The impact of changes in land-use patterns and rainfall variability on range condition and pastoral livelihoods in the Borana rangelands of southern Oromia, Ethiopia

by

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DECLARATION

I, Habtamu Teka Keba declare that the thesis, which I hereby submit for the degree Doctor of Philosophy in Pasture Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature: --

Date: --

DEDICATION

This work is dedicated to my late industrious mother Tsehaynesh Wakjira Aredo whose effort and sacrifice inspired me to pursue higher learning and my dreams always. Unfortunately she did not live to witness this moment. Words cannot convey my deepest gratitude to you.

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ABSTRACT

This study was conducted in the Borana rangelands, southern Oromia, Ethiopia with the aim of investigating land-use/cover changes, rangeland condition and indentifying major change drivers in the rangelands. Satellite image scenes, ground survey and people's perceptions were assessed to identify changes on herbaceous and woody species composition. Ordination techniques were used for correlation of grass and woody species into environmental variables. Piospheric effects on vegetation composition around patch resources were also examined. These assessments were designed to bring out both spatial and seasonal variation in vegetation parameters. Rangeland condition was determined using the ecological index (EIM) and the weighted palatability composition (WPC) methods. Grazing capacity assessment was largely based on rain-use efficiency, range condition, density of woody plants.

Woody cover in the Borana increased from 11.3% in the 1970s to 49.26% in 2000s, while, grassland cover declined from 58% to 32% during the same period. The cultivated/built up area also increased gradually over the years though the extent of increment was less compared to the woody cover changes. The calculated NDVI values for the 2000s were low relative to the 1970s.

Ground survey results demonstrated that herbaceous biomass production and woody plant density varied significantly ($P < 0.01$) for the different sites in Borana. Nevertheless, herbaceous plant diversity and evenness did not differ significantly ($P>0.05$) across the different sites and around patch resource areas. This confirms the resilience of the Borana rangeland to the effects of grazing pressure and climatic variability. Overall, the density of woody plants varied from moderate to sever encroachment, which corresponds to the rangeland condition classes from very poor to fair.

The results of the present study showed that the nutrient contents of herbaceous plants (CP, NDF, ADF, ADL and ash) were greatly influenced by species, stage of maturity, site and season. Herbaceous species with high crude protein content based on laboratory results were also ranked as the top important species by the pastoralists. Similarly, herbaceous forage species with a high structural fiber were considered inferior. Pastoralists' knowledge and laboratory results on the nutritive value of key herbaceous species complemented each other.

The stocking density of livestock units was higher than the grazing capacity for the Borana rangelands. Stocking density for the Borana rangeland using rain-use efficiency was 1.43 ha/TLU. There was no significant difference in the grazing capacity across the different sites in the study area under the existing management.

The majority of pastoralists believed that the rangelands in Borana have been degraded, as consequence of recurrent drought (83%), population pressure (65%), poor management and inappropriate government policy (38%). The majority of the respondents (94%) also asserted that the traditional coping mechanisms of Borana pastoralists have declined. There is therefore a need for designing appropriate pastoral land-use policies that fit the ecological potential of the region to ensure sustainable ecosystem functioning. We suggest a comprehensive and adaptive range management for the implementation of appropriate land-use systems for the different livestock species. There is need to adjust stocking rates based on seasonal availability of forage. This would foster economic feasibility and ecological sustainability of the Borana pastoral production system.

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LIST OF ABBREVATIONS

ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
ANOVA	Analysis of Variance
AOAC	Association Official Analyze Chemists
AVHRR	Advanced High Resolution Radiometer
BL	Bukkulboma
C/N	Carbon to nitrogen ratio
CADU	Chilalo Agricultural Development Unit
CEC	Cation exchange Capacity
CP	Crude Protein
CSA	Central Statistical Agency
DCA	Detrended Component Analysis
DMD	Dry Matter Digestibility
DTR	Did-Tuyura
DWR	Danbala-Wachu Ranch
EARO	Ethiopian Agricultural Research Organization
ENVI	Environment for Visualizing Images
ERDAS	Earth Resource Data Analysis
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization of United Nation
IEK	Indigenous Ecological Knowledge
IFAD	International Fund for Agricultural Development
LAC	Land Absorption Coefficient
LCR	Land Consumption Rate
LULC	Land use /Land cover
MSD	Mana-Soda
ME	Metabolizable Energy
MSS	Multi spectral sensor
NDF	Neutral Detergent Fiber
NDVI	Normalized Differences Vegetation Index

O: C	Organic Carbon
O.M	Organic Matter
OBPED	Oromia Bureau of Planning and Economic Development
OWWDSE	Oromia Water Work Design and Supervision Enterprise
PADS	Pastoral Area Development Study
PCA	Principal Component Analysis
PC-ORD	Principal Co-ordination
pH	pH in water
RFV	Relative Feed Value
SAS	Statically Analysis Software
SPSS	Special Package Software for Social
SUR	Surupha
T.N	Total Nitrogen
TLU	Tropical Livestock unit
TM	Thematic Mapper
TWINSPAN	Two- Way Indicator Species Analysis

CHAPTER 1

GENERAL INTRODUCTION

1.1 Rangeland management

Rangeland management is an applied ecology a principle involved in regulating the vegetation, soil and animal instruction in the ecosystem (Holecheck *et al.,* 2000). It deals with the environment to maximize its benefit for human being sustainably without destruction. Rangelands are a source of natural pasture for extensive livestock production that covers the largest portion of the world in arid and semi-arid environments, areas that are not suitable for cropping (Stoddart *et al*. 1975). They constitute about 50% of the land mass of the world of which 65% is on the Africa content (Friedel *et al*., 2000). They are home to about 30 to 40 million people of the world with over 50% of these people living in Africa, commonly referred to as "pastoralists" (Sandford, 1983). The nature and productivity of rangeland ecosystems are determined by the physical (climate, topography and soil), biological (e.g. grazing), pyric (fire) and anthropogenic factors (Herlocker, 1999, Gadzirayi *et al*., 2007). Climatic variability has been considered as one of the major factors that determined the rangeland primary production (Henry *et al*., 2007; McKeon *et al*., 2009). Rangeland has been an important economic resource for Borana pastoralists but has also been vulnerable to the impacts of a climatic variability (Cossins and Upton, 1988). Overall, climate change will likely add to and exacerbate existing pastoral management challenges such as declines in rangeland forage production, reduced forage quality and more frequent droughts (Fensham *et al.,* 2005).

The dynamics of the dry land of Africa are characterized by climatic variability and episodic unpredicted events (Scoones, 1995). Several studies revealed that in arid and semi-arid environments climate change and variability remains the dominant event that determines rangeland vegetation structure and function than the biotic factors like grazing pressure (Behnke and Abel, 1996; Hiernaux, 1996). Human interference (e.g. sedentarization) is also a more serious problem than overgrazing in determining the function of a rangeland (Warren and Rajasekaran, 1993). On the other hand, Niamir (1987) pointed out that piospheric effects contributed to the changes in rangeland ecosystem function due to grazing and trampling effects attenuated to the resource points.

In the last 40 years, most parts of Africa lost their rangelands as a result of land-use and tenure changes like expansion of crop cultivation, establishment of government and private ranches, tourist game parks and loss of common property resources (Fratkin *et al.*, 1999). The misconceptions arose from the very influential ideas grounded on the rangeland succession theory of Clements' (1916) and Hardin's (1968) 'the tragedy of the commons'; and these affected the rangelands of Africa severely. The common property resource hypothesis assumed an open access to everybody (Hardin, 1968). According to Clements (1916), grazing has a pioneer impact on arid rangelands than other driving forces. When these theories were introduced in many parts of Africa (Sampson, 1917) they affected the rangeland management practices (Westoby *et al.*, 1989) in arid environment. When the theories of equilibrium and the tragedy of the commons were applied in semi-arid rangelands of Africa little attention was given to the cultural practices accumulated over several years by indigenous pastoral communities (Behnke *et al.*, 1993). Among these practices seasonal herd mobility and traditional rules and regulations are important management aspects missed by the two theories. The rangeland succession model, which was developed for fenced pastures and cultures of western countries, was imposed onto the pastoral rangelands of Africa. Regardless of the wide application of the succession model, a rangeland would not remain at a climax point in arid environment (Westoby, 1980). Vegetation shifts from one state to another separated by thresholds are common in arid environments (Westoby *et al*., 1989). These transitions can be aggravated by biotic and abiotic factor and their combination. Once the transition crossed the threshold, it is not simple to reverse the situation even after removal of the trigger factors (Friedel, 1991). It may be practically irreversible or reversible only on a long time scale or following a different set of events and through a sequence of other vegetation states (Westoby *et al*., 1989).

The management of arid and semi-arid rangelands requires a combination of biological, physical, and social sciences (Stoddart *et al*., 1975; Mannetje and Jones, 2000). Development interventions that did not integrate traditional range management practices have not been successful. Development programs in arid and semi-arid rangelands of Africa largely failed due to ignorance of pastoralists' participation (Behnke *et al*, 1993; Scoones, 1995; Waters-Bayer *et al.* 1998). On the other hand, imposing the equilibrium solutions such as the ranch model to non-equilibrium environments and converting pastoral lands to non-pastoral activities (Waters-Bayer *et al*., 1998) triggered degradation of rangelands in semi-arid Africa. Similarly, past development interventions planned for the improvement of rangelands in Ethiopia failed due to the exclusion of pastoralists and adoption of the top-down development approach. Policy makers failed to understand the dynamic and holistic pastoral approach (Mesfin, 2001). Development programs implemented in the rangelands of Ethiopia actually contributed to rangeland degradation, which is characterized by the reduction of the quantity (biomass) and/or nutritional quality of the available vegetation (IFAD, 2003).

1.2 The Borana rangelands of Ethiopia

The arid and semi-arid rangelands of Ethiopia are characterized by lowland plains, variable climate with unreliable and erratic rainfall and regularly high temperatures (Alemayehu, 1998). About 61% of the national land mass of Ethiopia is categorized as arid and semi-arid rangelands (EARO, 2003). It is home to more than a 12 million pastoral population in Ethiopia (Gezahegn, 2003). In addition, the Ethiopian rangelands represent valuable resources to the pastoralists and the nation (Oba, 1998). About 40% of the national cattle herd, 50% of the small ruminants and almost all camels are found in the arid and semi-arid rangelands of the country (Hogg, 1997). The land mass of the pastoral areas of Oromia are about 63, 939 km^2 (7.6% of the nation's total; OBPED, 2000), carrying an estimated pastoral population of 4.2 million, which is the second major habitat of pastoralists in the country after Somalia Regional State (PADS, 2004).

Until the early 1980s, the Borana rangelands were considered one of the best remaining rangelands in East Africa (Cossins and Upton, 1987). Since then, the savanna ecosystems of southern Ethiopia have been experiencing greater livestock population growth (Cossin and Upton, 1988; Desta and Coppock, 2002); and deterioration of the rangeland condition as evidenced by severe bush encroachment and general decline in forage production (Oba *et al.*, 2000b). Previously, this robust natural resource base and the stable system of the traditional land-use were related to communities' knowledge of resource management and the extensive grazing lands used in different seasons (Upton, 1986). Under the communal rangeland management, seasonal movements of stock and the use of different landscapes between the dry and wet grazing season areas were the most common features of land-use (Oba *et al.*, 2000a). Today, the biological and physical degradation of the rangeland resources are serious challenges, bearing negative impacts on the pastoral ecosystems, livestock population and people's livelihoods

(Vetter, 2005). The degradation indicators include reductions in total vegetation cover and palatable plant species, increases in unpalatable plant species, and depletion of soil quality and nutrients due to the various forms of soil erosion (Mekuria *et al.,* 2007).

In the Borana lowlands, there has been a decline in the quality of grazing resources. Biomass production of the most palatable grasses is decreasing, contributing to poor forage quality. The mean percent cover of woody plants in the Borana increased by 52 (Dalle, 2004). The cover and density of woody plants apparently indicates that the Borana rangeland system has crossed the threshold. Previous studies (Oba and Kotile, 2001; Dalle, 2004) have also revealed that inappropriate external interferences have contributed to the deterioration of grazing lands. For example, about 60% of the Borana grazing land was given to other tribes (Oba and Kotile, 2001), and 54,000 ha of the rangelands was allocated to ranching (Oba and Kotile, 2001), and crop cultivation has been expanded presently covering some 4,000 ha (Angassa and Fekadu, 2003). The government ban of rangeland fires has over a period of times resulted in uncontrolled bush encroachment in the rangelands (Woldu and Nemomissa, 1998; Angassa and Fekadu, 2003).

Unfortunately, rangeland degradation is less understood by policy makers, development planners and researchers (Dalle, 2004; Vetter *et al*., 2006). It is confused with desertification (Mortimore, 2005), largely stemming from the biases of western intellectuals (Ellis and Swift, 1988). As a result, pastoralists' perceptions and years of experience on resource management are overlooked (Dalle *et al*., 2006b; Allsopp *et al*., 2007; Katjiua and Ward, 2007), and their production system is considered as ecologically unfriendly and not sustainable (Lamprey, 1983). Failure to understand and incorporate the indigenous ecological knowledge, practices, goals and strategies of the pastoral communities, as well as lack of their participation in planning, implementation and the evaluation process are the major contributors to the current rangeland ecological degradation.

The Borana pastoral communities have a traditional coping mechanism (i.e. mobility, communal enclosure and herd diversification) to frequent and often dramatic variation of climatic change and anthropogenic influences (Desta and Coppock, 2004). In recent decades, however, this life style has come under enormous pressure, which under-mined the ability to maintain the standard of living of a large sector of pastoralists. Similar to pastoralists of other African countries, the Borana pastoralists are experiencing considerable erosion of their traditional life style. A fundamental understanding of the perceptions and traditional management practices of the Borana is lacking. Despite rangeland degradation, the lessons learnt on related impacts on pastoral livelihood and pastoralists' perceptions are far less documented to guide mitigation and adaptation (Mesfin, 2001; Dalle *et al.,* 2006b; Mekuria *et al*, 2007).

1.3 Challenges in the Borana rangelands

The growth of livestock and human populations are at an increasing rate, while the rangeland resources on which they depend is limited or diminished both in terms of grazing area and productivity (Desta and Coppock, 2002). The increasing human population calls for an increase in livestock population. However, the increase in livestock population could probably exacerbate the ecological imbalance in Borana that might further contributed to overgrazing and rangeland degradation.

In the view of the majority of Borana pastoralists, the increasing density of people and expansion of cultivation is impeding free mobility. The government development strategy supports sedentary settlements, which influence the pastoral systems by allocating the key pastoral grazing areas for other purposes. Continuous expansion of settlers in the rangelands and the takeover of the permanent water points may have increased the vulnerability of the rangeland to climatic uncertainties and led to over-utilization and/or degradation of range resources.

Some studies (Takele, 2006; Tache, 2010) showed that the numbers of poor households have increased recently in the Borana, and these are now involved in cultivation, fire wood and charcoal production aggravating the deterioration of the rangelands. Apart from this, the expansion of private and cooperative ranches and subsequent shrinkage of the rangeland resource all together contributed to the denudation of rangeland.

On the other hand, the woody plant encroachment is continuously threatening the rangeland and livestock production and challenging the sustainability of rangeland productivity in the Borana lowlands. The study by Oba *et al*. (2000b) has shown that woody plant encroachment was negatively correlated with grass cover, and positively with bare soil. Grass cover was negatively correlated with bare soil and grazing pressure. Furthermore, they identified bush climax, loss of grass cover and increase of unpalatable forbs as the main threats to rangeland condition in the Borana. Woody plant encroachment into grassland and savannah can alter soil moisture and nutrients, microclimatic conditions, and can suppress grass productivity (Richter *et al*., 2001; Roques *et al*., 2001). White (1983) reported that woody plant cover becomes a problem when it exceeds 30%. According to Roques *et al*. (2001), 40% woody plant cover, which is approximately equal to a density of 2,400 plants per hectare, is accepted as the equilibrium but 2,500 tree equivalents per hectare is an encroached condition. In most parts of the Borana rangelands, woody plant encroachment has already crossed this threshold (Dalle *et al*., 2006a).

The Borana rangelands are also characterized by intense isolation from development, inaccessibility due to poor infrastructure and inability to support crop based agricultural production. External factors such as climatic variability, political instability, and macro-economic imbalances have interacted with internal phenomena such as livestock and human population growth, ethnic tensions, weak financial and marketing systems, and inadequate delivery of support services to exacerbate vulnerability of the rangeland. Besides, changes in the land tenure system influenced the productivity of rangelands (Helland, 1997). The overall degradation of rangeland in the Borana is therefore increasingly on a downward spiral and typified by poverty, recurrent famine, physical insecurity, and environmental degradation (Little *et al*., 2008).

1.4 Motivation of the study

In the Borana, there is degradation of rangelands as a result of grazing pressure, climatic variability, expansion of crop cultivation, bush encroachment, government and private ranches and sedentary settlement, which overall pushing pastoralists out of the ecosystems without providing them with alternative options. The major reasons for the rangeland degradation in Borana are complex and not clearly identified. There is a need to study the driving forces of changes to allow for proper design of strategies to halt rangeland degradation. The specific effect of land-use changes on grazing capacity of the Borana rangeland has not been studied. There is a paucity of information to guide policy makers and development actors in designing appropriate holistic interventions. This can also be aided by systematic establishment of base line information to help in setting up monitoring and evaluation of stocking rate and grazing capacity for sustainable rangeland management. The identified key herbaceous species and intruding woody plants in the study area can be used as a base information for change detection of the rangeland vegetation composition in future for researcher and development actors.

There is also a great need for the engagement of the pastoralists and the wisdom they accumulated over the years. This fundamental understanding of the perceptions of Borana pastoralists in relation to the traditional rangeland and livestock management practices has to be deepened. Failure to understand and incorporate the indigenous knowledge and practices into rangeland development plans, implementation and evaluation will negatively influence proper function of the ecosystem. The idea of interfacing the formal and informal institutions for situational rangeland management systems needs to be explored further.

1.5 Objective of the study and hypothesis

Both ecological and socio-economic information is highly needed to support informed rangeland management decisions. Waters-Bayer and Bayer (2000) pointed out that applied rangeland research should deal not only with plants and animals but also with people and their perceptions, aims, problems and needs. The “old” notion of portraying pastoralists as economically irrational and operating with inherently destructive communal land tenure systems has weakened the pastoral system. To challenge this notion systematic scientific information is needed to support proper rangeland development strategies in East Africa as well as in Borana rangelands of Ethiopia.

The Borana rangelands are in danger of becoming seriously degraded, which implies that reclamation is a major priority in these areas. Rangeland reclamation must be preceded by a thorough assessment of the current state of rangeland health. In the Borana, native or natural pastures make up the bulk of the feed (Abule *et al.*, 2005; Dalle *et al.*, 2006b). Fodder usually consumed by domestic animals and wildlife consists mainly of grass and woody plants. Vegetation is usually used to quantify the range condition since it is a more sensitive indicator of ecosystem change, and is easier to measure than is the soil (Teague and Smit, 1992). Soil loss may be regarded as an absolute measure of the "health" of grazing lands (Wilson *et al*., 1984) since it requires long periods of time to be reversible, and results in reduced productivity and affects future land use options. Rangeland resource assessment and analyses are generally carried out to quantify resource endowment, understand interrelationships between resource components, predict environmental impact, estimate livestock support capacity, and to appraise development options. Waters-Bayer and Bayer (2000) recommended that approaches and methods of rangeland research should be people-centered and development-oriented. In all these analyses, the concept of "rangeland condition and trend" is used to denote the change in vegetation composition, productivity and soil stability that occur when rangelands are grazed by domestic livestock (Wilson and Tupper, 1982). The purpose of measuring these changes in condition and trend is based on a concern for both the short and long-term productivity and stability of these rangelands (Snyman, 1998; Tefera, 2003).

This study addressed the following research questions:

1. What are the main driving forces for the changes in rangeland condition and trend in Borana?
2. Does the change of land-use system of the Borana rangeland affect vegetation composition? How does the resultant range condition and trend affect grazing capacity?
3. How have the recent dynamics in Borana impacted the utilization of patch key resources and the surrounding rangelands?

4. Do pastoralists recognize the current challenges they face? If so, what coping mechanisms do they have? How do these challenges affect their production system and livelihood?

Hypotheses

1. Changes in rangeland condition in Borana could be attributed to a few driving forces.
2. Changes in range condition and trend do not have an effect on the grazing capacity and land-use pattern of the Borana rangeland.
3. Changes in rangeland production dynamics had no effect on the utilization of key resource patches and their environs.
4. Pastoralists do understand the current challenges facing their production system and livelihood, and have ways of coping with them.

The objectives of this study were therefore:

1. To assess changes in land-use / cover pattern and range resource utilization in the Borana.
2. To evaluate the impacts of the main driving forces on changes in rangeland condition and trends in Borana rangeland.
3. To investigate the long-term changes in grazing capacity of the Borana rangeland.
4. To analyze vegetation changes and rangeland condition around rangeland patches resources.
5. To understand perceptions of the Borana pastoralists on the current challenges, changes in rangeland condition and trend, and local coping mechanisms.

1.6 Materials and methods

1.6.1 Study area

The Borana rangelands are located in the southern part of the country between 4^0 36\`to $6^0$ 38\` N latitude and 36^0 43\` to $42^0$ 30\` E longitude (Coppock, 1994). The landscape is slightly undulating and ranges in altitude from 900 to 1650 meter above sea level (masl), peaking at up to 2000 masl. The area has arid to semi-arid climate with annual rainfall ranging on average from 450 mm in the south east to 700 mm in the North West (Helland, 1980). Rainfall is bimodal with 60% of the annual precipitation expected during March-May (*Gana*) and the remaining expected during September-November (*Hagaya*). The long dry season extends from late November to early March with drought recurring every 5 to 10 years. The mean annual temperature varies from 15 to 24°C and shows little variation across seasons. Four vegetation types were described, namely: (1) evergreen and semi evergreen bush land and thickets, (2) rangeland with shrubby Acacia, Commiphora, (3) rangeland dominated by alien genera, and (4) dwarf shrub grassland or shrub grassland. The geology of the area is dominated by 40% quaternary deposits, 38% basement complex formation and 20% volcanic. The same author also suggested that verti soil occur more in valley bottoms (Coppock, 1994).

The study was conducted in five communal grazing areas (*Warra* and *Forra* grazing reserves included), one cooperative ranch (Dambala-Wachu), and one government ranch (Did-Tuyura). The communal grazing areas (pastoralist association) were Surupha in the north, Did-Hara in the east, Mana-Soda and Medhacho in the center and Bokkulboma in the south east of the Borana rangeland. The specific study sites were showed in Figure 1.1.

The altitude of the sampled plots ranged from 1269 to 1663 masl in the study area. The main production system in the Borana lowlands is extensive livestock rearing with the main focus on cattle (the Borana breeds). Crop cultivation in the area is a recent development. In general, the Borana pastoralists classify their communal grazing lands into *Warra* rangeland grazing areas for calves, lactating livestock, small ruminants, draught oxen and sick or weak animals and *Forra* rangelands for non-productive livestock, e.g. dry cow. Government and a cooperative ranch and communal patch resource areas (water and mineral lick) were also considered as land-use units. Land-use units in this study refer to those different grazing lands used for different purposes and are differentiated both spatially and temporally (Table 1.1).

Yabello, the capital town of the Borana zone is located 565 km south of Addis Ababa. Surupha and the Did-Tuyura ranch are located about 42 and 17 km northeast of Yabello town, respectively. Did-Hara is about 45 km east of Yabello town; and Dambala-Wachu ranch, Medhacho and Mana-Soda are located about 65, 85 and 105 km south east of Yabello town, respectively. Bokkulboma site is about 147 km south of Yabello town.

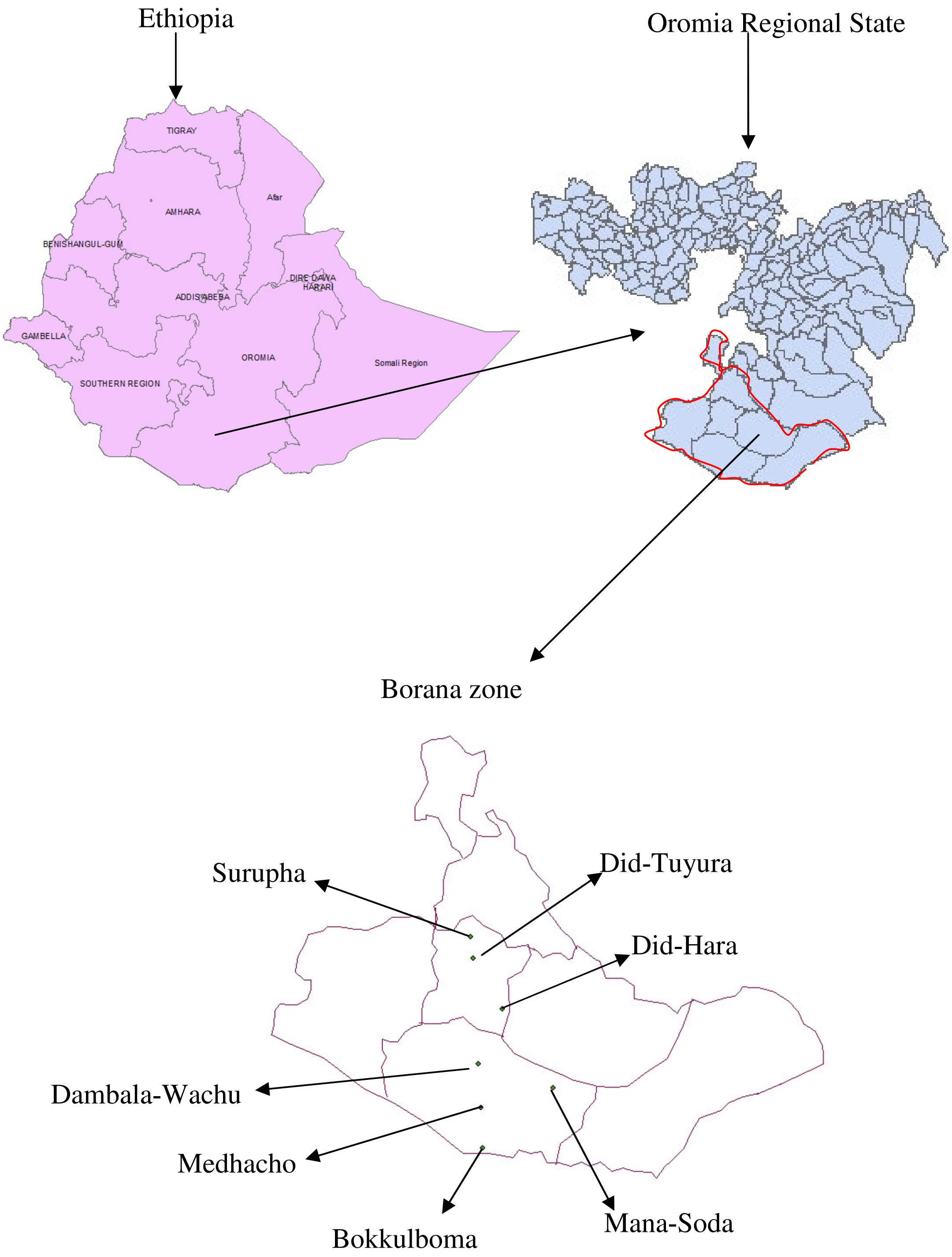

Figure 1.1 Map of the Borana lowlands showing the study sites

Table 1.1 Locations and descriptions of the land-use units studied in the Borana lowlands, Ethiopia

Land use unit	Abbreviation	Explanation	District	Sampling frequency
Surupha	SUR	Communal grazing area	Yabello	3 seasons
Did-Tuyura	DTR	Government ranch for breed conservation	Yabello	3 seasons
Did-Hara	DH	Communal grazing area	Yabello	3 seasons
Medhacho	MAD	Deep-well water point resource area	Dire	3 seasons
Mana-Soda	MSD	Mineral patch resource area	Dire	3 seasons
Dambala-Wachu	DWR	Cooperative grazing area	Dire	3 seasons
Bokkulboma	*BL*	*Communal grazing area*	Mi'o	3 seasons

1.6.2 Climatic characteristics

Rainfall and temperature data for Surupha, Did-Tuyura and Did-Hara were taken from Yabello town, which was the nearest meteorological station. For Dambala-Wachu, Medhacho and Mana-Soda sites climate data were taken from Mega station and for Bokkulboma from Moyale weather station. The monthly mean rainfall patterns based on records from Yabello, Mega and Moyale are presented in Figure 1.2.

Mean monthly rainfall ranged from 8 to 149.7 mm in Yabello, 6.7 to 128.2 mm in Mega and in Moyale 5.3 to 144.6 mm (Figure 1.2). The rainfall peaks demonstrate the bimodal nature of rainfall in the Borana lowlands. The main rainy season is between March and May with the peak in April, and the short rainy season is between September and November with the peak in October. In comparison, Yabello area had more rainfall than both sites and followed by Moyale and the lowest record observed in Mega.

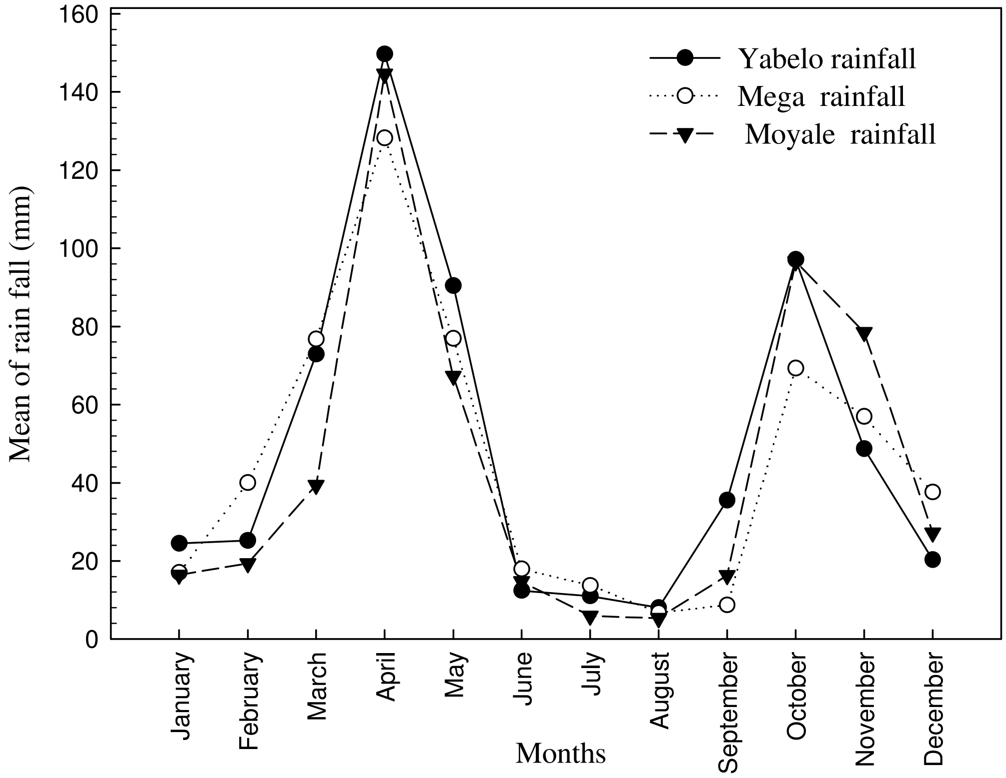

Figure 1.2 Mean monthly rainfall over a period of 24 years in the Borana lowlands of Ethiopia

Over the years, the total annual rainfall ranged from 327.4 mm to 873.8 mm in Yabello with a mean of 565.4 mm, in Mega 278.4 to 894.6 with a mean of 435.8 mm and in Moyale 112.2 to 1095.1 with a mean of 447.6 mm (Figure 1.3). The difference in annual rainfall between the three weather stations was not significant ($P > 0.05$). The mean annual rainfall for the three weather stations was about 476.6 mm.

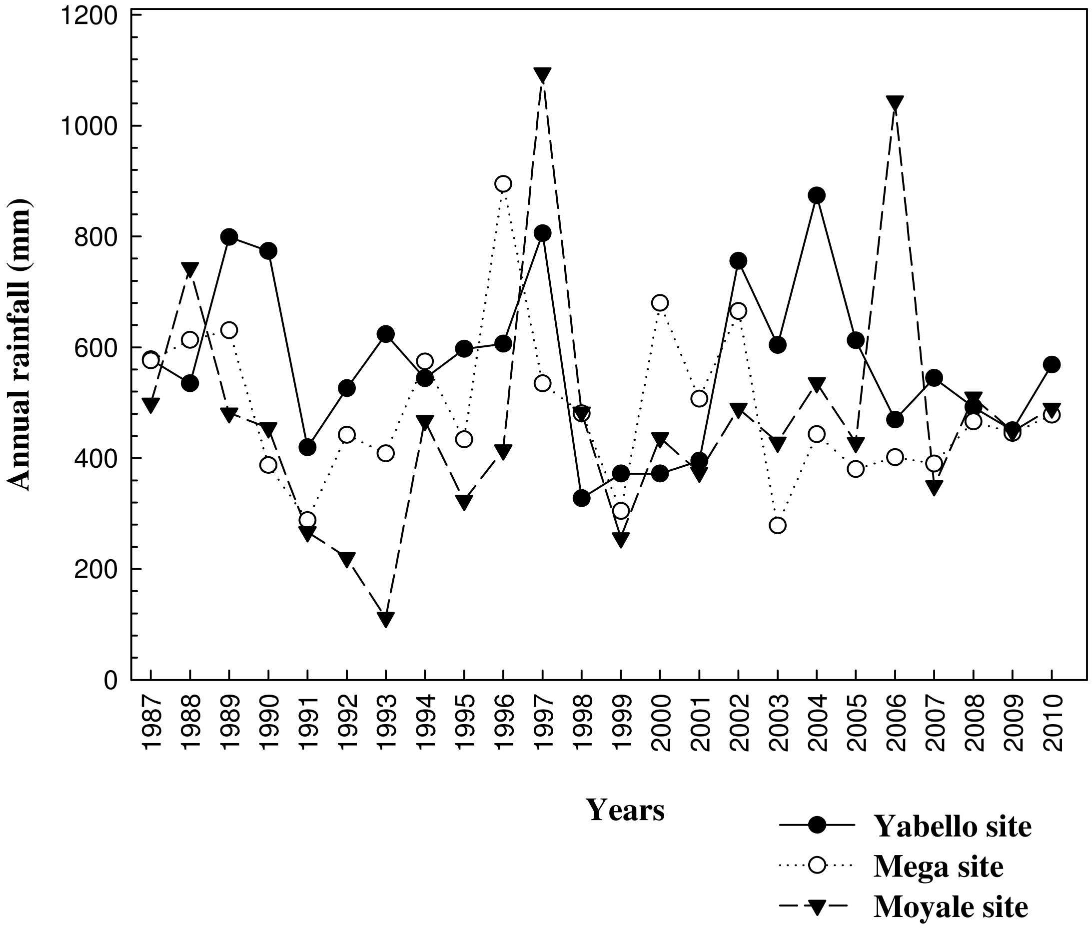

Figure 1.3 Annual rainfalls from (1987-2010) in the Borana region, Ethiopia

Alemayehu (1998) reported that the mean annual temperature of the Borana region varies from 19 to 24 °C. The mean maximum temperatures for Yabello station ranged from 23.78 to 28.55 °C and the minimum from 12.52 to 15.61^{0}C (Figure 1.4); the respective value for Mega were 20.46 to 27.13 °C and from 11.96 °C to 14.85 °C; for Moyale 24.18 °C to 31.75 °C and 16.08 °C to 19.28 °C. In general, December to February is the hot dry season, but March to May the long rainy season, whereas, June to August the cool dry season, and the period September to November the short rainy season.

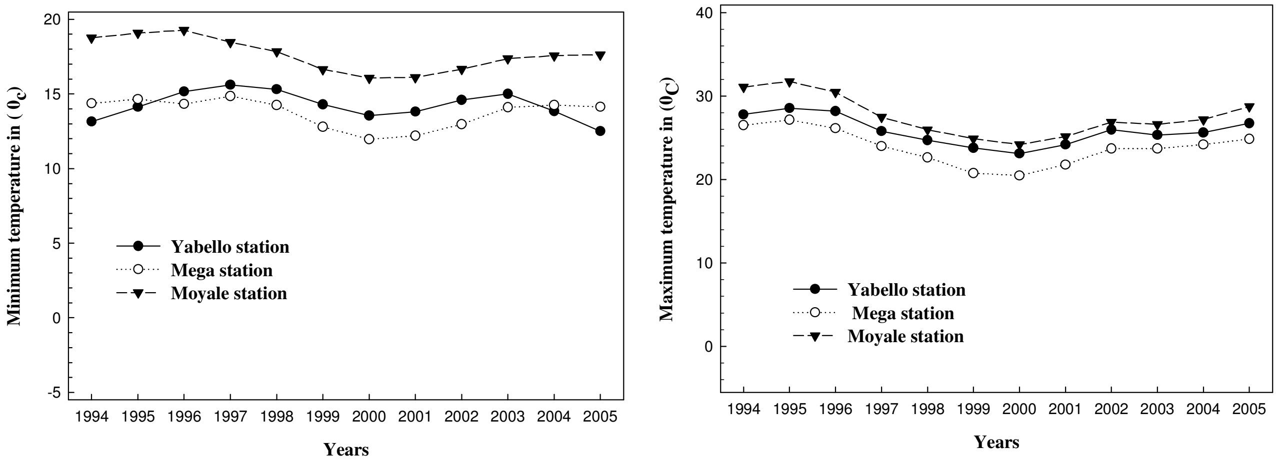

Figure 1.4 Mean maximum and minimum temperatures recorded at the region weather station (Source: data from the National Meteorological Services Agency of Ethiopia).

1.6.3 Soil characteristics

The soils in the study area are characterized by granite and volcanic soils and their mixtures (Coppock, 1994). The dominant soils textures in the study sites are presented in Figure 1.5.

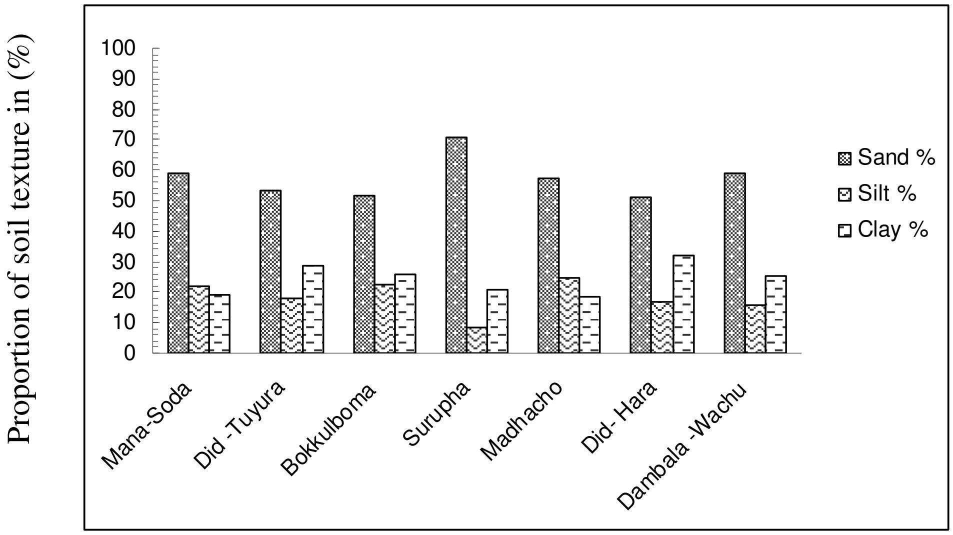

Figure 1.5 Comparison of soils texture of the study area

The pH of the soil across the study areas ranged from 6 to 8. The percent of organic carbon and nitrogen were in the range of 0.79 to 1.52 and 0.08 to 0.25, respectively (Table 1.2). In this study, the available phosphorus ranges from 2.83 to 16.11p/ppm and percent of organic matter varies from 1.11 to 2.63, respectively. The cation exchange capacity (CEC) of the study areas ranges from 7.39 to 36.09 Coml. /kg. Medhacho soils showed the highest available phosphorus, organic matter and CEC for the study areas.

Table 1.2 Chemical properties of soils collected in the Borana, Southern Ethiopia, and July 2010

Site	pH (meter)	CEC (Coml./kg)	T.N %	O.C %	O.M %	C/N	Phosphorus p/ppm
Mana-Soda	8.00	33.00	0.25	1.52	2.63	9.10	5.81
Did-Tuyura	6.85	21.93	0.14	1.27	2.39	9.27	6.17
Bokkulboma	7.15	23.34	0.11	1.06	1.84	10.27	6.24
Surupha	5.99	7.39	0.08	0.89	1.55	10.67	8.09
Medhacho	8.00	36.09	0.16	1.43	2.46	9.13	16.11
Did-Hara	6.30	19.39	0.08	0.84	1.44	10.93	4.86
Dambala-Wachu	6.67	12.84	0.08	0.79	1.11	8.93	2.83

CEC= Cation exchange capacity; T.N=total nitrogen; O.C= organic carbon; O.M= organic matter; C/N= carbon to nitrogen ratio.

1.6.4 Vegetation

The savannah vegetation type characterizes the Borana plateau. Haugen (1992) pointed out that the woodlands of the Borana rangelands are characterized by species from the genera *Combretum* and *Terminalia*, whereas, the bush lands and thickets, which cover the major parts of the Borana lowlands, are dominated by *Acacia* and *Commiphora* species. Besides, species of the genera *Boscia, Maerua, Lannea, Balanites, Boswellia* and *Aloe* are common in the study area.

1.6.5 Sampling techniques

In establishing the sampling plots combinations of stratification and systematic random sampling were used. Stratification was used to sample from the different districts and land-use units, whereas, within each land-use unit, the first sampling unit was established randomly and subsequent units were established at 1,000 m intervals on a linear transect. Samples for herbaceous biomass, frequency, density of woody plants, forage quality analysis, and rangeland condition assessments were collected using a 20 m x 50 m (1000 m^2) plot (Figure 1.6).

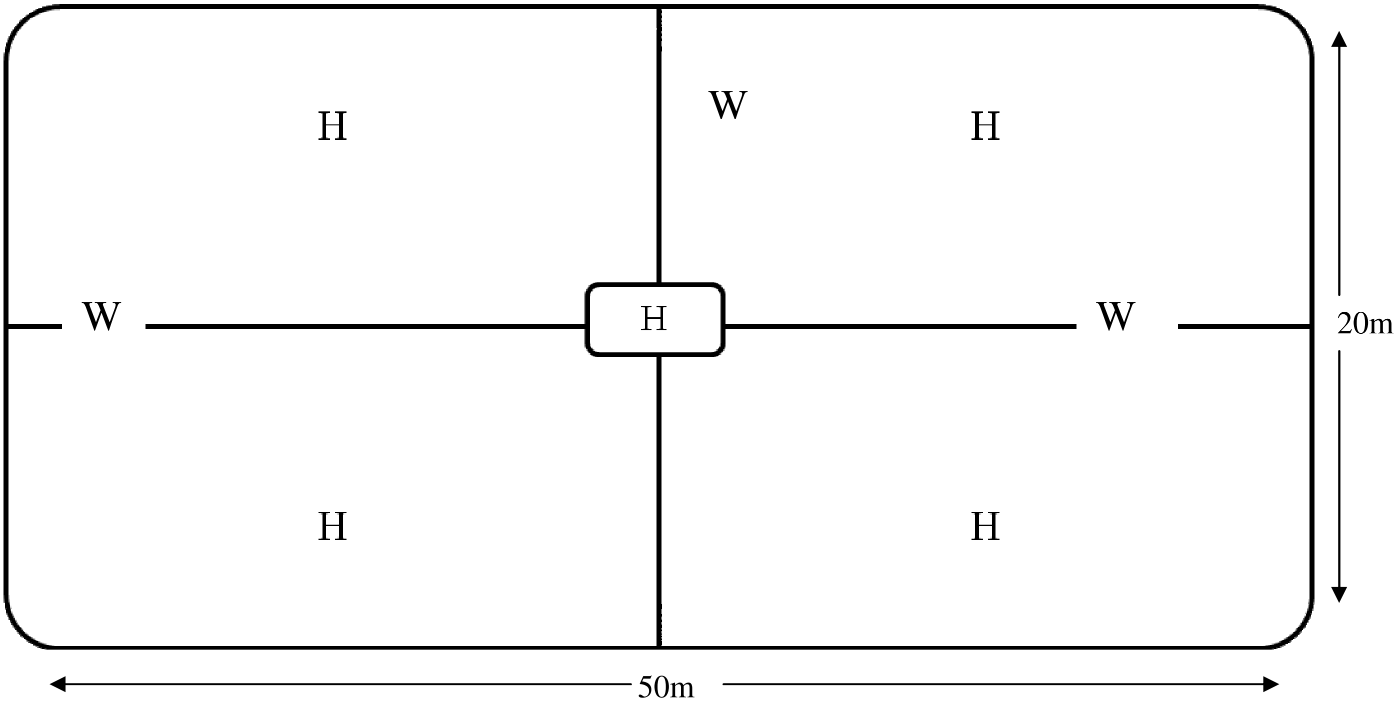

Figure 1.6 Design for the rangeland condition assessment and soil data sampling in the Borana lowlands.

Where, W = sampling plot for woody plants counts, H= herbaceous count for condition assessment and also sampling unit for soil.

Five subplots of 0.5 m x 0.5 m established within the larger plot of 20 m x 50 m, at five points within the main plot (Figure 1.6) were used for herbaceous sampling. To demarcate these subplots, a quadrat welded metal frame (0.5 m x 0.5 m), was used. All the grasses, herbaceous forbs and sedges rooted within the marked area of 0.25 m^2 were indiscriminately cut at 2 cm above the ground. Herbaceous fresh weight was recorded for each species and then oven-dried at 105°C for about 24 hours in a well-ventilated oven and weigh to determine the dry weight of individual species.

For woody plant sampling, a 50 m long meter tape was stretched and used as a base line and at 10 m distance on both sides plastic coloured ropes were used to mark the plot (Figure 1.6). All the woody plants rooted within plots were recorded and their height measured using graduated pole. Diameters at breast height were measured using a tree caliper. Trees/shrubs were divided into matured, sapling and seedling plants with height >2, $\geq$ 0.5 to 2 and <0.5 cm, respectively.

For soil sampling, surface soil samples (0-10, >10-20 and >20-30 cm) were collected from the main plots using a soil auger after scraping away any leaf litter. Soil samples were analysed for total nitrogen (N), available phosphorus (P), organic matter (OM), pH (pH_H_2O), potassium (K), calcium (Ca), Magnesium (Mg), Cation exchange capacity (CEC) and texture (sand, silt and clay).

1.6.6 Data collection

The data were collected in three seasons from April 2010 to January 2011. The main rain season, cold dry season and hot dry season were included in the collection of vegetation data. Seven sites (Surupha, Medhacho, Mana-Soda and Bokkulboma, Did-Hara, Dambala-Wachu and Did-Tuyura) were established as main plots for collection of samples.

1.6.7 Thesis outline

The thesis consists of nine chapters. In chapter 1, the background, description of the study area and methods used in the individual studies are presented. Chapters 2 and 3 present the changes in land-use /land-cover, condition and the current status of rangelands. In Chapter 4, the effects of salt patch-resource on vegetation composition were investigated, while the impact of a deep-well on the surrounding vegetation is in Chapter 5. Chapter 6 reports on the comparison of laboratory and local pastoral experience on the evaluation of the nutritive value of indicator herbaceous species. Analysis of changes in grazing capacity of the Borana rangeland is presented in Chapter 7. In chapter 8, attempts were made to investigate an understanding of the Borana pastoralists' perception to the current challenges and the role of traditional coping mechanisms towards mitigation. Chapter 9 provides the general conclusion and highlights future researchable areas. The chapters are written in a journal manuscript format complete with introduction, material and methods, results and discussion. However, to avoid duplication certain elements of material and method are referenced to previous chapters.

CHAPTER 2

EVALUATION OF LAND COVER/VEGETATION CHANGES IN THE BORANA RANGELANDS OF SOUTHERN ETHIOPIA USING REMOTE SENSING ANALYSIS METHODS

Abstract

Land-use/land-cover (LULC) change studies using remote sensing techniques are vital for generation of information and rational management of resources. The Borana rangeland has experienced substantial LULC changes since the 1970s due to various driving forces. This study was aimed at mapping LULC changes, identifying the associated major change drivers in the Borana rangelands. Landsat image scenes (Multi Spectral Sensor, Thematic Mapper and Enhanced Thematic Mapper Plus) acquired in the 1970s, 1980s and 2000s for the Borana were used to investigate LULC changes over time. Pastoralist's perceptions were also used to explain the driving forces associated with the LULC changes. The analyzed images revealed that woodland cover of the Borana increased from 11.3% in the 1970s to 49.26% in the 2000s. In contrast, grassland cover declined from 58% to 32% during the same period. Cultivated/built up area gradually increased from 2% to 5%, which relatively is less when compared to the woodland cover expansion rate. The calculated normal difference vegetation index (NDVI) values for 2000 were low as compared to the NDVI's in the 1970s, which implied the reduction of vegetation and increase of bare ground. The study demonstrated that the cultivated land consumption rate was inversely related with the absorption coefficient in the Borana. Pastoralists believed that the major events that explain the changes on LULC were severe droughts, population increase, government policy and poor management. It is suggested that the implementation of appropriate pastoral land-use policies based on the ecological potential of the region will ensure sustainable ecosystem functioning and improved livelihood for the Borana pastoralists.

Key words: Landsat images, land absorption coefficient, land consumption rate, normalized difference vegetation index.

2.1 INTRODUCTION

Human activities like cultivation, grazing, mining and settlements are the main drivers in influencing land-use/land cover (LULC) dynamics (Meyer, 1995). At present, the terrestrial land is under continuous changes with direct or indirect impacts on the environment. Rapid human population growth, increased frequency of droughts and expansion of settlement in arid and semi-arid environments in developing countries have also aggravated the changes in LULC at the local or global level. The changes of LULC have an influence on how the natural ecosystems function. At present, only few land surfaces remain in their original natural state as the majority of the land covers have been changed mainly due to anthropogenic driving factors (e.g. Vitousek *et al.,* 1997). Research on the dynamics of LULC plays an important role in the proper management and minimization of natural catastrophe (Moshen, 1999).

The primary factors that influence vegetation cover are climatic variability, soil nutrient, grazing pressures, pyric and management (Rolon *et al*., 2008). Land vegetation cover change assessments in arid and semi-arid areas are used to detect the healthiness of an ecosystem (Katjiua and Ward, 2007) because plants are key indicators of the state of the ecology. Arid and semi-arid ecosystems are highly susceptible and vulnerable to natural and anthropogenic perturbations. Identification of the driving forces (e.g. biotic and abiotic) that cause changes of land cover is important for appropriate management and sustainable ecosystem function. Associating vegetation variability with variations in environmental factors is often largely dependent on the type of ecosystems. For example, in the temperate zones change of vegetation composition is primarily due to anthropogenic factors relative to the natural processes (Burgos and Manuels, 2004). In arid and semi arid areas, vegetation changes are triggered by both anthropogenic and natural factors like soil moisture (White *et al*., 2008), erratic and uneven distribution of rainfall (Fensham *et al*., 2005) and grazing (Rahlao *et al*., 2008).

The development of remote sensing and geographic information systems have created capacity for economic and fast means of surveying land-use type and cover and their status at wide spatio-temporal scales (Shoshany *et al*., 1994). Satellite images have since been used to visualize the changes in land cover resulting from both anthropogenic and natural factors. Normalized Difference Vegetation Index (NDVI) values have been used for detecting change of vegetation covers and/or land-use (Eklundh and Olsson, 2003). Remotely sensed multi-temporal high-resolution satellite data sets have also become a valuable tool for monitoring of vegetation cover, expansion of settlement, soil degradation, and overall changes of land cover and mapping (Palmer and Fortescue, 2003). Using two or more satellite images acquired at different dates over the same study area enables the monitoring of changes in land cover by using proxy parameters such as vegetation index differencing (Purevdorji *et al*., 1998)

Until the late 1970s, the Borana rangelands were considered as one of the best grazing land in east Africa. These rangelands were under traditional pastoral management practices that included mobility of herds during wet and dry season and strong community norms in regulation of range and water resource use (Coppock, 1994; Angassa, 2007). A recent study by Oba *et al.* (2000b) has attributed the changes in vegetation and land cover in the Borana rangelands to the impact of anthropogenic and natural processes. The change of grassland cover is often associated with the loss of biodiversity, soil fertility, pollution of water and air in the Borana region. In addition, there has been weakening of the traditional institutions and strong intervention of governmental and non-governmental organizations on various aspects of pastoralists' livelihoods. These interventions have undermined for example the indigenous knowledge base necessary in monitoring LULC changes and management thereof, in the Borana rangelands.

