ECOLOGICAL FACTORS INFLUENCING DISTRIBUTION PATTERNS OF THREE *Aristida* SPECIES AND THEIR ASSOCIATED SPECIES IN KIFUKO RANCH, LAIKIPIA COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or for any other award.

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I dedicate this work to my wife Naomi N. Mumo and our daughters; Agnes Mbeke and Kerean Mutono for the support and inspiration they accorded to me during the period of my studies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASALs	Arid and Semi Arid Lands
CCA	Canonical Correspondence Analysis
DCA	Detrended Correspondence Analysis
DMR	Duncan’s Multiple Range
EAH	East African Herbarium
EC	Electrical Conductivity
GPS	Global Positioning System
Ha	Hectare
NMK	National Museums of Kenya
USA	United States of America
VIF	Variance Inflation Factor

ABSTRACT

Species of *Aristida* are a common component of rangelands of Northern Kenya. They provide high value pasture to livestock, especially during their young stage of growth. The ecological data relating to the distribution of *Aristida* species at a local scale is scanty. The objectives of this research were; to assess the distribution patterns of the three *Aristida* species occurring at Kifuko ranch during wet and dry seasons, to determine plant species associated with the three species of *Aristida* and the possible local ecological factors that influence the distribution of the three species. Data collection was conducted during wet and dry seasons. The data collected included floral data and micro–habitats' data of soil variables, slope directions, slope gradients, depressions, grazing intensity, soil depth and presence of cattle bomas, animal tracks, boulders, shade, termite hills and burning. This study used a total of 40 data collecting micro–sites and each micro–site measured 1 m^2. Ten of the 40 used data collecting micro–sites were established on ten randomly selected points and the points were selected along a 3 km long transect. Four transects, each measuring 3 km long, were used in this study. Out of the four transects used in this study, two were established on deep soil habitats and the other two transects were established on shallow soil habitats. Analysis of paired t-tests was used to test abundance differences for each *Aristida* species, between wet and dry seasons. Detrended Correspondence Analysis (DCA) was used to cluster plant species associations. Variability of soil attributes among the four sampled transects was analyzed using Analysis of Variance (ANOVA) and their means were separated using Duncan's multiple range (DMR) test. Descriptive analysis was used to analyze variability of other sampled micro–habitats' variables among the sample transects. Multivariate analysis of Canonical Correspondence Analysis (CCA) was used to model *Aristida* species–environmental gradients relationship clusters. Analyses of paired t-tests and of ANOVA were performed using software of Microsoft Office Excel 2007, and the DCA and CCA analyses were performed using software of CONOCO version 4. Results of this study showed that each *Aristida* species distributed into a distinct cluster. The abundance trends of *Aristida* species, during wet and dry seasons, showed a significant abundance increases for *Aristida. kenyensis* and *A. congesta* ($p = 0.01$; and $p = 0.04$), respectively, during the wet season compared to the dry season, and no significant abundance change for *A. adoensis* ($p = 0.26$) during wet season compared to dry season. During wet and dry seasons, each *Aristida* species clustered with specific plant species associates. Distribution of *A. kenyensis* during the wet season was positively influenced by soil pH and was positively influenced by boulders during the dry season. Distribution of *A. congesta* individuals, during wet and dry seasons, was negatively influenced by soil depth and positively by clay content. Distribution of *A. adoensis* individuals, during wet and dry seasons, was positively influenced by slope direction and by soil depth, and was influenced negatively by clay content. This study recommends species of *Aristida* to be used by pastoralist communities living around Kifuko ranch to monitor quality of their pasture, as source of dryland pasture and as stabilizing species of degraded landscapes. In addition, a replica study should be carried out in another part of Northern Kenya to ascertain whether the variables sampled in this study were taken at optimum.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Species survival in habitats is dependent on their capacity to adapt, and to tolerate the physical environment, obtain energy and nutrients and to avoid predators (Pidwirny, 2006). Species distribution is strongly correlated with the heterogeneous placement of environmental variables, both in spatial and temporal scales, a phenomenon promoted through species–environmental sorting and species niche specialization (Reynolds *et al*., 2007). The difference on species trade offs for the heterogeneously distributed environmental attributes in habitats is for example responsible for the specific species turnover in a community and also for coexistence (Chase and Leibold, 2003).

In the plant kingdom, environmental variables and their scale of occurrence are known to play a key role in determining fundamental and realized niches of species (Williamson and Harrison, 2002). The areas' resultant plant communities and species composition is therefore a manifestation of an array of biotic and abiotic factors (Ben–Shahar, 1987). A combination of ecological attributes such as the range of temperatures, intensity of light required for photosynthesis, specific humidity regime and minimum quantities of essential soil nutrients for uptake, is noted to be crucial in shaping the choice of ecological niches shown by many plant species (Pidwirny, 2006).

Though much literature on the generalized species–environmental sorting theory is available, little is known about the specific ecological factors that greatly influence specific species habitat selection and more so, in tropical rangelands. One good example of such knowledge gap exists on the explanation of the cause of the habitat preference displayed by three species of *Aristida* (*Aristida kenyensis*, *A. congesta* and *A. adoensis*), which are common grass species at Kifuko ranch.

1.2 Problem statement and justification

Species of *Aristida* are a common component of East African savanna (Clayton, 1970). They provide pasture to cattle, are useful in pasture quality monitoring and have also a high potential in reclaiming degraded and overgrazed pastures of savanna grasslands (de Winter, 1965). In Kenya, savannas cover more than half of the total land area and are mostly situated at Northern part of the country. Northern Kenya is exclusively inhabited by pastoralists who depend on livestock rearing economy. Though *Aristida* has immense potential for the region, ecological data that relate to distribution of its species is relatively scanty and the species are often described along with all other plant species that occur in the rangeland environment. The relative inadequate reliable environmental data that impact on such a useful genus has resulted into its long–term degradation in rangelands, as it is the case of other rangeland pasture resources in the region (Lusigi *et al*., 1984). Such knowledge gap coupled with the critical role played by *Aristida* in the rangeland, justifies the need to conduct this study**.**

1.3 Research questions

i. Are there differences in distribution patterns of the three *Aristida* species at Kifuko ranch during the wet and dry seasons?

ii. Are there species that associate with the three species of *Aristida* during wet and dry seasons at Kifuko ranch?

iii. Do ecological factors contribute to habitat selection among the three *Aristida* species during wet and dry seasons?

1.4 Hypotheses

i. There are no significant differences in distribution patterns of three *Aristida* species found in Kifuko ranch during the wet and dry seasons.

ii. The three *Aristida* species at Kifuko do not have specific association with other plant species.

iii. Ecological factors do not affect habitat affinities of the three *Aristida* species at the Kifuko ranch.

1.5 Objectives

1.5.1 General objective

To identify habitat preferences for three *Aristida* species and their associated plant species inhabiting Kifuko ranch and determine the ecological factors responsible for the species' sites preferences.

1.5.2 Specific objectives

i. To assess the distribution patterns of the three *Aristida* species occurring at Kifuko ranch during wet and dry seasons.

ii. To determine plant species associated with the three species of *Aristida* at Kifuko ranch.

iii. To determine the possible local ecological factors that influences the distribution of the three species of *Aristida* at Kifuko.

1.6 Significance of the study

Species’ compositional dynamics in response to different environmental pressures is an important aspect in the field of range management. A study at Kifuko which documented dynamics of an important grass genus of rangelands is therefore very important. The data generated from this study is required as it can be used to develop management strategies for pasture utilization at rangelands of Northern Kenya. Currently pasture resources at the region are highly declining and affecting livelihoods of the pastoralists in the region. Results of this study are of direct positive impact to the livelihoods of these poor pastoralists who depend mainly on animal productivity.

