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Mineral lick-centered land-use and its effects on herbaceous vegetation in Southern Ethiopia

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This study was conducted in the Mana-Soda salt crater area in Borana, southern Ethiopia to evaluate the effects of a mineral lick-centered distance gradient on herbaceous species composition and rangeland condition. Samples of herbaceous species were collected along a 12 km transect starting from the edge of the crater. The herbaceous species were clustered into communities and the indicator species of each community were identified. Biomass yields were estimated across the transect and the overall rangeland condition was rated using the ecological index and weighted palatability composition (WPC) methods. A total of 16 grasses, two forbs and sedges were identified. *Chrysopogon aucheri* was the most abundant grass species, while *Aristida adoensis, Themeda triandra* and *Digitaria naghellensis* were among the rarely occurring grass species. Forbs and sedges were also of rare occurrence. Decreaser species increased in abundance as distance from the crater increased. Herbaceous dry matter yield ranged from 408.3 to 2180 kg ha^{-1} along the 12 km transect. The biomass produced varied with time of year but generally increased with increasing distance from the salt crater. The ecological index values were 574 and 349 for the main and short rain seasons, respectively. The corresponding WPC values were 44.7 and 5%, respectively. The rangeland was therefore classified as poor to fair. The results showed a high proportion of increaser species leading to the poor to fair rangeland condition.

Key words: Grass yield, indicator species, patch resource, rangeland condition.

INTRODUCTION

Semi-arid rangelands comprise more than half of the land mass of Africa (Friedel et al., 2000). In these rangelands, patch resources like perennial water and mineral salt licks are naturally limited in their distribution. Where they are found, these resources attract both domestic and wild animals which create an increasing grazing pressure towards the resource center. This increased pressure leads to a gradual change in vegetation composition and soil properties. Such systematic changes have been called "piospheres". Piosphere effects result in changes in plant community or soil structure along the distance gradient from a central point of concentration (Andrew, 1988). Gradual reduction in biomass, changes in species composition from palatable plants to unpalatable, increased trampling and soil compaction as one approaches the focal point, are all examples of the piosphere effects. The situation in the Mana-Soda area of the Borana rangelands of southern Ethiopia is a classic example of a piosphere, where the focal point is the mineral salt in the Mana-Soda crater.

Previous studies indicated that the uneven distribution of mineral salt resources in combination with a high frequency of droughts, and anthropogenic factors accelerated the change of vegetation composition, which

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favoured tolerant woody plant expansion in the Borana rangelands (Tefera et al., 2007; Angassa and Oba, 2008). Aggregation and settlement of human and livestock around the patch resources (e.g. mineral salt and water) aggravated the vegetation change leading ultimately to a decline in rangeland condition (Oba, 1998; Angassa and Baars, 2000; Angassa and Oba, 2009).

In Ethiopia, arid and semi-arid rangelands constitute 61 to 67% of the total land mass of the country (Alemayehu, 1998). These areas are generally characterized by low and erratic rainfall, high temperatures and evapotranspiration. They are largely unsuitable for rain-fed cropping but are used primarily for extensive livestock production. In the southern part of the country, in the Oromia Regional State, the semi-arid Borana rangelands account for 7.6 to 12.3% (63 940 km^2) of the total land mass (OBPED, 2000).

The Borana rangelands are home to the largest pastoral communities in Ethiopia, owning high populations of cattle and other domestic animals (Alemayehu, 2003; Coppock, 1994; Cossins and Upton, 1987). These pastoralists have a remarkable social organization that has been cited as a model of pastoralism in Sub-Saharan Africa. Their livelihood is traditionally based on cattle husbandry and they have been successful in producing animal products while ensuring sustainability of rangeland resources for generations (Helland, 1997; Pratt and Gwynne, 1977). Traditionally, the resource utilisation was through transhumance pastoralism, where pastoralists would track rainfall patterns and availability of quality forage. In the dry seasons, animals would be watered from perennial deep wells. The animals had access to minerals mainly in the wet seasons, when pasture availability was expected to be good. This 'rotational grazing' between wet and dry season allowed for strategic utilization of scarce resources and reduced degradation of rangelands (Angassa and Oba, 2007; Coppock, 1994).

The scarce resources like mineral licks and perennial deep wells are sparsely distributed in the Borana and they represent key patch resources for various communities across the rangelands. For example, the Borana has four natural mineral sources for livestock and humans, *viz.* Mana-Soda in the central part; *Kulla* and *Magado* in the south-west (about 60 km from *Mana-Soda*), and Dillo in the far south (about 100 km from Mana-Soda). In addition, nine deep *Tulla* wells are the only perennial water sources for animals (one in the east, two in the central part, three in the far south-west and three in the north-east of the Borana rangelands). However, a recent review of research in the area indicated that the Borana region, despite having been utilized sustainably for centuries, is showing signs of both ecological and economic stress (Coppock, 1994; Oba, 1998).

Ecological stress is manifested by the progressive growth of bush cover, which is a common cause of loss of herbaceous species richness and cover in arid and semi-arid savannas, and is responsible for a decline in range condition (Oba et al., 2000; Smith, 1988). In particular, recent increases in human and livestock populations, expansion of cropping and the invasion of less palatable plant species in prime rangelands, have led to declines in desirable herbaceous species in Borana. These commutative challenges have also affected the pastoral social institution and have eroded the effectiveness of traditional means of range resource management (Scholes and Walker, 1993). Overall, this has put the Borana pastoral production systems under environmental stress. Several studies have reported encroachment of less palatable plants in the Borana rangelands of Ethiopia (Angassa, 2005; Angassa and Baars, 2000; Dalle et al., 2006; Oba et al., 2000; Tefera et al., 2007).This, coupled with the changing population dynamics, pose a great challenge to livestock production and livelihood of pastoralists and/or agro-pastoralists.

In recent years, and in reaction to the ever increasing environmental challenges, some of the pastoral communities have moved to settle around strategic patch resources of mineral licks and water, Traditionally, the pastoralists would come to these patch resources at strategic times and under traditional community guidance. A more sedentary settlement of humans and their livestock has potential to increase grazing pressure around the patch resources thereby affecting the rangeland potential and utilization patterns. There is a paucity of empirical data on how these changes in the mineral lick-centered have affected rangeland productivity and possibly contributed to the reported degradation of the rangelands. This study was conducted to: (a) investigate the composition of herbaceous species along a distance gradient from a mineral lick, and (b) determine range condition around the mineral lick. This would establish the baseline status of the changes that have been taking place around a patch resource and help in identifying intervention strategies.