The Borana pastoralists' livelihoods have recently changed considerably as a result of shifts in their rangelands from grazing land to crop land and other activities (Desta and Coppock, 2004). For example, cultivation expanded from five to 16 percent (Oba *et al.*, 2000b; Angassa, 2005). In addition, some grazing lands have been changed from communal grazing land to private enclosures. On the other hand, the expansion of woody plants cover and the decline of valuable herbaceous species have resulted in a general degradation of the Borana rangelands. These trends all have a negative impact on the overall grazing capacity of the ecosystem and hence would be detrimental to the traditional use of resources such as livestock grazing. It is therefore important to document land-use/cover changes in support of appropriate land-use planning. Remote sensed satellite image interpretations can be used in investigating these changes in the Borana. One primary advantage of using remote sensing techniques for earth observation is its capability to create an inventory of resources over a broad area with high temporal resolution at a relatively cheap cost (Trotter, 1998). The practical accurate and reliable land-cover classification for extensive areas have to be done at local, regional and national level by using a remote sensing technology like use of multi- temporal imagery (Dungan, 1998). There are various sources of satellite data, which allow analysis of the ecological variable. Among them, Landsat series (i.e., the multi- spectral scanner (MSS), the Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) have played a major role in detecting the changes in land-cover and monitoring of vegetation dynamics (Defries and Belward, 2000). Furthermore, the Advanced Very High Resolution Radiometer (AVHRR) also played a significant role in monitoring the global process (Schmidt and Gitelson, 2000).

The aim of this study was to examine land-use/cover in the Borana rangelands between the 1970s and 2000s with a view to detecting the type and rate of change. The rationale for this study is to address the gap connected with limitation of information on the changes of rangeland vegetation (grassland) to woodland and cultivated land in the Borana rangelands and its implication on the livelihood of pastoralists in the region. The specific objectives were to: (1) map and present the patterns of LULC over the last three decades using high-resolution satellite data analysis, and (2) detect the major driving forces of the land-use/cover changes.

2.2 MATERIALS AND METHODS

2.2.1 Study area

This study was conducted in the Borana rangelands which cover approximately 63,939 km^2, and hold the largest pastoral population in Oromia Regional State of Ethiopia (See the detailed in Chapter 1, section 1.6.1).

2.2.2 The satellite images

Satellite imagery was used as source of data for detection of vegetation cover changes. The image should be with minimum cloud cover (<20%). For this study, the MSS acquired in the 1970s, TM scenes obtained in the 1980s and the ETM+ (scenes obtained in 2000) were used. The present land-use/cover study used different remote sensed images for the different years to investigate the changes in land-use/cover type. The total study areas covered for the different periods were as follows: 4,091,877 ha for the 1970s, 4,482,859 ha for the 1980s and 4, 492,972 ha for the 2000s. A total of eight satellite images were combined to form a mosaic in order to cover the study area and thereafter the study area was extracted from the mosaic. The characteristics of the image data are described in Table 2.1.

Table 2.1 Mosaic data image acquired for three different times in the Borana rangelands of southern Ethiopia

1970s		1980s		2000s	
Path	Row	Path	Row	Path	Row
181	56	169	56	169	56
181	57	169	57	169	57
180	56	168	56	168	56
180	57	168	57	168	57
179	56	167	56	167	56
179	57	167	57	167	57

For the present study, four LULC classes based on the Pratt and Gwynne (1977) image classification criteria for East African rangelands (Table 2.2) were used.

Table 2.2 Land-use/land covers classes used in this study and their brief definitions in Borana, southern Ethiopia

No	Class	Definition
1	Wood land	area naturally covered by dense indigenous tree
2	Grassland	area dominated by indigenous grass and forbs
3	Bare land	area neither covered by vegetation nor used for crop production
4	Cultivated/built up area	areas used for cropping and settlement

2.2.3 Landsat image selection and pre-processing

For this study the Landsat images were obtained from the Global Land Cover Facility (see https://www.landcover.org). Several steps were employed in processing the images. These included pre-processing, design of classification scheme, preparation of normalized difference vegetation Index (NDVI) -false color band composition and unsupervised classification of the images. These applications were carried out using ENVI software. The procedure used in image classification is depicted in Figure 2.1.

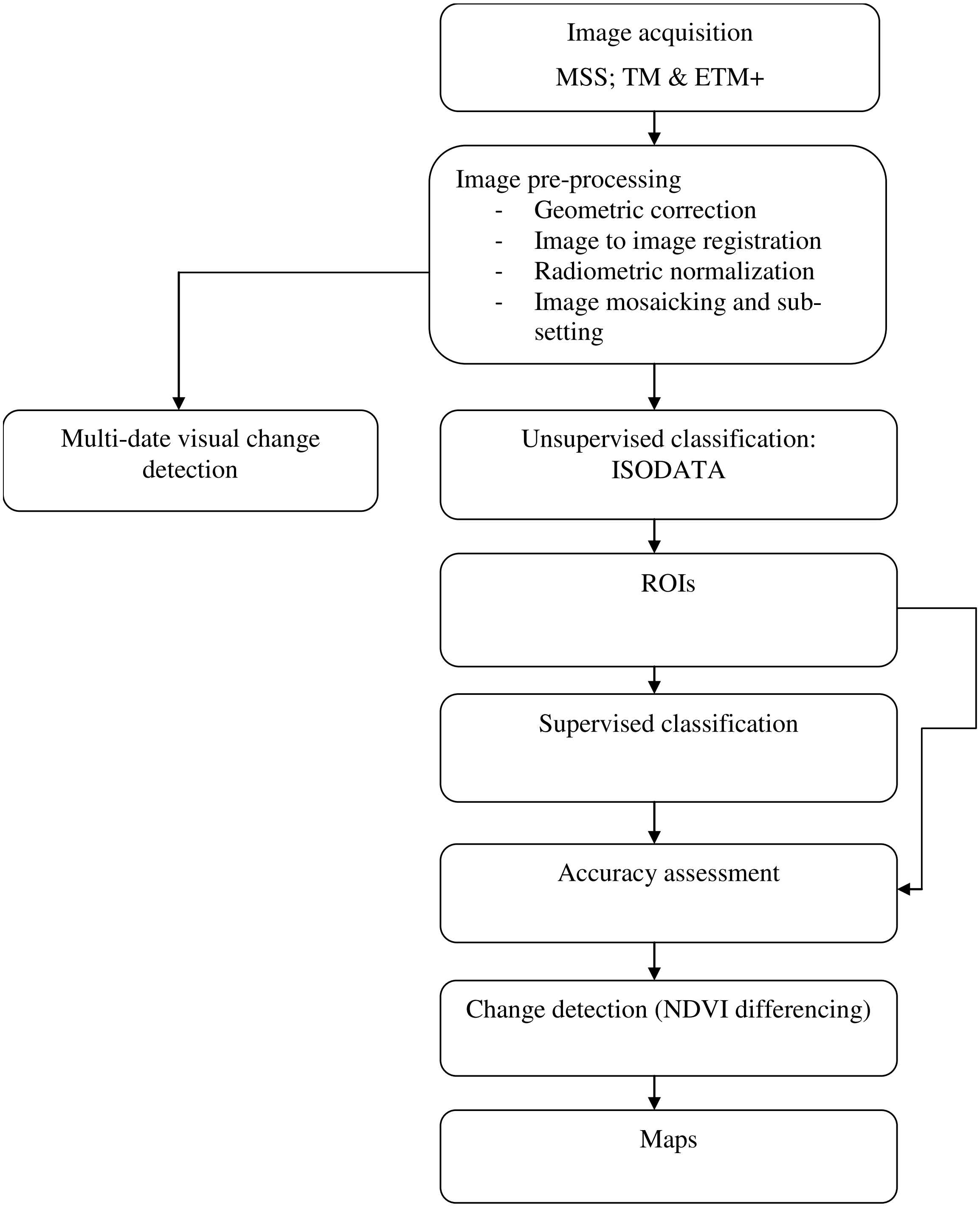

Figure 2.1 Satellite image processing flow chart for change detection

2.2.4 Classification and data analysis

For changes of vegetation cover a post classification comparison change detection method was used. This method requires rectification and classification of each remote sensed image. Then, the change detection matrix performed using maps for each pixel to compute the areal cover changes. The classification scheme and brief used is depicted in Table 2.2. The most widely used method of change detection is a comparative analysis of the spectral classifications for a series of time produced independently (Singh, 1989). Landsat of three years was independently classified using unsupervised classification method. Since class change precision depends on the spectral separation, the interest class group was created and used by the maximum likelihood classifier and smoothed with filter to reduce the misclassified pixels (ERDAS, 1999). Each separate classified image was visually compared for the detection of vegetation or land cover changes.

False color composite, NDVI image, unsupervised classified images were used for random sampling of the tested data. The type of vegetation and land cover could be visualized using false colour composition without any enhancement. For Landsat ETM+ and TM the false colour images represented with band 4=red, 3=green, and 2=blue. Similarly for MSS images band 4= red, 2=green and 1= blue (Jensen, 1996). The NDVI used in this study was the normalized difference of brightness values from the near infrared (NIR) and visible red (RED) bands and calculated as follows:

$$\text{NDVI} = (\text{NIR-RED})/\ (\text{NIR+RED})$$

Overall, our analysis was based on a hybrid classification approach (Odindi *et al*., 2012). In this approach, the interative self-organized data analysis techniques (ISODATA) unsupervised classification algorithm is used to categorize the natural classes. The reliability of such methodology is tested by using the separability parameters. Classes that show low degree of separability were regrouped until seven dominant classes were obtained. Together with the visual images inspection of false color composite and unsupervised classified image, two sets of samples each with twenty five points were created: the training set and post-classification set. The training sets were used as Regions of Interest (ROIs) in the supervised classification stage (here the maximum likelihood classifier was considered) while the post-classification ROIs for accuracy assessment using the confusion matrix (Congaton, 1991). Supervised classification was repeated three times and the derived outputs for the 2nd and 3rd land cover classifications yielded similar results which showed high levels of accuracy and consistence in our classification. Consequently, the land-use/cover classes were sized down from seven classes to four classes comprising of grassland, woodland, and bare-land and cultivated/built-up area.

The percentage change was calculated by dividing observed change by the sum of changes multiplied by 100 as follows,

% trend change = (observed change/sum of change) x 100

To obtain the annual rate of change, the percentage change was divided by the number of the study years 1970-1980 (10years) 1970-2000 (30years).

Markov chain model of change detection is based on the probability that a given piece of land will change from one mutually exclusive state to another (Aavikson, 1995). These probabilities are generated from past changes and then applied to predict future changes. Firstly, a transition matrix of pixels in each class for two time periods is created. The main diagonal of the matrix contains pixels that have not changed, while other cells contain pixels that have changed. Next, the probabilities of change between classes are computed. This is accomplished by dividing each cell value by its row total. The result is the probability that a given class in year one will convert to another class in year two out of all possible changes. On the other hand the spatial distribution of occurrences within each land use category was interpreted using land consumption rate (L.C.R) and land absorption coefficient (L.A.C) techniques. The land consumption rate and absorption coefficient formula are give below:

$$L.\ C.\ R = A/P$$

$$L.\ A.\ C = (A_2\text{-}A_1)/\ (P_2\text{-}P_1)$$

Where, A = areal extent of the rangeland in hectares, P = population. A_1 and A_2 are the area extents (in hectares) for the early and later years, and P_1 and P_2 are population numbers for the early and later years, respectively. Land consumption rate is a measure of compactness, which indicates a progressive spatial expansion of settlers. Land absorption coefficient is a measure of change in consumption of new state of land by each unit increase in human population. In other word, land consumption rate (LCR) is a measure of detecting the rate at which land is being consumed by the residing population. Through this measure, a prediction of land that is expected to be consumed by the pastoral resident population for different purposes can be determined. It could therefore be concluded that LCR is a function of increase in pastoralists' land use (that is change in pastoral land-use). Similarly, Land Absorption Coefficient (LAC) is used to determine the rate at which the available land is absorbing the population.

Both in the 1970s and 2000s, population figures were obtained from the censuses of Ethiopian Central Statistics Authority (CSA, 2010) and using the recommended 2% growth rate of pastoral area. The first task to estimating the population figures was to multiply the growth rate by the census figures of Borana in each year, while subsequently dividing the same by 100. The result was then multiplied by the number of years being projected for, the result of which was then added to the base year population.

This is represented in the formula below:

$$n = r/100 * Po \qquad (1)$$

$$Pn = Po + (n * t) \qquad (2)$$

Where Pn and Po are the estimated population and base year population, respectively, r = growth rate (2%), n = annual population growth, t = number of years projecting for. The population figures were obtained from the 1970s, 1980s and 2000s census report of the National Central Statistics Authority, from which projections were made using the base year population growth rate of 2% per year, which was provided by the authority.

2.2.5 Driver of change of vegetation and land cover

The major driving forces for change of vegetation and land cover dynamics in the study area were investigated using 200 key knowledgeable pastoral respondents. A group discussion was also carried out with local key informants, community development practitioners, and local and regional relevant professionals. Semi-structured interviews with the key informants were used to generate information identifying the major driving forces that caused the changes of vegetation or land cover, and to understand the perceptions of Borana pastoralists on the changes. Scores were given for the identified drivers of changes and these were put in order of priority. Secondary data were used for comparison of the present and past to identify the scale and degree of changes in vegetation cover. The correlations and strength of the relationships between independent and dependent variables were computed using SAS version 9.2.

2.3. RESULTS

2.3.1 Classification of land-use/land-cover

The changes in land use/land-cover from the 1970s - 2000s are presented in Table 2.3. Grassland was the dominant land cover in the 1970s (58%) and bare land covered a relatively large area at (29%). Woodland cover was relatively low (11.3%) in the Borana in the 1970s. On the other hand, in the 1980s and 2000s the woody plant cover increased significantly to 39.30% and 49.26%, respectively, as compared to the 1970s. Grassland cover declined in the 1980s and 2000s to 34% and 32%, respectively. Cultivated land and settlement areas were increased by 3% from the 1970s to the 2000s in the same area.

Table 2.3 Classification of land-use /cover changes in the Borana rangelands of southern Ethiopia

Land type	1970s		1980s		2000s	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Woody land	462294	11.3	1762173	39.31	2213242	49.26
Grassland	2363172	57.75	1505662	33.59	1425993	31.74
Bare land	1186877	29.01	1036548	23.12	630843	14.04
Cultivated	79533.6	1.94	178476	3.98	222895	4.96
Total	4091877	100	4482859	100	4492972	100

2.3.2 Change detection

The woody cover in the Borana rangelands were increased by 28.10% from the 1970s to the 1980s; by 9.95% from the 1980s to the 2000s and 37.96% for the period 1970 to 2000. On the contrary, grassland cover declined by 24.17% from the 1970s to the 1980s; 1.85% from the

1980s to the 2000s; and 26% from the 1970s to the 2000s (Table 2.4). However, the cultivated and settlement areas depicted subtle increases in 1970 (2%), 1980 (0.98%) and 2000 (3.02%) in the study area (Table 2. 4). Over the 30 year period, the changes of cover per year for woody, grass, bare and cultivated land were 1.27, 0.87, 0.50 and 0.1%, respectively.

Table 2.4 Changes in land-use/cover from 1970-2000 in the Borana rangelands of southern Ethiopia

Land type	1980-1970		2000-1980		2000-1970		Change per year
	(ha)	(%)	(ha)	(%)	(ha)	(%)	%
Woodyland	1299878.845	28.01	451068.6607	9.95	1750947.51	37.96	1.27
Grassland	-857510.1945	24.17	-79669.13513	1.85	-937179.33	26.01	0.87
Bareland	-150328.9557	5.88	-405705.3104	9.08	-556034.266	14.97	0.50
Cultivated	98942.28435	2.04	44419.0284	0.98	143361.313	3.02	0.10

These changes are corroborated by the remote sense images presented in Fig 2.2. The bare land cover appeared to decrease in 2000 as compared to the preceding years (i.e., 1970 and 1980). The decrease could be attributed to tree canopy cover effects when the remote sense images were taken in the study area. The remote sensed image for 1970 in some parts of the southern Borana was not included because there was no data available. Overall, the land-use/cover changes of the Borana rangelands could be driven by external (e.g. climate change, regulation speculated by government) and internal (e.g. demography, economic needs of pastoralists) factors.

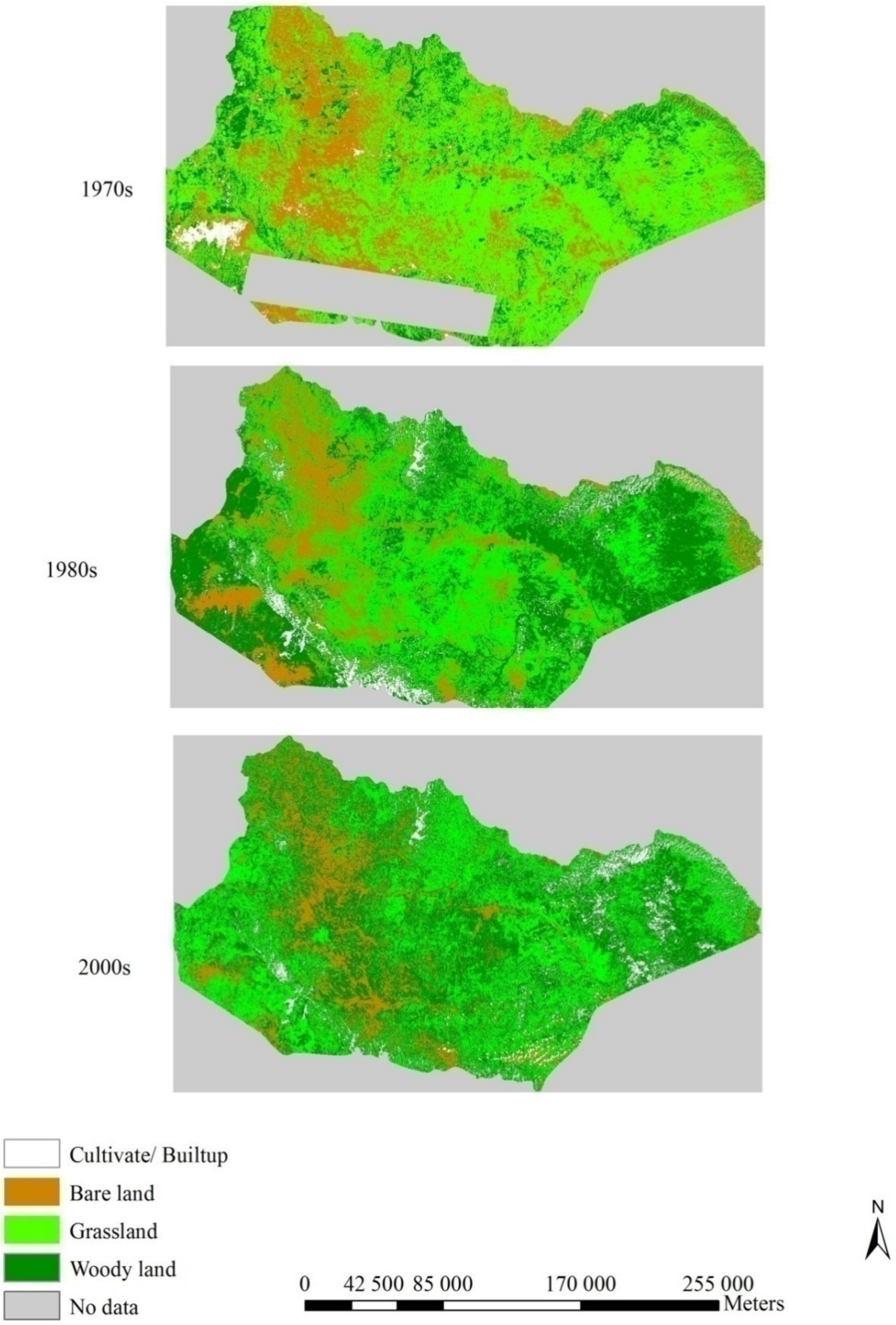

Figure 2. 2 Land-use/cover change classification maps during the different decades in Borana, southern Ethiopia

2.3.3 Transition probability matrix

After using the Markov model to detect land cover change a 4 by 4 matrix table of land cover categories in the 1970s and 2000s was constructed (Table 2.5). This matrix was used as a direct input for specification of the prior probabilities in maximum likelihood classification of the remotely sensed imagery.

Table 2.5 Land-use/covers changes: Transitional matrix for the 1970s and 2000s in Borana, southern Ethiopia

		Land-cover 2000s				
		Wood land	Grassland	Bare land	Cultivated	Total
Land-cover 1970s	Woodland	-1750948	-963699	-168549	239399	-2643797
	Grassland	4114120	3326871	2531721	2123773	12096485
	Bareland	-2927243	-2139994	-1344844	-936896	-7348977
	Cultivated	3006776.6	2219527.6	1424377.6	1016429.6	7667111.4

As indicated in Table 2.6, Woodland had a 0.66 probability of remaining wood land and a 0.36 of changing to grassland in the period 2000s. On the other hand, a 0.34 probability of change from grassland to woodland showed that there might likely be a high level of instability in grassland during this period. Grassland had a 0.28 probability of remaining grassland in 2000s. Bare land also had a probability of 0.18 to remain as bare land in 2000s. Cultivated land had a 0.13 probability of remaining as cultivated land. Moreover, cultivated land had a 0.29 probability of changing to grassland and a 0.19 probability of changing to bare land.

Table 2.6 Land-use/covers changes: Transition probability matrix from the year 1970 to 2000s in Borana, Southern Ethiopia

		Land cover 2000s			
		Wood land	Grassland	Bare land	Cultivated
Land cover 1970s	Woodland	0.66	0.36	0.06	0.09
	Grassland	0.34	0.28	0.21	0.18
	Bareland	0.40	0.29	0.18	0.13
	Cultivated	0.04	0.29	0.19	0.13

2.3.4 Detection of change of land consumption rate and land absorption coefficient

The land consumption rate (LCR) for cultivation was 0.12 in the 1970s, 0.23 in the 1980s and 0.16 in the 2000s (Table 2.7) demonstrating a slight increment over time. On the other hand, the land absorption coefficient (LAC) between the 1970s and 1980s was 0.69; it was 0.08 between the 1980s and 2000s, and the LAC was 0.21 between the 1970s and 2000s. These LCR and LAC results showed that increases in population resulted in a decline of the land absorption ability drastically.

Table 2.7 Land consumption rate and land absorption coefficient changes in Borana, southern Ethiopia

Year	Land consumption rate	Year	Land absorption coefficient
1970	0.12	1970-1980	0.69
1980	0.23	1980-2000	0.08
2000	0.17	1970-2000	0.21

The corresponding human population values for the sapling time period are also presented in Table 2.8. These are National Central Statistical Authority (CSA) figures from which projections were made using the base year population growth rate of 2 % per year (CSA). The population of the Borana zone has progressively being on increase (i.e., 641982 in the 1970s, 786364 in the 1980s and 1317409 in 2000).

Table 2.8 Human population of Borana zone, southern Ethiopia

Years	Population	Source
1970	641982	CSA
1980	786364	Projected
2000	1317409	Projected

2.3.5 The Normalized difference vegetation index value

The NDVI value for the 1970s showed that 46.14% of the total area was bare land, whereas, 53.86% was covered by vegetation (Table 2.9). The minimum negative NDVI value was -0.93, which showed the bare portion and the maximum NDVI value was 0.93, for the dense vegetation parts of the study area. On the other hand, for the year 2000 the bare land area was 57.20%, (while minimum NDVI value of -0.65) the vegetation covered area was 42.80% (maximum value of NDVI 0.83). The bare land portion was higher than the vegetation covered area for the year 2000 when compared to the 1970s (Table 2.9). This indicated that the vegetation cover or biomass had declined from the 1970 to 2000. The NDVI images showed immense differences in land cover between the 1970s and 2000. There was more vegetation cover loss in 2000 (high proportion of bareness). Generally, a transition from dense vegetation to sparse or bare land increased, which was confirmed in this study. The visual NDVI image observations indicated that there was a reduction of vegetation cover over the last 30 years. Areas with high negative NDVI value were an indicator of a poor vegetation cover (unhealthiness) of the rangeland; whereas, areas with high positive NDVI values were signs of dense vegetation cover or healthiness of the rangeland.

Table 2.9 Percentage of area coverage of different change class for the 1970s and 2000s in Borana, southern Ethiopia

	Value	Pixels count	Proportion -0.93:0.93 (4) in %
1970s			
NDVI	Negative	2190746	46.14
	Positive	2556878	53.86
	Total	4747624	
2000s			-0.65:0.83(4) in %
NDVI			
	Negative	5659858	57.20
	Positive	4234834	42.80
	Total	9894692	

2.3.6 Driving forces of land-use/cover change and their correlation

The eight major driving forces that influenced changes in land-use /cover in the Borana rangeland that were identified by the respondents are presented in Table 2.10. The top five major factors (>10%) in decreasing order were, recurrent drought (22.60% of the respondents), policy issue (21.56%), increment of livestock population (18.81%), bush encroachment (12.73%) and settlement (10.19 %). The pastoralists indicated that about three decades ago drought occurred once in every ten years but in recent times it has been occurring every three to five years. The severities of the droughts were classified as light, medium and severe and they also indicated the time series of their occurrence by referencing to the time of their traditional community leaders. There was a moderate drought during the *Gada* Goba (1968-1976), severe drought during the *Gada* Jilo Aga (1976-1984), light drought during the *Gada* Boru Guyyo (1985-1992), moderate drought during the *Gada* Boru Medha (1996-2000), light drought during the *Gada* Liben Jaldesa

(2000-2008) and light drought in the first year of Guyyo Gobba (2008) the current *Abba Gada,* i.e. leader of the Borana pastoralists. Respondents' understanding of the frequency of drought occurrence was coupled with policy issue (e.g. annexation of land for other land uses, ban of range fires and restricting mobility) which they believed contributed a lot to changes of land-use/cover.

The respondents also understood that the number of livestock was beyond the carrying capacity of their rangelands, and this contributed to changes of land cover from grassland to woodland. Apart from the direct effects human population catalyzed the increase of livestock numbers. Human population growth is partly due to the infiltration by highland farmers in the area. In addition, the recent expansion of public services like water points, school and health posts might have contributed to the expansion of settlements in the study area. From a policy perspective sedentarization of pastoralists is a government rural development strategy. This has widely affected the pastoral land-use patterns over the years. Moreover, the opportunistic farming activities also instigate the expansion of settlements in order to manage the farm plot as mentioned by our respondents. The steady increase of human population attracts the boom of livestock population which pressurizes the changes of land-use. Overall, the respondents stated that the changes in land-use/cover mainly caused by frequent droughts and increasing numbers of dry years among other drivers, highly affected their livelihoods.

The correlation and strength of their relation among different driving forces and dependent variables were presented in Table 2.11. The amount and distribution of rainfall declined recently as compared to the past three decades. In line with the decline of rainfall, the grassland cover reduced significantly.

Table 2.10 Pastoralists' perception related to rangeland cover changes in Borana, southern Ethiopia

Major driving forces	% respondents
Drought/rainfall variability	22.60
Policy issue	21.56
Increment of livestock population	18.81
Bush encroachment	12.73
Settlement	10.19
Change of livelihood	8.88
Increment of human population	5.10
Number of water points	0.13
Total	100

In contrast, the woodland, bare land and cultivated land cover were drastically increased. Similarly, the human and livestock population increased recently as compared to the previous years. The rainfall is positively correlated with grassland cover, but negatively correlated with woodland and bare land cover. The increase in human and livestock populations and expansion of cultivation were positively associated with decline of rainfall in the study area. Whereas, the woodland expansion negatively correlated with grassland cover, whilst positively associated with bare land, cultivated land and other parameters (Table 2.11). On the contrary, grassland negatively correlated with all parameter mentioned except rainfall. This study showed that a strong positive correlation between bare land, cultivated land and woodland expansion. The regression equation showed that as rainfall increased grassland cover also increased, while, other parameters declined (Table 2.11). In general over the years grassland cover declined, while, the other cover systems increased.

Table 2.11 Correlations between the different driving forces with dependent variables

Driving forces and measurable parameters	Year	Rainfall	Woody land	Grass land	Bare land	Cultivated land	Livestock population	Regression equation with rainfall	R^2	Regression equation with year time series	R^2
Rainfall	-0.78										
Wood land	0.89	-0.98						WL= 8896731+-18514x	0.95	WL= -1.04+53249x	0.80
Grassland	-0.89	0.99	-0.98					GL= -2570223+10820.7x	0.99	GL= 5.6+-27345.6x	0.64
Bare land	0.90	-0.97	0.99	-0.98				BL= 3290943+-5839.5x	0.94	BL=-3.27+16960.5x	0.81
Cultivated land	0.92	-0.96	0.99	-0.99	0.99			CL= 750724.9+-1473.72x	0.92	CL= -8592780+4413.32x	0.84
Livestock population	0.96	-0.57	0.73	-0.60	0.74	0.77		LS= 487946.9+-359.62x	0.32	LS =-3411217+1893.3x	0.92
Human population	0.99	-0.69	0.83	-0.72	0.83	0.86	0.98	HP= 2970867+-5130.91x	0.47	HP = -4.49+23091x	0.98

Key: WL= Wood land, GL= Grassland, BL= Bare land, CL= Cultivated land, LS= Livestock population, HP=Human population, R^2= Confidence of determination

2.4 DISCUSSION

2.4.1 Classification and change detection

The Borana rangelands demonstrated persistent land-use/cover changes spatially and temporally in the past 30 years from the 1970s to 2000s. The probable reasons for the change in grassland to woodland in recent years might be due to rainfall variability and heavy grazing pressure, which are consistent with previously published reports (Oba and Kotile, 2001; Angassa, 2007). The changes in the traditional management practices and regulations enforced by the government could have contributed to the expansion of woodland and reduction of grassland cover. The ban on rangeland fires and government's overlooking of the traditional land management might have favoured the rapid propagation of tolerant woody plants to perpetuate rapidly in the study area (McCarty *et al*., 2002; Angassa and Oba, 2008b). As woody plant density crossed the threshold they established dominant communities and this affected the survival of several susceptible herbaceous species as evidenced by present study and work by Smith (2004).

The population of Borana pastoralists has been increasing since the 1970s and as a result cultivation and settlement were increasing, which also contributed to the reduction of grasslands. Another probable explanation for the reduction of the grassland cover could be government's inappropriate intervention policy of annexing the communal rangelands for other purposes (Oba *et al.,* 2000a). On the other hand the change of woodland to grassland might be due to involvement of pastoralist's in woody plant clearing for charcoal making and other purposes. Those pastoralists now involved in crop activities were clearing woody plants for crop land preparation. The pastoral communities also cleared woody vegetation for home construction purposes and enclosure management (Dalle *et al.,* 2006a).

The observed change of cultivated/built up area to woodland was minimal, whereas, the changes in cultivated/built area to grassland were high (29%). Traditionally, the Borana pastoralists practiced mobility due to uneven distribution of rainfall and forage availability. In today's land-use patterns, it is plausible that when pastoralists move to new areas leaving a fallow land that was under cropping and when they come back to previous area few months later the fallow land will be grassland. The present study revealed that there was an increase in the cultivation rate between the 1970s and 2000s mainly due to livestock loss by several pastoralists' due to multiple droughts in 1972/1973 1984/85 and 1999/2000. These droughts also created food insecurity problems. Pastoralists were forced to start opportunistic farming as the situation would not allow them to rely solely on livestock for their livelihoods. Campbell *et al.* (2005) noted that crop cultivation in arid and semi-arid areas is an alternative means of risk aversion and a survival strategy. In addition, infiltration by large groups of farmers from neighboring areas also contributed to the expansion of cropping in the study area. King Minilik II expansion and/or invasion to the Borana region resulted in the increase of city dwellers that practiced small-scale horticultural farming around towns and this also contributed to the expansion of cultivated land.

Despite this, the government policy favoured the promotion and expansion of agro-pastoralism than pure pastoralism and the government strategy of sedentarization and dry land farming was enforced in the study area. Similar to other East African pastoral lands the expansion of cropland in the Borana rangelands has been a government driven process that played a significant role for the change of grassland to cultivated land (Reid *et al.,* 2004). In general, pastoralists resist expansion of cultivation and sedentarization as this reduces the size of their rangelands and mobility to utilize the unevenly distributed resources in this unpredictable environment (Chatty, 2007). However, there were several voluntary crop farming and settlements in the Borana area both due to external driving forces and as an opportunity for generating income and options for diversification (Reid *et al*., 2004).

The bare land cover which seems to have declined in 2000 as compared to the 1970s might be due to problems of satellite image sensed woody plant canopy whose large canopy cover might have been interpreted as vegetation cover as reported by Haile *et al.* (2010) in the southern Ethiopia. However, based on ground observation and NDVI values the bare land increased in recent years compared to the 1970s. The fragile arid environment exposed to cultivation often leads to pronounced soil erosion even during small rain events, as well as wind effects which aggravated bare land expansion. Similar changes have been reported in arid environments (Elmore *et al*., 2000), in the Afar low-land of north eastern Ethiopia (Tsegaye *et al*. 2010) and in southern Ethiopia (Mintesnot, 2009).

Previous studies (Dalle *et al*. 2006a; Tefera *et al*., 2007) have reported more woodland cover around patch resource areas and attributed this to increased grazing pressure around these areas. On the other hand, high density of woody plants was demonstrated in areas where there was low grazing pressure (Brown and Archer, 1999).

Interruption of the traditional rangeland management system (e.g. seasonal mobility between the wet and dry season grazing areas) in combination with the above mentioned drivers contributed to the change of ecosystem functioning that had negative implications on the livelihoods of pastoralists inhabiting the region. Increased artificial permanent water points and built up area contributed to reduction of grass vegetation cover and increased bareland and woodland. Woody plants increased in density and certain grass species became extinct, which greatly affected grazers as compared to browsers. Hence, livestock production was forced to shift from grazers to browsers such as camels, a class of livestock, which is not culturally preferred by the Borana pastoralists.

2.4.2 Detection of change of land consumption rate and absorption coefficient

The cultivation consumption rate of Borana increased from the year 1970 to 2000. This is mainly due to increased human population and severe drought impacts on the livestock sector. Drought weakened the ability of pastoralism to support the community for food and income. There were also changes in the Borana land consumption as result of demands by young 'pastoralists' who were not interested in maintaining pastoralism as a way of life (Gezahegn, 2008). Some of the young generation created private enclosures mainly for growing crops or fodder for commercial purposes. The land cultivation absorption rate of the Borana was inversely related with consumption coefficient as a consequence of the population increase. The higher the land consumption rate the lower the land absorption coefficient and vice versa (Tsegaye *et al*., 2010).

2.4.3 The Normalized difference vegetation index value

Principally NDVI is a measure of photosynthetically active vegetation in an area (Asrar *et al*., 1985; Myneni *et al*., 1995; Weiss *et al*., 2004). The NDVI has strong correlations with biomass, vegetation phenotype, density of leaf and canopy cover (Peters and Eve, 1995; Tucker *et al*., 1985; Weiss *et al*., 2004). From the NDVI analysis across the Borana rangeland, the highest positive and negative NDVI values were largely from the 1970s MSS imagery. Assuming the inherent biases in reflectance measurements of the MSS sensors and the atmospheric cloud cover, high positive value of NDVI could be associated with the high percentage of grassland cover (Peters and Eve, 1995). On the other hand, the low value of NDVI value in year 2000 might be due to the high proportion of woody plant cover (Nemani and Running, 1996). The other probable reasons for the low value of NDVI in year 2000 were the canopy coverage and the extent of bare soil that might contribute to the reduction of the NDVI value. Overall, NDVI values are useful in understanding the vegetation cover of the Borana rangelands and can be used in rangeland monitoring and management.

2.4.4 Driving forces of land-use/cover change

The changes of land use/cover in semi-arid areas of East Africa (including Ethiopia) have been hastened by government policies since the 1970s (Omiti *et al.,* 1999; Reid *et al.,* 2004). The other prominent natural catastrophe that caused changes of land cover is recurrent drought (Ndikumana *et al*., 2001). Previous studies (Coppock, 1994; Dalle, 2004; Angassa and Oba, 2010) have shown the shift from grassland to woodland and other land use forms, which was also confirmed by respondents in our study. Shifts in the rangeland cover were related to population of human and livestock, conversions of rangelands to crop land in valley bottoms (dry season grazing areas) and annexation of Borana grazing area by other tribes (e.g. *Gari and Somali)* and for other purposes like government ranch and private enclosures (Oba and Kotile ,2001). Although Campbell *et al*. (2005), describes dryland cropping as an opportunity for pastoralists to increase income without harming the land, others indicated that it is a way of increasing risk to the pastoralists (Little *et al*., 2008) by aggravating desertification and expansion of bareness. Traditionally, the Borana pastoralists used to regulate their rangelands by traditional by-laws, which have been violated since the 1970s by government's inappropriate intervention policies that contributed to the observed changes in rangeland cover.

Earlier studies (Coppock, 1994; Angassa, 2005; Arsano, 2000; Oba *et al*., 2000b; Angassa and Oba, 2008a) have shown that an increase in the abundance of woody vegetation cover could have been due to the ban of fire and continuously high grazing pressures. On the other hand, there is expansion of woody plant cover in areas where there is little grazing due to aggressiveness of some species (Brown and Archer, 1999). In the present study the encroachment of woody cover across the Borana rangeland is highly pronounced. The shifts of grassland to woodland would be approximately five-fold in just three decades. These changes might have significant implications especially on pure pastoralism that relies on livestock production alone. The recent demand of land parcels for farming has led to a push for more use of land for large scale mechanized farming and expansion of large private farming activities in semi-arid areas where climate variability plays a major role in regulating ecosystem function. In addition, undermining traditional land-use practices might have influenced the LULC changes in Borana. Overall, the observed LULC changes in the Borana rangelands adversely affect ecosystem dynamics, which in turn has an impact on the livelihoods of pastoralists. To sustain the normal ecosystem functioning and support of livelihood systems in the Borana rangelands, two important issues should be addressed: a) initiation of 'pastoralist need-oriented appropriate' land use policies that are ecologically friendly and b) regulating population growth in the rangelands.

2.5 CONCLUSIONS

Land-use/cover change information is vital for understanding the status of changes of land-use classes. This information could contribute towards formulation of appropriate managerial decisions based on scientific realities that help normal ecosystem function. The present study demonstrated the usefulness of satellite remote sensing image processing in producing land-use/cover maps and changes in the Borana rangelands for the past 30 years, which showed that: i) the proportion of woodland cover increased in the year 2000 as compared to the 1970s, whereas, the grassland proportion declined; ii) the increase in cultivated land/built up area is a recent phenomenon; iii) Bare land increased and this affected the productivity of land and ultimately the livelihoods of the pastoral communities in southern Ethiopia; and iv) Drought, population pressure, government policy and mismanagement are the major driving forces of changes in land-use in Borana. Therefore, pastoral oriented and environmentally friendly appropriate land-use policies are recommended for sustainable use of rangeland resources. In particular, efforts to promote lower stocking rates and reduction of population through education and public awareness have to be initiated to ensure normal ecological functioning and sustainable livelihood in the Borana rangelands of southern Ethiopia.

CHAPTER 3

SPATIAL VARIABILITY OF VEGETATION AND RANGELAND CONDITION IN BORANA, ETHIOPIA

Abstract

This study was conducted on seven sites in the Borana rangelands of southern Ethiopia to evaluate changes in vegetation composition and rangeland condition. Vegetation were assessed along 10 km transects. Ordination techniques were used for correlation of measured vegetation parameters with environmental variables. Rangeland condition was evaluated using the ecological index and the weighted palatability composition methods. A total of 23 grass species, 14 forbs, 20 shrubs and 46 woody plant species were identified. *Chrysopogon aucheri, Cenchrus ciliaris and Eragrostis papposa* were the dominant grass species. The most frequently occurred woody species were *Acacia tortilis, Lannea rivae, Grewia tembensis, Commiphora habessinica, Rhus ruspoli, Acacia nilotica, Commmiphora africana,* and *Acacia drepanolobium.* Grass biomass production and woody plant density varied significantly ($P< 0.01$) among the different sites. There were no variations in diversity and evenness of vegetation among the different sites. The encroachment of woody plants in the study region varied from moderate to severe encroachment. As a result of this and other factors the rangeland condition of the Borana was classified as very poor to fair.

Keywords: Bush encroachment, ecological index, indicator species, plant species diversity, weight palatable composition method

3.1 INTRODUCTION

In measuring the condition of rangelands in semi-arid environments vegetation parameters like richness, diversity and evenness are sensitive indicators of changes in rangeland condition (Tainton, 1999; Van oudtshoorn, 1999). The soil physical and chemical characteristics are also used as good indicators of range condition (Trollope, *et al*., 1990). Oba *et al*. (2000b) reported that the Borana rangelands of southern Ethiopia are gradually deteriorating as evidenced by the increased levels of bush encroachment. This deterioration could be demonstrated by changes in plant composition, reduced grazing capacity and poor animal body condition or production. There have been several other studies on the condition of the Borana rangelands (e.g. Oba *et al., 2000b;* Dalle, 2004; Angassa, 2007) in recent times.

These studies generally have limited quantitative data on rangeland condition. More often the studies addressed a particular component and not the three tiers of herbaceous, woody and soil together. In an area like the Borana, with its bimodal rainfall pattern, there is also a need to consider rangeland dynamics in each of the seasons. For example Takele (2006) focused on wood or settlements only, while Angassa *et al.* (2012) reported impact of wood encroachment on herbaceous plants during the main rain season. Although these studies are informative it is difficult to consolidate them into a general guide for sustainable management of the Borana. This is critical because most of the recent reports highlight rangeland degradation in the Borana zone.

Therefore, understanding the current status of rangelands in the Borana lowlands is imperative. This study was conducted to test the generalization that range condition is the same and in good condition for different sites in Borana. The other assumption tested is that the vegetation composition does not vary across the different sites. Thus, the specific objectives of this study were to: (1) evaluate the current rangeland condition across the Borana lowlands; (2) explore herbaceous and woody plant composition and production; (3) investigate the correlation among herbaceous biomass, woody plant encroachment and environmental variables across the Borana.

3.2 MATERIALS AND METHODS

3.2.1 Study area

The Borana rangelands are located in Oromia Regional State of Ethiopia (see the detail in Chapter 1 section 1.6.1). The annual rainfall for the last two decades showed pronounced variability in the Borana region (see Chapter 1 figure 1.3). The high rainfall recorded in 1997 in the region was as consequence of El Niño weather phenomenon. In contrast, the low rainfall amount recorded in 1991and 1999 are due to recurring droughts in the region. On the other hand, the recent mean annual temperature showed variation from 19 to 30^0C (see Chapter 1 figure 1.4). This figure is slightly higher than previous report of Coppock (1994) who mentioned variation across seasons ranging from 15 to 24°C. Generally, variation of temperature in the last three decades did not show significant variation. The maximum and minimum temperature followed the same pattern (see Chapter 1 figure 1.4)

3.2.2 Data collection methods

Rangeland condition assessment must incorporate three tiers of assessment, namely: the soil, herbaceous and shrub-tree layers (Danckwerts, 1982; Friedel, 1987). A number of methods are in use for the assessment of the herbaceous layer. Vorster (1982) described the ecological index method for assessing the karroid vegetation in Southern Africa. In this method, the grass species were classified in a similar pattern to that described by Foran (1976) and Tainton *et al*. (1999). Barnes *et al.* (1984) were criticized of the ecological methods and proposed a weight palatability composition method. These methods meet most of the requirements for the successful assessment of the herbaceous layer in terms of accuracy, objectivity and speed of evaluation of extensive areas. Similarly, Stuart-Hill and Hobson (1991) suggested assessment techniques for density of woody plants while Wilson (1987) proposed the assessment techniques for soil variables such as surface erosion and soil compaction.

3.2.2.1. Vegetation sampling

Data was collected in three seasons: March-May 2010, October-November 2010 and December-January 2010/11.Vegetation data were collected from three districts of five communal grazing areas, one government and one cooperative ranch. Line transects of 10 km each across the representative rangeland sites were marked and ten main sampling plots of 20 m x 50 m (1000 m^2) were established along each transect at an interval of 1 km from each other. In each of the main plot, data were collected for herbaceous plants using five quadrats of 0.5 x 0.5 m (0.25m^2) placed at random. Live herbaceous plants in each quadrant were identified, counted, clipped, and weighed for fresh biomass yield. The clipped material was put in a bag and transported to a laboratory and oven dried to a constant weight at 105°C for dry matter determination. Herbaceous species identification was done in the field by experienced personnel using an illustrated guide to the grasses of Ethiopia, Chilalo Agricultural Development Unit (CADU, 1974), and the guidelines of the National Herbarium for Flora in the National Herbarium of Ethiopia (Addis Ababa University Science Faculty) referring to the published volumes of Flora of Ethiopia (Hedberg *and Edwards, 1995*), while local names were determined with the help of pastoral community members. Each species was placed into its relevant ecological index (i.e., increaser, decreaser and invader) as described by Tainton (1999). Forbs of all species were treated as one group for purposes of dry matter determination. Woody plant density and frequency were collected from three sub-plots of 10 m x 10 m (100 m^2) size, over the three seasons. All trees and shrubs rooted within the plot were considered and diameter at breast height (DBH) for trees and shrubs were measured using a tree caliper. Height of trees/shrubs with DBH greater than 2.0 cm was estimated using a graduated measuring stick and then the tree plants were allocated to one of three class categories: seedling (0 - 0.5 m), sapling (> 0.5 - 2 m) and matured (>2 m) and tree data were standardized to tree equivalent/ha [1TE=1tree, 1.5 m high; Teague *et al*. (1981)]. The resident pastoralists were also involved in characterizing vegetation species and reflected their views on the degree of woody plant encroachment.

3.2.2.2 Soil sampling

Soil samples were collected from each main plot during vegetation sampling at different depths: (0 -10 cm, >10 - 20 cm, and >20 -30 cm). Soil samples were analyzed at the Oromia Water Works and Design Supervision Enterprise (OWWDSE). Soil texture was analyzed using the hydrometer method (Gee and Bauder, 1986), while soil pH was read in a 1:2.5 soil-water suspension using a pH meter (McLean, 1982). Organic carbon was analyzed by oxidation with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid medium; and 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 (AOAC, 1990) and available phosphorus by the Bray method for soil samples with pH > 7 and the Olsen procedure for samples with pH < 7 (Olsen and Sommers, 1982). Cation exchange capacity (CEC) was measured after ammonium acetate (1N NH_4OAC) extraction (Van Reeuwijk, 1995).

3.2.3 Data analysis

3.2.3.1 Vegetation diversity analysis

Shannon and Wieners Index method (Magurran, 1988) was used to determine species diversity, richness and evenness.

The Shannon diversity index was calculated using the formula:

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

Where: H = Shannon diversity index; pi = 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 values of evenness index, the more even the species are in distribution within the given area. Species richness is a count of the number of species in a quadrat, area or community.

3.2.3.2 Herbaceous, woody plants and environmental variable correlation analysis

Principal Component Analysis (PCA) were used when the axis was less than three and Detrended Component Analysis (DCA) when the axis was greater than three to analyze the patterns of distribution of herbaceous and woody plant species in relation to environmental variables like altitude and measured soil properties using PC-ORD for widows version 5 (MCCune and Mefford, 1999). The distribution patterns of correlation between herbaceous species and woody plants with environmental variables were done using SAS software.

3.2.3.3 Rangeland condition analysis

Range condition was estimated using the ecological index (Vorster, 1982) and weighted palatability composition method (Barnes *et al*, 1984). In calculating the rangeland condition grass species were categorized into five condition classes (decreasers, Increaser I, Increaser IIa and IIb, Increaser IIc). Each class was given a relative index value, namely; decreasers = 10; Increaser I = 7; Increaser IIa and IIb = 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 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). The calculated range conditions were divided into five classes: 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 by grouping 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 sampling site. This was calculated as a sum of the product 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):

$$\text{WPC} = (\text{PC} - 33.3) \text{ x}100 / 66.7.$$

The maximum WPC is 100 if all species fall under Class I and the minimum is 0 if all species are under Class III. 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).

The interpretation of the degree of woody plant encroachment was adopted from Bille and Asefa, (1984) as follows: Insignificant (0- 250 TE ha^{-1}); low (> 250 – 500 TE ha^{-1}); moderate (> 500 –

750 TE ha^{-1}); less severe (> 750 - 1000 TE ha^{-1}) and severe encroachment (> 1000 TE ha^{-1}). The relationships between herbaceous, woody plants and environmental variables were tested through correlation and linear regression analysis using SAS procedures (SAS, 2009).

3.3 RESULTS

3.3.1 Composition of herbaceous

A total of 23 grasses and sedge were identified across different grazing systems in the study areas. The frequency of distribution of herbaceous species varied across the sites. The most frequently occurring grass species were *Chrysopogon aucheri* (74.3%), *Cenchrus ciliaris* (60.0%) and *Eragrostis papposa* (55.7%). *Aristida adoensis, Digitaria spp., Bothriochloa insculpta, Pennisetum mezianum, Cyperus species* and *Heteropogon contortus* occurred moderately. Other species such as *Themeda triandra, Dactyloctenium aegyptium, Eleusine intermedia, Digitaria naghellensis, Cynodon dactylon, and Panicum maximum* were low in frequency across the different grazing systems. Overall, rarely recorded grass species included: *Sporobolus pellucidus, Setaria verticillata, Sporobolus pyramidalis and Bothriochloa radicans* (Figure 3.1).

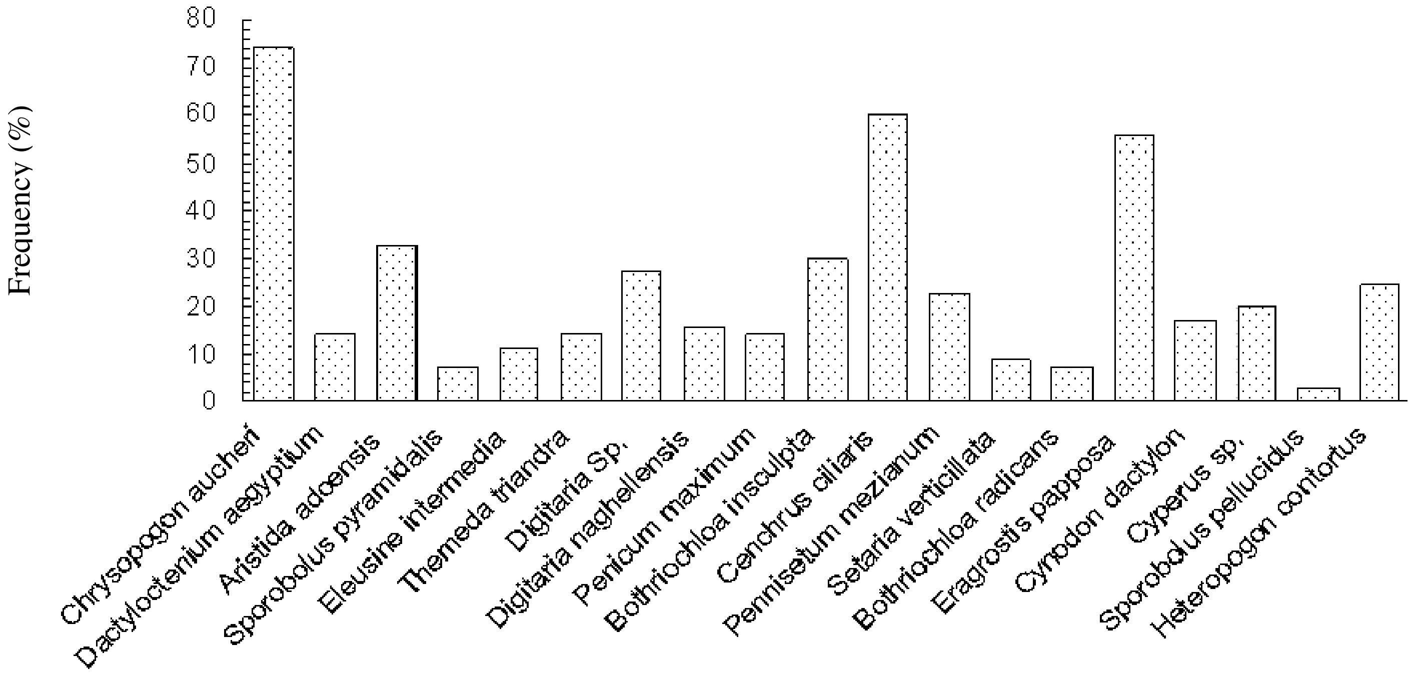

Figure 3.1 The general frequency of herbaceous species in the Borana, southern Ethiopia

The respective occurrence of the herbaceous species at the different sites is presented in Fig 3.2. Except for Surupha, grass species like *C. aucheri and C. ciliaris* were occurred frequently across the study area. In contrast, A. *adoensis* and *C. dactylon* were abundant at Surupha (Figure 3. 2). At Did-Tuyura ranch, the relative density of *C. aucheri, C. ciliaris, E. papposa* were high followed by *T. triandra, Digitaria species* and *H. contortus* grass. Generally, the relative densities of the remaining grass species were low compared to other sites. *Chrysopogon aucheri* had demonstrated the highest relative density at Dambala-Wachu cooperative ranch. Grasses like *B. radicans, S. pellucidus, C.ciliaris, Cyperus spp., Digitaria naghellensis, B. insculpta and E. papposa* exhibited moderate density at this site. The remaining grass species were of a low relative density. At Did-Hara the high relative density grass species were similar to those at the Did-Tuyura ranch. *Aristida adoensis, B. insculpta, H. contortus, C.ciliaris* and *T. triandra* grass species were moderate in density at Did-Hara area; the remaining species were low in relative density.

