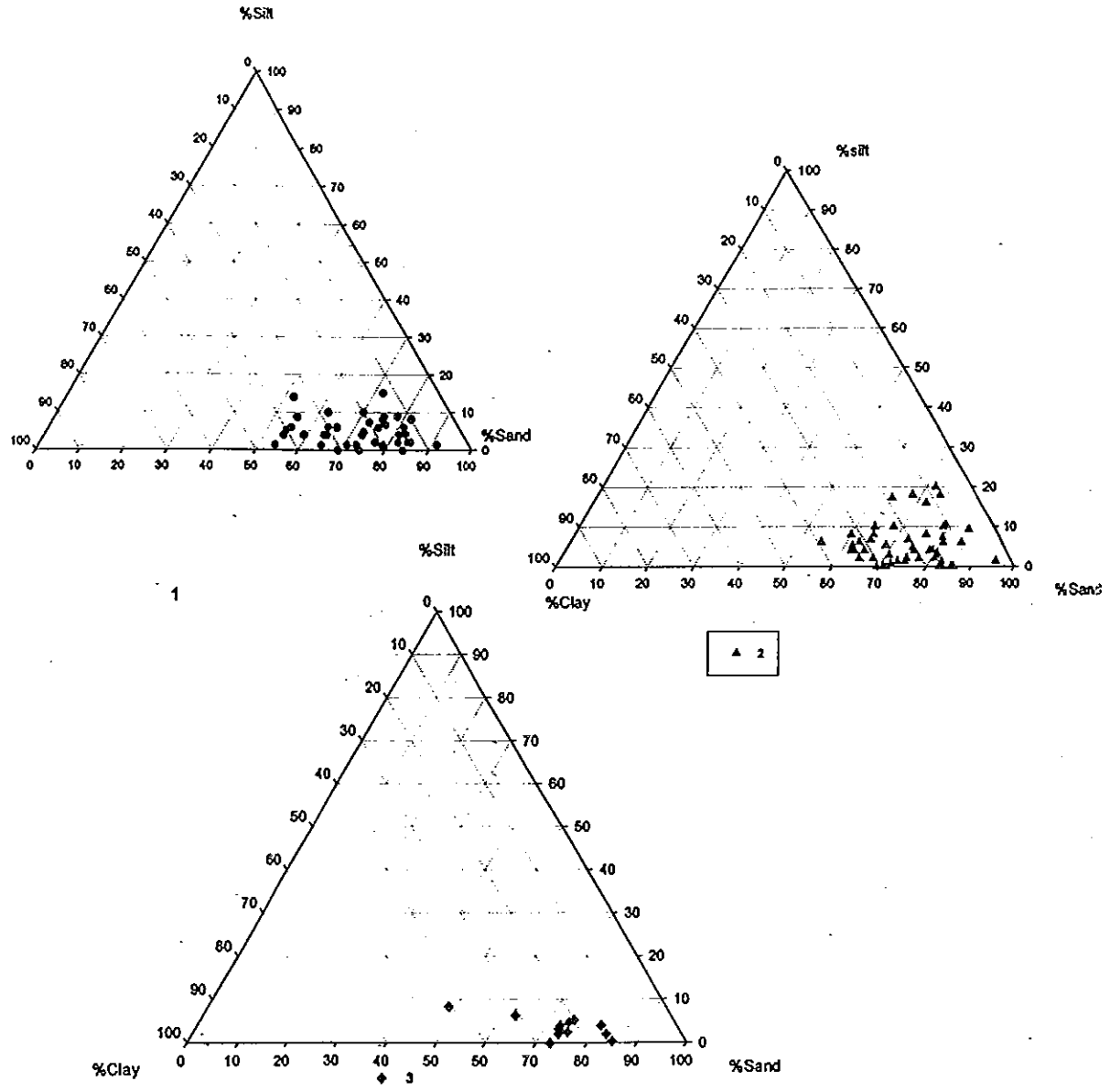


Figure 15 Ternary Plot showing the spread of sand, silt and clay in lower (1), central (2), and upper (3) part of the *Ericaeous* vegetation.

4.4.2.2. Soil moisture

The percentage soil moisture was found to decrease with increase in altitude. Regression analysis of soil moisture against altitude has shown inverse relation i.e. soil moisture decrease with increase in altitude (r^2=0.46). Percent soil moisture ranges between 0 and 50 percent. This altitudinal trend show also variability at different microsite (see scatter plot Figure 16).

The average percent soil moisture was higher at lower part although the variability in moisture was very high. The highest variability occurs at the central part of the Ericaceous vegetation.

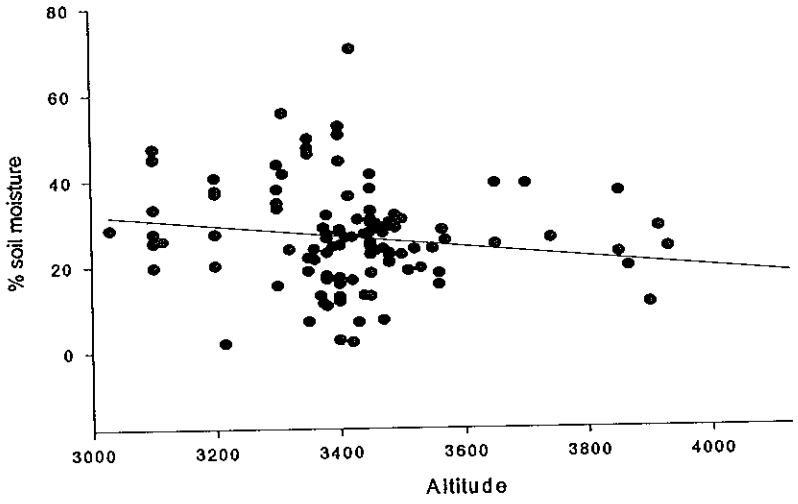


Figure 16. Regression analysis of percentage soil moisture against altitude.

4.4.2.3. Soil pH

Soil pH in the study area ranges between 3.98 and 6.7. There is a general tendency in decreasing soil acidity with increase in altitude (see Figure 17). The upper part is more acidic than the lower and the central part of the Ericaceous vegetation.

