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DRYLAND WOODY VEGETATION ALONG AN ALTITUDINAL GRADIENT ON THE EASTERN ESCARPMENT OF WELO, ETHIOPIA

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ABSTRACT: Vegetation data from plots (20 m X 20 m) on the eastern escarpment in Welo between 750 m and 1780 m a.s.l were analyzed. We found 216 species distributed in 61 families found out of which 104 were woody species and used for vegetation classification using Two-way Indicator Species Analysis (TWINSPAN). Seven woody plant community types were distinguished. Woody individuals were counted and higher Importance Value Indices (IVI) were calculated for *Euclea racemosa* ssp. *schimperi* (27.7), *Dodonaea angustifolia* (22.8), *Acacia asak* (21.9) and *Grewia bicolour* (14.4). The diversity and evenness of each community were compared using Shannon-Weiner diversity and evenness index. Pearson's correlation results reveal a strong correlation between altitude and soil depth and Tukey's test showed that the distribution of plant communities has strong correlation with altitude, soil depth and slope. Communities at inaccessible hill-slopes and protected areas are relatively species rich, while communities under high grazing pressure and other disturbance are poor in species richness. Most of the vegetation was observed highly disturbed except along inaccessible steep slopes, and in few protected and privately owned areas indicating some implications of conservation and management. The vegetation was compared with seven other vegetation types using Sorensen's similarity analysis and general description of the vegetation was made.

Key words/phrases: Diversity, dryland, environmental gradients, plant communities, TWINSPAN

INTRODUCTION

Environmental gradients with their complex interaction influence vegetation structure and composition (Whittaker, 1975; Begon, *et al.*, 1996); and hence, environmental gradient analysis is essential to understand factors governing the composition, distribution and abundance of species. In particular, altitudinal gradient influences the composition and floristic diversity of communities for changes in elevation are accompanied by changes in climatic variables mainly temperature and precipitation (Whittaker, 1967; Whittaker, 1975; Begon, *et al.*, 1996). In addition to temperature and precipitation, soil depth, slope and competition determine distribution and abundance of plant communities (Beals, 1969; Whittaker, 1975).

Over 60% of Ethiopian land surface is covered by drylands where 12% of human and 20% of livestock population is living (UNEP, 1992; CSA, 1995; IUCN, 1999). Ecological studies of Ethiopian drylands are crucial since drylands support high biodiversity and endemism (White, 1983) and support grazing, cropping, forestry, tourism, settlements and mining. However, they are given little attention and are little understood, underutilized and less managed. As a result, drylands in Ethiopia are affected by uncontrolled deforestation, overgrazing, land degradation, improper management and conflicts. This study contributes to understand the ecology of the degrading dryland vegetation in the eastern escarpment of South Welo.

Highland vegetation in South Welo was studied by Mesfin Tadesse (1990), Kebrom Tekle (1998), Mengistu Gonsamo (1998), Sebsebe Demissew (1998), Tesfaye Bekele (2000) and Abate Ayalew (2006). However, vegetation studies in the lowlands including the surrounding Afar region are scanty. On the other hand, the vegetation in the lowlands is increasingly degraded due to deforestation, overgrazing, settlement and an increasing presence of invasive species. The major objectives of this study are, therefore, to examine the species composition of plant communities, to analyze the distribution of woody plant species along altitudinal and few other environmental gradients of the escarpment and to assess the status of the vegetation and to recommend some management and conservation measures.

The study area

The study was carried out on the eastern escarpment of the Rift Valley in South Welo Administrative Zone (Amhara Region) and Afar

Region between 750 m to 1780 m altitudes. The study plots covered a total of 80 km between 12 km below Kombolcha town (11° 05'N and 39° 45E; 1900 m altitude) and a small village called Eliwuha (11° 15'N and 40° 22'E; 750 m altitude), which is about 92 km far from Kombolcha along the Kombolcha-Mile road (EMA, 1988). Topographic map was constructed to produce and generate topographic information for the study area (Fig. 1).

The study area is characterized by predominant arid and semi-arid climatic conditions (Daniel Gemechu, 1977) with mean annual precipitation between 314 mm and 728 mm (NMSA, 2003). The climatic diagrams following Walter (1975) were constructed based on mean monthly rainfall and mean monthly temperature (Fig. 2 a-c). Topography of the area includes terrains, gorges, mountains and plateaus. According to MoPED (1993), volcanic rocks, mainly basalts of tertiary age with cambisols, lithosols and vertisols cover most of the area of South Welo. Vertisols, cambisols, solenetz, leprosols and fluvisols are found. Brown (54%) with red (12%), black (23%) and gray (11%) soils are recorded in Bati wereda (BWDA, 2001). Several catchments in and around the study area like the River Chachatu, River Gelana, River Burka and River Busidima while few perennial rivers such as River Borkana, River Mile and River Logia are found. Land use in the highlands is mainly mixed agriculture while the main occupation of the people in the lowlands is pastoralism.

MATERIALS AND METHODS

Sampling methods

Vegetation was sampled between December 2002 and August 2003 following selective sampling of a total of 70 (20 m X 20 m) plots as described by Mueller-Dombois and Ellenberg (1974) along 1100 m elevation gradient from 1850 m to 750 m above sea level. Selection of sampling plots was based on homogeneity and representativeness of the vegetation some distance on the left and right sides of the main road to avoid effects of disturbance. Plant specimens in each plot were collected and pressed for identification at the National Herbarium, Department of Biology, Addis Ababa University. Vernacular names of the plant species were also recorded in the field.