The occurrence of *C. aucheri* at Bokkulboma; *E. papposa, C.aucheri,* and *C. ciliaris* at Mana-Soda, *T. triandra* were relatively high at Did-Tuyura, Surupha and Did-Hara. *Sporobolus pellucidus* had a relatively unique occurrence at Dambala-Wachu. Other unique occurrences were that of *S. pyramidalis* which was only recorded at Mana-Soda and Medhacho; *S. verticillata* and *D. aegyptium* relatively *high* at Medhacho. There was a high occurrence of *P. maximum* at Mana-Soda and Surupha compared to the other sites. On the overall, *C. aucheri* had the highest relative density throughout the study area with *E. papposa* and *C. ciliaris* as the second most frequently abundant grass species.

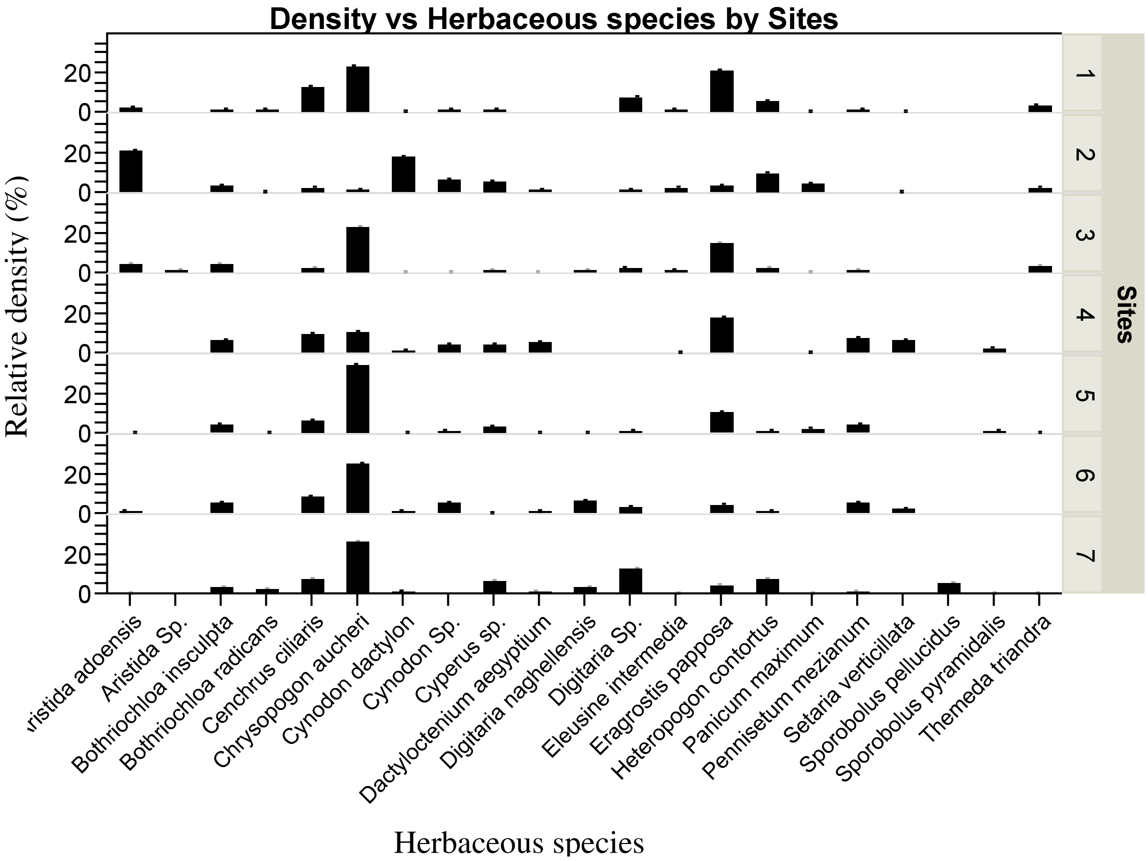

Figure 3.2 Relative densities of herbaceous species at different sites in the Borana

Key: Site 1= Did-Tuyura; site 2 = Surupha, site 3= Did-Hara; site 4= Medhacho; site 5= Mana-Soda; site 6= Bokkulboma and Site 7= Dambala-Wachu

3.3.2. Diversity, richness and evenness of herbaceous plants

The calculated Shannon-Wiener indices are presented in Table 3.1.There were no significant difference (P>0.05) in herbaceous species diversity and evenness across the sites. The herbaceous species richness was significantly high (P<0.05) at the Did-Hara site.

Table 3.1 Herbaceous species diversity, richness and evenness at different sites of Borana

Site	Richness	Diversity*	Evenness*
Did- Tuyura	21^{ab}	2.17	0.73
Surupha	25^{ab}	2.54	0.81
Mana-Soda	24^{ab}	1.99	0.67
Bokkulboma	19^{ab}	2.21	0.77
Medhacho	17^{b}	2.34	0.87
Did- Hara	28^{a}	2.53	0.77
Dambala-Wachu	24^{ab}	2.37	0.77
LSD	10.8	1.19	0.21
	S	*NS	*NS

Mean within the column with same letter were not different significantly (P>0.05)

*NS= non significant, S=significant

The herbaceous plant richness seemed to be positively correlated with diversity (as richness increased diversity also enhanced; Table 3.1). In general all sites had high evenness indices.

3.3.3 Herbaceous dry matter production

Dry matter production at the different sites across the Borana was significantly different (P<0.01) (Table 3.2). The general ranking of mean dry matter production was Dambala-Wachu > Did-Tuyura, Did-Hara, Mana-Soda, Bokkulboma, > Surupha and Medhacho.

In addition, the mean dry matter production showed significant (*P*< 0.01) seasonal variation. The maximum dry matter production was obtained at the end of the main rainy season and the least was recorded in the short rainy season (Table 3.2). There were no significant (P>0.05) differences observed in dry matter production between the early main rainy and short rainy seasons.

During early main rainy season, the dry matter recorded in Did-Tuyura was significantly higher ($P<0.05$) than the other sites except Dambala-Wachu. Within the same season, the dry matter observed in Surupha, Medhacho, Bokkulboma and Mana-Soda were not different ($P>0.05$). On the other hand, Dambala-Wachu had the highest ($P<0.001$) dry matter production during the end of the main rainy season compared to other grazing areas. The dry matter yields for Medhacho and Surupha remained low at the end of the main rainy season and did not differ with dry matter production of Did-Tuyura and Did- Hara. The highest dry matter production was recorded at Mana Soda and Dambala-Wachu during the short rainy season. Low dry matter was produced at Medhacho, Surupha and Bokkulboma during the short rainy season compared to the other sites. In general, the dry matter production in Borana rangelands showed significant spatial and seasonal variation.

Table 3.2 Seasonal dry matter production (kg ha^{-1}) at different sites in the Borana

	Early main rainy season	End of main rainy season	Short rainy season	Mean
a) Sites				
Did-Tuyura	5537.89^{a}	5548.29^{bc}	2591.05^{ab}	4559.08^{b}
Surupha	1360.41^{c}	5608.44^{bc}	1391.93^{b}	2786.93^{c}
Did-Hara	3875.13^{b}	7348.29^{b}	2236.1^{ab}	4486.57^{b}
Dambala-Wachu	5006.01^{ab}	14571.89^{a}	3477.20^{a}	7685.03^{a}
Bokkulboma	1412.34^{c}	8588.04^{b}	1614.20^{b}	3871.53^{b}
Mana-Soda	1769.05^{c}	7915.66^{b}	3545.06^{a}	4409.92^{b}
Medhacho	909.09^{c}	1850.10^{c}	912.58^{b}	1223.92^{c}
LSD$_{(0.05)}$	1486.00	4036.80	1717.00	1730.90
b) Season				
Early main rainy season		2838.56^{b}		
End of main rainy season		7347.20^{a}		
Short rainy season		2252.58^{b}		
LSD$_{(0.05)}$		982.23		

Mean within the column with same letter were not significantly different ($P>0.05$)

The bulk of the produced biomass was largely from decreaser species (59.2 %) as shown in Table 3.3. Increaser I grass group contributed the least dry matter compared to the other ecological categories. Increaser IIa and IIb species also had a significant dry matter contribution of 29%. Specifically, the grass species that produced the highest dry matter were *C. aucheri, C. ciliaris* and *P. mezianum,* respectively. In all land use systems, the moderate dry matter producers were *E. papposa, H. contortus, D. milanjiana, B. insculpta* and *A. adoensis*. The least dry matter producers were *S. verticillata, C. dactylon* and *S. pyramidalis.* The respective contributions of each ecological grouping varied from site to site.

The decreasers and increasers IIa had high percentage contributions to dry matter production in the government and cooperative ranches compared to the communal grazing areas (except at Mana-Soda (Figure 3.3). In the communal rangelands increaser IIb and increaser IIc species had high yield contributions relative to the government and cooperative ranches. Dry matter production at Surupha was largely from increaser IIc species.

Table 3.3 Ecological categories of herbaceous and their respective dry matter production (kg/ha) for different land use systems

Species	Ecological categories	Land use systems							Species Total	% out whole
		Government ranch	Cooperative ranch	Communal land						
				Surupha	Did-Hara	Bokkulboma	Medhacho	Mana-Soda		
Themeda triandra	Decreaser	686.80	361.51	172.44	239.43				1460.18	
Panicum maximum	Decreaser	54.40		352.48				215.13	622.01	
Cenchrus ciliaris	Decreaser	417.24	1264.64	0.00	501.43	489.20	114.58	702.22	3489.30	
Eragrostis papposa	Decreaser	374.03	55.13	46.12	133.16	43.40	143.11	351.60	1146.54	
Chrysopogon aucheri	Decreaser	1624.37	3732.24	47.20	1592.39	1291.48	266.41	1854.98	10409.08	
Subtotal for decreaser		3156.84	5413.51	618.25	2466.42	1824.03	524.11	3123.93	17127.10	59.2
Digitaria spp.	Increaser I			124.65			88.91	14.70	228.26	
Sporobolus pyramidalis	Increaser I		19.16				23.35	8.94	51.45	
Subtotal for Increase I			19.17	124.65			112.53	14.67	271.01	0.94
Heteropogon contortus	Increaser IIa	424.72	636.68		210.74	69.31	16.77	106.32	1464.54	
Digitaria milanjiana	Increaser IIa	465.15	1304.78		592.69	95.16			2457.78	
Digitaria naghellensis	Increaser IIa		96.55		2.08	64.48			163.11	
Dactyloctenium aegyptium	Increaser IIa			5.93	5.55		91.83		103.31	
Cynodon dactylon	Increaser IIa		14.05	1.36		15.25	13.85	17.35	61.86	
Subtotal for increaser IIa		889.87	2052.05	117.76	811.05	244.21	122.46	123.67	4361.07	15.07
Bothriochloa insculpta	Increaser IIb	36.86		271.52	438.69	122.47	124.12	258.33	1251.98	
Bothriochloa radicans	Increaser IIb	176.20		3.48					179.68	
Pennisetum mezianum	Increaser IIb	68.79	73.09		260.22	898.45	357.67	889.41	2547.64	
Subtotal for Increase IIb		282.00	73.10	275.50	698.80	1021.12	481.79	1147.74	3980.05	13.76
Sub for Increaser IIa &b		1171.87	2125.15	393.26	1509.85	1265.34	604.25	1271.40	8341.12	28.83
Setaria Verticillata	Increaser IIc					50.45			50.45	
Aristida adoensis	Increaser IIc	118.28		1246.30	294.97	75.57			1735.12	
Cyperus spp.	Increaser IIc	1.69	156.38	146.78	0.03		6.72		311.59	
Eleusine intermedia	Increaser IIc	110.34		257.79	215.73	21.54			605.40	
Subtotal for Increaser IIc		230.30	156.38	1650.80	510.73	147.56	6.72		2702.49	9.34
Total		4559.00	7695.00	2787	4487.00	3872	1224.00	4410	28930.00	

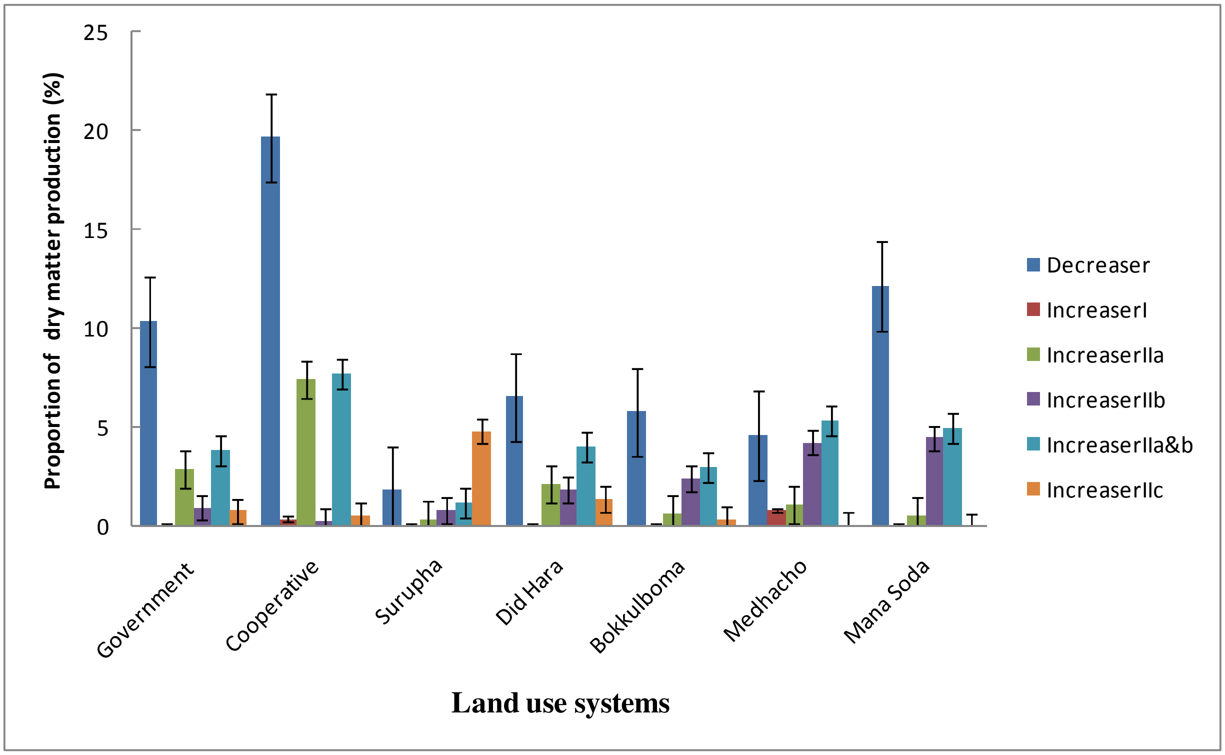

Figure 3.3 Dry matter productions of different ecological classes of grasses at different sites in Borana, southern Ethiopia

3.3.4 Range condition

The computed weighted palatability composition values for the different sites ranged from 1 to 33 (Table 3.4). According to the WPC values the condition of the Borana rangelands ranged from very poor to poor. Using ecological index method Did-Tuyura and Mana-Soda had fair range condition while the rest were classed as poor. On the overall, using both methods the Borana rangeland condition varies between very poor to fair.

Table 3.4 Rangeland condition scores of various sites of the Borana rangelands, Ethiopia

Sites	Range condition score	
	WPCM	EIM
Did-Tuyura	33	520
Surupha	6	317
Dambala-Wachu	15	407
Did-Hara	22	452
Bokkulboma	1	314
Mana-Soda	27.6	474
Medhacho	5	338

WPCM= Weighted palatability composition method; EIM= ecological index method

3.3.5 Composition of woody plants, shrubs and forbs

A total of 46 woody species, 20 shrub species and 12 forbs were indentified and recorded. The most frequently occurred woody species were *Acacia tortilis, Lannea rivae, Grewia tembensis, Commiphora habessinica, Rhus ruspoli, Acacia nilotica, Commiphora Africana,* and *Acacia drepanolobium* (Figure 3.4). The moderately distributed woody plants were *Grewia bicolor, Commiphora fluviflora, Acacia etabaica, Acacia bussei, Commiphora spp.*, and *Acacia mellifera.*

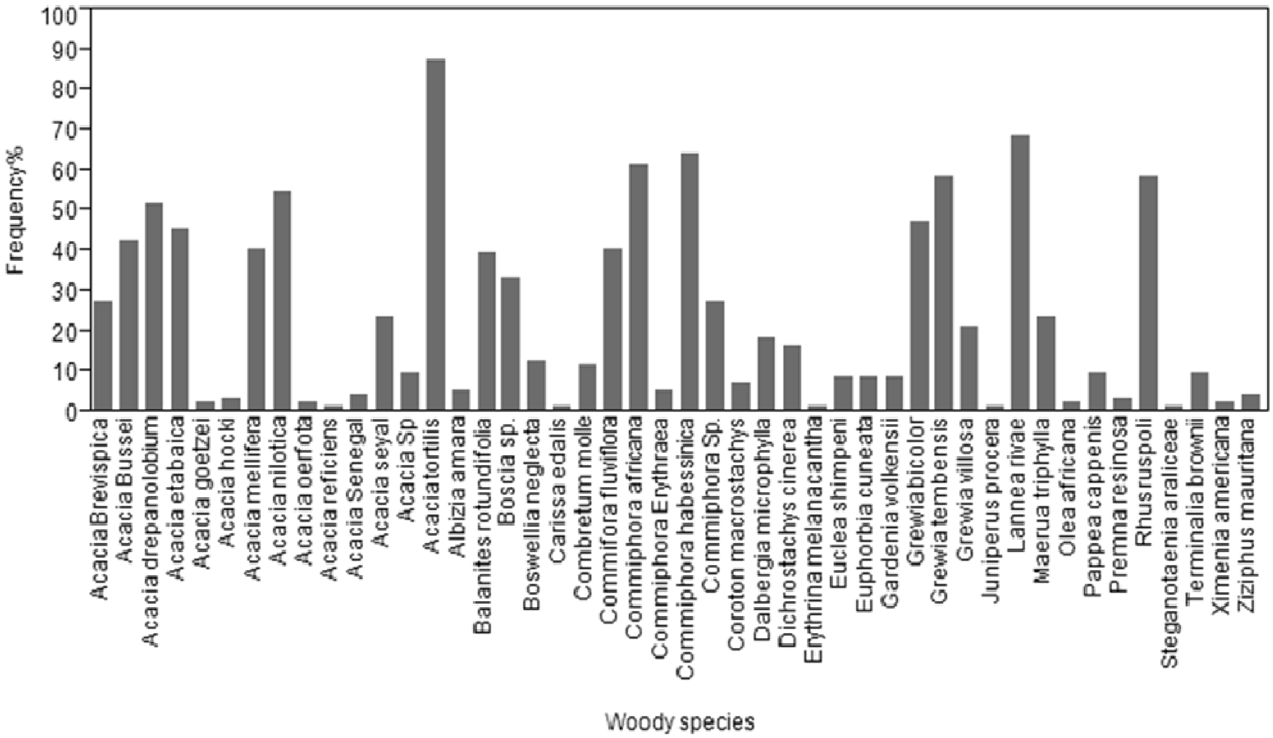

Figure 3.4 Frequency of woody plants across the Borana rangelands of Ethiopia

The most frequently recorded shrub species were *Ormocarpum trichocarpum, Solanum species, Vernonia phillipsiae, Hibiscus species* and *Bidens hildebranditi* (Figure 3.5). The other moderately distributed shrubs were *Aloeceae, Plectranthus ignarius, Ipomoea hildebrandtii, Ozoroa insignis* and *Maytenus senegalenis*

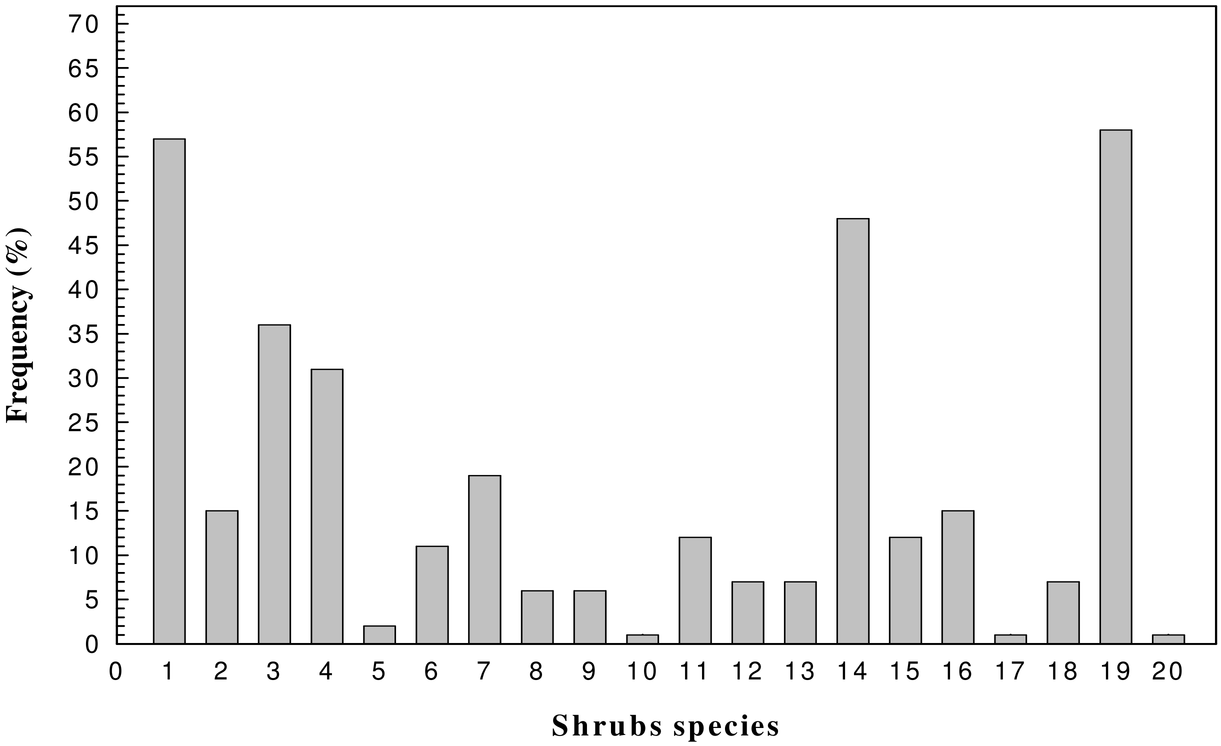

Figure 3.5 Frequency of shrubs in the Borana rangelands of Ethiopia, 2010

Key:*1=Ormocarpum trichocarpum ,2=Plectranthus ignarius, 3=Hibiscus Sp., 4=Bidens hildebrandti, 5=Hibiscus sparseaculeathus ,6=Maytenus senegalenis, 7=Aloe Sp, 8=Canthium bogosensis, 9=Ehretia cymosa, 10=syris lanceolata, 11=Ozoroa insignis, 12=Phyllanthus sepialis, 13=Chiopodium opalifolium, 14=Vernonia phillipsiae, 15=Cordia gharaf, 16=Ipomoea hildebrandtii, 17=Cappparis tomentosa, 18Lantana vibumoides,19=Solanum Sp., 20=Solanum solmalense.*

Various forbs species were found in the study areas, e.g. *Kleinia squarrosa* and *Asparagus spp.* (Figure 3.6).The forbs *Carllumpa priogonium* and *Dyschoriste hildebrandtii* were generally of rare occurrence.

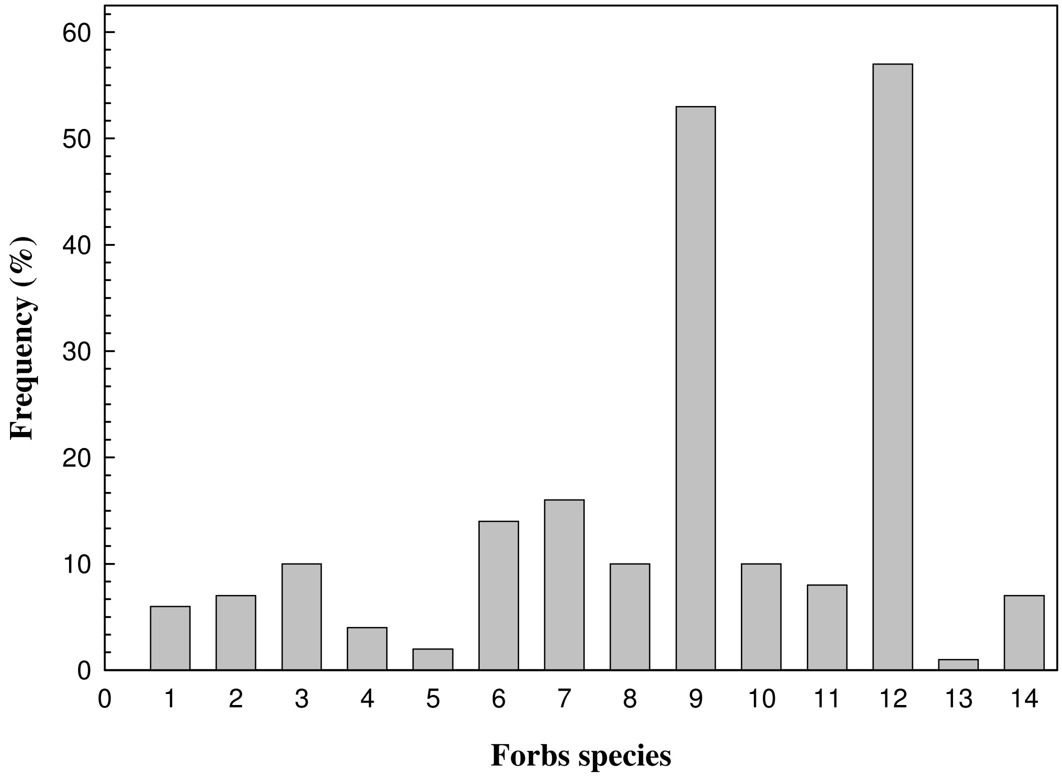

Figure 3.6 Frequency of forbs in the Borana rangelands of Ethiopia

Key: *1=Erythrocanmys cufodonti, 2=Sansevieria ehrenbergi, 3=Cissus Sp., 4=Cladostigma hildebrandtiodes, 5 =Dyschoriste hildebrandtii, 6=Dyschoriste sp., 7=Aspilia Mossambicensis, 8=Ipomoea kituensis, 9=Kleinia squarrosa, 10=Beciumverticillifolium, 11=Ipomoea marmorata, 12 =Asparagus Sp., 13=Carllumpa priogonium, 14=Indigofera arrecta*

3.3.6 Diversity, richness and evenness of woody plants

The diversity and evenness of woody plant across the different sites did not differ (P>0.05). However, richness of woody plants were significantly high (P<0.01) at Surupha site compare to other sites (Table 3.5). The least richness and diversity of woody plant recorded at Medhacho site. On the other hand, Surupha site exhibited high richness and diversity as compared to other sites. All sites had high value of evenness.

Table 3.5 Woody plant diversity, richness and evenness in different land use systems

Land use systems	Richness	Diversity*	Evenness*
Did-Tuyura	28^{b}	2.26	0.69
Did-Hara	25^{b}	2.55	0.83
Surupha	41^{a}	2.94	0.78
Dambala-Wachu	30^{b}	2.69	0.81
Mana-Soda	28^{b}	2.45	0.72
Medhacho	18^{c}	2.22	0.76
Bokkulboma	29^{b}	2.63	0.78
LSD	5.54	1.48	0.27
	S	*NS	*NS

Mean within the column with the same letter were not significantly different (P>0.05)
*NS= Non significant, S=significant

3.3.7 Density of woody plant

The mean density of woody plants differed significantly (P<0.01) across the study sites (Table 3.6). The density of woody plants was highest at Did-Hara, Dambala-Wachu, Did-Tuyura and Surupha and least at Medhacho and Mana-Soda.

Table 3.6 Density of woody plant in different land-use systems in Borana, Ethiopia

Sites	Density of woody plant ha^{-1}	Status of bush encroachment
Did- Hara	2960 ± 240^{a}	Severe encroachment
Medhacho	885 ± 125^{bc}	Less severe encroachment
Mana-Soda	640 ± 93^{c}	Moderate encroachment
Surupha	2710 ± 384^{a}	Severe encroachment
Dambala-Wachu	2930 ± 371^{a}	Severe encroachment
Did-Tuyura	2830 ± 428^{a}	Severe encroachment
Bokkulboma	1900 ± 187^{ab}	Severe encroachment
LSD	1225	

Mean within column with the same letter were not significantly different (*P*>0.05)

Woody plant encroachment across the region varied from moderate encroachment to severe encroachment. Mana-Soda and Medhacho had moderate and less severe woody plant encroachment, respectively. The other sites all had severe woody plant encroachment condition. No consistent patterns could be discerned from the variations in woody plant encroachment. It is plausible that each site had a unique history to its encroachment.

3.3.8 Correlation of herbaceous, woody plants and environmental variables

Panicum maximum, Aristida adoensis and *Cynodon dactylon* grasses species are strongly affiliated to sandy soil texture (Annex 1). *Pennisetum mezianum* was the dominant grass species annexed to silt soil texture. On the contrary, *Eleusine intermedia* and *C. dactylon* negatively correlated to silt soil texture. On the other hand, among the grass species *P. mezianum* had positive correlation with pH, however, *E. intermedia* was negatively correlated. *Dactyloctenium aegyptium; Sporobolus pyramidalis* and *Setaria verticillata* grass species were positively correlated with sodium rich soil type. Similarly, grass species *D. aegyptium, S. pyramidalis* and *S. verticillata* had strong affiliation with potassium rich soil type. Moreover, *P. mezianum* was positively related to CEC and calcium content of soil. However, *E. intermedia* and *Heteropogon* contortus were negatively correlated with CEC. Growth of *D. aegyptium, S. pyramidalis* and *S.* verticillata also positively correlated with phosphorus (Annex 1).

Regarding woody plants the present study demonstrated that *Grewia tembensis, Acacia nilotica* and *Acacia seyal were* positively correlated with clay soil texture (Annex 2). However, *Acacia tortilis* was negatively correlated to silt soil texture and potassium content. On the other hand, *Grewia bicolor, Rhus ruspoli, A. tortilis,* and *Boscia species* were negatively correlated with pH of the soil. The calcium content of soil was negatively correlated with *G. bicolor, R. ruspoli, A.*

tortilis and *Boscia spp.* as compared to other woody plants. In addition, CEC level negatively influenced the growth of *G. bicolor, A. tortilis* and *Boscia spp. Grewia bicolor* was negatively correlated with total nitrogen, organic carbon and organic matter of the soil content. The woody plant *Maerua triphylla*, *Acacia Bussei* and *Acacia mellifera* dominated in the low altitude as compared to other woody plants (Annex 2).

The correlations of vegetation and environmental variables are presented in Figure 3.7. There was a negative correlation between the densities of woody and herbaceous plants. Generally, herbaceous plants dominance was associated with silt and clay soils but woody plants were predominant in sandy areas. High densities of woody plants were recorded in Surupha and Did-Hara, whereas, low densities recorded in Medhacho and Mana-Soda. The prevalence of woody plants was associated with low pH values. In Medhacho and Mana-Soda the presence of high content of OM, CEC and phosphorus contributed to ameliorate infiltration capacity of soil.

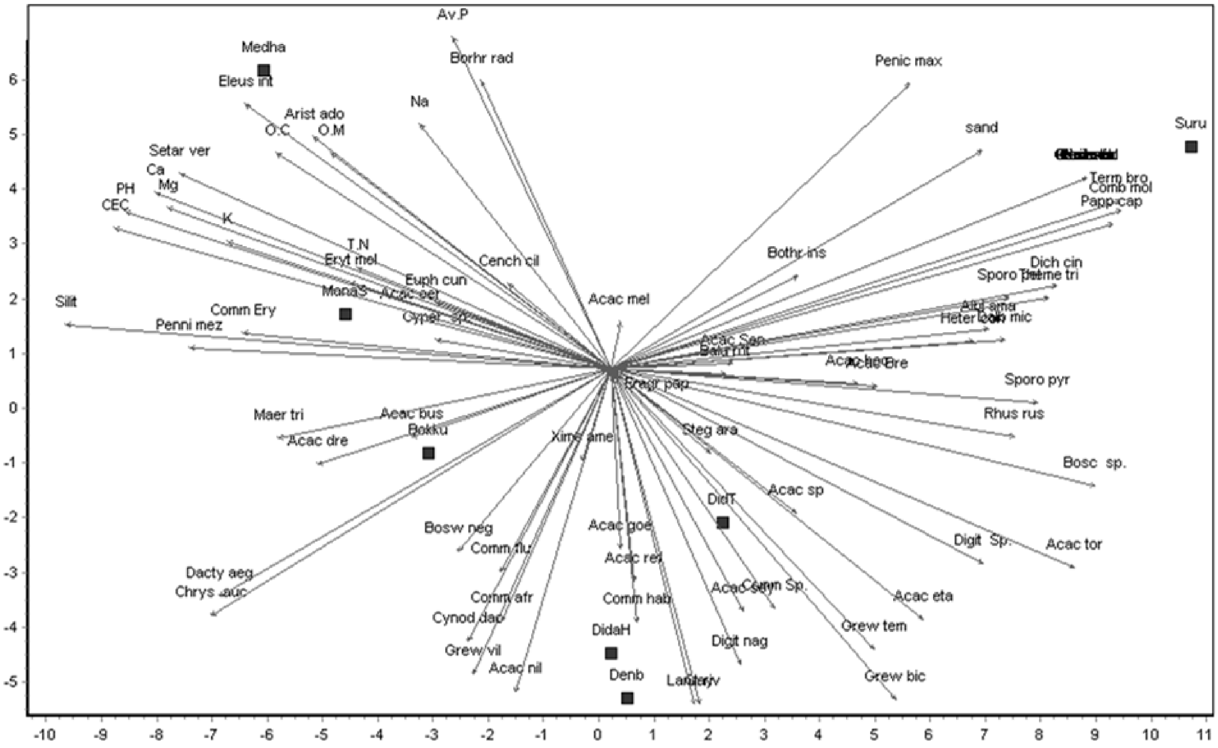

Figure 3.7 PCA correlations of herbaceous and woody species with environmental variables

Key: ManaS= Mana-Soda, DidT= Did-Tuyura, DidH= Did-Hara, Medha= Medhacho, Suru= Surupha, Bokku= Bokkulboma, Denb=Dambala-Wachu*,Chry auc =Chrysopogon aucheri, Dacty aeg=Dactyloctenium aegyptium, Arist ado=Aristida adoensis,sporo pyr = Sporobolus pyramidalis, Eleus int =Eleusine intermedia, Them tri= Themeda triandra, Digitaria Sp., Digit nag =Digitaria naghellensis, Pan max =Panicum maximum, Bothr ins =Bothriochloa insculpta, Cench cil =Cenchrus ciliaris, Penni mez =Pennisetum mezianum, Setar ver = Setaria verticillataBothr rad =Bothriochloa radicans, Eragr pap =Eragrostis papposa, Cynod dac =Cynodon dactylon, Cyperus sp., Sporo pel= Sporobolus pellucidus, Heteropogon contortus,Comm afr =Commiphora africana, Comm ery = Commiphora Erythraea, Grew bic =Grewia bicolor, Bala rot=Balanites rotundifolia, Acac nil =Acacia nilotica, Comm flu =Commifora fluviflora, Rhus rus =Rhus ruspoli, Bosw neg =Boswellia neglecta, Acac tor =Acacia tortilis, Grew tem =Grewia tembensis, Maaer tri = Maerua triphylla, Acac dre = Acacia drepanolobium, Euph cun = Euphorbia cuneata, Acac eta =Acacia etabaica, Acac bus = Acacia Bussei, Commiphora Sp= Commiphora species, Comm hab =Commiphora habessinica, Lann riv =Lannea rivae, Boscia sp., Grew vil =Grewia villosa, Acac mel = Acacia mellifera, Eryt mel = Erythrina melanacantha, Acac oer =Acacia oerfota, Acac sen =Acacia Senegal, Acac sey =Acacia seyal, Acac goe =Acacia goetzei, Coro mac = Coroton macrostachys, Papp cap =Pappea cappenis, Term bro =Terminalia brownie, Cari eda =Carissa edalis, Olea afr =Olea africana, Garde vo =Gardenia , Bosc sp = Bosic species, Acac sp= Acacia species, Xime ame = Ximenia Americana, Acac hoc =Acacia hocki, =Acac ref= Acacia reficirns, Dalb mic= Dalbergia microphylla, Albi ama = Albiza amara, Acac bre= Acacia brevispica, Steg ara= Steganotaenia araliceae, Zizi mua= Ziziphus mauritana, Eucl shi= Euclea shinpeni, Prem res= Prema resinosa, Comb mol = Combretum molle, Dich cin= Dichrostachys cinerea*

3.4 DISCUSSION

3.4.1 Composition of herbaceous species

The dominance of *Chrysopogon aucheri, Eragrostis papposa* and *Cenchrus ciliaris* could have been due to their tolerance to grazing pressure. These species modify their stomata structure and develop branched root deeply to ameliorate moisture stress (Coppock, 1994; Angassa, 2005; Dalle *et al*., 2006a; Tefera *et al*., 2007). The moderate abundance of *Aristida adoensis, Digitaria species, Borthriochloa insculpta, Pennisetum mezianum, Cyperus species* and *Heteropogon contortus* is probably linked to individual species' resistance to disturbance and capacity of coping of tiller after grazing (Angassa, 2005; Dalle *et al*., 2006a).

Several factors are assumed to contribute to the spatial and temporal variation of herbaceous species composition; among which are grazing pressure, woody plant encroachment, ban of fire, recurrent drought and edaphic factors to mention a few. Grazing can affect plant species composition through the suppression of desirable species and facilitation of less palatable species (Morton *et al*., 1995). Vegetation composition, soil physical and chemical properties are believed to be measurable indicators of range condition (Herlocker, 1999 and Scoones, 1995).

3.4.2 Herbaceous species richness, evenness and diversity

High richness of herbaceous species was recorded in Did-Hara communal grazing area as compared to the other sites. This could be attributable to the variations rainfall, grazing pressure and soil factors (Dorgeloh, 1999) among the sites. This could also linked the robust traditional range management practices by the local herders (Angassa and Oba, 2010). However, herbaceous species diversity and evenness were not significantly different in the study sites. The high richness in Did-Hara site did not demonstrated high biomass production. Similarly previous studies (e.g. Dalle, 2004; Cox *et al*., 2006; Gillman and Wright, 2006; Anderson and Hoffman,

2007) have shown that the relationship between productivity and species diversity is not consistent and is scale dependent, implying that productivity is a weak predictor of species diversity in arid areas. The diversity index for the Borana rangeland ranges from 1.98 to 2.54 which in line with (Magurran, 1988; Kent and Coker, 1992; Takele, 2006; Dirbaba, 2008), who reported that the range of diversity index of 1.5 to 3 for arid rangelands.

The high value of richness of herbaceous species demonstrated in the present study at Did-Hara might be due to the communal grazing areas had high grazing pressure as a result, dominancy of specific species were restricted (Angassa and Oba, 2009). This is in contrast with the results of (Gaston, 2000; Tuomisto *et al*., 2003) who suggested that in situation of over-utilized conditions, species richness decreases with an accompanying increase in the dominance of few species adapted to high grazing pressures. Understanding plant species richness is important to identify the status of range condition and to take correction measures (Lovett *et al*., 2000). Richness, diversity and evenness of species in a given plant community are used to interpret the relative variations between and within the community and help to explain the underlying reasons for such a difference. Our finding revealed more evenness of herbaceous species in the study region which is in line with report of (Takele, 2006; *Dirbaba,* 2008; Angassa and Oba, 2009) in southern part of Ethiopia.

3.4.3 Dry matter production

In this study the dry matter production across the study areas ranges from 1.21 tons ha^{-1} to 7.69 tons ha^{-1}. Similarly, Cossins and Upton (1988) have reported that the dry matter production of Borana rangeland was 1 to 8 tons ha^{-1} year^{-1}. The Dry matter production in both ranches (Did-Tuyura and Dambala-Wachu) was significantly higher compared to Medhacho and Surupha sites. This was mainly due to less grazing pressure in both the government (12 TLU km^{-2}) and cooperative ranches (17.6TLU km^{-2}) whilst the grazing pressure of communal rangelands was 25 TLU km^{-2}. Several studies in East African rangelands revealed that dry matter production decreased as grazing pressure is increased (Oba *et al*., 2000a; Augustine and McNaughton, 2004; Tefera *et al*., 2007).

Generally, there were no significant differences in terms of dry matter production in Did-Tuyura, Did-Hara, Bokkulboma and Mana-soda, this could be attributed to the severity of bush encroachment (Dalle *et al*. 2006a, Angassa and Oba 2008a). There was significantly low production of dry matter production in Surupha as compare to the ranch management due to replacement of herbaceous species by woody plants. On the other hand, in the case of Medhacho the reason for low dry matter production might be due to the presence of permanent deep-well water points, which attracts heavy grazing. Generally, the low accumulation of dry matter production in the communal rangelands as compared to the ranch management is also reported by a previous study (Angassa and Oba, 2010), suggesting that heavy grazing, encroachment of woody plants, shrinkage of rangeland and poor management were contributing factors. In addition, the reason for the low dry matter production in Surupha might be related to the effect of soil erosion. Generally, rangeland degradation and climatic variability are major contributing factors for the low biomass production in the Borana pastoral ecosystems (Dalle, 2004). Moreover, the high dry matter production in the cooperative ranch could be due to the low stocking rate (17.6TLU km^{-2}) and management intervention (Angassa and Oba, 2007). Our findings indicated that low dry matter production in the study region as consequence of low precipitation and high grazing pressure which are in line with the report of Gebremeskel and Peieterse (2006) in Afar, Gezahegn (2003) in Somali regions and Abule *et al.* (2005) in the rift valley areas of Ethiopia.

The present study confirmed that seasonal variation of dry matter production in the study region. The dry matter produced during end of main rain season was significantly higher as compared to the remaining season. This might be attributed to the availability of rain and traditional management of pastoralists. Traditionally, Borana pastoralists do not allow animals to grazing wet season grazing areas until the end of main rainy season that might be provided time for complete growth of plant and high biomass production. The probable reason for the reduction in biomass production during the mid main rainy season might be due to the fact that plants were not at their full growth stage. On other hand, the variability of rainfall in short rainy could be the possible reason for the observed low dry matter production. Abusuwar and Yahia (2010) in the Sudan semi-arid areas and Dalle (2004) in the southern Ethiopia reported precipitation as major determinant of biomass production.

Moreover, the study result showed that grass species ecological category of decreaser produced the highest proportion of dry matter in both ranches (Did-Tuyura and Dambala-Wachu) and increaser group produced the high dry matter production in communal grazing areas. This might be due to high grazing pressure at communal grazing area promoting increaser group, while low grazing pressure (12 TLU km^{-2}, 17.6 TLU km^{-2}) at Did-Tuyra and Dambala-Wachu ranch, respectively, favoured the decreaser. High proportion of decreaser is an indication of good range condition (Tainton, 1999). On the basis of these events, ranch management systems were in a better range condition as compared to communal rangelands in terms of dry matter production. The higher proportion of increaser group in communal rangelands as compared to the ranch management systems might be an indicator of rangeland denudation.

3.4.4 Range condition

Range condition is a change in vegetation community in a short period of time while, range trend is changes in condition or state of rangeland over long period of time (Soddart *et al.,* 1975). This study found that the largest areas of the Borana rangeland are in a poor condition. The probable reason could be that the type of management intervention that was adopted might not be compatible with the ecological potential of the region. The low precipitation and high grazing pressure contributed for poor range condition. The traditional land management which practiced mobility of herd and resting of key grazing areas is more appropriate for the management of arid and semi-arid environments as oppose to the concept of equilibrium (e.g. Illius and O'Connor, 1999; Briske *et al*., 2003) which is weakened recently and contributed for denudation of rangeland. The previous study in southern Ethiopia also reported the poor condition of rangeland (Dalle *et al*., 2006b; Angassa, 2007; Tefera *et al*., 2007).

3.4.5 Woody plant richness, diversity and evenness

The high woody plant richness in Surupha site resulted in severe encroachment and subsequently reduction of potential herbaceous production. This is partially due to woody plant competition for nutrient and moisture as well as influence of canopy effect. The other reason contributed for high woody plant richness at Surupha site compare to other grazing areas might be high rainfall and slope (Didita *et al*, 2010). For example, Desalegn and Zerihun (2005) reported a similar result in southern Ethiopia, suggesting that high woody species richness was associated with high rainfall and altitude. Animal factor can play a significant role in Borana rangeland in terms of changes in vegetation structure and composition as a result of preference of grazing/browsing, which encourage some species to increase in abundance and/or others decrease and this is in line with the work report of (Yates *et al*., 2000). In addition, abiotic factor specifically moisture constraints are the main causes for variation in vegetation growth and composition in semi-arid areas of Borana which agree with work reported by (Alemayhu, 2004). In contrast to our findings, in southern Ethiopia Dalle (2004) has reported a negative correlation between altitude and woody plant richness. Regarding woody plant diversity and evenness our study findings showed no variation across the sites which in line with the report of Takele (2006) in Gamo Gofa Ethiopia and Dirbaba (2008) in southern Ethiopia. Correspondingly, Mohammad and Bekele (2009) have found homogeneity of woody species diversity and evenness in the rift valley of Ethiopia.

Overall the high richness of woody plant in Borana rangeland which leads to encroachment of woody plant contributed to the decline in perennial grass species which markedly affects the productivity of rangeland and also an indicator of rangeland degradation.

3.4.6 Density of woody plant

Densities of woody plants were significantly varied across different sites of Borana. However, this variation is not consistent across all sites (eg. there were no variation in density of woody plants among government ranch, Surupha and Did-Hara communal grazing areas). Increase in woody plant density beyond a threshold is normally accompanied by a decrease in herbaceous biomass production due to succession of herbaceous plant as result of competition for available water, soil nutrients and light reaching to the grass layer (Thurrow, *et al*., 2000; Oba and Kotile, 2001; Dalle *et al.,* 2006a). The increase in woody plant cover is a major concern for conservation and savanna rangeland management, due to its adverse effect on rangeland carrying capacity and biodiversity (Van-Wijngaarden, 1985). In East African savanna ecosystems an increases in bush cover by 10% reduced grazing by 7%, while grazing is eliminated completely when the bush cover reaches 90% (Van-Wijngaarden, 1985). Similarly, Alemayehu (2004) reported that an increase in bush encroachment was a good indicator of the low range carrying capacity and degradation.

Overall for major rangelands of Borana the density of woody plants were crossed the threshold 1000 TE ha^{-1} (Bille and Assefa, 1984). The present study results showed that the average density of woody plants recorded in the Borana was 1742 TE ha^{-1} which was higher than the threshold. Several thought explored the density of woody plants with a 2,400 TE ha^{-1} considered as a border line between non-encroached and encroached condition (Roques *et al.,* 2001) and 2,500 TE ha^{-1} is considered as a highly encroached site (Richter *et al.,* 2001). When the density of woody plants exceeds beyond threshold level, the production of herbaceous biomass and grazing capacity of the rangeland would decline mainly due to heavy grazing pressure, created severe competition for available soil water (Smit and Rethmann, 1998; Oba *et al*., 2000b; Augustine and McNaughton, 2004; Tefera *et al*., 2007). The woody plant encroachment in Borana rangeland aggravates the worse situation in Borana unless its expansion is halted in urgent and integrated control measures should be in place.

3.4.7 Correlation of herbaceous, woody plants and soil variables

This study used both descriptive and quantitative methods mostly quantitative analysis using PC-ordination techniques. The present findings explored that the density of woody plants was negatively correlated with the relative density of herbaceous species. This implies that as density of woody plants increased the relative density of herbaceous plants were declined. The environmental variables (soil, precipitation, and altitude) accounted for the changes of woody and herbaceous species composition of the different sites. Dalle (2004) also reported these factors are played the major role in variation of vegetation dynamics. In contrast, the present finding differ from the result reported by Woldu and Nemomesa (1998), who presented no clear influences of environmental factors on plant composition in the central part of Ethiopia. The current findings showed that woody plants areas were generally adapted to sandy soil. In contrast, silt and clay soils were dominated by herbaceous plants. The reason for high density of woody plants in sandy soils might be due to leaching of soil nutrient and run off that could accelerate the pH of a soil in which herbaceous plants could not tolerable. On the other hand, silt and clay soil were less exposed to run off as compared to sandy soil and as a consequences might be rich in soil nutrients favouring herbaceous plant species to grow well in such environment.

Generally, it seems that environmental variables are not homogenous across the study areas in terms of nutrient richness resulting in varied types of plant communities in a given area depending on species ability to adapt. The current study finding showed that topographic variable; the extent of calcium, organic matter and soil texture might be the most important environmental variables limiting the distribution of vegetation across a wider geographical region. Others (e.g.Woldu and Nemomesa, 1998; Dalle, 2004) have reported a similar result suggesting that topographic variation is a major environmental factor in determining the structure and composition of vegetation. On the other hand, the present findings demonstrated that with increased altitude the extent of sandy soils was increased while, silt soil texture and soil nutrient status showed a decline trend as altitude increases which was also reported by (Woldu and Nemomesa, 1998). The high fertility of soil at lower altitude might be due to the effect of soil erosion and leaching from higher altitude. Some, woody plants were commonly found in association with high proportion of clay soils. *Acacia drepanolobium* and, *Acacia bussei were* dominant on vertisols in the bottomlands, which concurs with previous results (Haugen, 1992; Woldu and Nemomesa, 1998).

Furthermore, the result of this study found that some herbaceous species were positively correlated with high proportion of clay soils. Similarly previous scholars (Dalle, 2004*;* Woldu and Nemomesa, 1998*)* have also reported herbaceous species are adapted to nutrients-rich soils*.* The results of the study showed that the distribution of *Themeda triandra* and *Panicum maximum* was highly associated with the presence of sandy soils at higher elevations. In contrast to the report by Woldu and Nemomesa (1998), the study found that the occurrence of *Aristida adoensis* was more common at highest altitudes.

Overall as reported by Herlocker (1999) vegetation is a function of rainfall and soil in the arid and semi-arid regions. Losses of soil organic matter and increases in soil compaction could affect vegetation composition that can be reflected on the condition of rangelands. Therefore, any fundamental problems associated with moisture, grazing pressure and land-use management need to be corrected for healthy ecosystem function and sustainable livelihood of the pastoral communities.

3.5 CONCLUSIONS

In this particular study, a total of 23 herbaceous species, 46 woody species, 21 shrubs and 14 forbs species were identified. *Chrysopogon aucheri*, *Cenchrus ciliaris* and *Eragrostis papposa* were recorded as the most frequently occurring herbaceous species. Similarly *Acacia tortilis, Lannea rivae, Grewia tembensis, Commiphora habessinica, Rhus ruspoli, Acacia nilotica, Commiphora Africana* and *Acacia drepanolobium* were the frequently occurred woody species. Generally, vegetation compositions were highly influenced by the availability of rainfall, topographic variation, edaphic factor, soil nutrients and moisture, grazing pressure and management aspects.

The richness of vegetation varied across the different site of Borana but there was no variation in vegetation diversity and evenness. Nevertheless, richness was positively correlated with the diversity of species, however, negatively correlated with evenness. On other hand there were significant differences in the dry matter production among different sites of Borana. There were no distinct variation in dry matter production between ranch management and communal grazing system. Grass species that belongs to the ecological categories of decreasers produced the highest proportion of dry matter (59%). But ecological classes of increaser produced low dry matter in the study area (41%). Overall the encroachments of woody plants in the Borana rangeland were in the ranges of moderate to severe encroachment. In response to these and other driving forces, the rangeland condition was in the category of very poor to fair. The critical challenges in semi-arid rangelands are the spatial and seasonal variability of rangeland production. The concept of adaptive rangeland management looks appealing and should be researched to be exercised at the grass root level.

CHAPTER 4

ASSESSMENT OF THE IMPACT OF A MINERAL LICK CENTRED LAND-USE SYSTEM ON CHANGE OF VEGETATION COVER IN THE BORANA

Abstract

This study was conducted in the semi-arid rangelands of southern Ethiopia to evaluate changes in vegetation composition around a mineral salt crater. The diversity and density of herbaceous and woody species were assessed along a transect at 0, 1, 4, 6, 9 and 12 km from the salt crater. Ordination techniques were used for correlation of measured herbaceous and woody parameters into environmental variables. 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. Six woody plant families were identified of which Fabaceae and Burseraceae were the dominant families. *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 density of woody plants differed significantly ($P < 0.01$) along the distance gradient from the salt crater. Diversity, richness and evenness of herbaceous species did not show any significant variations along the 12 km distant gradient from the salt cater. However, species richness, diversity and evenness of woody plants varied significantly ($P < 0.05$) along the distance gradient from the salt crater. The high densities of *Lannea rivae*, *Acacia tortolis* and *Commiphora* species nearby the crater was correlated positively with sodium and high pH. The low pH and high proportion of sandy soils further away from the crater favoured the dominancy of *Acacia drepanolobium* and *Acacia nilotica*. Among the identified woody species, *A. drepanolobium, Commiphora africana and Acacia mellifera* were the most encroaching. Generally, a high proportion of seedlings and saplings was recorded indicating vigorous recruitment of the woody plants in the area. The status of woody plant encroachment along the 12 km transect ranged from low to heavily encroached areas. Around the sacrifice zone there was severe encroachment, which translated into poor rangeland condition for the area. The results showed a high proportion of increaser species leading to the poor to fair rangeland condition. The ecological index values were 574 and 349 for the main and short rainy seasons, respectively, and the corresponding WPC values were 44.7 and 5%, respectively. The rangeland condition was therefore classified as poor to fair. It is suggested that a combination of bush clearing and thinning and reduction of grazing pressure in the heavily bush encroached areas be implemented.

