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Comparative Study of Species Diversity and Soil Nutrients in Different Land Use Units of Borana Rangelands, Southern Oromia, Ethiopia

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Abstract. Quantitative study of species diversity across different land use units and districts is important to document status of local plant biodiversity, to evaluate impact of management and for planning future management. This study aimed at determining impacts of land use units on species diversity and spatial distribution of species in two districts of Borana zone, Oromia, Ethiopia. Stratification and systematic random sampling techniques were used for data collection. Plot size of 500 m^2 for woody species and subplots of 0.25 m^2 for herbaceous species and soil samples were used. Data was analysed using both descriptive and inferential statistics. Shannon diversity index and Simpson index were determined. Relationships between vegetation and environmental variables were analysed using Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA). The overall mean alpha, beta and gamma diversities were 29.2, 2.5 and 102.6, respectively. Average total number of species in enclosures and open access grazing sites was 113 and 96 species, respectively. Enclosures or relatively protected land use units (*Kalos*) had more species diversity than their corresponding open access grazing lands (*Worras*). Shannon diversity index ranged from 3.11 in the grazing land for dry livestock to 3.78 in the Web grazing land for lactating cattle. Similarly, Simpson index of dominance ranged from 0.034 in the Web Worra to 0.089 in grazing land for dry livestock (*Foora*). Kalos had higher Simpson diversity index than their corresponding Worras. Soil nutrients varied across land use units. Cation Exchange Capacity (CEC) was higher in enclosed than in open access grazing land use units. The study also showed that there was significant variation in P, Ca, CEC, silt and sand across the two districts ($p<0.05$). RDA and CCA results revealed that altitude, OM, K and N were the most important environmental variables that significantly accounted for the spatial distribution and abundance of species. It was concluded that enclosures had contributed to increased species diversity. Promoting the area enclosure as a viable strategy for biodiversity management and rehabilitation of rangelands were recommended as a result of this study.

Key words: Enclosure, Arid and Semi-arid, Diversity Indices, Rangeland Biodiversity

Introduction

Conservation of biological diversity is a prerequisite for sustainable development (SCBD, 2003). Biological diversity is a global asset of tremendous value to present and future generations and intergenerational equity as one of the basic principles of the Convention on Biological Diversity (CBD) was adopted in 1992 (UN 1992). However, there has been increasing threat to the survival of species and integrity of habitats and ecosystems and therefore, there is a high need to document the biological resources and determine their conservation status. In the study of biological diversity, the most widely used level of biological organization is the species level (Arellano and Halffter, 2003).

Ohmann and Spies (1998) reviewed that, when climate is more stressful for the plant life, species respond to smaller scale variations in substrate, topography and biotic interactions. This was supported by Heikkinen *et al.* (1998) and Korvenpää *et al.* (2003), who also pointed out that species compositions are mainly determined by fine-scale local factors. Therefore, in the stressful semi-arid rangeland of the Borana lowlands, species-environment relationships were analysed at local levels using data from functional land use units called *Kalo*, *Worra* and *Foora,* and sites (Dida Hara and Web areas).

Traditional communities in general and pastoralists in particular depend on plant resources mainly for herbal medicines, wild food, forage, local constructions, making of household implements, tools, beds and sleeping mats, firewood and shade. Besides, some species have ritual and commercial values. Especially pastoralists in developing countries, such as the Borana pastoralists, are highly dependent on their plant resources for most of their basic needs.

The importance of area enclosure for restoring biodiversity and its sustainable management has been reported from both Ethiopia and other countries. Many previous studies in Borana lowlands focused on floristic composition, ethnobotany, vegetation analysis and rangeland management strategies (e.g., Haugen 1992; Coppock 1994; Woldu and Nemomissa, 1998; Angassa and Baars, 2000; Oba *et al.,* 2000; Oba and Kotile 2001; Dalle *et al.,* 2005; Dalle *et al.,* 2006).

However, data on impacts of different land use units on species diversity and spatial distribution of these species in Arero and Yaballo districts of Borana zone were limited. Therefore, this study aimed at assessing the diversity and distribution of plant species in different functional land use units of Arero and Yaballo Districts in Borana zone. Furthermore, this study aimed at determining impacts of land use units on species diversity and spatial distribution of species and soil nutrients in the two districts of Borana zone, Oromia, Ethiopia.

Materials and Methods

Study area

The study was conducted in Arero and Yaballo Districts of Borana Zone, Oromia, Ethiopia (Fig. 1). Field data were collected from 2001 to 2003 in different seasons.

The main study sites were Dida Hara in Yaballo and Web in Arero. *Foora* (an area used for grazing dry or non-lactating livestock) was also selected for this study. Yaballo town is 570 km south of Addis Ababa. Dida Hara and Web are located about 30 km northeast and 85 km southeast of Yaballo town, respectively. *Foora* is located in Dida Hara, about 48 km southeast of Yaballo town.

Climatic characteristics

The elevation of the study area ranges from 750 to about 2000 m above sea level. Rainfall is bimodal, with the long rains during March-May and short rains during October-November (Haugen, 1992; Coppock, 1994). Mean annual rainfall was 412 mm in Web (Web weather station;

data from Southern Range Development Unit) and 545 mm in Dida Hara (Yaballo town as the nearest station; data from the National Meteorological Services Agency of Ethiopia). While mean annual temperature varies from 19 to 24°C (Mengistu, 1998). The maximum temperatures for Yaballo stations ranged from 24.4 to 26.4°C and minimums from 13.8 to 14.8°C (1989-2001 raw data from the National Meteorological Services Agency of Ethiopia). In general, December-February is the hot dry season, March-May is the long rainy season, June-August is the cool dry season and September-November is the short rainy season. The difference between the long rains and short rains is the amount of rain that the area receives.