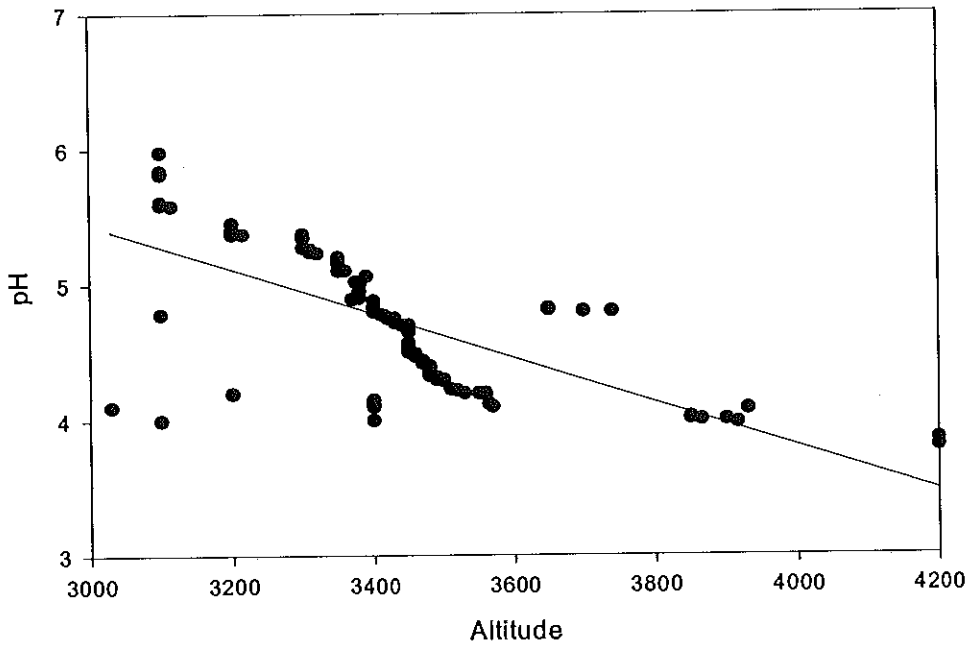


Figure 17. Linear regression curve for pH plotted against altitude

4.4.2.4 Total Nitrogen

The percentage total nitrogen ranges between 0 and 1.4%. It was found to decrease as one climb from 3000 to 3400m and is followed by a sharp increase from 3400 (1%) to 4200 (1.4%) The highest percent total Nitrogen was recorded the upper part.

4.5. Information on Fire

The indicator species were observed more frequently on the upper part than the lower. It was less common in areas where the moss cover is higher and around big boulders.

4.6. Gradient Analysis

An ordination diagram of the environmental variables with CCA biplot (Figure 18) has shown similar result with Pearson's correlation coefficient. The arrow indicates individual variable and the length shows the relative strength of correlation to ordination axes (ter Braak, 1995). All the arrows start projecting form the origin. The longest was altitude. The first axis has an eigen value of 0.2 and significant with $P < .05$. This axis explains 39.6% of the variation and the second axis has an eigen value of 0.1 explaining 51.4% which is significant ($P<0.05$). The species environment correlation for the first axis is 0.732 and 0.659 for the second.

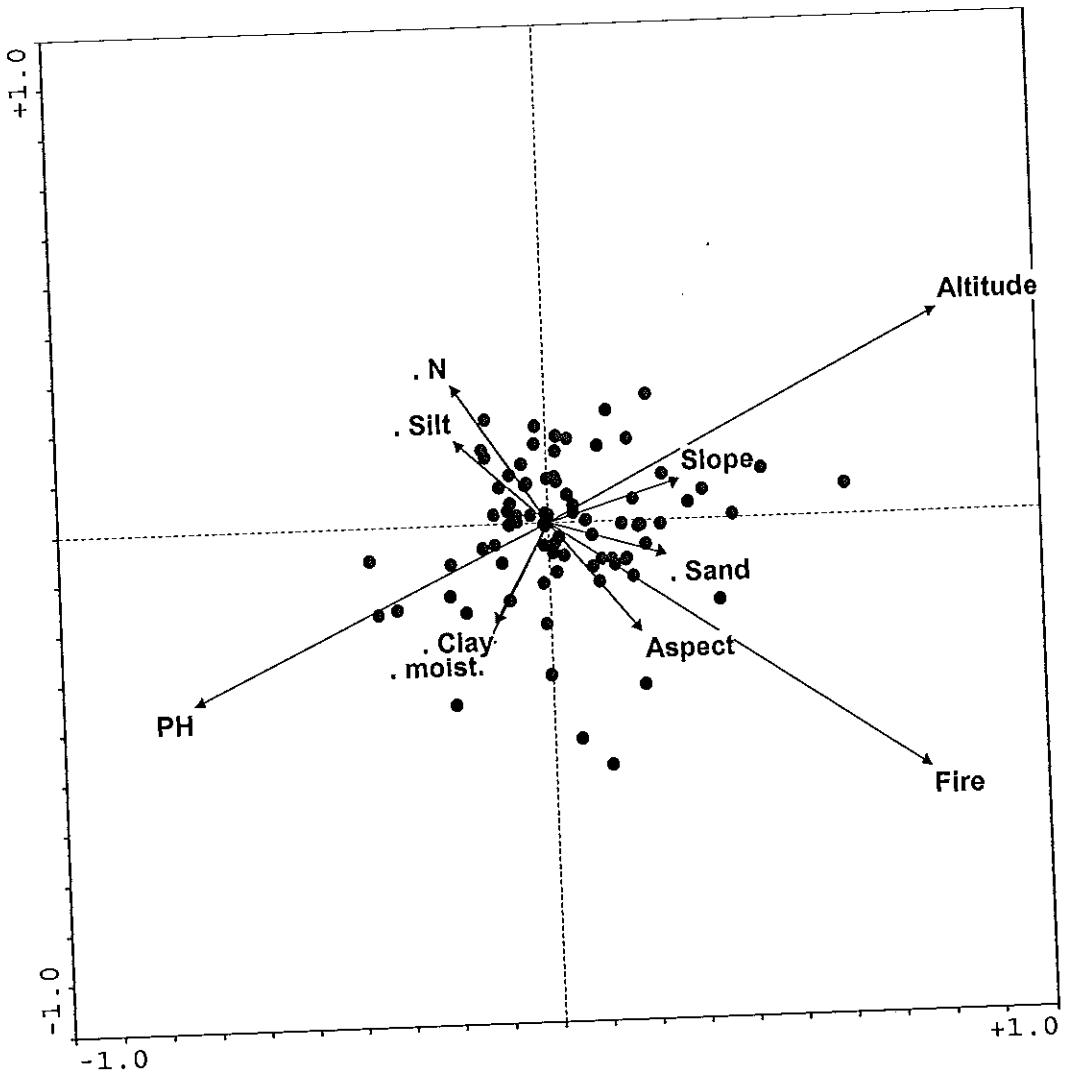


Figure 18. CCA Biplot diagram showing the correlation of environmental parameters.

The analysis of the environmental factors with Pearson's coefficient of correlation has shown a strong positive correlation between altitude and slope (0.725). The stronger negative correlation was between altitude and pH i.e. pH decrease with increase in altitude. Percent silt and clay also show negative correlation -0.605 and -201, respectively. The correlation coefficient of the environmental parameter is presented in Table 7.

Table 7. Pearson's correlation coefficient matrix for environmental parameters. Number in bold indicate significant correlation at $p < 0.5$.