MATERIALS AND METHODS

Study site

The study was conducted in the Borana rangelands of southern Ethiopia. Agro-ecologically, the Borana plateau is classified as 69% lowland, 29% midland and 2.4% highland. The Borana rangelands are slightly undulating, ranging in altitude from 1000 m.a.s.l in the south to 1650m.a.s.lin the north, with peaks up to 2000 m.a.s.l in some areas (Buttolph, 1998). The arid, semi-arid and humid zones constitute 62.7, 30.8, and 6.5% of the Borana, respectively. These climatic characteristics have led to certain resource dynamics and management systems (rangeland management in particular) in the area (Coppock, 1994). The region is characterized by a bi-modal rainfall regime with mean annual rainfall ranging from 400 mm in the south to 600 mm in the north. There are two main rainy seasons, the main season or *Ganna* and short rainy season or *Hagaya*. Distribution of rainfall between the two rain seasons is such that *Ganna* rains account for 59% of the total rain and are received from March to May; *Hagaya* rains account for 27% and fall between Septembers to November. Angassa and Oba (2007) indicated that the coefficient of variability for rainfall ranges from 18 to 69% and droughts are common every five years. Generally, the rainfall limitations, recurrent drought, increased grazing pressure and bush encroachment are believed to be responsible for the reported ecological stress (Coppock, 1994; Dalle et al., 2006; Oba, 1998).

The specific study site was Mana Soda (GPS coordinates 37425415 E and 0465012 N) in Dire District of the Borana, Oromia Regional State.This area is centred on a circular depression formed by collapse of the summit or flanks of a volcano into underlying chambers evacuated by very large explosive eruptions or the effusion of large volumes of lava flows (VHP WWW Team, 2000). The volcanic crater is a source of mineral salt for livestock and humans. It is also a tourist attraction, earning the pastoralists some income.

The Mana-Soda area ranges in altitude from 1497 to 1511 m.a.s.l. The rainfall is bimodal with annual rainfall ranging from 304 to 894 mm. The surrounding pastoral communities previously exercised transhumance pastoralism, characterised by mobility of herds to wet and dry grazing areas. They regulated utilisation of their grazing areas and water resources by splitting herds into a sedentary portion or *warra* and a satellite herd or *forra*. *Warra* herds comprised of milking cows, small ruminants and weak animals which stayed near the homestead. The *forra* herds were comprised of dry cows, bulls and heifers which grazed and watered at far away distances from the homestead**.** In addition to the resident communities around Mana- Soda the area was also used as wet season grazing by pastoralists who came from as far as 100 km to feed minerals salts to their animals for about two months twice a year, in the main and short rainy seasons. In the whole of the Borana, Mana Soda is central in location, easily accessible and is generally acknowledged to have the best quality mineral salt.

Data collection

Sampling of herbaceous plants

The study was conducted from March 2010 to January 2011and data was collected in three seasons: March-May 2010, October-November 2010, and December 2010-January 2011. Given the general uniformity of vegetation around Mana-Soda a single line transect, of 12 km from the edge of the crater, was used for vegetation sampling. The main sampling plots, measuring 20 m × 50 m were established along the transect at distances of zero, one, three, six, nine and 12 km. In each main plot, data was collected from five 0.5 × 0.5 m randomly placed quadrats. Live herbaceous plants in each quadrats were identified, counted, clipped and weighed for fresh biomass. The clipped material was dried to constant weight in an oven at 105°C. Species identification was done in the field by an experienced practitioner using CADU (1974) guidelines. The various species were grouped into ecological groups of decreasers, increasers and invaders as described by Tainton (1999). Pastoralists' indigenous knowledge was also valuable in detailing the ecological characteristics of the herbaceous plants.

Soil sampling

Soil samples were also collected from each main plot at different depths: 0 (surface), > 0.1 - 10 cm, >10.1-20 cm, and >20.1 – 30 cm. Soil texture was analyzed using the hydrometer method; soil pH was read in a 1:2.5 soil-water suspension using a pH meter. Organic carbon was analyzed by oxidation with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid medium, whereas organic matter content was calculated by multiplying the value of organic carbon reading with a constant (K = 1.724). Total nitrogen was estimated by the Kjeldahl method; and available phosphorus by the Bray method for the soil samples with pH > 7 and the Olsen procedure for samples with pH < 7. Cation exchange capacity (CEC) was measured after the ammonium acetate (1N NH_4OAc) extraction.

Data analysis

Herbaceous diversity analysis

The Shannon-Wiener Index method was used to determine species diversity, richness and evenness. The Shannon diversity index was calculated using the formula:

$$H = -\sum_{i=1}^{n} \mathrm{pi}\ (\ln \mathrm{pi})$$

Where: H = Shannon diversity index; p*i* = the proportion of individuals or the abundance of i^{th} species expressed as a proportion of total cover in the sample, and *ln* = natural logarithm. Evenness was calculated from the ratio of observed diversity to maximum diversity using the equation.

$E = H/\ln(S) = H/H_{max}$

Where: E = Evenness; H = Shannon-Wiener Diversity Index; S = total number of species in the sample, Hmax = lnS. The value of the evenness index falls between 0 and 1. The higher the evenness index, the more even a species is in its distribution within the given area. Species richness is a count of the number of species in a quadrat, area or community.

Community clustering and identification indicator species

A hierarchical cluster analysis was performed using PC-ORD for Windows version 5 (McCune and Medford, 1999) to classify the vegetation into plant community types using relative density and number of each species. Also a two-way indicator species analysis (TWINSPAN) was performed for each community type (Dufrene and Legendre, 1997) to identify species that had a strong and significant association with a given community type (when indicator value > 25, $P < 0.05$). Detrended Correspondence Analysis (DCA) was used to analyze the patterns of distribution of herbaceous plant species in relation to environmental variables like altitude and measured soil properties when the cut of axis was greater than 3.0. Principal Component Analysis (PCA) was performed to analyze the patterns of distribution of herbaceous species in relation to the environmental variables when the cut of axis was less than three.

Rangeland condition analysis

Range condition was estimated using the ecological index (Vorster, 1982) and weighted palatability composition methods (Barnes et al., 1984). For calculation of the rangeland condition based on ecological index the grass species were categorized into four classes (decreasers, Increaser I, Increaser IIa and b, Increaser IIc). Each class was given a relative index value, namely decreasers = 10; Increaser I = 7; Increaser IIa and b = 4; and Increaser IIc = 1 (Vorster, 1982). The percentage composition of grass species in each class were summed up, after which the sum for each class