Soil Characteristics

The soils in the study area are granitic and volcanic soils and their mixtures (Coppock, 1994). Valley bottomlands of the Borana rangelands are dominated by vertisols. Review of studies that described upland rangeland soils in the study area showed that the soils vary in colour (yellow, brown, grey or red) and have almost equal proportions of sand, silt and clay (Mengistu, 1998).

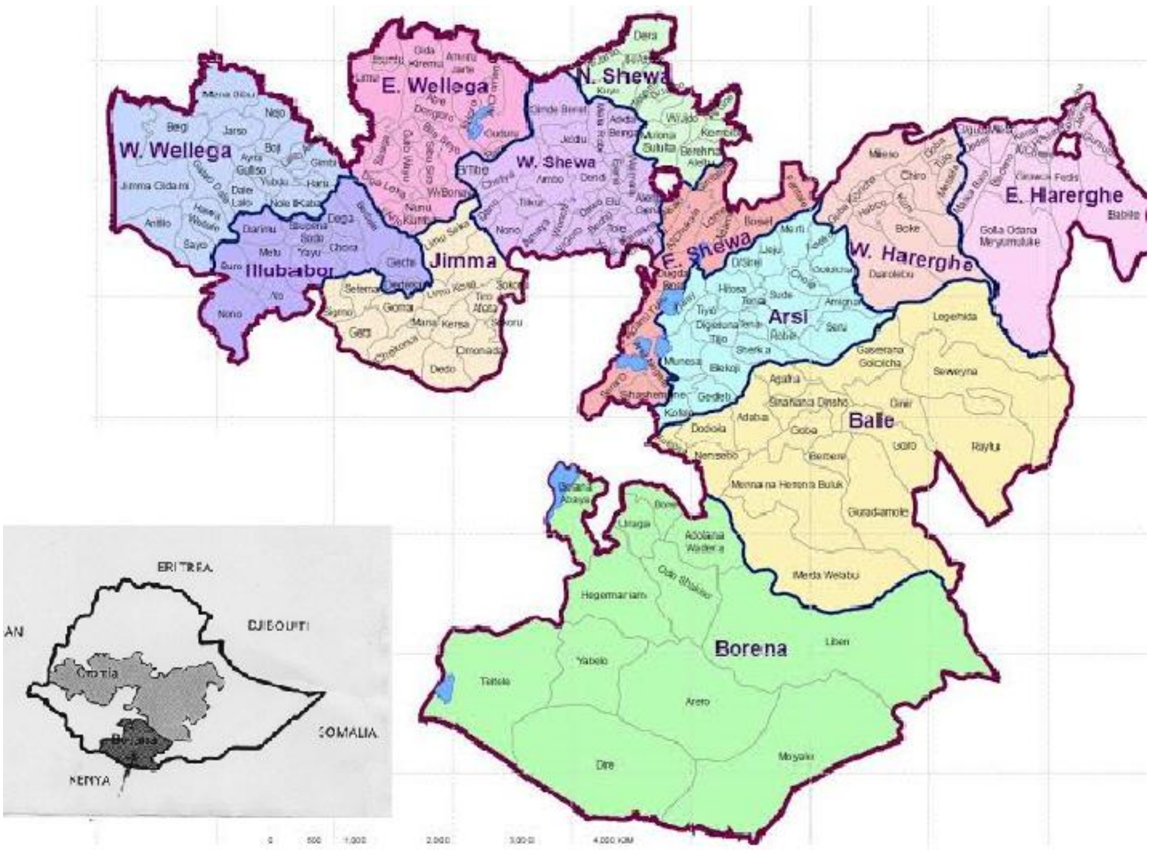

Fig. 1. Location of Borana Zone, in Oromia, Southern Ethiopia

Sampling strategy

Borana pastoralists classify their grazing lands into enclosed grazing lands for calves (*Kalo*), grazing lands for lactating livestock (*Worra*) and grazing lands for dry livestock (*Foora*). Based on suitability for different classes of livestock (i.e. availability of forage and watering points), the pastoralists establish their villages (pastoral camps) locally called *Olla*. Classification and demarcation of the grazing land into *Kalo*, *Worra* and *Foora* is based on distance from the villages and accessibility of watering points: *Kalo* is adjacent to the villages, *Worra* the next removed and *Foora* the most remote.

Similarly, *Kalo* and *Worra* are located within walking distance (distance from water covered by grazing livestock in a single day, which is about 12 km) from watering points, whereas *Foora* is remote from the watering points (having no permanent watering point within the grazing area) and dry livestock utilizing this area depend on surface rainwater or must walk long distances to access watering points. *Kalo* was fenced and protected from grazing from early wet season to hot dry season, and was accessible for grazing only during the hot dry season. *Worra* and *Foora* were open to livestock throughout the year.

A stratification sampling technique was used to collect samples from these functional land use units. Within each land use unit, the initial sampling point was established randomly, but subsequent units were established at 200 m intervals on a linear transect. Samples of both herbaceous and woody forage species were gathered from different land use units.

Data Collection

A total of 109 plots of 50 m x 10 m (500 m^2) were used for collecting data on both abiotic environmental factors and vegetation. Density of trees/shrubs was determined in the entire 500 m^2, whereas, frequency of the herbaceous species for each main plot was determined using the five subplots. The environmental data included altitude, slope, soil nutrients, pH and texture.