Key words: Herbaceous yield, patches resource, rangeland condition, recruitment of woody plant, bush encroachment.

4.1 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 its 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 favoured tolerant woody plant expansion in the Borana rangelands (Tefera *et al*., 2007; Angassa and Oba, 2008a). 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). The increase in woody cover in previously grass dominated rangelands is considered to be an ecological threat to both biodiversity and livestock production (Coppock, 1994). According to White (1980), woody cover in excess of 30% causes a decline in range condition. The overall shifts in the ecological balance of the savanna vegetation with the thickening of woody plant cover are a major cause of the loss of herbaceous vegetation in dry savanna ecosystems (Oba *et al*., 2000b). These vegetation changes have been exacerbated by increased sedentary human settlement in the Borana rangelands.

The current study focused on the vegetation changes along a distance gradient from the Mana-Soda salt crater. Mana-Soda is a crater from a volcanic eruption (VHP WWW Team, 2000) and is one of the four sources of mineral salt in Borana. These sources of salt have been used for both livestock and humans for centuries (Takele, 2006).This usage was governed by strong traditional institutions, e.g. the *Gada* system. In addition, to the dwellers of the Mana-Soda area, several pastoralists from other places (distance up to 100 km) come to the salt crater to feed mineral salt to their animals for about two months twice a year, during the main and short rainy seasons. Recently, these areas have seen an increase in permanent settlers and encroachment of crop cultivation. This peri-urban expansion around such resources is contrary to the traditional rangeland management systems. The natural ecological pressure on patch resources, increased livestock and human population, sedentary settlement, and the general breakdown of traditional institutions have put immense pressure on Mana-Soda and its environs. The broad objective was to study the impact of these changing dynamics on the vegetation around Mana-Soda. The specific objectives were to (a) investigate the composition of herbaceous and woody 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.

4.2 MATERIALS AND METHODS

4.2.1 Description of the study area

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. A general description of the study area was briefly presented in Chapter 1 section 1.6.1. The specific study site was Mana-Soda *(GPS coordinates 37425415E and 0465012N*) in Dire district of the Borana zone, 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 both livestock and humans. It is also a tourist attraction, which might enable pastoralists to earn income.

The Mana-Soda area ranges in altitude from 1497 to 1511 masl. 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 between the wet and dry season grazing areas. They regulated the 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 region, Mana-Soda is central in location, easily accessible and is generally acknowledged to have the best quality mineral salt.

In recent years, Mana-Soda has seen an increase in the number of permanent village settlers and an expansion of cultivation. Significant numbers of people around Mana-Soda now engage in crop cultivation, mainly maize, haricot bean, sorghum, teff and wheat. These cropping activities are concentrated around the 'salt house' or crater, near to the permanent settlers' villages. There has been an increase in human and livestock population around Mana-Soda. Pastoralists from the neighbouring communities still come for the mineral salt. This has led to a mushrooming of peri-urban development, which has aggravated the conflict between grazer and crop farmers for key resource areas. Unfortunately, social mores and principles have been weakened and are no longer as functional as in previous times.

4.2.2 Data collection

4.2.2.1 Sampling of herbaceous plants

Data was collected during three seasons: (i) mid main rainy season (March-April 2010); (ii) end of main rainy season (July-August 2010) and (iii) short rainy season (October - December 2010). A 12 km transect established from the edge of Mana-Soda salt crater was used for sampling. Main sampling plots of 20 m x 50 m size were fixed along the established transect at 0, 1, 4, 6, 9 and 12 km from the edge of the crater. Herbaceous samples were collected from five 0.5 x 0.5 m ($0.25m^2$) randomly placed quadrats. Live herbaceous plants in each quadrat were identified, counted, clipped and weighed for fresh biomass. The clipped material was dried to constant weight in an oven at 105°C for 24 hours. The various species were grouped into ecological groups of decreasers, increasers and invaders as described by Tainton (1999). Woody plants were recorded in three 10 m x10 m sampling quadrats, in each of the main sampling plots. These were categorized into three classes: (1) seedling (0 - 0.5 m), sapling (> 0.5 - 2 m) and matured (> 2 m). The tree data was standardized to tree equivalent ha^{-1} (1 TE = 1 tree 1.5 m tall) following

Teague *et al.* (1981). Herbaceous and woody species identification was done in the field by using an experienced practitioner using CADU (1974) guidelines. Pastoralists' indigenous knowledge was also valuable in detailing the ecological characteristics of the herbaceous plants and encroached woody plants.

4.2.2.2 Soil sampling

Soil samples were also collected from each main plot at different depths: 0 (surface), > 0- 10 cm, >10-20 cm, and >20-30 cm. (For detail soil physical and chemical properties analysis see Chapter 3 section 3.2.2.2).

4. 2.3 Data analysis

4.2.3.1 Herbaceous and woody plant diversity analysis

The Shannon-Wiener Index method was used to determine species diversity; richness and evenness (see the detail in Chapter 3 section 3.2.3.1). The principal Component Analysis (PCA) was performed to analyze the patterns of distribution of herbaceous and woody species in relation to environmental variables.

4.2.3.2 Rangeland condition analysis

Range condition was estimated using the ecological index (Vorster, 1982) and weighted palatability composition methods (Barnes *et al.*, 1984) see the detail in Chapter 3 section 3.2.3.3.

4.2.3.3 Statistical analysis

The analysis of variance (ANOVA) was used to examine the seasonal variation of herbaceous and woody species density, richness and diversity along the distance gradient from the salt crater. The relationships between the distance from the salt crater (independent variable) and the density of herbaceous mass and woody plants (dependent variable) were analysed using correlation and linear regression. All statistical analysis was done using SAS procedures (SAS, 2009).

4.3 RESULTS

4.3.1 Composition of herbaceous

A total of 16 grass species, two forbs and one sedge species were identified in the Mana-Soda area (Figure 4.1). *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 species* had moderate occurrence in the area. In contrast, *Sporobolus pyramidalis, Heteropogon 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 4.1). *Commelina africana* had also of a very low density in the area.

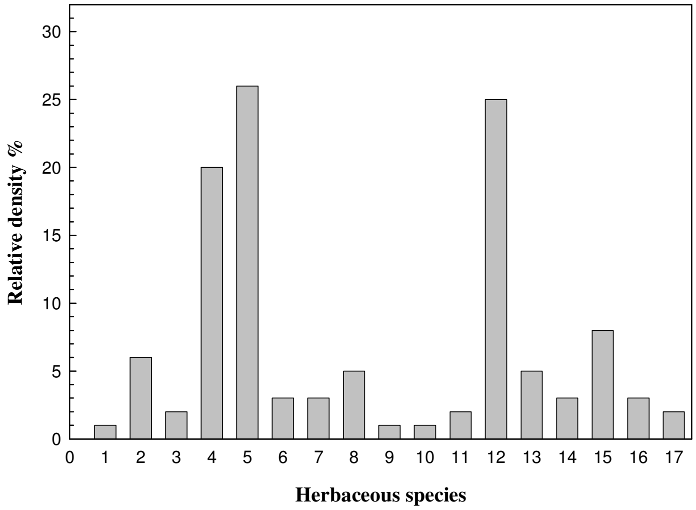

Figure 4.1 Relative density of herbaceous plants around the Mana-Soda salt area

Key: 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

The two dominant grass species *C. aucher*i and *C. ciliaris* were acknowledged by the local people as species with good palatability aspect. Locally, they call them “*Motii Merga*”, which means ‘queen of grasses’. Despite their relatively high abundance, pastoralists noted that these species were declining in density over the years. *Themeda 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 4.2. In general, species richness was low nearby (< 3 km) the crater but increased at distances beyond 3 km. As shown in Figure 4.2 P. *maximum* and *T. Triandra* were the most prevalent species at 12 km from the salt crater. *Chrysopogon 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.

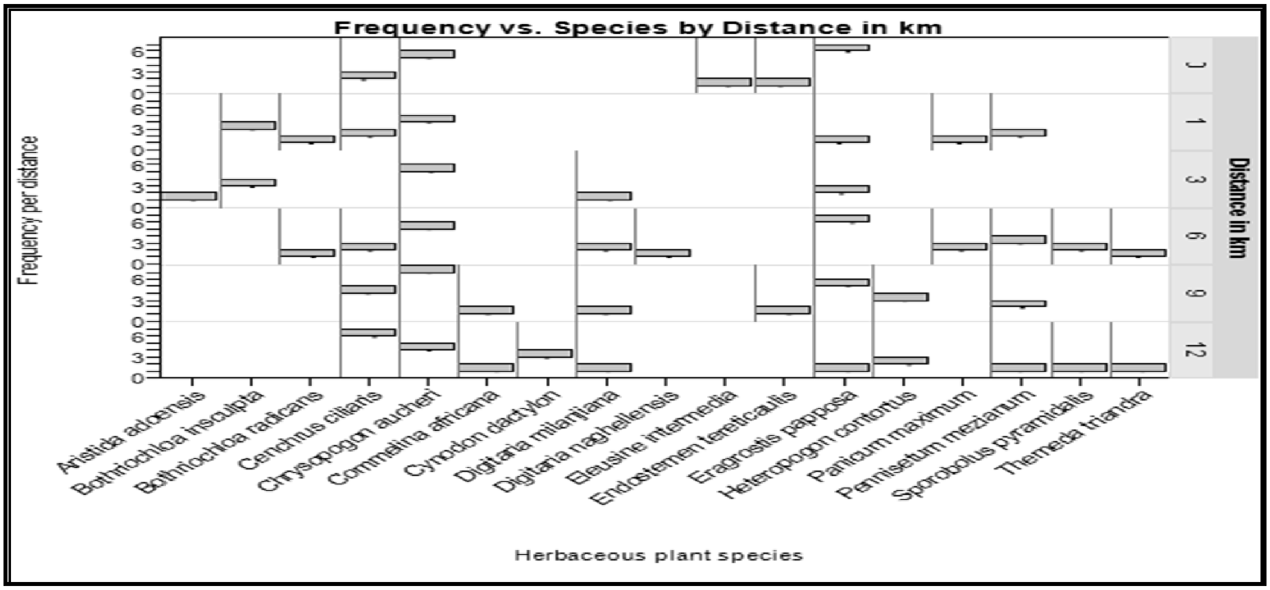

Figure 4.2 Frequency of herbaceous plant species in relation to distance from the salt crater

Using the Shannon-Weiner index, species richness was not significantly different (P>0.05) along the distance gradient, from the salt crater (i.e. within a distance 0 km to 12 km), but was generally higher in the main than the short rainy season (Table 4.1). Herbaceous plants were more even in the short than the main rainy season. Species richness was positively correlated (r=0.80) with diversity (but weak and negatively correlated with evenness). As richness increased diversity also increased and could be estimated using the regression equation Y=0.514+0.141x. In general species diversity in Mana-Soda was low and a few species were dominant.

Table 4.1 Diversity of herbaceous plants a long distance gradient in Mana-Soda area of the Borana, southern Ethiopia

Distance	Richness			Diversity			Evenness		
(km)	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
4	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
Significance			NS[c]			NS[c]			NS[c]

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

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 (Figure 4.3 and 4.4). 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. *Aristida adoensis* had the highest relative density at the 4 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.

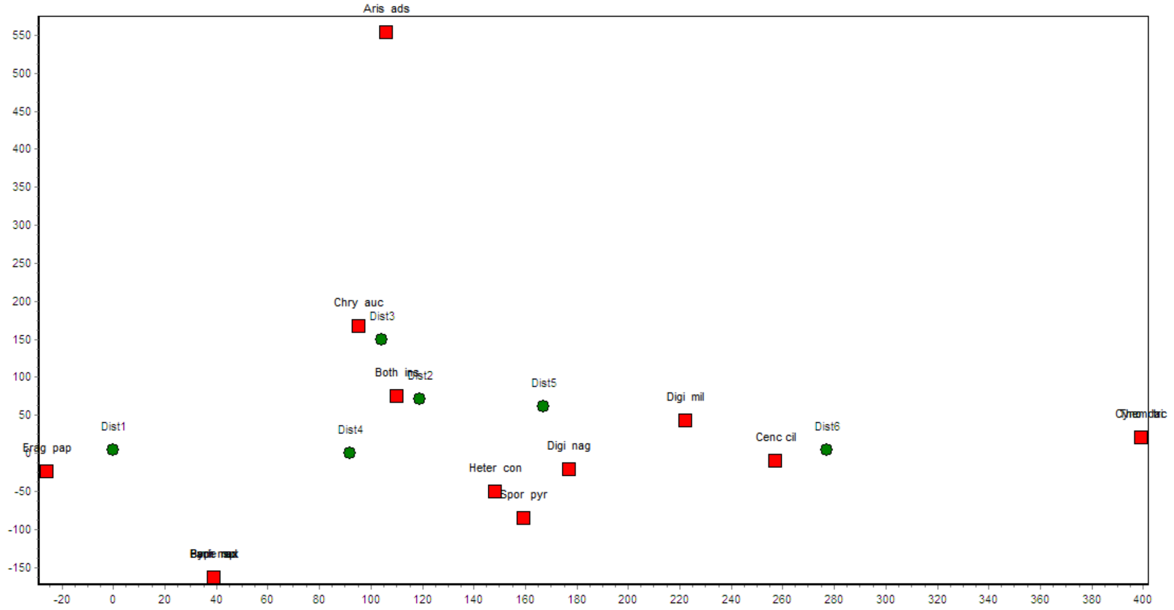

Figure 4.3 DCA ordination plots of herbaceous plant species along the distance gradient from the salt crater

Key: Dist1= 0km, dist2= 1km, dist3 =4km, dis4= 6km, dis5= 9km, dis6 =12km from salt, crater. *Chry au: Chrysopogon aucheri, Aris: Aristida adoensis, Digi mi :Digitaria milanjiana, Both in: Bothriochola insculpta, Digi sp: Digitaria spp, Spor py, Sporobolus pyramidalis, Pani Ma: Panicum maximu, Cype sp: Cyperus spp., Both ra: Bothriochola radican, Digi na :Digitaria Naghellensis, Heter c : Heteropogon contortus, Cenc cil : Cenchrus ciliaris, Penn mez : Pennisetum mezianum, Erag Pa :Eragrostis papposa, Them tr :Themeda triandra, Cyno dac : Cynodon dactylon*

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 the 9 km, *T. triandra* and *C. dactyl*on were dominant at the 12 km zone. Overall, *C. aucheri* and *C. ciliaris* were the two species that had high relative densities across 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.

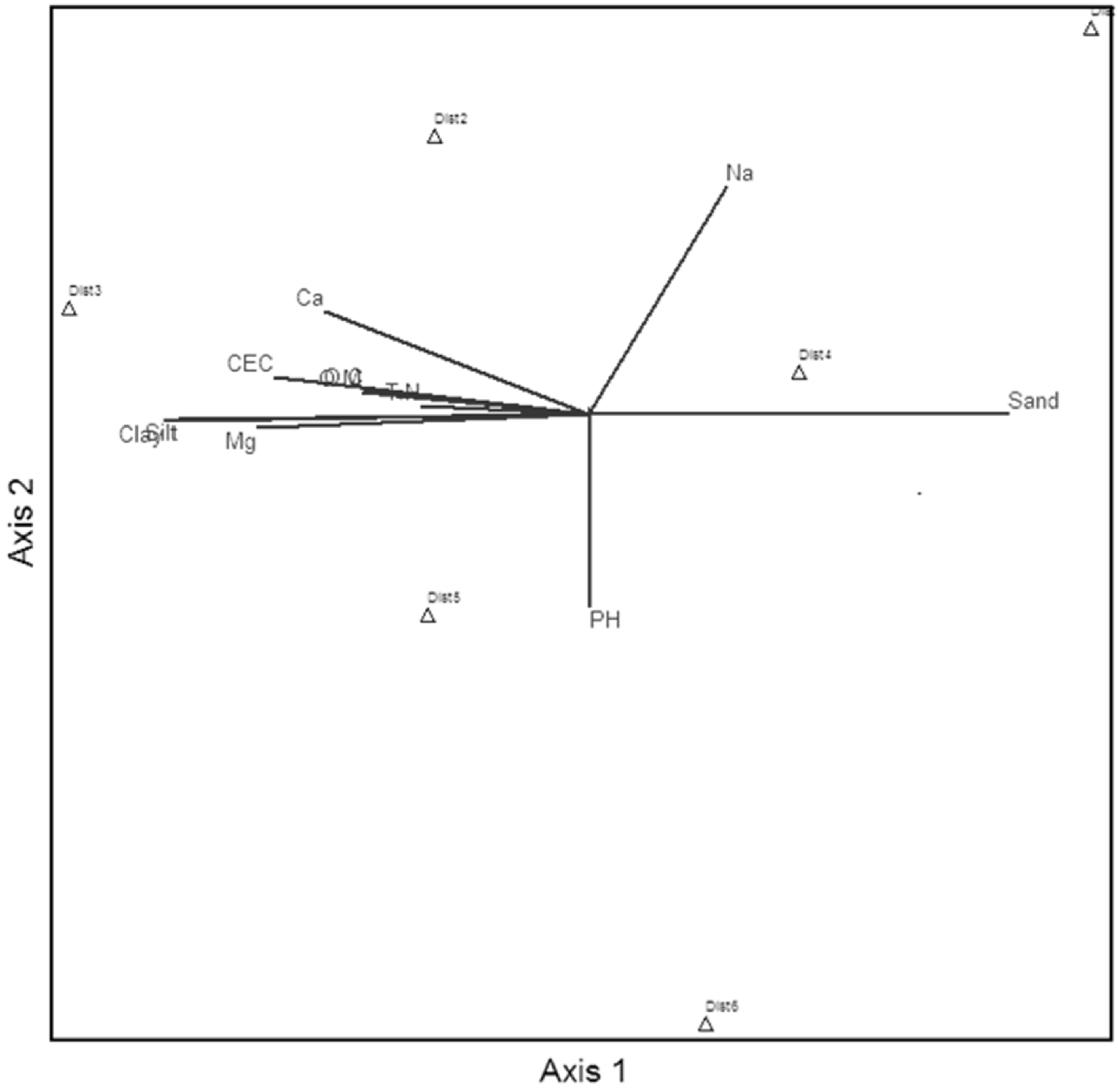

Figure 4.4 PCA ordination diagram of environmental variables with distance from the salt crater

Key: Dist1= 0km, dist2=1km, dist3 =4km, Dis4 =6km, dis5 =9km, dis6 =12km from the salt crater

4.3.2 Dry matter production of dominant herbaceous plants

The ecological classification of the dominant herbaceous plants sampled at Mana-Soda is presented in Table 4.2. The estimated total dry matter produced over the 12 km gradient was 8 340.34 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 were highly contributed to the dry matter production than the annual grasses. The contribution to the 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.

The dry matter production of the ‘highly desirable’ grasses increased from 291.2 to 1 799.2 kg ha^{-1} along the 0 -12 km distance gradient (Table 4.2). In this group, *C. aucheri* and *C. ciliaris* had the highest dry matter production followed by *E. papposa,* and *P. maximum,* while *T. triandra* contributed the least. The dry matter production of the ‘intermediate desirable’ grass species was highest at the 6 and 9 km sampling distances, being 792.86 and 995.35kg ha^{-1}, respectively. Other than the considerable dry matter contribution of *B. insculpta* at 1 km and 4 km and *P. mezianum* at 6 km 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 30.4kg ha^{-1} at the 4 and 12 km site, respectively). The contribution from the rest of the species in this group was relatively insignificant in the main.

Table 4.2 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	4 Km	6 km	9 km	12 km	Total
Highly desirable									
Eragrostis papposa	*P*	*Dec*	82.8	20.6	124.92	48.92	84.132	49.56	410.932
Cenchrus ciliaris	*P*	*Dec*	45.6	93.8	86.8	236.5	258.72	58	779.42
Chrysopogon aucheri	*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
Themeda triandra	*P*	*Dec*						20.16	20.16
Sub total			**291.2**	**343**	**631.32**	**1052.93**	**971.66**	**1799.22**	**5089.33**
Intermediate desirable									
Digitaria milanjiana	*P*	*Inc I*			13.152	18.04	51.22	19.71	102.122
Digitaria naghellensis	*P*	*Inc I*				10.86	11.02		21.88
Sub total					**13.152**	**28.9**	**62.24**	**19.71**	**124.002**
Cynodon dactylon	*P*	*Inc IIa*	12.4			5	26.8	49.2	93.4
Heteropogon contortus	*P*	*Inc IIa*	64.48			8	49.6	169.6	291.68
Sub total			76.88	0	0	13	76.4	218.8	385.08
Bothriochola insculpta	*P*	*Inc IIb*	23.1	210	260.48		72		565.58
Sporobolus pyramidalis	*P*	*Inc IIb*				9.96	4.11	11.36	25.43
Bothriochola radicans	*A*	*Inc IIb*				10.44			10.44
Pennisetum mezianum	*P*	*Inc IIb*		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*	*Inc IIc*					4		4
Eleusine intermedia	*P*	*Inc IIc*	17.12						17.12
Aristida adoensis	*P*	*Inc IIc*			3.2				3.2
Commelina africana	*A*	*Inc IIc*				19.2	5.44		24.64
Endostemen tereticaulis	*A*	*Inc IIc*			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: Perennial; [b] Ecoca= Ecological Categories: Dec=Decreaser; Inc = Increaser I; Inc IIa = Increaser IIa; Inc IIb = Increaser IIb; Inc IIc = Increaser IIc

The seasonal distribution of biomass produced along the distance gradient is presented in Figure 4.5. Generally, little biomass had accumulated across the gradient in the mid-main rainy season. At this stage, there were no significant (P>0.05) yield differences for the 1-12 km sampling zones, although on average these yielded higher than the sacrifice zone (0 km). There was a considerable biomass accumulation between the mid and end of the main rainy season. The proportionate contribution of annual grasses and forbs to the 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 2 289 kgha^{-1} (12 km). The 1-12 km zones yielded higher than the sacrifice zone.

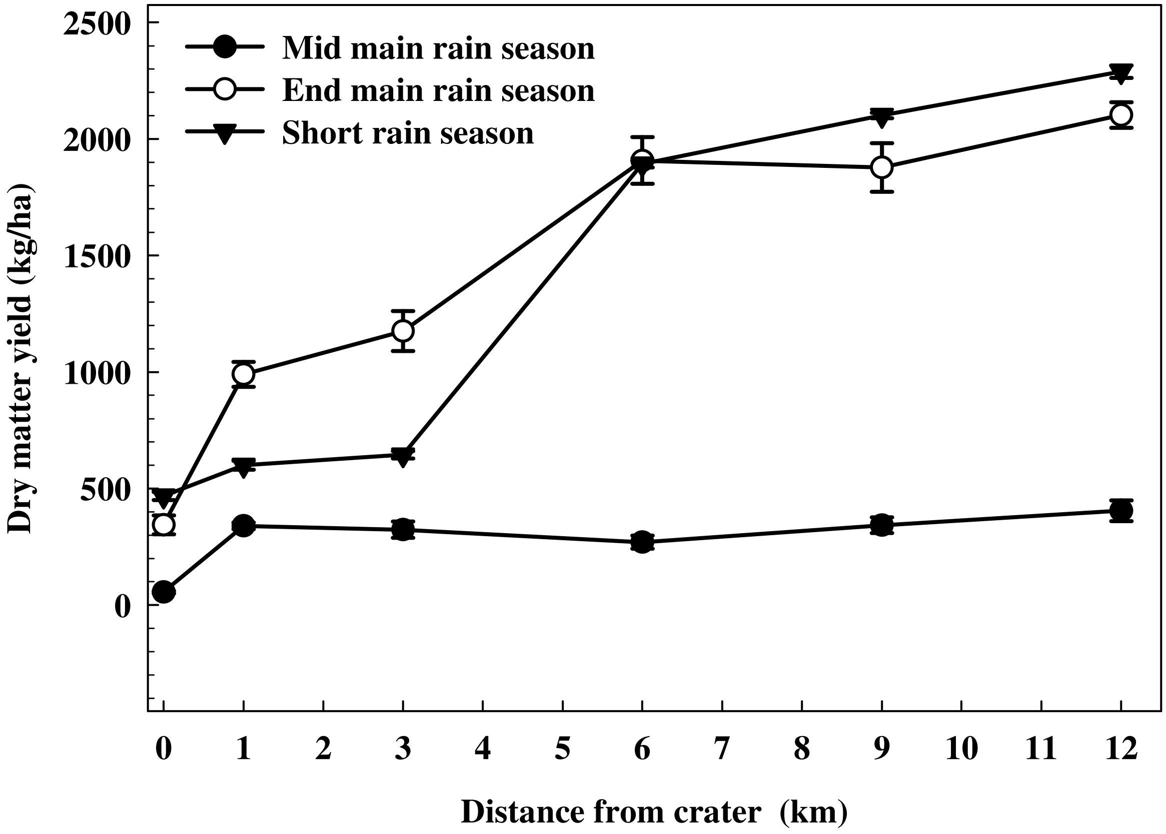

Figure 4.5 Seasonal dry matter productions along a distance gradient from the Mana-Soda salt crater. Bars extending beyond the means denote standard error of the mean.

The general ranking of the zones in terms of dry matter yield was 12 km > 9 and 6 > 4 and 1 during the main rainy season. The dry matter yields during the short rainy season also increased with increasing distance from the salt crater. However, significant yield differences were only recorded beyond the 4 km zone. From the 6-12 km zones the short rainy season had comparable yields to those of the main season.

4.3.3 Range condition

The ecological index and WPC values for the main and short rainy seasons were 574 and 349, respectively (Table 4.3). The calculated mean ecological index value for both seasons was 464, giving a fair condition score for the rangeland. The WPC values for the main and short rainy season were 44.7 and 5%, respectively. Using the WPC the rangeland condition was classified as poor in the short rainy season and fair in the main rainy season. 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. Overall, the proportion of increaser species was high around Mana-Soda and that of decreasers low.

Table 4.3 Rangeland condition of Mana Soda salt areas in Borana, southern Ethiopia

Main rain season				Short rain season			
Scientific name	Class	WPC[a]	EI[b]	Scientific name	Class	WPCM	EIM
Eragrostis papposa	Decreaser	30	100	*Eragrostis papposa*		27	90
Endostemen tereticaulis	Increaser IIb	9	36				
Cenchrus ciliaris	Decreaser	33	110	*Cenchrus ciliaris*	Decreaser	6	20
Chrysopogon aucheri	Decreaser	39	130	*Chrysopogon aucheri*	Decreaser	51	170
Bothriochloa insculpta	Increaser IIb	18	36	*Panicum maximum*	Decreaser	6	20
Commelina africana	Increaser IIb	8	16	*Commelina africana*	Increaser IIb	4	8
Digitaria milanjiana	Increaser I	10	20				
Aristida adoensis	Increaser IIc	2	2				
Sporobolus pyramidalis	Increaser IIb	10	20				
Bothriochloa radicans	Increaser IIb	4	8				
Digitaria naghellensis	Increaser I	6	14				
Heteropogon contortus	Increaser IIa	4	8	*Heteropogon contortus*	Increaser IIa	4	8
Panicum maximum	Decreaser	6	20	*Panicum maximum*	Decreaser	6	20
Cyperus sp.	Increaser IIc	4	4				
Themeda triandra	Decreaser	6	20				
Cynodon dactylon	Increaser IIa	4	8	*Cynodon dactylon*	Increaser IIa	6	21
Eleusine intermedia	Increaser IIc	2	2				
Digitaria Sp	Increase IIb	4	8				
Pennisetum mezianum	*Increaser IIb*	6	12	*Pennisetum mezianum*	Increaser IIb	6	12
Point score value		205	574	Point score value		110	349
WPC		44.7		WPC		5	

[a] Weighted palatability composition; [b] Ecological index

4.3.4 Density, composition and diversity of woody plant

A total of 20 woody species from eight families were identified in the Mana-Soda area (Table 4.4). The majority of the species belonged to Fabaceae and Burseraceae families. The family Tiliaceae occurred moderately in the study area. Rosaceae, Capparidaceae and Euphorbiacea species had low occurrence. Fabaceae species were distributed widely across the distance gradient and Burseraceae species were dominant close to the salt crater. At distances close (<3 km) to the salt crater *Lannea rivae, Commiphora africana* and *Acacia tortilis* had the highest density compared to the other woody species. However, density of *L. rivae* declined with distance away from the sacrifice zone. Overall, *A. drepanolobium* had the highest relative abundance, followed by *Commiphora africana*, *Acacia mellifera*, *L. rivae Acacia nilotica* and *A. tortilis* (Table 4.4). *Commiphora habessinica, Commiphora fluviflora, Balanites rotundifolia, Euphorbia cuneata, Acacia bussei,* and *Grewia tembensis* were of moderate density. The lowest relative densities were recorded for *Acacia seyal, Grewia villosa* and *Boswellia negelecta.*

Table 4.4 Density of woody plants along distance gradient in Mana-Soda, Borana, southern Ethiopia

Type of woody	Family	Density (plant ha^{-1})	Relative density (%)
Distance (0 km)			
Acacia etabaica	Fabaceae	33	1.24
Acacia mellifera	Fabaceae	133	5.00
Acacia nilotica	Fabaceae	33	1.25
Acacia tortilis	Fabaceae	433	16.26
Boswellia neglecta	Burseraceae	33	1.25
Commiphora africana	Burseraceae	500	18.76
Commiphora erythra	Burseraceae	66	2.48
Commiphora habessinica	Burseraceae	200	7.50
Commiphora Sp.	Burseraceae	233	8.76
Grewia bicolor	Tiliaceae	67	2.50
Grewia tembensis	Tiliaceae	133	4.99
Grewia villosa	Tiliaceae	33	1.25
Lannea rivae	Anacardiaceae	767	28.77
Distance (1 km)			
Acacia drepanolobium	Fabaceae	2200	61.11
Acacia mellifera	Fabaceae	700	19.44
Acacia nilotica	Fabaceae	100	2.78
Balanites rotundifolia	Balanitaceae	100	2.78
Commifora fluviflora	Burseraceae	33	0.93
Commiphora africana	Burseraceae	67	1.85
Commiphora habessinica	Burseraceae	67	1.85
Commiphora Sp.	Burseraceae	200	5.56
Maerua triphylla	Capparidaceae	67	1.85
Rhus ruspoli	Rosaceae	67	1.86
Distance (4 Km)			
Acacia Bussei	Fabaceae	133	6.06
Acacia drepanolobium	Fabaceae	767	34.85
Acacia etabaica	Fabaceae	33	1.52
Acacia nilotica	Fabaceae	67	3.03
Acacia tortilis	Fabaceae	33	1.52
Balanites rotundifolia	Balanitaceae	100	4.55
Commifora fluviflora	Burseraceae	167	7.58
Commiphora africana	Burseraceae	567	25.76
Commiphora habessinica	Burseraceae	100	4.55
Euphorbia cuneata	Euphorbiaceae	167	7.58
Lannea rivae	Anacardiaceae	67	3.03
Distance (6 km)			
Acacia drepanolobium	Fabaceae	533	76.19
Acacia mellifera	Fabaceae	67	9.52
Acacia seyal	Fabaceae	33	4.76
Acacia tortilis	Fabaceae	33	4.76
Commifora fluviflora	Burseraceae	33	4.76
Distance (9 km)			
Acacia nilotica	Fabaceae	33	4.00
Acacia drepanolobium	Fabaceae	800	96.04
Distance (12 km)			
Acacia nilotica	Fabaceae	333	25.01
Acacia drepanolobium	Fabaceae	967	72.52
Acacia tortilis	Fabaceae	33	2.50

Overall, 49.07% of the woody cover was found nearby (< 4 km) the crater. Only 7.3% of the total woody was found far away from the crater centre. The woody plant densities declined significantly ($P < 0.05$) across the distance gradient from the salt crater (Table 4.5). In general, woody plant density was negatively correlated (r = -0.72) with the distance from the salt crater. The richness of woody plants was significantly high ($P < 0.01$) close to the salt crater compared to the distant sampling zones. The richness along the distance from 0 to 4 km did not show significant variation. The highest woody plant richness was recorded at 0 and 1 km (Table 4.5). A sharp decline in richness was observed after 4 km from the salt crater. Similarly, diversity of woody plants increased significantly ($P < 0.01$) near the sacrifice zone and this declined sharply from 6 km onwards. Correspondingly, the woody plant species evenness differed significantly (P < 0.01) along the distant gradient from the salt crater (Table 4.5).

Table 4.5 Woody plant density and diversity along a distance gradient from Mana-Soda salt crater in Borana, Southern Ethiopia

Distance (km)	Density (TE ha^{-1})	Diversity	Richness	Evenness
0	1944.44^{a}	1.07^{a}	3.56^{a}	0.91^{a}
1	1366.67^{b}	0.74^{ab}	2.78^{ab}	0.65^{a}
4	977.78^{c}	0.69^{ab}	2.33^{ab}	0.67^{a}
6	577.56^{d}	0.46^{bc}	1.67^{bc}	0.64^{a}
9	411. 11d^{e}	0.00^{d}	0.78^{c}	0.00^{b}
12	277.78^{e}	0.15^{d}	1.00^{c}	0.20^{b}
LSD $_{(0.05)}$	235.63	0.49	1.45	0.44

Means in a column with same letter are not significantly different ($P > 0.05$).

4.3.5 Age-class composition and seasonal recruitment of woody plants

The bimodal rainfall pattern of the study site is presented in Figure 4.6. The main rainy season (March-May) was flanked by the short rainy seasons of two different years (September-November, 2009 and September-November, 2010). Throughout 2010, the study area received 559 mm of rainfall. Fifty percent (282 mm) was received in the main rainy season, while 30% (169 mm) was received in the short rainy season. The mean monthly temperature in 2010 ranged from 22.6°C in July to 29.2°C in February. The rainfall and temperature figures fall within the long-term averages reported for the area (Angassa and Oba 2007; CSA, 2010).

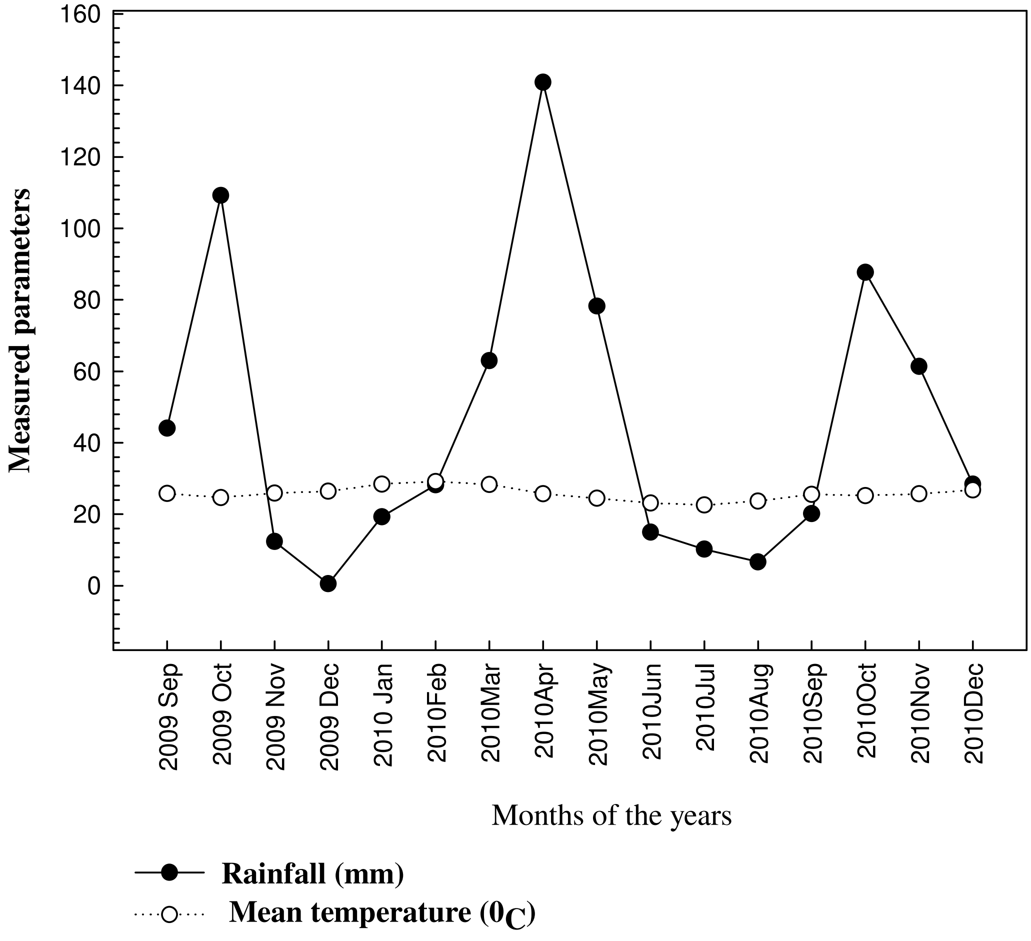

Figure 4.6 Seasonal variability of rainfall and temperature at Mana-Soda, 2009 to 2010

The age-class composition of woody plants around the salt crater varied along the distance gradient (Figure 4.7). At each of the sampling distances, except at 12 km, saplings constituted the highest proportion of the woody plants. This was followed by the seedlings and then mature trees. At 12 km the proportions ranked seedlings > saplings > mature trees. Overall, the density of mature woody plants was low compared to the other age classes, which indicated a rather aggressive establishment of woody plants in the study area (Figure 4.7).

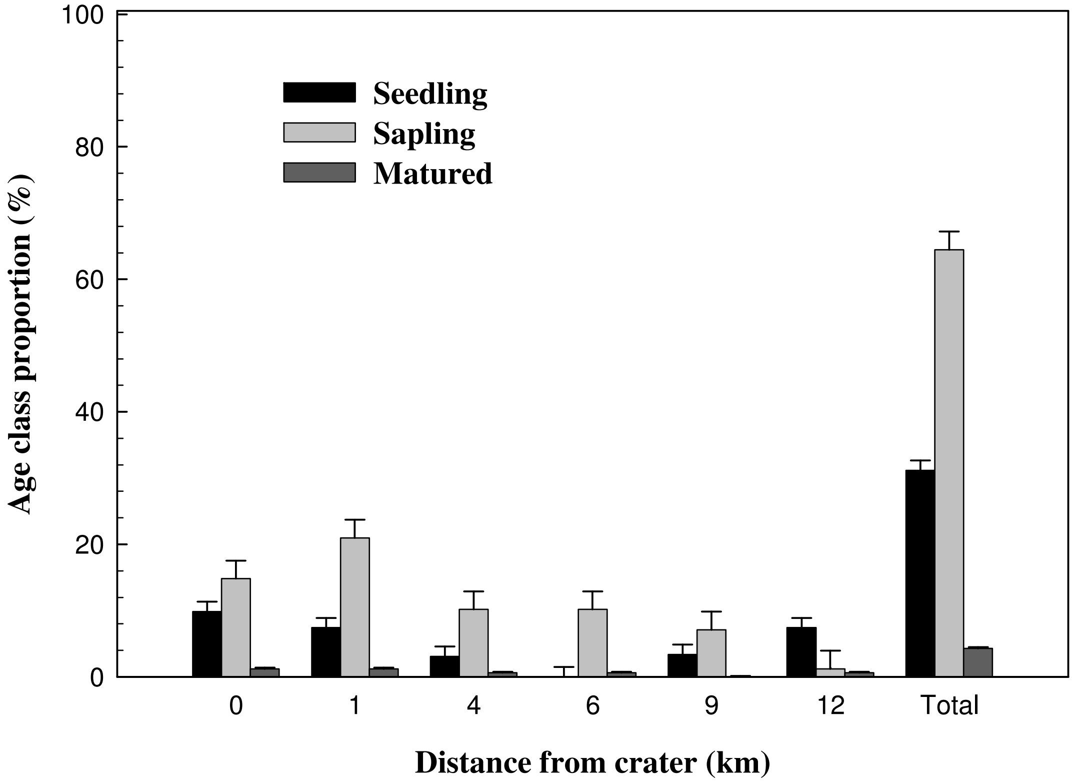

Figure 4.7 Age-class composition of woody plants along a distance gradient around Mana-Soda salt crater

The seasonal distribution of seedlings and saplings is presented in Figure 4.8. The recruitment of seedlings was large at the end of the main and short rainy seasons. This recruitment was more evident for 0-6 km from the crater. Beyond 6 km, there were no differences in recruitment among seasons. The number of saplings counted also varied with season and distance from the salt crater. In general, the highest number of saplings was recorded in the short rainy season, followed by the mid-rain season. This general ranking was maintained across all sampling distances but with high sapling counts nearby the salt crater. The density of mature trees did not differ ($P > 0.05$) along the distance gradient for all seasons.

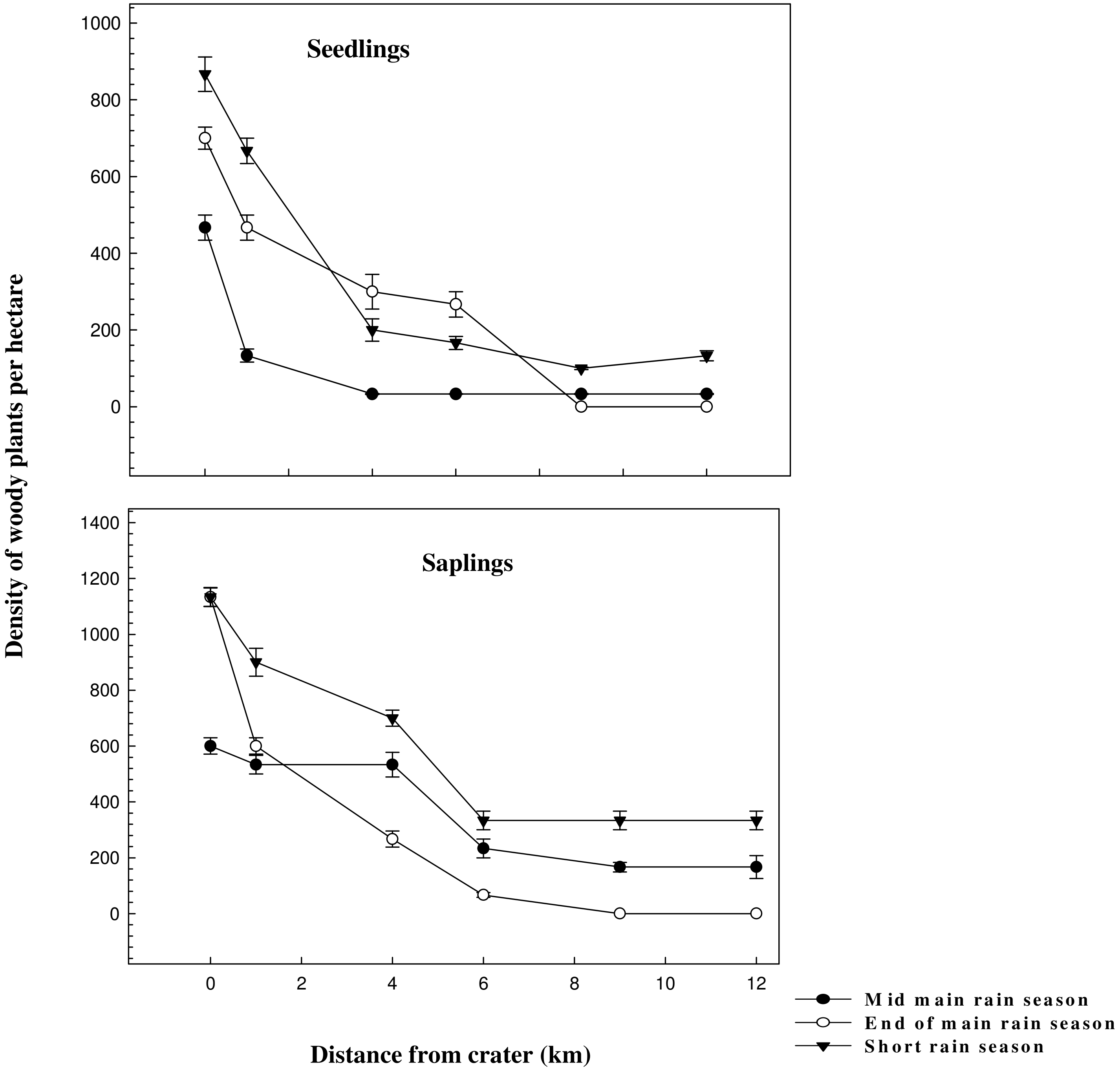

Figure 4.8 Seasonal recruitment of woody plants along a distance gradient from the Mana-Soda salt crater

The relationship between the woody species and biophysical environment were explored using PCA. In general, the soils closest to the crater were sandy loams with high levels of Na^+, Ca^{2+} and CEC (Table 4.6). The middle distance zones were characterised by loam and sandy loam soils. The 9 and 12 km zones have sandy clay loams. The pH was generally alkaline but it decreased with distance from the crater. Total nitrogen content and nitrogen-carbon ratio did not show significant variation along the 12 km transect. However, soil organic carbon declined, while phosphorous content increased with increasing distance from the crater. The PCA diagram of the correlation of the density of woody plants along the distance gradient and the soil features is presented in Figure 4.9 read in conjunction with Table 4.6. There were positive associations of *L. rivae, A. tortilis* and *Commiphora spp.* and the high sodium levels around the sacrifice zone (Table 4.6). High densities of *C. habessinica, C. fluviflora* and *B. rotundifolia* were recorded at the middle distance zones which were characterised by relatively high organic matter, calcium, magnesium, total nitrogen and CEC (Table 4.6). *Acacia seyal* and *A. drepanolobium* showed a particular association with high potassium levels in the silt and sandy soils of the middle zones (Figure 4.9 and Table 4.6). Correspondingly, at 9 and 12 km *A. nilotica* and *A. mellifera* had high densities at sites with relatively low pH values.

Table 4.6 Variability of soil texture and nutrients along a distance gradient from Mana-Soda salt crater in Borana

Distance (km)	Soil texture	pH(meter)	Na^{+}	K^{+}	Ca^{+}	Mg^{+}	CEC^{+}	TN %	OC %	OM %	C:N ratio	P (mg kg^{-1})
			(Coml. kg^{-1})									
0	Sandy loam	8.20^{a}	0.14^{a}	0.45^{b}	$2\ 7.20^{a}$	7.60^{a}	31^{a}	0.20^{a}	1.80^{a}	3.10^{ab}	9.00^{a}	4.50^{b}
4	Loam	8.00^{ab}	0.07^{b}	0.80^{ab}	27.90^{a}	7.60^{a}	32^{a}	0.20^{a}	1.60^{ab}	3.40^{a}	9.70^{a}	4.70^{b}
6	Sandy loam	8.30^{a}	0.06^{b}	0.86^{ab}	27.70^{a}	6.20^{ab}	29^{ab}	0.30^{a}	1.20^{ab}	2.20^{bc}	7.30^{a}	4.60^{b}
9	Sandy clay loam	7.80^{b}	0.05^{b}	0.92^{ab}	25.70^{a}	5.60^{b}	27^{ab}	0.15^{a}	1.20^{ab}	2.20^{bc}	11.00^{a}	5.50^{b}
12	Sandy clay loam	7.70^{b}	0.06^{b}	1.10^{a}	18.00^{b}	5.50^{b}	20^{b}	0.13^{a}	1.10^{b}	1.90^{c}	8.30^{a}	8.90^{a}
LSD (0.05)		0.47	0.04	0.50	5.48	1.43	6.54	0.26	0.71	1.22	5.81	5.04

Means in a column with same letter are not significantly different ($P > 0.05$)

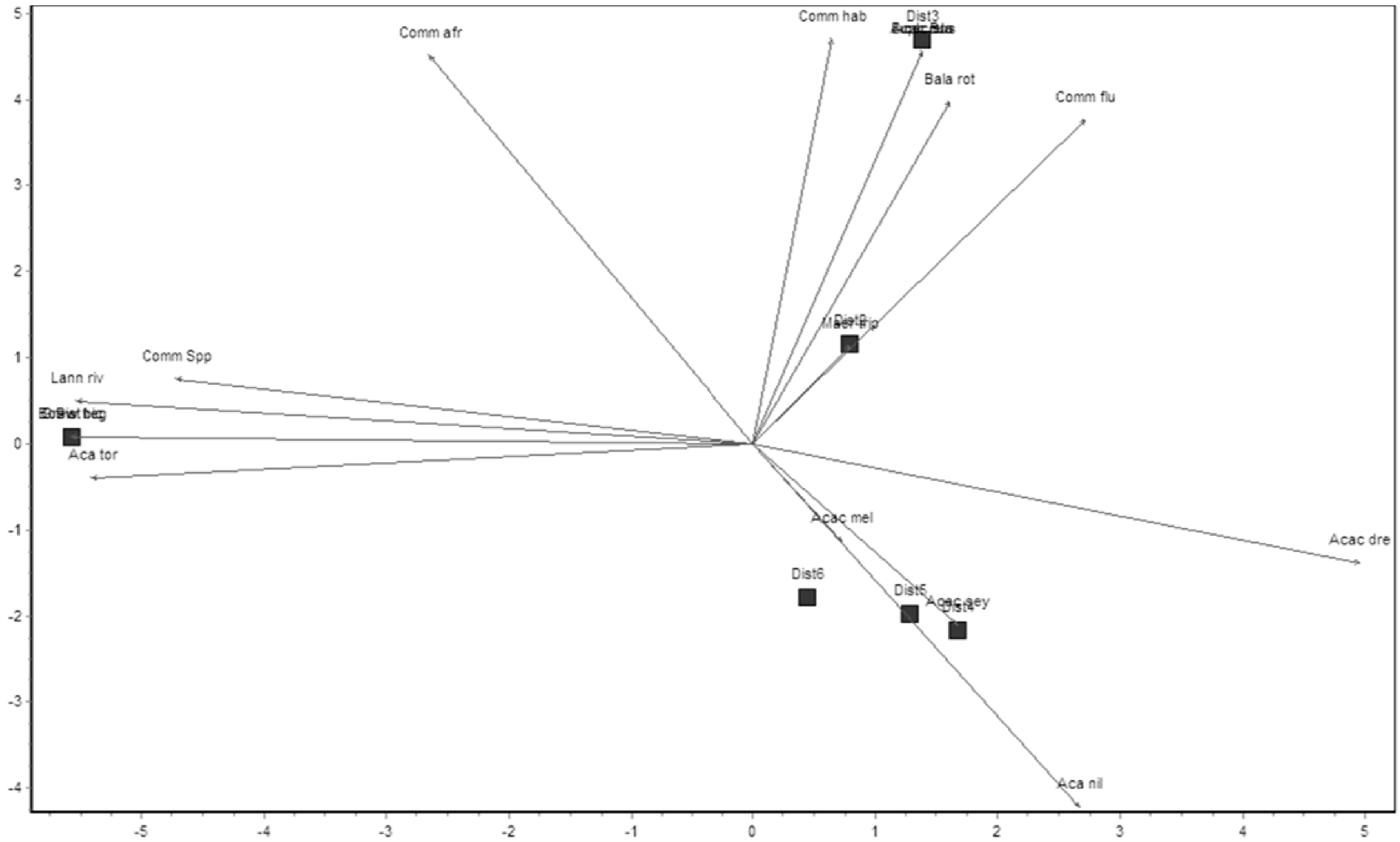

Figure 4.9 PCA plots of woody plants along a distance gradient from the Mana-Soda salt crater

Key: Dist1= 0, dist2= 1km, dist3= 4km,dist4=6km, dist5= 9km, dist6=12km, *Acac Bus: Acacia bussei, Acacia eta: Acacia etabaica, Bosw neg: Boswellia neglecta,Comm ery: Grew bic: Grewia bicolor, Lann riv : Lannea rivae, Comm afr: Commiphora Africana, Comm spp: Commiphora species, Acac dr : Acacia drepanolobium, Acac mel : Acacia mellifera, Bala rot : Balanites rotundifolia, Maer trip: Maerua triphylla , Aca ni: Acacia nilotica, Aca tor: Acacia tortilis, Comm flu: Commifora fluviflora , Comm hab : Commiphora habessinica, Euph cun: Euphorbia cuneata, Acac sey; Acacia seyal*

4.3.6 Woody plant encroachment

The total woody plant density ranged from 278 TE ha^{-1} (12 km) to 1 944 TE ha^{-1} (0 km; Tables 4.5 and 4.7) putting the study site under low to heavily encroached. There was variation in the proportions of individual species contributed to the overall density across the distance gradient. The density of *A. drepanolobium* was fairly constant across the distance gradient, with a total density of 1 659 TE ha^{-1} and it was the most heavily encroaching species (Table 4.7). With the density of 754 TE ha^{-1}, C. *africana* was the second highest encroaching woody species around Mana-Soda area. This was followed by *A. mellifera* with the density 750 TE ha^{-1}. These two less heavily encroaching species were mainly aggregated nearby the salt crater. *Lannea rivae* was a moderately encroaching species with a density of 687 TE ha^{-1}. Even for this species, the density was highest nearby the crater. The low encroachment status of *A. nilotica* (251 TE ha^{-1}); Commiphora spp. (284 TE ha^{-1}) and *A. tortilis* (417TE ha^{-1}) complete the list of encroaching woody species. Of these three species, *A. nilotica* was evenly distributed across the distance gradient while the other two were unevenly distributed and aggregated at distances closer to the salt crater. The rest of the species had insignificant levels of encroachment.

