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Ecological study of the vegetation in Gamo Gofa zone, southern Ethiopia

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Abstract: The vegetation and some associated environmental variables were investigated at Key Afer-Shala Luqa and Southwest of Lake Chamo, in the Gamo Gofa Zone, southern Ethiopia. To determine the species richness and classify the plant community types, analyze the species richness, evenness and diversity of the identified plant community types, and relate the plant community types with the environmental factors, 71 quadrats (size = 20 x 20 m = 400 m^2) were sampled at both sites. In each quadrat, data on the identity and cover abundance of species, altitude, slope and aspect as well as soil samples were collected. The pH, sand, silt, clay, potassium, sodium and phosphorus contents of the soil were analyzed in the laboratory. Two hundred sixteen plant species representing 58 families were recorded. The Fabaceae family was represented by the highest number of species (33 spp. = 15%), followed by Poaceae (22 spp. = 10%) and Capparidaceae (12 spp. = 7%). Seven plant community types were identified. Post-hoc comparison of means among the community types showed significant variation in altitude indicating that altitude was the most important factor in determining community type. The *Hyparrhenia filipendula-Combretum molle* dominated community was richer in species and higher in diversity than others, while the *Commiphora cyclophylla-Actiniopteris radiata-Sansevieria ehrenbergii* dominated community exhibited the least species richness and diversity. Recommendations for the sustainable utilization of the vegetation resources at the study sites are discussed.

Resumen: La vegetación y algunas variables ambientales asociadas fueron investigadas en Key Afer-Shala Luqa y el suroeste del Lago Chamo, en la Zona Gamo Gofa, sur de Etiopía. Para determinar la riqueza de especies y clasificar los tipos de comunidad vegetal, analizar la riqueza de especies, equidad y diversidad de los tipos de comunidad vegetal identificados, y relacionar los tipos de comunidad vegetal con los factores ambientales, se muestrearon 71 parcelas (tamaño = 20 × 20 m = 400 m^2) en ambos sitios. En cada parcela se colectaron datos sobre la identidad y abundancia por cobertura de las especies, y la altitud, pendiente y orientación, así como muestras de suelo. El pH y los contenidos de arena, limo, arcilla, potasio, sodio y fósforo en el suelo fueron analizados en el laboratorio. Se registraron 216 especies de plantas pertenecientes a 58 familias. La familia Fabaceae estuvo representada por el mayor número de especies (33 especies = 15%), seguidas por Poaceae (22 especies = 10%) y Capparidaceae (12 especies = 7%). Se identificaron siete tipos de comunidad vegetal. Una comparación post-hoc de las medias entre tipos de comunidad mostró variación significativa en la altitud, indicando que la éste fue el factor mas importante en la determinación del tipo de comunidad. La comunidad dominada por *Hyparrhenia filipendula-Combretum molle* tuvo una mayor riqueza de especies y una diversidad más alta que las otras, mientras que la comunidad dominada por *Commiphora cyclophylla-Actiniopteris radiata-Sansevieria ehrenbergii* exhibió la menor riqueza de especies y diversidad. Se discuten recomendaciones para el uso sostenible de los recursos vegetacionales en los sitios de estudio.

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Resumo: A vegetação e algumas variáveis ambientais associadas foram investigadas em Key Afer-Shala Luqa e sudoeste do lago Chamo, na zona de Gamo Gofa no sul da Etiópia. Para determinar a riqueza específica e classificar os tipos de comunidades de plantas, analisar a riqueza específica, a uniformidade e diversidade dos tipos de comunidades de vegetação identificadas, bem como relacionar os tipos de comunidades de plantas com os factores ambientais, foram amostrados 71 quadrados (dimensão = 20 x 20 m = 400m^2) nas duas estações. Em cada quadrado, a informação da identidade e abundância de espécies na cobertura, altitude, declive, e aspecto bem como das respectivas amostras de solo forem colhidas. O pH, os teores de areia, limo e argila, potássio, sódio e fósforo no solo foram analisados no laboratório. Duzentas e dezasseis espécies, representando 58 famílias foram registadas. A família Fabaceae era a mais representada (33 spp. = 15%), seguida da Poaceae (22 spp. = 10%) e Capparidaceae (12 spp. = 7%). Sete tipos de comunidades de plantas foram identificados. Uma comparação posterior das médias entre os tipos de comunidade mostrou uma variação significativa na altitude indicando que esta variável era o factor determinante mais importante na determinação do tipo de comunidade. A comunidade dominada pela associação *Hyparrhenia filipendula-Combretum molle* era a mais rica em espécies e com a maior diversidade em relação às restantes, enquanto que a comunidade dominada pela *Actiniopteris radiata-Sansevieria ehrenbergii* exibia a menor riqueza específica e diversidade. Recomendações para a utilização sustentável dos recursos vegetais nas estações estudadas são discutidas.

Key words: Altitude, diversity, environmental variables, evenness, plant community types, species richness.

Introduction

Ethiopia has the fifth largest flora in Africa (Anonymous 1997a,b). The flora is very heterogeneous and has a rich endemic element owing to the diversity in climate, vegetation and terrain. It is estimated to contain between 6,500–7000 species of higher plants, of which about 12% are endemic (Tewolde 1991). Endemism is particularly high in the high mountains and in the Ogaden area, south-eastern Ethiopia.

Despite these realities, the vegetation resources, particularly forests, are disappearing at a very alarming rate in Ethiopia before we even have a chance to study and document them (EFAP 1994). If this trend of deforestation/devegetation continues unabated, there is a great danger of serious decline or loss of biodiversity. Since the population is growing at a rate of about 3% per year (Anonymous 1988), the need for more arable land to cultivate crops becomes inevitable, further aggravating the rate of deforestation and associated land degradation. It is, therefore, urgent and important to study and document the vegetation resources of the country.