Within each plot, herbaceous samples were taken from five places (four at the corners and one at the centre of the major plot) for the determination of frequency of each species. Species richness (the total number of species) was determined in the entire 500 m^2 plot for woody plants and from the five subplots for the herbaceous species. Nomenclature of plant species follows published volumes of Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1995; Edwards *et al.*, 1997).

Soil samples were collected from the topsoil (surface soil from 0-15 cm) of the five subplots used for sampling herbaceous species. The samples from the subplots were pooled and analysed for total nitrogen (N), available phosphorus (P), organic matter (OM), pH (pH_H_2O), potassium (K), Calcium (Ca), Magnesium (Mg), caption exchange capacity (CEC) and texture (Sand, Silt and Clay) in the laboratory of the International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia. N, OM and soil texture were measured in percentage, P in ppm (parts per million), pH in 1:1 suspension (pH_H_2O), and K, Ca, Mg, and CEC results in meq/100g (milli-equivalents per 100 grams).

The methods used for the analyses of soil samples were ammonium acetate (at pH 7) extraction method for exchangeable bases, ammonium replacement method for CEC, 1:1 soil to water ratio for pH, Keltec or H_2SO4 wet digestion titration method for total N, Walkley-Black titration method for OM, Bray II method for available P, and hydrometer method for texture.

Data analysis

Descriptive statistics was used in organizing, summarizing and describing sample data. Diversity of plant species in the different land use units was compared in terms of their alpha, beta and gamma diversities using the following definitions after Ohmann and Spies (1998):

1.Alpha (α) or intercommunity diversity was defined as the mean number of species sampled (species richness) per main sampling plot.

2.Gamma diversity (S) is the diversity of an entire landscape or region, from the total number of species sampled on all plots within each geographic area. Gamma diversity in this paper is the total number of plant species in each community type. Similarly, the total number of plant species per each land use unit was defined as gamma diversity.

3.Beta diversity $ß = [S/\alpha] - 1$, which is a measure of relative change.

Diversity indices were calculated using the following formula:

Shannon Diversity Index

$(H) = -\Sigma Pi ln Pi$

Shannon's Equitability (Evenness) Index $EH = H/Hmax = H/lnS$

Simpson Index $(D) = \Sigma P_i^2$

Where:

S =total number of species in each land use unit

P_i = proportion of S made up of the i^{th} species.

Furthermore, different multivariate techniques of CANOCO version 4.0 (ter Braak and Šmilauer, 1998) were employed for analysis of the relationships between vegetation and environmental variables. In the analysis, both herb and shrub layers (trees/shrubs) were considered. The abundance data used for the analysis of woody plants interacting with their environment was density (number per ha), whereas for herbaceous species frequency was used. Because of this difference in input data, results for the two species groups are presented separately. The ordination methods used for the vegetation and environmental data analysis were Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA). In CCA, biplot-scaling was used and in RDA the centre and standardize option was followed as recommended by ter Braak and Šmilauer (1998).

Most important environmental variables per each land use units were identified using the "Manual Forward Selection" option of CANOCO 4.0. These variables were considered as most important based on the "Extra fit" value of each and when their contribution was significant ($P \leq 0.05$) to the model.

Results

Species diversity of the land use units

The overall mean alpha diversity of the land use units was α=29.2 with a range from 26.5 in Web *Worra* to 32.9 in Dida Hara *Kalo*. On the other hand, the overall mean beta diversity was β=2.51 with a range from 1.97 in *Foora* to 3.15 in Web *Worra*. Similarly, mean gamma diversity was γ=102.6 with a range from 81 in *Foora* to 117 in Dida Hara *Kalo* (Table 1). On average, there were 113 total species in enclosures and about 96 in open access grazing land use units.

Both beta and gamma diversities were positively and strongly correlated with the number of plots (r =0.86 and 0.79, respectively). In general, *Kalos* had relatively more alpha diversity than their corresponding Worras (Table 1).

Shannon diversity index ranged from 3.11 in *Foora* to 3.78 in Web Worra (Table 2). Similarly, Simpson index of dominance ranged from 0.034 in the *Web Worra* to 0.089 in *Foora*. In general, Web sites (*Kalo* and *Worra*) had the highest Shannon diversity index whereas, Dida Hara sites (*Kalo*, *Worra* and *Foora*) had the highest Simpson index of dominance. *Kalos* (enclosures) had higher Simpson diversity index than their corresponding *Worras* (unenclosed grazing lands).

Table 1. Species Diversity in the different Land Use Units of the Borana Lowlands, Ethiopia

Land Use Unit	No	Species Diversity		
		Alpha± SD*	Beta diversity	Gamma diversity
Dida Hara *Kalo*	22	32.9±6.40	2.55	117
Dida Hara *Worra*	22	29.9±5.22	2.21	96
Web *Kalo*	22	29.5±6.46	2.69	109
Web Worra	21	26.5±8.10	3.15	110
Foora	22	27.2±7.41	1.97	81
Mean± SD*		29.2±2.53	2.51±0.45	102.6±14.26

*SD = Standard Deviation

Table 2. Diversity Indices of Species in the different Land Use Units of Borana Lowlands, Ethiopia

Land Use Unit	Shannon Diversity Index (H)	Shannon's Equitability Index (E_H)	Simpson Index of dominance (D)
Dida Hara Kalo	3.391	0.712	0.085
Dida Hara Worra	3.297	0.722	0.076
Web Kalo	3.645	0.777	0.045
Web Worra	3.782	0.805	0.034
Foora	3.111	0.708	0.089