CHAPTER TWO

LITERATURE REVIEW

2.1 The three-awn grass (*Aristida*)

Aristida, the so called three-awn grass or wire grass or needle grass, is a medium-sized genus with ca. 300 described species and it belongs to the grass family, and subfamily Aristidoideae (Clayton and Renvoize, 1986). It is densely tufted perennial (Figures 2.1A and 2.1B) or annual (Figure 2.1C), usually with slender culms and without a rootstock. The perennial species of *Aristida* have usually linear leaves in basal tufts, but the annual species leaves are mainly on the culms. Panicle (inflorescence) of the group is either loosely spreading or congested. *Aristida* is easily recognized by its distinctive tripartite awn (Figure 2.1D).

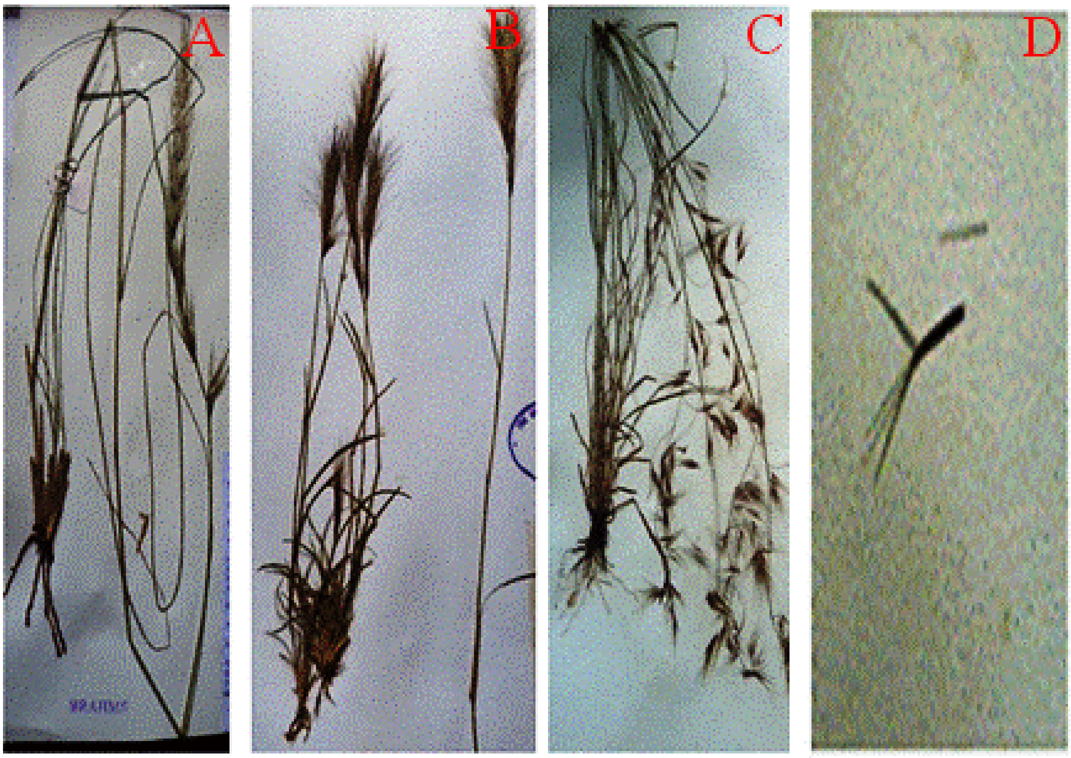

Figure 2.1: Tufts of *Aristida adoensis* (A**),** *A. congesta* (B) and *A. kenyensis* (C), and a three awned lemma for the genus (D).

2.2 The grass family

Grasses are the most economically important plant family across the world and they include cultivated rice (*Oryza sativa* L.), maize *(Zea mays* L.), bread wheat (*Triticum aestivum* L.), sugar cane (*Saccharum officinarum* L.) and bamboos (Van Oudtshoorn, 2012). Grasses dominate many important ecosystems and they contribute 20–25 % of terrestrial primary production (Still *et al*., 2003). Grasses are the most thoroughly studied and the best taxonomically documented among the large flowering plant families, in spite of its high species number: 11,290 currently accepted grass species in 707 genera (Clayton *et al*., 2013). To date, modern flora treatments are available for West Africa (Hutchinson and Dalziel, 1972), East Africa (Clayton, 1970; Clayton and Renvoize, 1982), Zambia and Mozambique (Launert, 1971; Clayton, 1989; Cope, 1999, 2002), Central America (Davidse *et al*., 1994) and North America (Flora of North America Editorial Committee, 2007), and the available global compilations of grass species descriptions and keys (Clayton *et al*., 2013; Simon *et al*., 2013).

2.3 Evolution of grasses

The earliest grasses evolved from shady tropical forests to open habitats with relatively high temperature and low precipitation (Vogel *et al*., 1978; Ehleringer and Cerling, 2002; Sage, 2004; Edward and still, 2008). Christin *et al*. (2008) has for example, pointed out 18 independent origins of C_3 ancestors to the current C_4 grasses. The C_4 evolution and spreading of grasses to drier habitats have undoubtedly resulted to them adapting to seasonality and more so in the tropical rangelands ecosystems. The herbaceous perennial grasses, for example, grow and reproduce for many years, irrespective of seasonality (Clayton, 1970; Ibrahim and Kabuye, 1987). During dry season, they die and revert back to perennial root and when suitable moisture conditions returns, these perennial grasses grow stems and photosynthetic leaf blades before flowering. The new stems and leaves are pushed up from basal meristems. The advantage of this basal meristemic growth form is that when the above ground plant parts are grazed, the stem and leaves can be replaced rapidly using energy stored in the roots. The annual grasses, on the other side, complete their life cycles from seed through reproduction and death in one season, with their abundance mainly dependent on seasonality (Agnew, 2012). Their common trend is to evolve toward smaller size and shorter life spans, adaptations that allow them avoid environmental extremes by existing most of the time as seeds in the soil.

2.4 Distribution and dispersal of *Aristida*

Species *Aristida* are primarily distributed in the tropics and subtropic (Clayton, 1970). They occur in grasslands, forests and semi-desert bushlands, and are scarcely found in true deserts (Clayton and Renvoize, 1986). In Kenya, the genus is represented by 15 species, with an overall altitudinal range of 0 to 2300 m, above sea level (Clayton, 1970; Ibrahim and Kabuye, 1987; Agnew, 2012). Among the 15 *Aristida* species found in Kenya, *Aristida adscensionis* occupies the widest altitudinal range (0 to 2000 m), while the other species of *Aristida* grow either on a moderate to narrow or on a very narrow altitudinal ranges (Ibrahim and Kabuye, 1987). The species in the country grow mostly on disturbed habitats of poor soils and in rangeland ecosystems (Clayton, 1970; Agnew, 2012).

Dispersal is the means by which seeds are transported to new sites for establishment. *Aristida* species that grow on open arid environments are dispersed by wind. Wind blow seeds of *Aristida*, with the help of spreading awns (Bansal and Sen, 1981). The awns allow the wind to catch seeds of *Aristida* to far distances. For *Aristida* species that grow on grasslands, they are dispersed by animal transport (Morton and Baynes, 1985; Jakobsson and Eriksson, 2000). The awns together with the hard callus readily entangle the seeds in the fur of animals and then seeds are moved away from their mother plant as the animal graze.

2.5 Survival strategies for *Aristida* in rangeland ecosystems

Rangelands are characterized by strongly seasonal rainfall patterns and soils of low nutrients (Kurt *et al*., 2011). The ecosystems support continuous layer of grasses of C_4 photosynthetic pathway (Walker, 1987). The C_4 photosynthetic pathway in savanna grasses, is a coordinated set of anatomical and biochemical modifications that acts to concentrate CO_2 at the site of fixation by Ribulose 1, 5-bisphosphate carboxylase oxygenase (Rubisco) enzyme during the Calvin cycle, which assists the these grasses in reducing photorespiration and saturating photosynthesis (Edwards and Still, 2008; Osborne and Freckleton, 2009).