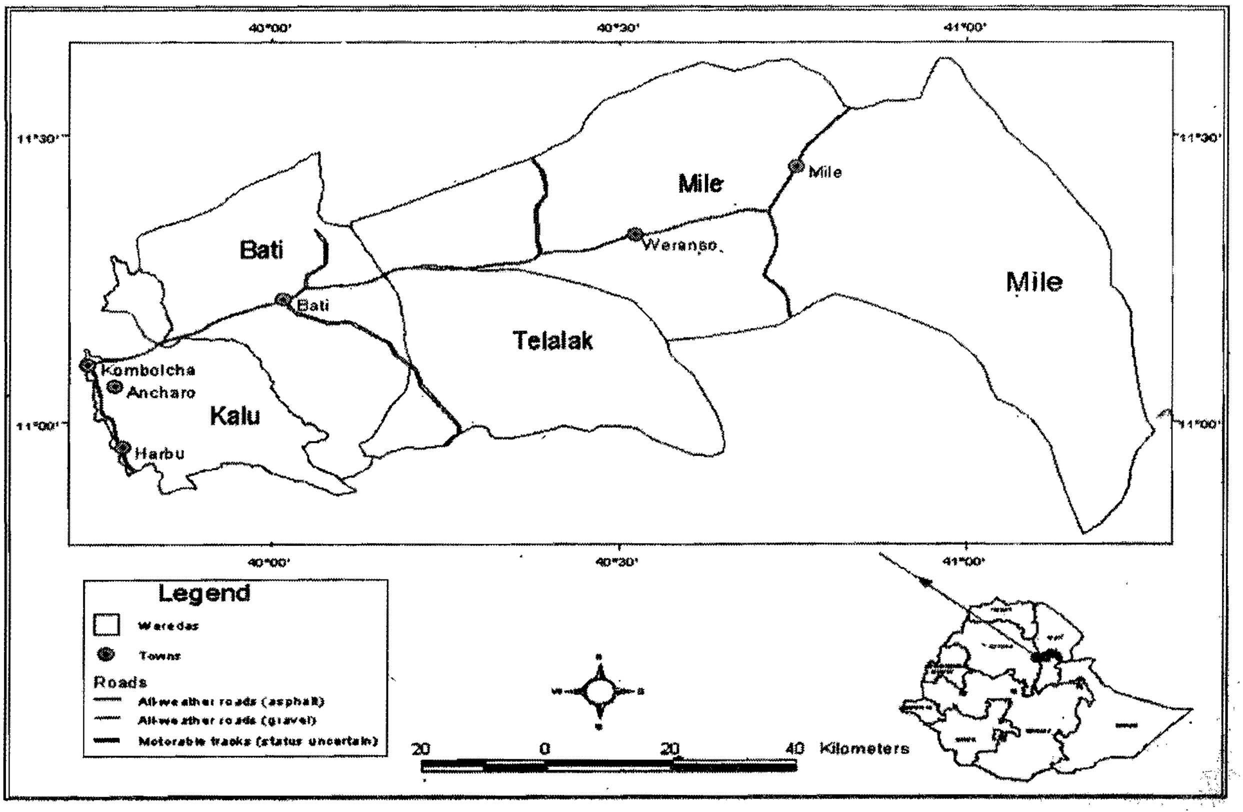


Fig. 1. Map of the study area (EARO, 2000)

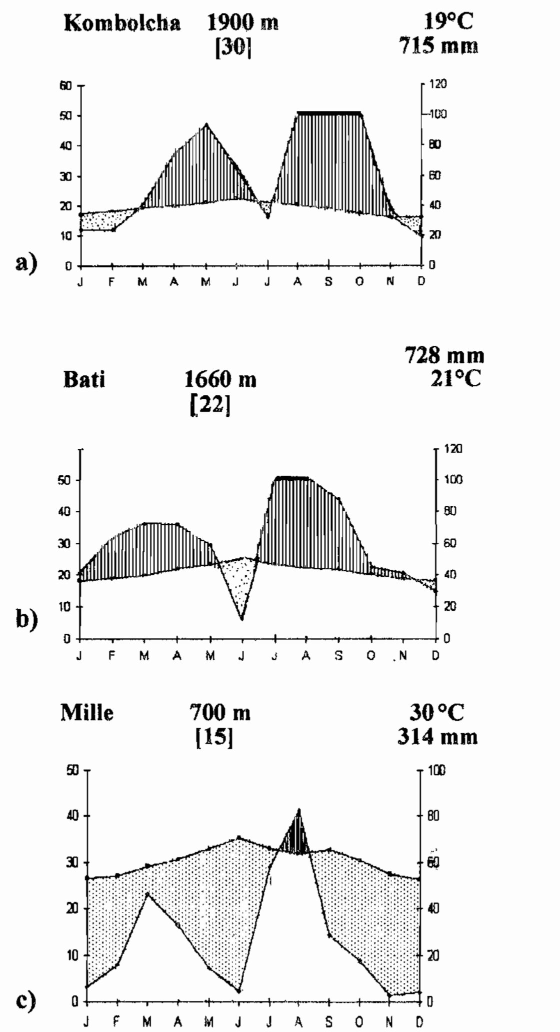


Fig. 2. Climatic diagram for: a)Kombolcha; b)Bati; and c)Mile. Data source: National Meteorological Services Agency, Addis Ababa. Mean monthly rainfall values above 100 mm was log transformed following Walter (1975).

Canopy Cover

The cover/abundance values of all woody plant species in each plot were visually estimated using a 1-9 modified Braun-Blanquet scale (van der Maarel, 1979) as follows:

1 = Rare, generally one individual
2 = Occasional or sporadic with less than 5% cover of the total area
3 = Abundant with less than 5% cover of the total area
4 = Very abundant, with less than 5% cover of the total area
5 = 5-12% cover of the total area
6 = 12.5-25% cover of the total area
7 = 25-50% cover of the total area
8 = 50-75% cover of the total area
9 = >75% cover of the total area

Woody species density

The number of individuals (greater than 1 m height) of each woody species was counted in each plot. Then, the average number of individuals of each woody species was converted into individuals per hectares for each community as indicated in Kent and Coker (1992).