Impacts of land uses on soil characteristics

In general, Dida Hara soils, containing the highest proportion of sand, whereas Web soils had higher levels of available P, Ca, Mg, CEC and pH. Mean available P ranged from 2.0 ppm in *Foora* to 29.9 ppm in Web Worra. Concentrations of P and Ca and CEC were highly variable in both Dida Hara and Web (Table 3). Compared with open access grazing sites (Worra and Foora), relatively protected sites (Kalo) had more CEC and sand. On the other hand, open access grazing sites had more P, clay, silt and K. The other soil nutrient contents (N, OM and Mg) were similar in both enclosed and open access grazing sites. Furthermore, using T test the mean values of P, Ca, CEC, silt and sand showed significant variation across the two districts ($p<0.05$) (Table 3).

Table 3. Mean values of the soil nutrients and texture in different land use units of the Borana lowland, Ethiopia

Soil Characteristics	Dida Hara Kalo n=15	Dida Hara Worra n=10	Mean n=25	Web Kalo n=8	Web Worra n=10	Mean n=18	Foora n=18
N (%)	0.10±0.02	0.11±0.04	0.10±0.03	0.11±0.04	0.11±0.02	0.10±0.03	0.08±0.02
P (PPM)	6.45±10.45	1.99±1.37	**4.67±8.33**	7.91±9.23	29.97±28.34	**20.53±24.04**	2.01±1.36
OM (%)	2.05±0.58	2.17±0.93	2.10±0.73	1.69±0.82	1.72±0.40	1.69±0.60	1.73±0.59
pH-H_2O	6.11±0.32	5.61±0.11	**5.91±0.36**	6.59±0.52	7.19±0.29	**6.93±0.49**	6.20±0.51
K (meq/100g)	3.08±1.56	2.72±0.80	2.93±1.30	1.38±0.80	2.74±1.01	2.16±1.12	2.30±1.13
Ca (meq/100g)	9.61±11.72	5.66±2.72	**8.03±9.32**	14.11±14.45	23.14±15.16	**19.74±14.94**	5.66±1.78
Mg (meq/100g)	2.09±0.92	1.91±0.66	**2.02±0.82**	3.19±1.16	3.53±1.60	**3.46±1.39**	2.46±1.01
CEC (meq/100g)	24.20±15.48	19.76±4.63	**22.42±12.36**	37.33±16.71	27.33±16.48	**33.47±16.67**	18.39±4.34
Sand (%)	60.46±10.15	52.02±12.77	**57.08±11.80**	50.01±7.22	53.26±14.18	**50.74±11.68**	55.29±9.56
Silt (%)	14.40±3.58	16.96±8.33	15.42±5.93	20.29±5.75	20.05±6.43	20.66±6.00	18.04±4.15
Clay (%)	25.14±7.31	31.02±6.53	27.49±7.47	29.70±2.70	26.69±12.04	28.60±9.20	26.67±7.31

CCA Analysis between woody plants and environmental variables

a) Dida Hara Site

CCA biplot of woody plants and environmental variables scaling in Dida Hara site (combined is shown in Fig. 2. The first axis was positively correlated with clay and Mg but negatively with sand and altitude. There was positive correlation between the second axis and OM, N, Ca, silt, clay, CEC and K. The correlation between this axis and sand and altitude was negative (Fig 2). The first axis was a gradient of clay and the second axis gradient of OM.

The eigenvalues of the first two axes showed that there was modest distribution of woody plants along the gradients. These first two axes cumulatively explained 25.2% of the variance in species data and 39.4% of the species-environment relationships.

There was strong positive correlation between OM and N, Ca and K, CEC and K and Ca and CEC (Fig. 2). Sand was strongly and negatively correlated with clay and silt. The most important environmental variables in Dida Hara sites were sand, altitude, OM, clay and N.

The spatial distribution of woody plants were in relation to clay texture and soil nutrients and sandy soil was in relation to higher elevations. Woody plants that were most abundant on nutrient-rich clay soils included *Grewia villosa, Hibiscus* sp., *Steganotaenia araliceae, Combretum* *molle, Balanites rotundifolia, Dalbergia microphylla, Acacia bussei, Rhus natalensis, Acacia seyal, Pappea capensis,* and *Grewia tembensis.* On the other hand, *Plectranthus ignarius, Acacia brevispica, Acacia etabaica, Commiphora habessinica, Ormocarpum trichocarpum, Commiphora africana,* and *Acacia nilotica* were most abundant on sandy soils and areas of higher elevations (Fig. 2).