Aristida species, like many grass lineages growing at rangeland ecosystems, have kranz anatomy (Osborne and Freckleton, 2009), which helps the species to adapt to the xeric conditions of savannas. The species have also evolved an array of other adaptive characteristics to survive on rangeland ecosystems, *e.g.* it has species with annual and perennial life forms. The annual attribute makes such species to escape droughts by limiting their growth periods to times when soil water potentials are high and taking advantage of resource pulses released after rainfall, to complete their life cycle before the dry periods (Scholes and Walker, 1993; Partel and Wilson, 2002). The perennials, on the hand, are capable of maximizing growth in times of favorable soil water conditions, and also are able to withstand severe water stress by shoot dieback and development of new tiller from life basal buds, when water becomes available (Slatyer, 1974).

2.6 Importance of *Aristida* in rangeland ecosystems

Aristida is a common component of rangelands (Clayton, 1970; Tucker, 1990). Globally, rangelands cover approximately 20 % of the land surface, they produce almost 30 % of global net primary productivity and sustain considerable cultural and economic activity (Scholes and Walker, 1993). In Africa, rangelands are largely exploited through grazing (Bilotta *et al*., 2007). Generally, *Aristida* species grow on soils of low nutrient status and on habitats that are overgrazed (Jackson and Jacobs, 1985). Species of *Aristida* are a weed or an invader of barren land and degraded pastures (Van Oudtshoorn, 2012). During their mature stages of growth, due to their wire stems, hard involute leaves and seeds with hard lemmas and sharp callus (Jackson and Jacobs, 1985), species of *Aristida* provide pasture of low nutrient value to livestock and wildlife, *e.g.* pasture of *Aristida* during their maturity is not acceptable by livestock and wildlife, as seeds of *Aristida* cause injures to the livestock and wildlife (Stubbendieck *et al*., 1992; Lazarides, 2002).

Nevertheless, the genus during its early vegetative stage of growth it provides high value fodder to livestock and wildlife (Schweickerdt, 1941; de Winter, 1965), *i.e.* before the stem elongation and flowering and when forage quality is greatest as cell contents and nutrient concentrations in metabolically active tissues are greater and contain less cell wall structure. *Aristida* species are also useful soil binders and colonizers of badly degraded rangeland ecosystems (Clayton, 1970). Additionally, *Aristida* species due to their frequent presence in the low rainfall rangelands and also their easy recognition from other grass species, due to their tripartite awns (Clayton, 1970), they can be appropriate operational units for studying the dynamics of African savannas.

2.7 Ecological factors influencing distribution of rangeland plant species

Distribution of plant species in an area is not accidental, but it is reflection of environmental gradients (Bahram *et al*., 2012). While plant growth and development are controlled by internal regulators, these regulators are modified according to environmental conditions (Manske, 1997). In tropical rangeland ecosystems, distribution of plant species is highly influenced by the physical environmental variables affecting water availability, soil chemistry and also by anthropogenic activities (Enright *et al*., 2005; Mesdaghi, 2007). It is reported that soil moisture highly limits plant growth and distribution and soil nutrients have generally secondary effects to the distribution of rangeland plants (Mesdaghi, 2007).

The Physical environmental variables affecting water availability include: (1) topography; (2) soil depth; (3) shade and termite hills; and (4) soil texture. Topography is reported to affect soil and climate, and it in addition affects temperature and evapo-transpiration (Jenny, 1980). Slope and aspect, and depressions, are parameters of topography, and they determine local water retardation rates. Soils that are on steep grounds are for example drained fast and are likely to be subjected to erosion which makes them lose some depths. However, such soils are not subjected to flooding. Moisture availability, ventilation and distribution of plant roots are reported to affect distribution of a range plant species (Mehrjardi *et* *al*., 2009), including species of *Aristida*. Soil depth affects a number of environmental variables that may affect the local plant community processes. Topographic gradients are for example associated with changes in plant rooting depth (Abrams and Hulbert, 1987), soil texture and nutrient availability (Schimel *et al*., 1991; Turner *et al*., 1997) and soil moisture (Barnes and Harrison, 1982). According to Clayton (1970), species of *Aristida* grow on shallow soils showing that they are affected by environmental variables that are related with soil depth. Termite hills alter soil profile and subsequently water availability and vegetation composition (Smith and Yeaton, 1998; Ackerman *et al*., 2007). Smith and Yeaton (1998) reported termite hills to act as the focal point of biotic disturbance on grassland ecosystems of South Africa (Smith and Yeaton, 1998). Ackerman *et al*. (2007) reported termite hills as constraints to plant establishment due to alteration of physical strength of soil, which discourage water absorption and retention.

Shade and large boulders in hot dry savanna environment have been reported to act as facilitating agents (Cody, 1993; Callaway, 1995; Pugnaire and Haase, 1996) and may contribute to distribution of some plant species. Large boulders provide shade to plant species and they also do not compete for resources as opposed to if the nursing is by other plants. Shading of the soil thus reduces soil evaporation and smaller temperature fluctuations (Cody, 1993; Pugnaire and Haase, 1996). *Aristida* is reported to be susceptible to shade (Clayton, 1970), and hence it may not benefit directly from the shade, it can still benefit indirectly from shade and boulders facilitated microclimates. Soil texture includes proportions of clay, sand and silt. It greatly controls distribution of plants by affecting moisture availability, ventilation and distribution of plant roots (Jafari *et al*., 2004). The role of soil moisture, as a key element in the distribution of plants, is described by Zohary and Orshan (1949) and El-Sheikh and Yousef (1981).

In general, most plants grow by absorbing nutrients from the soil. The ability of plants to absorb nutrients from soils depends on the nature of the soil. Depending on the soils' locations, its sand, silt, clay, and organic matter combinations varies. Loam soil, which is the perfect balance soil of the three elements (clay, sand and silt), it is for example both free-draining and moisture retentive. Clay soil, on the other hand, is made up of very tiny particles that stick together easily. It is heavy and slow draining, and when dry, it become hard rock. It is though a very fertile soil. For the sandy soil, it is light and free draining, and it is usually low in nutrients. Correlation of soil texture and distribution of rangeland plants is reported by many authors (Zare *et al*., 2011; Gholinejad *et al*., 2012; Tavili, 2014). Tavili (2014) reported positive effects of soil texture on separation of grassy vegetation types at rangelands of Iran. According to Zare *et al*. (2011), attributes of soil texture had a great influence on the distribution of plant communities in Shahriyar Rangelands, Iran whereas Gholinejad *et al*. (2012) reported gradients of clay and sand at the soils of Kamyaran rangelands in Iran as the principal components which had a significant effect on plant communities' distribution in semi-arid rangelands.

Soil chemical properties encompass: (1) soil electrical conductivity (EC) and pH; and (2) nutrients including nitrogen, phosphorus and potassium. Soil electrical conductivity is the total amount of exchangeable cations that a soil can hold at a specific pH. The EC of the soil is reported to influence the availability of nutrients in the soil for plant use and also plants distribution at local scale (Sylvia *et al*., 2005).

Soil pH, which is the measure of the acidity or alkalinity in soils, controls many chemical processes that take place. It specifically affects plant nutrient availability by controlling the chemical forms of the nutrient. The optimum pH range for most plants is between 5.5 and 7.0, however many plants have adapted to thrive at pH values outside this range (Sylvia *et al*., 2005). Influence of soil electrical conductivity (EC) and pH on distribution of rangeland plants has been reported (Shahriary *et al*., 2012; Tavili, 2014). Shahriary *et al*. (2012) reported that plant species composition around Iranian piospheres, were greatly influenced by soil pH and EC. Tavili (2014) found grass species in Iran, were greatly influenced by soil pH and EC, texture, gravel percentage and soil gradients of nitrogen and organic matter.