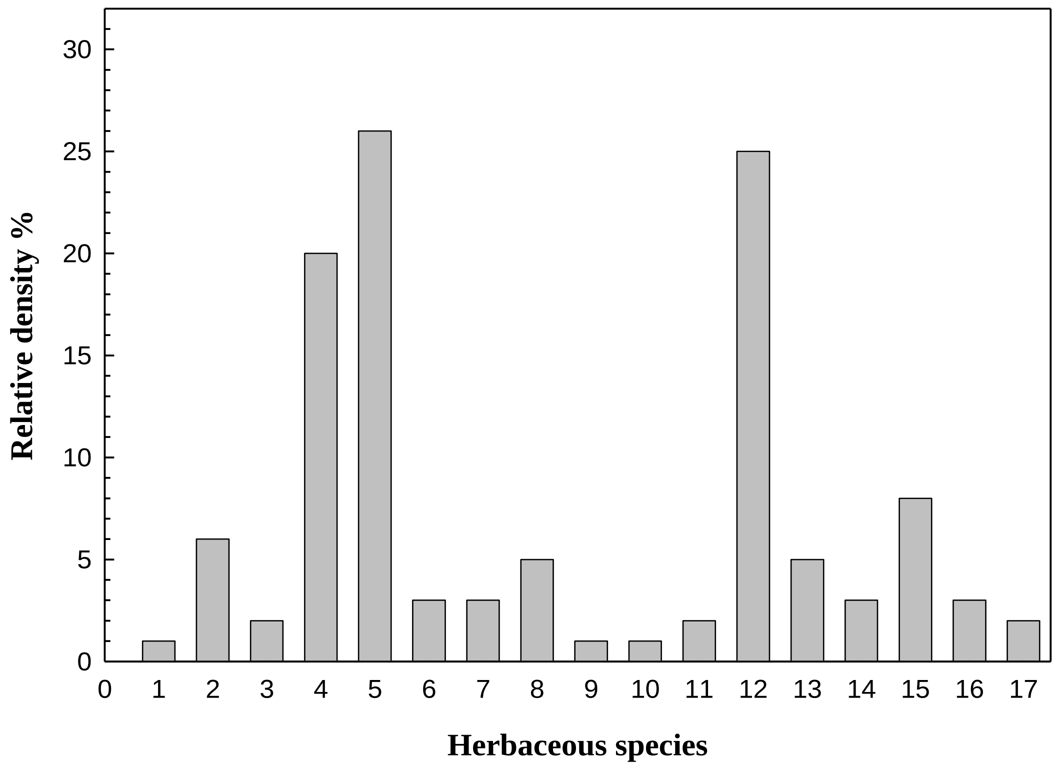

Figure 1. Relative density of herbaceous plants around the ManaSoda salt area. 1=*Aristida adoensis; 2=Bothriochloa insculpta;*3=*Bothriochloa radicans;* 4=*Cenchrus ciliaris;* 5=*Chrysopogon aucheri;* 6=*Commelina africana;* 7=*Cynodon dactylon;* 8=*Digitaria milanjiana;*9=*Digitaria naghellensis;*10=*Eleusine intermedia;*11=*Endostemen tereticaulis;* 12=*Eragrostis papposa;* 13=*Heteropogon contortus;* 14=*Panicum maximum;* 15=*Pennisetum mezianum;* 16=*Sporobolus pyramidalis;* 17=*Themeda triandra.*

was multiplied by its relative index value. The amounts were then totalled to give the condition index. A condition score of 1000 was the probable maximum when assuming that all species were decreasers and a condition score of 100 was taken as the most probable minimum (Tainton, 1999). Using this method, range condition is divided into five ranges: very poor (100 - 280); poor (280.1 - 460); fair (460.1- 640); good (640.1 - 820) and excellent (> 820).

The weighted palatability composition (WPC) of grasses was calculated after dividing the species into palatability classes (Class I - highly palatable, Class II-intermediate, and Class III less palatable/unpalatable). Multiplier weightings of 3, 2 and 1 for Class I, II and III, respectively, were used to derive a palatability composition rating (PC) for each sample site. This was calculated as a sum of the products of the relative abundance of each species and its weighting, and was expressed as a percentage of maximum PC (*viz.* 300) to produce a scale ranging from 33.3 (all species in Class III) to 100 (all species in Class I). These PC values were then converted into WPC values by means of the following formula (Barnes et al., 1984):

$$WPC = (PC- 33.3) \times 100 / 66.7.$$

The maximum WPC is 100 if all species fall under Class I and the minimum is 0 if all species are under Class III. With this method rangeland condition could be divided into five classes: very poor (0-20); poor (20.1-40); fair (40.1-60); good (60.1-80) and excellent (>80).

Statistical analysis

Analysis of variance (ANOVA) was used to examine variation in density, richness and diversity of herbaceous grasses, and biomass yields along the distance gradient from the patch resource.

The relationships between the distance from 'source of mineral salt' (independent variable) and the dependent variables (density, herbage mass etc) were analysed using correlation and linear regression. All these were done using SAS procedures (SAS, 2001).

RESULTS AND DISCUSSION

Composition of herbaceous

A total of 16 grass species, two forbs and one sedge species were identified in the Mana-Soda area (Figure 1). *Chrysopogon aucheri* was the most frequently occurring grass species around Mana-Soda followed by *Eragrotis papposa* and *Cenchrus ciliaris*. Species that were of moderate density in the area were *Pennisetum mezianum*, *Panicum maximum* and *Bothriochloa insculpta*. *Cyperus spp.* had moderate occurrence in the area. In contrast, *Sporobolus pyramidalis, Heteropogon*

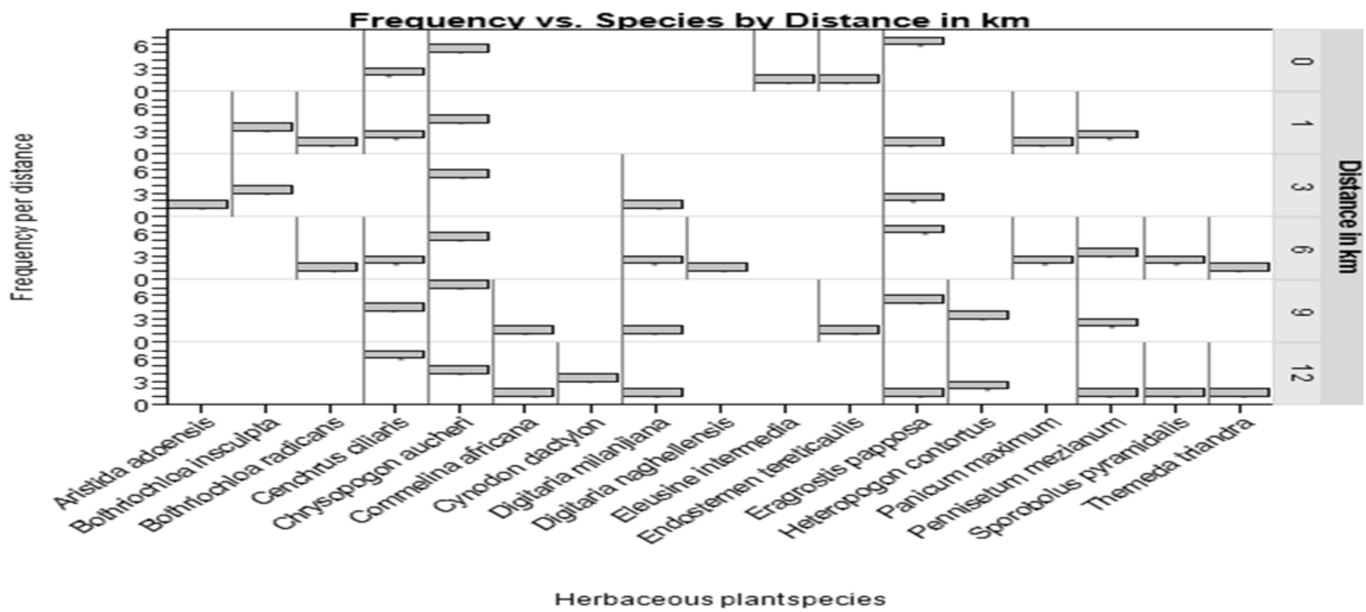

Figure 2. Frequency of herbaceous plant species in relation to distance from the salt crater.