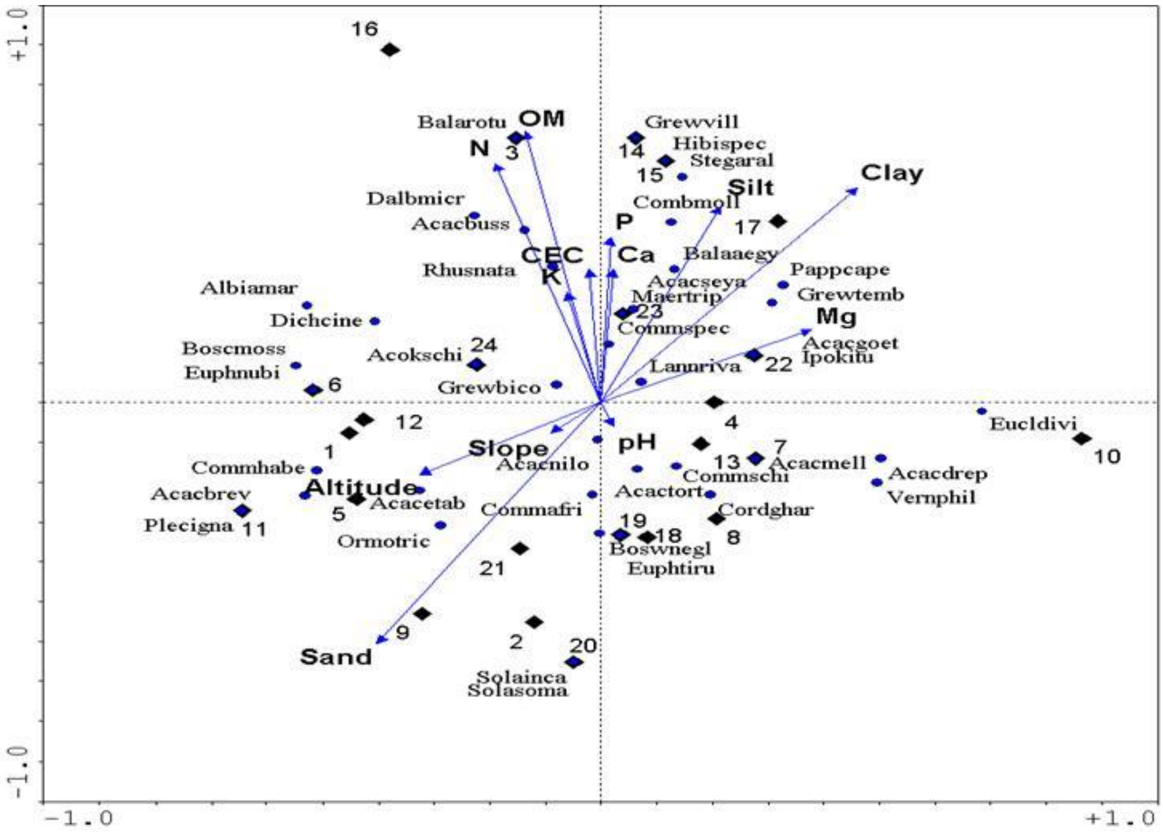

Fig. 2. Woody plants-environmental variables CCA biplot scaling with focus on species in Dida Hara, Borana lowlands, Ethiopia. The numbers represent plots. The first four letters of genus and specific epithet were used for species. For example, Grewvill stands for *Grewia villosa.*

b) Web Site

The CCA biplot scaling with focus on woody species in Web, Borana lowlands, is shown in Fig. 3. The first axis was strongly and positively correlated with Ca, N, OM, CEC, K, and Mg and negatively with altitude and slope. The second axis was positively correlated with P and silt and negatively with altitude, clay, Mg, and Ca. The first two axes cumulatively explained 33.7% of the variance in species data and 43.9% of the variance in species-environment relationships. CEC, N, OM, Ca and Mg were strongly correlated with each other and negatively with slope, sand and altitude (Fig. 3). Altitude was negatively correlated with all soil nutrients. Furthermore, it was strongly and negatively correlated with soil pH.

The most important environmental variables that significantly contributed to the spatial distribution of species in Web were Ca, N, altitude, OM, CEC, pH, Mg and K. Woody plants that preferred nutrient-rich and alkaline soils included *Acacia oerfota, Acacia reficiens, Acacia melliphera, Acacia bussei, Acacia drepanolobium, Vernonia phillipsiae, Acacia zanzibarica, Euphorbia cuneata, Rhus natalensis, Acacia tortilis* and *Ormocarpum trichocarpum.* On the other hand, some of the woody plants that were more abundant on sandy soils and higher elevations were *Commiphora africana,* *Grewia tembensis, Boswellia neglecta, Acacia senegal, Lannea rivae, Acacia etabaica, Acacia brevispica, Grewia villosa,* and *Dalbergia microphylla* (Fig. 3).