Table 4.7 The density and encroachment status of the main woody species along a distance gradient from the Mana-Soda salt crater in Borana, southern Ethiopia

Woody species	Density (TE ha^{-1}) across distance in (km)							Current status
	0	1	4	6	9	12	Total	
Acacia mellifera	114	585	0	50	0	0	750	LS*
Acacia nilotica	28	84	29	25	16	69	251	L
Acacia tortilis	372	0	14	25	0	7	417	L
Boswellia neglecta	28	0	0	0	0	0	28	I
Commiphora africana	429	56	244	32	0	0	754	LS
Commiphora habessinica	28	56	43	0	0	0	127	I
Commiphora Sp.	200	84	0	0	0	0	284	L
Grewia bicolor	58	0	0	0	0	0	58	I
Grewia villosa	28	0	0	0	0	0	28	I
Lannea rivae	658	0	29	0	0	0	687	M
Acacia drepanolobium	0	335	331	397	395	202	1659	S
Balanites rotundifolia	0	84	43	0	0	0	127	I
Commifora fluviflora	0	28	72	25	0	0	124	I
Maerua triphylla	0	56	0	0	0	0	56	I
Acacia Bussei	0	0	57	0	0	0	57	I
Acacia etabaica	0	0	14	0	0	0	14	I
Euphorbia cuneata	0	0	72	0	0	0	72	I
Lannea rivae	0	0	29	0	0	0	29	I
Acacia seyal	0	0	0	25	0	0	25	I
Total	1944	1367	978	577	411	278		
Current status	S	S	LS	M	L	L		
Range condition	VP[†]	VP	P	F	F	F		

*Key to level of encroachment: I= Insignificant (0-250 TE ha^{-1}); L= Low (>250-500 TE ha^{-1}; M= moderate (>500-750 TE ha^{-1}); LS= less severe (>750-1 000 TE ha^{-1}); S=Severe (>1 000 TE ha^{-1}),

[†] Range condition: VP = very poor (>90%) woody cover; P=poor (>60-90); F=fair (30-60%); G= good (10-30%); E= excellent (<10%)

The age-class distributions of the main encroaching woody species are presented in Figure 4.10. *Acacia drepanolobium* showed considerable seedling recruitment along the distance gradient. The number of saplings for this species was highest nearby (<4 km) the crater and declined steadily over the 12 km gradient. For *C. africana, A. mellifera, A. tortilis* and *L. rivae,* the seedlings and saplings were aggregated around the sacrifice zone. Although it had a low encroachment status, *A. nilotica* had the second widest spread (after *A. drepanolobium*) of seedlings and/or saplings across the distance gradient. Except for *A. drepanolobium* which had mature trees at the 1 km zone, *A. nilotica* at 12 km, and *A. tortilis* at the sacrifice zone the recruitment of woody species around the crater seems to be a recent ecological event.

The overall status at 0 and 1 km was severely encroached, less severely at 4 km, moderate at 6 km, and low at 9 and 12 km (Table 4.7). The bulk of the increased woody plant density was up to 4 km. The corresponding rangeland condition was fair from 6 to 12 km and deteriorated through ‘poor’ at 4 km to ‘very poor’ at 0 and 1 km (Table 4.7).

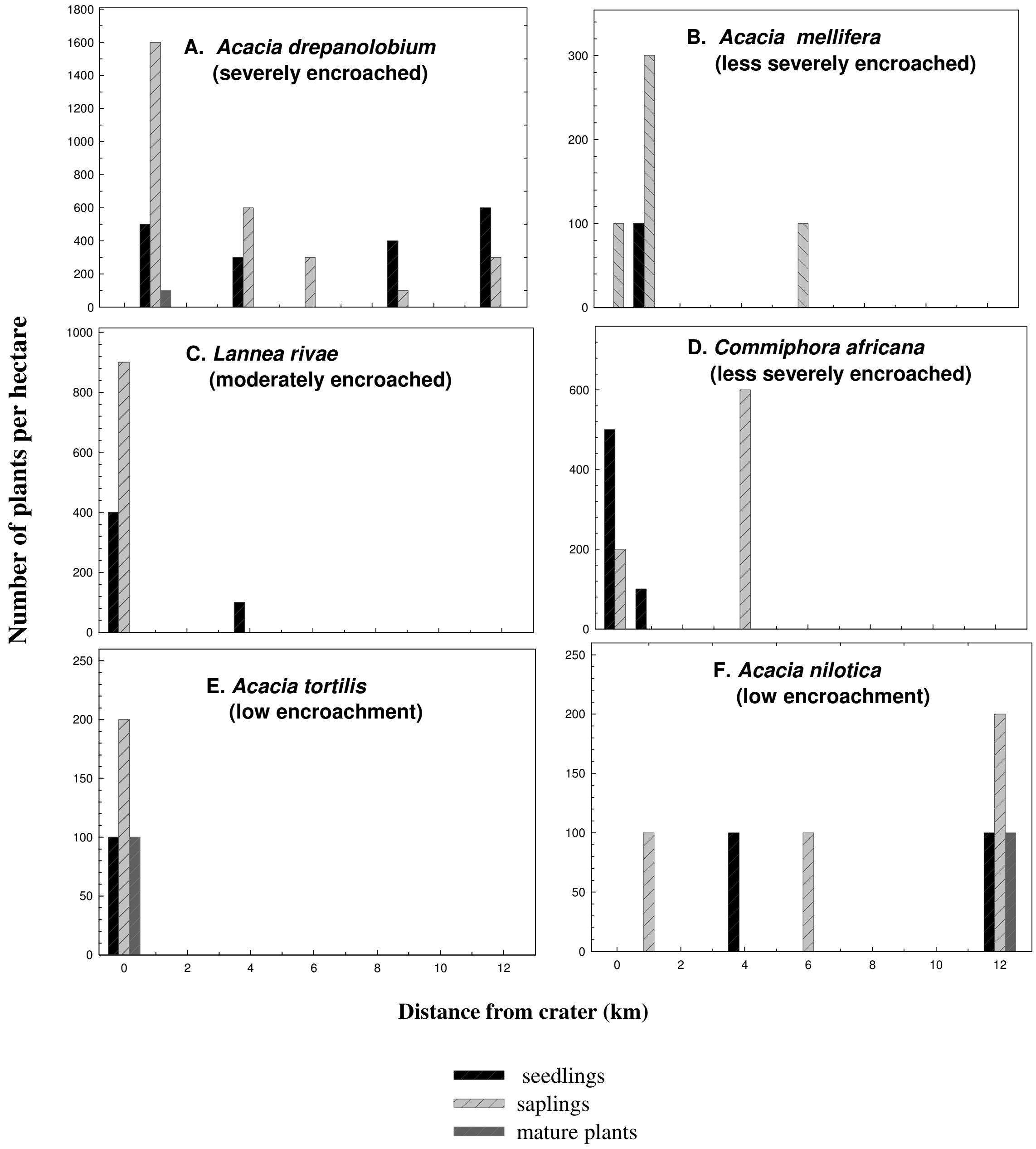

Figure 4.10 Age-class distribution of woody plants along a distance gradient from the Mana Soda salt crater

4.4 DISCUSSION

4.4.1 Herbaceous composition

The findings of this study, with regard to the composition and distribution of herbaceous plants, are in agreement with earlier studies in southern Ethiopia (Coppock, 1994; Angassa and Baars, 2000; Angassa, 2005; Dalle *et al*., 2006b; Tefera *et al*., 2007). The composition of herbaceous species in the main rainy season was not different from that of the short rainy season in Mana-Soda; this might be due to grazing pressure, which is in agreement with the results reported by Angassa (2005). The relatively widespread occurrence of *C. Aucheri* based on the results of the present finding is in general agreement with reports by Coppock (1994), Angassa (2005) and Tefera *et al*. (2007). Previous studies (Angassa, 2005; Dirbaba , 2008) have also reported high occurrence of *E. papposa* and *C. ciliari*s, which is in agreement with the present finding in Mana-Soda. However, in the studies by Tefera *et al*. (2007) *C. ciliaris* occurrence was generally low in the Borana rangeland.

In the present study, the probable reasons for the increase in *T. Triandra* far away from the salt crater might be a reflection of decreased grazing pressure away from the patch resource. This is in general agreement with the finding by Tefera *et al*. (2007) who reported <1% frequency for *T. triandra* under the 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 the highest frequency closest to the patch resource (water point) and higher in under communal and/or traditional reserve management. In the present study, *B. radicans* occurred with comparable frequencies at the 6 and 12 km distances. Overall, the highest proportions of *C. ciliaris, C. aucheri and E. papposa* were potentially an indication of good range condition, while increased occurrence of *A. adoensis, Cyperus spp*. and decline of *T. triandra, P. maximum* were an indication of the poor range condition in Mana-Soda.

The PCA analysis of herbaceous plant species responses to environmental variables indicated that *E. papposa*, *P. mezianum, C. aucheri* and *C. ciliaris* were tolerant to exchangeable sodium which in agreement with the finding of Dalle *et al.* (2006b). 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 Dirbaba (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 soils 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.* (2006b). The same authors noted that *B. radicans* increased with increasing altitude, similar to current findings. The results of the current study also indicated that *T. triandra* and *Cyperus spp.* are sensitive to altitude because both species completely disappeared as the altitude decreases. The observation that herbaceous plants were generally negatively correlated with pH in this study is in contrast to the report by Dirbaba (2008), but in agreement with Dalle (2004).

4.4.2 Dry matter production and range condition

The observed variation in terms of dry matter production in the present study along the distance from the salt crater is in line with the piosphere analysis of grazing lands around patch resources (Dalle *et al*., 2006b). Generally, there is a positive correlation between the dry matter production and the distance from the sacrifice zone of the patch resource (Landsberg *et al*., 2002). The dry matter production for the different plant ecological groups presented by current study is in general agreement to those results reported by Dalle (2004) who suggesting moderate amounts of biomass in the mid-main rainy season, but considerable biomass production at the end of the main and short rainy seasons. Angassa (2005) has also reported decreased contribution of annual grasses to the 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 rainy season might explain the low dry matter production in the mid main rainy season in this study. At the end of summer, the high yielding perennial grasses were more abundant, hence the higher dry matter production. The 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 declined in density or eliminated and replaced by unpalatable and/or short-lived species at distances closer to the patch resources (e.g. mineral lick; watering point) found in this study are in concurrence with several other studies (Hunt, 2001; Brits *et al*., 2002; Landsberg *et al*., 2002). The desirable species might decrease due to the effects of increased grazing pressure. This increased utilization pressure nearby the patch resource is the most likely explanation of the changes in herbaceous cover around Mana-Soda salt crater. Similar condition estimates have been made in recent times in the Borana rangelands (Oba *et al*., 2001; Dalle 2004; Angassa, 2005; Tefera *et al*., 2007; Angassa, 2010).

4.4.3 Woody species composition and density

The significant increase in the density and composition of woody species nearby the crater is most likely due to the convergence of livestock around the mineral lick. This in turn created an increasing grazing pressure gradient towards the crater and a decline of desirable herbaceous species. It is generally accepted that the increased grazing pressure around a patch resource results in over-utilisation and damage of the herbaceous layer (Henkin *et al*., 2011). Similar results have been reported around watering points (Dalle *et al*., 2006a; Tefera *et al*., 2007). The impact of livestock around the crater might also have been accentuated by the increase in human settlement around Mana-Soda. Also, once beyond threshold, the density of woody vegetation out-competes the herbaceous layer for the available water and nutrients (Smit and Rethman, 1998; Oba *et al*., 2000b). It is quite conceivable that the changes in soil nutrients and characteristics might have encouraged a particular plant species around the crater. In general, the six woody plant communities reported in this study are in agreement with those reported by previous studies (Takele, 2006; Dirbaba, 2008). Melesse (2003) and Takele (2006) also reported that *A. drepanolobium, C. africana* and *A. mellifera* to be among the dominant encroaching woody species in the Borana rangelands of the southern Ethiopia.

The Shannon-Weiner diversity index and evenness of woody species increased towards the crater (being the highest nearby the crater < 4 km). Given that the original vegetation of the study area is mainly grassland dominated savannah (Haugen, 1992), these observations reflect environmental changes and pressure around the crater. The high values nearby the crater are in line with the high grazing pressure around the patch resource. Tefera *et al.* (2007) also recorded the highest number of woody species in a communal area characterised by high grazing intensities.

4.4.4 Woody plant recruitments

Seedlings and saplings constituted the greater proportion of the woody plant population structure than the mature plants across the distance gradient. This indicated active recruitment and/or encroachment of woody plants, especially nearby the crater. This might be due to changes in grazing pressure and the biophysical environment towards the crater. These results are in general agreement with the work by Abule *et al* (2005), Dalle *et al* (2006a) and Tefera *et al* (2007). The low numbers of reproductive mature tree might be indicative of: (a) the fact that this recruitment is a recent ecological event, (b) regeneration failure of the woody species, and/or (c) exploitation/utilization or removal by both humans and animals. The observed few numbers of mature trees might also imply the limited seed production. This poses the question of where the seed could be coming from. While these might be recruited from the seed bank the most likely source is the increased livestock movement, which contributed to the increased grazing pressure around the salt crater, could be effective seed dispersal mechanism. The growing practice of mixed herding of camels (browsers) with cattle in the same rangeland might have accentuated seed dispersal.

Although saplings had a higher density than seedlings there seems to be little to infer in terms of spatial and temporal competition for nutrients and water. Both had relatively high densities across the distance gradient. Seasonal variation in density of both seedlings and saplings might also simply the responses of seed germination and emergency to the amounts of rainfall received. The mid main rainy season received about 140 mm (Figure 4.6), which fostered the seedling counts at the end of the main rainy season. Similarly, the short season rains peaked at 87 mm in October, which resulted in high counts end-November to early December, when the counts were made. The high densities of seedlings at the end of the main rainy season resulted in high sapling counts in the short rainy season. By the same token, the sapling counts in the mid rainy season might be in part influenced by the rains received in the preceding short rainy season (109 mm having been received in October, 2010; Figure 4.6). The previous rainfall may have influenced the patterns of woody plant regeneration, which is also reported elsewhere (O’Connor and Roux, 1995; Jeltsch *et al.,* 1997; Angassa, 2005). It may be accepted that naturally it would be more than just rainfall influencing the regeneration patterns process of woody plants. It still would be desirable to study these regeneration patterns over a number of years to shed some light on the ‘cause-effect’ relationships. There is a need to establish whether the recorded large numbers of seedlings and saplings will be developed into mature trees over the next couple of years. If they develop to the stage of maturity, the range condition will deteriorate even further. It is imperative to have control measures in place to avert rangeland degradation in southern Ethiopia.

4.4.5 Encroaching woody plants

The present study showed the general encroaching status of woody species encroachment in Mana-Soda area was moderate. Classes in the method by Bille and Asefa (1984; used in this study) are more conservative than those suggested by Roques *et al.* (2001) where 2400 TE ha^{-1} would be the threshold for a site to be deemed encroached. Under Richter *et al.* (2001) heavy encroachment occurs at a woody plant density of 2500 TE ha^{-1}. While the present study is not feeding into the argument of which method is better, it submits that it is better to be conservative and avert disaster at the higher densities of woody plants.

The findings of the present study concur with what the pastoralists observed. According to the pastoralists, the woody species that had increased in density were *A. drepanolobium, C. Africana, A. mellifera* and *L. rivae*. Over the years, they have noted an increase in the density of *A. drepanolobium*, a species which to them has adversely reduced the potential of rangeland productivity. Dalle *et al.* (2006b) described *A. drepanolobium* as an invasive woody species in the rangelands of southern Ethiopia. This species is fire-adapted and coppices readily after "top kill" by fire or after cutting (Okello *et al.*, 2008). Although elsewhere in East Africa the species is used for charcoal (Okello *et al.,* 2001) to the Mana-Soda pastoralists it has no economic value. Although the remaining encroaching species (*L. rivae*, *A. nilotica* and *A. tortilis*) contributed to rangeland deterioration, pastoralists viewed them slightly different because these species have several economic and social values. Overall, there is need for further studies into the economic/social versus ecological value of these woody species to help reconcile the scientific findings and perceptions of the pastoralists.

Several authors have reported the general decline in range condition with increased woody plant encroachment once a particular threshold had been crossed (Angassa and Baars, 2000; Oba and Kotile, 2001; Dirbaba, 2008). This decline in condition is due to a reduction of herbaceous species because they cannot compete with woody plants for available water, nutrients and light. The reduced grass cover aggravates soil erosion, further leading to poor range condition.

4.5 CONCLUSIONS

The increased pressure on the Mana-Soda salt lick has resulted in significant vegetation changes. Taken together, these results indicate the changes in plant composition and abundance as the distance from the salt crater increased. The increased abundance of annual species nearby 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, herbaceous species richness was the same along the distance gradient from the crater. This might be an indication of an already exceeded degradation threshold in terms of species richness along the gradient. The 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. A predominantly grassland dominated savanna is now showing significant woody vegetation cover. Six woody plant communities were identified. Overall the highest density of woody plants was recorded in the nearby salt crater. This was probably due to the increased grazing pressure towards the crater. It is most likely that increased sedentary settlement and the break-down of the traditional institutions also contributed to these vegetation changes. This study confirmed that in addition to *A. drepanolobium* other species like *C. africana, A. mellifera, L .rivae, A. nilotica and A. tortilis* are already encroaching into the Borana rangelands. The increased woody vegetation cover translated into poor rangeland condition. This has affected the livestock production and livelihood of the Borana pastoralists. Serious bush clearing and/or thinning is required if the original productivity of the rangeland is to be restored. However, these programmes should take into account both scientific and economic /social values of the woody plants. Some of the plants have economic/social value to the pastoralists and the strategy should be focused on selective thinning instead of complete clearing of these particular species.

CHAPTER 5

THE IMPACT OF A PERENNIAL DEEP-WELL WATER POINT ON VEGETATION COMPOSITION AND RANGELAND CONDITION IN BORANA, ETHIOPIA

Abstract

This study was conducted in Medhacho deep-well water point area of Borana-Ethiopia. The objective was to investigate the impact of grazing pressure around perennial deep-well on vegetation composition changes and rangeland condition. Changes in vegetation composition pattern and soil nutrients were examined along a 12 km transect. Principal component analysis was used to analyze the pattern and distribution of herbaceous species and woody plant encroachment along the distance gradient. Rangeland condition was evaluated using the ecological index and weighted palatability composition method. A total of 13 grasses, six forbs, 12 shrubs and 24 woody species were identified. At the far zone (12 km) the highest relative densities were recorded for *Eragrostis papposa, Cenchrus ciliaris* and *Chrysopogon aucheri,* whereas, at the sacrifice zone (0 km) *Setaria verticillata, Cyperus spp* and *Digitaria spp* had the highest relative densities. Herbaceous species richness and diversity along the distance gradient did not differ ($P > 0.05$). However, the dry matter production showed significant differences ($P<0.05$) at far distance from the sacrifice zone. The density of woody plants declined significantly ($P < 0.05$) with increasing distance from the sacrifice zone. Woody plant encroachment was less severe (886 TE ha^{-1}) in the Medhacho area. The encroaching woody species included: *Acacia bussei, Acacia drepanolobium, Acacia mellifera, Acacia nilotica, Acacia tortilis, Commiphora habessinica,* and *Euphorbia cuneata*. The area nearby (0-1 km) to the deep-well was characterised by high contents of organic matter, nitrogen, phosphorus, sodium and potassium, whereas, the far distances (>6 km) were dominated by sandy soils with a high calcium, magnesium contents and CEC. Overall the rangeland condition around the Medhacho deep-well ranged from very poor to poor. It can be concluded that perennial water points are critical in determining vegetation composition with a significant implication on rangeland condition.

Key words: Bush encroachment, indicator species, piosphere analysis, relative density, species diversity

5.1 INTRODUCTION

In the world water is a limited resource that determines agriculture and normal ecosystems function (Duffy *et al.,* 2007). Distribution of water is a critical management issue for both livestock production and human settlement. In rangeland ecology water distribution is used to increase habitat heterogeneity and therefore biodiversity (Gaylard *et al.,* 2003).

The uneven distribution of perennial water points has effects on soil and vegetation composition around the water points. These are typically described as piosphere effects that cause disturbance of soils and vegetation along distance gradient (Andrew, 1988). The piosphere model helps in distinguishing the impact of grazing from climatic impact on rangeland degradation (Howes and McApline, 2008). Animals are attracted by water points that gradually lead to continuous grazing around permanent water points (Kalikawa, 1990; James *et al*., 1999). Grazing pressure is usually high nearby the water points and this could result in the decline of decreaser species in favour of less palatable species (Wilson, 1990; Raph, 1991; Leigh and Brigg, 1992; Nsinamwa *et al.,* 2005).

Distance from water points determines the type of vegetation, soil moisture and nutrients and microclimatic conditions (Richter *et al*., 2001; Roques et *al*., 2001). Along a distance gradient the sacrifice zone is characterised with a high density of increasers and low density of decreasers (Oba *et al.,* 2000b, Sankaran *et al*., 2004; Angassa, 2005; Dalle *et al*., 2006b). Areas nearby water points exhibit a reduction in biodiversity and increased homogeneity both with implications for productivity (Howes and McAlpine, 2008). Behnke *et al*. (1993) have associated the dynamics of vegetation diversity to the impacts of water source and grazing pressure.

In Ethiopia, rangeland degradation is a common phenomenon and it is often linked to uneven distribution of water points, sedentarization, grazing pressure, recurrent drought, cultivation and bush encroachment (Coppock, 1994; Oba, 1998). This situation has led to the reduction in rangeland potential for livestock grazing in the region (Oba, 1996).

The sources of perennial water in Borana are deep-wells, boreholes, while the ephemeral sources of water are ponds, cisterns and earth dams (OWWDE, 2009). Deep-wells are the major source of water for livestock and human in the Borana region. Particularly, during the dry season, the entire livestock and wildlife relied on deep-well as a source of water. The spatial distributions of these water points are different and some are closely spaced in some sites and very far apart in other sites. The amount and availability of water also vary seasonally. During dry season the concentration of humans and livestock population is increased around perennial water points and this has implications on vegetation and soil characteristics.

There are nine clusters (*Tula saglan*) of the Borana traditional deep-wells. These deep-wells found in deepest volcanic erupted valley such as Medhacho, Dillo and Goray. The deep-wells have never run dry even during severe droughts. The deep-wells of the Borana have been existed for over 600 years and today they still serve as a crucial resource of the Borana pastoralists production system (Asmarom, 1973). In principle, access to the deep-well water points is the right of all the Borana communities by maintaining the traditional regulation and by-law. As a result, the Borana have devised a strong traditional institution to manage this vital resource. The management body is made up of three major components: *Confi* (the founder who oversees the general management), *Chora ella* (the management council, overall authority in use of wells) and *Aba herrega* (the daily supervisor of water use). This traditional and community owned institution ensures equitable use of water resources, reducing resource-based conflicts within and between pastoralist communities, and improving rangeland management in the area. Regulation of the seasonal use of water and pasture around deep-well are a major task in maintaining normal ecosystem function.

Recently, the traditional institutions responsible for rangeland and water point management have been weakened. In addition, there is limited information on the impact of deep-wells on vegetation dynamics of their surroundings in Ethiopian rangelands. This led to inappropriate rangeland management guidelines by development actors and researchers around these deep-wells. An effort was made to study the ecological dynamics around a deep well, using distance from the water point to provide a spatial gradient in the accumulated impact of long-term exposure to livestock. The general aim of the study was to investigate the plant ecology around a watering point using piosphere analysis.

The specific objectives were: (1) to study vegetation dynamics around a perennial deep-well (2) to understand the current range condition around deep-well.

5.2 MATERIALS AND METHODS

5.2.1 Description of the study area

The study was conducted in Medhacho area southern Ethiopia from March 2010 to January 2011. Specifically, the study area Medhacho deep-well water point ranges in altitude from 1489-1579 masl (see the detail in Chapter 1 section 1.6.1).

5.2.2 Data collection

5.2.2.1 Vegetation sampling

The data reported in this paper was collected in three rounds: March-May 2010, October-November 2010, and December-January 2010/11 representing the mid-main rainy season, end of the main rainy season and short rainy season, respectively. For herbaceous and woody plants sampling procedure (see Chapter 4 section 4.2.2.1). To examine the interaction between rarity and grazing response along a distance gradient species distribution classified as: uncommon if the frequency at each distance plot < 5%; common if the frequency ≥5%; restricted, if it was recorded only at one or two plots; locally wide spread if it occurred at three or more plots.

5.2.2.2 Soil sampling and analysis

Soil samples were collected from each main plot at different depths length: 0 (surface), > 1- 10 cm, >10-20 cm, and >20- 30 cm. The soil samples were analyzed at Oromia Water Works and Design Supervision Enterprise (OWWDSE) (see the detail in Chapter 3 section 3.2.2.2).

5.2.3 Vegetation data analysis

5.2.3.1 Plant species richness and evenness analysis

Shannon Wiener index method was used to determine species diversity; richness and evenness (see the detail in Chapter 3 section 3.2.3.1).

5.2.3.2 Response of vegetation species analysis

To investigate the response of individual species a simple classification procedure was applied as follows: restricted increaser for species occurring at 0 and 1km only; restricted decreaser if the species only occurred at distance 9 and 12 km and restricted medial if they occurred at distance 3 and 6 km.

5.2.3.3 Correlation between herbaceous, woody species and environmental variables

Principal Component Analysis (PCA) was used to analyze the patterns of distribution of herbaceous and woody plant species in relation to environmental variables such as altitude and soil properties. In addition, the correlation between distance from the deep-well water point (independent variable) and the dependent variables (density, herbage mass, soil nutrient) were analysed using SAS version 9.2 procedures. Seasonal effects on vegetation composition were analyzed using the same method that kept variation of distance at a constant.

5.2.3.4 Rangeland condition

Both agronomic weight palatability composition method (WPCM) and ecological index method (EIM) were used to evaluate the rangeland condition of Medhacho deep-well water point area. (For calculation of EIM and WPCM (see the details in Chapter 3 section 3.2.3.3). The degree of woody plant encroachment interpretation was adopted from Bille and Asefa, (1984) based on defined scale categorizes of woody structure: Insignificant (0-250 TE ha^{-1}); low (> 250 – 500 TE ha^{-1}); moderate (> 500 – 750 TE ha^{-1}); less severe (> 750 - 1000 TE ha $^{-1}$) and severe encroachment (> 1000 TE ha $^{-1}$).

5.2.4 Statistical analysis

The relationships between the distances from deep-well water point (independent variable) and the dependent variables (density, herbage mass and dry matter yield) were analysed using SAS (2009) procedures. Analysis of variance (ANOVA) was used to examine variation in density, richness and diversity of herbaceous and woody plants along the distance gradient from the deep-well water point.

5.3 RESULTS

5.3.1 Density and composition of herbaceous species

Generally, a total of 13 grasses, six forbs and a sedge species were identified around the Medhacho deep-well water point (Figure 5.1). The grass species, which had the highest relative density in Medhacho deep-well area included *Eragrostis papposa, Setaria verticillata, Chrysopogon aucheri, Sporobolus pyramidalis Cenchrus ciliaris* and *Dactyloctenium aegyptium.* Two grass species *Bothriochloa insculpta and Pennisetum mezianum* had moderate in relative density. The relative densities of *Eleusine intermedia, Cynodon dactylon, Heteropogon contortus* and *Cyperus spp* were generally low. At a nearby distance (< 3 km) from the deep-well water point, increaser such as *S. verticillata* and *D. aegyptium* had higher relative densities. At middle distances (6 km) the relative densities of increaser species (*S. pyramidalis* and *P. mezianum)* were high as compared to other species. At far distances (> 9 km) the relative densities of decreaser species (*C. ciliaris, C. aucheri* and *E. papposa* were high (Figure 5.1). Forbs, which classified as increaser (*Cyperus* spp, *Ocimum species* and *Amarathus thunbergi)* were relatively higher in densities nearby deep-well water point.

Among key grass species, *E. papposa, D. aegyptium, P. mezianum* and *C. ciliaris* were the most frequently occurring grass species along the distance gradient followed by *B. insculpta*, *S. pyramidalis* and *C.aucheri* (Figure 5.2). The moderately occurring forbs species around Medhacho deep-well area were *Commelina africana* and *Endostemen tereticaulis*. *Eleusine intermedia* and *H. contortus* were generally of rare occurrence.

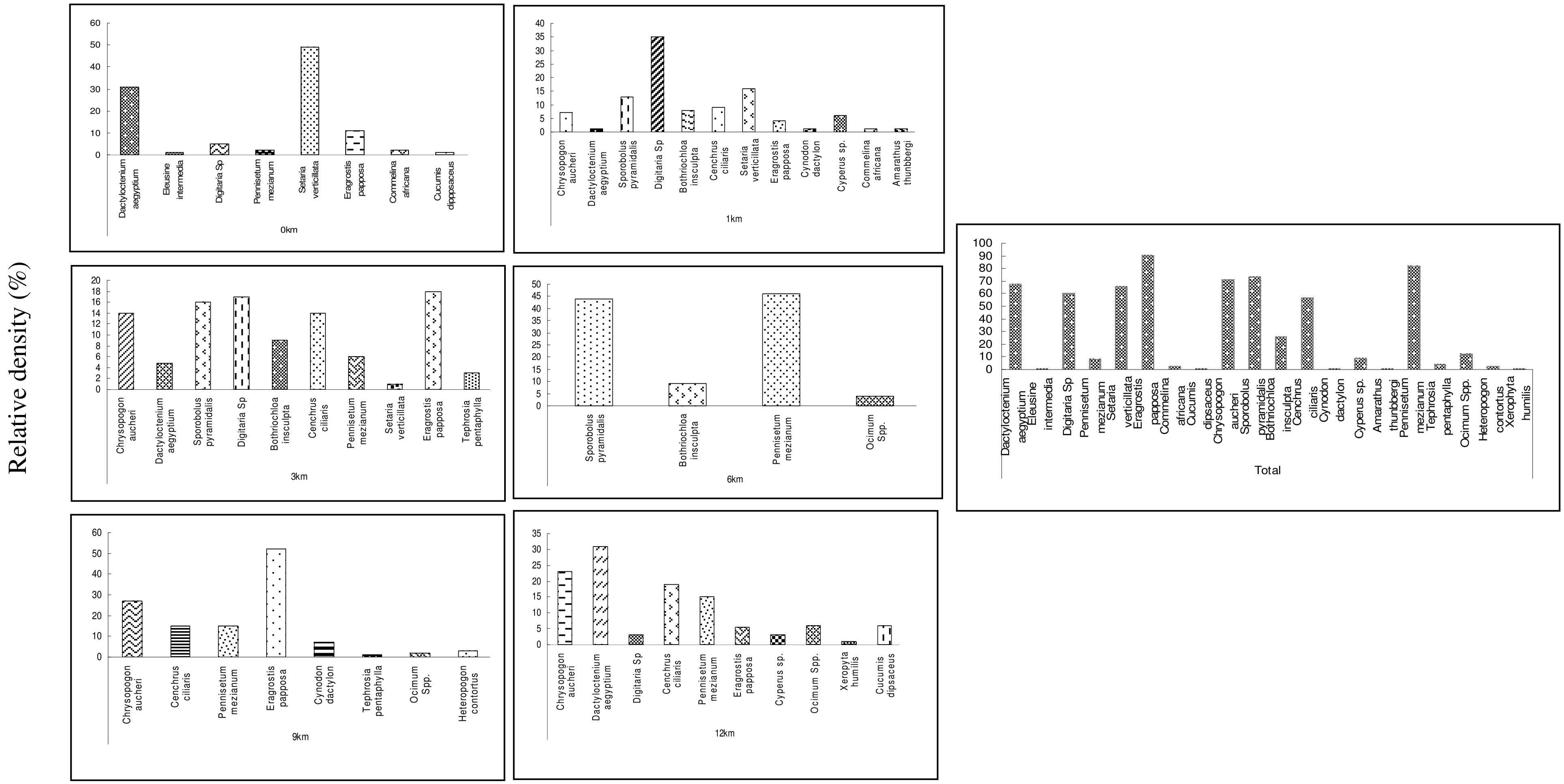

Figure 5.1 Relative densities of grass species at different distances from the deep-well water point in Borana rangelands, southern Ethiopia

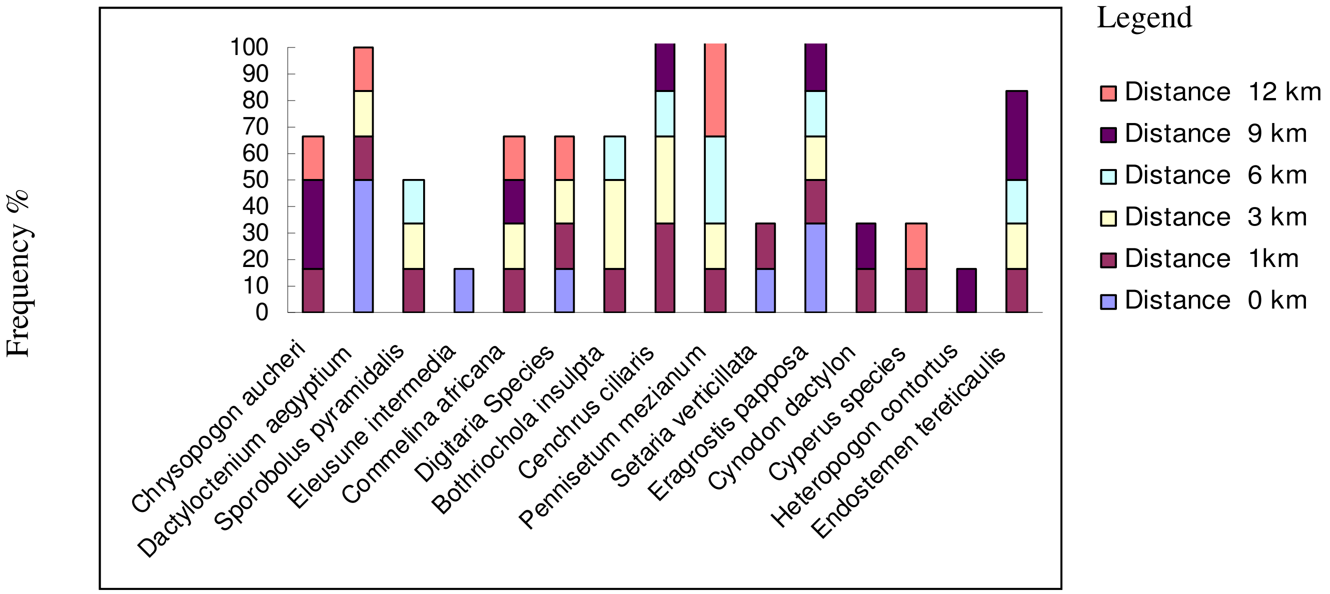

Figure 5.2 Frequency of key grass species around Medhacho deep-well water point

5.3.2 Diversity, richness and evenness of herbaceous species

The overall mean diversity, richness and evenness of the herbaceous species around the deep-well water point were 0.93, 3.0 and 0.87, respectively. Low herbaceous richness but relatively high species evenness were recorded (Table 5.1). The high value of evenness, demonstrated the homogeneities of plant communities around deep-well. However, there was a slight decline in evenness at the 12km distance from the well water point compared to the other distances. Generally, herbaceous species richness and diversity did not differ significantly (P> 0.05) along the grazing gradient. Seasonal herbaceous species richness, diversity and evenness also did not show any significant (P>0.05) differences around the deep-well water point (Table 5.1).

Table 5.1 Seasonal diversity of herbaceous species along distance gradient from Medhacho deep-well water point in Borana, Ethiopia

Distance in km	Richness	Diversity	Evenness
0	2.0^{a}	0.63^{a}	0.91^{ab}
1	2.0^{a}	1.00^{a}	0.81^{ab}
3	3.0^{a}	0.88^{a}	0.98^{a}
6	3.0^{a}	0.99^{a}	0.90^{ab}
9	4.0^{a}	1.16^{a}	0.94^{a}
12	4.0^{a}	0.89^{a}	0.68^{b}
Mean	3.0	0.93	0.87
Season			
Mid Main rain season	3.33^{a}	0.97^{a}	0.86^{a}
End of main rain season	4.33^{a}	1.18^{a}	0.72^{a}
Short rain season	2.83^{a}	0.88^{a}	0.88^{a}

Means within column with same letter are not significantly different ($P > 0.05$)

5.3.3 Dry matter production of indicator herbaceous species

Herbaceous grass species ecological groups, life form and dry matter yield along a distance gradient were presented in Table 5.2. Among the highly desirable grasses species the highest dry matter contribution was from *C. ciliaris*. For the intermediate desirable grasses the highest dry matter producer was *P. mezianum* followed by *B. insculpta* and *D. aegyptium. Eleusine intermedia* the rarely occurring had the least low dry matter yield in the Medhacho deep-well water point area. *Chrysopogon aucheri, C. ciliaris, P.mezianum and E. papposa* had relatively high 'r' value which indicates those grass species are the indicator species in the area.

The grasses species which were categorized as decreaser contributed to 49% of the dry matter production, while the increaser IIa, Increaser IIb and IIc produced 4.69%, 44.55% and 1.49% of dry matter production, respectively. The percent contribution of decreaser grasses species was higher than the other ecological class, which might point to good range condition in the area.

Dry matter production at the sacrifice zone was largely from the moderate desirable species when compared to the highly desirable and less desirable groups. From the mid distances (> 6 km) to the distant areas the highly desirable grasses produced higher dry matter than the moderately and less desirable groups. Nevertheless, the less desirable grasses were low in frequency as well as in terms of dry matter production along the distance gradient. On the overall dry matter production of the desirable grass species increased with distance from the sacrifice zone of the deep-well water point. The perennial grasses were the major dry matter yield contributor in the area. The total dry matter production of key grass species in Medhacho deep-well water point area was 7 952 kg ha^{-1}. On the overall dry matter production of the highly desirable grass species was significantly higher ($P < 0.01$) than for the moderate and less desirable grass species around the deep-well water point (Table 5.3). The dry matter production of less desirable grasses was significantly low ($P < 0.05$) as compared to both ecological group. The highly desirable ecological group dry matter production increased with distance from sacrifice zone. Nevertheless, the less desirable ecological group dry matter production was significantly high ($P < 0.01$) in the nearby zone as compared to far distance zone.

Table 5.2 Dry matter production (kg ha^{-1}), life form and ecological grouping of key herbaceous plants along distance gradient from Medhacho deep-well water point in Borana, Ethiopia

			DM production (kg ha^{-1})								
Herbaceous species	L.F	Ecoca	0 km	1 km	3km	6 km	9km	12 km	Total	%	r
1.Highly desirable											
Eragrostis papposa	P	Dec	173	57	39	77	145	29	521		0.27
Cenchrus ciliaris	P	Dec	0	245	180	436	742	526	2129		0.66
Chrysopogon aucheri	P	Dec	0	169	112	152	332	504	1269	49.28	0.75
Sub total			173	470	331	664	1220	1060	3918		
2.Moderately desirable											
Setaria verticillata	P	Inc IIa	125						125		-0.8
Heteropogon contortus	P	Inc IIa					248		248		
Subtotal (Inc IIa*)*			125				248		373	4.69	
Bothriochloa insculpta	P	Inc IIb	0	200	349	88	0	0	637		-0.27
Dactyloctenium aegyptium	P	Inc IIb	216	0	46	59	0	0	322		-0.03
Cynodon dactylon	P	Inc IIb	0	4	0	0	42	0	46		0.34
Sporobolus pyramidalis	P	Inc IIb	0	59	0	0	0	0	59		-0.03
Pennisetum mezianum	P	Inc IIb	292	0	719	654	120	682	2467		0.47
Forbs		Inc IIb	6	6	0	0	0	0	11	44.55	
Subtotal(Inc IIb)			513	270	1114	802	162	682	3542		
3.Less desirable											
Cyperus sp.	A	Inc IIc		93	0	0	0	0	93		-0.06
Eleusine intermedia	P	Inc IIc	25	0	0	0	0	0	25		-0.65
Subtotal (Inc IIc)			25	93	0		0	0	118	1.49	
Total			837	833	1445	1465	1631	1742	7952		

NB: P: Perennial; A: Annual; L.F: Life form; Ecoca: Ecological categories Dec: decreaser; Inc IIa: increaser IIa; Inc IIb: Increaser IIb; Inc IIc: Increaser IIc; r: correlation coefficient value

Generally, highly desirable grasses species produced the largest dry matter in the study region as compared to both increaser and invader species. In addition, the seasonal dry matter production of desirable grass species across the distance gradient was significantly high ($P<0.05$) beyond > 9 km from water point (Table 5.3).

Table 5.3 Seasonal, ecological group dry matter production kg ha^{-1} of grasses species and range condition a long distance gradient from deep-well water point

Parameters	Distance(km)						
	0	1	3	6	9	12	LSD
Season							
Mid main rain season	210^{c}	377^{bc}	578^{bc}	787^{bc}	1153^{b}	2361^{a}	812
End main rain season	884^{c}	1477^{bc}	1807^{bc}	2291^{bc}	2550^{ab}	3844^{a}	1536
Short rain season	246^{d}	734^{c}	785^{c}	947^{c}	1466^{b}	1848^{a}	369
Ecological group							
Highly desirable	744^{d}	2276^{c}	2654^{c}	3865^{b}	5529^{a}	3375^{bc}	1105
Moderately desirable	2710^{a}	154^{b}	1948^{a}	662^{b}	331^{b}	2618^{a}	917
Less desirable	993^{a}	103^{e}	396^{c}	268^{d}	122^{e}	675^{b}	88
Total ecological group overall					Highly desirable 3074^{a}	Moderately desirable 1404^{b}	Less desirable 426^{c}
Range condition							
EIM	283	306	14	277	380	351	319
WPCM	2	16	11	29	19	13	15

Means within the row with same latter were not significantly different ($P > 0.05$), WPCM: Weight palatability composition methods, EIM: Ecological index methods

5.3.4 Range condition

The range condition along distance gradient was presented in Table 5.3. The calculated ecological index value was 319 and rangeland was classified as poor. In addition, the WPC value of Medhacho deep-well water point area was 15%, which classified the rangeland status as 'very poor'. Rangeland condition around the Medhacho deep-well water point area was classified as poor at all distances from 0 km to 12 km.

5.3.5 Composition and density of woody plants

Overall, 24 woody plants were identified around Medhacho deep-well water point area (Table 5.4). The woody species belonged to eight families. Fabaceae was the dominant family followed by Burseraceae. The moderately distributed families were Tiliaceae, Balanitaceae and Euphorbiaceae. The families Anacardiaceae, Rosaceae and Capparidaceae were occurred rarely around the study area. Generally, density of woody plants around Medhacho deep-well water point was about 1 368 plant ha^{-1}. Woody species which had the highest relative density were *Acacia drepanalobium, Acacia bussei, Euphorbia cuneata, Acacia mellifera and Acacia tortilis.*

The density of woody plant across the distance gradient from deep-well water point varied ($P <$ 0.01) significantly (Table 5.5). The nearby distance (0 and 1 km) had a significantly higher density than the far away zones (> 3 km). Among distance 3, 6 and 9km the density of woody plants did not exhibit significant differences. Significantly low density was recorded at far (12km) from the sacrifice zone along the distant gradient from deep-well. In addition the density of woody plant recorded for end of main rainy season was high ($P < 0.01$) as compared to the mid and short rainy seasons (Table 5.5). Woody plant density recorded in the mid main rainy season was low compared to that at the end of the main rain season and short rain season.

Table 5.4 Density of woody plant species along distance gradient from deep-well water point

Woody plant species	Family	Density (plant ha^{-1})	Relative density (%)
Distance (0 km)			
Balanites rotundifolia	*Balanitaceae*	1300	2.11
Grewia villosa	Tiliaceae	200	0.32
Grewia bicolor	Tiliaceae	400	0.65
Grewia tembensis	Tiliaceae	500	0.81
Acacia tortilis	Fabaceae	300	0.49
Acacia drepanolobium	Fabaceae	3100	5.03
Euphorbia cuneata	Euphorbiaceae	4600	7.47
Acacia Bussei	Fabaceae	500	0.81
Acacia mellifera	Fabaceae	300	0.49
Distance (1 km)			0.00
Acacia nilotica	Fabaceae	600	0.97
Lannea rivae	Anacardiaceae	1000	1.62
Acacia tortilis	Fabaceae	2100	3.41
Acacia Senegal	Fabaceae	100	0.16
Commiphora Erythraea	Bursseraceae	100	0.16
Maerua triphylla	Capparidaceae	100	0.16
Euphorbia cuneata	Euphorbiaceae	4300	6.98
Acacia Bussei	Fabaceae	1000	1.62
Commiphora africana	Bursseraceae	600	0.97
Commiphora habessinica	Bursseraceae	1000	1.62
Boswellia neglecta	Bursseraceae	200	0.32
Acacia oerfota	Fabaceae	300	0.49
Grewia villosa	Tiliaceae	200	0.32
Distance (3 km)			0.00
Balanites rotundifolia	*Balanitaceae*	400	0.65
Acacia nilotica	Fabaceae	1800	2.92
Commifora fluviflora	Bursseraceae	400	0.65
Acacia etabaica	Fabaceae	100	0.16
Acacia tortilis	Fabaceae	700	1.14
Acacia drepanolobium	Fabaceae	400	0.65
Euphorbia cuneata	Euphorbiaceae	700	1.14
Acacia Bussei	Fabaceae	400	0.65
Acacia mellifera	Fabaceae	3600	5.84
Acacia seyal	Fabaceae	1400	2.27
Distance (6 km)			0.00
Balanites rotundifolia	*Balanitaceae*	0	0.00
Acacia nilotica	Fabaceae	2200	3.57
Commifora fluviflora	Bursseraceae	1100	1.79
Acacia tortilis	Fabaceae	3300	5.36
Euphorbia cuneata	Euphorbiaceae	2200	3.57
Distance (9 km)			0.00
Acacia tortilis	Fabaceae	800	1.30
Erythrina melanacantha	Fabaceae		0.00
Acacia drepanolobium	Fabaceae	300	0.49
Euphorbia cuneata	Euphorbiaceae	300	0.49
Acacia Bussei	Fabaceae	5800	9.42
Commiphora africana	Fabaceae	1100	1.79
Commiphora habessinica	Fabaceae	1400	2.27
Acacia mellifera	Fabaceae	300	0.49
Distance (12 km)			0.00
Acacia nilotica	Fabaceae	900	1.46
Acacia tortilis	Fabaceae	500	0.81
Acacia drepanolobium	Fabaceae	5900	9.58
Euphorbia cuneata	Fabaceae	500	0.81
Rhus ruspoli	Rosaceae	300	0.49
Acacia Bussei	Fabaceae	700	1.14
Commiphora habessinica	Bursseraceae	200	0.32
Acacia mellifera	Fabaceae	1100	1.79

Table 5.5 Density of woody plants along distant gradient from deep well water points

Distance (Km)	Density TE ha^{-1}
0	866.70^{a}
1	655.60^{b}
3	433.33^{c}
6	422.22^{c}
9	333.30^{c}
12	133.30^{d}
LSD	126.85
Season	
Mid main rain season	322^{c}
End of main rain season	622^{a}
Short rain season	478^{b}
LSD	72.87

Mean of different letter within the column is different significantly ($P < 0.01$)

5.3.6 Proportion of age composition and seasonal recruitment of woody plants

The recruitment of woody plants along the distance gradient from the deep-well water point varied significantly ($P < 0.01$) Table 5.6. The seedlings were highest at 0 km. Largest saplings were recorded at sacrifice zone (0 and 1 km) compared to the other zones. The highest density of matured woody plants was recorded at (0, 1 and 3 km) zones. Density of seedling plants was not different ($P > 0.05$) at sacrifice zone (1 and 3 km). Densities of matured woody plants at 9 and 12km did not show significant differences ($P<0.05$).

Table 5.6 Recruitment of woody plants (TE ha^{-1}) along the distance gradient from the Medhacho deep-well water point by age classes in Borana, Ethiopia

Distance (Km)	Seedling	Sapling	Matured	LSD	Total
0	247.0^{aA}	421.8^{aA}	229.8^{aA}	296	898.60
1	82.0^{bB}	413.22^{aA}	166.9^{bB}	124	662.12
3	70.9^{bcB}	278.4^{bA}	113.7^{bcB}	54	463.00
6	61.7^{cB}	269.4^{bA}	80.56^{cB}	73	411.66
9	27.8^{dB}	236.1^{bA}	69.4^{cdB}	96	333.30
12	22.7^{dB}	83.33^{cA}	16.67^{dB}	38	122.27
LSD	12.6	74.9	58.1		

Mean in the columns with different lower case letters (ab--etc) and upper case in rows (AB—etc) are significantly different ($P<0.05$)

The density of mature trees around the deep-well was low compared to that of saplings. Saplings had the largest proportion of the total density of woody plants followed by seedling. However, at far distances (12 km) the density of all age group significantly decreased ($P<0.05$) Table 5.6. In addition, the seasonal recruitment of woody plant was varied significantly with high densities of seedlings at the end of the main rainy season. Within far distance (>9 km) from sacrifice zone seedling establishment were homogeneous along distance gradient. On the other hand, saplings recruitment was high at closer zone (< 3km) for three seasons (Figure 5.3). The saplings recruitment sharply decreased at middle zone (6 km) for three seasons. The trend of saplings recruitment demonstrates increase after middle zone for three seasons. The mature tree density was high at sacrifice zone (0 and 1km) for three seasons. There were homogeneities of recruitment of mature tree at middle (6 km) zone. Similarly at far zone (>9 km) there is trend of increase of density of mature tree (Figure 5.3).

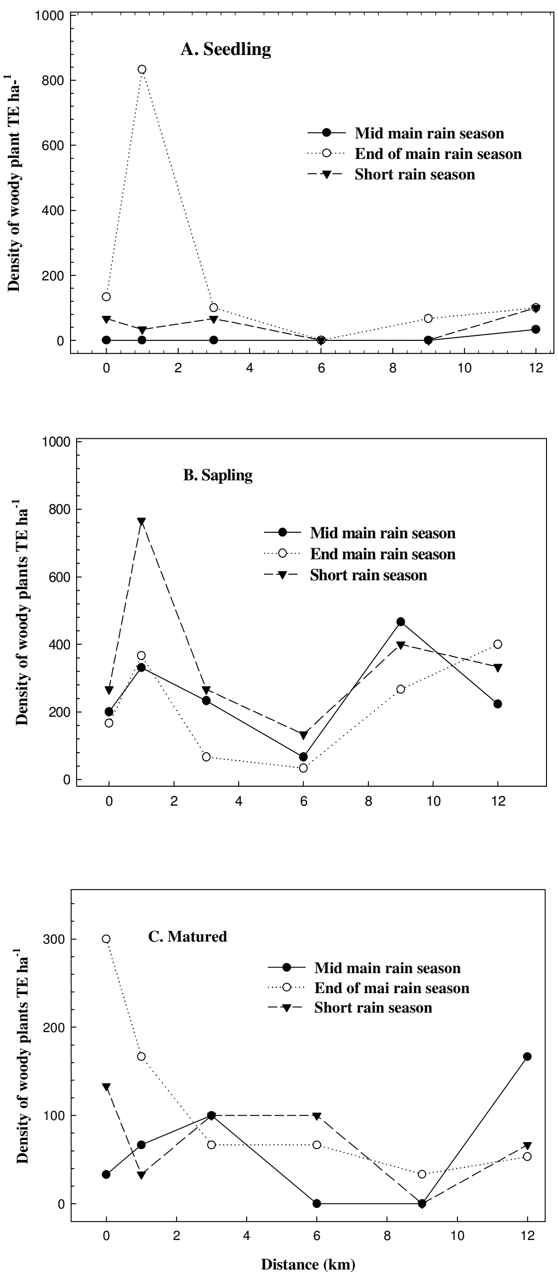

Figure 5.3 Seasonal recruitments of woody plants along the distance gradient from the deep-well

5.3.7 Richness, diversity and evenness of woody plants

The richness of woody plants along the distance gradient from the Medhacho deep-well was significantly different (*P*<0.05) from 0-12km (Table 5.7).The woody plants richness significantly decreased with distance from the 0 km zone. The richness of combined herbaceous and woody vegetation increased at the 3 km (middle) zone. However, diversity and evenness of woody plants, as well as for the combined vegetation, along the distance gradient did not show significant differences (P>0.05). The evenness of woody plant showed a decreasing 12 km, but an increased value for the combined vegetation. In both cases the values recorded for evenness were greater than (0.5), which indicated homogeneity of the vegetation community in the study area.