Table 1. Diversity of herbaceous plants along distance gradient in Mana Soda area of the Borana, southern Ethiopia.

Distance (km)	Richness			Diversity			Evenness		
	MRS[a]	SRS[b]	Mean	MRS	SRS	Mean	MRS	SRS	Mean
0	4	3	3.5	0.55	0.96	0.76	0.5	0.87	0.69
1	4	3	3.5	1.34	0.79	1.07	0.97	0.72	0.85
3	4	2	3	0.9	0.69	0.8	0.65	0.99	0.82
6	11	5	8	1.76	1.37	1.57	0.73	0.85	0.79
9	7	3	5	1.75	1.06	1.41	0.9	0.96	0.93
12	6	5	5.5	1.19	1.31	1.25	0.66	0.81	0.74
P value level of significance	0.34NS[c]			0.18NS			0.77NS		

[a]MRS = main rain season; [b]SRS= short rain season; [c]NS= not significant (p>0.05).

contortus, Bothriochloa radicans, Cynodon dactylon, and *Dactyloctenium aegyptium* had relatively low densities. Overall, *Aristida adoensis, Themeda triandra, Eluesine intermedia* and *Digitaria naghellensis* were the grass species with the least density (Figure 1). *Commelina africana* was also of a very low density in the area.

The two dominant grass species *C. aucher*i and *C. ciliaris* were acknowledged by local people as species with good nutritive and palatability aspects. Locally they call them "*MotiiMerga*" which means 'queens of grasses'. Despite their relatively high abundance, the pastoralists noted that these species were declining in density over the years. *T. triandra* was the other grass species which was valued by the community but reported as sparsely distributed species.

The frequency for each species along the distance gradient from the crater is presented in Figure 2. In general, species richness was low closest to the crater but increased at distances beyond 3 km. As shown in Figure 2, *P. maximum* and *T. Triandra* were most prevalent at 12 km from the salt crater. *C. aucheri* was distributed evenly across all distances followed by *C. ciliaris* and *E. papposa*. It was observed that the major grass species in Mana-Soda were perennial, an aspect that has positive implications on rangeland condition.

Using the Shannon-Weiner index, species richness was not significantly different (p>0.05) along the distance gradient, from the salt crater (0 to 12 km), but was generally higher in the main than the short rain season (Table 1). Herbaceous plants were more even in the short than the main rain season. Species richness was positively correlated (r=0.80) with diversity (but weakly negatively correlated with evenness). As richness increased diversity also increased and could be estimated

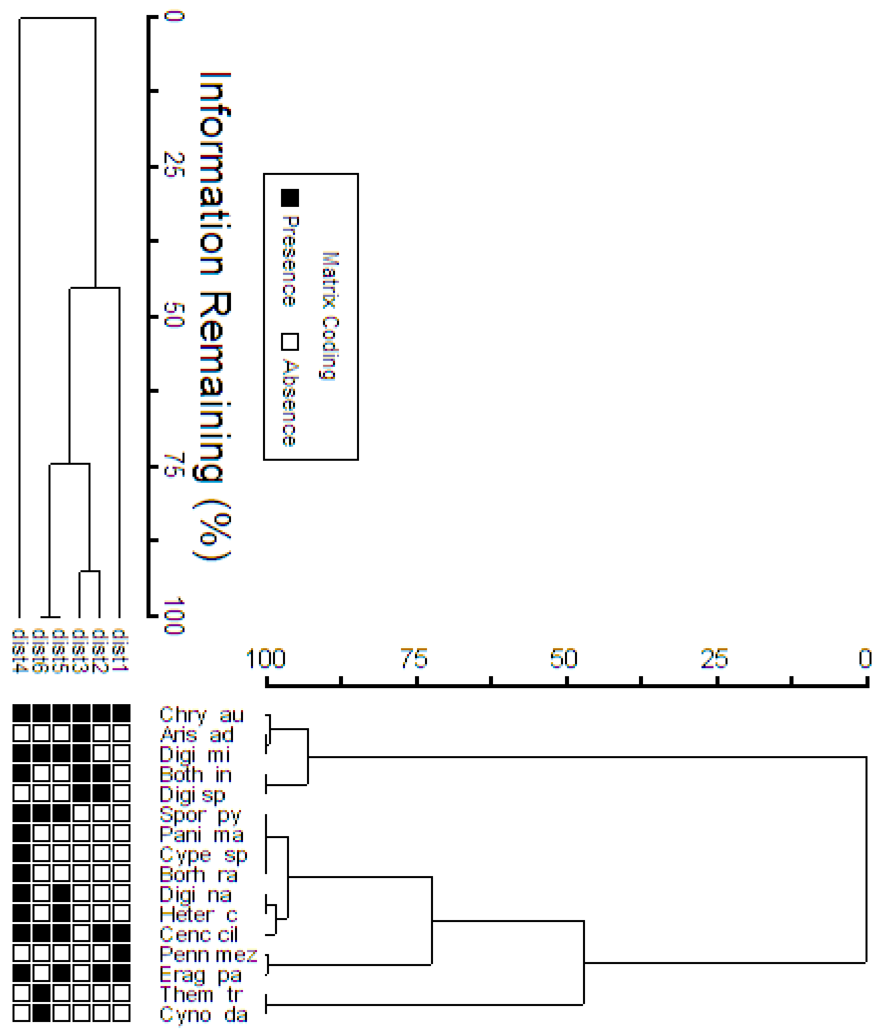

Figure 3. Dendrogram cluster analysis of herbaceous plant species around Mana Soda. Dist 1= 0 km, dist2= 1 km, dist 3 =3 km, dist4= 6 km, dist5=9 km, dist6 =12 km from salt, crater. *Chryau: Chrysopogon aucheri, Aris: Aristida adoensis, Digi mi :Digitaria milanjiana, Both in: Bothriochola insculpta, Digisp: Digitaria spp, Sporpy: Sporobolus pyramidalis, Pani Ma: Panicum maximum, Cypesp: Cyperu ssp, Bothra: Bothriochola radican, Digina :Digitaria naghellensis, Heterc : Heteropogon contortus, Cenccil : Cenchrus ciliaris, Penn mez : Pennisetum mezianum, EragPa :Eragrostis papposa, Themtr :Themeda triandra, Cynodac : Cynodon dactylon.*

using the regression equation Y=0.514+0.141X. In general species diversity in Mana-Soda was low and a few species were dominant.