	Altitude	Slope	Aspect	Moisture	pH	N	Fire	Sand	Clay
Slope	**0.725**								
Aspect	-0.001	-0.216							
Moisture	-0.33	-0.299	0.668						
pH	**-0.785**	0.629	-0.206	-0.375					
N	0.028	0.129	-0.066	0.013	0.196				
Fire	**0.512**	0.411	0.476	0.224	0.1	-0.564			
Sand	0.638	**0.871**	-0.349	-0.457	**0.637**	0.226	0.15		
Clay	-0.201	-0.469	**0.554**	0.202	-0.48	-0.338	0.186	-0.418	
Silt	**-0.605**	**-0.733**	0.126	0.41	-0.475	-0.089	-0.248	**-0.902**	-0.014

5. DISCUSSION

5.1. Distribution

As it has been indicated in the result, the distribution of community types was showing altitudinal pattern. Community type 5 and 8 were restricted to the lower part, community type 4, and 12 to central and community type 13 to the upper part of the *Ericaceous* vegetation. But over half of the community types are distributed both in the lower and the central part of the Ericaceous vegetation. Community type 9 and 10 are distributed in all three parts of the *Ericaceous* vegetation. The distribution of the 13 *community types* at different parts of the *Ericaceous* vegetation is presented with Venn diagram (Figure 19).

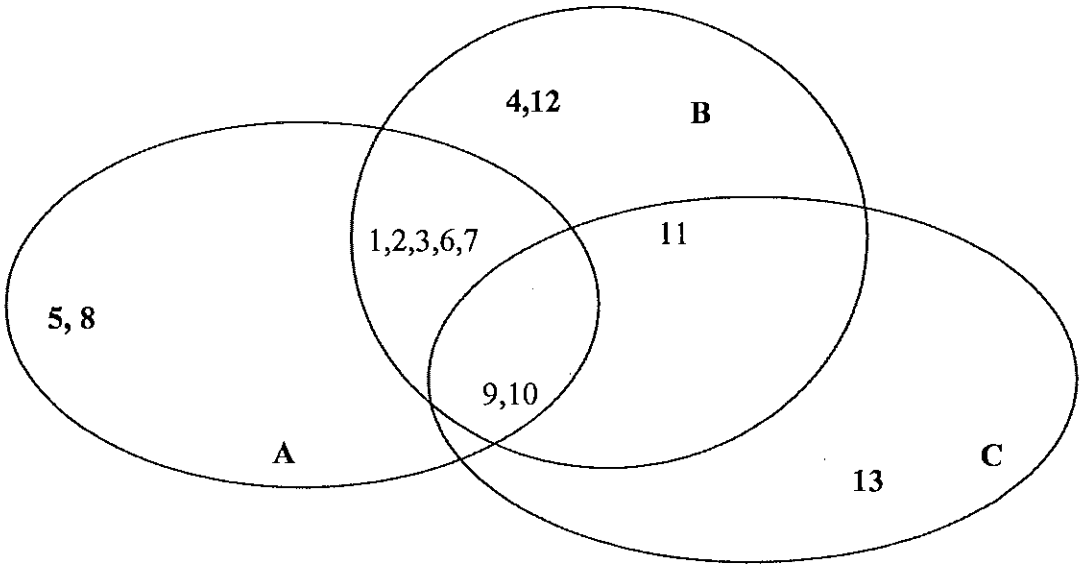


Figure 19 Venn Diagram showing the distribution of the 13 community types at lower (A), central (B), and upper part (c) of the *Ericaceous* vegetation.

The distribution of *Ericaceous* vegetation that was stretching on 1.2 km vertical distance (altitude) continuously makes this vegetation unique of its kind. No other treeline species shows such a wide altitudinal range in distribution. As indicated in the result part, the non-*Ericaceous* treeline species show limited distribution, *S. volkensii* was restricted to the lower part of the *Ericaceous* vegetation. *H. abyssinica* occurs in lower and upper parts of the *Ericaceous* vegetation. While *H. revolutum, R. melanophloes* and *D. penninervium* distributed at lower and central parts of the *Ericaceous* vegetation.

Community type 1 which is designated as *E. trimera-Hagenia abyssinica-Hypericum revolutum,* is typical in lower parts of the *Ericaceous* vegetation. Similar community types have been described in other east African mountains (Hedberg, 1964; Schmitt, 1991; Wesche, 2000) The most conspicuous characteristics of this community type are the emergent *Hagenia abyssinica* and its stratification (specially the luxuriant epiphytes), and highest diversity in trees and shrubs. The overall diversity of species was found to be relatively higher (H' = 3.27). The ground layer is also rich in species.

The distribution of this community type was mainly below 3400m and rarely occurs above this limit (near rock boulders). This could be interpreted from two angles. The occurrence of the two stands could be an indication for the possible distribution of this tree up to 3700m which is interrupted in between by disturbance. The other possibility is that it occurs at such high altitude because of the protection from wind and low temperature by rock boulders and so it is extrazonal vegetation. Extrazonal vegetation is found scattered in the middle of zonal vegetation with favorable environmental conditions, mostly in terms of

surplus of humidity and temperature (Walter, 1954 cited in Walter 1973). The second possibility is in agreement with the recent explanation to out post problems (Miehe & Miehe, 1994; Korner, 1999). Revising the works of various authors, Korner (1999) has suggested that it is difficult to explain the occurrence of groove of forest with surplus of the environmental conditions alone. A substantial and more convincing explanation for the out post problem had been given earlier (Miehe and Miehe, 1994). They explain the out post problem for another species *E. trimera* by "The ecological law of habitat constancy and changing biotopes" which was first proposed by Walter (Walter, 1954 cited in Walter 1973). Disturbance factors are shaping the current vegetation to a different form and the out post vegetation are indicators of the natural distribution of the forests. A groove of this community was also found at Mt. Elgon at similar altitude (Wesche, 2000).

As it has been shown in previous section, diversity decrease with increase in altitude. This agrees with similar study on neotropical mountain (Ferreya *et al.*, 1998). The higher diversity of this community could be accounted for moderate environmental conditions. The higher RH and moderate temperature (Figure 5 and 16) in one hand and the relatively moderate pH and soil moisture on the other hand account for the higher diversity of the tree and shrub species. The mossy vegetation is known to play a crucial role in the hygric buffering (Gradstein *et al.*, 1996). In present study, the epiphytic mosses was observed to cover most parts of the branch, as well as the stem (see plate 2). The ecological significance and the impact on the vegetation need more thorough research, although there are reports from elsewhere that the epiphytic community creates humid condition. For instance the

epiphytic community in Uluguru mountains, Tanzania has been found to hold water as high as 50,000 liters (Pocs, 1976).

The central part of *Ericaceous* vegetation is noted for its monotony and lack of stratification. As it was seen in community type 4, it is poor in tree and shrub species. Generally, there is a tendency of decline of species diversity with increase in altitude. In some of the stands Shannon-Wiener diversity index have a value as low as 2.9 (even lower than the community *types* in the upper part of the *Ericaceous* vegetation). This could be due the more closed crowns in some of the stands that limit the penetration of light. The luxuriant mossy vegetation that some times occurs on the ground could also account for the lower diversity. However, in some of the stands at the upper part the species diversity are higher owing to openness of the canopy, water and temperature surplus. This microsite variation in a similar altitudinal range made it resemble the afroalpine community forming mosaics.