Environmental data

The environmental variables measured include altitude, soil depth, soil colour, conductivity, and salinity. Altitude and slope for each relevé were measured using Everest altimeter and Suunto Clinometer, respectively. Soil depth was estimated using a locally prepared iron stick whose length is labeled in centimeters. Meteorological data of three stations (Kombolcha, Bati and Mile) representing the study area were collected. GPS records were also taken for plots. In each relevé, soil samples were collected from the depth of 0-30 cm in the five spots and were mixed to obtain a composite sample for analysis. Electrical conductivity and salinity were analyzed following EARO (2000) and soil color was identified using Munsell's color charts as described by Anonymous (1975). These soil parameters were analyzed at the soil laboratory of Biology Department, Addis Ababa University.

Data analysis

Hierarchical, polythetic and agglomerative technique was employed to classify the vegetation (Digby and Kempton, 1987; Kent and Coker, 1992). The cover-abundance data were entered into a spreadsheet and analyzed by Two-Way Indicator Species Analysis (TWINSPAN). Only woody species were considered for vegetation classification. This program was used to analyze the vegetation data based on the following options: 70 relevés and 104 species, 5 pseudospecies cut levels (0 5 15 30 50), 5 maximum group size for division, maximum number of indicators per division 7, maximum division level 6, and maximum number of species in final tabulation was 57. The weights for levels of pseudospecies established to 5 as 1 2 2 2 2 indicating that pseudospecies corresponding to four higher cut levels were given twice the weight of pseudospecies at the lowest level (Hill, 1979). Indicator potentials for cut levels was arranged as 0 1 1 1 1, which represents all pseudospecies cut levels except level one are used as indicators. Synoptic cover abundance value for each species in all communities was calculated following Kent and Coker (1992). Then, the naming of communities was after two or three species having highest synoptic values (Table 1).

Table 1. **Synoptic cover abundance values for species having a value of >1.0 in at least one community type.** (Values in bold refers to occurrences as species with fidelity).

Species	**Type and cluster size**						
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**
	8	**13**	**13**	**16**	**4**	**10**	**4**
Dodonaea angustifolia	**8.7**	0.0	0.0	0.0	0.0	0.0	0.0
Calpurnia aurea	**2.7**	0.0	0.0	0.0	0.0	0.0	0.0
Rhus retinorrhoea	**1.4**	0.0	0.0	0.0	0.0	0.0	0.0
Cadia purpurea	**5.0**	4.4	4.3	0.0	0.0	0.0	0.0
Olea europaea ssp. *cuspidata*	**1.5**	1.3	2.0	0.0	0.0	0.0	0.0
Euclea racemosa ssp. *schimperi*	**5.4**	7.0	7.1	0.0	0.0	0.0	0.0
Carissa spinarum	**5.1**	2.0	3.5	0.0	0.0	0.0	0.0
Rhus natalensis	**5.3**	4.9	2.8	1.6	0.0	0.0	0.0
Cissus rotundifolia	**2.4**	2.2	2.0	3.0	2.0	0.0	0.0
Grewia tembensis	**1.8**	4.0	1.3	1.7	0.0	0.0	0.0
Diospyros abyssinica	0.0	4.0	2.5	2.5	0.0	0.0	0.0
Grewia bicolor	0.0	3.0	2.8	**3.9**	3.0	**1.8**	0.0
Dichrostachys cinerea	0.0	**4.5**	0.0	0.0	0.0	0.0	0.0
Sageretia thea	0.0	**3.1**	0.0	0.0	0.0	0.0	0.0
Combretum aculeatum	0.0	**2.0**	0.0	0.0	0.0	0.0	0.0
Ziziphus mucronata	0.0	**2.0**	0.0	0.0	0.0	0.0	0.0
Pterolobium stellatum	0.0	**4.0**	0.0	0.0	1.0	0.0	0.0
Ziziphus spinachristi	0.0	**3.7**	0.0	0.0	0.0	0.0	0.0
Stegnataenia araliacaea	0.0	**2.0**	0.0	0.0	0.0	0.0	0.0
Opuntia ficus-indica	0.0	**3.0**	0.0	0.0	0.0	0.0	0.0
Euphorbia abyssinica	0.0	2.3	**1.9**	0.0	0.0	0.0	0.0
Acacia lahai	0.0	5.7	**2.7**	0.0	0.0	0.0	0.0
Capparis tomentosa	0.0	1.8	**2.0**	0.0	0.0	0.0	0.0
Acacia seyal	0.0	4.2	**2.7**	0.0	0.0	0.0	0.0
Cissus quadrangularis	0.0	2.5	1.8	3.2	0.0	0.0	0.0
Euphorbia candelabrum	0.0	3.3	**5.0**	3.0	0.0	0.0	0.0
Acacia asak	0.0	5.2	4.2	**6.4**	**6.8**	3.0	1.0
Ximenia americana	0.0	0.0	1.5	1.0	**4.0**	0.0	0.0
Acacia mellifera	0.0	0.0	0.0	1.0	0.0	**5.9**	1.0
Dobera glabra	0.0	0.0	0.0	1.0	0.0	**2.7**	0.0
Acalypha fruiticosa	0.0	0.0	0.0	0.0	0.0	**5.8**	0.0
Acacia oerfota	0.0	0.0	0.0	0.0	0.0	**6.5**	0.0
Balanites aegyptiaca	0.0	0.0	0.0	0.0	0.0	**5.4**	1.0
Boscia coriacea	0.0	0.0	0.0	0.0	0.0	**2.5**	0.0
Phyllanthes sepialis	0.0	0.0	0.0	0.0	0.0	**3.0**	0.0
Salvadora persica	0.0	0.0	0.0	0.0	0.0	**4.3**	0.0
Prosopis juliflora	0.0	0.0	0.0	0.0	0.0	0.0	**8.5**

One-way analysis of variance (ANOVA) and Tukey's HSD test in SPSS for Windows Version 10.0 were used to analyze the community-environment relationships. Importance Value Index (IVI) was calculated to find out the relative importance of species in the communities following Mueller-Dombois and Ellenberg (1974).