The vegetation resources of Ethiopia, including forests, woodlands and bushlands, have been studied by several scholars (Chaffey 1979; EFAP 1994; Friis 1986, 1992; Friis & Mesfin 1990; Logan 1946; Mesfin 1992; Pichi-Sermolli 1957; Russ 1945 compiled by Wolde Michael 1979; Tewolde 1986, 1988, 1991; von Breitenbach 1961, 1963; Westphal 1975) who have employed different methods of vegetation classification. Several studies focusing on forests or vegetation of specific regions in Ethiopia (Coetzee 1978; Friis *et al.* 1982; Gilbert 1970; Hailu 1982; Haugen 1992; Hedberg 1951, 1957; Kumelachew & Tamrat 2002; Lisanework & Mesfin 1989; Miehe & Miehe 1994; Menassie & Mesresha 1996; Mooney 1963; Sebsebe 1988; Tamrat 1993a,b, 1994; Tesfaye *et al.* 2001; Uhlig 1988; Uhlig & Uhlig 1990; Weinert & Mazurek 1984; Zerihun 1985; Zerihun *et al.* 1989; Zerihun & Mesfin 1990; Zerihun & Backeus 1991) have also been carried out.

Based on the results of most of these studies, the various vegetation types of Ethiopia have been grouped into nine general categories for the purpose of developing the Conservation Strategy of Ethiopia. The nine vegetation types are: (i) Afro-Alpine and sub-Afroalpine vegetation; (ii) Dry evergreen montane forest and montane grassland; (iii) Montane evergreen thicket, which is further divided into: (a) Montane evergreen thicket and (b) Montane evergreen scrub; (iv) *Acacia-Commiphora* or small-leaved deciduous woodland; (v) Moist evergreen forest; (vi) Lowland semi-evergreen forest; (vii) *Combretum-Terminalia* or broad-leaved deciduous woodland; (viii) Desert and semi-desert scrubland; and (ix) Riparian and swamp vegetation (Anonymous 1997; Demel 2000).

Despite the aforementioned general and specific studies conducted in Ethiopia, detailed ecological investigation on the vegetation of Gamo Gofa Zone in southern Ethiopia is still lacking. Therefore, the objectives of this study were to: (a) characterize and classify the vegetation types at Key Afer-Shala Luqa and Southwest of Lake Chamo in Gamo Gofa Zone; (b) relate the distribution of plant communities to some environmental parameters and compare the species richness of the different community types recognized; and (c) obtain information that could provide some guidelines to implement sustainable management of these resources.

Materials and methods

Study sites

The study sites, namely Key Afer-Shala Luqa (hereafter abbreviated as KASL) and Southwest of Lake Chamo (hereafter abbreviated as SOLC), are located in Gamo Gofa Zone of the Southern Nations, Nationalities and Peoples National Regional State, southern Ethiopia (Fig. 1). The two sites were selected since the area between them is an agricultural land, which covers some 90-100 km and the vegetation at the two sites is physiognomically similar. The altitude ranges between 600 and 1900 m at KASL and between 1100 and 1900 m at SOLC. In the Lake Chamo basin, faulting accompanied by wide spread volcanic activity lead to the formation of basaltic lava. Most of the area around Lake Chamo is covered by gravel and stones, while hard rocks occur within 50 cm of the surface around KASL (Anonymous 1988). Basalts also form the greater part of the trap series in Gamo Gofa Zone, in which the sites are located and more silicic lavas are lying above the basalts (Mohr 1971).

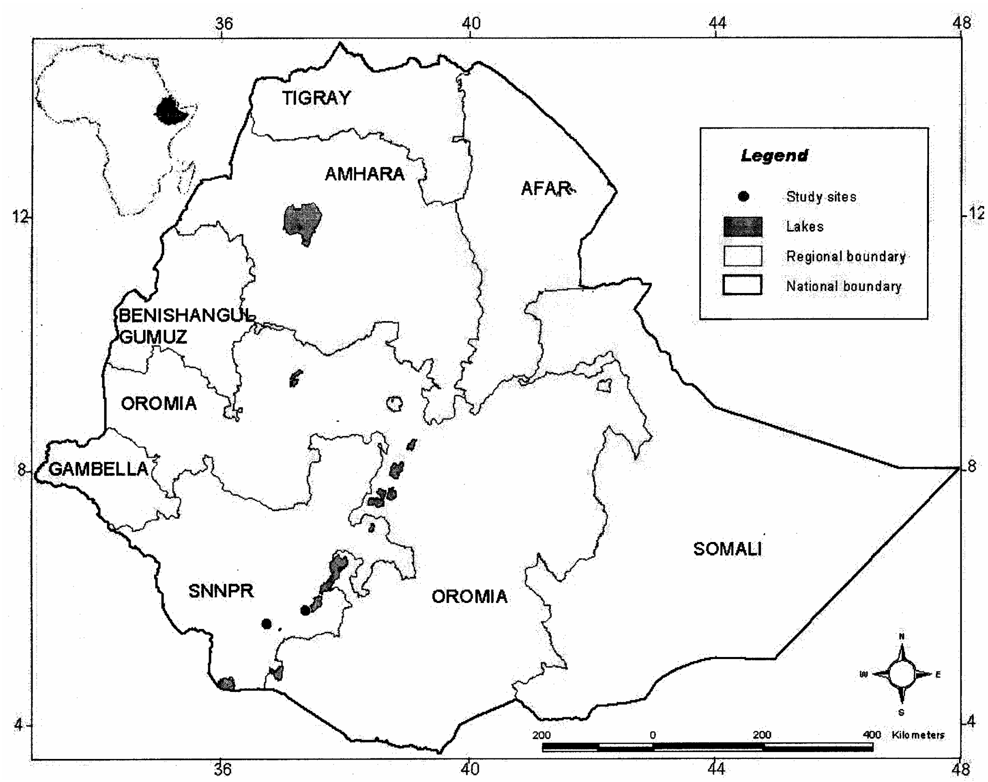

Fig. 1. A map showing the study area.

The highlands of Gamo Gofa Zone are characterized by nine rainy months, which occur between March and October and in January. Furthermore, the southern parts of Gamo Gofa, Zone are characterized by eight rainy months from February to July and from September to October (Daniel 1977). High concentration of rainfall occurs in the month of April.

The inhabitants of SOLC are primarily Zeyise people. The Zeyise people depend on rain-fed agriculture and cultivate maize and sorghum as their main crops. During the early and late dry period of the year, the Zeyise people burn vegetation to clear bushes for agricultural purposes. The agro-pastoral Benna and Tsemay people inhabit KASL. The major annual crops grown by the Benna and Tsemay are maize and sorghum. The major perennial crop cultivated by the Benna is banana. Apiculture and burning of vegetation in the dry season is a common practice by all ethnic groups. A number of plants are used traditionally by both Zeyise, Benna and Tsemay peoples (Teshome & Sebsebe 2002).