Adaptive mechanism of the plant to cope up with the environmental extremities is observed in the upper part of the *Ericaceous* vegetation which is found near the afroalpine zone. This was evident in community type 9 and 11. These community types were found at much lower altitude than their zonal distribution i.e. the afroalpine belt. This implies the afroalpine vegetation is probably expanding to the *Ericaceous* belt due to disturbance. Despite their difference in species composition with the other communities of the *Ericaceous* vegetation, their diversity was not showing very much deviation. The effect of this expansion on the composition and diversity has not been studied for the Bale

composition change substantially in response to the environmental change, while species diversity was maintained within narrow limits (Brown *et al.*, 2001). As the finding of their study indicated the regulation of diversity requires maintenance of relatively constant level of productivity and resource availability and an open system. This could be an indication for the possibility of re-establishment of the replaced *Ericaceous* communities if this vegetation is left undisturbed. However, in the area under investigation no meaningful action toward reducing the pressure has been taken around Rira. If the clearing and burning is not managed in such a way that it will not devastate the whole *Ericaceous* vegetation, there is a possibility to this area to be vulnerable to invasive species. This has been observed in grassland communities in temperate region (Duke, 2000; Mazia *et al.*, 2001).

Eventhough the current measurement was for a very short period of time, the result is comparable to previous observation both in Bale mountains and elsewhere in east Africa (Schimitt, 1992; Miehe & Miehe, 1994; Wesche, 2000). The microclimatic conditions at the upper part of the *Ericaceous* vegetation are not conducive for normal growth of tree proper. (see Figure 4 and 14). The RH at lower part of *Ericaceous* vegetation (Toyu camp) was ranging 41-95% and mostly above 70%, while the range for the upper part of the *Ericaceous* vegetation was between 21% and 92% and often below 60% (Figure 14). This problem is compounded by soil physical and chemical properties. The low temperature could have also an indirect effect on nutrient cycling. Gonzalez *et al.* (2001) have found that the microbial activity was more important in subalpine forest than tropical rainforest. The texture is predominantly sand which is attributed to low temperature that are not

conducive for chemical weathering (Smith, 1983). The lower pH and moisture is also critical in community type 13 which have value of 4 and 9%, respectively.

These environmental extremities made the upper part of the *Ericaceous* vegetation to be dominated by herbaceous species and grass communities. The plants in these community types have special adaptation. *Festuca*, member of the tussock grass in community type 11 has dried leaves at the outer part. According to Hedberg (1964), the peculiar characteristic of this life-form is the living culms and leaves are largely concentrated on the central part of the tussock whereas the marginal part consist of decaying leaf calm bases. The innovation shoots are effectively protected. Beck *et al.*, (1987) have measured a temperature of -5 ° C in the tussock and 2.5 ° C in the innovation shoot on Mt. Kenya at 4200m. The rosette forming *Haplocarpha ruepelii* (member of community type 9) has acaulescent rosette leaves attached very close to the ground. The leaves are equipped with indumentum which help in insulation (Hedberg, 1964).

5.2. Structure

The height and DBH of *E. trimera* and the other treeline species decrease with increase in altitude (see Table 6). This is common to other treeline species elsewhere in east Africa (Hedberg 1964; Lovett, 1993; Wesche, 2000) except the paradoxical woody treeline species in neotropical environment, *Espeltia schulzi.* This species show increase in height and stem diameter with altitude (Smith, 1980). The regression analysis for *E. trimera* has shown a gradual decrease in height with increase in altitude (r^2= 0.588). But this trend of decrease in altitude did not show a sudden drop (Figure 11). *E. trimera* which has an average height

10.2m at the lower part of the *Ericaceous* vegetation where it shares the tree layer with *H. abyssinica* and *H. revolutum* and *R. melanophloes* is changed to a less stratified and more monotonous shruby habit at the central part. The change in height is coupled with change in habit. The more or less single stemmed *E. trimera* at the lower part becomes more shruby at the central part and ends up as a dwarf shrub near the alpine zone.

The lower part of the *Ericaceous* vegetation has the higher species richness up to 45 as a measure of diversity. This could be accounted for more favorable environmental condition pH, soil texture and soil moisture (Figure 6, 7, 8).

As the objective of the study was to document the "natural" trend, the vegetation for present investigation was chosen in such a way that more continuos and homogenous sample of the vegetation is taken. This in turn will exclude highly disturbed vegetation from sample.

At central part of the vegetation the most dominant woody phanerophyte is *E. trimera* and *D. penninervium. H. revolutum* and *R. melanophloes* also occurs less frequently. It is difficult to apply UNESCO's definition of tree consistently for the dominant species. According to this definition tree is any scapose (single stemmed) phanerophyte no matter how tall they are. Tree formations however, must be at least 5m tall (Mueller - Dombois and Ellenberg, 1974). But the scapose habit is not consistent for *E. trimera*. Applicability of 'Tentative Physiognomic Ecological Classification' (TPEC) toward treeline is questioned by various *authors* (Wardle, 1971; Tranquillini, 1979; Korner, 1998).

Korner (1998) define tree as a single stemmed individual that escape the surface and reach free air thus being at least 2m high. However, various authors have used the term tree and the subsequent formation, forest to similar physiognomic and structural conditions in east Africa. The *Ericaceous* formations were described as Subalpine forest (Schmitt, 1991), *Ericaceous* forest (Miehe and Miehe, 1994; Zerihun Woldu, 1999; Wesche, 2000).

The *Ericaceous* forest in present investigation has shown a gradual change in height in contrast to Uhlig's observation. Uhlig (1988) suggests the natural treeline in Bale mountain is abrupt. The abrupt physiognomic change is less common as one travels far from the Rira village. However, a firm conclusion need more evidence about fire and its influence on the structure including charcoal from the profile that indicate the history of fire. Because the present physiognomy and distribution of a vegetation is affected by past disturbance factor (Crawley, 1997).

Although the average height of *E. trimera* is 2.1 at the upper part of the *Ericaceous,* there were a lot of individuals with dwarf shruby habit with a height of 0.5-1m. There was no continuous tree (proper) formation in this part. But small groove of *E. trimera* forest out side the releve was found at 3900m. The trees were having height of about 6m (plate 4). But the decrease in height continues gradually and finally end up forming small scrub less than a meter. The extreme example of this scrub having a height of 0.8m is shown in (plate 5). In area where it is close to afroalpine zone, it becomes more open and scattered. As opposed to the central and lower parts, the upper part is poor in luxuriant epiphytic mosses rather xerophytic lichens are more commonly observed. However, structure and distribution of the

Ericaceous vegetation at lower, upper and central part of the *Ericaceous* vegetation has shown a considerable variation from site to site (Figure 12).