Table 5.7 Woody and combined woody-herbaceous vegetation diversity along distance gradient from deep-well water point

Distance (km)	Woody plant only			Combined herbaceous & woody vegetation		
	Richness	Diversity	Evenness	Richness	Diversity	Evenness
0	6.00^{a}	1.3^{a}	0.91^{a}	8.00^{c}	1.50^{a}	0.73^{a}
1	5.00^{ab}	1.3^{a}	0.90^{a}	8.00^{c}	1.63^{a}	0.78^{a}
3	4.00^{bc}	0.9^{a}	0.81^{a}	9.00^{bc}	1.84^{a}	0.82^{a}
6	3.00^{c}	0.94^{a}	0.76^{a}	10.00^{b}	1.84a	0.83^{a}
9	3.00^{c}	0.91^{a}	0.75^{a}	10.00^{b}	1.92^{a}	0.83^{a}
12	3.00^{c}	0.81^{a}	0.67^{a}	13.00^{a}	2.11^{a}	0.83^{a}
LSD	1.71	1.43	0.35	2.33	1.04	0.33

Mean within the column with the same letter were not different significantly ($P > 0.05$)

5.3.8 Encroaching woody plant species

The severely encroached woody plants around Medhacho deep-well were *A. bussei, A. drepanolobium, A. mellifera, A. nilotica, A. tortilis, C. habessinica,* and *E. cuneata;* while, the moderately encroached were *B. rotundifolia, C. fluviflora, A.seyal* and *C. africana* (Table 5.8).

Closer to the well the species were *E. cuneata*, and *B. rotundifolia*; farthest from the well *A. drepanolobium* and *A. bussei* were the main encroaching species and at middle distance *A. nilotica*, *A. tortilis* and *E. cuneata* (Table 5.8).

Table 5.8 Encroaching woody species across the distance gradient from the deep-well

	*TE ha^{-1} across distance in (km)						
Woody plant species	0	1	3	6	9	12	Total
Acacia Bussei	265	530	212	0	1629	371	3007
Acacia drepanolobium	1643	0	212	0	84	3127	5066
Acacia mellifera	159	0	1908	0	84	583	2734
Acacia nilotica	0	318	954	1166	0	477	2915
Acacia oerfota	0	159	0	0	0	0	159
Acacia seyal	0	0	742	0	0	0	742
Acacia tortilis	159	1113	371	1749	225	265	3882
Balanites rotundifolia	689	0	212	0	0	0	901
Commifora fluviflora	0	0	212	583	0	0	795
Commiphora africana	0	318	0	0	309	0	627
Commiphora habessinica	0	530	0	0	393	106	1029
Commiphora Sp.	0	0	212	583	0	106	901
Euphorbia cuneata	2438	2279	371	1166	84	265	6603
Grewia villosa	0	106	0	0	0	0	106

* TE= Tree equivalent (1TE=1tree, 1.5 m high)

5.3.9 Distribution pattern and response of vegetation

A summary of the species distribution along the distance gradient is presented in (Table 5.9). Most species were uncommon but had wide spread distribution pattern (35%) along the distance gradient; followed by a common and wide spread pattern (31%). Few species had a common but restricted pattern (4%) of distribution. About 29% of the species showed an uncommon and restricted pattern.

Table 5.9 Distribution pattern vegetation species a long distance gradient

Distance (km)	Uncommon and restricted species	Common but restricted species	Uncommon but locally wide spread species	Common and locally wide spread species	Total
0	8	1	9	7	25
1	7	1	6	12	26
3	6	1	7	10	24
6	8	1	12	5	26
9	7	2	11	6	26
12	10	0	10	9	29
Total	46 (29%)	6 (4%)	55 (35%)	49 (31%)	156

Key: Uncommon= Species occurring at <5%, restricted= species occurring at one or two sites only, Common= species occurring ≥3 sites

5.3.10 Physical and chemical characteristics of soil

Sandy soils were significantly ($P < 0.01$) high at mid-distance (6 km) from the deep-well. On the other hand, there were no significant differences ($P > 0.05$) in silt and clay soils along the distance gradient. Soil pH significantly ($P < 0.01$) low at the 12 km zone; at 0 km Na+ content was significantly higher than the other distances (Table 5.10). The content of $K^{+,}$ Ca^{2+}, CEC, TN and OC content in the middle zones (3 and 6 km) was significantly ($P < 0.01$) lower than the 0 km and 12 km zones. The soil Mg^{2+} and organic carbon contents were not significantly ($P > 0.05$) different across the distant gradient from deep-well.

5.3.11Correlation of herbaceous and woody plants with environmental variables

The correlation of herbaceous and woody plants with environmental variables is presented in Figure 5.4. The herbaceous species at sacrifice zone (0 km) from the deep-well were dominated by the less palatable species *E. intermedia* and *S. verticillata* and these were positively associated with *A. drepanolobium, B. rotundifolia* and *E.* cuneata. The sacrifice zone around the deep-well was characterized by high Na^+ and low slope which probably contributed to the type of vegetation composition. In the 3-6 km zone *S. pyrmidalis* and *B. insculpta* grass species showed strong affinity with *A. melliffera* and *C. fluviflora* woody plants (Figure 5.4).

Beyond 6 km from the deep-well C. *aucheri, E. papposa, C. ciliaris* and *C. dactylon* showed strong association with the woody species *A. mellifera, C. habessinica* and *M. triphylla.* Zones around 12 km from the deep-well were characterized by sandy soil type. On the overall, areas < 3 km from the deep-well had high densities of woody plants, and the densities of herbaceous were low in the same zones. The interaction of woody plant and herbaceous were not homogenous as moved along distance gradient.

Table 5.10 Variability of soil nutrient along a distance gradient from a deep-well water point in Borana, Ethiopia

Distance (km)	Sand	Silt	Clay	pH	Na	K	Ca	Mg	CEC	T.N	O.C	O.M	C:N	P
0	55^{ab}	33^{a}	13^{a}	7.9^{a}	3.2^{a}	6.3^{a}	31^{a}	5.7^{a}	43^{a}	0.3^{a}	2.1^{a}	3.5^{a}	8.3^{a}	26^{a}
3	60^{ab}	21^{a}	18^{a}	8.2^{a}	0.1^{b}	2.0^{b}	18^{c}	4.8^{a}	24^{b}	0.1^{b}	1.1^{ab}	1.9^{ab}	9.7^{a}	9.5^{b}
6	67^{a}	17^{a}	16^{a}	8.3^{a}	0.3^{b}	1.0^{b}	23^{bc}	4.8^{a}	26^{b}	0.1^{b}	0.9^{b}	1.7^{b}	8.7^{a}	9.4^{b}
9	55^{b}	26^{a}	19^{a}	8.1^{a}	0.1^{b}	1.1^{b}	33^{a}	8.8^{a}	47^{a}	0.2^{ab}	1.4^{ab}	2.4^{ab}	9.7^{a}	8.9^{b}
12	52^{b}	25^{a}	23^{a}	7.5^{b}	0.1^{b}	5.2^{a}	21^{c}	8.2^{a}	42^{a}	0.2^{ab}	1.6^{a}	2.7^{ab}	9.3^{a}	27.2^{a}
P	<0.01	>0.05	>0.05	<0.01	<0.01	<0.01	<0.01	>0.05	<0.001	<0.01	<0.03	<0.03	>0.05	<0.01
LSD	14.8	19.9	12.9	0.57	2.7	2.1	9.6	5.2	14.1	0.1	1.0	1.7	1.6	10.5

Mean within the column with the same letter are not different significantly (P>0.05)

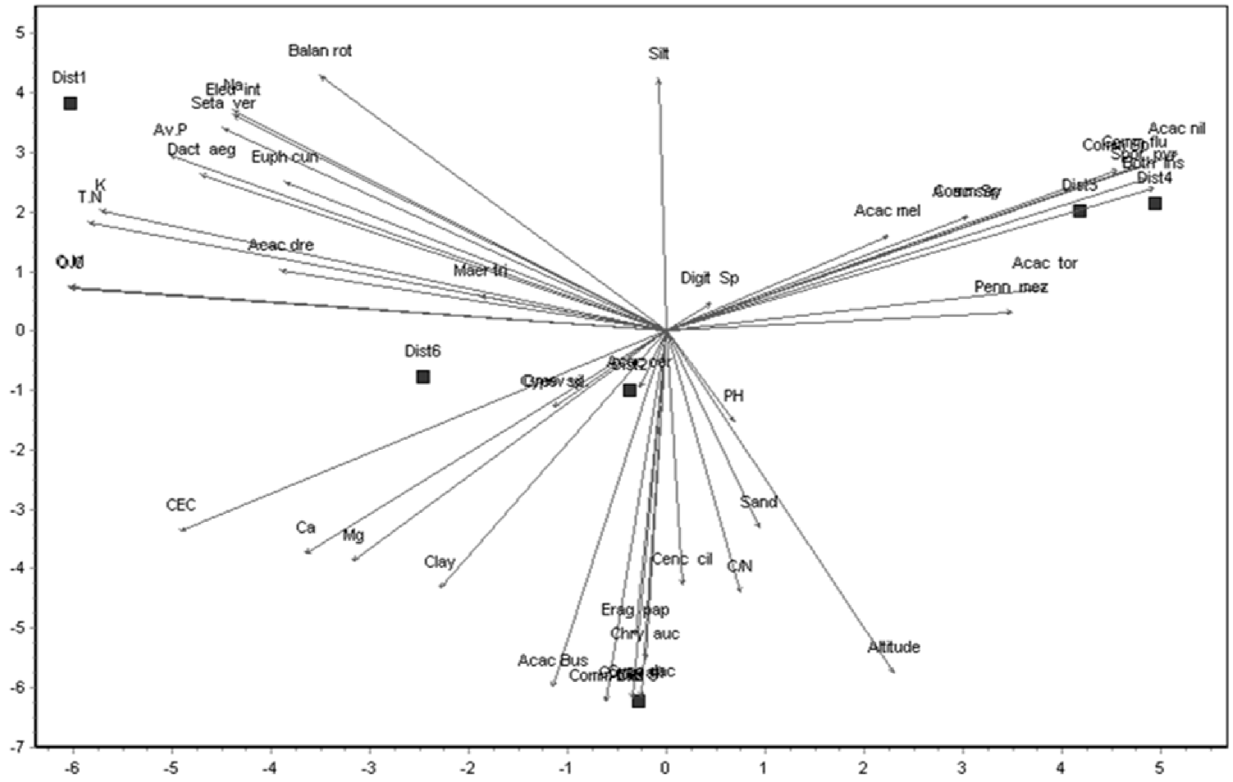

Figure 5.4 PCA correlations of herbaceous and woody plant species with environmental variables and distance from deep-well

Key: Dist1: 0km, dist2: 1km, Dist3; 3km, dis4: 6km, dis5: 9km, dis6:12km from deep-well water point

Chry au: Chrysopogon aucheri,, Both in: Bothriochola insculpta, Digi sp: Digitaria spp, Spor py: Sporobolus pyramidalis, Cype sp: Cyperus Cenc ci : Cenchrus ciliaris, Penn mez : Pennisetum mezianum, Erag Pa :Eragrostis papposa, , Cyno dac : Cynodon dactylon, Dact ae :Dactyloctenium aegyptium, Eleu in :Eleusine intermedia, Set ve :Setaria verticillata,. Comm Sp: Commiphora species, Balan rot: Balanites rotundifolia, Acac nil: Acacia nilotica, Comm flu: Commiphora fluviflora, Acac tor: Acacia tortilis, Maer tri: Maerua triphylla, Acac dre: Acacia derpanolobium, Euph cun: Euphorbia cuneata, Acac Bus: Acacia bussei, Comm hab: Commiphora habessinica, Comm afr: Commiphora africana, Grew vil: Grewia villosa, Acac mel: Acacia mellifera, Acac sey: Acacis seyal, Acac oer: Acacia oerfan

5.4 DISCUSSION

5.4.1 Density, composition of herbaceous and woody plants

The variation in relative density of species might be due to their different ability to tolerate grazing pressure, adaptation to different edaphic conditions and tolerance to moisture stress. The effects of grazing intensity across the distance gradient caused changes in the floristic composition (Angassa and Baars, 2000). Decline in herbaceous species, as a response to grazing pressure is a major challenge in savanna ecosystems (Oba *et al*., 2000a). In East African pastoral systems, savanna rangelands are important in terms of biodiversity and for livelihoods of millions of households (Oba *et al*., 2000a). However, the potential of savanna ecosystems is destabilized by heavy grazing (Coppock, 1994), recurrent drought (Oba, 1998), suppression of fire (Angassa and Oba, 2008b) and bush encroachment (Oba *et al*., 2000b). The composition and distribution of grass species around the Medhacho deep-well are generally in line with the earlier reports of various researchers (Coppock, 1994; Angassa and Baars, 2000; Angassa, 2005; Dalle *et al*., 2006b). But at variance with Tefera *et al*. (2007) who reported a low occurrence of *C. ciliaris* in the southern Ethiopia.

The dominating desirable perennial grasses after 4 km from the deep-well were E. *papposa, C. ciliaris and C. aucheri* which agree with the finding of Hodder and Low (1978). The reason for high frequency of C. *ciliaris* and *E. papposa might* be due to species resistance ability to grazing and drought. On the other hand, *E. papposa* can grow easily in areas where the soil is disturbed.

Although the woody plant density recoded in the present study was lower than that reported by Takele (2006) and Dirbaba *et al*. (2008). It is showed significant differences in density across the distance gradient from the deep-well, as reported in earlier studies (Dalle *et al*., 2006a; Tefera and Mlambo, 2010). Deep-wells are the main source of water during dry season for domestic and wildlife in the region. This attracts large populations of animals and settlement which contributed to the change of vegetation composition, particularly the increase in density of woody plants. In addition the ban of range fire use, weakening of traditional institutions of rangeland management and the coppicing ability of certain woody species after mechanical clearing contributed to the advancement of woody plants. The current study results showed that density of woody plants were higher at adjacent to sacrifice zone and lower as distance far away from water point in contrast to the work of Brits *et al* (2002) who reported reduction of woody plant density at closer zone.

The present study result showed severe encroachments of woody plant in the study region in line with the report of (Oba *et al*., 2000b). But Tefera and Mlambo (2010) reported woody encroachment particularly *Acacia drepanolobium* was not serious in influencing growth of herbaceous also they concluded that thinning of these woody plant is not indispensable. In general several factors like climate change, human and livestock population and settlement put its own pressure around the deep-well which contributed for encroachments of woody plants and reduction of palatable herbaceous plant as of intricacy in competition with woody plants.

5.4.2 Diversity, richness and evenness of herbaceous and woody species

The study results regarding diversity and evenness of vegetation across distance gradient from deep-well water point were not significantly different. The present study indicated the decrease of the Shannon species diversity index (H'), relative number of species present (evenness index) and total number of species present (richness) of grass species with increased woody plant density in the Borana rangelands.

The vegetation cover and composition of the Medhacho might be exhibiting relative resilience to livestock grazing. This manifest would be supported by the following: (i) the majority of the species will recover rapidly away from watering point and will be reduced only in the highly impacted zone immediately adjacent to the watering point. (ii) Those species abundant only in areas distant from watering points will, first, be in the minority and, secondly, be species known to be highly palatable to livestock. (iii) Vegetation structure and diversity will not be severely impacted by livestock grazing and will recover rapidly away from watering points. Spatio-temporal variability of rainfall might have contributed to non significant differences of species diversity along the distance. Overall low diversity of herbaceous species in Medhacho deep-well area concur with the reports by Todd (2006) and Milgo (2006) who also reported low richness and diversity of herbaceous species in nearby water points due to heavy grazing. On the other hand, low grazing pressures have potential of reducing diversity as a result of dominancy of certain species over others as suggested by Willoughby and Michael (2007). However, Glantz (1977) reported absence or reduction of perennial and highly palatable herbaceous species diversity up to distance about 30 km far from deep-well water point. However, the current finding disagrees with the work of Rapp (1976) who reported significant difference of diversity of vegetation around water point up to a 10 km distance.

5.4.3 Dry matter production

Grass species like *C. aucheri, C. ciliaris* and *E. papposa* grasses were superior in terms of dry matter production, whereas, *E. intermedia* and *C. dactylon* were inferior in terms of dry matter production around Medhacho deep-well areas due to tolerance ability of the species to grazing pressure and drought. The study results confirmed further away from the deep-well highly desirable and intermediate grasses species provided the bulk of biomass produced. This is due to reduction of grazing pressure at distant zones. Landsberg *et al.* (2002) also reported that highly palatable and perennial species are more likely to decline in abundance with proximity to water points. Brits *et al.* (2002) also suggested that the high utilization pressure around patch resources favours the increaser species. Several studies reported declines of dry matter production similar to our results at the sacrifice zone are (Foran, 1980; Fusco *et al.,* 1995; James *et al.,* 1999; Fynn and O'Connor, 2000; Yates *et al.*, 2000; Harrison, 2001; Del-val and Grawley, 2005; Macopiyo, 2005).

The study result confirmed the higher dry matter production of decreaser grass species at sacrifice zone of Medhacho deep-well which contradicts the concept of piosphere. This might be due to the strong traditional management of Borana pastoralist around deep-well areas. Deep-well area is strictly regulated and grazed only during dry season. In Borana, the particular deep-well belongs to *Abba ella* or well father who coordinates the management aspects based on *Aadaa-seera Borana (*Borana traditional by-law) and daily routine water related work is handled by *Abba Herrega* or father of water in charges nominated by well council and issues related to pasture is regulated by *Abba dheedaa /*range pasture father (Helland, 1980). Soil texture and disturbance also contributed to variation of vegetation composition (e.g *C. ciliaris* and *C. aucheri)* dominant in undisturbed and sandy soil; and, C. *dactylon* and *E. papposa* in the disturbed area of Medhacho deep-well.

Seasonal dry matter production recorded varied significantly at Medhacho deep-well. The high dry matter production recorded during the end of main rainy season and low in the mid main rain and short rainy season. This is largely due to the variability of rain and management (e.g. resting and rotational grazing) by the pastoralists. Similar results were reported by Abusuwar and Yahia, (2010) in the Sudan and Dalle (2004) in southern Ethiopia.

5.4.4 Range condition

Poor range condition was found around the Medhacho deep-well. The limited distribution of water points is a vital factors that determining rangeland condition. In addition to this the degradation of rangeland condition might have been aggravated by bush encroachment, soil nutrient erosion, and population pressure and management aspects. Previous studies have also reported degradation of the Borana rangeland (Angassa, 2005; Dalle *et al.,* 2006b; Tefera *et al.,* 2007).

Generally, in the Medhacho area 41% of the grass species were categorized as increaser II which is an indication of change of herbaceous vegetation from categories of decreaser to increasers group and that might help to predict rangeland condition. The increase of less palatable species is an indication of poor rangeland condition (Vallentine, 1990; Metzger *et al.*2005; Gezahegn *et al*., 2008).

5.4.5 Correlation of herbaceous and woody plants and environmental variables

Grazing intensity closer to the water point affected both vegetation and the physical environment. The present study revealed that soil with higher sand content had low pH values, possibly due to increased leaching. Shifts in savanna land-use can be a major driver of soil nutrient dynamics (Abule *et al*., 2007). Also shifts in soil nutrient contents are influenced by the process of bush encroachment (Asner *et al*., 2003). Soil nutrient status can be directly or indirectly affected by livestock grazing, trampling and recycling of nutrients (Tefera *et al*., 2007). However, the functional connections between savanna land-use, soil characteristics, bush encroachment and herbaceous vegetation production are highly complex and not yet fully understood (Tefera *et al.*, 2007).

The soil nutrient declined due to intensive and frequent grazing that diminishes recycling of organic matter around water points (Landsberge *et al*., 2003; Todd, 2006). Soil compactness also limits infiltration of water and nutrient uptake of plant due to trampling effect (Risch *et al*., 2007). We observed high density of less palatable herbaceous species like *Eleusine intermedia* and *Cyperus spp* closer to the water point, while the highly desirable species declined. Woody plant *B. rotundifolia* and *E.cuneata* were high closer to sacrifice zone and had positive correlation with sodium, potassium, available phosphorus, total nitrogen and organic matter which in line with the work reported by Dirbaba *et al.*(2008) and Dalle *et al.(*2006b). The dominancy of sandy soil texture around Medhacho is favoured growth of woody than herbaceous species due to acid nature of the soil and high loss of nutrients. The current study confirmed that *A. derpanolobium* had a positive correlation with low pH and low altitude is consistent with the earlier studies (Dalle, 2004; Takele, 2006; Didita *et al*., 2008).

5.5 CONCLUSIONS

The abundance of palatable herbaceous species was significantly low at sacrifice zone and the reverse was true at far zones from the deep-well. About 67% of the grasses species were increasers which is an indication of deteriorating rangeland condition. Dry matter yield of highly desirable grasses species were relatively high at far zones compared to the sacrifice zone. However, the herbaceous species diversity and richness were not significant different along the distance gradient from deep-well up to 12km might be due to resilience of the system to the piosphere effect. The density of woody plants was 886 TE ha^{-1} and was classified as moderately encroached. The indicator woody species idetified were *B. rotundifolia*, *A. busssei, A. nilotica*, C. *fluviflora*, *A. drepanolobium*, *A. mellifera*, *A. tortilis* and *E. cuneata*. The density of woody plants varied with distance from the sacrifice zone. High recruitment of saplings and seedling close to sacrifice zone was indicating that encroachment of woody plant was recent in the study region. Rangelands condition in Medhacho ranged from very poor to poor.

CHAPTER 6

NUTRITIVE VALUE OF GRASSES IN SEMI-ARID RANGELANDS OF ETHIOPIA: LOCAL EXPERIENCE BASED HERBAGE PREFERENCE EVALUATION VERSUS LABORATORY ANALYSIS

Abstract

The nutritive value of common grass species in the semi-arid rangelands of Borana in southern Ethiopia was examined using local experience based herbage preference (LEBHP) (pastoralists' perceptions) and laboratory techniques. Local pastoralists in the study area were asked to identify common grass species and rank them according to the species' preferences and palatability to cattle. The pastoralists listed a total of 15 common grass species which were then sampled during the main rain and cold dry seasons and analyzed for crude protein (CP), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and ash content to verify pastoralists' claim regarding the quality of individual species. The relative feed value (RFV) and dry matter digestibility (DMD) were also calculated using NDF and ADF contents. Spearman's rank correlation was used to examine possible relationships between laboratory results and pastoralists' experience on grass quality. *Cenchrus ciliaris, Chrysopogon aucheri, Digitaria milanjiana, Eragrostis papposa* and *Panicum maximum* were the top five species based on LEBHP perception. There were indications of inconsistency in terms of LEBHP perception among the different pastoral communities. The chemical composition of all grass species showed significant ($P<0.05$) variation between sites, seasons and species. The results showed that the CP values for the Borana rangelands were in the range of 8.7% in the main rain season to 5.1% for the cold dry season. The fiber constituents were relatively low in the main rain season compared to the cold dry season. Overall, *Cynodon dactylon* and *Digitaria milanjiana* had the highest CP 9.3% and

7.4 respectively, while the least was recorded for *Heteropogon contortus* and *Aristida adoensis* (5.9%) during the main rain season. It seems that the spatial variability of landscapes within the wider geographical regions, soil properties and texture, and land-use patterns were probably contributed to site differences in species quality. Generally, the RFV of individual grass species was significantly ($P<0.05$) varied between and within sites. The ranking of species by pastoralists according to their preferences by cattle was highly correlated with the chemical composition of laboratory results of individual grass species with ‘r’ values for CP (0.94), ash (0.95), NDF (-0.98), ADF (-0.93) and ADL (-0.93). It is suggested that there be complimentary use of LEBHP and laboratory techniques in evaluating the nutritive quality of rangeland forage species for sustainable animal production.

Keywords: Forage preference ranking, grass nutritive value, relative feed value, semi-arid rangelands, spatial variation in feed quality

6.1 INTRODUCTION

Herbaceous species play an important role in livestock feeding in arid and semi-arid regions (Arzani *et al*., 2006) and also improve ecosystem services for the welfare of pastoral societies (Stoddart *et al*., 1975). In general, production of herbaceous biomass is primarily determined by the amount, distribution and duration of rainfall. Recently, most pastoral areas of Ethiopia, including the Borana rangelands, are exhibiting a shift from herbaceous species to woody plants, a feature that is accompanied with some degree of degradation resulting from overgrazing, expansion of cultivation and settlement (Oba, 1998; Dalle *et al.,* 2006b; Angassa and Oba, 2010). This is up and above the general decline in forage biomass yield due to changes in the amount and distribution of rainfall. Both internal and external pressures on the rangeland-use policy have influenced the environmental soil characteristics and changes in the vegetation composition and diversity (Oba *et al.,* 2008). The expansion of cultivated areas has been increased nutrient leaching from the soil and run off from the rangelands. This has the potential of reducing the nutrient content and nutritive value of herbaceous plants, an aspect that has implications on livestock production and livelihood of pastoralists.

The Borana rangelands in southern Ethiopia are used for communal grazing and extensive livestock production system with natural grazing as the main feed base. The Borana pastoralists have been practicing transhumance to counter seasonal fluctuations in forage and water resources. A recent study (Angassa and Oba, 2010) has highlighted shifts in species composition and declines in dry matter production of herbaceous plants. These ecological changes would also imply changes in the nutritive value of the rangeland plants. The factors that have been reported to affect the nutrient value of herbaceous plants are seasonal variability (Snyman, 1999), species variation (Arzani *et al.,* 2008), soil nutrient status of production location (Tessema *et al.,* 2011), grazing pressure (Henkin *et al*., 2011) and management aspects (van der Westhuizen *et al*., 2005). In the semi-arid Borana, this translates into exacerbated seasonal shortages and low nutritive value of the available forage (Alemayehu, 2006) further hindering growth and sustainable livestock production.

Recent literature (Ganskopp and Bohnert, 2001) has shown that knowledge of the nutritional dynamics of rangeland forage species is important to sustain satisfactory growth and reproduction of livestock without deterioration of rangeland. Such awareness further assists in planning for proper utilization and to envisage nutrient deficiencies, a basis for suggesting supplemental requirements for animals (Arzani *et al*., 2006). There is a gap between the traditional and formal interpretations of changes occurring in the field. The Borana pastoralists have been known to exist since before the thirteenth century (Oba and Kotile, 2001) and have adapted to the local situation and manage their land in such a way as to be able to survive and develop there without destroying it. Their traditional strategies for rangeland management have been reported to be superior to the approaches used by modern ecologists. The LEBHP evaluation that allows for this evolves through adaptive processes and is handed down through generations by cultural transmission (Beever *et al*., 2000). In terms of access to forage, pastoralists would have significant insights into the shortage of forage resources as a result of rainfall variability, rangeland shrinkage and degradation, and the changes in the quality of common forage species. Pastoralists' experiences and perceptions of forage species and changes in quality were mirrored against laboratory based assessments. The objectives of the study were to: (1) determine the nutritive value of the common indigenous grass species in Borana using both LEBHP perceptions and laboratory analysis, and (2) evaluate seasonal and spatial variability of the nutritive value of the common grass species.

6.2 MATERIALS AND METHODS

6.2.1 Study sites

The study was conducted in Oromia Regional State of Ethiopia, Borana Zone between March and August 2010. The region is dominated by arid and semi-arid climate that is characterized by high temperature and bimodal type of rainfall (see the detail in Chapter 1 section 1.6.1). The average plant growing days vary from 100 to 140 in the west and north of the study areas, respectively. This corresponds to 1.5 to 2.0 ton DM ha^{-1} year^{-1} of herbaceous forage production. The Borana rangelands have perennial herbaceous cover that is interrupted in place by woody vegetation that is dominated by *Acacia* and *Commiphora* species (Coppock, 1994). The soils of the rangelands were derived from sedimentary and volcanic materials and the soil texture ranges from sandy, silt to clay (Dalle *et al.*, 2006b).

6.2.2 Sampling procedure

Five communal grazing areas and two ranches were selected following discussions with district experts and knowledgeable community representatives. The communal grazing areas selected for sample collection included: Surupha, Did-Hara, Mana-Soda, Medhacho and Bokkulboma. The selected study areas represented different histories of land-use and grazing intensities. Two communal grazing areas (Surupha and Did-Hara) and one of the ranches (Did-Tuyura) are located in the former wet season grazing areas and upper semi-arid zone (Coppock, 1994). Mana-Soda, Medhacho, Bokkulboma and Dambala-Wachu ranch were located in the former dry season grazing areas, which are also classified as the lower semi-arid zone. Wet season grazing areas refers to those portions of rangelands utilized only during the rainy season due to lack of surface water, while dry season grazing areas are rangelands associated with permanent deep-well water points. Generally, the concepts of wet and dry season grazing areas have been abandoned due to the expansion of sedentarization and crop cultivation in the rangelands. Land-use management and the slope of these sites were also taken into consideration to select comparable grazing areas for the purpose of this study.

The common grass species were selected and sampled based on the relative abundances and pastoralists' experiences of preferences on each grass species. The samples were collected in two seasons *viz*: during the main rain season (March to May, 2010) and cold dry season (July to August, 2010). For vegetation and soil sampling procedure (see Chapter 1 section 3.2.2.1 and 3.2.2.2, respectively). Herbaceous chemical analysis was conducted in Debere-Zeit, Ethiopian Agricultural Research Center Laboratory and the soil chemical analysis was performed in Oromia Water Work and Design Supervision Soil Laboratory Unit.

6.2.3 Perception analysis

Data for analysis of perceptions of pastoralists was collected at the same time during sample collection on herbaceous plants. Seven community level group discussions were held at a village level in each study site (Mana-Soda, Did-Tuyura, Medhacho, Bokkulboma, Did-Hara, Surupha, and Dambala-Wachu) to select key local informants. Selection was based on the individual's indigenous knowledge and ability to feedback the issues and experiences during the exercise to the parent group. Pastoral communities from each study site selected 10 respondents, giving a total of 70 respondents across the seven locations, for the identification and ranking of species based on their preferences by livestock. Then, the selected respondents participated in the ranking of the same common grass species used for laboratory analysis. Species preference ranking was according to LEBHP and importance for a particular livestock type. Individual interviews were followed by group discussions with respondents' groups at each study location.

A semi-structured questionnaire was administered to elderly community leaders and three agricultural extension agents at each study site. The cumulative match of respondents' perception of prioritizing a particular species across the study sites was divided by the total number of respondents (i.e. 70) and multiplied by 100 to obtain the percentage value for that particular species. Then, all the species were ranked in descending order based on their percentage value in relation to other species under investigation. The perception value of individual species was then correlated with the results of the chemical composition of that particular species using Spearman's rank correlation (Fowler and Cohen, 1996).

6.2.4 Grass chemical analysis

The ash and nitrogen contents of individual grass species were analyzed using the standard procedures of AOAC (1990). Nitrogen content was determined by the micro-Kjeldahl method, while crude protein (CP) was calculated by multiplying the nitrogen content with a factor of 6.25. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) in the forage samples were determined using the method of Van Soest *et al.* (1991). The RFV was calculated according to Stallings (2005) using the following procedure:

RFV= [Dry matter digestibility (DMD) x Dry matter intake (DMI)]/1.29

[where1.29 = the expected digestible dry matter intake as % of body weight;

DMD = 83.58 - 0.824xADF% + 2.626 N% after Oddy *et al.* (1983); DMI = 120/ % NDF].

6.2.5 Soil sample analysis

Soil texture was analyzed using the hydrometer method (Gee and Bauder, 1986), while soil pH was read in a 1:2.5 soil-water suspension using a pH meter (McLean, 1982). 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 (AOAC, 1990) and available phosphorus by the Bray method for soil samples with pH > 7 and the Olsen procedure for samples with pH < 7 (Olsen and Sommers, 1982). Cation exchange capacity (CEC) was measured after ammonium acetate (1N NH_4OAC) extraction (Van Reeuwijk, 1995).

6.2.6. Statistical Analysis

Descriptive statistics was used in summarizing and describing the survey data. We used season, species type and site differences as categorical predictor variables. Grass species nutritive values and soil parameters were considered as numerical response variables. The experimental design was completely randomized and analyzed as a three factor experiment (season, site and species). Data were subjected to analysis of variance using SAS version 9.2 (SAS institute, 2001). Correlation of dependent and independent variables were performed using SPSS version 17. Statistical significance was reported at $P<0.05$.

6.3 RESULTS

6.3.1 Variation in nutritive value of the grass species

The relative frequencies of the collected grass species across all sites are presented in Figure 6.1. *Chrysopogon aucheri, Cenchrus ciliaris* and *Eragrotis papposa* had high frequencies of >50%. Six other species were of intermediate frequency (20-25%), while the rest six grass species had frequencies below 20%. Overall, season, site and species type and their two and three-way interactions were significant (*P*<0.01) in terms of ash, CP, NDF and ADF contents. The results on chemical constituents are presented by site for each season in Tables 6.1-6.5.

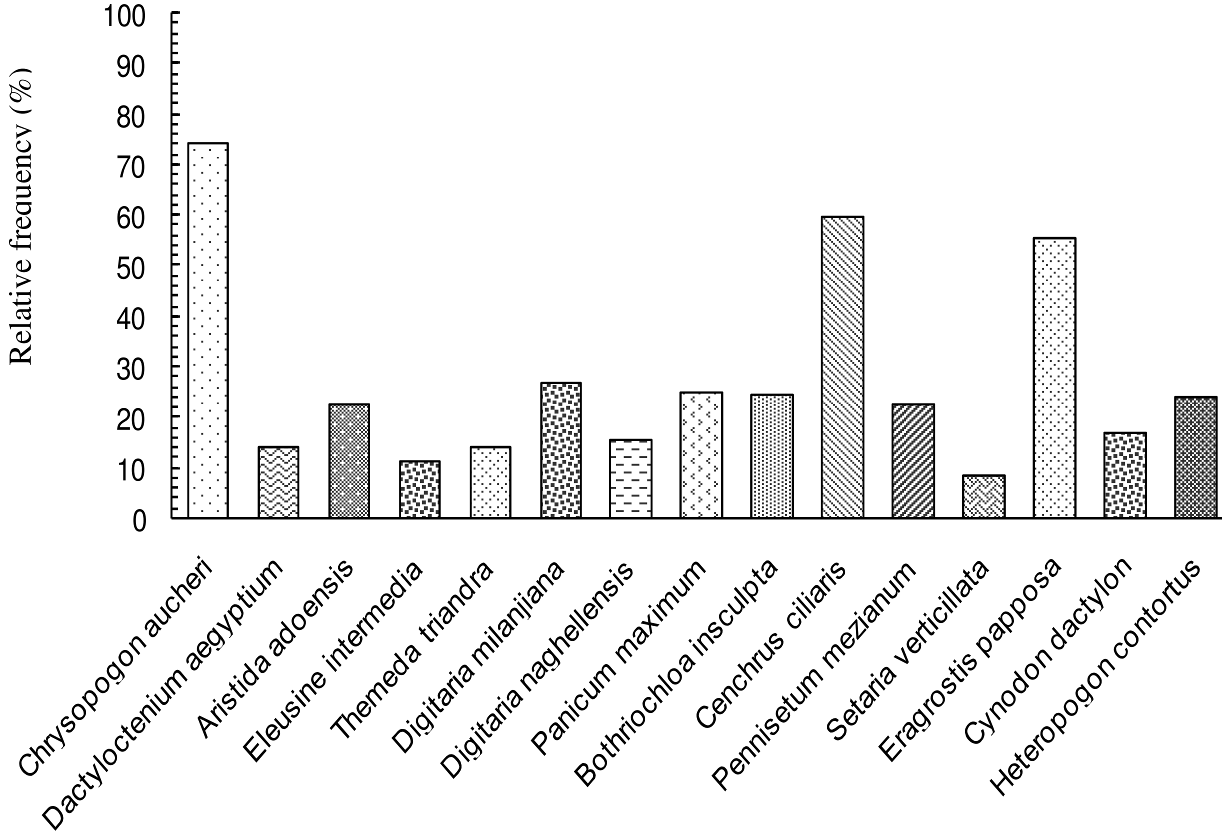

Figure 6.1 Relative frequency of herbaceous plants in the Borana rangelands of Ethiopia in the main rain season

There was some variation in crude protein content of the herbaceous species at Did-Tuyura, Dambala-Wachu and Surupha but this did not vary within site for the remaining sites (Table 6.1). Those species which showed relatively low CP content at Did-Tuyura site included: *E. papposa, C. aucheri* and *Themeda triandra*. Similarly, the CP recorded for *Heteropogon contortus* at Dambala-Wachu site was significantly ($P<0.05$) lower as compared to the CP of other grass species. Across sites and at species level only *C. ciliaris, D. milanjiana, E. papposa* and *H. contortus* showed a significant ($P<0.05$) variation in terms of CP (Table 6.1). Overall, the highest CP content was recorded in Bokkulboma as compared to the other sites. This was followed by values recorded for CP contents of samples from Did-Hara, Did-Tuyura, Mana-Soda, Surupha and Medhacho. We recorded a significantly ($P<0.05$) lowest average CP content at Dambala-Wachu.

Within site, the ash content of grass species in the main rain season was significantly ($P<0.05$) varied among the grass species at Mana-Soda, Bokkulboma, Did-Hara, Surupha, Dambala-Wachu and Did-Tuyura. The grass species collected from Medhacho did not show variation in terms of ash content (Table 6.2). Across sites, the majority of the grass species exhibited significant ($P<0.05$) differences in their ash content. *Themeda triandra, P. maximum* and *E. intermedia* did not show any variation in terms of their ash content across the different sites. On average, the ash content recorded at Did-Hara was the highest (16.7%), while the lowest ash contents were recorded at Surupha (12.8%) and Did-Tuyura (12.5%).

Table 6.1 Species variation in crude protein across different sites in the Borana rangelands during the main rain season

	Crude Protein (%)							
Species	Did-Tuyura	Mana-Soda*	Medhacho*	Bokkulboma*	Did-Hara*	Surupha	Dambala-Wachu	LSD
Cenchrus ciliaris	7.6^{abAB}	6.3^{B}	5.7^{B}	8.2^{AB}	7.3^{AB}	9.8^{aA}	6.1^{abB}	3.2
Chrysopogon aucheri	5.4^{bA}	7.7^{A}	6.4^{A}	7.6^{A}	6.6^{A}	6.4^{abA}	6.9^{abA}	4.9
Digitaria milanjiana	7.8^{abAB}	8.9^{A}		8.1^{AB}	5.6^{B}	-	7.4^{aAB}	2.9
Eragrostis papposa	5.5^{bB}	5.6^{B}	7.2^{AB}	-	6.2^{AB}	8.7^{abA}	5.3^{abB}	2.9
Panicum maximum	7.7^{abA}	6.9^{A}	-	-	6.3^{A}	6.3^{abA}	6.2^{abA}	3.2
Themeda triandra	5.4^{bA}	-	-	-	7.3^{A}	7.1^{abA}	-	5.5
Heteropogon contortus	6.2^{abAB}	6.2^{AB}		7.6^{A}	6.1^{AB}	5.5^{bBC}	3.8^{bC}	1.9
Bothriochloa insculpta	5.5^{bA}	5.9^{A}	8.7^{A}	6.1^{A}	5.8^{A}	6.0^{abA}	6.0^{abA}	4.2
Eleusine intermedia	-	-	-	-	-	6.8^{abA}	6.8^{abA}	1.7
Digitaria naghellensis	-	-	-	6.8^{A}	6.9^{A}		7.3^{aA}	4
Cynodon dactylon	10.2^{aA}		7.0^{A}	11.18^{A}	8.9^{A}	9.4^{abA}	-	4.9
Dactyloctenium aegyptium	-	-	6.6^{A}	8.6^{A}	-	-	4.7^{abA}	4.7
Setaria verticillata	-	-	7.4^{A}	7.4^{A}	-	-	-	3.1
Pennisetum mezianum	-	6.5^{A}	7.4^{A}	5.8^{A}	6.1^{A}	-	7.1^{abA}	1.9
Aristida adoensis	6.5^{abA}	-	-	-	5.4^{A}	5.9^{abA}	-	3.8
Mean	6.8^{B}	6.9^{B}	7.1^{B}	8.0^{A}	6.6^{BC}	7.2^{B}	6.1^{C}	0.92
LSD	4.5	4.4	3.6	6.5	5.4	4.2	3.3	

Means in a column followed by different lower case letters (ab--etc) and mean with upper case letters in a row (AB--etc) are significantly different ($P<0.05$)
*Species differences within site were not significant ($P>0.05$)

Table 6.2 Variation of ash content among herbaceous species and across different sites in the Borana in the main rain season

	Ash (%)							
Species	Did-Tuyura	Mana-Soda	Medhacho	Bokkulboma	Did-Hara	Surupha	Dambala-Wachu	LSD
Chrysopogon aucheri	14.5^{aA}	13.9^{bcAB}	14.9^{aAB}	17.1^{bcA}	15.6^{abA}	11.1^{bB}	17.0^{aA}	4.2
Digitaria milanjiana	14.3^{aAB}	13^{cB}	-	16.4^{bcdeA}	16.5^{abA}	-	13.1^{abcB}	3.1
Cynodon dactylon	13.7^{abAB}	-	13.0^{aAB}	16.2^{bcdeA}	13.4^{abAB}	11.5^{bB}	-	4.4
Themeda triandra	13.5^{abA}	-	-	-	13.4^{abA}	12.6^{abA}	-	5.1
Heteropogon contortus	13.2^{abAB}	15.4^{abcA}		11.4^{eAB}	13.7^{abAB}	10.8^{bB}	13.3^{abcAB}	4.4
Cenchrus ciliaris	12.4^{abA}	16.7^{aAB}	11.3^{aB}	19.2^{aA}	13.7^{abAB}	15.5^{abAB}	14.5^{abAB}	6.4
Eragrostis papposa	11.6^{abB}	13.4^{bcB}	12.9^{aB}	-	18.9^{abA}	15.2^{abAB}	15.1^{abAB}	4.6
Panicum maximum	11.2^{abA}	13.8^{bcA}	-	-	20.7^{aA}	20.6^{aA}	13.8^{abA}	13.1
Bothriochloa inscuipta	11.1^{abB}	13.4^{bcB}	12.7^{aB}	11.9^{deB}	18.1^{abA}	11.1^{bB}	11.1^{bcB}	2.9
Aristida adoensis	9.5^{bB}	-	-	-	21.9^{aA}	9.1^{bB}	-	3.9
Pennisetum mezianum	-	13.7^{bcB}	13.6^{aB}	17.1^{bcA}	11.4^{cB}	-	14.7^{abA}	3.2
Dactyloctenium aegyptium	-	-	14.6^{aAB}	16.7^{bcdA}	13.3^{abB}	-	12.1^{bcB}	3.4
Setaria verticillata	-	-	15.1^{aA}	11.7^{deB}	-		-	2.6
Digitaria naghellensis	-	-	-	16.7^{bcdeA}	-	10.6^{bA}	9.5^{cC}	1.9
Eleusine intermedia	-	-	-	-	-	10.6bA	11.6^{bcA}	2.3
Mean	12.5^{D}	14.6^{BC}	13.9^{CD}	15.9^{AB}	16.7^{A}	12.8^{D}	13.6^{CD}	1.9
LSD	4.7	3.3	3.9	5.1	8.7	9.1	4.5	

Mean in columns with different lower case letters (ab--etc) and upper case in rows (AB—etc) are significantly different ($P<0.05$)

Generally, the NDF content during the main rain season for the sampled herbaceous species was high >70% (Table 6.3). There was a significant variation between sites in terms of NDF with the highest value at Did Tuyura (76.8%), while the lowest values were recorded at Medhacho (71.7) and Bokkulboma (71%). Within site, the NDF content was generally significant among the different grass species with the exception of Mana-Soda site. The ranking of individual grass species within site was also greatly differed. There were a few species that had NDF values below 70%. These included: *S. verticillata* (65%) at Medhacho; *S. verticillata* (67.2%) and *D. aegyptium* (67.2%) at Bokkulboma and *E. papposa* (63.1%) at Surupha. Overall, across the study sites, the NDF content of *T. triandra, A. adoensis, P.mezianum, D. aegyptium, S. verticillata* and *E. intermedia* did not show any significant variations, while the remaining grass species exhibited significant variations across sites.

Table 6.3 Variation of neutral detergent fiber between species and different sites in the Borana in the main rain season

	Neutral Detergent Fiber (%)							
Species	Did-Tuyura	Mana-Soda	Medhacho	Bokkulboma	Did-Hara	Surupha	Dambala-Wachu	LSD
Chrysopogon aucheri	78.9^{abAB}	77^{abAB}	76.8^{aAB}	73.2^{abB}	79.2^{abA}	79.8^{aA}	77.9^{abAB}	5.9
Digitaria milanjiana	75.9^{abcA}	75.9^{abA}	77.3^{aA}	74.2^{abAB}	72.8^{cdB}	-	72.7^{bB}	2.9
Cynodon dactylon	73.3^{bcA}	-	-	75.5^{abA}	77.5^{abcdA}	75.2^{abA}	-	8.5
Themeda triandra	72.2^{cA}	-	-	-	75.3^{abcdA}	73.5^{abA}	-	4.2
Heteropogon contortus	76.8^{abcAB}	78.9^{aA}		71.6^{abB}	74.7^{abcdAB}	73.4^{bB}	75.9^{abAB}	5.2
Cenchrus ciliaris	77.8^{abcA}	74.6^{abB}	74.3^{aB}	75.2^{abAB}	74.9^{abcdAB}	76.6^{abAB}	74.5^{bB}	2.9
Eragrostis papposa	77.3^{abcA}	76.7^{abA}	72.9^{aA}	-	73.9^{bcdA}	63.1^{cB}	74.1^{bA}	6.8
Panicum maximum	77.3^{abcA}	78.0^{abA}	-	-	74.9^{abcdA}	74.9^{abA}	78.0^{abA}	11.2
Bothriochloa inscuipta	76.7^{abcAB}	78^{abA}	77.9^{aA}	77.4^{aAB}	71.9^{dB}	77.1^{abAB}	75.4^{bAB}	5.8
Aristida adoensis	81.4^{aA}	-	-	-	78.5^{abcA}	78.2^{abA}	-	4.3
Pennisetum mezianum	-	73.6^{abA}	72.9^{aA}	72.1^{abA}	-	-	72.1^{bA}	5.2
Dactyloctenium aegyptium	-	-	74.5^{aA}	67.2^{bA}	-	-	72.8^{bA}	7.9
Setaria verticillata	-	-	65.0^{bA}	67.2^{bA}	-	-	-	8.4
Digitaria naghellensis	-	-	-	78.9^{aB}	80.4^{aB}		82.9^{aA}	2.1
Eleusine intermedia	-	-	-	-	-	77.9^{abA}	75.7^{abA}	3.2
Mean	76.8^{A}	75.4^{AB}	71.7^{C}	71.0^{C}	74.2^{B}	75.0^{AB}	74.8^{AB}	3.4
LSD	6.2	12.1	6.7	8.4	6.1	6.4	7.1	

Mean in columns with different lower case letters (ab--etc) and upper case in rows (AB—etc) are significantly different ($P<0.05$)

The average ADF content across the sites was 46.5% and there was significant ($P<0.05$) site and within site variation (Table 6.4). Nevertheless, herbaceous species like *C.aucheri, T. triandra, D. aegyptium, S. verticillata and P. mezianum* did not demonstrate variation across sites. At Medhacho, ADF content showed no significant ($P>0.05$) variation among species. The ADF content of *C. aucheri, T. triandra, D. aegyptium, S. verticillata* and *P. mezianum* were not different across the different sites. Overall the ADF content of the studied forage samples was higher for Did-Tuyura and Did-Hara as compared to other sites. For the remaining sites ADF content was not differ ($P>0.05$) from each other (Table 6.4).

There were significant differences ($P<0.05$) in relative feed value among the herbaceous species except at Mana-Soda (Table 6.5). Only *C. aucheri, P. maximum, D. aegyptium* and *S. verticillata* did not show significant differences ($P>0.05$) in relative values across the sites. Sites variation can greatly influence the nutritive value of herbaceous plants in arid and semi-arid environments. Generally, the CP, NDF and ADF contents of *T. triandra, D. aegyptium* and *P. mezianum* were not significantly ($P>0.05$) different across the study region.

Table 6.4 Variation of acid detergent fiber between species and different sites in the Borana in the main rain season

	Acid detergent fiber (%)							
Species	Did-Tuyura	Mana-Soda	Medhacho	Bokkulboma	Did-Hara	Surupha	Dambala-Wachu	LSD
Cenchrus ciliaris	49.2^{abcA}	47.0^{aAB}	43.6^{aB}	48.5^{abcAB}	45.9^{abAB}	43.5^{bcB}	45.1^{bcdAB}	4.5
Chrysopogon aucheri	50.5^{abA}	46.7^{abA}	46.6^{aA}	47.6^{aA}	50^{abA}	47.8^{abA}	48.8^{abA}	4
Digitaria milanjiana	46^{cdA}	41.8^{cC}		45.0^{abcAB}	44.3^{bABC}	-	42.9^{cdBC}	3
Eragrostis papposa	48.3^{bcAB}	45.0^{abcBC}	46.4^{aAB}	-	49.7^{abA}	41.1^{cC}	49.8^{abA}	4.4
Panicum maximum	50.5^{abA}	43.5^{bcB}	-	-	51^{abA}	$51..9^{aA}$	43.5^{cdB}	6.3
Themeda triandra	44.1^{deA}	-	-	-	48.2^{abA}	47.9^{abA}	-	4.1
Heteropogon contortus	50.8^{abA}	47.7^{aAB}	-	45.9^{abcAB}	48.5^{abAB}	44.1^{bcB}	46.9^{abcAB}	5.9
Bothriochloa insculpta	53.4^{aA}	46.4^{abBC}	44.3^{aC}	46.5^{abBC}	48.5^{abB}	46.2^{abcBC}	46.2^{abcdBC}	3.4
Eleusine intermedia	-	-	-	-	-	47.7^{abA}	45.1^{bcdB}	1.9
Digitaria naghellensis	-	-	-	46.5^{abB}	47.7^{abB}	-	51.1^{aA}	2.7
Cynodon dactylon	40.0^{eB}	-	46.2^{aA}	43.4^{bcAB}	46.6^{abA}	42.2^{abB}	-	3.5
Dactyloctenium aegyptium	-	44.5^{aA}	44.5^{aA}	43.2^{bcA}	-	-	41.5^{dA}	5.6
Setaria verticillata	-	-	44.9^{aA}	42.1^{cA}	48.9^{abA}	-	47^{abcA}	5.8
Pennisetum mezianum	-	46.5^{abA}	47.2^{aA}	47.9^{aA}	47.9^{aA}	48.9^{abA}	-	4.2
Aristida adoensis	51.7^{aA}	-	-	-	47.3^{abB}	47.7^{abB}	-	1.5
Mean	48.5^{A}	45.7^{B}	45.3^{B}	45.5^{B}	48.1^{A}	46.0^{B}	46.2^{B}	1.8
LSD	4.2	3.3	5.6	4.2	6	5.9	4.9	

Mean in columns with different lower case letters (ab--etc) and upper case in rows (AB—etc) are significantly different ($P<0.05$)

Table 6.5 Variation of relative feed value for herbaceous species across the different sites

	RFV							
Species	Did-Tuyura	Mana-Soda	Medhacho	Bokkulboma	Did-Hara	Surupha	Dambala-Wachu	LSD
Cenchrus ciliaris	48.1^{cdB}	52.8^{aAB}	56.9^{aAB}	52.7^{dAB}	53.1^{bAB}	53.1^{abAB}	54.9^{abcA}	6.0
Chrysopogon aucheri	47.0^{cdA}	50.8^{aA}	51.7^{cA}	52.6^{dA}	47.1^{cA}	48.7^{bA}	48.4^{cdA}	7.5
Digitaria milanjiana	52.2^{bcB}	55.9^{aAB}	-	54.2^{cdAB}	57.2^{aA}	-	57.9^{abA}	3.9
Eragrostis papposa	50.0^{cdB}	53.8^{aB}	54.3^{abB}	-	50.6^{abB}	69.4^{aA}	50.8^{bcdB}	10.4
Panicum maximum	46.8^{cdA}	54.8^{aA}	-	-	47.4^{abA}	47.5^{bA}	54.8^{abcA}	10.3
Themeda triandra	58.2^{abA}	-	-	-	50.5^{abB}	52.1^{bB}	-	5.9
Heteropogon contortus	47.5^{cdB}	49.7^{aAB}		55.5^{bcAB}	51.1^{abAB}	57.2^{bA}	53.3^{abcAB}	8.1
Bothriochloa insculpta	45.5^{dB}	51.3^{aAB}	52.2^{cA}	51.6^{dA}	53.5^{abA}	52.2^{bA}	53.2^{abcA}	5.9
Eleusine intermedia	-	-	-	-	-	49.6^{bB}	53.8^{abcA}	3.5
Digitaria naghellensis	-	-	-	50.2^{dA}	48.0^{abA}	-	43.0^{dB}	4.7
Cynodon dactylon	59.1^{aA}	-	51.9^{cAB}	53.4^{dAB}	50.3^{abB}	55.8^{bAB}	-	7.3
Dactyloctenium aegyptium	-	-	55.7^{abA}	62.2^{abA}	-	-	60.7^{aA}	9.4
Setaria verticillata	-	-	62.8^{aA}	64.3^{aA}	-	-	-	12.4
Pennisetum mezianum	-	53.9^{aA}	53.4^{abA}	53.9^{cdA}	50.7^{abA}		54.5^{abcA}	7.5
Aristida adoensis	43.8^{dB}	-	-	-	50.4abA	49.8^{bA}	-	1.7
LSD	6.3	14.2	10.1	8.4	10.1	10.1	8.7	

Mean in columns with different lower case letters (ab--etc) and upper case in rows (AB—etc) are significantly different (P<0.05)

6.3.2 Ranking of species by pastoralists compared to chemical analysis

The ranking of the common grass species by Borana pastoralists is presented in Table 6.6. *Cenchrus ciliaris, C. aucheri, D. milanjiana, E. papposa* and *P. maximum* were ranked as the top five grass species in the region. *Digitaria naghellensis, C. dactylon, D. aegyptium, S. verticillata, P. mezianum* and *A. adoensis* were perceived as species of low preference and palatability. The remaining grass species were considered as moderately valuable/palatable species (Table 6.6).