Four major types of herbaceous plant communities were identified using PC-ORD hierarchical classification, using presence or absence of each species. The dendrogram presented in Figure 3 was produced using different similarity indices and the sorting strategies were evaluated for their differences. *Pennisetum mezianum* was the dominant grass species closest to the salt crater. Similarly, *T. triandra* and *C. dactylon* were the dominant species furthest away from the crater. Using TWINSPAN classification the indicator grass species identified at distances closer to the salt source were *C. aucheri, A. adoensis, P. mezianum, C. ciliaris, E. papposa and B. insculpta*. Between 3 and 6 km from the crater the indicator species were *C. aucheri, A. adoensis, S. pyramidalis, E. papposa, D. milanjiana, B. insculpta, P. maximum, B. radi*cans and *H. contortus*. Farthest from the salt source (12 km) the indicator grass species were *C. aucheri, C. ciliaris, A. adoensis, S. pyramidalis, T. triandra, D. milanjiana, and C. dactylon* and *H. contortus.* In general, plant communities were relatively more similar in areas less than 4 km from the mineral salt source compared to plant communities beyond the 6 km zone. While *P. mezianum* was the dominant grass species

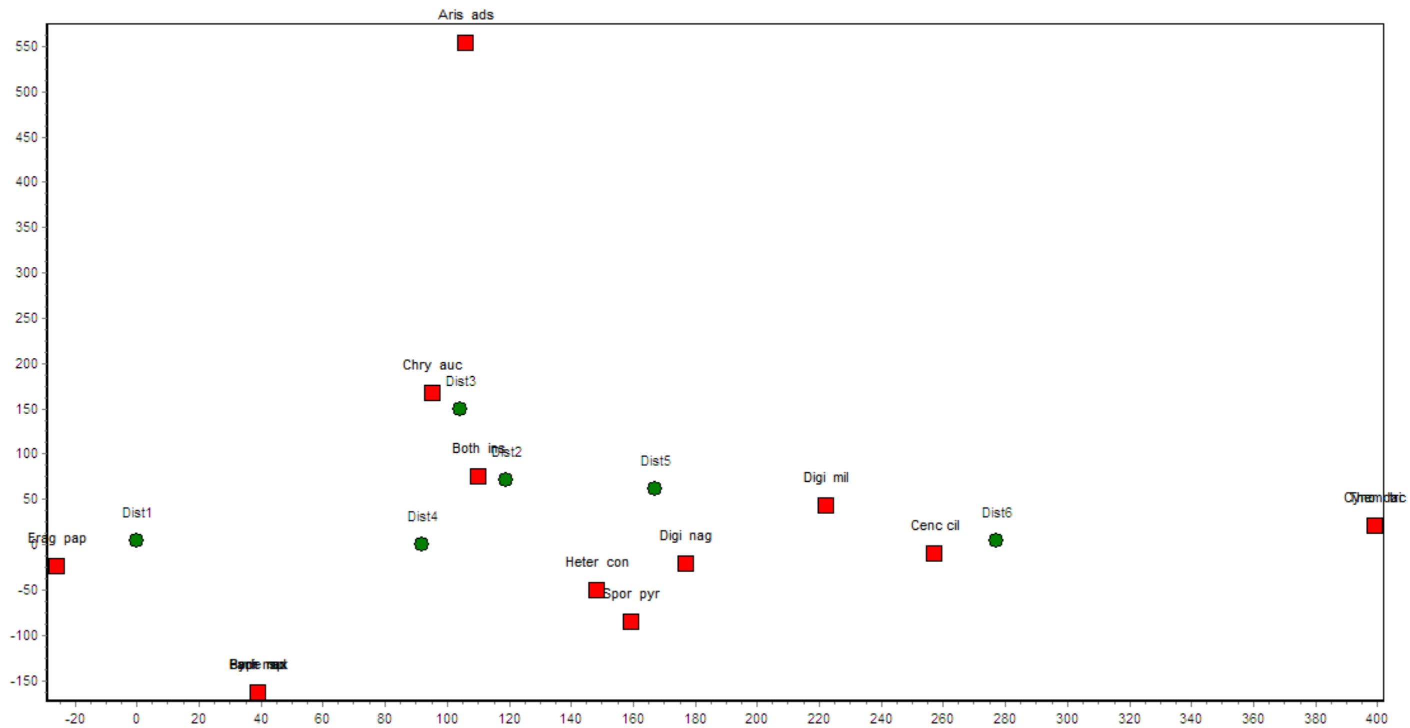

Figure 4. DCA ordination plot of herbaceous plant species along the distance gradient from the salt crater. Dist1= 0 km, dist2= 1 km, dist3 =3 km, dist4= 6 km, dist5= 9 km, dist6 =12 km from salt, crater. *Chry au: Chrysopogon aucheri, Aris: Aristida adoensis, Digi mi :Digitaria milanjiana, Both in: Bothriochola insculpta ,Digisp: Digitaria spp, Sporpy, Sporobolus pyramidalis, Pani Ma: Panicum maximum, Cypesp: Cyperus spp., Bothra: Bothriochola radican, Digina :Digitaria naghellensis, Heterc : Heteropogon contortus, Cenccil : Cenchrus ciliaris, Pennmez : Pennisetum mezianum, EragPa :Eragrostis papposa, Themtr :Themeda triandra, Cynodac : Cynodon dactylon.*

closest to salt source, *B. radicans* and *Cyperus* spp. were the dominant herbaceous plants at middle distances (6 km) from the crater. Correspondingly, *C. dactylon* and *T. trian*dra were the dominant grass species 12 km from the crater.

The DCA indicated that a high population of *E. papposa* was found closest (0 km) to the salt source, an area which was characterised by sandy soils and high levels of sodium (Figures 4 and 5). Between 0 and 1 km sandy clay soils were predominant and these were associated with a high population of *B. insculpta* compared to the other grasses. *A. adoensis* had the highest relative density at the 3 km zone from the salt crater, compared to other distance zones. This zone was characterized by clay and silt soil types and high contents of Ca, Mg, N and CEC.

The grasses *P. maximum, S. pyramidalis, B. radicans* and *D. naghellensi*s were densely distributed at the 4 km zone. This zone was rich in available phosphorus and potassium compared to the other distance zones. The 6 and 9 km zones had similar species despite the latter having sandier soils of higher pH. Although the soil type for the 12 km zone was similar to that of 9 km, *T. triandra* and *C. dactyl*on were dominant at the 12 km zone. On the overall, *C. aucheri* and *C. ciliaris* were the two species that had high relative densities across the transect, being particularly dominant in the areas where the soil was relatively undisturbed. On the contrary, *E. papposa* and *B. insculpta* were dominant in areas where the soil showed signs of recent disturbance.The proportions of desirable species increased with increase in distance away from the salt crater.