Altitude was a good explanatory environmental variable. The CCA has shown altitude accounts about 36.9% of the variation. Nevertheless, altitude *per se* could not explain all the variation. As indicated in the Pearson's correlation coefficient matrix pH and moisture and slightly texture has shown correlation with altitude. The lower pH is due to the accumulation of peat. Low temperature especially in water surplus field suppresses the complete break down of organic matter. Except few stands which are strongly acidic the pH range (4-6) is comparable with the finding of other east African mountains. The pH range in mount Kenya was found to be between 4.75 and 6.25 while it was 4.5 and 6 in Mt. Aberdare and 3-4 in Mt. Ruwanzori (Schmitt, 1991). The result of Pearson's correlation Coefficient agrees with the CCA. As it was shown in the biplot the eigen value was small but highly significant for both axes. Moreover, the species environment correlation was stronger.

As indicated in Pearson's correlation coefficient matrix (Table 7), the soil textural class is also correlated with altitude. The soil in the *Ericaceous* vegetation has the same parent material (Weinert and Mazurek, 1984). However their physical and chemical property was found to show variation with rise in altitude. The percent sand was found to increase with altitude this could be seen from Pearson's correlation coefficient (0.638) and from the biplot of the canonical analysis. But this increase was not significant ($P > 0.05$), as sand is the most dominant fraction almost in all stands.

The soil textural classes were also found to be correlated inversely with soil moisture of the soil (Table 7). The lower soil moisture percentage was found in soils that have higher proportion of sand. This could be accounted for low water holding capacity of sand particles. But this was not significant.

The percent total nitrogen has rather a different trend than the other environmental variables. It was found to be more correlated to the microsite conditions than altitude. The ANNOVA between the community types has shown a significant difference in percent total nitrogen between community types at $p < 0.05$. Price (1971) has suggested that microsite exerts a great influence on the nutrient and other parameters in the environment. This could be considered from the point that despite the higher accumulation of organic matter (Minase & Masresha, 1997 has found 1.2 - 13.4 %), the release of nitrogen is lower due to low rate of microbial activity and microrihizal associatiation (Lipson & Nasholm, 2001). Since plants discriminate on the form of nitrogen, percent total nitrogen is a crude value. Study on the *Ericaceous* vegetation of the Boreal forest has revealed that the ammonium form of nitrogen was dominating than the nitrate form showing the preference on one form of nitrogen than other (Nordin *et al.*, 2001). The amount of nitrogen also depend on the stage of succession of the community. Future research should take into account this parameters as this nutrient is important in dry matter production.

The observation of information on fire is less than the lower part of the *Ericaceous* vegetation. This could be due to the shortage of the raw material and the humid

microhabitat with epiphyte that might protect the spread of fire depending on the intensity and frequency. The dry twigs at the upper part are easy to burn. The scelerphyllous leaves also contains also some oily substance (Wesche, 2000).

Nevertheless, past history of fire is more important for present physiognomy of the vegetation. It should be a research priority. The importance of fire for this vegetation is very high as described by some authors (Beck, 1994; Wesche, 2000). According to Miehe & Miehe (1994) the potential treeline of Bale mountain which was estimated to be between 4000-4100 m is suppressed by anthropozogenic effect from which fire is the leading one This hypothesis was supported both by ecological data and comparison of areal photos. But the mechanisms how fire affect the *Ericaceous* vegetation is not clearly understood for the east African mountains. However, study on effects of fire on the *Ericaceous* vegetation of the boreal forest has revealed that the charcoal (after fire) adsorbs secondary metabolites that retard rejuvenation and nutrient cycling (Wardle *et al.*, 1998). Hence study on the effect of fire in relation to the physiognomy and structure of the *Ericaceous* vegetation will contribute a lot in resolving controversies on treeline globally.

One of the limitation of the study is analysis of history of fire which is more important for present physiognomy of the vegetation. It should be a research priority. The importance of fire for this vegetation is very high as described by some authors (Beck, 1994; Wesche, 2000). According to Miehe & Miehe (1994) the potential treeline of Bale mountain which was estimated to be between 4000-4100 m is suppressed by anthropozogenic effect from which fire is the leading one This hypothesis was supported both by ecological data and

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6. CONCLUSION

A total of 13 *community types* were identified in the *Ericaceous* vegetation of the Harenna escarpment. From this investigation it was found that the distribution of plant *community types* was found to be varied along altitudinal gradient. Some of the *community types* occur at all altitudinal range, others are restricted to certain altitudinal limit. For instance community type 5 which is dominated by *S. volkensii* restricted to lower part while community type 13 to upper part of *Ericaceous* vegetation. Some of the afroalpine *community types* were found at much lower altitude than their zonal distribution. This might indicate the expansion of the afroalpine communities to lower parts of *Ericaceous* vegetation possibly due to interference of man.

Generally, species diversity was found to decrease with altitude. The highest diversity was found at the lower part and the lowest at the upper part of the *Ericaceous* vegetation. But diversity has shown some deviation from this trend at the central part of the *Ericaceous* vegetation. It was found to be lower at the central part than at the upper. However, the diversity of woody species shows a consistent decrease with increase in altitude.

On the other hand this vegetation shows change in structure along the altitudinal gradient. The most distinct pattern of stratification was obtained in the lower (3000-3400m), central (3400-3600m) and upper part of the *Ericaceous* vegetation (3600-40000m). At the lower

part, the *Ericaceous* vegetation has shown more stratification with *H. abyssinica* emergent tree and *E. trimera* and *H. revolutum* and *R. melanophloes* occupying the next tree layer. *S. volkensii* occurs in limited sites. *E. trimera* hosts quite a large number of Epiphytes. *Discopodium penninervium* was found to be the most frequent shrub that occurs in association with *E. trimera.*

The central part of *Ericaceous* vegetation is composed of *D. penninervium* and *E. trimera H. revolutum* and *R. melanophloes* occurs less frequently. The upper part of the *Ericaceous* vegetation has similar structure with alpine zone. The vegetation has a patchy occurrence in some sites, and scattered with more opening in others.

The general trend of decrease in height and DBH with an increase in altitude was found for all tree and shrub species. The change in height and DBH for *E. trimera* was gradual and become more conspicuous between 3400 and 3600m.

The change in structure of the vegetation was found to be positively correlated with altitude. The microclimate (moderate temperature and RH) of lower *Ericaceous* vegetation allows more stratification than the other two parts. Soil pH and soil moisture decrease with increase in altitude increases. Total nitrogen was more correlated with microsite conditions than altitude.

7. RECOMMENDATION

The *Ericaceous* vegetation in the southern slope of Bale mountain range is the most extensive than anywhere in Africa. It is relatively less disturbed than other *Ericaceous* vegetation in east Africa. The *Ericaceous* vegetation hosts quite large number of epiphytes that could play important role in hygric buffering in the area. It is also a home of wild animals like Mountain Nyala.

Eventhough the gradual physiognomic change was evident from the result, abrupt structural change due to fire was evident along the roadsides around Rira. In addition some of afroalpine communities are encountered at the lower part of the *Ericaceous* vegetation.

The following recommendations that focus on two important areas are forwarded: -

A. Research priorities

1. The present investigation has gathered some preliminary information on the change in structure and distribution in a relatively less disturbed vegetation. This information will be more comprehensive if a comparative study on the highly disturbed transect is made.