Nitrogen and phosphorus are major nutrients limiting plant growth in several regions (Owensby *et al*., 1970; Wight, 1976; James and Jurinak, 1978; Morrow *et al*., 1978; Fischer *et al*., 1987). Their presence in soils increases vigor of grasses and improves plants water usage efficiency, forage quality and palatability (Wight, 1976; Vallentine, 1980). However, plants' response to these two nutrients varies with soil moisture availability (Sneva and Hyder, 1965; Wight and Black, 1979; Power, 1983; Rauzi and Fairbourn, 1983). Nitrogen and phosphorus may not be of great influence to *Aristida* species which largely inhabit tropical rangelands of low rainfall (Clayton, 1970). According to Armstrong *et al*. (1993) and Dufek *et al*. (2014), increased levels of either or both nitrogen or phosphorus in a plenty moisture habitat, increases the relative crowding coefficients and the degree of suppression of *Aristida*, a situation that negatively affects distribution for *Aristida*.

Anthropogenic activities affect distribution of rangeland plant species. Most grasses in savanna ecosystems are fairly tolerant to grazing, however, prolonged intense grazing coupled with fires and cultivation, eventually leads to shift in species composition (Skarpe, 1992). Selective grazing of palatable herbaceous plants by livestock in rangelands, has been shown to enhance growth of annuals and unpalatable herbaceous plant as well as woody plants (Skarpe, 1992), and decline of palatable species (Fensham *et al*., 2010). Overgrazed rangelands have been reported to be dominated by increaser species, which include species of *Aristida* (Trollope *et al*., 1989). At rangelands, species of *Aristida* are repeatedly reported to dominate sites of disturbed soils, they persist with repeated severe grazing and reduce with burning, and grow as weed on areas opened as farms (de Winter, 1965; Clayton, 1970; Dufek *et al*., 2014).

Overgrazing or uneven distribution of grazing can lead to a loss of plant species diversity, changes in plant composition, and decreases in net primary production and ground cover (Noss and Cooperrider, 1994). Excessive trampling by grazers can cause soil compaction, decrease water infiltration into the soil, increase overland soil erosion, and cause large reductions in plant growth (Andrews, 1988). Concentrated trampling by many animals will have a larger influence on the soil structure and vegetation than continuous trampling by fever animals (Savory, 1988). *Aristida* species are reported to establish on degraded habitats (Clayton, 1970).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out at Kifuko ranch in Laikipia County. The ranch lies between latitudes 00.2097° – 00.8753° N and longitudes 36.5349° – 36.6339° E (Figure 3.1). It covers an area of 3000 ha and it is characterized by a gently undulating topography, an extension of the extensive Laikipia plateau which has an elevation of around 1800 m above sea level (Government of Kenya, 1983). Laikipia plateau falls in the larger Laikipia-Samburu-Isiolo ecosystem which falls within the category of Arid and Semi-Arid Lands (ASALs) (Government of Kenya, 1994; Thuita, 2001). The area gets an annual average rainfall of about 250 – 600 mm yr^{-1} (Berger, 1989). The rain falls in a typical bimodal pattern, with the ‘long rains’ coming between April and June, and the ‘short rains’, between October and December (Berger, 1989).

Rangelands in Laikipia are mainly used for extensive livestock grazing but are also habitats for a wide range of wildlife with free movements across private and communal land holdings. Kifuko ranch is fenced off to restrict entries of wildlife. The ranch’s cattle herds are kept in enclosures and are rotationally grazed.

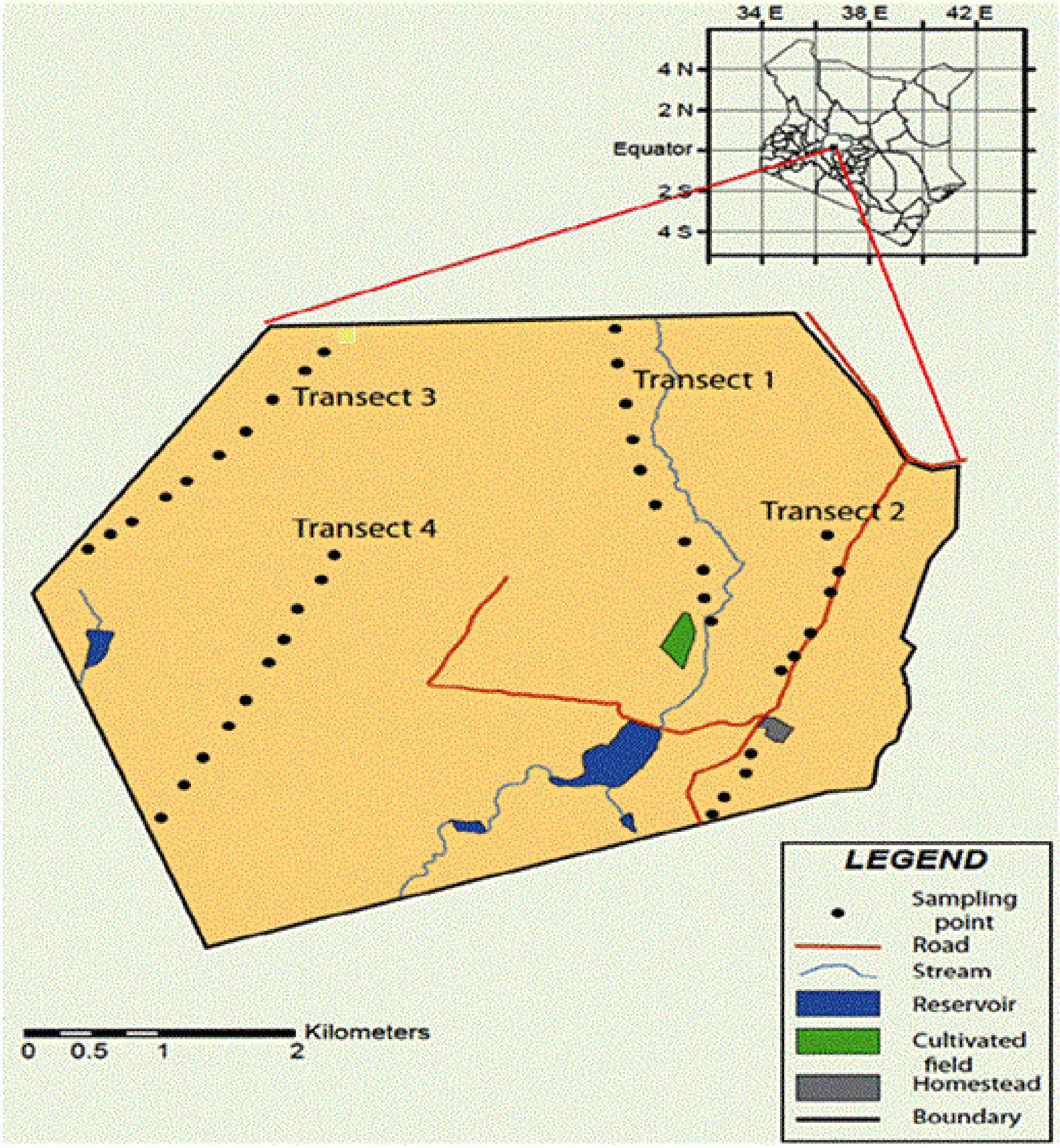

Figure 3.1. A map of Kifuko ranch showing study transects.
Source: Digitised and extracted from Google Earth Map, accessed July 2014.