Importance value Index = Relative Density + Relative Dominance + Relative Frequency

where:

$$\text{Relative density} = \frac{\text{Total no. of individuals A}}{\text{Total no. of individuals of all species}} \times 100$$

$$\text{Relative dominance}^{*} = \frac{\text{Dominance of species A}}{\text{Dominance of all species}} \times 100$$

* Dominace was expressed in terms of cover abundance values (Kent and Coker, 1992).

$$\text{Relative frequency} = \frac{\text{Frequency of species A}}{\text{Frequency of all species}} \times 100$$

The Shannon-Weiner diversity index was used to estimate the species richness and relative abundance in each community (Shannon and Weiner, 1949; Magurran, 1988; Kent and Coker, 1992).

The Shannon index was calculated as follows:

$$H' = \sum_{i=1}^{S} (p_i)(\log p_i)$$

where,

H′ = diversity of species,
S = number of species,
Pi = proportion of individuals of the total sample belonging to the i^{th} species

Species evenness (E) was calculated using the Shannon Evenness index following the equation:

$E = H'/H_{max}$ where,
H′ = Shannon diversity index
$H_{max} = \ln S$
$\ln S$ = the natural logarithm of the total number of species in each community
S = Number of species in each community (Shannon and Weiner, 1949).

Phytogeographical comparison was made using similarity analysis index based on all species recorded from the study area. The similarity index used was Sørensen's similarity coefficient:

SS= 2c/(a+b)
where:
"c" is the number of species shared by the two vegetation types compared,
"a" and "b" are the number of species confined to each vegetation. Both woody and herbaceous species were used for similarity analysis.

RESULTS AND DISCUSSION

Floristic composition

A total of 216 species, belonging to 61 families were collected and identified during the study. Poaceae and Fabaceae are the two most dominant families having 13% (28 species) and 11% (24 species) abundance, respectively. Acanthaceae, Asteraceae, Boraginaceae and Euphorbiaceae are the next dominant families. Thirty four families were represented by more than one species while the remaining 27 families were represented by a single species. There are two frequent climber species with photosynthetic stems belonging to the family Vitaceae and other woody and herbaceous climber species belonging to Convolvulaceae, Fabaceae, Oleaceae and Cucuribtaceae are found. Succulents such as *Aloe camperi*, *Sansevieria ehrenbergii*, and *Euphorbia* spp. were also recorded.

Shrubs primarily dominated the growth form composition comprising 43% of the total species. Herbs apart from grasses are the next dominant groups (28%) and there are about 29 grass species identified, which comprise 13% of the total composition. Tree species mainly found along the rivers compose only 11% of the flora and climbers are the least represented growth forms (5%) (see Fig. 3). Generally, vegetation in the study area consists of short-stemmed and multibranched shrubs of about 3 m tall sometimes forming thickets and scattered umbrella shaped trees reaching 8 m heights. Ephemerals and annual herbs like *Tribulus terrestris* commonly flourish after rain.

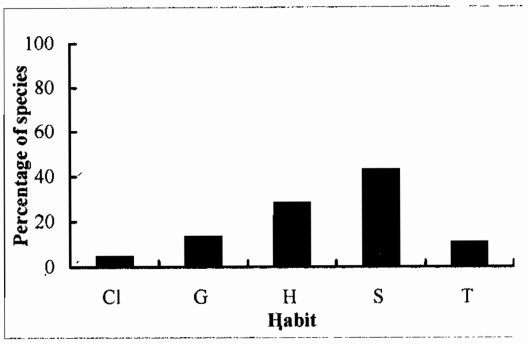


Fig. 3. Growth form of species from the study area.
Cl= Climbers, G= Grasses, H= Herbs other than grasses, S= Shrubs, T= Trees

Vegetation classification and description

Out of the 216 species collected and identified, only woody species (104 species) were used in vegetation classification. Seven plant community types were identified based on TWINSPAN (Hill, 1979). Two outlier relevés were found due to the presence of rare species. The seven different types of classified communities are described as follows:

Community I. Dodonaea angustifolia type:

This community is found between 1646 and 1747 m altitudes. It is dominated by *Dodonaea angustifolia*, which is both character and dominant species. This species and *Euclea racemosa* ssp. *schimperi* are species regenerating in this community. *Grewia tembensis, Rhus retinorrhoea* and *Calpurnia aurea. Cissus rotundifolia* are also found. *C. quadrangularis* and *Jasminum floribundum* are the common climbers found. *Opuntia ficus-indica* is the succulent found on the rocky slopes in patches where shallow surface soil and steep slopes occur. This vegetation is under hillside closure although there is some grazing recently (Kebrom Tekle, 1998).

Community II. Euclea racemosa-Acacia lahai-Dichrostachys cinerea type:

This community found between 1562 and 1688 m altitudes, is dominated by *Euclea racemosa* ssp. *schimperi*, *Acacia lahai* and *Dichrostachys cinerea*. Various trees and shrubs including *Cadia purpurea, Rhus natalensis, Pterolobium stellatum, Ziziphus spina-*

christi, Olea europaea ssp. *cuspidata, Combretum aculeatum, Sageretia thea, Carissa spinarum, Diospyros abyssinica, Grewia tembensis, G. bicolor,* and *Ziziphus mucronata* make up this community. *Steganotaenia araliacea* and *Dichrostachys cinerea* were the characteristic species for this community. Succulents like *Aloe camperi, Euphorbia candelabrum, E. abyssinica,* and *Kalanchoe spp.* commonly occur in this community.

Community III. Euphorbia candelabrum-Cadia purpurea- Euclea schimperi type:

This community is found between 1554 and 1688 m altitudes. The tree-shrub layer is dominated by *Euphorbia candelabrum, Acacia asak* and *Euclea racemosa.* Other trees and shrubs with low cover value include *Acacia seyal, A. tortilis, Opuntia ficus indica, Diospyros abyssinica, Carissa spinarum, Grewia bicolor, G. tembensis, G. velutina, G. villosa, Cadia purpurea* and climbers such as *Capparis tomentosa, Cissus quadrangularis, C. rotundifolia* and *Jasminum* spp are found.