Vegetation sampling

Following a reconnaissance survey, actual sampling of vegetation was done focusing on homogeneity via preferential means. From both study sites, 71 quadrats (each measuring 20 x 20 m = 400 m^2) were sampled. The co-ordinates of each sample stand were determined using Garmin GPS (Geographical Position System) 45XL and the points are indicated in the geographical position of the sample stands (Fig. 2). The presence-absence and cover abundance data, defined here as the proportion of area in a quadrat covered by every species recorded, gathered from each quadrat were later converted to cover abundance values using the modified 1-9 Braun-Blanquet scale (van der Maarel 1979).

Voucher specimens of plants were pressed and brought to the National Herbarium of Addis Ababa University for identification. Similarity ratio was used as an index for classification and Shannon-Wiener Diversity Index was employed to determine diversity (Krebs 1989).

Environmental data and soil analysis

Physiographical variables, namely altitude, slope and aspect, were recorded for each quadrat using a Thommen altimeter (5000 m), Type 65 Silva Clinometer and Type 15T Silva Ranger Compass, respectively. For analyzing soil variables, soil samples were collected with a soil auger from the top 10 cm depth. Composite soil samples from samples collected from the four corners and the middle of quadrats were brought to the soil laboratory at Addis Ababa University. The soil samples were air-dried, rolled and passed through a 2 mm sieve for laboratory analyses. These soil samples were analyzed following the procedures outlined by Juo (l978), Cottenie (1980) and Tamirie *et al.* (unpublished).

Soil pH was measured in water suspension (1:1 soil/water ratio) using a glass electrode pH-meter, which was standardized using buffers of pH 7 and 4. Soil texture was determined using the Bouyoucos Hydrometer Method. Sodium hexamethaphosphate was used as the dispersing agent. For the determination of potassium and sodium, standard solutions of potassium and sodium were prepared. The bases were extracted with 1N ammonium acetate at pH 7. Using a Gallenkamp flame photometer analyzer, both sodium and potassium concentrations were determined. Phosphorous concentration was determined using the Bray No. 1 Method. Soil color was determined using a Munsell's Color Chart. Textural analysis of soil samples was carried out using the triangular diagram relating particle size distribution to textural classes (Hunt 1972; Fitzpatrick 1974).

Data analyses

Before the analysis, the data collected from the two sites were pooled since the vegetation at the

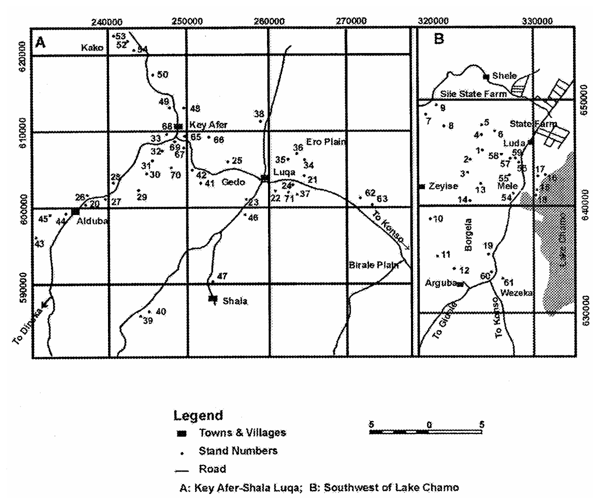

Fig. 2. Geographical position of the quadrat samples in the study.

two sites is physiognomically similar. Multivariate numerical methods were employed to summarize the vegetation data sets. Classification was carried out by similarity ratio from the various options provided under hierarchical clustering by distance optimization using the program SYNTAX (Podani 1988). The physiographical and soil variables were averaged for each of the major community types identified. In order to examine the significant differences and/or similarities between the community types identified, a post-hoc comparison test was employed for the measured environmental parameters using the Least Significant Difference test (Statsoft 1993). The values of soil analysis were averaged in accordance with the community types identified and tested using Analysis of Variance (ANOVA) for significant differences among the plant communities.

In this paper, plant nomenclature follows Cufodontis (1953-1972), Hedberg & Edwards (1989, 1995), Friis (1992) and Edwards *et al.* (1995, 1997, 2000).

Results and discussion

Species richness

A total of 216 plant species representing 58 families were recorded (Appendix 1). The family Fabaceae was represented by 33 species (15%), Poaceae by 22 species (10%), Capparidaceae by 12 species (7%), Asteraceae and Lamiaceae by 10 species, Acanthaceae and Anacardiaceae by 9 species each, Euphorbiaceae and Combretaceae by 6 species each, Tiliaceae, Vitaceae and Rubiaceae by 5 species each, Burseraceae, Asclepiadaceae, Sapindaceae and Solanaceae by 4 species. Other families were represented by one to three species. All the recorded families belonged to angiosperms except the family Selaginellaceae and Actiniopteridaceae.

The species richness at the two study sites combined was much higher than those reported for Gara Ades forest in southeastern Ethiopia, i.e. 124 species (Uhlig & Uhlig 1990) and the Afromontane and transitional rainforest vegetation in southwestern Ethiopia, i.e. 139 species (Kumelachew & Tamrat 2002), more or less comparable with that reported for the vegetation of the Gambelia region in southwestern Ethiopia, i.e. 220 (Tesfaye *et al.* 2001) and lower than that reported for the Wof-Washa forest, in central Ethiopia, i.e. 252 species (Demel & Tamrat 1995).

Plant community types

Seven plant community types (clusters) were identified (Fig. 3). The plant communities were named after two or three of the dominant species, which occur in each group using the relative magnitude of mean cover abundance, defined as the mean cover abundance value of a species in different quadrats that occurs in a given community (Table 1). The seven community types are described below:

1. *Heteropogon contortus-Acacia hockii* community type

This community type was described from SOLC and KASL and the dominant tree species were *Acacia hockii* and *Combretum molle*. Other dominant tree species included *Acacia seyal* and *Terminalia brownii*. *Heteropogon contortus*, *Hypoestes forskolei* and *Sporobolus ioclados* dominated the ground flora of the community.