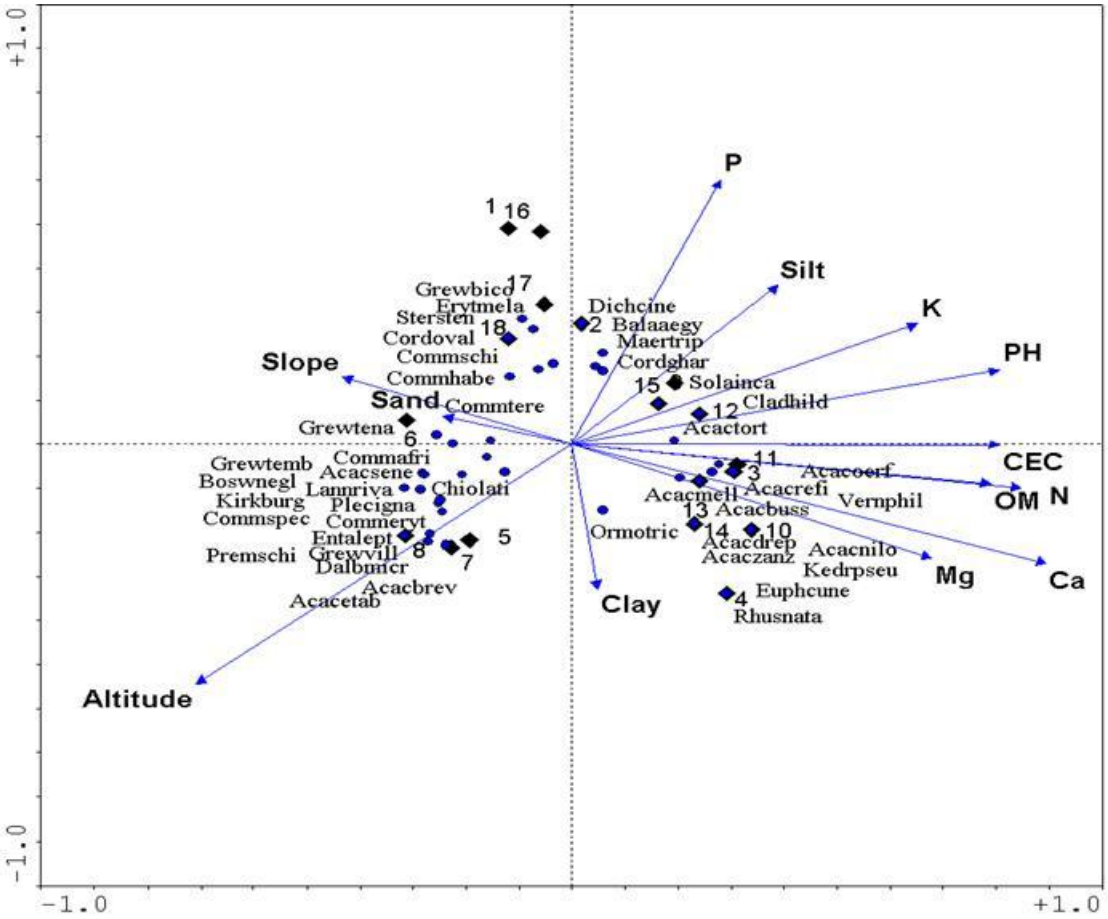

Fig. 3. CCA triplot in biplot scaling with focus on woody species in Web, Borana lowlands, Ethiopia. The numbers represent plots. The first four letters of genus and specific epithet were used for species. For example, Grewvill stands for *Grewia villosa.*

RDA analysis between herbaceous species and environmental variables

1) Dida Hara site

RDA analysis of the combined herbaceous species and environmental data from Dida Hara *Kalo* and *Worra* revealed that the first two axes explained 23.2% of the variance in the species data and 43.0% of the variance in the species-environment relationships.

The first axis was positively correlated with sand, pH and altitude and negatively with soil nutrients Similarly, the second axis was positively correlated with OM, N and altitude and negatively with sand (Fig. 4).

Monte Carlo test showed that the first canonical axis was statistically highly significant (P<0.01) demonstrating the relationship between the herbaceous species and the environmental variables in Dida Hara (*Kalo* and *Worra*) was significant. The most important environmental variables were K, clay and N (Fig. 4).

Herbaceous species that preferred nutrient-rich clay soil were *Pennisetum mezianum, Barleria spinisepala, Heteropogon contortus, Commelina africana* and *Harpachne schimperi.* On the other hand, species more frequent on relatively nutrient-poor sandy soil were *Digitaria milanjiana, Indigofera volkensii,* *Eragrostis papposa* and *Cynodon dactylon. Cenchrus ciliaris* and *Chrysopogon aucheri* were negatively correlated with altitude whereas, *Themeda triandra* and *Panicum maximum* were positively correlated with higher elevations.