3.2 Study site selection and the experimental design

Sampling was carried out in 40 microplots (quadrats), each measuring 1 × 1 m. Four transects, each measuring 3 km long, were used in this study. The 40 microplots were distributed equally among the four sample transects *i.e.* ten microplots per every sample transect. Of the four sampled transects, two transects were established at one habitat type and the other two transects at a different habitat type. Spacing of the two transects within one habitat type was done at a distance of half a kilometer. Soil depth was the criteria used to select those two used sampling habitat types and the habitat types were selected during the period of reconnaissance survey, which was carried out in the month of January, 2013. Habitat type of transects one and two was of relatively shallow soil, while that of transects three and four, was on a relatively deeper soil stratum. The points where the sample microplots per transect were established were randomly picked from a pool of all *Aristida* species sub-populations present at each transect. Data collection was carried out in the months of July and November, 2013 during the dry and wet seasons, respectively.

3.3 Field sampling

3.3.1 Vegetation data collection and plant identification

Vegetation sampling was carried out by techniques and procedures described by Sorrells and Glenn (1991) for conducting vegetation sampling in a limited and definitely circumscribed area. Species lists per every micro – site were compiled and the lists were used later to generate micro – sites' presence/absence species data. Most plants in the species list were identified to species level in the field and plants that were difficult to identify in the field, samples were collected, labeled and identified later at the East African Herbarium (EAH), National Museums of Kenya (NMK). The identifications were carried out using botanical identification manuals (Ibrahim and Kabuye, 1987; Beentje, 1994; Agnew, 2012). All the collected plant samples for this work were accessioned and stored at the EAH as voucher specimens for future reference (Bridson and Forman, 1992).

3.3.2 Soil collection and analysis

Three soil samples, scooped at a depth of 5 cm, depth appropriate for sampling in grasslands with extensive rooting systems and organic matter accumulations (Houba *et al*., 1990; Okalebo e*t al*., 2002), were collected per micro – site. These three soil samples were mixed to makeup one composite soil sample of 500 g. Forty 500 g composite soil samples representative of all the sampled micro – sites were collected, packed in a labeled manila paper bag and sun-dried in the field to halt biological activities.

Analyses of physical and chemical properties of the collected soil samples were carried out at the NMK ecology laboratory. To determine soil pH of every micro – site, subsamples each weighing 5 g were prepared from the collected plots soil samples. The soil subsamples were ground using mortar and pestle into fine particles and saturated with double–distilled water (12.5 ml) in labeled shaking plastic bottles (60.0 ml). Shaking was carried out for thirty minutes and then the mixtures were left for twenty minutes to settle, but was agitated at intervals of two minutes. pH was determined on the prepared saturation extracts by a calibrated pH meter (Mettler Toledo and model – Seven Multi) (McLean, 1982). To determine the soil conductivity, 5 g of dried and fine grounded soil particles was put into a labeled 60 ml shaking bottle and 50 ml of double–distilled water was added. Stirring was carried out for 10 minutes before filtering using Buchner funnel fitted with Whatman 42 filter paper. Soil conductivity (EC) for the forty soil subsamples was read using an electrical conductivity meter (Mettler Toledo and model – Seven Multi), which was calibrated in micro Siemens (µs) (Rhoades, 1982). Soil phosphorus content was determined by putting a 2.5 g subsample of each soil into 60 ml labeled Nalgene bottle, after which 50 ml of 0.5 M sodium bicarbonate (pH 8.5) solution was added to each sample and then shaken for 30 minutes. Each mixture was then filtered through Whatman filter paper and the ortho–phosphate in the filtered extract was determined colorimetrically (at 630 nm in a Technicon AutoAnalyzer II) by reacting it with ammonium molybdate using ascorbic acid as the reducing agent. Results were reported as parts per million (ppm) of phosphorus (P) (Olsen and Sommers, 1982). Soil particle size of the forty sub samples was measured using 50 grams of air–dry soil sieved to pass a 2 mm sieve. The fines were placed into 400 ml beakers to which 100 ml of deionized water was added to each sample and stirred to wet the soil thoroughly. Beakers with soil were placed into a hot water bath at 90 °C and the percentages of clay, sand and silt in the soil samples were determined by the Bouyoucos hydrometer method (Bouyoucos, 1951).

3.3.3 Data collection of other environmental variables

Data on shade, burning, cattle bomas, animal tracks, boulders, termite hills and depressions were collected by observation of either the variable is present or absent in the sampling micro plots. If a variable was for example found present, it will be scored 1 and if absent scored 0, and the data captured on a structured datasheet (Appendix iv). Data on the levels of herbivores grazing was also collected by observation. Recordings were categorized into either minimal grazing = 1 or moderate grazing =2 or high grazing =3. Collection of soil depths was executed by piercing a sharp calibrated metal rod to the ground. Soils found with depths of 0-5 cm to bedrock were described as "shallow" and those with depths > 5 cm were recorded as "deep". Micro – sites' elevations and locations were captured using a handheld global positioning system (GPS)–Garmin etrex model, set into lat/long degrees coordinates to take micro – sites positions and metres to measure micro – sites altitudes. Slope aspects in the micro – sites which included slope direction and gradient, were determined using a compass and a clinometer.

3.4 Data analysis

Analysis of paired t-tests was used to test abundance differences of *Aristida* species, between wet and dry seasons. Detrended Correspondence Analysis (DCA) was used to analyze clustering of plant species across micro-sites. Variability of soil attributes among transects was analyzed using Analysis of Variance (ANOVA) and their means between transects were separated using Duncan's multiple range (DMR) test. Descriptive analysis was used to analyze variability of other micro habitats ecological variables, among transects. Multivariate analysis of Canonical Correspondence Analysis (CCA) was used to model responses of *Aristida* species to the analyzed ecological gradients. The Analyses of paired t-tests and of ANOVA were performed using software of Microsoft Office Excel 2007. The DCA and CCA analyses were performed using software of CONOCO version 4 (Braak and Šmilauer, 1998; Šmilauer and Lepš, 2003). Prior to execution of the DCA and the CCA analyses, data were log transformed to meet the criteria of normality (Ramette, 2007). The variance inflation factor (VIF), which is a measure of multi-colinearity of a variable with other variables was computed and variables that exceeded multi-colinearity threshold at $VIF > 20$ were eliminated before performing the CCA (ter Braak and Šmilauer, 1998). Monte Carlo permutation tests (499 times) were performed to determine the environmental factors that related significantly with *Aristida* species. Statistical significance was accepted at $p \leq 0.05$.

CHAPTER FOUR

RESULTS

4.1 Distribution patterns of *Aristida*

4.1.1 Distribution of *Aristida kenyensis*, during the wet and dry seasons

Individuals of *A. kenyensis* were more at transects one and two (Figure 4.1; Appendix II and III) and the group's abundance increased significantly during the wet season compared to the dry season (p = 0.01; Table 4.1).