The correlation coefficients between the perception ranking and the chemical constituents of the common grass species are presented in Table 6.7. The ranking of individual grass species for CP and ash content based on our respondents' perceptions was positively correlated with the laboratory-based analysis of the same species both in the main rain and cold dry seasons. The structural constituents of NDF and ADF were negatively correlated with perception-based respondents' ranking in both seasons. Generally, the laboratory-based analysis confirmed pastoralists' experience and knowledge of forage quality and species preferences by a particular class of livestock. It seems that integration of these two sources of information can complement each other in future development endeavors.

Table 6.6 Rank of herbaceous species according to Borana pastoralists' interest

Herbaceous species	Rank by respondent	Did-Tuyura	Dambala-Wachu	Mana-Soda	Medhacho	Did-Hara	Surupha	Bokkul boma	Frequency of respondent%
Cenchrus ciliaris	1	9	9	10	10	9	8	9	91
Chrysopogon aucheri	2	9	8	8	9	9	7	8	83
Digitaria milanjiana	3	8	8	7	8	7	6	7	73
Eragrostis papposa	4	8	7	8	6	5	4	5	61
Panicum maximum	5	7	6	5	6	5	6	5	57
Themeda triandra	6	7	5	5	5	6	6	5	56
Heteropogon contortus	7	6	6	5	5	6	5	5	54
Bothriochloa insculpta	8	6	7	5	5	4	4	6	53
Eleusine intermedia	9	6	5	5	4	6	5	5	51
Digitaria naghellensis	10	5	4	6	5	4	4	6	49
Cynodon dactylon	11	4	5	4	5	4	5	3	43
Dactyloctenium aegyptium	12	5	4	4	3	4	5	4	41
Setaria verticillata	13	5	4	5	4	3	4	4	41
Pennisetum mezianum	14	4	4	5	6	3	3	3	40
Aristida adoensis	15	3	0	0	0	3	5	4	21

Notes: Rank by respondents 1-5= best, 6-10= moderate, 11-15 =worst

Table 6.7 Correlation coefficient between experience based herbage value rank and chemical composition determined by laboratory analysis

Season	Site	r value for				
		CP	Ash	NDF	ADF	ADL
Main rain season	Mana-Soda	0.45	0.75	-0.65	0.16	-0.74
	Surupha	0.69	0.91	-0.97	-0.79	-0.91
	Medhacho	0.84	0.81	-0.92	-0.93	-0.93
	Danbala-Wachu	0.84	0.94	-0.8	-0.74	-0.77
	Did-Tuyura	0.72	0.95	-0.98	-0.87	-0.79
	Bokkulboma	0.88	0.8	-0.93	-0.77	-0.62
	Did-Hara	0.94	0.93	-0.86	-0.76	-0.52
Dry clod season	Mana-Soda	0.78	0.43	-0.82	-0.79	-0.72
	Danbala-Wachu	0.83	0.81	-0.95	-0.94	-0.92
	Surupha	0.74	0.16	-0.74	-0.74	-0.62
	Medhacho	0.53	0.45	-0.84	-0.74	-0.3
	Bokkulboma	0.63	0.95	-0.91	-0.71	-0.77
	Did-Tuyura	0.78	0.84	-0.86	-0.89	-0.92
	Did-Hara	0.66	0.93	-0.84	-0.84	-0.63

6.3.3 Seasonal effect on the nutritive value of herbaceous species

The annual rainfall variability on the study sites are presented in Figure 6.2. Based on the nearest weather station at Yabello, Did-Tuyura, Did-Hara and Surupha had a better rainfall than the other study sites. Accordingly, Moyale is the nearest weather station for Bokkulboma, which had a better rainfall than Mega station (Dambala-Wachu, Medhacho and Mana-Soda). The mean monthly rainfall ranged from 8 to 150 mm at Yabello area, 6.7 to 128.2 mm at Mega area, and 5.3 to 144.6 mm for Bokkulboma. The rainfall peaks are illustrating the bimodal nature of rainfall in the Borana. The main rain season was between March and May with the peak in April, and the short rain season was between September and November with the peak in October.

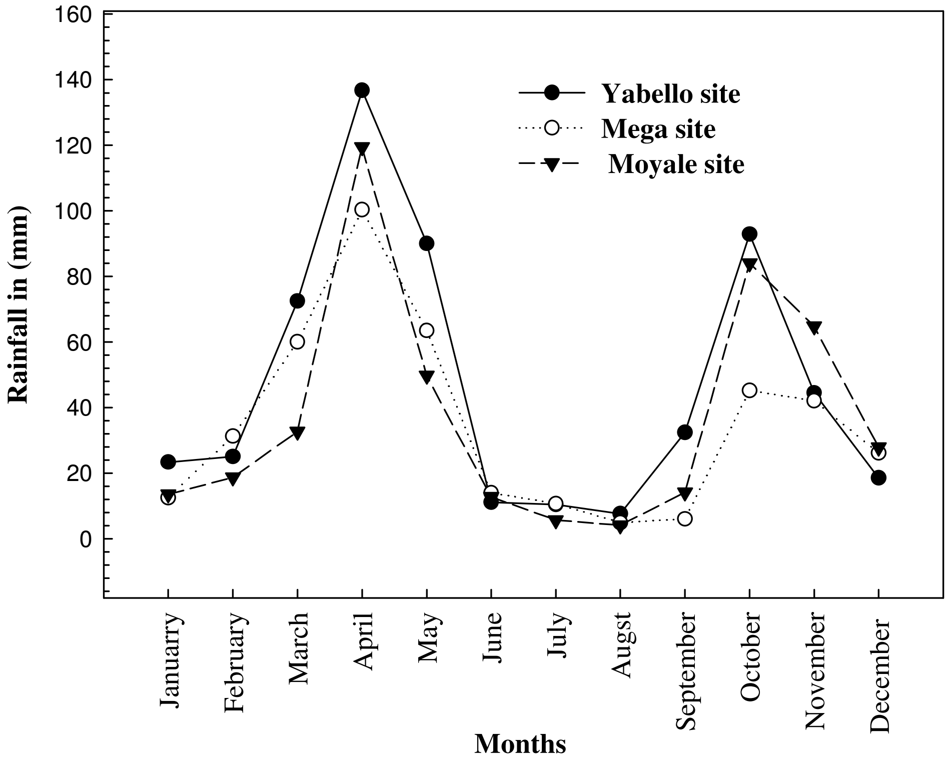

Figure 6.2 Annual rainfalls for year 2010 in the Borana region, Ethiopia

Figure 6.3 presents the seasonal fluctuation of chemical constituent of the common grass species in the study sites. There was a general decline in CP content from the main rain season towards the cold dry season. Generally, the highest CP content was recorded at Bokkulboma during the main rain season. The structural constituents (i.e., NDF, ADF) of the common grass species showed a slight increase during the cool dry season. The highest value for NDF was recorded during the cold dry season at Did-Tuyura and Mana-Soda. The lowest NDF value was recorded at Bokkulboma in both seasons. The ADF and ash contents of the herbaceous species did not show significant (*P*>0.05) differences between the two seasons.

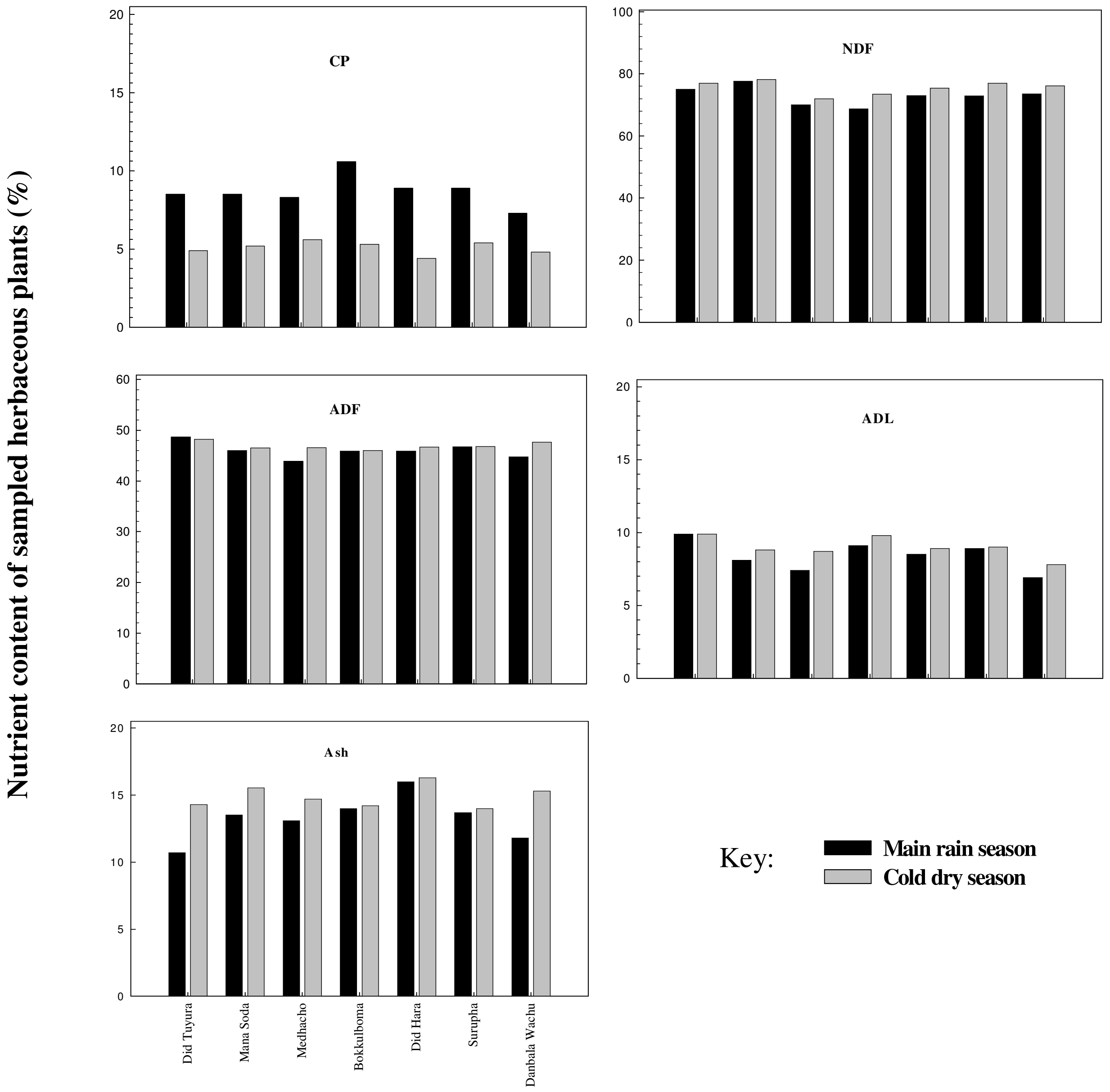

Figure 6.3 Seasonal and spatial variability of chemical constituents of herbaceous plants in the Borana rangelands

6.3.4 Physical and chemical properties of soil

The textural and chemical properties of soils from the Borana rangelands were significantly different ($P<0.05$) across the various sites (Table 6.8). Surupha soils had the highest proportion of sand and the least was recorded at Did-Hara. The silt texture was significantly high ($P<0.05$) in soils at Medhacho and least at Surupha. Clay content was highest in soils from Did- Hara and lowest at Mana-Soda area. The soils in the area were generally alkaline with a mean pH value of 7. Mana-Soda and Medhacho had the highest pH values of 8; Surupha and Did-Hara recorded the lowest with values of 5.99 and 6.30, respectively. These pH values were corroborated by the base metal levels in respective soils. In general, there were variations in the soil chemical constituents across the sites.

The correlation coefficients between the chemical constituents of the herbaceous plants and soil properties are presented in Table 6.9. The CP content of the common grass species was negatively correlated with the proportion of sandy soils and Na^+ in the studied soils (Table 6.9). On the other hand, there was a weak positive correlation between CP, silt, clay and the rest of soil nutrients. A negative correlation between the ash content of herbaceous plants and proportion of sandy soils was also observed. The ADF content of the herbaceous plants was positively correlated with the proportion of clay in the soil. The lignin content of the plants was positively correlated with the Na^+ content in the study area. Furthermore, the ADL was positively correlated with the proportion of sandy soils, and negatively associated with silt and clay soils. The NDF content was negatively correlated with clay content in the soil but also positively associated with the proportion of sandy and silt soils.

Table 6.8 Physical and chemical properties of soil at the different sites

Component	Mana-Soda	Did-Tuyura	Bokkulboma	Surupha	Medhacho	Did-Hara	Dambala-Wachu	LSD
Sand	58.73^{b}	53.33^{bc}	51.86c	71.10^{a}	57.10^{bc}	51.30^{c}	58.90^{b}	10.8
Silt	22.10^{ab}	17.87^{bc}	22.40^{ab}	8.40^{d}	24.70^{a}	16.70^{c}	15.90^{c}	7.2
Clay	19.20^{d}	28.80^{ab}	25.70^{bc}	20.50^{cd}	18.30^{d}	32.00^{a}	25.20^{bc}	8.4
pH	8.00^{a}	6.85^{c}	7.20^{b}	5.99^{e}	8.00^{a}	6.30^{d}	6.70^{c}	0.2
Na^{+}	0.18^{b}	0.16^{b}	0.14^{b}	0.21^{b}	0.70^{a}	0.16^{b}	0.20^{b}	0.5
K^{+}	0.76^{c}	0.99^{c}	1.35^{b}	0.28^{d}	3.10^{a}	1.39^{b}	3.10^{a}	0.4
Ca^{+}	27.96^{a}	13.27^{c}	14.40^{c}	4.05^{e}	25.00^{b}	9.30^{d}	6.70^{de}	4.7
Mg^{+}	6.03^{a}	4.36^{b}	3.30b^{c}	0.77^{e}	6.50^{a}	2.30^{cd}	1.70^{de}	2.2
CEC	33.00^{a}	21.93^{b}	23.30^{b}	7.40^{d}	36.10^{a}	19.40^{b}	12.80^{c}	6.5
TN	0.58^{a}	0.14^{b}	0.11^{b}	0.08^{b}	0.16^{b}	0.08^{b}	0.08^{b}	0.2
OC	1.52^{a}	1.27^{b}	1.10^{bc}	0.89^{c}	1.40^{a}	0.80^{a}	0.80^{c}	0.5
OM	2.62^{a}	2.39^{a}	1.84^{b}	1.60^{bc}	2.50^{a}	1.40^{cd}	1.10^{d}	0.6
C:N	9.10^{b}	9.26^{b}	10.30^{ab}	10.70^{a}	9.10^{b}	10.90^{a}	8.90^{b}	2.2
P	5.81^{c}	6.17^{c}	6.20^{bc}	8.10^{b}	16.10^{a}	4.90^{c}	2.80^{d}	3.0

Means within a row followed by the same letter were not significantly different ($P > 0.05$).
pH: pH in water; Na^{+}:Sodium; K^{+}: Potassium; Ca^{+}: Calcium; Mg^{+} :Magnesium; CEC: Cation exchange capacity; TN: Total nitrogen; OC: Organic carbon; OM: Organic matter; C:N = Carbon to nitrogen ratio; P: Phosphorus, LSD=least significant difference

Table 6.9 Correlation between chemical constituents of herbaceous plants and soil properties in Borana, southern Ethiopia

	pH	Sand	Silt	Clay	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC	TN	OM	P
CP	0.293	-0.714*	0.429	0.333	-0.586*	0.333	0.429	0.238	0.333	0.206	0.143	-0.143
NDF	0.293	0.238	0.048	-0.238	-0.098	-0.238	0.238	0.238	0.143	0.309	0.143	-0.0333
ADF	-0.195	-0.333	0.048	0.524*	0.098	0.333	-0.143	0.048	-0.048	-0.206	-0.238	-0.143
Lignin	0.05	0.195	-0.098	-0.293	0.550*	0.195	-0.098	0	0	-0.158	-0.293	-0.098
Ash	0.098	-0.619*	0.0333	0.048	-0.098	0.429	0.143	0.143	0.0238	-0.103	-0.143	-0.048

* = correlation significant ($P \leq 0.05$), CP=Crude protein, NDF=neutral detergent fiber, ADF=acid detergent fiber, ADL=acid detergent lignin; pH: pH in water; Na^+: Sodium; K^+: Potassium; Ca^+: Calcium; Mg^+: Magnesium; CEC: Cation exchange capacity; TN: Total nitrogen; OC: Organic carbon; OM: Organic matter; P: Phosphorus.

6.4 DISCUSSION

6.4.1Variation in nutritive value

Data presented in this study are consistent with the general observations of spatial, seasonal and species variation in terms of the quality of common grass species (Mutanga *et al.*, 2004; Mahala *et al.*, 2009; Da Silva, 2011). The CP content of individual grass species declined as the stage of maturity increases from the main rain season towards the cool dry season. This is largely due to the changes associated with the advancing stage of maturity of individual species (Ammar *et al.,* 1999; Moore and Jung, 2001). The present study results are also consistent with published data (e.g. Michiels *et al*, 2000; Mahala *et al.*, 2009) that suggest that CP often declines with increasing plant structural constituents (NDF, ADF and lignin) and increasing age of maturity. Ludwig *et al.* (2004) argued that differences in the quality of forage species are usually attributed to the type of species present, phenology of a species and the above-ground biomass. In the present study, the observed differences in terms of the quality of grass species across sites could probably be explained by the variations in slope, altitude and aspect of the study sites. Similarly, previous studies (Moore and Jung, 2001; Mutanga *et al.*, 2004) have indicated that both the effects of climatic and physical factors are responsible for the variation in the quality of forage species across sites. This is corroborated by documentation of fine-scale redistribution of sediments and nutrients through run-off and run-on under different topographical characteristics (Rietkerk *et al.*, 2002; Ludwig *et al.*, 2005).

Results of this study indicated that the average CP value for the Borana rangelands was 8.7% during the main growing season, but reduced to value of 5.1% in the dry season with an overall average value of 6.9%. This is generally within the recommended range (6-8%) deemed adequate for maintenance requirements of most wild and domestic herbivores (Ganskop and

Bohnert, 2001; Hussain and Durrani, 2009), but lower than the critical limit of 10.6% proposed by Minson (1990). Using either scale, it is clear that the common grass species could provide inadequate levels of nitrogen for a considerable part of the year.

In addition to soil nutrients, spatial variation is also mediated through variations in soil structure and texture (Mutanga *et al.,* 2004). Although sandy soils are dominant in the Borana region (which is in agreement with reports by Tefera *et al*., 2007 and Angassa *et al*., 2012), the recorded a fairly wide range of soil texture across the study sites. This might have the potential of contributing to the variation in plant quality across the study sites. The recorded pH values in the present study are in agreement with those reported by Angassa *et al.* (2012). The high content of sandy soils at Surupha might explain the relatively more acidic soils than the other study sites, with significant implications on plant quality. The results of current findings related to the levels of soil exchangeable bases, low N and organic matter (OM) are in agreement with previous reports (Thompson and Frederick, 1978; Abule *et al.,* 2007). The lowest OM values in our study were recorded at sites grazed heavily on a relative basis. It is likely that the high grazing pressure in the study sites would reduce the available biomass for the process of decomposition in the soil. Angassa *et al.* (2012) also noted that woody plant encroachment, which is an increasing problem in the study area, leads to low soil OM content. The low C: N ratios in the present study are consistent with the limited recyclable plant biomass in arid environments.

The data presented in this study also indicate negative correlations between CP and proportion of sandy soils and Na^+, and a tendency for positive correlation with K^+, Ca^{2+}, Mg^{2+} and CEC. This and the correlation for ADF, lignin and ash are generally in agreement with the results reported by Dalle (2004). Overall, there is a significant potential for the various biotic and abiotic processes to interact and foster variation in forage quality at both landscape and fine-scale. These interactions are represented by the variations in RFV of a species within and across the study sites.

6.4.2. Grass quality as perceived by pastoralists

The current study was showed that pastoralists are knowledgeable of grass species preferences and palatability by a particular class of livestock. However, there are indications of some disagreements among pastoral communities of different localities. This inconsistency of LEBHP perception was also noted in other studies elsewhere (Knapp and Fernendez-Gimenez, 2008; Kassam, 2009). Given that the study sites had spatial variation in topography, land-use patterns and soil characteristics, there was bound to be heterogeneity in species composition and their relative abundances. Different communities would therefore develop LEBHP perceptions on species prevalent in their particular area.

In general, the ranking values of common grass species by our respondents was strongly correlated with chemical composition values obtained from the laboratory analysis. The correlations were positive for CP and ash, but negative for NDF, ADF and ADL. The variations in correlation coefficients between species' ranking values and their chemical composition again indicate inconsistency of the LEBHP perceptions among the different communities groups across the study sites and spatial variation in plant constituents. Overall, the data demonstrate the ranking value of LEBHP perception in the assessments of the quality of common grass species in Borana. In the past, such knowledge has largely been overlooked by researchers (Pierotti and Wildcat, 2000). Thus, there is a potential for the integration of LEBHP evaluation and laboratory analysis to complement each other in rangeland assessments in future development endeavors.

6.5 CONCLUSIONS

The chemical constituents of herbaceous plants in the Borana rangelands showed significant site, season and species variation. Although soil texture and chemical properties influenced the quality of the grass species, advances in the stage of plant maturity and climate variability in general were critical in determining the quality of grass species in Borana. The CP content was greatly declined with advances in plant maturity and associated climatic condition. Crude protein was also negatively correlated with soil Na^+ content. The fiber constituents were increased markedly as the stage of plant maturity increased towards the dry season and showed a positive correlation with Na^+. There were a positive and strong correlation between the LEBHP perception and laboratory based constituents of a particular species. The present study results from laboratory analysis of species confirmed that grasses ranked as superior by the pastoralists also had higher CP than those species perceived as inferior. Generally, grass species categorized as low palatability had high structural fiber levels as confirmed by the laboratory analysis. Such correlations indicate the potential of these assessment methods to complement each other in future research strategies.

CHAPTER 7

GRAZING CAPACITY OF THE BORANA RANGELANDS SOUTHERN ETHIOPIA

Abstract

The study was conducted in Borana, southern Ethiopia where livestock production system is entirely dependent on natural grazing. Grazing capacity was estimated using the average rain use-efficiency of (29) years and survey data of range condition and density of woody plants for 2010. Grazing capacity for the year 2010 was about 1.43ha/TLU, which was in the range of safe grazing capacity. There were no major differences in the grazing capacity for the different land-use systems in the Borana due to low precipitation and high density of woody plants. The calculated total dry matter production for several years did not meet the livestock feed requirements. The dry mater production for year 2010 was 1 518 929 ton, whereas, the required dry matter for livestock intake was 3 686 682 ton, giving a feed deficit of 2 167 753 ton DM/year to feed the estimated tropical livestock units (TLU). Determining the grazing capacity is a useful concept for appropriate planning in range improvement program. Therefore, the identification of the proper type of species to be reared and seasonal adjustment of stocking rate (i.e., destocking and restocking) with the potential seasonal availability of forage could be vital for economic feasibility and ecological sustainability of the Borana pastoral production system.

Keywords: Density of woody plants, grazing value, range condition, rain use-efficiency.

7.1 INTRODUCTION

In recent years, the Borana have seen growth in human and livestock populations, expansion of cultivation in the rangelands, settlements and distribution of water points and changes of land tenure policy (Desta and Coppock, 2002). These factors have exacerbated deterioration of rangeland condition and have the potential to cause rangeland degradation Chesterton (2006) with a direct implication on the grazing capacity of the rangeland. The grazing capacity of rangelands is primarily influenced by precipitation, animal factor and management schemes (Lemus, 2010).

Grazing capacity was defined by Galt *et al*. (2000) as the potential of an area to support livestock through grazing and/or browsing over a long period of time without deterioration of the ecosystem. Lemus (2010) defined grazing capacity as the maximum possible stocking of herbivores that rangeland can support on a sustainable basis for a specific length of time without deterioration. This can be expressed numerically where grazing capacity is the theoretical consideration and stocking rate is the practical implementation (Galt *et al.,* 2000). Depending on the level of disturbance, plant species composition shifts either towards pioneer or climax vegetation (Vetter, 2005). A downward spiral in vegetation succession is usually as a result of overgrazing, and on the removal of the disturbance plant community progresses towards the climax state (Abella, 2010). In this complex interaction management intervention could be used to match animal numbers with the available feed resources and to improve the health of the range rangeland. A general assumption is that livestock require a daily dry matter (DM) intake of about 2.5% of their body weight. Cossins and Upton (1987) reported that in Southern Ethiopia the total dry matter (TDM) contained 40% of the edible forage with a mean utilization rate of about 30%. The Borana rangelands are typical of arid and semi-arid areas, which are characterized by fluctuating primary productivity and irregular dry matter yield that consequently influences animal performance and production per animal (Okello *et al.,* 2005). Earlier studies (Coe *et al.* 1976, Mei *et al*., 2004; Miehe, *et al*., 2010) have indicated that rainfall is a major factor limiting the primary productivity of a rangeland in arid and semi-arid environments.

The other important issue related to safe grazing capacity and sustainable livestock production is determination of rangeland-use type. Land-use evaluation is an important tool in making decisions in planning types of animals to be used and land suitable to them. Land-use type determination aims at identifying the most appropriate land-use according to specified requirements, preferences, and predictors of specific activities. In the Borana region, of southern Ethiopia, the need for rangeland condition evaluation is due to increasing livestock population, which causes an increased demand for forage. Livestock population growth and rangeland regeneration is not coping to each other and hence this situation leads to economic problems to the pastoralist. Given the challenges and changes in the Borana in recent years there is a paucity of information on how these have affected the rangeland grazing capacity and stocking rates. The large bodies of research reports on the Borana are largely silent on grazing capacity and stocking rate issues. It was hoped that this study would generate information to guide appropriate rangeland management. The specific objectives of the study were to: (1) establish herbage production patterns across the Borana; (2) determine the grazing capacity of the Borana rangelands; (3) estimate the current stocking rates of various sites across the Borana.

7.2 MATERIALS AND METHODS

7.2.1 Study area

The study was carried out in the Borana rangelands of Oromia Regional State, southern Ethiopia (see the detail in Chapter 1 section 1.6.1).

7.2.2 Data collection

Rainfall and temperature data for the period 1982-2010 were collected from the national network of meteorology stations in the study areas. Long-term, i.e. 29 years, mean annual, seasonal and monthly precipitation was collated for the study region. The dry matter production of the rangeland was estimated based on the precipitation. The occurrences of drought periods were identified by using recorded data and interviewing knowledgeable pastoral elders and key informants. Livestock numbers of the study area were also collected for the same years as weather data from the National Statistics Authority

7.2.3 Livestock feed resources

The total amount of livestock feed that could be produced (herbaceous, browse and crop residues) was estimated from the land cover data using coefficients (herbage yield tones ha^{-1}) for the different cover types (PADS, 2004). The area under each of the land cover types was multiplied with the respective coefficients to estimate the total amount of livestock feed that could be produced within the region. The browse production (mainly the leaf component) was estimated using the Biomass Estimation from Canopy Volume (BECVOL) method (Smit, 1996). The corresponding amount of rainfall in mm was also used to estimate the dry matter yield.

7.2.4 Data analysis

The underlying assumption was that rainfall can determine vegetation growth and using the rain use-efficiency (RUE) in mm an estimate of the above ground biomass production (kg DM ha^{-1}) could be made. The rain-use efficiency factor for semi-arid areas was assumed to be 1 mm of rainfall for 4 kg DM ha^{-1} (Le Houérou *et al.,* 1988). This refers to a relationship between the maximum standing crop at the end of a rainy season and the total annual rainfall. Forage growth was simulated in monthly time step using a multiplicative function of the rain use-efficiency and monthly rainfall (Mulindwa *et al*., 2009). Seasonal forage growth was then obtained by summation of forage growth that occurred during the months that constituted a particular season. Annual rainfall was modeled as the summation of the individual monthly rainfalls within a given year. Grazing capacity was calculated by taking the total amount of forage at the end of the growing season, multiplied by a correction factor and then divided by the average yearly feed requirements of a livestock unit (Hocking and Mattick, 1996). A proper use factor of 30% was used as suggested by Cossins and Upton (1987) for the rangelands of southern Ethiopia. In this study a Tropical Livestock Unit (TLU) was defined as a ruminant of 250 kg live weight (Serunkuuma and Olson, 1998) and all animal units were converted to TLU. Daily feed intake per TLU was taken at 2.5% of the body weight. Grazing capacity was calculated as follows:

i) Using rainfall methods (Coe *et al*.,1976)

The carrying capacity (cc) of semi-arid rangeland can be estimated using rainfall data for herbivorous animals using the relationship, Herbivore biomass (kg km^{-2}) = 8.684 X (mean annual rainfall) – 1205.9

ii) Herbaceous biomass methods (Moore and Odendal, 1987)

Carrying capacity (CC) $= D / \left[\frac{(DM \text{ x} UF)}{R}\right]$

Where, D = number of the day in the year; DM = total herbage dry matter yield ha$^{-1;}$ UF= utilization factor, and R= daily DM requirement kg/TLU.

The observations recorded included number of animals, and size of grazing area. All cattle age groups were converted to Tropical Livestock Units (TLU).

iii) Using the combined method (Danckwerts, 1989)

Grazing capacity was calculated using linear regression analysis using the relations between grazing capacity, veld condition, rainfall and woody plant density as follow:

$$GC = [-0.03 + 0.00289 \text{ X } (x_1) + [(x_2) - 419.7 \text{ x } 0.000633]] \text{ x } [(-0.054 \text{ X } (x_3) + 235) \text{ X } 1/100]$$

Where GC= Grazing capacity TLU per hectare, X_1 = percent of veld condition score, X_2= mean rainfall in mm per year, X_3 = Woody plant density per hectare.

7.3 RESULTS

7.3.1 Grazing capacity

The mean rainfall, herbage production and grazing capacity of the Borana rangelands using RUE data for 29 years are presented in (Table 7.1). The mean DM values for the 29 year period were 1 907 kg ha^{-1} year^{-1} for herbage production, 2 933 kg km^{-2} for the livestock mass, and a grazing capacity of 4.49 ha/TLU. Grazing capacity of the study region was explained as good for 14years, fair for 6 years and worst for 9 years out of the 29 years. The highest biomass production was estimated for 1997, which coincided with El Niño weather phenomenon. The years with low herbage production or grazing capacity matched with the drought years (1982-1985, 1991-1992, 1999-2000, 2007 and 2009) in the study areas. The grazing capacity of the study region ranges from 2.12-6.09 ha/TLU.

The grazing capacity values for the different land-use systems were calculated using the combined methods, which are presented in Table 7.2. Annual precipitation and density of woody plants played a significant role in determining the grazing capacity of the study sites. Mana-Soda and Medhacho (communal grazing areas) had relatively higher grazing capacities as compared to the other sites. Complementary to this the densities of woody plants observed in both sites were low compared to the other. This relationship between high wood densities and low grazing capacity was contestant over all the sites. Surupha (communal grazing area) had a lowest grazing capacity and relatively high density of woody plants as compared to other sites.

Table 7.1 Mean annual rainfall, herbaceous production and estimated grazing capacity in Borana rangelands of southern Ethiopia

Year	Mean annual rainfall (mm)	Mean production of kg DM ha^{-1} year^{-1}	Grazing capacity ha/TLU
1982	458.60	1834.40	4.31
1983	374.70	1498.80	5.27
1984	379.70	1518.80	5.21
1985	326.70	1306.80	6.06
1986	552.60	2210.40	3.58
1987	550.97	2203.88	3.59
1988	630.43	2521.72	3.14
1989	636.83	2547.32	3.11
1990	538.37	2153.48	3.67
1991	324.67	1298.68	6.09
1992	373.05	1492.20	5.29
1993	392.47	1569.88	5.04
1994	473.40	1893.6	4.18
1995	498.33	1993.32	3.97
1996	485.00	1940.00	4.08
1997	931.83	3727.32	2.12
1998	448.33	1793.32	4.41
1999	369.57	1478.28	5.35
2000	371.20	1484.80	5.35
2001	483.13	1932.52	4.09
2002	583.93	2335.72	3.39
2003	566.07	2264.28	3.49
2004	562.53	2250.12	3.51
2005	494.37	1977.48	3.99
2006	504.33	2017.32	3.92
2007	325.10	1300.40	6.08
2008	500.45	2001.80	3.95
2009	325	1300	3.92
2010	450	1700	4.41

The density of woody plants contributed to the low grazing capacity of a rangeland regardless of the high rainfall in respective site. Dambala-Wachu (cooperative ranch) and Did-Tuyura (government ranch) were also showed a low grazing capacity compared to Mana-Soda and

Medhacho communal areas. The magnitude and distribution of rainfall and density of woody plants were determinant factors in limiting the grazing potential of Borana rangeland (Table 7.2).

Table 7.2 Grazing capacity in relation to range condition and density of woody plant

Sites	Range condition%	Mean annual rainfall (mm)	Woody density plant ha^{-1}	Grazing capacity TLU/ha
Did Tuyura	520	574	2830	1.29
Surupha	317	574	2710	0.87
Danbala Wachu	407	471	2930	0.91
Did Hara	452	574	2960	1.03
Bokkulboma	314	478	1900	1.21
Mana Soda	474	471	640	2.75
Medhacho	338	471	885	1.83

Seasonal grazing capacity of the study sites was the highest at the end of the main rainy season (1.17ha/TLU) compared to both the early rainy season (4.18 ha/TLU) and short rainy season (4.8ha/TLU). The seasonal variation in the grazing capacity was largely due to rainfall patterns and the resultant herbage production. For example, the relatively high grazing capacity during the end of main rainy season was related to the high biomass production (Figure 7.1). The least grazing capacity recorded in Surupha grazing area, whereas, the highest grazing capacity exhibited in Mana-Soda.

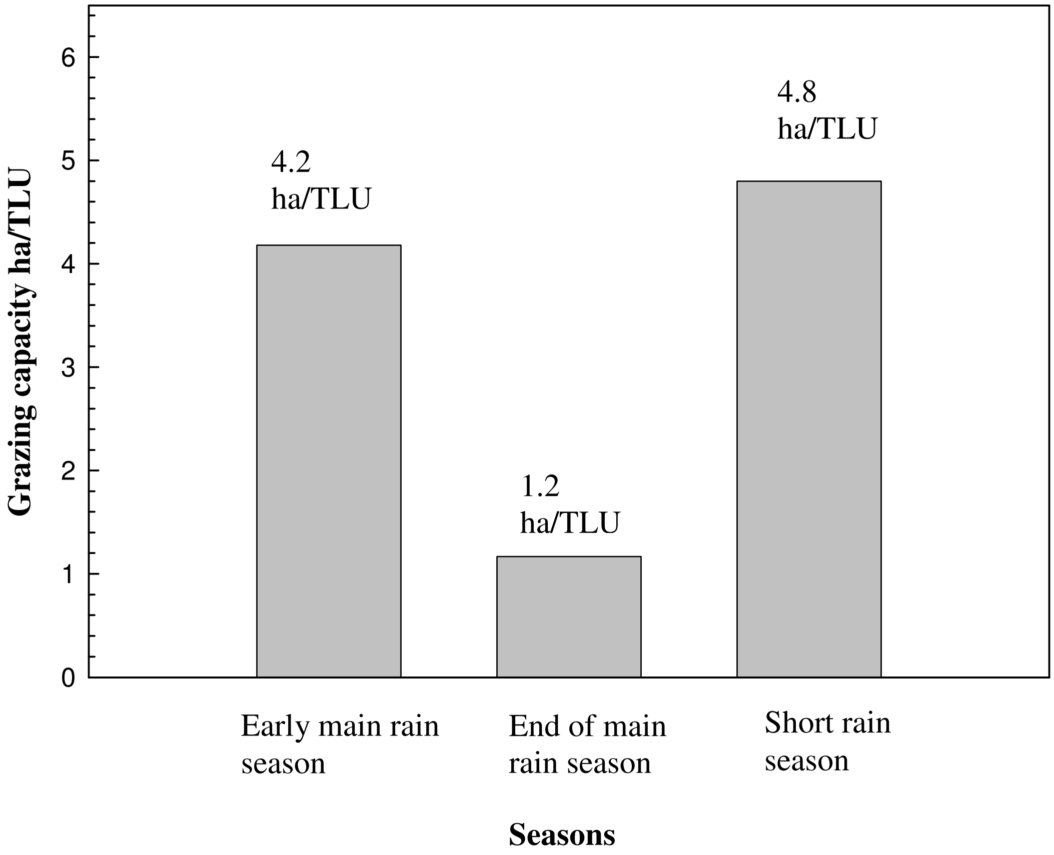

Figure 7.1 Mean seasonal grazing capacity in Borana, Southern Ethiopia

The numbers of Tropical Livestock Unit (TLU) in the study region for the year 2010 were high, which is about 1.6 millions (Table 7.3). Cattle contributed to the largest TLU as compared to other livestock species and followed by camel. This study showed that the number of head of camel was not greater than goats and sheep but as of its high conversion equivalency it becomes the second largest tropical livestock unit.

Table 7.3 Tropical livestock unit and feed required of Borana rangelands for year 2010

Livestock species	Livestock head number	TLU	Kg DM required/day	Kg DM required/year
Cattle	1567010	1096907	7129895.5	2602411858
Sheep	286680	28668	186342	68014830
Goat	664980	66498	432237	157766505
Camel	251675	251675	1635887.5	597098937.5
Mule	42890	34312	223028	81405220
Horse	56969	45575	296237.5	108126687.5
Donkey	60576	30288	196872	71858280
Total	2930780	1553923	10100499.5	3686 682317

7.3.2 Land-use and forage yield

The main sources of herbage were open grassland, dense shrub land and wood-grassland type of vegetation. The density of livestock for 2010 was higher than the estimated grazing capacity of the Borana rangelands, indicating a deficit of 2 167 753 ton DM per year to feed the estimated total TLU (Table 7.4).

The livestock population trends for the last 29 years are presented in Figure 7.2. Cattle numbers showed an increase from 1982- 1988 with a peak in 1987. The sharp decline of cattle population exhibited in years 1991/1992, 1995/1996 coincided with severe droughts in the region. In recent years (1998 to 2010) cattle numbers have been increasing steadily. Numbers of the other livestock species did not exhibit wide variations over the 29 years.

Table 7.4 Land-use and estimated amount of livestock feed produced in Borana, Ethiopia

Land-use	Herbage yield(ton/ha)*	Parameters			
		Area (ha)	DM (ton)	Contribution (%)	Grazing value
Moderately cultivated	0.9	6045	5441	0.4	Source of crop residue
Open grassland	2.3	107757	247841	16.3	Good for cattle and sheep production given proper management
Open grassland shrub	1.4	217254	304156	20	Has grazing and browsing value
Dense shrub-land	0.3	1394639	418392	27.5	Source of browse with appropriate bush management
Open shrub land (Open bush shrub land)	0.8	247772	198218	13	Good for camel and goat
Open woodland	0.9	13840	12456	0.8	Good for grazers and browsers
Wooded grassland shrub bed	1.5	216311	324467	21.4	Good for grazers and browsers
Riparian wood/shrub land/bush land	0.5	166	83	0	Can serve as dry season grazing and browsing area
Forest	0.5	2799	1400	0.1	Forest use
Perennial swamp	0.7	197	138	0	Very limited grazing value
Dense woodland	0.4	4235	1694	0.1	Can be good source of grass and browse with appropriate woody management
Exposed rock surface with scattered shrubs	0.5	3455	1728	0.1	Very limited importance for goats
Exposed soil surface with scattered shrubs	0.5	5837	2918	0.2	No grazing value
Total		2220306	1518929		
Ton DM produced/year			1518929		
Required ton DM/year			3686682		
Deficit ton DM/year			2167753		
Stoking density ha/TLU			1.43		

*Coefficients taken from PADS (2004)

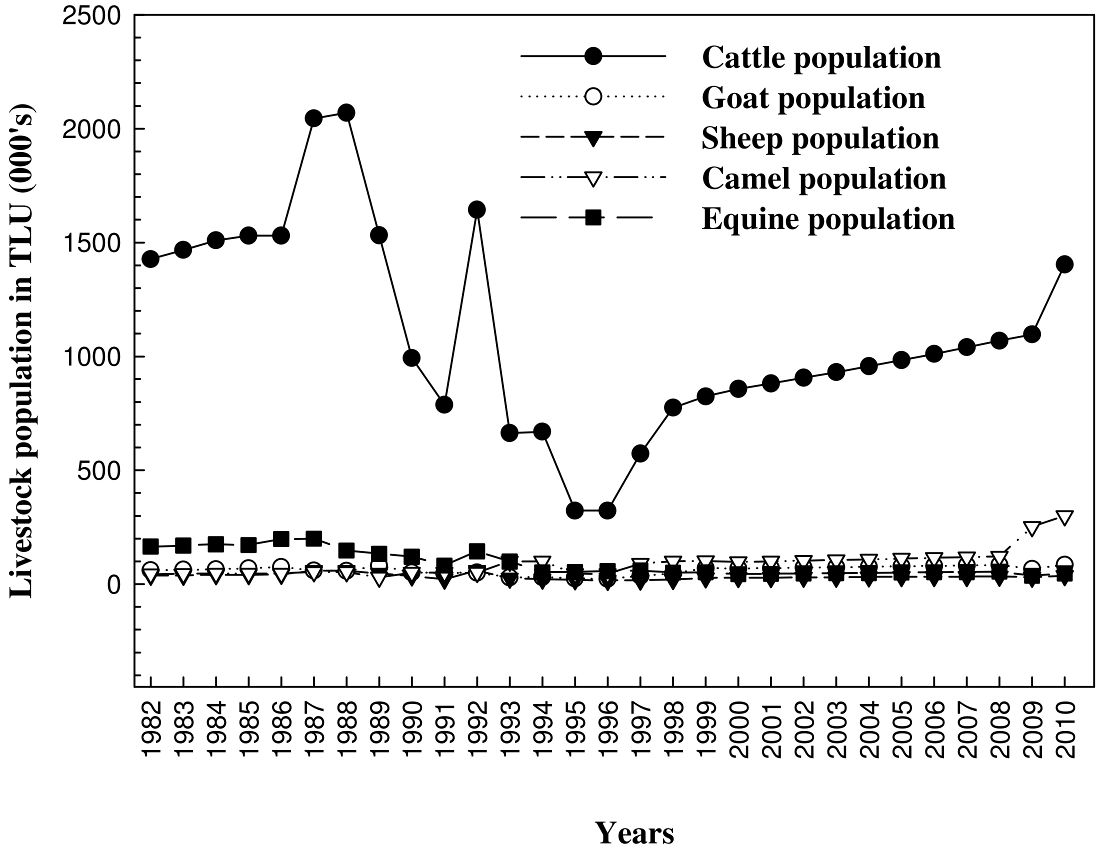

Figure 7.2 Livestock population trend over long-period in Borana, Ethiopia

The compatibility of herbage production and livestock population are presented in Figure 7.3. The livestock numbers and biomass production for the last 29 years considered were varying in the study area. For a few years (1982-1988), a surplus herbage production was recorded above the demand of the livestock population. Moreover, the consequence of drought of 1991 contributed to the decrease of livestock population, which also directly affected herbage production. On the other hand, the El Niño of the 1997 contributed for high primary biomass production in the same year. The dry matter deficit increased substantially from 1998 to 2006, which coincide with an increase in livestock head number in the study area. The dry matter production and livestock population in the study region highly fluctuated and affected the balance of demand and supply in the region. Overall for the majority of the year's the dry matter production did not meet the feed requirements of the animals in the region. Increased livestock numbers and a decrease in rainfall could account for the deficits (Figure 7.3).

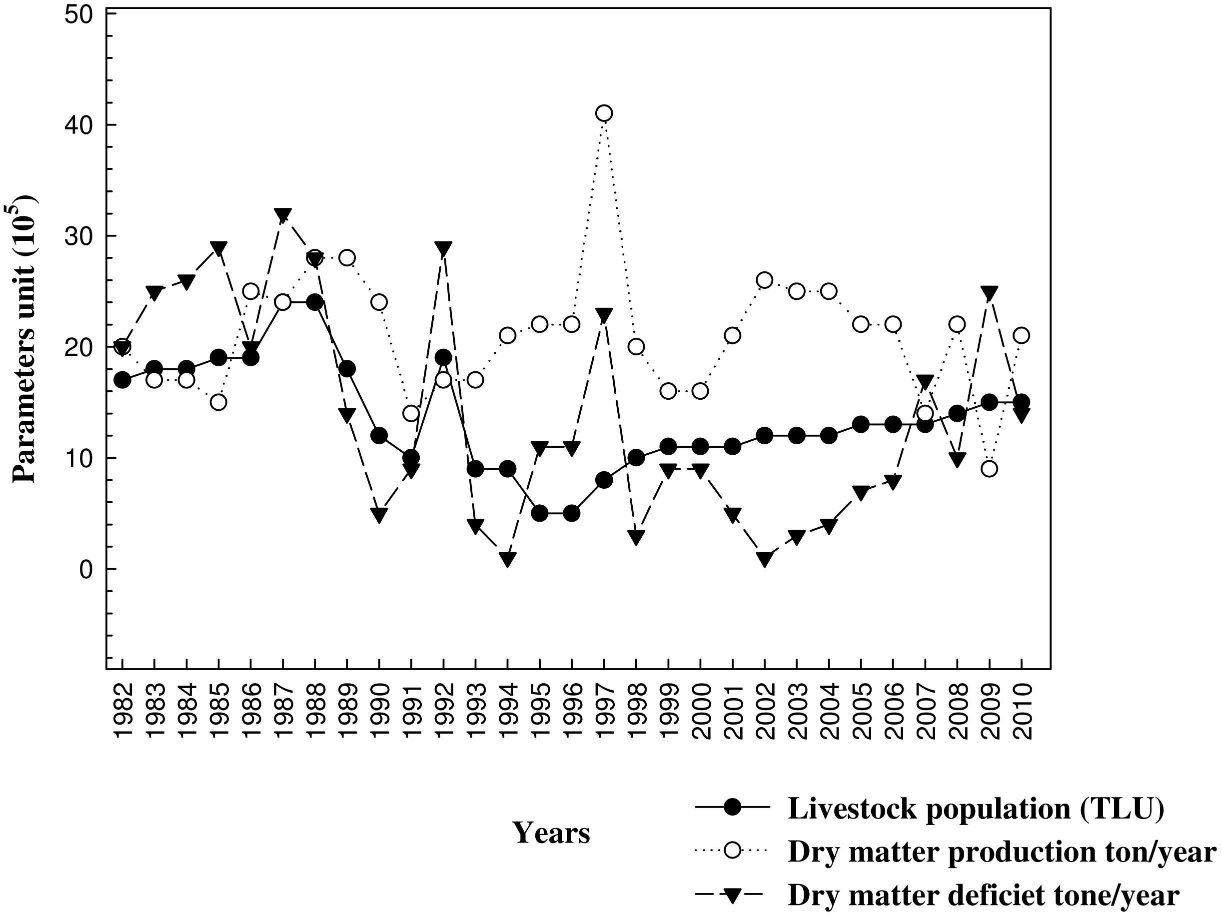

Figure 7.3 Compatibility of livestock population and dry matter production

7.4 DISCUSSION

7.4.1 Grazing capacity

Recently, various factors were affecting the potential of a rangeland grazing capacity. The grazing capacity estimation is highly important for range management decisions on public and private rangelands. In the last two decades, several attempts have been made to determine the grazing or stocking rate by taking into consideration animal intake rate and forage production (Galt *et al*., 2000; Dube 2005). Estimation of the grazing capacity using the rain-use efficiency and combined survey biomass methods has considerable merit. The grazing capacity surveys provide a basis for annual adjustments in stocking rates that promote conservative stocking densities. Sound grazing capacity estimation can help to determine the number of livestock to be maintained at specific period in a given area to minimize the rate of degradation. So, this can help managers for rangeland management to make decision by providing information on a rangeland trend, grazing use and range condition.

The overall predicted biomass production for the Borana rangeland using the rainfall use-efficiency data was 1.91 tons ha^{-1} $year^{-1}$, and this is agrees with previous studies (e.g., Pratt and Gwynne, 1977; Cossins and Upton, 1988) where the average biomass production for the Borana rangelands was between 1-3 tons ha^{-1} $year^{-1}$. Seasonal variation of rainfall and woody plants density are the main cause for the variation in vegetation biomass (Alemayehu, 2006; Desalew, 2008). The present study results demonstrated that precipitation and density of woody plants were the major factors that limit the grazing capacity of rangeland in arid and semi-arid area. The negative impact of increased woody vegetation in this study concurs with the reports by Wijngaarden (1985) and Dalle *et al*. (2006a). According to Wijngaarden (1985), an increase in woody plant density of 10% could reduce herbaceous biomass productivity by 7% of the potential biomass production.

The predicted grazing capacity using the rainfall use-efficiency was varied from 2.12 ha/TLU to 6.09 ha/TLU in the study region. The variation of grazing capacity was mainly due to the increase in the number of animal heads, woody plants density and deterioration of rangeland condition. The other probable determinant factor that contributed to the reduction of grazing capacity may be the amount and distribution of rainfall. Cossins and Upton (1987) also suggested that the grazing capacity in the central Borana rangeland ranged from 4 to 8.8 ha/TLU. The safe grazing capacities are at which livestock production is not compressed and vegetation biomass production is not exhausted by grazing pressure. However, the current situation in the Borana rangeland grazing capacity declined due to the combined effects of rainfall variability, increase of livestock population and expansion of woody plant in the study areas. In general, grazing capacity can be used as a tool for interpreting rangeland system dynamisms.

During the dry season the rangeland grazing capacity declined compared to the wet season which is consistent with the work reported by Angassa and Oba (2007) in the region. The variations in the grazing capacity with seasonal changes in herbage production imply a need for seasonal adjustment of stocking rate for sustainable productivity of the Borana rangeland. The Borana pastoralists traditionally respond to these seasonal variations of grazing capacity through mobility. They optimized stocking rates by utilizing the different grazing areas (spatially and temporally). In recent times these traditional mechanism/tool of managing the rangeland have been weakened in the study area.

Government and cooperative ranches were no better than the communal areas in stocking rate. This might be due to recurrent drought that causes rangeland degradation. In addition, the reason for the low stocking rate of government, cooperative as well as communal grazing area was due to the density of woody plant and deterioration of rangeland condition (Dalle, 2004; Angassa and Oba, 2007). On the other hand, pastoralists keeping large number of livestock over the grazing capacity of the rangeland without understanding how it affects their rangeland and production systems. This overstocking resulted that overgrazing of the area lead to the succession of some herbaceous species and increase of less palatable woody plant as in turn resulted reduction of sustainable productivity of the rangeland. In this study, the grazing capacity was estimated using the dry matter yield without considering the nutrient quality of a pasture, however, it is also important to consider the nutrient content of pasture, which had significant influence on the grazing capacity of a rangeland and it's stocking rate. The seasonal variation of rainfall in Africa contributed to the fluctuation of crude protein (CP) and digestibility of forage (Pratt and Gwynne, 1977). Generally, wet season is characterized by the high CP content, energy and digestibility from new growth as compared to dry season.

Overall, the rangelands of Borana were over stocked and degraded seriously which affect the livelihood of pastoralists. The stocking rate of the study region was varied seasonally and spatially. Adjustment of stocking rate to the grazing capacity for the different season and sites are required. However, sudden reduction of livestock number within a short period might lead to the failure of price and discouraging the pastoralists to participate in the events. Though, policy makers have to involve in awareness creation among pastoralists in terms of destocking and re-stocking of livestock situational based on the availability of feed for sustainable production. This study had determined the potential grazing capacity value (2.12 to 6.09 ha/TLU), hence there is a need to correct the stoking rate to the safe potential for economic viability and environmental friendship and sustainable production. Finally, the future study have to focus on alternative optimization of stocking rate by considering marketing facilities for increase off-take, supplement feeds and improved productive breeds.