The findings of this study, with regard to the composition and distribution of herbaceous plants, are in partial agreement in different aspects of earlier studies in southern Ethiopia (Coppock, 1994; Angassa and Baars, 2000; Angassa, 2005; Dalle et al., 2006; Tefera al., 2007). The composition of herbaceous species in the main rain season was not different from that of the short rain season in Mana Soda, which concurs with the results reported by Angassa (2005) in the southern Borana rangelands. The relatively widespread occurrence of *C. aucheri* we are reporting is in general agreement with reports by Coppock (1994), Angassa (2005) and Tefera et al. (2007). Angassa (2005) and Nigusse (2008) also reported high occurrence of *E. papposa* and *C. ciliari*s, in agreement to what we are reporting in Mana-Soda. However, in the studies by Tefera et al. (2007) *C. ciliaris* occurrence was generally low in the Borana.

In our study *T. triandra* only increased in occurrence furthest away from the salt crater. This might be a reflection of the decreasing grazing pressure as one

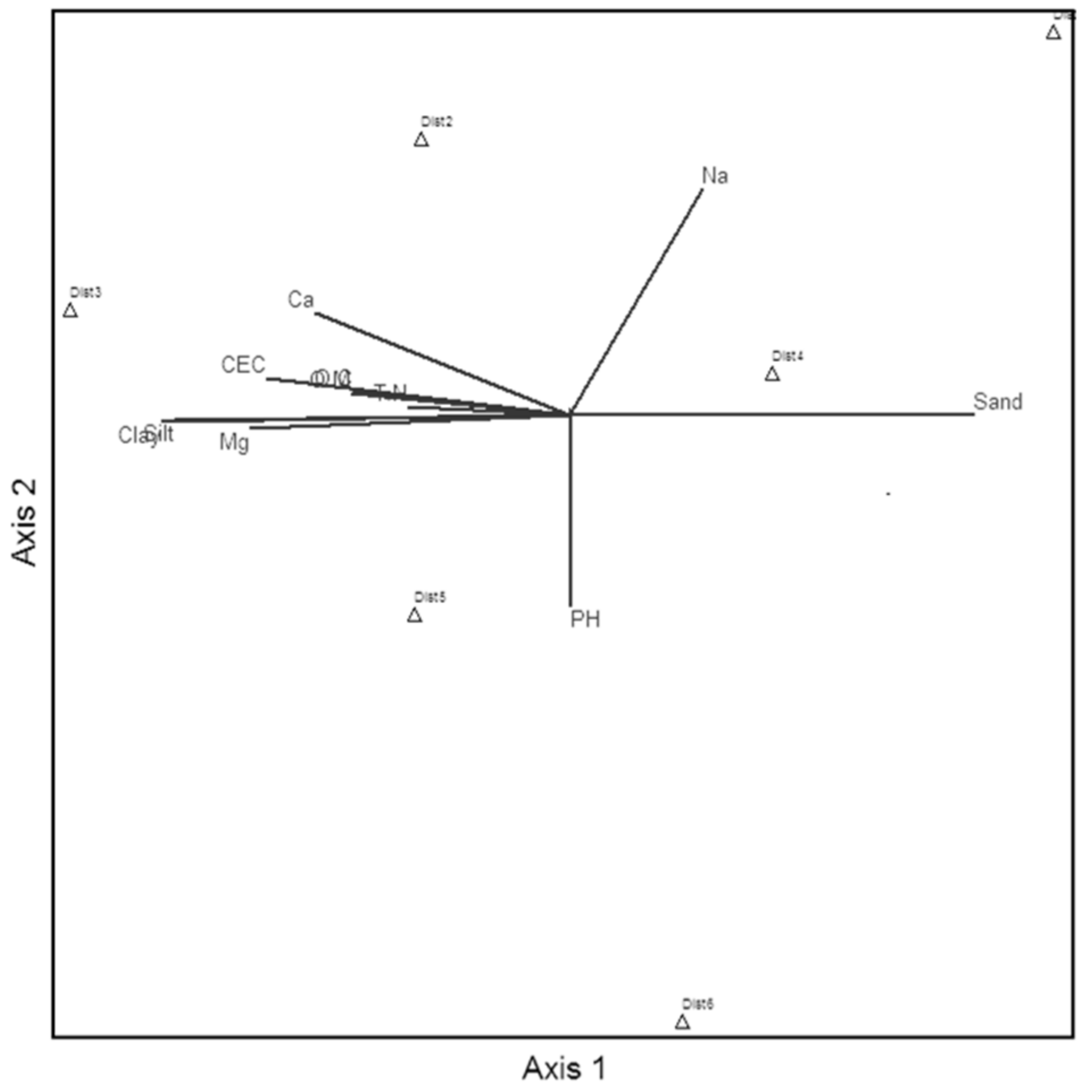

Figure 5. PCA ordination diagram of environmental variables with distance from the salt crater. Dist1= 0 km, dist2=1 km, dist3 =3 km, dist4 =6 km, dist5 =9 km, dist6 =12 km from the saltcrater.

move away from the patch resource. This is in general agreement with Tefera et al. (2007) who reported <1% frequency for *T. triandra* under communal and reserve grazing systems (presumably high grazing pressures) and about 12% under more controlled grazing management on a government ranch. However, this does not seem to be a plausible explanation for *B. radicans* which they reported highest closest to the patch resource (water point) and higher in under communal and/or traditional reserve management. In the study we are reporting *B. radicans* occurred at comparable frequency at the 6 and 12 km zones. On the overall, the high proportions of *C. ciliaris, C. aucheri and E. papposa* were potentially indicative of good range condition while increased occurrence of *A. adoensis, Cyperus* spp. and decline of *T. triandra, P. maximum* were indicative of poor condition or degraded rangeland in Mana Soda.

The PCA analysis of herbaceous plant species response to environmental variables indicated that *E. papposa*, *P.mezianum, C. aucheri*, and *C. ciliaris* were tolerant to exchangeable sodium in agreement with Dalle et al. (2006). Species such as *A*. *adoensis, Digitaria milanjiana* and *B. insculpta* were more influenced by organic matter, total nitrogen and moisture content than the other grass species, which was also noted by Nigusse (2008). The herbaceous plants which were responsive to phosphorus and potassium were *P. maximum, and D. naghellensis*. Similarly, *T. triandra, S. pyramidalis, C. dactylon B. radicans* and *C. ciliaris* were dominant in sandy soil areas and in areas where the pH was relatively high.

The increased occurrence of *H. contortus* and *E. papposa* as the altitude decreased in the Borana concurs with the report by Dalle et al. (2006). The same author

Table 2. Dry matter production (kg ha^{-1}), life form and ecological class of herbaceous plants for the main and short rain seasons along a distance gradient from the Mana Soda salt crater, southern Ethiopia.