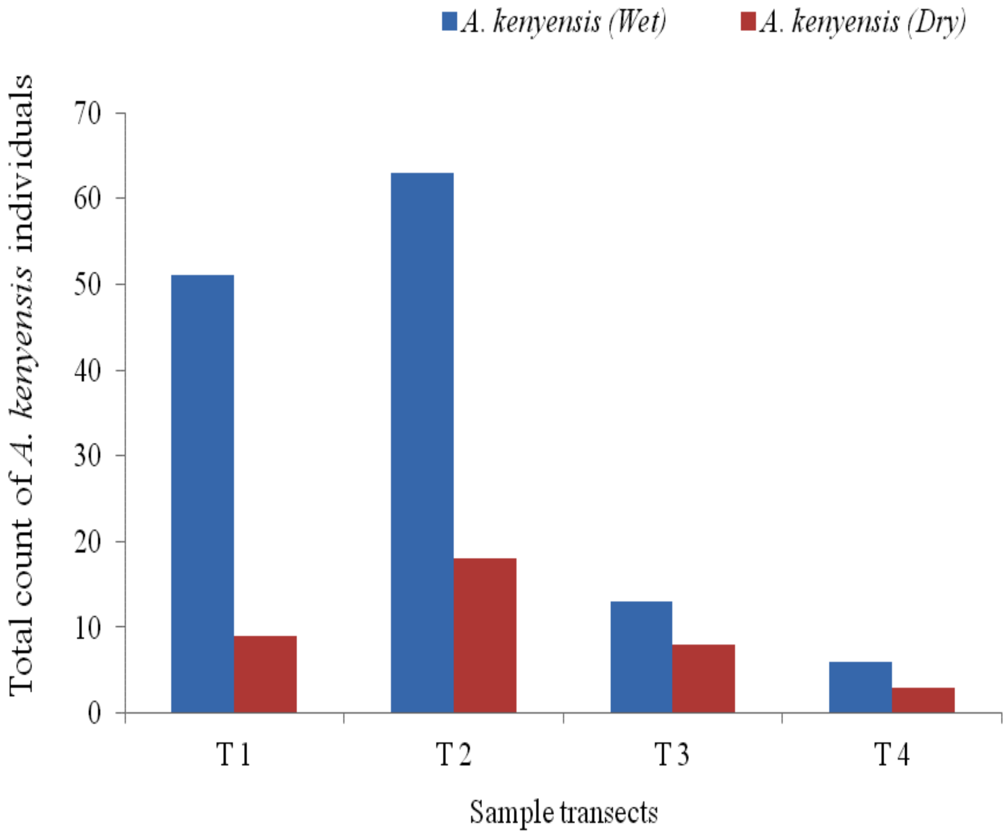

Figure 4.1. Distribution patterns for *Aristida kenyensis* during the wet and dry seasons.

Table 4.1. Variation of *A. kenyensis* during the wet and dry seasons

Species	Season	Mean number of individuals	Standard Deviation	T	P – value
Aristida kenyensis	Wet	3.18	4.39		
	Dry	0.97	2.06	3.83	0.01

4.1.2 Distribution of *Aristida congesta,* during the wet and dry seasons

Aristida congesta individuals were mostly found at transect one during wet and dry seasons (Figure 4.2; Appendix II and III) and its population increased significantly during the wet season compared to the dry season (p = 0.04; Table 4.2).

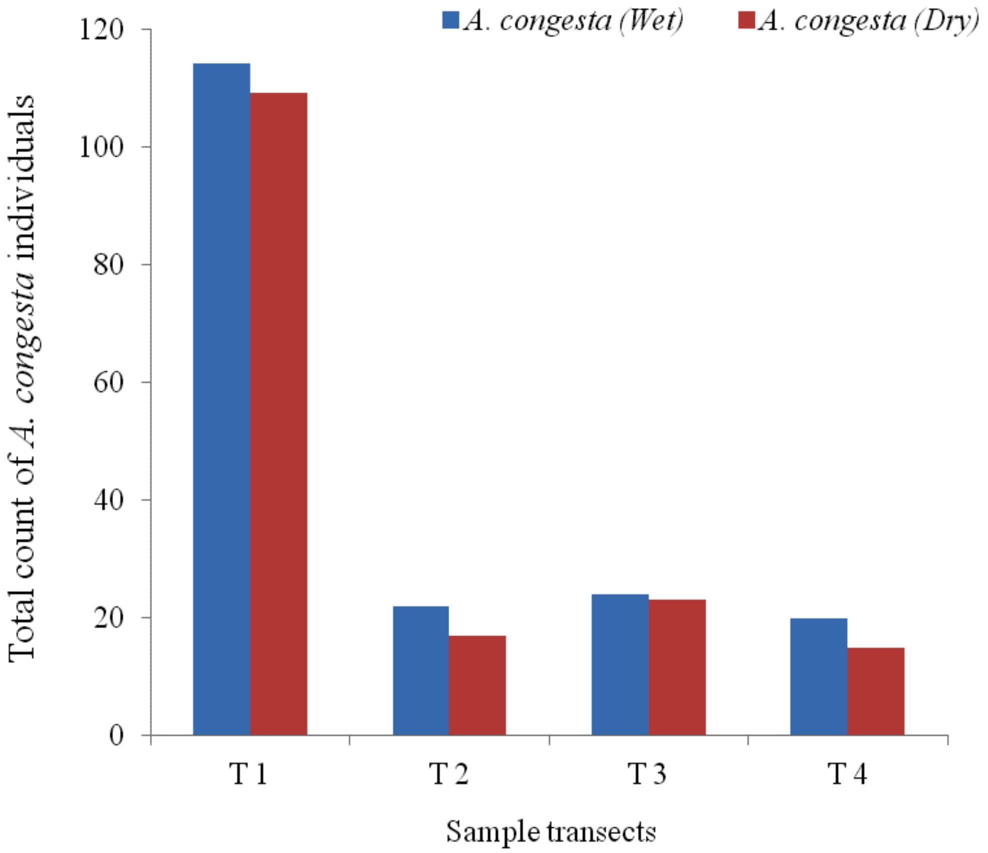

Figure 4.2. Distribution patterns for *Aristida congesta* during the wet and dry seasons.

Table 4.2. Variation of *A. congesta* during the wet and dry seasons

Species	Season	Mean number of individuals	Standard Deviation	T	P–value
	Wet	3.82	6.51		
Aristida congesta	Dry	3.38	6.20	2.14	0.04

4.1.3 Distribution of *Aristida adoensis* during the wet and dry seasons

During wet and dry seasons, individuals of *A. adoensis* were concentrated at transects three and four (Figure 4.3; Appendix II and III) and the group's population did not differ significantly during the two seasons (p = 0.26; Table 4.3).

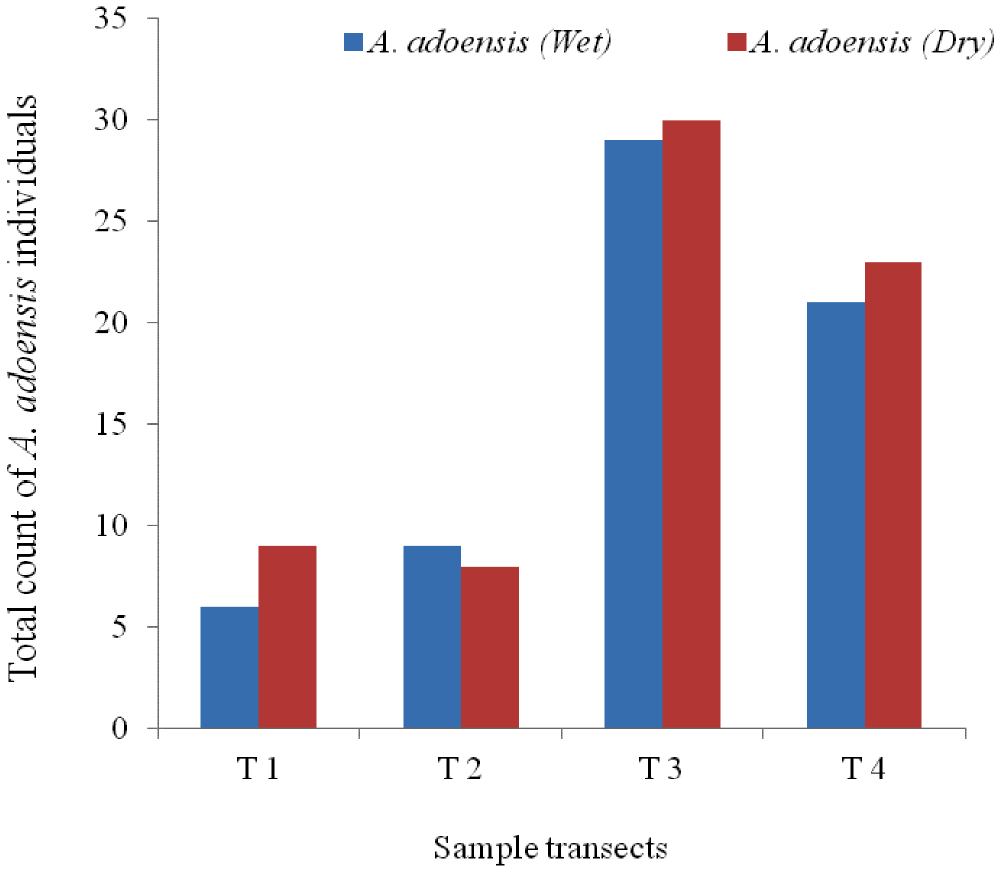

Figure 4.3. Distribution patterns for *Aristida adoensis* during the wet and dry seasons.