7.4.2 Land-use suitability

The major reasons for unsuitability of the rangelands for livestock production were scarcity of rainfall (<300 mm) and bush encroachment, the type of soil and slope (Amiri, 2009). Overall, the density of woody plant is believed to suppress the production of the grass layer, thereby reducing the grazing capacity of a rangeland under low management input. Several studies (Wijngaarden, 1985; Dalle *et al.* 2006a) indicated that an increase in the woody plant density beyond a critical limit is normally accompanied by a decrease in herbaceous composition. These resulted in the reduction of herbage production and grazing capacity. The summary of research finding of Oba (1998), revealed that rangeland use classification mainly based on the type of vegetation, precipetation, soil and slope of the area. Additional points to be taken into consideration during evaluation of rangeland-use are grazing behavior of the different species of livestock and suitability of the area from management aspect. Furthermore, biodiversity and occurrence of disturbance have to be considered because a desirable grass can be replaced with a less desirable woody species as result of succession and competition for nutrient and water.

Amiri, (2009) underscored the need for land-use assessment as an important management tool for rangeland resources for the improvement of livestock production and livelihoods of the pastoralists. FAO (1991) revealed that characterization of rangeland into suitability classes does not necessarily mean express utilization of the land but other factors, e.g. overall sustainability, have to be taken into account for determination of proper rangeland use.

This study revealed that among all factors that determine production of biomass and potential of area for livestock production, precipitation (rainfall) is the most important one and most rangelands are characterized by low total precipitation (less than 500 mm per year). This implies that as rainfall increases the production of grasses increase. In marginally suitable areas grass production can be improved through management interventions. For example, maintaining a sound soil and water management are very critical in arid and semi-arid areas to increase herbage production as in turn contributed for better grazing capacity for sustainable livestock production.

7.5 CONCLUSIONS

Range management decisions depend heavily on estimation of the grazing capacity and ability of the rangeland to sustain production without deterioration. In arid and semi-arid environments, pastoralists and livestock industry owners are more challenged by several factors with regards to proper rangeland management. The main objectives of predicting the grazing capacity is to quantify the resource endowment, understand the interrelationships between resource components, forecast environmental impact, estimate livestock support capacity, and envisage the physical sustainability of a land for livestock feeding. Such information is enabling the rangeland managers to identify limiting factors and apply practical managerial decision.

The grazing capacities of arid and semi-arid area are mainly determined by the variability of inter-annual precipitation. The condition of rangeland and density of wood plants might also contribute to the inconsistency of grazing capacity of the region. The overall dry matter production in the Borana rangelands was not adequate to meet the requirement of Tropical Livestock Unit in the region. There was no difference in terms of the grazing capacity for the different land-use systems of the Borana rangeland due to limitation of precipitation, grazing pressure and density of woody plants. Therefore, determination of grazing capacity is required for the economic feasibility and ecological sustainability of the production systems in the region. The adjustment of stocking rate to the potential of grazing capacity is also suggested.

CHAPTER 8

PERCEPTIONS AND COPING MECHANISMS OF PASTORALISTS TO THE CHANGES AND CHALLENGES IN THE BORANA RANGELANDS

Abstract

Rangeland deterioration or degradation is a worldwide phenomenon; more to a traditional management systems. More often the challenge is whether the custodian of the resources understands these changes and their potential impact. This study was conducted in the Borana rangelands to assess pastoralists' perceptions towards the changes to the rangeland and their traditional coping mechanisms. Data were collected from a total of 200 respondents in five villages i.e. 40 respondents per village using individual interviewees. The majority of respondents believed that their rangelands were degraded and the reasons given were recurrent droughts (83%), shrinkage of rangeland (78%), increased livestock population (65%), expansion of bush encroachment (49%), settlement (38%), increased human population growth (20%), expansion of private enclosures (18%) and cropping (17%). About 5% believed this was due to the weakening of the traditional institution, while 3% attributed degradation of rangelands to tribal conflicts. Only 1% of the pastoralists implicated climatic change and the expansion of peri-urbanization as cause of rangeland denudation. The majority (94%) of respondents believed that their traditional coping mechanisms of natural and man-made catastrophe had declined, while 4% of the respondents asserted that their coping mechanisms had increased or remained unchanged. The moderate numbers of respondents (38%) agreed that the influence of formal government institution and infiltration of the highland farmers to the area and grabbing their rangelands contributed to the weakening of the Borana pastoralists coping mechanisms. In addition, those pastoralists who lost their livestock due to the recurrent droughts and conflicts started involving in opportunistic cropping, which hinders strategic mobility of pastoralists as a coping strategy. On the overall the pastoralists had a good knowledge of their rangelands and reasons of the weakening of the traditional coping strategies. Therefore, designing appropriate intervention strategies based on three important pillars namely management, social and economic, would enhance communities' resilience and reduce their vulnerability to risks of drought and rangelands degradation.

Key words: Traditional resource management, livestock productivity, semi-arid rangeland, range condition, bush encroachment.

8.1 INTRODUCTION

Pastoralists are people whose lives are based on livestock economies and occupy the bulk of the arid and semi-arid regions of the world (Sandford, 1983; Friedel *et al.*, 2000). An estimated 59% of all ruminant livestock in Africa is reported to be found in pastoral areas, and this represents a significant portion of Africa's agricultural production (Scoones, 1995). In the eastern part of Africa, pastoralism is the predominant way of life and occupies about 85% of the land mass of Somalia, 95% of Djibouti and 60% of Uganda (IGAD, 2004). In Sudan, pastoralism involves about 20% of the population and accounts for almost 40% of the livestock wealth (WISP, 2007). An estimated 62% of the land mass of Ethiopia belongs to pastoralists who make up about 12-15% of the country's population (Gezahegn, 2003). The Ethiopian rangelands are a valuable resource not only to the pastoralists but also to the nation (Oba, 1998) and they hold 40% of the national cattle herd, 50% of small ruminants and almost all camels (Hogg, 1997). The Borana rangelands account for 7.6% of the total land mass of Ethiopia (Oba, 1998).

In the past, in a rather stereotypic perception, pastoralist production systems were considered as archaic and that they damaged the environment by hoarding large numbers of livestock for localized social values and prestige rather than for marketing (Sandford, 1983). The concept of the tragedy of the commons (Hardin, 1968) unfairly characterized pastoral management as irrational and destructive, much to the detriment of true pastoralism in the eyes of international and national policy makers. Consequently, pastoralists have largely been marginalized and deprived of their right to land and pushed out of the rangelands and replaced by non-pastoral settlers who have cultivated large portions of the rangelands (Fratkin and Roth, 2004) with a resultant loss of livestock from shortages of feed and water.

However, modern scholars have acknowledged the rationality of pastoralism and have since questioned the premise of the “destructive theory” of traditional pastoral management (Mace, 1991; Azadi *et al*., 2009). It is now widely accepted that pastoralism is the best-bet system in arid/semi-arid areas. In reality, pastoralists invest a lot of effort in maintaining rangeland health and sustainability by using several customary by-laws and indigenous ecological knowledge (IEK) accumulated over centuries (Dube and Moyo, 2010). Misunderstanding of pastoral dynamics and their internal mechanisms of rangeland management by policy makers, development actors and researchers contributed immensely to the deterioration of the rangelands of East Africa, including the Borana (EARO, 2002; Gezahegn, 2003; Dalle *et al*., 2006b).

The traditional pastoral institutions in Ethiopia that have managed the socio-economic and political issues of the communities are Abba *Gada* in Borana, *Ugaz* in Somalia and *Edo Aba* in Afar. These institutions are governed by indigenous norms and values that enable the smooth operation of the pastoral system in the dry-lands (WISP, 2007). The systems encourage consensus based decision-making and peaceful co-existence in the community. This strongly refutes the assumption of the theory of the 'tragedy of the commons' as baseless and unrealistic. As more studies are conducted on pastoralism, it has become apparent that there is a need to use both Indigenous ecological knowledge (IEK) and modern rangeland science in a complimentary rather than conflicting manner (Dalle, 2004; Mortimore, 2005).

Since the 1980, the Borana rangelands have gradually been shrinking and the quality has been declining as significant areas are converted to wood and crop lands (Oba and Kotile, 2001, Angassa and Baars, 2002; Dalle et *al.,* 2006b). This has largely been due to overpopulation, overgrazing, improper intervention, and adverse effects of droughts. Regarding the Borana rangeland management, little has been reported about the role of traditional management and coping strategies (Oba and Kotile, 2001; Dalle *et al*., 2006 and Tefera *et al*., 2007). Improper national and international interventions coupled with settlements by non-pastoralists have weakened their traditional institutions (Mesfin, 2001 and Dalle, 2004). There are genuine fears that because of the weakened traditional institutions there has been a gradual erosion of IEK and reduced transmission of traditional coping mechanisms to the modern pastoralist (Angassa and Oba, 2007; Dube and Moyo, 2010). This poses a direct threat to sustainability of pastoralism in the Borana area.

However, there is still inadequate information on aspects of the traditional pastoralism (e.g. coping mechanisms to challenges) to guide policy makers and development agents. This study was designed with the following objectives:

a) To understand pastoralists' perceptions of the recent changes to the rangelands and the resultant pastoralist-rangeland interactions in Borana and
b) To assess pastoralists' mitigation and coping mechanisms to the changes and challenges of traditional pastoralism.

8.2 MATERIALS AND METHODS

8.2.1 Description of the study area

The Borana zone is one of the known pastoral areas of Oromia Regional State in Ethiopia. The basic information of the study areas are briefed in detail in Chapter 1 section 1.6.1.

8.2.2 Data collection

A questionnaire survey was conducted among 200 respondents. The questionnaire explored issues on livestock and rangeland management, crop production and aspects of demography. The survey also examined land-use changes, current challenges and coping mechanisms. Group discussions were conducted with the development actors in the study area to elicit information on the communal land-use patterns and changes in vegetation characteristics around settlements. Joint transect walks were conducted with knowledgeable herders and experienced experts to assess environmental changes.

The respondents were selected from five villages namely: Surupha, Did-Hara, Mana-Soda, Medhacho and Bokkulboma in August-October 2010. The villages were systematically selected after discussion with the community leaders and government officials, who have the knowledge of the study region. Systematic adjustments were performed to allow for accessibility and general representatively of the study area. After general discussions in each village 40 respondents per village were selected by the community based on their experience and ability to articulate the local situation as well as their environs ability to feed back to the community. All the selected respondents had spent their entire lives in the study area and depended on pastoralism for their livelihoods. The survey data was analyzed using SPSS software (version 17.2).

8.3 RESULTS AND DISCUSSION

8.3.1 Respondents profile and traditional practices

Of the 200 respondents interviewed 90% were men, while the rest were women with an average age of 40 years old. The majority of the respondents (96%) were married, (3.5%) single, and a small group (0.5%) was widowed. The size of a household ranged from 1-16 members with a weighted average of seven. The majority of respondents (68%) followed the Oromo religion *Waqqeefnaa, 26.5%* Muslim and 5.5% Christian. The level of illiteracy was high with 79% of the respondents without primary education, 16% with primary school level and only 2% with junior and/or senior school education (Table 8.1).

Table 8.1 Demographic information of the Borana pastoralists

Family size	%	Education	%	Livelihood activity	%
1-4	31	None	79	Livestock rear only	59
5-10	54	Primary	16	Cropping only	8
11-15	9	Junior	2	Mixed	22
>16	5.5	Senior	2	Other	12
		Tertiary	1		

The general household sizes and structure are typical of the east African pastoral communities (Abule *et al*., 2005; Terefe *et al*., 2010). The main livelihood occupation was livestock herding (59%), cropping 8%; mixed farming 22% and 12% of the respondents had other non-farming activities (Table 8.1). Income per household ranged from “500 to 3000 Birr” with a weighted average of 605 Ethiopia birr (US$ 34) per month closer to poverty line and below per capita in Ethiopia.

The income of Borana pastoralists was mainly from livestock which is in agreement with the report of Abule *et al*.(2005) in central rift valley of Ethiopia and the East African countries (Ndikumana *et al*., 2001). Less number of pastoralists involved in small petty trade as means of income generation. The present study indicated that as a consequence of increase of human population and climatic variability livestock cannot be able to support the Borana pastoralists as source of food and filling of their other requirement which initiate opportunistic cropping that agree with report of (Takele, 2006).

8.3.2 Pastoralists and their environment

8.3.2.1 Perceptions of range condition

The perceptions of pastoralists on the condition of the Borana rangeland are presented in Fig 8.1. About 95% of the respondents rated the range condition from poor-to-very poor, and the remaining 5% as fair to good. The various reasons given for the poor condition of the rangeland are presented in Table 8.2. The top five reasons given were: recurrent droughts (83%); reduction of rangeland area (78%); increased livestock numbers (65%); bush encroachment (49%) and increased sedentary settlements (38%). Some of the respondents indicated that weakening of traditional by-laws and tribal conflicts contributed to the degradation of rangeland. Pastoralists who linked poor rangeland condition to climatic change and expansion of peri-urbanization were relatively insignificant compared to the top reasons advanced.

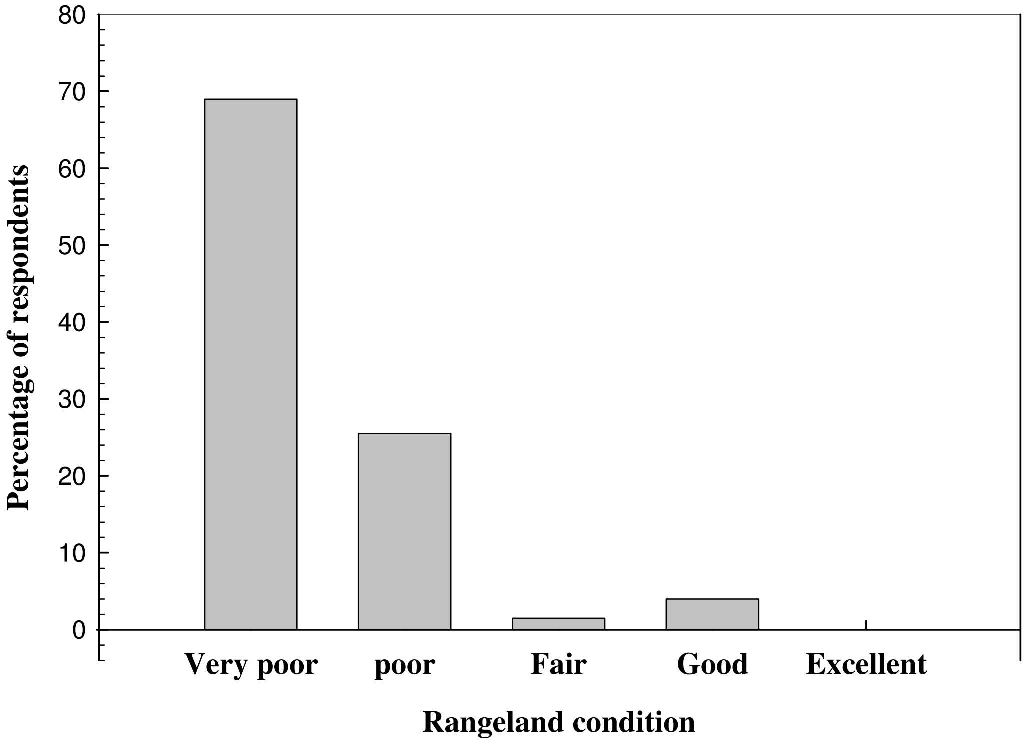

Figure 8.1 Borana pastoralists' perceptions on rangeland condition

It is considered that the Borana pastoralists have a strong traditional system "Seera *Gada*" which they have been using to regulate rangeland use and management. The identification of weakened traditional by-laws as a causal factor to rangeland degradation has significant ramifications. On the overall, the perceptions of the pastoralists on rangelands degradation are in agreement with studies, of Angassa and Fekadu (2003); Tefera *et al*. (2007); Dalle *et al.* (2006b).

Table 8.2 Perception of Borana pastoralists on the causes of rangeland degradation

Major rangeland problems	percent
Drought	83
Shrinkage of rangeland and feed scarcity	78
Increment of livestock population	65
Bush encroachment	49
Settlement	38
Increment of human population	20
Expansion of private enclosure	18
Expansion of cropping	17
Livestock diseases	7
Weakening of traditional by-laws	5
Conflict	3
Peri-urban expansion	1
Number of water points	1
Termites	1
Change of climates	1

8.3.2.2 Recurrent droughts

Drought was the main causal factor for the poor range condition. The impact of droughts on rangelands is influenced by their intensity and frequency (Snyman, 1999). Pastoralists noted that droughts used to occur every 10 years but in recent years droughts have been occurring every three to five years. The severity of the drought and time serious of its occurrences indicated as below:

Table 8.3 Traditional and official record on severity and frequency occurrences of drought

Traditional period (Gada)	Years	Official record of drought	Classification of the drought
Goba	1969-76	1972; 1974	Moderate
Jilo Aga	1977-84	1984	Severe
Boru Guyyo	1985-92	1991	Light
Boru Medha	1997-2000	1999; 2000	Moderate
Liben Deljesa	2001-2008	2005;2006	Light
Guyyo Gobba	2009	2009	Light

OWWDSE (2009)

The direct impacts of drought were manifested through the scarcity of water and forage for livestock. The Borana pastoralists also believed that the frequently occurring droughts were responsible for the shifts from herbaceous species to woody vegetation such as *Acacia* and *Commiphora spp*.

8.3.2.3 Human population, settlement, cropping and rangeland resource

Among the respondents about 38% and 20% believe that rangeland degradation is due to the settlement and growth of human population, respectively (Table 8.2). The human population growth is as result of infiltration of the high land farmers to the area as well as possibility of polygamy marriage of the community. The main purpose of such settlement emanates from the desire for effective and efficient use and easy management of the communal grazing lands in their area. On the other hand, the recent expansion of public service like school and health posts contributed to settlement of pastoralists as supported by government which aimed for sedentariztion of pastoralists as clearly stated in rural development strategy of the government.

Despite this the opportunistic farming activities also contributed to settlement to manage the farm plot as mentioned by respondent pastoralists. In addition, the water development intervention started in the 1970s (Coppock, 1994) by the government and other development actors in the wet grazing areas resulted in permanent settlers affected that contributed to the shrinkage and degradation of rangelands. The settlers started opportunistic farming on the same grazing land, which resulted in conflict between pastoralists and farmers due to competition for limited resources (Alemayehu, 1998). The Borana plateau recently engaged in large population of pastoralists that are settled in certain area, which minimize the transhumance movement of pastoralists to utilize the scarce resource in time and space.

Some respondents among the Borana pastoralists (18%) argued that the introduction of private enclosures considerable contributed to the shrinkage of rangeland that restricted easy of mobility for livestock, which was practiced by the Borana pastoralists as the rangeland was owned in common (Table 8.2). Moreover, the current proliferated private enclosures were different from the previous and not managed by the customary institution as according to their norms. It is private belongings which reduced the communal grazing areas leading to the deterioration of the rangeland. On the other hand, the expansion of cropping as a result of increment of destitute pastoralists contributed to the establishment of private enclosures. In addition, the beginning of commercialization of hay by destitute people and certain market oriented pastoralists accelerated the private enclosure. The challenging issue is that the inability of the traditional institutions like (*Ardaa and Reera)* are not governing the defacto private enclosure into the communal grazing area, which contributed to the dwindling of the Borana rangelands (Tache and Oba, 2010)

The present study confirmed that there is an expansion of cropping in the study area. Among the interviewed pastoralists, about 85% were involved in cropping and they had farming plot, while only 15% are not involved in farming. Historically, farming in the Borana areas were restricted to the sub-humid rangelands near towns and cultivators were largely non Borana immigrants (Oba, 1998). Previously, the Borana rangelands were exclusively used for grazing and strictly regulated by customary norms and traditional rules, which were obeyed by the pastoralist communities (Angassa and Oba, 2008b). However, in the late nineteenth century after the expansion of Menelik II to the other part of the present Ethiopia, the military families who settled in towns started cultivation of the rangelands closer to the city to fulfill their food subsistence need (Angassa and Oba, 2008b; Tache and Oba, 2010). In addition to this, the neighboring high land farmers were migrated to the Borana rangelands and started opportunistic cropping (Helland, 1997; Waston, 2004) around the bottom valleys. These bottom valleys had better moisture and forage for dry season grazing for calves and the expansion of cultivation in such areas created conflict with the need of the Borana pastoralists (Oba, 1998). A large scale expansion of crop cultivation is a recent phenomenon, especially since 1997 of the El Nino year, where people had good harvest that year.

As the frequency of droughts increased from time to time, the role of livestock production to supplement pastoralists' livelihood was declined. On the other hand, the need to maximize options for drought survival also increases more than any other time (Tache and Oba, 2010), which contributed to the denudation of rangeland. In addition, the 1970s Ethio-Somalia war created a large number of destitute pastoralists due to the loss of their animals as consequence of war that forces the drop-out of pastoralists from pastoralism to start opportunistic farming for survival even if the erratic nature of rainfall is not favouring farming activities. The competition between cultivars and pure pastoralists for bottom valleys was accelerated, however, cultivars are supported by the government policy as they are paying tax for a plot of land they own but pastoralists were less favoured by the current government policy and as result they lose their communal lands from time to time, which led to the deterioration of rangelands (Yacob, 2001; Helland, 2006).

8.3.2.4 Pastoralists' perception on rangeland ecology

Pastoralists' perceptions on the condition of rangeland ecology are presented in Table 8.4. The listed parameters are the main ones they have traditionally used to monitor rangeland health. In general, they believed that the basal cover of herbaceous plants, the proportion of perennial species and density of desirable species were reduced in the recent years. On the other hand, the proportion of undesirable species, woody plants and bare ground increased. This translated into reduced grazing capacity or overgrazing. This general trend is an indicative of the deterioration of the rangeland resources.

Table 8.4 Indicators of rangeland ecology as understood by Borana pastoralists

Indicators of rangeland degradation	Respondents (%)			
	Increased	Decreased	Unchanged	Not clear
Basal cover of herbaceous	2	98	1	0
Perennial to annual herbaceous ratio	8	93	0	0
Density of highly desirable herbaceous	6	94	0	0
Density of less desirable herbaceous	93	7	1	0
Degree of bare ground	88	6	5	0
Rangeland grazing capacity	8	90	2	0
Woody plant encroachment	91	9	0	0
Overgrazing /grazing pressure	94	7	0	0

Regarding bush encroachment, the majority of the respondents (79%) indicated that their rangelands were severe encroached by invasive woody species (Figure 8.2). The most frequently occurring woody species were *Acacia tortilis, Lannea rivae, Grewia tembensis, Commiphora habesssinica, Rhus ruspoli, Acacia nilotica, Commmiphora Africana,* and *Acacia drepanolobium*. The other species moderately distributed included *Grewia bicolor, Commiphora fluviflora, Acacia etabaica, Acacia bussei and Acacia mellifera.* According to the view of pastoralists, the expansion of bush encroachment was a recent phenomenon. Bush encroachment was viewed as a threat to rangeland health although a few of them took it as an opportunity for timber based products.

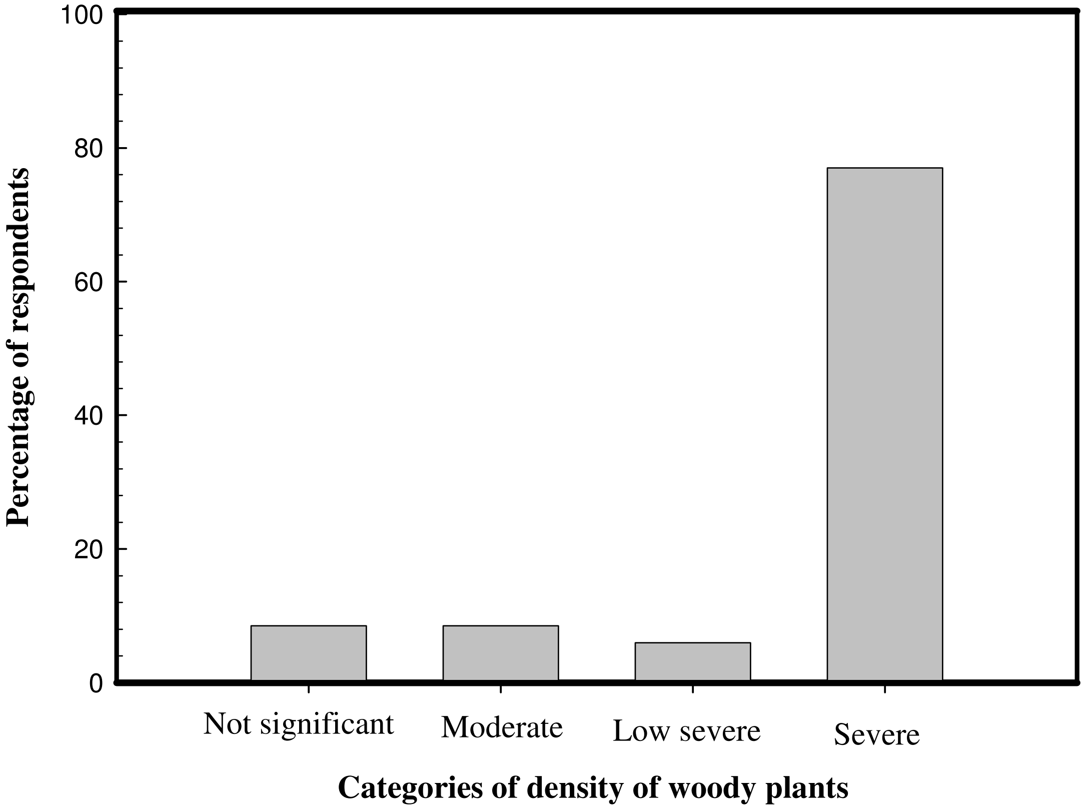

Figure 8.2 Perceptions of Borana pastoralists on the density of woody plants on the rangeland

Previous studies (Dalle, 2004; Tefera *et al*., 2007; Angassa and Oba, 2010) have also indicated that shrubs and woody plants were generally replacing the desirable herbaceous plants in the Borana rangelands. Bareness of the rangeland was considered by pastoralists as a good indicator of rangeland degradation and they explained the situation as follows "*Barbadaa diilluun huba hinfunnee*", which have meaning of severe degradation of environment.

Factors that might have triggered the expansion of woody encroachment included frequent droughts, ban of range fire, increased number of browsers and mix herding of grazers and browser (Abule *et al*., 2005; Dalle *et al*., 2006a), which has a potential of dispersing seeds of encroaching woody species through dung deposition. On the other hand Borana pastoralists appreciated the negative correlation between the density of invasive woody cover and herbaceous plant species composition. According to Roques *et al*. (2001), the density of the wood plants is considered beyond the threshold when it exceeds 40% or 2500 TE ha^{-1}. The observation by pastoralists was that the increased woody cover is a recent phenomenon. Beyond the reduction of herbaceous biomass, woody vegetation restricts mobility of animals to graze freely, and harbor ticks and wild beasts that harm livestock (Dalle *et al.,* 2006a). Some respondents highlighted the use of woody plants for construction, fuel, and medicinal purposes.

8.3.2.5 Water availability

Pastoralists perception on the of water situation in the Borana areas are presented in Table 8.5. Inadequate rainfall and frequent droughts have led to decreased surface water availability and low water table. This translated to a reduced access to water by both humans and livestock. The general reaction of the communities and government was to construct more artificial ponds and deep wells. This, however, had also contributed to the degradation of the rangeland as animals tended to concentrate around the ponds and wells.

Table 8.5 Perceptions of Borana pastoralists on water resources

Indicator of rainfall & water resources availability	Respondents (%)			
	Increased	Decreased	Unchanged	Not clear
Adequacy of rainfall	6.4	92	1.6	0
Surface water availability	4.3	95.2	0	0.5
Depth of water table	54.3	12.8	3.7	29.3
Access to water by human and livestock	5.05	94.5	0.55	0
Drought frequency	88.2	8.6	1.1	2.1

Earlier studies (Yates *et al*., 2000; Landsberg *et al*., 2002; Dalle, 2004) in semi arid areas have confirmed that the uneven distribution of water points in the rangeland created degradation of the rangeland as a consequence of increased grazing pressure. The limited water points attract animals and have a piosphere effect causes on vegetation composition around the water point, favouring the woody plants at the expense of palatable herbaceous species (Tefera *et al*., 2007). Denudation of the rangeland closer to the water point is largely due to the effects of heavy grazing and trampling.

8.3.2.6 Traditional resource management

8.3.2.6.1 Historical perspective

Under a normal situation a rangeland is managed by the traditional system based on consensus of the local communities when and where to graze and to manage the key resources which are distributed unevenly in the study area. The traditional land tenure system, on the other hand is under the jurisdiction of the traditional institution (the *Gada*), in which the customary laws and regulations are applied. According to the local custom, the authority of land ownership lies with the *Raba Gada* (a supreme governing council of the *Gada* system). The *Raba Gada* creates rules and regulations on how resources can be utilized. One of the tasks of the assembly of *Gumi Gayo* every eight years is to make pronouncements of new rules to cope with the ecological, socio-economic and political changes. The loss of land can therefore only confirmed at the assembly of *Gumi Gayo*. Without this authority the land may not be disposed or sold. The communities of *dheeda* or the *mada* have use and management rights but lack judicial powers to dispose the land (Oba, 1998). The traditional institutions like the *Gada* system has no formal legal recognition by the government on matters of administration of the land, although, the rules and regulations are approved and implemented by their respective communities. The institutions have the defacto right to rule over the pasture lands in their areas. However, in strictly legal terms, all pastoral lands are now owned by the state (Helland, 2006).

The Borana communities in the study area did not settle in a haphazard manner, rather they have over a long ago developed rules and regulation for settlement. Their settlement pattern is directly related to the location and direction of the main communal grazing land (*mata tika* and *kalo*), on the one hand and *madda* (water source) on the other. No one in the community is allowed to settle in the main communal grazing land (*mata tika*).This type of settlement is called *seera dongora,* which literally means customary rule and regulation that guides and controls the pattern of settlement of the community in the area. Also special enclosures are governed by the customary rules and norms for management of the key resources or maintaining fodder banks for use during times of feed scarcity.

8.3.2.6.2 Weakening of traditional institutions

Some respondents asserted that the traditional *Gada* system was losing its power of administration and this contributed to the denudation of the rangeland. More than 94% of the respondents agreed that the traditional coping mechanisms had decreased and this contributed to the degradation of the rangeland through abeyance of rules and regulations of the traditional system (Table 8.6).

Table 8.6 General Borana pastoralists understanding of situation in the Borana rangeland

Parameter as indicators	Respondents (%)			
	Increased	Decreased	Unchanged	Not clear
Expansion of cultivation	70	24	5	1
Possession of animals per household	29	69	1	1
Traditional copying mechanism	4	94	2	1
Poverty trend	89	8	2	1
Conflict on resources limitation	43	27	23	7
Expansion of settlement & peri-urbanization	83	15	2	1

Respondents mentioned that the expansion of settlement had increased by 83% and this contributed to the reduction of the communal grazing area leading to the restrictions of livestock mobility, and ultimately decrease coping mechanisms especially scanning of feed resource. A moderate number of respondents (43%) believed that conflicts in the study area had increased, which also contributed to scarcity of grazing area. Poverty had increased in the study region, resulting in violations of the traditional norms of the communities. All these and other challenges in combination weakened the traditional coping mechanisms of the Borana pastoralists. Findings of other different studies indicate that the *Gada* system in Borana still exists in principle but is weakened in practice due to the influences of different natural and human factors (Fasil *et al*., 2001; Helland, 2006).

8.3.3 Livestock production and feed availability

The main livestock performance indicators from the survey are presented in Table 8.7. Relative to the historical indicators, pastoralists mentioned that fertility levels were declined; calving intervals and growth periods to maturity were increased. According to pastoralists, the general animal body condition and milk yield were decreased. The majority of respondents (71%) perceived that the numbers of livestock had increased, while 20% believed there had been no change in livestock population. Few respondents (10%) had no views on livestock population trends (Table 8.7). The majority of respondents (90%) believed there had been a decrease in feed availability for the existing livestock population. Few 9% felt had not change, with 1% indicating an increase in feed availability. About 44% of the respondents believed there had been an increase in livestock marketing, and a similar proportion had an opposite view.

Table 8.7 Reflections of Borana pastoralists on animal performance indicators

Animals performance indicator	Respondents (%)			
	Increased	Decreased	Unchanged	Not clear
Period laps for growth to adult	79	20	1	1
Body condition	2	97	2	0
Milk yield	1	98	1	0
Susceptibility to disease	75	22	3	0
Calving interval	82	14	4	0
Fertility	4	93	2	1
Number of livestock	71	0	20	10
Feed availability	1	90	9	0
Marketing	44	42	10	4

Pastoralists' observations also showed that, the increase in human and livestock population put severe pressure on the rangelands which also in agreement with previous reports (Coppock, 1994; Desta and Coppock, 2002; Tefera *et al.*, 2007). The inadequate feed availability reflected by pastoralists in the present study are in agreement with reports by Amsalu and Baars (2000) for the rift valley of Ethiopia and Dalle *et al.* (2006b) for southern Ethiopia, who documented poor range condition and the resultant low forage production in their respective study areas.

Because of low livestock productivity, household income had declined and the pastoral household became food insecure. The most vulnerable households turned to cropping and cutting trees for timber and charcoal making as alternative sources of income. These low levels of productivity are directly linked to reduced rangeland productivity and poor feed availability for the animals. Pastoralists generally believed that livestock production is becoming difficulty and this is exacerbated by poor marketing systems in the study region.

8.3.4. Coping mechanisms

Traditional coping mechanism to rangeland degradation and other social challenges are presented in (Table 8.8). The majority of respondents believed mobility (52%) to be the most practiced traditional coping mechanism followed by communal enclosures (15%) and herd diversification (10%). Few (1%) respondents indicated the building of fixed assets like houses in town, selling of water and sending children to school as recent phenomena. The traditional social credit (*Busa Gonofa*) was also used as a coping mechanism although it has declined in recent times. The respondents mentioned that women were more involved in petty trading for income generation activities than men.

The destitute pastoralists are involved in cross border trading and also participate in the traditional mining activities as coping mechanisms rather than creating pressure on their rangeland. Collection of fire wood and charcoal had increased as a coping mechanism and this exacerbated the devastation of remittent forest and aggravated aridity. Furthermore, the Borana pastoralists have been forced to diversify their herd stock to include camels which cope with the encroaching woody plants and recurrent droughts. Sandford and Habtu (2000) reported the traditional coping mechanisms of pastoralists are not effective but Dahl (1979) appreciated the tradition coping strategies of pastoralists.

Table 8.8 Coping mechanism to rangeland degradation and other social challenges

Traditional coping mechanism	Response (%)
Mobility	52
Enclosure	15
Herd diversification	10
Selling animals	6
Petty trade	5
Cropping	5
Social credit (*Busa Gonofa*)	2
Fire wood and Charcoaling	1
Mining	1
Building fixed asset	1
Selling of water	1
Educating child	1

Recently, rich pastoralists started selling animals at good condition and building houses in towns and rent these as a risk aversion strategy and source of income. The selling of animals also helps in reducing the grazing pressure. The establishment of savings and credit cooperatives by government and non- government actors also helped the poor men and women to access credit. This created opportunity for poor pastoralists to participate in grocery (sugar, salt, tea, coffee) and trading of small ruminants. Women were involved in the beverage business which might had both positive and negative results. Income generating was a positive aspect but these beverages also led to the deteriorating traditional culture.

Generally, water and forage utilization were determined by the *Gada* system (*Abba hirega* for water management, *Aba dheeda* for grazing pasture). The time of grazing and watering were determined by the *Gada* system and also at times of shortages the *Gada* decided the number of animals to drink and/or graze in a given area as well as the number of animals to be sold to balance the existing resources with the number of animals. Currently, private water cistern development is a newly phenomenon which has been selling of water from private belongings as a coping strategy. Private enclosures have also been adopted by individuals as adaptive strategies contrary to the pastoralists' norms. Communal enclosures which have been used as a reserve in times of severe shortage to feed particularly calves, milking animals and small ruminants that stayed around the homestead. Some ever-green trees such as *Acacia tortilis* and *Balanities aegyptica* are used as fodder during serious feed shortage. Mobility was one of the mechanisms in utilizing the grazing or water resources that varies in space and time. Recently, the *Gada* system retrieves in restricting the expansion of opportunistic farming activities and random settlement as the customary rules and regulation; however, cropping and settlement are supported by government. Overall the Borana pastoralists inhabited in the study area about six hundred years ago and the pastoral system is the best mechanism in such arid environments as a means of life than other activities like opportunistic farming and has developed several coping mechanisms (Helland, 1997).

8.4 CONCLUSIONS

This study confirmed that pastoralists are knowledgeable about the changes in their rangeland and the weakening of their traditional coping strategies. They believed that their rangelands were deteriorated and contributed to the weakening of the traditional coping strategies. They also asserted that there were changes in the rangeland conditions and traditional institutions that resulted in food insecurity. The Borana pastoralists agreed that their rangelands has degraded due to recurrent droughts, shrinkage of the rangelands, grazing pressure, expansion of cultivation, settlement and weakening of the traditional institution and procedures. The traditional coping mechanisms had weakened from time to time and now the pastoralists are unable to manage the complex problems. It is concluded that the current communal rangelands cannot be sustainable unless appropriate interventions are put in place. Wrong interventions like unplanned settlements, expansion of private enclosures and ignorance of traditional practices by different stakeholders have affected the pastoral communities in the study area. Restriction of herd mobility and alienation of rangeland to non-pastoralist use exacerbated the erosion of the traditional coping strategies of pastoralists. Therefore, to alleviate the problems pastoralists are facing, it is vital to understand the rangeland condition and wisdom that the pastoralists have accumulated over several years. The development plan should be inclusive of all stakeholders in planning, implementation, monitoring and decision making processes for long lasting solutions. The pastoralists' experience and modern scientific knowledge have to complement each other.

CHAPTER 9

GENERAL CONCLUSIONS AND RECOMMENDATIONS

In arid and semi-arid areas pastoralism is an efficient means of utilizing the spatially and seasonal distributed natural resources with a low risk of degrading the environment. Arid rangelands are generally characterized by low rainfall and limited potential for arable farming, low human population density and extensive livestock production. However, the scenario is changed today due to recurrent droughts, shrinkage of the rangeland, and increase in human population in the regions.

Land-use patterns in the Borana plateau have drastically changed from communal to private ownership as the classical pastoral way of life has changed to a sedentary agro-pastoralism due to inappropriate government policy and expansion of cropping. The rangeland biomass production has declined and this was exacerbated by the poor management and uneven distribution of the limited patch resources. The traditional way of range resource utilization and management relied on seasonal mobility to overcome scarcity of feed. However, the indigenous wisdom of pastoralists is not widely appreciated by modern technocrats and this has led to ill-treatment of the eco-system with detrimental effects on the livelihood of pastoralists.

Generally, the study identified grazing pressure, recurrent drought, anthropogenic factors, altitude and soil texture and chemical properties are the most important variables in driving vegetation dynamics and rangeland condition in the study areas. In the present study, a total of 23 herbaceous species, 46 woody species, 21 shrubs and 14 forbs were identified as the components of the vegetation. *Chrysopogon aucheri*, *C. ciliaris* and *E. papposa* were the most frequently appeared herbaceous species, while the most frequently emerged woody species included: *A. tortilis, L. rivae, G. tembensis, C. habesssinica, R. ruspoli, A. nilotica, C. Africana* and *A. drepanolobium*. The distributions of these plants were influenced by the amount and distribution of rainfall, intensity of grazing, range management, topographic variation, soil types and nutrients.

There were significant differences in dry matter production between the different study sites of the Borana. The dry matter production in the cooperative ranch (Dambala-Wachu) was significantly higher than the other sites. Surupha and Medhacho communal grazing areas produced the lowest biomass. The decreaser species produced the highest proportion of dry matter (60.73%). Increaser IIa and IIb produced the second highest dry matter (29.86%) production, while increaser IIc contributed low biomass (7.88%).

The mean density of woody plants was significantly differed among the different sites; however, there were no significant differences in the density of woody plants among the Government ranch, Cooperative ranch, Surupha and Did-Hara communal grazing areas. The density of woody plants was low at Medhacho and Mana-Soda compared to the government and cooperative ranches. The different management interventions contributed for the variation in dry matter production at the different sites.

The intensity of bush encroachment across the study sites in Borana greatly varied from moderate to severe encroachment probably due to the combined effects of climatic variability, edaphic factors, grazing pressure, anthropogenic and management aspects. Consequently, the rangelands of the study areas were in the category of poor to fair condition.

The soils of the Borana ranged from sand, silt to clays. Sandy soils were dominated by woody plants relative to herbaceous species. In contrast, silt and clay areas had a positive association with the herbaceous plants. The probable reason for the high density of woody plants associated with sandy soils might be the excessive leaching of nutrients run off and low pH. Soil chemical properties like calcium and organic matter contributed to the variation of herbaceous and woody vegetation composition.

Overall the density of livestock of 2010 year was higher than the grazing capacity for the Borana rangeland, there was a deficit of about 2 167 753 ton DM to feed the existing livestock.The mean grazing capacity of the Borana rangeland using rainfall data of 2010 year was 1.43 ha/TLU. There were no differences in the grazing capacities of the different sites studied.

Patch resource centered grazing and settlements have created a large piosphere effect in the region, which is largely devoid of vegetation and exposed to erosion. The vegetation cover and biomass production were declined nearby water and mineral lick points. The plant composition underwent dramatic changes from grassland to woodland around the sacrifice zones of the water and/or mineral lick points. The most desirable grasses could not tolerate the repeated impacts of livestock grazing and trampling and eventually replaced by less palatable woody and forbs species. The dry matter yield of herbaceous vegetation nearby patch resource sites was significantly lower than those at far away zones. The study showed the negative impacts of perennial water points and mineral salt points to herbaceous and woody plant composition and productivity. However, the grassland exhibited signs of resilience to grazing pressure in terms of diversity and species richness. Despite the resilience, it is a concern that the negative impacts will extend more widely as the palatable species are diminished at sacrifice zone of water points and mineral sites. The current mixed herding of grazers and browsers has created a favourable condition for the dispersal of woody plants seeds in the Borana. Significant variation in woody plant diversity, richness and evenness were observed along a distance gradient from water point. The recruitment of woody species saplings and seedlings were high, and contributed to the decline in rangeland condition.

Forage value varied mainly with species, site, season and the stage of maturity. The CP content of herbaceous species was adequate during the main rainy season but drastically declined as plants maturity was advanced, towards the dry season. Crude protein was negatively correlated with NDF, ADF and ADL and with the sodium content of soil. On the contrary, the structural fiber contents (NDF, ADF and ADL) were positively correlated with the sodium content of the soil. Crude protein declined as the proportion of sandy soils increased, while the ADF content was high from clay soils.

In Ethiopia, the contribution of mobile pastoralism in environmental protection has not been well understood and appreciated by policy makers. There have been many official government policies and strategies designed to resettle and sedentarize pastoralists against their will and the ecological reality. Such ecological negligence in reality led to rangeland degradation and loss of biodiversity. In addition, in appropriate development interventions in pastoral areas such as large-scale state farm schemes and other natural and human-induced factors have increased the pressure on the transhumance way of pastoral life, and accelerated sedentarization. Loss of key forage resources due to expansion of crop farming and woody encroachment in key grazing areas has forced the Borana pastoralists to change the traditional land-use patterns. This was resulted in the introduction of private enclosure, limited access to patch resource and establishment of permanent settlements.

The existing livelihood system of pastoralists which is founded on livestock herding, is probably unsustainable as forage resources decline due to various reasons. The Borana people know that the range condition is deteriorating due to overgrazing and invasion of woody plants. The study confirmed that pastoralists are knowledgeable about the ongoing changes in their environment and they also acknowledged the weakening of their traditional coping strategies. The ban of rangeland fire, unplanned settlement, expansion of private enclosures and ignorance of community participation and their traditional practices greatly affected the pastoral communities' way of life. Pastoralists' perception with regarding to the increasing number of animals indicated that lack of marketing and proper prices for their animals considerably contributed to the accumulation of livestock and degradation of rangeland conditions. Restriction of herd mobility and alienation of rangeland to the non-pastoral form of land use facilitated rangeland deterioration and weakening of the traditional coping strategies of pastoralists.

In conclusion, the study indicated how the management system, biotic and abiotic factors in rangelands exacerbate the change of vegetation composition, which have implication on rangeland condition. In addition, the distributions of patch resources (water points and mineral lick) play an important role in determining rangeland condition. Generally, rangeland degradation is aggravated by permanent settlement of the community nearby water points and mineral lick, leading to restricted grazing in the area. Overall, rangeland is the center of livelihood of the Borana pastoralists. The following points are recommended:

- Both remote sensing and ground survey study results demonstrated degradation of the Borana rangeland. Appropriate management intervention need to be put in place for the sustainable use of rangelands and betterment of the livelihood of pastoralists.
- Piospheric effects accelerated the changes in vegetation composition and production around patch resources due to their limitation in distribution. Regular monitoring of the rangeland condition around the center of patch resources is crucial management aspect to halt exploration of rangeland degradation.
- Encroaching woody species in the Borana were identified. This should facilitate appropriate control methods to halt the expansion of invaders species and devastation of the rangeland.
- Nutritional constituents of indicator herbaceous species were studied and these varied across season and sites. Complimentarily use of both the laboratory and local pastoralists' knowledge should foster widespread use of this valuable parameter by both the pastoralists and modern scientists.
- The Borana rangelands are overstocked way beyond their grazing potential. This should be the basis for interaction. Mechanism of regulating the numbers need to be developed to halt further deterioration of the range resource.
- The development and application of appropriate extension services, holistic and integrated development approaches based on harmonization of scientific and traditional practice are recommended to recover the denuded rangelands from excessive bush encroachment.
- Promotion of applied research-based information with the intention to fill the gap in the knowledge base in the country in general, and in the Borana in particular, is of paramount

importance. The need of collaboration of all stake holders to tackle the situation in the arid semi-arid environment is becoming imperative.

Future research should focus on:

- Recently the Borana rangelands endures dwindling in condition which have implication on livestock production and pastoral livelihood, therefore, regular evaluation of range condition of the region and establishment practical management guidance for each land units are areas of future study.
- There is need to investigate the social, economic and environmental values of the identified encroaching woody plants, to guide control and utilization potential harmony with the perceptions of the pastoralists.
- The browsing capacity of the Borana region was not addressed in this study. In addition to the grazing capacity based on herbaceous species dry matter yield, potential of the browse yield and animal behavior need to be studied.
- Precipitations has an immediate influence on primary rangeland production, thus, the synergy of forecasting the variability of rainfall using modern technologies and traditional wisdoms has to be considered in future studies.
- Future research has also to consider identification of the breed(s) of livestock that could suitably adapt to limited forage resources, disease prevalence and limited availability of water.
- To have normal ecological function in the Borana rangelands appropriate pastoral oriented land-use policies have to be initiated and put in place for the betterment of the livelihood of pastoralists.

This study contributed the following:

- Verified the Borana rangelands into categories of poor condition.
- Confirmed the woody encroachment in major area was severe.
- Resilience of the Borana rangelands in diversity and evenness of herbaceous species.
- Confirmed complementarities of laboratory and indigenous knowledge of nutrient constituent of herbaceous.
- Verified that government and cooperative ranches management were not better in rangeland condition compared to communal.
- The Borana traditional knowledge on rangeland management and copying mechanisms are appreciated.

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APPENDICES

Annex Table 1 Correlation of herbaceous with environmental variable

	PH	sand	Silt	Clay	Na	K	Ca	Mg	CEC	T.N	O.C	O.M	Av.P	Altitude
Chry auc	.39	-.64	.50	.31	-.52	-.13	.37	.32	.36	.52	.23	.17	-.58	-.24
Dact aeg	.43	.19	.34	-.61	.97**	.81*	.37	.41	.43	-.13	.32	.27	.94**	.07
Aris ado	-.67	.79*	-.84*	-.16	-.12	-.50	-.58	-.63	-.68	-.30	-.41	-.33	.04	.18
Spor pyr	.75	.01	.61	-.65	.89**	.84*	.71	.74	.75	.26	.63	.55	.87*	.11
Eleu int	-.87*	.53	-.91**	.27	-.20	-.48	-.75	-.73	-.77*	-.48	-.61	-.50	-.16	.43
Them tri	-.68	-.11	-.54	.71	-.30	-.31	-.53	-.39	-.44	-.39	-.36	-.21	-.28	.34
Digi Sp.	-.28	-.07	-.21	.31	-.29	-.25	-.47	-.43	-.47	-.33	-.53	-.61	-.59	.32
Digi nag	-.04	-.37	.23	.24	-.27	-.02	-.20	-.26	-.13	-.29	-.35	-.38	-.33	-.72
Pani max	-.26	.89**	-.62	-.52	-.19	-.58	-.16	-.29	-.37	.25	-.02	.00	.03	.18
Both ins	.44	-.01	.47	-.48	.63	.68	.38	.27	.43	.00	.13	.03	.60	-.35
Cenc cil	.58	-.47	.63	-.05	.26	.40	.47	.65	.54	.14	.59	.59	.24	-.13
Penn mez	.854*	-.32	.875**	-.51	.57	.73	.791*	.757*	.833*	.33	.67	.60	.65	-.57
Seta ver	.57	-.08	.58	-.50	.94**	.91**	.50	.55	.60	-.10	.43	.39	.92**	-.16
Borh rad	-.24	.09	-.28	.18	-.22	-.29	-.41	-.34	-.44	-.22	-.38	-.45	-.50	.54
Erag pap	.32	-.49	.40	.23	.36	.49	.41	.61	.54	.09	.53	.60	.37	.23
Cyno dac	-.57	.882**	-.79*	-.32	-.05	-.48	-.52	-.58	-.64	-.25	-.36	-.30	.09	.17
Cype sp.	-.12	.74	-.42	-.52	.28	-.09	-.22	-.27	-.34	-.07	-.24	-.35	.10	.69
Heter con	-.73	.65	-.88**	.07	-.32	-.67	-.785*	-.74	-.880**	-.42	-.59	-.55	-.39	.50
Spor pel	-.18	.09	-.19	.08	-.12	-.15	-.37	-.38	-.40	-.23	-.49	-.61	-.45	.45

Annex Table 2 Correlation of woody plants with environmental variable

	PH	Sand	Silit	Clay	Na	K	Ca	Mg	CEC	T.N	O.C	O.M	Av.P	Altitude
Grew bic	-.779*	-.06	-.62	.73	-.55	-.52	-.799*	-.75	-.756*	-.48	-.805*	-.780*	-.771*	.44
Bala rot	-.38	-.02	-.18	.21	-.31	-.21	-.34	-.47	-.31	-.28	-.44	-.39	-.17	-.69
Acac nil	-.21	-.64	.07	.772*	-.68	-.28	-.13	-.18	-.06	.09	-.28	-.26	-.73	-.20
Comm flu	.03	-.04	.02	.03	-.56	-.41	-.04	-.23	-.15	.33	-.27	-.40	-.69	-.09
Rhus rus	-.861*	.19	-.69	.48	-.39	-.46	-.777*	-.806*	-.73	-.59	-.73	-.61	-.30	-.18
Bosw neg	.15	.00	.08	-.09	-.17	-.11	.00	-.08	-.07	.20	-.20	-.36	-.44	.31
Acac tor	-.851*	.23	-.829*	.58	-.69	-.808*	-.781*	-.73	-.819*	-.33	-.60	-.49	-.69	.33
Grew tem	-.75	-.26	-.51	.877**	-.32	-.25	-.71	-.57	-.58	-.62	-.65	-.55	-.48	.39
Maer tri	.50	-.71	.71	.18	-.16	.20	.45	.48	.51	.22	.44	.47	-.05	-.766*
Acac dre	.43	-.64	.58	.23	-.47	-.08	.50	.45	.50	.54	.46	.49	-.29	-.69
Acac eta	-.67	-.04	-.56	.65	-.32	-.38	-.71	-.53	-.64	-.55	-.54	-.47	-.50	.53
Acac bus	.08	-.55	.41	.28	-.14	.19	.03	-.03	.15	-.20	-.12	-.09	-.07	-.919**
Comm afr	-.10	-.15	.00	.21	-.10	.01	-.26	-.31	-.23	-.19	-.50	-.64	-.45	.31
Comm hab	-.18	-.03	-.16	.21	-.22	-.22	-.36	-.32	-.37	-.21	-.41	-.50	-.53	.43
Lann riv	-.47	-.27	-.29	.67	-.24	-.14	-.54	-.45	-.44	-.42	-.61	-.63	-.57	.56
Bosc sp.	-.876**	.25	-.820*	.55	-.30	-.49	-.814*	-.68	-.776*	-.60	-.59	-.46	-.32	.43
Grew vil	-.13	-.37	.09	.40	-.31	-.07	-.29	-.35	-.24	-.23	-.53	-.64	-.60	-.08
Acac mel	.02	-.09	.09	.02	-.50	-.36	.09	-.03	.03	.24	.12	.19	-.19	-.857*
Acac Sen	-.18	.50	-.32	-.32	.33	.06	-.35	-.35	-.39	-.35	-.41	-.52	.06	.57
Acac sey	-.42	-.41	-.22	.779*	-.21	-.11	-.36	-.16	-.23	-.36	-.23	-.12	-.33	.42
Acac Bre	-.28	.04	-.31	.28	-.18	-.30	-.23	-.03	-.22	-.17	.12	.26	-.07	.22

N.B: Abbreviation of herbaceous and woody species in annex 1and 2 are the same as Fig 3.13