Community IV. Acacia asak - Grewia bicolor type:

The vegetation in the mid-altitudes (mean of 1260 m) of the study area is dominated by *Acacia asak.* Both *A. asak* and *Sansevieria ehrenbergii* were found to have a higher cover value. Most of the shrubs in this community are deciduous among which *A. senegal, Grewia bicolor, G. villosa, G. velutina,* and *Commiphora africana* are common. *Balanites aegyptiaca, Acacia tortilis* and *Ziziphus spina-christi* rarely occur in this vegetation except in drier riverbeds. The *Acacia* shrubs in this community have shorter stature (< 3 m) except in riverbeds where relatively taller individuals are found.

Community V. Ximenia americana-Acacia asak-Sansevieria ehrenbergii type:

This type has a relatively dominant *Ximenia americana* species with still dominant *Acacia asak. Cissus* spp., *Kleinia* sp. and *Sansevieria ehrenbergii* occur abundantly. This community occurs around a village below Bati between 1045 and 1515 m altitudes.

Community VI. Acacia mellifera-A.oerfota type:

It is found between 800 and 1300 m altitudes and is characterised by *Acacia mellifera* and *A. oerfota* dominated vegetation. The most dominant species forming thickets in areas where flood deposits and riverbanks is *A. oerfota. Acacia mellifera* is the most dominant shrub in the drier soils and plots far from riverbeds. The riverine community found along riverbeds has a distinct physiognomy with taller *Acacia tortilis, Balanites, Salvadora persica, Dobera glabra, Boscia coriacea* and *Ziziphus spina-christi.*

Community VII. Prosopis juliflora type:

This is a community found at the foot of the escarpment between 750 and 765 m altitudes. It is dominated by the invasive species *Prosopis juliflora* established on flood deposits. Annual herbs particularly *Tribulus terrestris* flourish after the rainy season. This community is the poorest in species diversity and richness. Associated species with low cover values include *A. tortilis, Balanites aegyptiaca* and *A. asak.* This vegetation type is appearing green during the dry season.

Species diversity and richness

The results of the Shannon-Weiner Index showed that communities I, II, III and VI have high species diversity and richness while community V and VII have low diversity and richness (Table 2). Evenness showed no difference with altitude. The low species diversity in communities IV and V might be due to overgrazing and deforestation observed while high species diversity in community III might be attributed to man-made and natural protection by inaccessible hill-slopes. Community VII is species poor as it is a community dominated by the invasive species *Prosopis juliflora* that is displacing most of the native plant species. *Prosopis juliflora* is an alien species, and according to the information from local communities, it has excluded different indigenous species like *Acacia asak, A. mellifera,* and *A. oerfota* from their natural habitats. High species diversity in community VI may be due to riparian habitat supporting diverse species. Communities with low diversity and richness tend to suffer tragedy of the commons since they are in communal grazing lands that are battleground for resource conflicts. In contrast, communities with high diversity are found in private lands owned by local farmers or protected by the government.

Table 2. Comparison of plant species diversity, evenness and richness among the seven community types following Shannon-Weiner Index.

	Community Types						
	I	II	III	IV	V	VI	VII
Species Diversity (H')	3.14	3.46	3.52	3.24	2.65	3.30	1.34
Species Evenness (E)	0.93	0.94	0.97	0.90	0.94	0.94	0.69
Species Richness (N)	29	40	38	30	17	33	7

Generally, differences in the diversity of species among the communities may be correlated with soil depth, altitude, slope, soil moisture, electrical conductivity and disturbances. With respect to altitude, species diversity and richness in the study area is relatively high relatively higher between 1000 and 1200 m and 1500 and 1700 m altitudes (Fig. 4). Species richness of the vegetation in the study area is positively correlated with altitude as in the vegetation of Borana lowlands described by Gemedo Dalle (2004). However, Burger *et al.* (2003) reported that species richness normally drops with increasing altitude, but not absolutely so in Ethiopia since there is middle-upper altitude diversity hump particularly around 1600 m and upwards. Species richness is also positively correlated with soil depth as shown in Figure 5. In general, altitude has no significant impact on species evenness and invasion by alien species has the highest impact on species diversity.

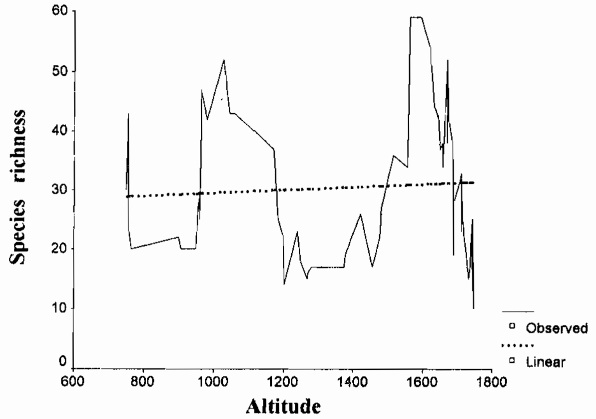


Fig. 4. Species richness and altitudinal distribution.

Density of woody species

The average number of tree and shrub individuals as calculated from the data taken from all plots is 3146 per hectare (Fig. 6).

The mean density of woody species of the study vegetation was more or less similar to that of Borana lowlands (3149 per ha) (Gemedo Dalle, 2004). High density in community I is due to either natural or man-made protection and the small-sizedness of *Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi* contributing to higher total count within a given quadrat size. In contrast, low density in community IV and V may be due to high grazing and browsing pressure and cutting of shrubs for firewood and charcoal production. Community type VI has higher density due to dense thickets in drier riverbeds and flooding sites and low deforestation for charcoal production. Altitude, growth forms, overgrazing and deforestation tend to affect density in the study area. A higher density observed at high altitudes in the study area is in contrast to density of woody species in Borana lowlands (Gemedo Dalle, 2004). This might be attributed to the minimum disturbance level maintained by conservation activities and natural protection in inaccessible hillslopes.