Herbaceous species	L.F[a]	Ecoca[b]	0 km	1 km	3 km	6 km	9 km	12 km	Total
Highly desirable									
Eragrostispapposa	*P*	*Dec*	82.8	20.6	124.92	48.92	84.132	49.56	410.932
Cenchrusciliaris	*P*	*Dec*	45.6	93.8	86.8	236.5	258.72	58	779.42
Chrysopogonaucheri	*P*	*Dec*	162.8	215.6	419.6	559.952	586.568	1671.5	3616.02
Panicum maximum	*P*	*Dec*		13		207.56	42.24		262.8
Themedatriandra	*P*	*Dec*						20.16	20.16
Sub total			**291.2**	**343**	**631.32**	**1052.93**	**971.66**	**1799.22**	**5089.33**
Intermediate desirable									
Digitariamilanjiana	*P*	*Inc I*			13.152	18.04	51.22	19.71	102.122
Digitarianaghellensis	*P*	*Inc I*				10.86	11.02		21.88
Sub total					**13.152**	**28.9**	**62.24**	**19.71**	**124.002**
Cynodondactylon	*P*	*IncIIa*	12.4			5	26.8	49.2	93.4
Heteropogoncontortus	*P*	*IncIIa*	64.48			8	49.6	169.6	291.68
Sub total			**76.88**	**0**	**0**	**13**	**76.4**	**218.8**	**385.08**
Bothriocholainsculpta	*P*	*IncIIb*	23.1	210	260.48		72		565.58
Sporoboluspyramidalis	*P*	*IncIIb*				9.96	4.11	11.36	25.43
Bothriocholaradicans	*A*	*IncIIb*				10.44			10.44
Pennisetummezianum	*P*	*IncIIb*		256.2		730.56	780.6	100.8	1868.16
Sub total			**23.1**	**466.2**	**260.48**	**750.96**	**856.71**	**112.16**	**2469.61**
Less desirable									
Cyperus spp.	*A*	*IncIIc*					4		4
Eleusineintermedia	*P*	*IncIIc*	17.12						17.12
Aristidaadoensis	*P*	*IncIIc*			3.2				3.2
Commelinaafricana	*A*	*IncIIc*				19.2	5.44		24.64
Endostementereticaulis	*A*	*IncIIc*			28.8		10.08	30.4	69.28
Sub total			**17.12**	**0**	**32**	**19.2**	**19.52**	**30.4**	**272.32**
Total			**408.3**	**809.2**	**936.952**	**1864.99**	**1986.53**	**2180.29**	**8340.34**

[a]L.F= Life form; A: annual; P: Prennial; [b]Ecoca= Ecological Categories: Dec=decreaser; Inc = Increaser I; IncIIa = Increaser IIa; IncIIb = Increaser IIb; IncIIc = Increaser IIc.

noted that *B. radicans* increased with increasing altitude, similar to our findings. Our study also indicated that *T. triandra* and *Cyperus* spp are sensitive to altitude because both species completely disappeared as the altitude decreased. The observation that herbaceous plants were generally negatively correlated with pH in our study is in contrast to work reported by Nigusse (2008), but in agreement with Dalle (2004).

Dry matter production of dominant herbaceous plants

The ecological classification of the dominant herbaceous plants sampled at Mana-Soda is presented in Table 2. The estimated total dry matter produced over the 12 km gradient was 8340.34 kg ha^{-1}. Dry matter production of herbaceous plants increased with distance away from the salt crater, from 408.3 to 2 180.29 kg DM ha^{-1} for the 0 and 12 km sampling distances, respectively. The perennial grasses contributed higher dry matter than the annuals. The contribution to total dry matter production by decreasers, increaser I, increaser IIa and b, and increaser IIc in the study area were 61.02, 1.48, 34.22 and 3.27%, respectively.

Dry matter production of the ‘highly desirable’ grasses increased from 291.2 to 1799.2 kg ha^{-1} along the 0 to 12 km distance gradient (Table 2). In this group *C. aucheri* and *C. ciliaris* were the high dry matter producers followed by *E. papposa,* and *P. maximum,* while *T. triandra* contributed the least. Dry matter production of the ‘intermediate desirable’ grass species was highest at the 6 and 9 km sampling distances, being 792.86 and 995.35 kg ha^{-1}, respectively. Other than the considerable

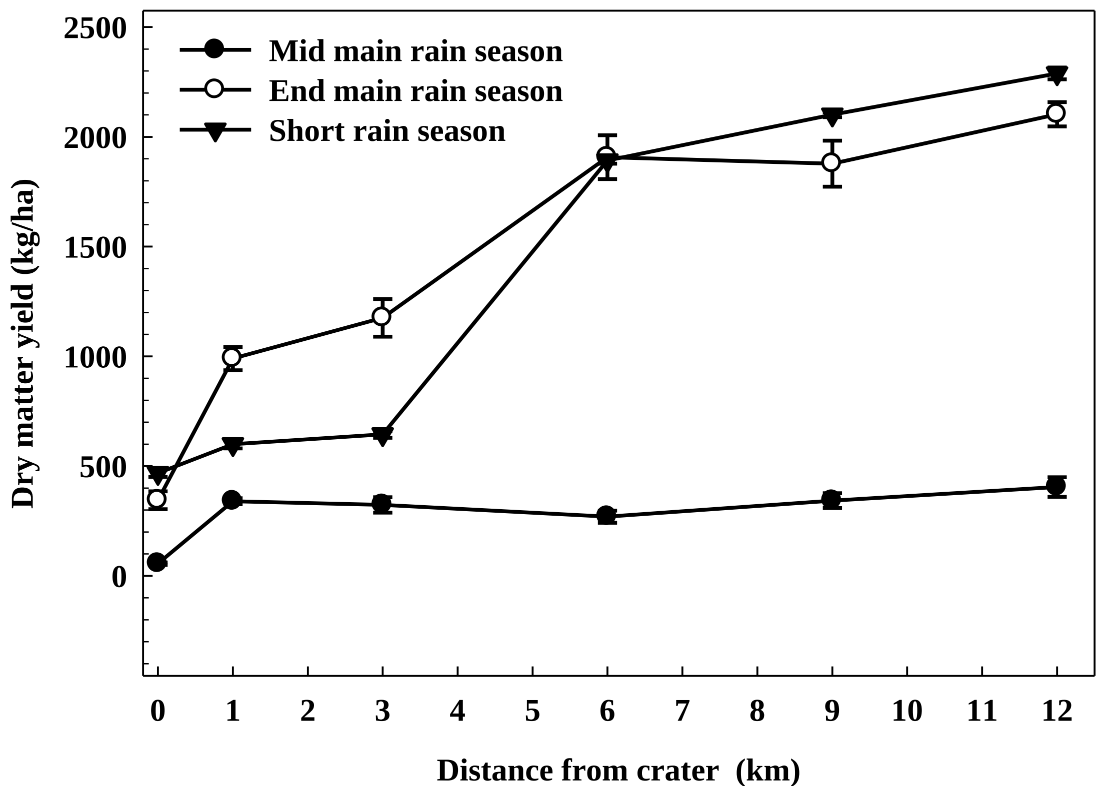

Figure 6. Seasonal dry matter production along a distance gradient from the Mana Soda salt crater. Bars extending beyond the means denote standard error of the mean.