2. The relative humidity and temperature which was found to be more favorable at lower part of the *Ericaceous* vegetation than the upper one. Measurement on wet and dry season on altitudinal basis is also very important in description of the area. This point has to be emphasized because no such measurement has been made in the southern slope.

3. In present study no *Erica* seedling was observed (from seed). This triggers another research question on how fire and regeneration of Erica are related. This is important in

understanding the current and the potential position of treeline. All the above mentioned points are important in designing a sound conservation strategy

B. Conservation and Management consideration

From the results of the study and experience some conservation and management strategies can be forwarded, however, it is difficult to give a strong suggestion due to the limitation of the study.

1. The most influential anthropozogenic factor is fire. Local people burn the *Ericaceous* vegetation mainly for grazing. Therefore, strategies that may reduce the rate of fire should take into account the pasture and the semi –pastoral local communities.

2. Creating income-generating alternatives for increasing population at Rira village. For instance, at present it is only the "Ketcha" view that is frequently visited by tourists. However, it is possible to include some other areas for ecotourism which might require a horseback and a day from the frequently visited sites.

3. Barley used to be cultivated around Rira village in limited places. But now, indigenous settlers who were mainly depending on animal rearing are shifting to mixed farming practices with increasing population. This impact of crop farming has to be checked. Because on the long run it could affect the water shade of the area, in addition to the loss of biodiversity.

It is also important to increase the awareness of the people; especially younger generations on nature and conservation through their environmental school as this will reduce at least uneconomical use of their resource.

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Appendices

Appendix 1. List of Plants

No	*Scientific Name*	Family
1	*Agrocharis melanantha* Hochst.	Apiaceae
2	*Agrostis quinqueseta* (Hochst. ex steud.) Hochst	Poaceae
3	*Aira caryophylleae* L.	Poaceae
4	*Alchemilla abyssinica* Fresen	Rosaceae
5	*Alchemilla fischeri* Engl.	Rosaceae
6	*Alchemilla haumanni* Rothm	Rosaceae
7	*Alchemilla microbetula* Th.C.E.Fries	Rosaceae
8	*Alchemilla pedata* A.Rich.	Rosaceae
9	*Anthemis tigreensis* (L.)	Asteraceae
10	*Anthriscus sylvestricus* Hoffm.	Apiaceae
11	*Arabis alpina* L.	Brassicaceae
12	*Arabis thaliana L.*	Brassicaceae
13	*Argyrolobium ramosissmum* Bak.	Fabaceae
14	Asplenium abyssinicum Fee	
15	*Asplenium aethopicum* (Berm.f.) Bechester	
16	*Cardamine hirusta* L.	Brassicaceae
17	*Carduus nyassanus* (S.Moore) R.E. Fries	Asteraceae
18	*Carex steudneri* Bock.	Cyperaceae
19	*Carex petitiana* A.Rich	Cyperaceae
20	*Centella asiatica* (L.) Urban	Apiaceae
21	*Cerrastium afromontanum* T.C.E. Fries & Weim	Caryphillaceae
22	*Cineraria abyssinica* Schultz-Bip. Ex A.Rich	Asteraceae
23	*Conyza vernoides* Schultz-Bip. Ex A.Rich	Asteraceae
24	*Crassula schimperii* Fisch.& Mey	Crassulaceae
25	Crepis ruepellii Schultz-Bip.	Asteraceae
26	*Cynoglossum amplifolium* DC.	Boraginaceae
27	*Deschampsia caespitosa* (L.) P.Beauv.	Poaceae

28 *Deschampsia flexuosa* (L.) Trin.	Poaceae
29 *Discopdium penninervium* Hochst.	Solanaceae
30 *Dryopteris enequqlensis*	
31 Echinops longisipus A.Rich.	Asteraceae
32 *Erica arborea* L.	Ericaceae
33 *Erica tenupilosa* (Engl.ex Alm & Fries.)	Ericaceae
34 *Erica trimera* (Engl.) Beentje	Ericaceae
35 *Festuca abyssinica* Hochest. ex A.Rich	Poaceae
36 *Festuca richardii* Alexeev	Poaceae
37 *Festuca simensis* Hochest. ex A.Rich	Poaceae
38 *Galium simense* Fresen.	Rubiaceae
39 *Geranium aculeolatum* Oliv.	Geraniaceae
40 *Geranium arabicum* Forssk.	Geraniaceae
41 *Hagenia abyssinica* (Bruce) J.F.Gmel.	Rosaceae
42 *Haplocarpha rueppelii* (Sch.Bip) P.Beauv	Asteraceae
43 *Haplosciadum abyssinicum* Hochst.	Apiaceae
44 *Zehneria scabra* (Linn.f.) Sond.	Cucurbitaceae
45 *Hebenstratia dentata* L.	Scrophulariaceae
46 *Helichrysum citrispinum* Del.	Asteraceae
47 *Helichrysum cymosum* (L.) Less	Asteraceae
48 *Helichrysum formosissimum* Schultz-Bip. Ex A.Rich	Asteraceae
49 *Helichrysum splendidum* (Thumb) Less	Asteraceae
50 *Hypericum revolutum* Vahl.	Hypericaceae
51 *Impatiens ethopica* Grey-Wilson	Balsaminaceae
52 *Isoglossa somalensis* Lindau	Acanthaceae
53 *Isolopis setacea* (L.) R.Br.	Cyperaceae
54 *Lotus discolor* E.mey	Fabaceae
55 *Luzula abyssinica* Parl.	Juncaceae
56 *Luzula johnstonii* Buchenau	Juncaceae
57 *Lythrus*	
58 *Myosotis abyssinica* Bois. & Reuter	Boraginaceae

59 *Pittosporum viridiflorum* Sims.	Pittosporaceae
60 *Poa annua* L.	Poaceae
61 *Poa leptoclada* Hochest. ex A.Rich	Poaceae
62 *Polygala steudneri* Chod.	Polygalaceae
63 *Polystichum fuscopalaceum*	
64 *Rapanea melanophloes* (L.) Mez.	Myrsinaceae
65 *Rubus steudnerii* Schweinf.	Rosaceae
66 *Rumex nepalensis* Spreng.	Polygonceae
67 *Saginea abyssinica* A.Rich	Caryophyllaceae
68 *Satureja abyssinica* (Benth.) Briq.	Lamiaceae
69 *Satureja simensis* (Benth.) Briq.	Lamiaceae
70 *Satureja paradoxa* (Vatke) Engel.ex Seybold	Lamiaceae
71 *Satureja pseudosimensis* Brenan	Lamiaceae
72 *Satureja punctata* (Benth.) Briq.	Lamiaceae
73 Scabiosa columbaria L.	Dipsacaceae
74 Schefflera volkensii (Engl.) Harms	Araliaceae
75 *Sedum mooneyi* M. Gilbert	Crassulaceae
76 *Senecio fresenii* Oliv. & Hiern.	Asteraceae
77 *Stachys aculeolata* Hook. f.	Lamiaceae
78 *Swertia abyssinica* Hochst.	Gentianaceae
79 *Thymus schimperi* Ronninger	Lamiaceae
80 *Trifolium acaule* Steud.ex A Rich.	Fabaceae
81 *Trifolium burchellianum* Ser.	Fabaceae
82 *Trifolium semipilosum* Fres.	Fabaceae
83 *Vernonia*	Asteraceae
84 *Veronica abyssinica* Fres.	Scrophulariaceae