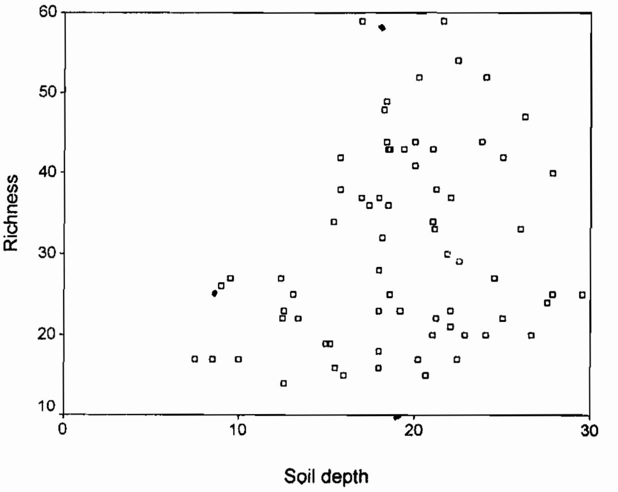


Fig. 5. Species richness and soil depth.

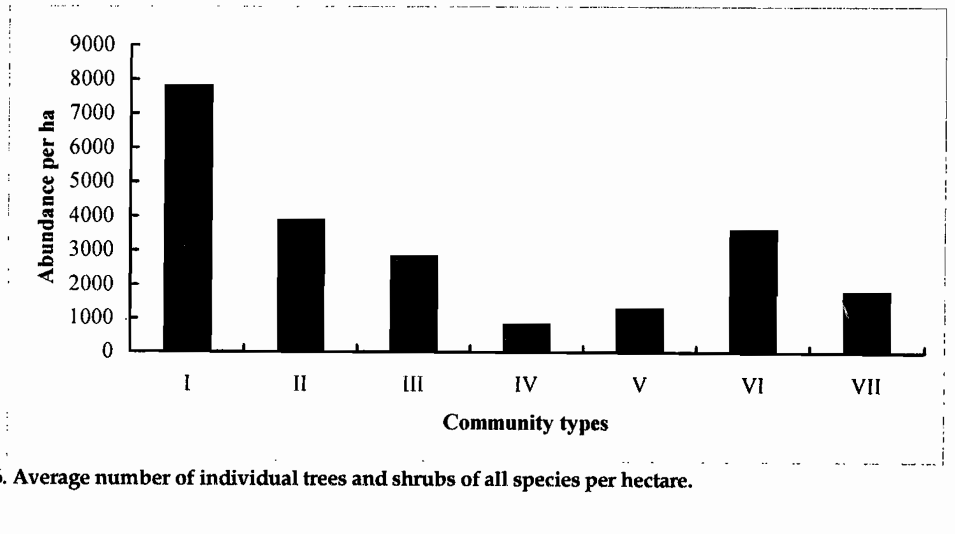


Fig. 6. Average number of individual trees and shrubs of all species per hectare.

Importance value index

The results of Importance Value Index (Table 3) showed that *Euclea racemosa* ssp. *schimperi* (27.7), *Dodonaea angustifolia* (22.8), *Acacia asak* (21.9) and *Grewia bicolor* (14.4) are the four species having high IVI. *Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi* are having the highest relative density, 21 and 20, respecitvely. *Acacia asak* is the most dominant species since it has the largest relative dominance value (9.5). The second most dominant species is *Grewia bicolor* with a relative dominance value of 5.9. In terms of relative frequency, *Grewia bicolor* is the most frequent species followed by *A. asak* (5.4) and *Euclea racemosa* ssp. *schimperi* (4.2).

Environmental correlation analysis

Altitude, salinity, conductivity, soil colour, slopes and soil depth were correlated with plant communities (Table 4). Figs 2 a-c show the presence of wide variations in temperature and rainfall distribution. Varying with altitude, mean monthly temperature varies between 19°C to 30°C and mean annual rainfall varies between 314 and 728 mm. Altitudinal differences affect species composition and distribution of plant communities (Fig. 7). At relatively low temperatures and high rainfall distribution, evergreen scrubs, herbs and grasses are relatively dominant while deciduous and spiny shrubs are dominant in areas with higher temperatures and low rainfall distribution. *Acacia oerfota* and *Salvadora persica* were observed to be restricted to limited microclimatic conditions to bank of rivers and flooding sites. *Acacia oerfota* prevails in areas that may be waterlogged during rainy seasons like that of *Acacia drepanolobium* in Borana lowlands (Gemedo Dalle, 2004).

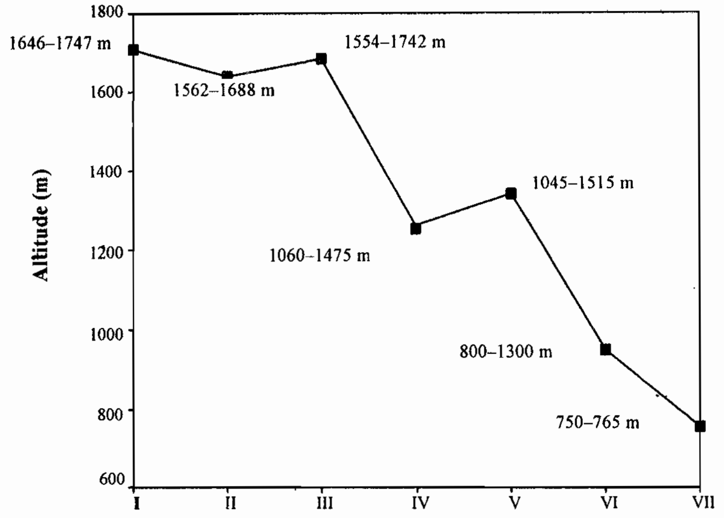
Table 3. Importance value indexes of 20 most dominant shrubs and trees.