dry matter contribution of *B. insculpta* at 1 and 3 km and *P. mezianum* at 6 and 9 km the 'intermediate and less desirable' grass species did not show a particular yield trend across the distance gradient from the salt crater. The notable dry matter producers among the 'less desirable' species were *Eleusine intermedia* (17.12 kg ha^{-1}) at the 1 km sampling site and *Endostemen tereticaulis* (28.8 kg $ha^{-1}$and 30.4 kg ha^{-1} at the 3 and 12 km site, respectively). The contribution from the rest of the species in this group was relatively insignificant in the main.

The seasonal distribution of biomass produced along the distance gradient is presented in Figure 6. Generally, little biomass had accumulated across the gradient by mid-main rain season. At this stage there were no significant yield differences for the 1 to 12 km sampling zones, although on average these yielded higher than the sacrifice zone (0 km). There was considerable biomass accumulation between the mid- and end of the main rain season. The proportionate contribution of annual grasses and forbs to total dry matter yield decreased as the season advanced. The yields increased with distance from the salt crater and ranged from 55.97 kg ha^{-1}(0 km) to 2289 kg ha^{-1} (12 km). The 1 to 12 km zones yielded higher than the sacrifice zone. The general ranking of the zones in terms of yield was 12 km > 9 and 6 > 3 and 1 during the main rain season. Yields during the short rain season also increased with increasing distance from the crater. However, significant yield differences were only recorded beyond the 3 km zone. From the 6 to 12 km zones the short rain season had comparable yields to those of the main season.

The variation of dry matter production with distance from the salt crater we are reporting is in line with the piosphere analysis of grazing lands around patch resources. Generally, there is a positive correlation of dry matter production as distance increases from the sacrifice zone of the patch resource (Landsberg et al., 2002). The dry matter production for the different plant ecological groups we are reporting are in general agreement to those reported by Dalle (2004) who reported moderate amounts of biomass by mid-main rain season but considerable biomass at the end of the main rain season and during the short rain season. Angassa (2005) also reported decreased contribution of annual grasses to total yield at the end of summer relative to early summer. The fact that forbs and annual grasses (short life cycle) were more abundant during the early rain season might explain the low dry matter production by the mid main rain season in our study. At the end of summer the high yielding perennial grasses were more abundant, hence the higher dry matter production. The

Table 3. Rangeland condition of Mana Soda salt areas.

Scientific name	Main rain season			Short rain season			
	Class	**WPC[a]**	**EI[b]**	**Scientific name**	**Class**	**WPCM**	**EIM**
Eragrostispapposa	Decreaser	30	100	*Eragrostispapposa*		27	90
Endostementereticaulis	Increaser IIb	9	36				
Cenchrusciliaris	Decreaser	33	110	*Cenchrusciliaris*	Decreaser	6	20
Chrysopogonaucheri	Decreaser	39	130	*Chrysopogonaucheri*	Decreaser	51	170
Bothriochloainsculpta	Increaser IIb	18	36	*Panicum maximum*	Decreaser	6	20
Commelinaafricana	Increaser IIb	8	16	*Commelinaafricana*	Increaser IIb	4	8
Digitariamilanjiana	Increaser I	10	20				
Aristidaadoensis	Increaser IIc	2	2				
Sporoboluspyramidalis	Increaser IIb	10	20				
Bothriochloaradicans	IncreaserIIb	4	8				
Digitarianaghellensis	Increaser I	6	14				
Heteropogoncontortus	Increaser IIa	4	8	*Heteropogoncontortus*	Increaser IIa	4	8
Panicum maximum	Decreaser	6	20	*Panicum maximum*	Decreaser	6	20
Cyperus sp.	Increaser IIc	4	4				
Themedatriandra	Decreaser	6	20				
Cynodondactylon	Increaser IIa	4	8	*Cynodondactylon*	Increaser IIa	6	21
Eleusineintermedia	Increaser IIc	2	2				
DigitariaSp	Increase IIb	4	8				
Pennisetummezianum	*Increaser IIb*	6	12	*Pennisetummezianum*	Increaser IIb	6	12
Point score value		205	**574**	Point score value		110	**349**
WPC		**44.7**		**WPC**		**5**	

[a]Weight palatability composition; [b]Ecological index.

fact that decreasers and increaser II species contributed the bulk of the biomass produced might be indicative of a good range condition.

The results that palatable perennial plants decline in density or are eliminated and replaced by unpalatable and/or short-lived species at distances closer to the patch resource (e.g. mineral lick; watering point) we are reporting are in concurrence with several other studies (Hunt, 2001; Brits et al., 2002; Landsberg et al., 2002). The desirable species decrease due to the effects of increased grazing pressure. This increased utilization pressure closer to the patch resource is the likely explanation of the changes in herbaceous cover around the Mana Soda salt crater.

Range condition

The ecological index and weighted palatability composition values for the main and short rain seasons were 574 and 349, respectively (Table 3). The calculated mean ecological index value for both seasons was 464, giving a fair condition score for the rangeland after Vorster (1982). The WPC values for the main and short rain season were 44.7 and 5%, respectively. Using the WPC the rangeland condition was classified as poor in the short rain season and fair in the main rain season, following Barnes et al. (1984). Although the ecological index and WPC methods produced different range conditions for the area across the seasons the two methods classified the rangelands around Mana-Soda as poor to fair.On the overall, the proportion of increaser species was high around Mana-Soda and that of decreasers low. This might explain the poor to fair range condition estimations. Similar condition estimates have been made in recent times in the Borana rangelands (Oba and Kotile, 2001; Dalle, 2004; Angassa, 2005; Tefera et al., 2007; Angassa and Oba, 2010).

Conclusions

Taken together, these results indicate changes in plant composition and abundance as the distance from the salt crater increased. The increased abundance of annual species closest to the crater is testimony to the high utilization pressure in the sacrifice zone. The frequently occurring indicator grass species in Mana-Soda were *A. aucheri, C. ciliaris and E. papposa*. However, species richness was the same along the distance gradient from crater. This might be an indication of an already exceeded degradation threshold in terms of species richness along the gradient. Dry matter production of grasses of 'high and intermediate' desirability increased with distance away from the sacrifice zone. The rangeland condition around Mana-Soda ranged from poor to fair. It can be concluded that the distribution of sources of natural mineral salt in rangelands can affect herbaceous plant species composition and rangeland condition.

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