2. *Hyparrhenia filipendula-Combretum molle* community type

This community type was described from SOLC and KASL, and the dominant tree species, in addition to the two included in the community name, were *Terminalia brownii* and *Ozoroa insiginis*. The herbaceous layer was dominated by *Hyparrhenia filipendula*. Due to encroachment of *Acacia* species and over utilization of *Terminalia* and *Combretum*, the community appears to be dominated by *Acacia hockii*. From the grass cover and the woody species composition, it seems that both communities (community type 1 and type 2) belong to the savanna woodland vegetation type with a varying degree of interference and canopy cover.

3. *Achyranthus aspera-Acacia tortilis* community type

This community type was described from SOLC only. The tree layer of this community was dominated by *Acacia tortilis*. Other dominant tree species included *Acacia seyal* and *Acacia nilotica*. *Achyranthus aspera*, *Cynodon dactylon* and *Cenchrus ciliaris* dominated the herbaceous layer.

4. *Acacia mellifera-Acalypha fruticosa-Acacia brevispica* community type

This community type was described from the bushlands of SOLC and from the Shala plain including its mountain chains. The dominant shrubs *Acacia mellifera*, *Acalypha fruticosa* and *Acacia brevispica* characterized this community. Another abundant shrub of the community was *Combretum aculeatum*. The most important herbaceous layer species were *Sansevieria ehrenbergii*, *Barleria*

Table 1. Mean cover abundance of major species in the community types.

Community type	**1**	**2**	**3**	**6**	**4**	**5**	**7**
Community size*	**14**	**24**	**3**	**4**	**11**	**7**	**5**
Terminalia brownii Fres.	**1.4**	1.2	0.0	0.0	0.4	0.0	0.0
Heteropogon contortus Roem & Sch.	**5.8**	0.9	0.0	0.0	2.0	0.7	0.0
Acacia hockii De Wild	**4.8**	3.2	0.0	0.0	0.0	0.0	0.0
Hypoestes forskolei Roem & Sch.	**3.0**	1.5	1.7	0.3	0.9	0.1	0.0
Acacia seyal Del	**2.4**	2.2	1.7	0.3	0.9	0.1	0.0
Combretum molle G. Don	**4.1**	**4.3**	0.0	0.0	0.0	0.0	0.0
Hyparrhenia filipendula Stapf.	1.1	**4.6**	0.0	0.0	0.0	0.0	0.0
Ozoroa insiginis Del	0.6	**1.2**	0.0	0.0	0.0	0.0	0.0
Euclea divinorum Hiern	0.6	**1.5**	0.0	0.0	0.0	0.0	0.0
Sporobulus ioclados Nees	1.7	1.2	0.0	0.0	0.0	0.0	0.0
Dodonoae angustifolia L.f.	0.3	0.9	0.0	0.0	0.0	0.0	0.0
Cynodon dactylon Pers.	0.0	0.2	1.7	0.0	0.5	0.0	0.0
Achyranthus aspera L.	0.0	0.1	**6.0**	0.3	0.0	0.1	0.0
Acacia tortilis Hayne	0.4	0.1	**4.0**	**4.0**	0.7	0.4	0.4
Indigofera spicata Forssk.	0.1	0.2	0.3	**3.0**	0.5	0.7	1.2
Cenchrus ciliaris L.	0.0	0.1	1.7	0.0	0.5	0.0	0.0
Acacia mellifera Benth.	0.0	0.1	0.0	1.3	**5.3**	1.9	2.6
Acalypha fruticosa Forssk.	0.1	0.8	2.3	0.0	**3.6**	1.6	0.0
Acacia brevispica Harms	0.7	0.3	0.0	0.0	**3.3**	0.0	0.0
Cissus quadrangularis L.	0.0	0.3	0.3	0.3	**2.4**	1.6	0.0
Barleria quadrispina Lindau	1.7	0.1	0.0	0.3	1.0	**2.3**	0.0
Cissus rotundifolia Vahl	0.6	0.2	0.0	1.5	1.1	**2.7**	0.2
Sansivieria ehrenbergii Back	0.0	0.0	0.0	0.0	1.8	**2.9**	0.0
Commiphora cyclophylla Chiov.	0.0	0.0	0.0	0.8	0.0	**3.3**	0.8
Actiniopteris radiata Link	0.0	0.0	0.0	0.0	0.1	**3.0**	0.0
Selaginella philipsiana Alston	0.0	0.0	0.0	0.0	0.1	**2.4**	0.0
Premna recinosa Schouer.	0.0	0.0	0.0	0.0	0.0	**2.4**	1.6
Combretum aculeatum Vent.	0.0	0.0	0.0	0.0	1.6	0.3	0.0
Sansivieria forskaoliana Hepper & Wood	0.0	0.0	0.0	0.3	0.5	0.0	0.0
Aristida kenyensis Henr.	1.3	0.5	0.0	0.0	0.7	0.4	0.0
Boswellia neglecta S. Moore	0.0	0.0	0.0	0.0	0.5	1.7	0.0
Tarenna graveolensis Bremek	0.0	0.0	0.0	0.3	0.2	1.8	0.8
Euphorbia tirucalli L.	0.1	0.0	0.0	0.3	0.0	0.7	0.0
Acacia reficiens Wawra.	0.0	0.0	0.0	0.0	0.0	0.3	**5.6**
Megalochlamys violacea Vollesen	0.0	0.1	0.0	0.0	0.0	1.6	**3.4**
Acacia oerofata Schweinf.	0.0	0.0	0.0	0.0	0.2	0.0	**2.2**
Grewia tenax Fiori	0.0	0.0	0.0	0.0	0.1	0.1	**1.6**
Balanites rotundifolia Blatter	0.0	0.0	0.0	0.3	0.0	0.0	**1.4**
Salvadora persica L.	0.0	0.0	0.0	0.3	0.1	0.0	0.5
Delonix elata Gamble	0.0	0.0	0.0	0.0	0.0	0.1	0.2

*Number of quadrats grouped in each community type; Hilighted numbers in the table represent the dominant species in each plant community.

quadrispina and *Sansevieria forskaoliana*. Climbers associated with this community, although not dominant, were *Cissus quadrangularis* and *Cissus rotundifolia*.