Table 4.3. Variation of *A. adoensis* during the wet and dry seasons

Species	Season	Mean number of individuals	Standard Deviation	T	P – value
Aristida adoensis	Wet	1.67	1.80		
	Dry	1.79	1.85	1.15	0.26

4.2 Plant species associations at Kifuko during wet and dry seasons

Plant species that associated with *A. congesta* during wet season were *Evolvulus alsinoides*, *Cymbopogon pospischilii* and *Enneapogon schimperanus* (Figure 4.4). During the dry season, the *A. congesta* cluster retained only *Evolvulus alsinoides* (Figure 4.5). *Aristida kenyensis*, during the wet season, was associated with *Microchloa kunthii*, *Eragrostis superba*, *Rhynchelytrum repens*, *Harpachne schimperi* and *Indigofera circinella* (Figure 4.4). *Aristida kenyensis* had less species associates (*Eragrostis superba* and *Rhynchelytrum repens*) during the dry season (Figure 4.5). *Aristida adoensis* (Figures 4.4 and 4.5) on the other hand, during wet season was associated with *Microchloa kunthii*, *Eragrostis superba*, *Rhynchelytrum repens*, *Harpachne schimperi*, *Indigofera circinella*, *Themeda triandra* and *Schkuhria pinnata* and with *Bothriochloa insculpta*, *Themeda triandra*, *Indigofera sp. Indigofera circinella*, *Harpachne schimperi*, *Sida ovata* and *S. massaica*, during dry season.

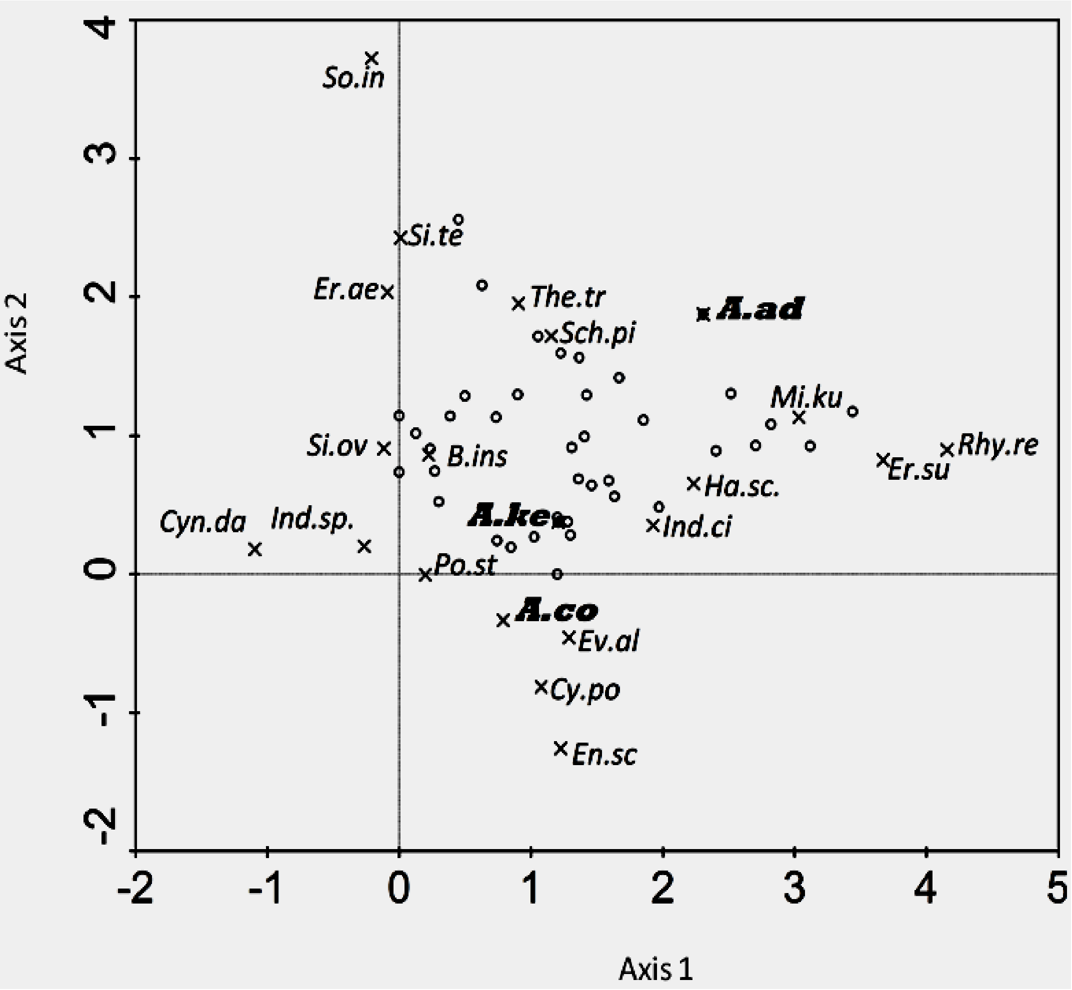

Figure 4.4. A DCA biplot showing distribution patterns of *Aristida* species and their associated plant species during the wet sampling season. $^{x\ \text{and}\ 0}$ Symbols in the figure denote a species and a plot respectively. *Aristida adoensis* (A.ad), *Aristida congesta* (A.co), *Aristida kenyensis* (A.ke), *Bothriochloa insculpta* (B.ins), *Cymbopogon pospischilii* (Cy.po), *Cynodon dactylon* (Cyn.da), *Enneapogon schimperanus* (En.sc), *Eragrostis aethiopica* (Er.ae), *Eragrostis superba* (Er.su), *Evolvulus alsinoides* (Ev.al), *Harpachne schimperi* (Ha.sc.), *Indigofera circinella* (Ind.ci), *Indigofera sp.* (Ind.sp.), *Microchloa kunthii* (Mi.ku), *Polygala stenopetala* (Po.st), *Rhynchelytrum repens* (Rhy.re), *Sida ovata* (Si.ov), *Sida tenuicarpa* (Si.te), *Solanum incanum* (So.in), *Themeda triandra* (The.tri).