No	Species	Relative Density	Relative Frequency	Relative Dominance	Importance Value index
1	*Euclea racemosa* ssp. *schimperi*	20	4.21	3.3	27.71
2	*Dodonaea angustifolia*	21	1.15	0.4	22.76
3	*Acacia asak*	7	5.36	9.5	21.93
4	*Grewia bicolor*	3	5.45	5.9	14.38
5	*Cadia purpurea*	5	3.06	4.9	13.01
6	*Acacia mellifera*	3	3.92	5.8	12.75
7	*Grewia tembensis*	2	4.09	4.3	11.01
8	*Acalypha fruticosa*	7	1.05	1.6	9.72
9	*Acacia tortilis*	1	4.5	4.1	9.61
10	*Euphorbia candelabrum*	4	2.3	3	9.34
11	*Rhus natalensis*	4	3.92	1	8.96
12	*Acacia senegal*	1	4.02	3.7	8.73
13	*Acacia lahai*	1	4.02	3.6	8.63
14	*Carissa spinarum*	2	2.78	3.3	8.1
15	*Rhus retinorrhoea*	0	1.34	6.6	7.94
16	*Acacia seyal.*	1	3.54	2.7	7.25
17	*Grewia villosa*	1	3.54	2.2	6.75
18	*Acacia oerfota*	2	2.39	2.2	6.61
19	*Euphorbia candelabrum*	1	2.49	2.5	6
20	*Sageretia thea*	1	3.06	1	5.07

Table 4. Tukey HSD test to compare the seven community types using some environmental variables*.

Environmental variables	Plant community types						
	I	II	III	IV	V	VI	VII
Salinity	.11	.12	.09	.17	.13	.16	.34
	a	a	a	a	a	a	b
Conductivity	.15	.15	12	.22	.18	.43	.46
	ns	ns	ns	ns	ns	ns	ns
Soil color	2	2.83	2	1.9	2	2.3	3
	ab	bc	ab	a	ab	abc	c
Altitude	1708	1642	1686	1258	1338	950	750
	d	d	d	c	c	b	a
Soil depth	20.4	19.7	18.9	15	15.6	23.9	23.6
	ab	ab	ab	a	a	b	b
Slope	31.1	27.3	28.8	12.75	23.75	5.2	3.4
	c	c	c	ab	bc	a	a

*significance differences at $p<0.05$ are indicated by different letter notations at each row, ns=nc significance.



Community types

Fig. 7. The relative distribution of communities with respect to altitude.

Altitude may be the most important factor determining species composition in the region. *Acacia* species, particularly, *A. mellifera* and *A. oerfota* dominate in lower altitudes whereas *A. senegal* prevails between the relatively higher altitude species *A. asak* and the low altitude species *A. mellifera. A. lahai, A. seyal, Acokanthera schimperi* and *Terminalia brownie* were found at higher altitudes. *Euphorbia candelabrum* dominated zone is found just above *A. asak. Euclea racemosa* ssp. *schimperi, Dodonaea angustifolia, Diospyros abyssinica,* and *Calpurnia aurea* dominate the high altitudes while *A. tortilis, Dobera glabra, Balanites aegyptiaca, Delonix elata* and *Berchemia discolor* are occurring at low altitudes of the study area.

Soil depth is also correlated with the communities. Soils in steep slopes are shallow while those of gentle slopes and valleys are deep. Shrubs are well adapted to shallow soils whereas trees are not dominant partly due to low soil depth. However, areas with rocky outcrops and very shallow soils will remain covered by open vegetation even if such areas become protected and human intervention is controlled (Kebrom Tekle *et al.*, 1997). Community VII is found to exist in a relatively saline soil and is different from the rest because *Prosopis juliflora* resist saline soils and is used to reclaim saline soils of cultivated fields abandoned because of salinization. This is because the area is a flood plain that concentrates different salts. There was no significance difference in soil electrical conductivity among communities.

In areas where the vegetation of the degraded slopes is regenerating, the unpalatable species *Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi* are dominant. Anthropogenic and climatic factors are increasingly contributing to the deterioration of shrublands in the region. According to Kebrom Tekle (1998), most of the shrublands in Kalu district deteriorated to remaining open areas, as there was an increase of 14.3 Km^2 of the open areas and a matching decrease of 15.5 Km^2 of the shrublands between the years 1958-1986. Afar pastoralists increased firewood and charcoal production as a survival mechanism and sell it along main roads to counteract income losses emanating from deteriorated terms of trade for livestock against grain. And thus, by cutting down trees and shrubs they are further damaging on an already fragile biophysical environment, increasing the depletion of shrublands and other natural resources (Piguet, 2002).

Endemic and invasive plant species

The following taxa endemic to Ethiopia have been recorded from the study area: *Aloe camperi, Aloe trichosantha* and *Rhus glutinosa* ssp. *glutinosa.* There are various indicator species for disturbance, some of which with invasive nature found along the roads, flooding sites and highly disturbed places (Table 5). Fire, flood, disturbance and overgrazing provide open space, creating areas of open soil or reducing competition from other plants. This is favorable for colonization by invasive plants. Floods or good rainfall years may recruit some invasive species like *Prosopis juliflora*. According to Hailu Shiferaw (2002), *Prosopis juliflora* is dispersed due to rain floods and livestock mobility routes.

Phytogeographical description

The vegetation of the study area is mainly *Acacia*-dominated deciduous scrubland (White, 1983). The species are distributed in various habitats like rocky outcrops, rocky slopes, disturbed habitats, vicinity of habitations, dry riverbeds, riverbanks, open dry scrub and semi-desert flood plains. The study vegetation was compared to seven different vegetation types based on similarities in species composition and distribution. Woody species were considered for analysis (Table 6). Although there is no complete floristic list and the sizes of the different vegetation types may not be equal, phytogeographical comparison will give some indications of relationships (Tamrat Bekele, 1993).