5. *Commiphora cyclophylla-Actiniopteris radiata-Sansevieria ehrenbergii* community type

This community type was described from the Shala Luqa plains, including the ridges and peaks. The dominant tree species in the community was *Commiphora cyclophylla*. Other tree and shrub species included *Boswellia neglecta*, *Euphorbia tirucali*, *Acacia mellifera, Tarenna graveolensis* and *Premna recinosa*. The most dominant herbaceous layer species were *Actiniopteris radiata* and *Sansevieria ehrenbergii*. Other herbaceous layer species were *Selaginella phillipsiana*, *Sansevieria forskaoliana* and *Barieria quadrispina*. Two climber species, *Cissus rotundifolia* and *Cissus quadrangularis*, were also associated with this community.

6. *Acacia tortilis-Indigofera spicata* community type

This community type was described from the Luqa plain. *Acacia tortilis* was the dominant tree in this community and *Balanites rotundifolia* was a tree associated with the community. The most dominant herbaceous layer species was *lndigofera spicata*.

7. *Acacia reficiens-Megalochlamys violacea* community type

This community type was described from the Luqa plain and around Birale farm. The dominant shrub of this community was *Acacia reficiens*. Other tree and shrub species included *Commiphora cyclophylla*, *Balanites rotundifolia, Acacia oerfota, Acacia mellifera, Salvadora persica* and *Grewia tenax*. The herbaceous layer of the community was dominated by *Megalochlamys violacea*.

Results from the classification of plant community types also produced outliers from both sites, represented by quadrat numbers 5, 18 and 38 (Fig. 3). These quadrats did not show sufficient similarity with any of the seven plant community types. They were, therefore, considered as a group by themselves, and were not considered in further analyses since they were not amenable for statistical analyses.

The species composition of quadrat 5 included *Aristida kenyensis, Themeda triandra, Hyparrhenia filipendula, Dodonoea angustifolia, Plectranthus barbatus, Ozoroa insignis, Acacia seyal, Commiphora confusa, Terminalia brownii, Combretum molle, Rhus glutinosa, Acacia hockii, Grewia tricho-carpa* and *Balanites aegyptiaca*. These species also occurred in community types 1, 2 and 4. Although these species occurred in three communities, quadrat 5 was sampled from a transitional area between community type 2 and community type 4, a probable reason for its being an outlier. On the other hand, quadrat 18 was composed of a unique species composition near the Lakeshore, namely *Typha angustifolia, Aeschynomene elaphroxylon, Sesbania goetzei* and *Echinochloa pyramidalis*. Quadrat 38 was sampled from a former settlement of the people where *Balanites rotundifolia* was selected as a shade plant and became so abundant as to dominate the plot.

Species richness, evenness and diversity of the plant community types

The plant community types showed variation in their species richness, evenness and diversity (Table 2). The highest species richness and diversity as well as second highest evenness were found in community type 2, which was recorded from SOLC and KASL sites. The high species richness could probably be attributed to the optimum environment that supports the savanna woodland species and the minimum level of disturbances. Community type 1 exhibited the second highest species and diversity but third highest evenness. Community type 4 had the highest evenness but the third highest

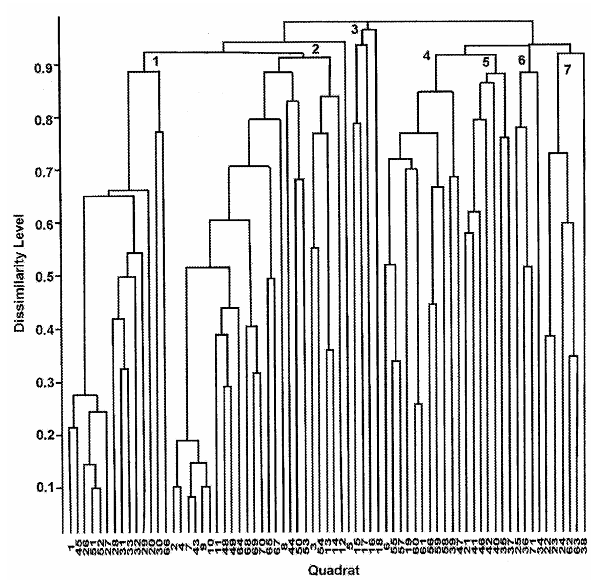

Fig. 3. Dendrogram of the vegetation data using similarity ratio.

Table 2. Species richness, evenness and diversity in the seven plant community types.

Community Types	Species Richness*	Evenness	Diversity	H'MAX
1	83	0.889	3.930	4.419
2	123	0.908	4.367	4.812
3	38	0.821	2.988	3.638
4	67	0.918	3.861	4.205
5	58	0.764	3.102	4.060
6	22	0.877	2.711	3.091
7	31	0.868	2.980	3.434

H'MAX = diversity assuming all the constituent species are evenly distributed; *Species richness = total number of species recorded in all of the quadrats grouped (refer to community size in Table 1) in each plant community type.

species richness and diversity. The least species richness and diversity were found in community type 6, which was recorded from the Luqa plain.

Community-environment relationships

Textural analysis of soil samples revealed that all soils fall in the textural class of sandy loam. The highest percentage of sand was found in the Luqa plain where *Commiphora* species and *Acacia reficiens* were recorded. The test on soil particle size, especially in sand and clay, showed significant variation among the plant community types (Table 3). Soil pH ranged between 7.1 and 7.5 and could be classified as neutral (Young 1976).

Sodium and potassium contents of the soil were low in the *Commiphora cyclophylla-Actiniopteris radiata-Sansevieria ehrenbergii* community type. This plant community was found on rocky terrain with relatively steep slope and poor nutrient content, and showed the highest percentages of sand as well as low percentages of clay and silt.

Phosphorous contents of the soil samples were uniformly low and, hence, no significant difference was found among the plant community types (Table 3). It has already been reported that a large proportion of phosphorous is stored in forms unavailable to plants (Murphy 1958). For example, $H_2P0^-_4$, which becomes available at low pH values, suffers from fixation by hydrous oxides and silicate minerals. This phenomenon may explain the low phosphorous contents encountered in the soil samples collected from the study sites.