Appendix 2. Average values of the environmental parameters for the thirteen community types.

community type	Altitudinal range (m)	Slope	Aspect	Moisture(%)	PH	% N	% Sand	% Clay	% Silt
1	3030 3740	20.29	1.51	27.18	4.37	1.08	70.52	7.12	22.36
2	3200 3550	27.19	1.47	26.64	4.81	1.13	72.98	4.08	22.94
3	3380 3490	31.67	1.00	24.75	4.51	1.62	74.84	0.00	21.17
4	3350 3450	40.00	1.47	35.42	4.36	0.51	69.85	6.24	23.91
5	3100 3300	19.00	1.60	31.62	4.34	0.59	70.14	2.26	27.60
6	3100 3450	17.50	1.00	22.65	5.26	0.98	63.00	8.00	29.00
7	3310 3560	25.00	1.86	25.13	4.96	0.76	74.80	7.11	18.08
8	3300 3320	12.50	2.00	33.75	4.46	0.03	83.64	3.08	13.28
9	3300 3900	30.83	1.96	35.14	4.96	0.76	72.78	3.11	24.23
10	3300 3900	28.33	1.73	23.44	4.94	0.69	74.41	6.80	18.79
11	3400 3650	40.00	2.75	17.73	4.76	1.17	79.33	4.79	15.88
12	3350 3480	22.78	1.11	17.89	4.84	0.90	72.44	1.68	25.88
13	4200	32.50	3.50	9.92	5.91	0.98	73.72	3.36	22.92

Appendix 3. ANNOVA among the 13 plant community types

		Sum of squares	df	Mean Square	F	Sig.
Slope	Between Groups	4366.34	12.00	363.86	1.45	0.15
	Within Groups	24260.02	97.00	250.10		
	Total	28626.36	109.00			
Aspect	Between Groups	19.99	12.00	1.67	1.82	0.05
	Within Groups	88.71	97.00	0.91		
	Total	108.70	109.00			
% moisture	Between Groups	10.63	12.00	0.89	1.18	0.31
	Within Groups	72.76	97.00	0.75		
	Total	83.39	109.00			
pH	Between Groups	10.44	12.00	0.87	4.59	0.00
	Within Groups	18.37	97.00	0.19		
	Total	28.81	109.00			
% N	Between Groups	3512.87	12.00	292.74	2.30	0.01
	Within Groups	12352.33	97.00	127.34		
	Total	15865.20	109.00			
Fire	Between Groups	31.93	12.00	2.66	5.78	0.00
	Within Groups	44.62	97.00	0.46		
	Total	76.55	109.00			

(Appendix 3 continued)

% Sand	Between Groups	872.56	12.00	72.71	0.91	0.54
	Within Groups	7785.13	97.00	80.26		
	Total	8657.69	109.00			
% clay	Between Groups	412.56	12.00	34.38	2.04	0.03
	Within Groups	1633.28	97.00	16.84		
	Total	2045.84	109.00			
% Silt	Between Groups	1061.36	12.00	88.45	1.17	0.31
	Within Groups	7315.86	97.00	75.42		
	Total	8377.22	109.00			

Appendix 4. Analysis of variance for the height and DBH at the lower, central and upper part of the *Ericaceous* vegetation.

A) Height

Source	DF	SS	MS	F	p
Category	2	1298.17	649.08	113.37	0.000
Error	274	1568.73	5.73		
Total	276	2866.90			

B) DBH

Source	DF	SS	MS	F	p
Category	2	8440.8	4220.4	49.08	0.000
Error	274	23559.2	86.0		
Total	276	32000.0			