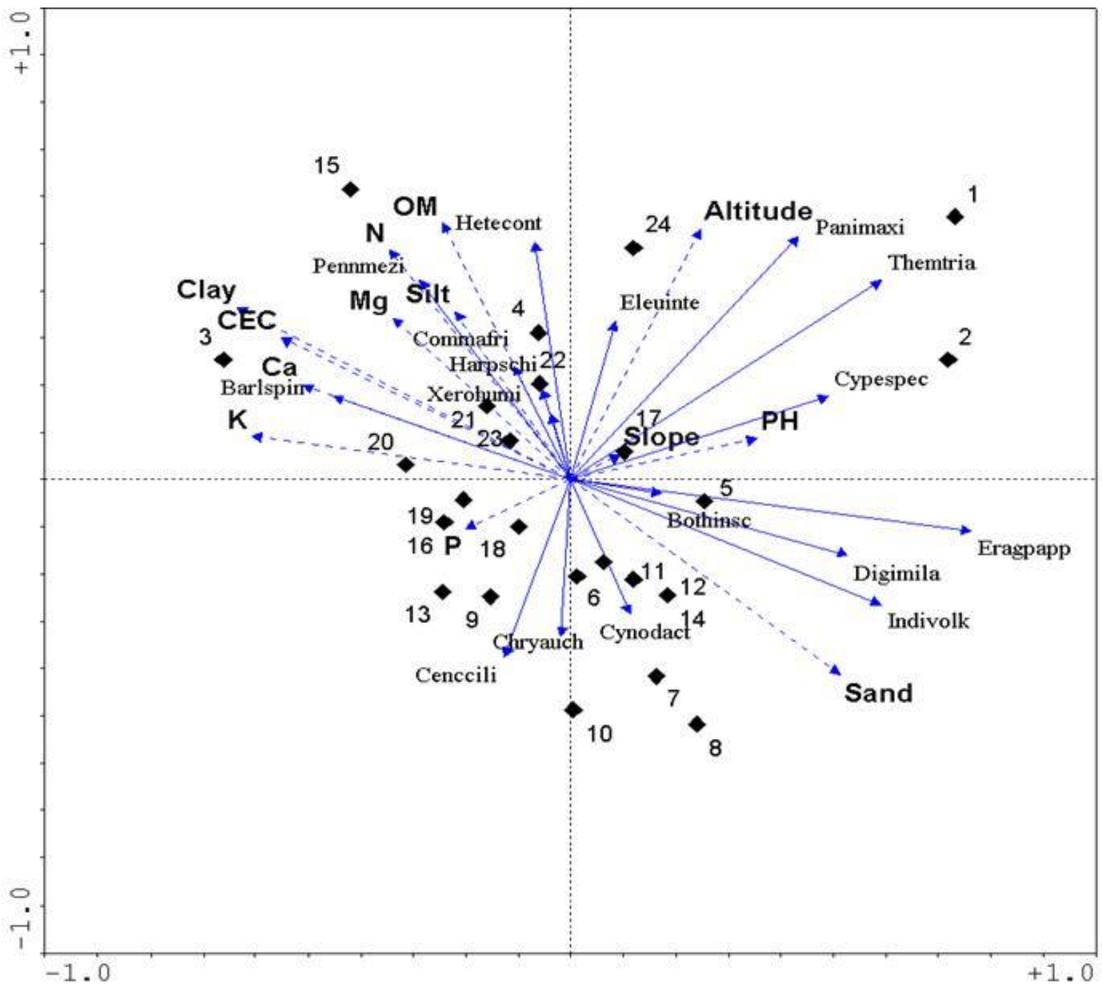

Fig. 4. RDA ordination diagram of the relationship between herbaceous species and environmental variables in Dida Hara, Borana lowlands, Ethiopia. The first four letters of genus and specific epithet were used for species. For example, Digimila stands for *Digitaria milanjiana*.

2) Web Site

In Web study area, the first two axes of RDA cumulatively explained 35.7% of the variance in the species data and 46.5% of the variances in the species-environment relationships. The first axis was positively correlated with altitude and slope and negatively with the soil nutrients (Fig. 5). On the other hand, the second axis was positively correlated with altitude, N and OM and negatively with P and K. The most important environmental variables in combined data of Web *Kalo* and *Worra* were K, altitude, Ca, CEC and N. There was positive and strong correlation among OM, N and Ca. Similarly CEC, pH, K and P were positively correlated with each other and negatively with altitude (Fig. 5).

Herbaceous species that were most frequent on soils with high proportion of clay included *Ischaemum afrum*, *Heteropogon contortus*, *Bothrichloa radicans*, *Pennisetum mezianum*, *Panicum maximum* and *Digitaria milanjiana. Chrysopogon aucheri*, *Chloris roxburghiana* and *Commelina africana* were closely associated with higher elevation and slopy terrain in Web.

Herbaceous species associated with lower elevations were *Cynodon dactylon, Setaria verticillata* and *Eragrostis papposa*. *Cenchrus ciliaris* showed strong and positive correlation with OM, N and Ca (Fig. 5).