Generally soil color is strongly influenced by the humus content and iron compounds in the soil (Fitzpatrick 1974; Young 1976). Humus coats the soil particles and imparts a black coloration, while red, yellowish red and yellow colors are mainly caused by iron products. Most soil samples from the study sites exhibited hue, the dominant spectral color or quality, values of about 10YR and 7.5YR. Values for the lightness of color as compared with absolute white ranged between 2.5 and 6 while the chroma, i.e. strength of the color or departure from neutral gray or white, ranged between 1 and 6. Although there were variations, the general color of soils appeared to be dark yellowish to strong brown.

Classification of the identified plant communities matched more or less with the altitudinal variation recorded, implying that altitude is the most important environmental element that determined occurrence and distribution of the plant communi-

Table 3. Post-hoc comparison of means between environmental variables and plant community types.

Environmental variables	Plant Community Types						
	1	2	3	4	5	6	7
Sand (%)	68.2ab	56.2b	52.9b	74.2ab	81.6a	50.7b	76.3ab
Clay (%)	16.2ab	21.6b	14.4ab	11.0ab	3.7a	26.8b	8.1ab
Silt (%)	17.7ab	26.3b	32.6ab	14.8ab	10.3a	22.5ab	15.9ab
pH (in water)	7.1b	7.1b	7.5ab	7.2ab	7.4a	7.3ab	7.5a
K (ppm)	29.1ab	27.3ab	49.1a	14.8bc	13.4c	42.4a	33.2ab
Na (ppm)	0.8ab	1.6a	1.5ab	0.3ab	0.2b	0.4ab	0.4ab
P (ppm)	1.6ns	2.1ns	2.1ns	1.2ns	2.9ns	3.6ns	2.2ns
Altitude (m)	1430a	1528a	1095b	1232b	884c	725c	662c
Slope (%)	4.2a	10.6b	0a	18.8c	14.3bc	0a	0a

Values in a row with different letters are significantly different ($P<0.06$).

ties. In agreement with our finding, it has been reported that altitude resulted in the major discrimination among the community types recognized in the vegetation of Afromontane and the transitional rainforests of southwestern Ethiopia (Kumelachew & Tamrat 2002). Similarly, the presence of altitudinal zonation delimiting vegetation types in southwestern Ethiopia had been reported from palynological studies of forests and woodlands (Bonnefille *et al.* 1993). It has been long recognized that altitude is an important environmental factor that affects radiation, atmospheric pressure, moisture and temperature, all of which have strong influence on the recruitment, growth and development of plants and the distribution of vegetation types (Hedberg 1964; Kumelachew & Tamrat 2002).

Slope was also an important. environmental element, which influences run-off and drainage, thereby, determining also the nutrient, depth and water content of the soil. The effect of slope was prominent in plant community type 5 owing to rockiness of the area and low herbaceous cover with limited ability to reduce run-off. Moreover, soil samples collected from the area exhibited low contents of potassium, sodium and phosphorous as well as percent clay and silt compared with other areas, suggesting the significant role of slope.

Conclusions

Results from our study indicated that a relatively high number of species is found in the two study sites, and the vegetation could be grouped into seven different plant community types. This classification would make the future management of the vegetation feasible since recognition of more or less homogeneous communities and the associated environmental settings facilitates the choice of appropriate management regimes or tools.

Of all the environmental factors studied, altitude and slope determined distribution of the plant communities identified in the study. For instance, greater vegetation cover and higher number of species were found at higher altitudes than in the lower altitudes. Plant community type 2, which was found at an altitude of 1528 m, exhibited the highest species richness and diversity of plants. Conversely, plant community type 6, which was found at an altitude of 725 m, had the least species richness and diversity among all plant community types. The soils at KASL and SOLC fall in the textural class of sandy loam and neutral pH, and exhibited excessive drainage.

Our results and casual observation in the field suggest that sustainable utilization of the vegetation resources at KASL and SOLC in particular and the Gamo Gofa Zone in general could be possible if the following recommendations are taken into consideration. As indicated earlier, traditional use of fire aimed at clearing bushes for cultivating crops and/or stimulating growth of new grass for domestic animals at the study sites, seems an inevitable activity. This activity may influence species richness, diversity, evenness and structure of the plant communities identified in the study. Prohibition of the traditional use of fire could affect the livelihood of the people. Therefore, to minimize or stop the current use of fire by the people, there is a need for detailed study on fire ecology, provision of viable livelihood diversification alternatives for the people and creation of an intensive awareness program. The study on fire ecology and change in plant communities associated with fire over a long period will provide clues for evaluating management practices and utilizing the resources in a sustainable way.

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Appendix 1. Plant species recorded from the study areas and their plant families.