Appendix 5 Plates

Plate 1. Spring water at Senatie plateau

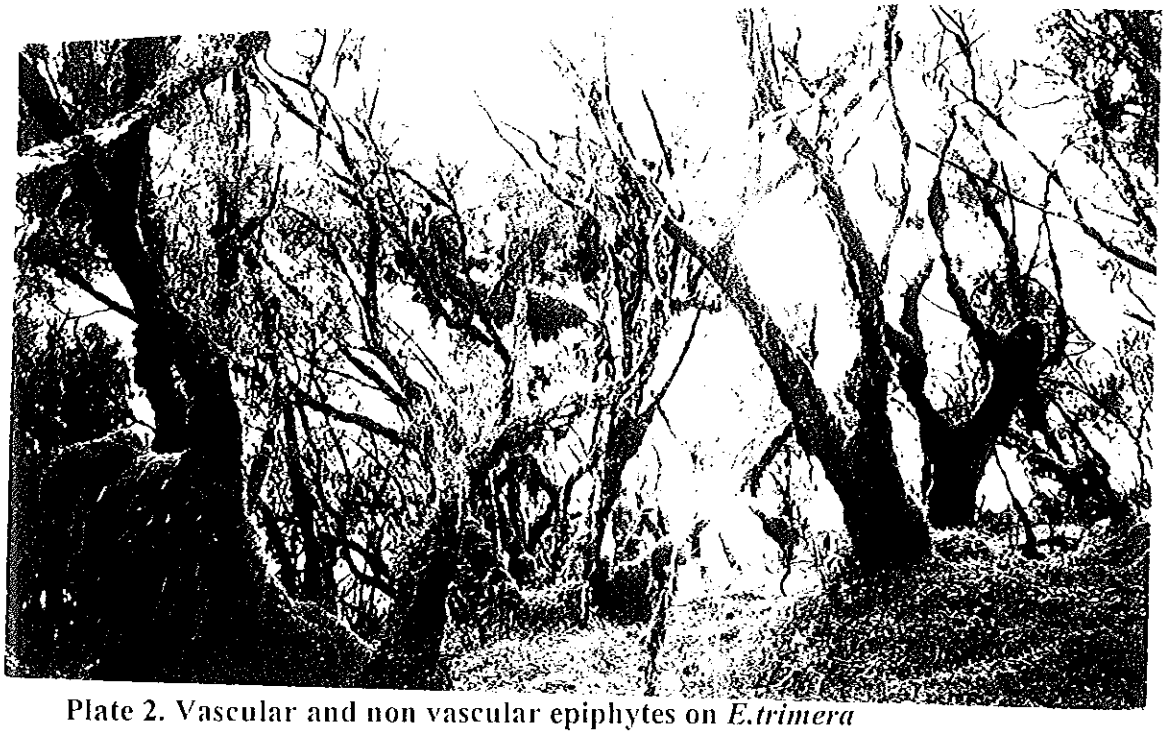

Plate 2. Vascular and non vascular epiphytes on *E.trimera*

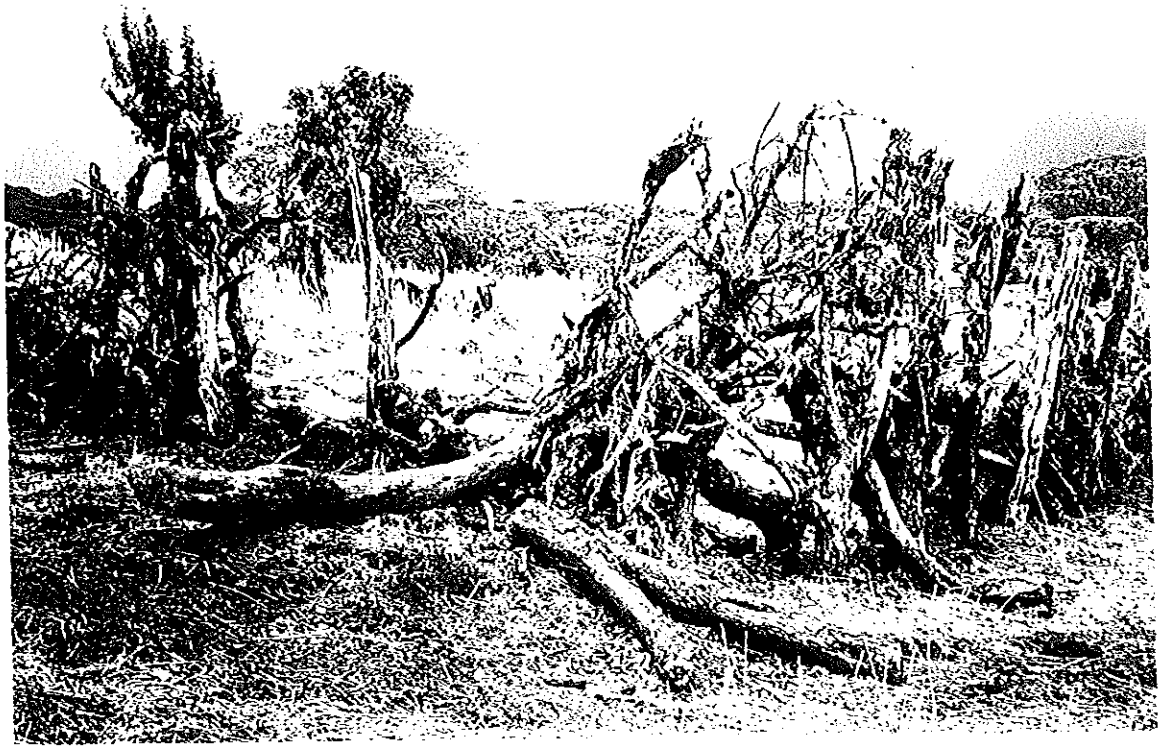

Plate 3. Uneconomic utilization of Hagenia and Erica tree near Rira village

Plate 4. Erica outpost at 3900 m (the trees are 6m tall)

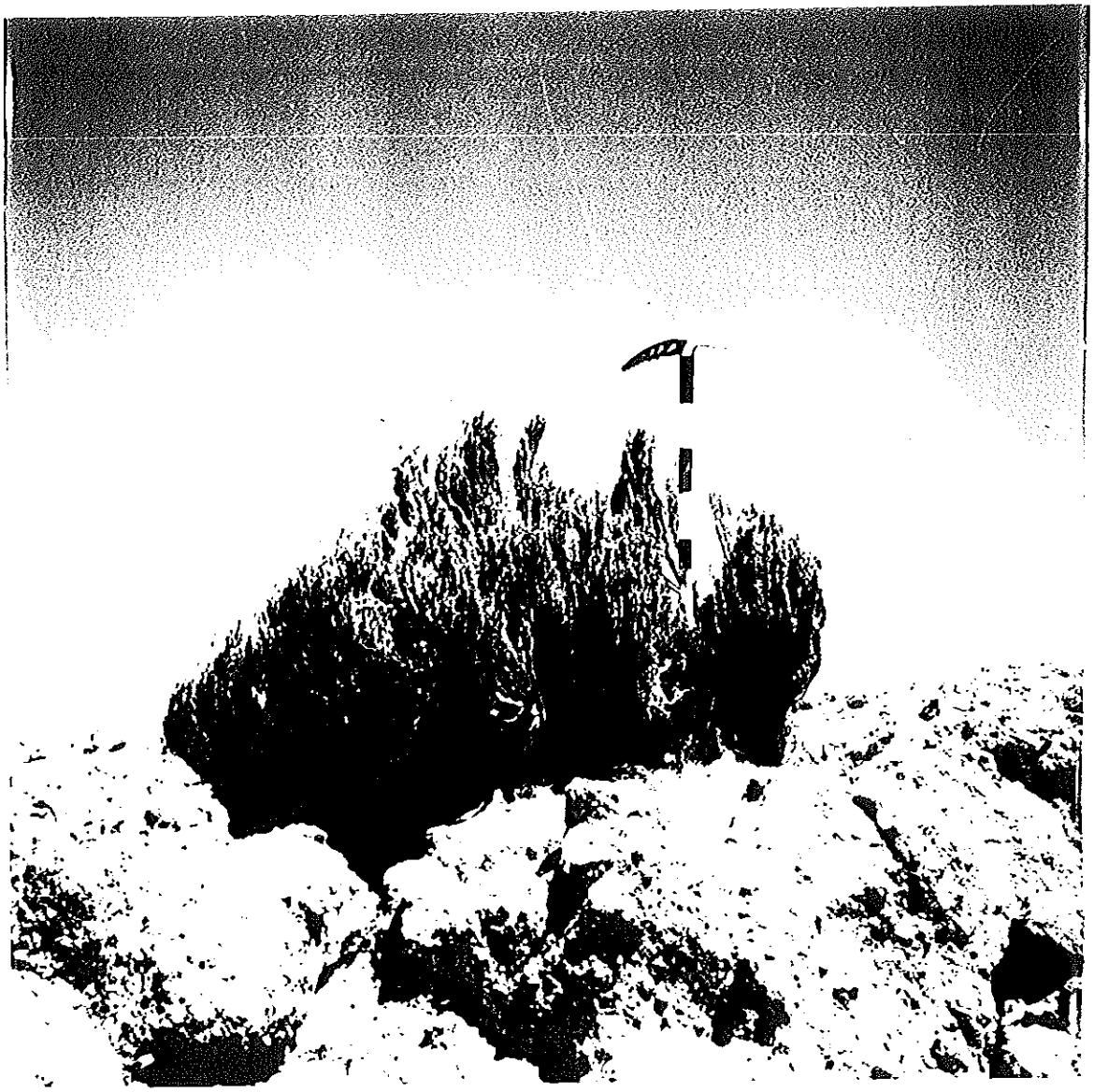

Plate 5. Erica outpost at 4220m near Tulu Dimtu (0.8 m tall)