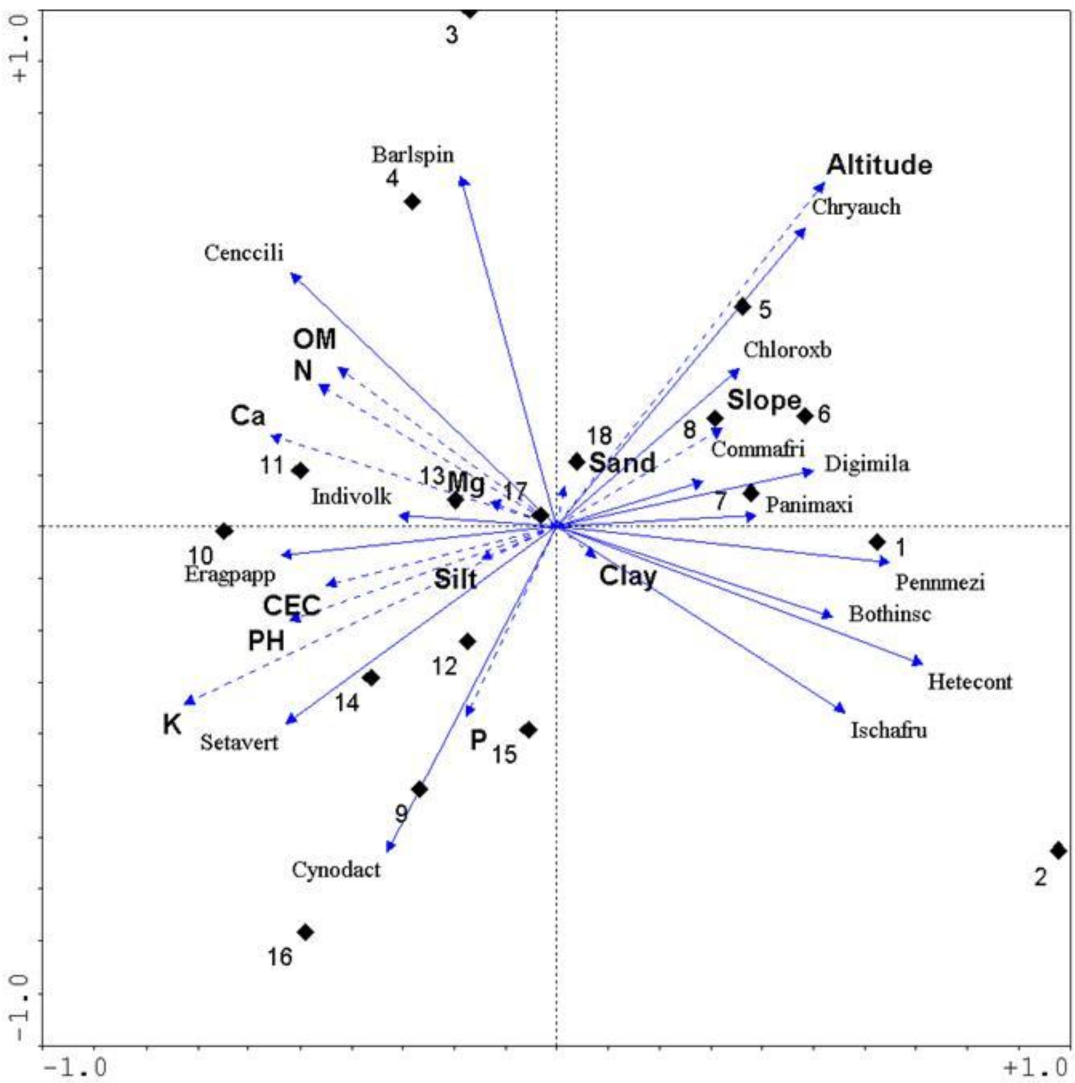

Fig. 5. RDA ordination diagram of the herbaceous vegetation and environmental variables of Web sites, Borana lowlands, Ethiopia. The first four letter of genus and specific epithet were used for species. For example, Digimila stands for *Digitaria milanjiana*.

Discussion

Role of enclosures on plant biodiversity

Species number is one of the most important features of a plant community both with respect to community organization and nature conservation (Wiegleb and Felinks, 2001). Alpha diversity in the study area ranged from 26.5 to 32.9, beta from 1.97 to 3.15, and gamma from 81 to 117. The different land use units had different alpha, beta and gamma diversities demonstrating the fact that land use system in the study area had impact on plant biodiversity. *Kalos* (enclosed land use units) had more alpha diversity than their corresponding open access grazing lands (*Worras*). Similar results were reported by from different parts of Ethiopia (e.g. Angassa *et al.*, 2010; Mekuria *et al.*, 2018). According to study report by Angassa *et al.* (2010), both species richness and diversity of herbaceous species were significantly higher in the enclosures than in the open access grazed sites during main rainy season. In other words, overgrazing had a negative impact on species diversity. The positive contribution of enclosures for rangeland restoration/rehabilitation, biomass production and species composition has been established by many researchers. For example, Verdoodt *et al.* (2010) reported that rangeland enclosure fostered regeneration of both annual and perennial grasses, and significantly increased grass cover and standing crop.

Changes in land use (such as clearing for agriculture, deforestation and habitat fragmentation) and overgrazing greatly affect biological diversity. Overgrazing may result in loss of biological diversity. According to SCBD (2003) such loss in species causes many undesirable effects including but not limited to:

- Breaking of critical links in the biological chain can disrupt the functioning of an entire ecosystem and its biogeochemical cycles. This disruption may have significant effects on larger scale processes.
- Loss of species can have impacts on the organism pool from which medicines and pharmaceuticals can be derived.
- Loss of species can result in loss of genetic material, which is needed to replenish the genetic diversity of domesticated plants that are the basis of world agriculture.

As was reported earlier (Dalle *et al.*, 2005), many species in the Borana lowlands have direct economic value (food, building materials, fuel, clothing, medicine, etc.) and also direct role in ritual and cultural practices of the pastoral communities. Furthermore, rich plant biodiversity gives alternative options to enrich lives and promote diverse ecosystem services.

Impacts of land uses on species distribution and soil nutrients

The higher alpha diversity in Dida Hara site than in Web may be attributed to the higher proportions of soil nutrients in Web. RDA and CCA analysis results revealed that environmental variables significantly accounted for the spatial distribution and abundance of species. The most important environmental variables in Yaballo District were sand, altitude, OM, clay, K and N whereas Ca, N, altitude, OM, CEC, pH, Mg and K significantly contributed to the spatial distribution of species in Arero District. Overall, altitude, OM, K and N were most important environmental variables that accounted for the spatial distribution and abundance of species in the two study areas. This finding was in agreement with the previous report for Borana lowlands in which altitude and soil Ca, CEC, Mg and pH were identified as the most important environmental factors that contribute to the differences in spatial distribution of both herbaceous and woody species (Dalle *et al.*, 2014). According to Vogiatzakis *et al.* (2003), elevation has significant impact on vegetation distribution and abundance.

This study showed that area enclosure had a significant impact on species diversity and distribution. Enclosures are important for conserving not only forage species but also multipurpose plants (Dalle *et al.*, 2005) and also for carbon sequestration both in plant biomass and soil (Gharmakher *et al.*, 2015). Overgrazing and rangeland degradation had contributed to less species diversity and variations in soil nutrients.

Improving livestock production and animal products is the major possible option available to sustain the pastoral system and improve food security in semi-arid ecosystems of the Borana rangelands. To achieve these goals, sustainable use and conservation of plant resources using rangeland area enclosures was identified as one viable option that needs to be well addressed by development programs.

Studies from the Borana Lowlands (e.g. Dalle *et al.*, 2006) showed that weakening of the traditional rangeland management strategies have resulted in rangeland degradation and woody plants encroachment which in turn negatively affected diversity of pant species. Therefore, it was concluded that strengthening traditional rangeland management strategies using *Kalo* (enclosure) should be promoted as viable strategy for reversing rangeland degradation, enhancing sustainably use of rangeland resources and conserving local plant biodiversity.

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