Scientific Name	Family	Scientific Name	Family
Abutilon figarianum Webb.	Malvaceae	*Cissus rotundifolia* (Forssk.) Vahl	Vitaceae
Acacia abyssinica Hochst. ex Benth.	Fabaceae	*Clematis hirsuta* Perr. & Guill.	Ranunculaceae
Acacia asak (Forssk.) Wilid.	Fabaceae	*Cleome monophylia* L.	Capparidaceae
Acacia brevispica Harms.	Fabaceae	*Coccinia adoensis* (A. Rich.) Cogn	Cucurbitaceae
Acacia drepanolobium Harms. ex Sjosted	Fabaceae	*Coccinia grandis* (L.) Voight	Cueurbitaceae
Acacia etbaica Schweinf.	Fabaceae	*Combretum aculeatum* Vent.	Combretaceae
Acacia goetzei Harms.	Fabaceae	*Combretum collinum* Fres.	Combretaceae
Acacia hockii De Wild	Fabaceae	*Combretum hereroens* Schinz.	Combretaceae
Acacia mellifera (Vahl) Benth.	Fabaceae	*Combretum molle* G. Don	Combretaceae
Acacia nilotica (L.) Willd. ex Del.	Fabaceae	*Commelina africana* L.	Commelinaceae
Acacia oerfota (Forssk.) Schweinf.	Fabaceae	*Commelina imberbis* Ehrenb. ex. Hassk.	Commelinaceae
Acacia reficiens Wawra.	Fabaceae	*Commicarpus plumbagineus* (Cav.) Standl.	Nyctaginaceae
Acacia senegal (L.) Willd.	Fabaceae	*Commiphora bruceae* Chiov.	Burseraceae
Acacia seyal Del.	Fabaceae	*Commiphora confusa* Vollesen	Burseraceae
Acacia tortilis (Forssk.) Hayne	Fabaceae	*Commiphora cyclophylla* Chiov.	Burseraceae
Acalypha fruticosa Forssk.	Euphorbiaceae	*Cordia sinensis* Lam.	Boraginaceae
Acanthus pubescens (Thoms.) Engl.	Acantbaceae	*Croton zambesicus* Muell. Arg	Euphorbiaceae
Achyranthus aspera L.	Amaranthaceae	*Cussonia ostinii* Chiov.	Araliaceae
Actiniopteris radiata (Swartz) Link	Actiniopteridaceae	*Cynodon dactylon* (L.) Pers.	Poaceac
Adenia venenata Forssk.	Passifloraceae	*Cyphostemma adenanthum* Descoings	Vitaceae
Adenium obesum Roem. ex Schult.	Apocynaceae	*Cyphostemma adenocaule* Wilid. & Drumm.	Vitaceae
Aerva lanata (L.) Juss.	Amaranthaceae	*Delonix elata* (L.) Gamble	Fabaceae
Aeschynormne elaphroxylon Taub.	Fabaceae	*Dichrostachys cinerea* (L.)Wight & Arn.	Fabaceae
Albizia amara (Roxb.) Boiv.	Fabaceae	*Digitaria abyssinica* (A Rich.) Stapf.	Poaceae
Aloe gilbertii Sebsebe & Brandham	Aloaceac	*Diospyros scabra* (Chiov.) Cufod.	Ebenaceae
Aloe macrocarpa Tod.	Aloaceae	*Dissotis decumbens* (P. Beauv.) Triana	Melastomataceae
Aristida kenyensis Henr.	Poaceae	*Dodonoae angustifolia* L.f.	Sapindaceae
Asparagus africanus Lam.	Asparagaceae	*Dombeya torrida* P. Bamps	Sterculiaccae
Asparagus falcatus L.	Asparagaceae	*Drimia altissima* Ker-Gawl.	Hyacinthaceae
Asparagus flagellaris (Kunth) Bak.	Asparagaceae	*Echinochloa pyramidalis* Hitchc. & Chase	Poaceae
Aspilia gillettii Wilid.	Asteraceae	*Echinops amplexicaulis* Oliver	Asteraceae
Asystasia gangetica (L.) T. Anders	Acanthaceae	*Enteropogon macrostachyus* Benth.	Poaceae
Balanites aegyptiaca Del.	Balanitaceae	*Eragrostis aspera* (Jacq.) Nees	Poaceae
Balanites rotundifolia Blatter	Balanitaceae	*Eragrostis papposa* (Roem. & Schult.) Steud	Poaceas
Barleria eranthermoides C. BCI.	Acanthaceae	*Eragrostis superba* Peyr.	Poaceae
Barlieria quadrispina Lindau	Acanthaceae	*Erianthemum dregai* (Eckl. & Zeyh.) V. Teigh.	Loranthaceae
Blepharis ciliaris L.	Acanthaceae	*Eriosema* spp.	Fabaceae
Blighia unijugata Bak.	Sapindaceae	*Erythrina abyssinica* Lam.ex DC.	Fabaceae
Boerhvia erecta L.	Nyctaginaceae	*Euclea divinorum* Hiern	Ebenaceas
Boscia angustifolia A. Rich.	Capparidaceae	*Euphorbia borenensis* M. Gilbert	Euphorbiaceae
Boscia salicifolia Oliv.	Capparidaceae	*Euphorbia tirucalli* L.	Euphorbiaceae
Boscia senegalensis Lam. ex Poiret	Capparidaceae	*Faurea rochetiana* (A. Rich.) Pichi-Serm.	Proteaceae
Boswellia neglecta S. Moore	Burseraceac	*Ficus vallis-choudae* Del.	Moraceae
Cadaba farinosa Forssk.	Capparidaceae	*Ficus vasta* Forssk.	Moraceae
Cadaba rotundifollia Forssk.	Capparidaceae	*Gardenia ternifolia* Schum. & Thonn.	Rubiaceae
Calotropis procera (Ait.) Ait. f.	Asclepiadaceae	*Glycine wightii* verdc.	Fabaceae
Calyptrotheca somalensis Gilg.	Portulacaceae	*Gnidia glauca* (Fresen.) Gilg.	Thymelaeaceae
Canthium satiflorum Hiern	Rubiaceae	*Gnidia involucrata* A Rich.	Thymelaeaceae
Capparis tomentosa Lam.	Capparidaceae	*Grewia tenax* (Forssk.) Fiori	Tiliaceae
Cardiospermum halicacabum L.	Sapindaceae	*Grewia trichocarpa* Hochst. ex. A. Rich.	Tiliaceae
Carisa edulis (Forssk.) Vahl	Apocynaceae	*Grewia velutina* (Forssk.) Vahl	Tiliaceae
Cenchrus ciliaris L.	Poaceae	*Harpachne schimperi* Hochst. ex. A. Rich.	Poaceae
Cissus quadrangularis L.	Vitaceae	*Harrisonia abyssinica* Oliv.	Simaroubaceae

Contd.