The results of Sørensen's coefficient of similarity shows, that the vegetation of the eastern escarpment of Welo is more close to the vegetation of eastern slopes of South Welo highlands and that of Shoa Robit area. These areas have many species in common and the similarity in floristic associations may be due to geographical proximity and similar climatic and edaphic conditions and exposure to more or less similar anthrogenic interferences. Despite there is no geographical proximity; similar association of species between the vegetation of the study area and the eastern escarpment of Eritrea, shrubland vegetation of Adwa and Borana lowlands exists owing to similar climatic conditions.

Table 5. Invasive plant species and/or indicators of disturbance from the study area.

No	Species Name	Family	Habit	Indicators of Disturbance	Invasive nature
1	*Achyranthes aspera*	Amaranthaceae	Herb	++	-
2	*Althernanthera pungens*	Amaranthaceae	Herb	+	-
3	*Argemone mexicana*	Papaveraceae	Herb	++	++
4	*Calotropis procera*	Asclepiadaceae	Shrub	++	-
5	*Cleome gynandra*	Capparidaceae	Shrub	+	-
6	*Commelina benghalensis*	Commelinaceae	Herb	++	-
7	*Dichrostachys cinerea*	Fabaceae	Shrub	+	-
8	*Heliotropium ovalifolium*	Boraginaceae	Herb	++	+
9	*Opuntia ficus-indica*	Cactacea	Shrub	+	-
10	*Parthenium hysterophorus*	Asteraceae	Herb	++	++
11	*Prosopis juliflora*	Fabaceae	Shrub/Tree	+	++
12	*Sansevieria ehrenbergii*	Dracenaceae	Herb	+	-
13	*Solanum nigrum*	Boraginaceae	Shrub	+	-
14	*Tagetes minuta*	Asteraceae	Herb	+	-
15	*Tribulus terrestris*	Zygophyllaceae	Herb	++	+
16	*Xanthium spinosum*	Asteraceae	Herb	++	-
17	*Xanthium strumarium*	Asteraceae	Herb	++	+

Table 6. Floristic similarities between vegetation of the eastern escarpment of Welo and seven other vegetation types.

No	Vegetation	Altitudes (m)	Total No.of species.	Common species	Similarity Index
1	Vegetation of hill slopes of South Welo[1]	1350-2700	53	23	.17
2	Vegetation of eastern slopes of South Welo highlands[2]	1200-2800	144	60	.34
3	Vegetation of Borana lowlands[3]	1250-1780	109	35	.21
4	Eastern escarpment of Eritrea[4]	190-2075	284	51	.2
5	Denkoro forest[5]	2330-3415	174	17	.08
6	Shewa Robit area[6]	1050-1290	152	56	.31
7	Shrubland vegetation of Adwa[7]	1500-2030	203	53	.23

Source: [1]Kibrom Tekle *et al.* (1997); [2]Mengistu Gonsamo (1998); [3]Gemedo Dalle (2004); [4]Sahle G/Kirstos (1984); [5]Abate Ayalew (2006); [6]Hussien Adal (2004); [7]Zerihun Woldu and Feoli (2001).

There is very little similarity between Denkoro afromontane forest and the study vegetation due to differences in altitudinal, climatic and edaphic conditions regardless of geographical proximity. This indicates that climatic factors are much more influential than geographical proximity for species distributions. *Juniperus procera, Acacia abyssinica, Cordia africana* and *Dovyalis abyssinica* cover most of the higher altitude hills and mountain slopes between Dessie and Kombolcha (Kebrom Tekle, 1998; Tesfaye Bekele, 2000). However, the hillslopes of the lowlands between Kombolcha and Bati are covered by different species such as *Euclea racemosa* ssp. *schimperi, Dichrostachys cinerea, Diospyros abyssinica* and *Calpurnia aurea.* The vegetation at higher altitudes (1700–1780 m) has some elements of dry evergreen Afromontane forest characterized by *Olea europaea* ssp. *cuspidata* and scrubs of *Carissa spinarum, Dodonaea angustifolia* and *Euclea racemosa* ssp. *schimperi.*

The study vegetation has high floristic similarity to sub-desert scrub on the eastern escarpment of Eritrea with common species of *Acacia, Ziziphus, Maerua, Cadaba* and *Boscia* are found (Sahle G/Kirstos, 1984). *Opuntia ficus-indica* is found above 1800 m through the eastern Eritrea escarpment and was observed to hold soils well (Sahle G/Kirstos, 1984). However, the species in eastern escarpment of Welo is mainly limited to rocky hills, shallow soils and highly disturbed sites and is found at altitudes below 1800 m.

CONCLUSION AND RECOMMENDATIONS

The study vegetation is characterized by Xerophilous woodland and small-leaved deciduous bushland and thicket. Despite variation in species composition and diversity, the area is rich in diversity and abundance of plant species and is home for at least three endemic plant species. Altitude, soil depth and slope have a strong correlation with the types and diversity of plant communities. Physical attributes such as steepness of a slope and altitude influence the nature of the plant communities since they influence soil and climatic factors. These features contribute to natural protection of the vegetation cover too.

Apart from climatic and edaphic conditions, anthropogenic factors have influenced the nature of the vegetation. Shrubs were found to be more dominant than trees and herbaceous cover is also low partly due to overgrazing and invasion. Deforestation, charcoal production, overgrazing, bush encroachment and invasion combined with recurrent drought are resulting in deterioration of range and loss of vegetation. The presence of invasive species as one plant community is something to give due attention since it is a threat to biodiversity in the area. Area closure, soil conservation, management of invasive species and minimizing anthropogenic pressure will be helpful for regeneration of the vegetation. Further in-depth studies on the ecology of the region including the aspects of degradation and potentials of regeneration in the context of the prevailing climatic and socioeconomic environment will be beneficial in the planning and implementation of conservation activities and biodiversity use in the study region.

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