Appendix 1 *(contd.)*

Hetropogon contortus (L.) Roem. & Schuk.	Poaceae	*Psydrax schimperiana* Bridson	Rubiaceae
Hibiscus crassinervius A. Rich.	Malvaceae	*Pupalia lapacea* (L.) Juss.	Amaranthaceae
Hibiscus diversifolius A. Rich.	Malvaceae	*Rhoicissus tridentate* (L.) Willd & Drumm	Vitaceae
Hyparrhenia filipendula (Hochst.) Stapf.	Poaceae	*Rhus glutinosa* A. Rich.	Anacardiaceae
Hyparrhenia hirta (L.) Stapf.	Poaceae	*Rhus natalensis* Krauss.	Anacardiaceae
Hyperthelia dissoluta (Steud.) W.D. Clayton	Poaceae	*Rhus quartiniana* A. Rich.	Anacardiaceae
Hypoestes forskolei Roem. & Schult.	Acanthaceae	*Rhus ruspolii* Engl.	Anacardiaceae
Indigofera schimperi Jaub. & Spach.	Fabaceae	*Rhus vulgaris* Meikle	Anacardiaceae
Indigofera spicata Forssk.	Fabaceae	*Rhynchosia resinosa* (A. Rich.) Bak.	Fabaceae
Indigofera spinosa Forssk.	Fabaceae	*Salvadora perisca* L.	Salvadoraceae
Ipomoea cairica (L.) Sweet	Convolvulaceae	*Sansevieria ehrenbergii* Schw. Ex Back.	Dracaenaceae
Ipomoea kitiuensis Vatke	Convolvulaceae	*Sansevieria forskaoliana* Hepper & Wood	Dracaenaceae
Jasminum floribundum L.	Oleaceae	*Sarcostemma viminale* (L.) R. Br.	Asclpiadaceae
Justicia caerulea Forssk.	Acanthaceae	*Satureja abysinica* (Benth.) Briq.	Lamiaceae
Kalanchoe crenata Haw.	Crassulaceae	*Satureja punctata* (Benth.) Briq.	Lamiaceae
Kalanchoe lanceolata Forssk.	Crassulaceae	*Scherebera alata* (Hochst.) Welw.	Oleaceae
Kleina odora (Forssk.) DC.	Asteraceae	*Sclerocarya birrea* (A. Rich.) Hochst.	Anacardiaceae
Kleina squarrosa Cufod.	Asteraceae	*Secamone parviflora* (Oliv.) Bullock	Asclepiadaceae
Laggera alata (D. Don) Sch. Bip. ex. Oliv.	Asteraceae	*Selaginella phillipsiana* Alston	Selaginellaceae
Lannea humilis (Oliv.) Engl.	Anacardiacaeae	*Senecio hadiensis* Forssk.	Asteraceae
Lannea schimperi (Hochst. Ex A Rich.) Engl.	Anacardiacaeae	*Senna septemtrionalis* Irwin & Barneby	Fabaceae
Lepidagathis scariosa Nees	Acantbaceae	*Senna singueana* (Del.) Lock	Fabaceae
Leptadenia hastata (Pres,) Decne	Asclepiadaceae	*Sesbania goetzei* Harms.	Fabaceae
Leucas abyssinica Briq.	Lamiaceae	*Setaria incrassata* (Hochst.) Hack.	Poaceae
Leucas martiniensis (Jacq) R. Br	Lamiaceae	*Solanum incanum* L.	Solanaceae
Lippia abyssinica (Otto & Dietr.) Cuf.	Verbenaceae	*Solanum panduriform*	Solanaceae
Loudetia arundinacea (A Rich.) Steud.	Poaceae	*Solanum somalense* Franch.	Solanaceae
Maerua angolensis DC.	Capparidaceae	*Sporobolus pyramidalis* P. Beauv.	Poaceae
Maerua crassifolia Forssk.	Capparidaceae	*Sporobolus consimilis* Fresen.	Poaceae
Maerua oblongifolia (Forssk.) A. Rich	Capparidaceae	*Sporobolus ioclados* (Trin) Nees	Poaceae
Maerua subcordata (Gilg.) De Wolf	Capparidaceae	*Steganotaenia aralicea* Hochst.	Apiaceae
Maerua triphylla A Rich.	Capparidaceae	*Sterculia rhynchocarpa* K. Schum.	Sterculiaceae
Maytenus gracilipes (Welw. ex Oliv.) Exell.	Calastraceae	*Steresphermum kunthianum* Cham.	Bignoniaceae
Maytenus senegalensis Excell	Celastraceae	*Strychnos spinosa* Lam.	Loganiaceae
Megalochlamys violecoa (Vahl) Vollesen	Acanthaceae	*Tagetus minuta* L.	Asteraceae
Myrsine africana L.	Myrsinaceae	*Tamarindus indica* L.	Fabaceae
Ocimum canum Sims	Lamiaceae	*Tapinanthus globiferus* (A Rich.) V. Tiegh	Loranthaceae
Ocimum forskolei Benth.	Lamiaceae	*Tarenna graveoless* Bremek.	Rubiaceae
Ocimum urticifolium Roth	Lamiaceae	*Terminalia brownii* Fres.	Conbretaceae
Olea europea L. subsp cuspidate	Oleaceae	*Terminalia laxiflora* Engl. Ex Diels	Combretaceae
Oncoalyx fischeri (Engl.) M. Gilbert	Loranthaceae	*Themeda triandra* Forssk.	Poaceae
Ormocarpum tricocarpum (Taub.) Engl.	Fabaceae	*Thephrosia elata* Defl.	Fabaceae
Osyris quadripartite Decn.	Santalaceae	*Tragia abortive* M. Gilbert	Euphorbiaceae
Ozoroa insighis Del.	Anacardiaceae	*Triumfetta flavescens* Hochst.	Tiliaceae
Panicum maximum Jacq.	Poaceae	*Triumfetta rhombiodea* Jacq.	Tiliaceae
Pappea capensis Eckl. & Zeyn.	Sapindaceae	*Typha angustifolia* L.	Thyphaceae
Pavetta crassipes Schum.	Rubiaceae	*Vernonia karaguensis* Oliv. & Hiern	Asteraceae
Perotis patens Gand.	Poaceae	*Vernonia myriantha* Hook f.	Asteraceae
Phyla nodiflora (L.) Greene	Lamiaceae	*Vigna membranacea* (L.) A. Rich.	Fabaceae
Phyllanthus sepialis Muell Arg.	Euphorbiaceae	*Viscum tuberculatum* A. Rich.	Viscaceae
Plectranthus barbatus Benth.	Lamiaceae	*Withania somnifera* (L.) Dunal.	Solanaceae
Plectranthus defoliatus Hochst. Ex Benth.	Lamiaceae	*Ximenia americana* L.	Olacaceae
Pluchea ovalis DC.	Asteraceae	*Ximenia caffra* Sond	Olacaceae
Premna recinosa Schauer.	Verbenaceae	*Zanthoxylum chalybeum* Engl.	Rutaceae
Pseudarthria hookeri Wight & Arn.	Fabaceae	*Zizyphus mucronata* Willd.	Rhamnaceae