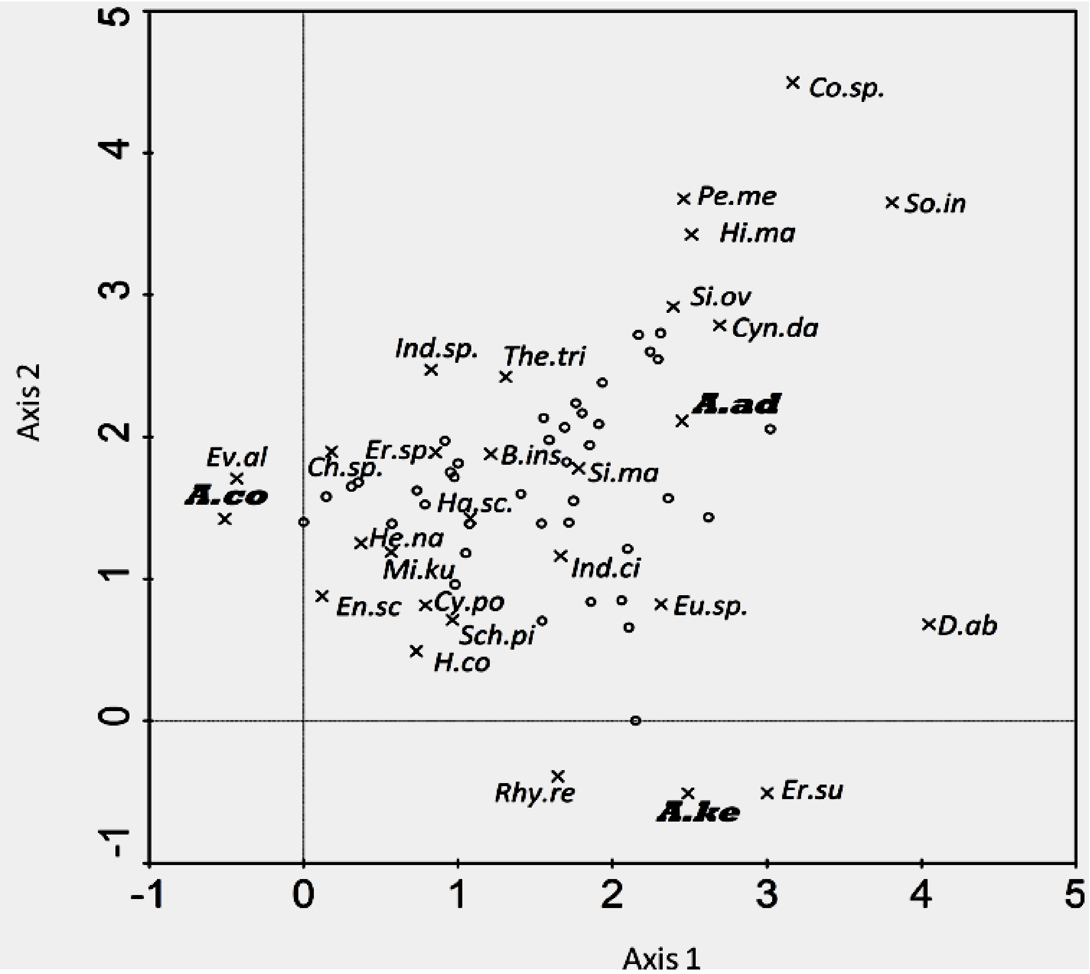

Figure 4.5. A DCA biplot showing distribution patterns of *Aristida* species and their associated plant species during the dry sampling season**.** $^{\text{x and 0}}$ Symbols in the figure denote a species and a plot respectively. *Aristida adoensis* (A.ad), *Aristida congesta* (A.co), *Aristida kenyensis* (A.ke), *Bothriochloa insculpta* (B.ins), *Chamaecrista sp.* (Ch.sp.), *Commelina sp.* (Co.sp.), *Cymbopogon pospischilii* (Cy.po), *Cynodon dactylon* (Cyn.da), *Digitaria abyssinica (*D.ab) *Enneapogon schimperanus* (En.sc), *Eragrostis sp.* (Er.sp.), *Eragrostis superba* (Er.su), *Euphorbia sp.* (Eu.sp.), *Evolvulus alsinoides* (Ev.al), *Harpachne schimperi* (Ha.sc.), *Helichrysum nandense* (He.na), *Heteropogon contortus* (H.co), *Hibiscus macranthus* (Hi.ma), *Indigofera circinella* (Ind.ci), *Indigofera sp.* (Ind.sp.), *Microchloa kunthii* (Mi.ku), *Pennisetum mezianum* (Pe.me), *Rhynchelytrum repens* (Rhy.re), *Schkuhria pinnata* (Sch.pi), *Sida massaica* (Si.ma), *Sida ovata* (Si.ov), *Solanum incanum* (So.in), *Themeda triandra* (The.tri).

Species variances in the DCA clusters, during wet and dry seasons, were mostly explained by the first two axes with eigenvalues of 0.457 and 0.246 during the wet season (Table 4.4) and 0.383 and 0.249 during the dry seasons (Table 4.5). DCA axes three and four had low eigenvalues 0.177 and 0.115 during the wet season

(Table 4.4) and 0.195 and 0.108 during the dry season (Table 4.5) and were left out of presentation as they did not explain much on how species clustered.

Table 4.4. Variance explained by DCA's axes during the wet sampling season

Axes	1	2	3	4	Total inertia
Eigenvalues	0.457	0.246	0.177	0.115	2.929
Lengths of gradient	3.440	2.559	2.754	2.905	
Cumulative % variance of species	15.6	24.0	30.1	34.0	
Sum of all eigenvalues					2.929

Table 4.5. Variance explained by DCA's axes during the dry sampling season

Axes	1	2	3	4	Total inertia
Eigenvalues	0.383	0.249	0.195	0.108	2.889
Lengths of gradient	3.022	2.731	2.799	2.000	
Cumulative % variance of species	13.3	21.9	28.6	32.4	
Sum of all eigenvalues					2.889

4.3 Relationship between environmental factors and *Aristida* species

Results on the presence of boulders, termite hills, depressions, shade, animal tracks, burning and animal bomas (Table 4.6) at the four transects sampled for abundances of *Aristida* species showed that; boulders were much higher at transects one and two compared to transects three and four. Transects one and two were highly inhabited by individuals of *A. kenyensis* and of *A. congesta* (Fig. 4.1 and 4.2), whereas, transects three and four were highly inhabited by individuals of *A. adoensis* (Fig 4.3). Presence of other sampled environmental parameters *i.e.* termite hills, depressions, shade, animal tracks, burning and animal bomas at the four transects was either equally distributed or very minimal or even absent (Table 4.6).

Table 4.6. Distribution of boulders, termite hills, depressions, shade, animal tracks, burning and animal bomas among the four sampled transects (sample size is ten micro–sites per transect; n=10)

Variables	Transect 1	Transect 2	Transect 3	Transect 4
Boulders	7	7	4	1
Termite hills	0	0	0	1
Depressions	0	4	3	1
Shade	0	0	0	1
Animal tracks	10	10	9	10
Burning	0	2	1	3
Animal bomas	0	0	0	0

A summarized microhabitats' data of slope direction and gradient, soil depth and grazing intensity among the four sampled transects shows that, most micro – sites of transect one to four were generally facing East and with a slope gradient of 1—5 % (Table 4.8). Soil depths and grazing intensity showed that transects one and two, which were majorly occupied by *A. congesta* and *A. kenyensis*, had relatively shallow soil (Table 4.8) compared to deep soils of transects three and four, which were mainly occupied by *A. adoensis* (Fig. 4.3). Grazing intensity among the four transects was high at transects one and two, and moderate for transects three and four (Table 4.7).

Table 4.7. Distribution of slope, soil and grazing intensity attributes among the four sampled transects (sample size is ten micro – sites per transect; n = 10)

	Attributes occurrences per transect				
Factors	Attributes	T1	T2	T3	T4
Slope direction	South	0	2	3	1
	South West	0	0	0	0
	East	4	6	7	5
	North East	6	0	0	0
	North	0	0	0	0
	North West	0	0	0	3
	West	0	2	0	0
	South Eest	0	0	0	1
Slope gradient	1—5 %	9	10	9	8
	6—10 %	1	0	0	1
	11—15 %	0	0	1	1
Soil depth	Shallow	10	6	3	3
	Deep	0	4	7	7
Grazing intensity	Minimal	1	1	2	2
	Moderate	2	3	7	8
	High	7	6	1	0

Among the sampled soil attributes (Table 4.8), percentage of clay content in the soil clustered transects one and two into one cluster (transects largely occupied by *A. congesta* and *A. kenyensis*; Figures 4.1 and 4.2), and transects three and four to another distinct cluster (transects mainly occupied by *A. adoensis*; Figure 4.3). Other soil attributes that showed differences among the four sampled transects at Kifuko ranch included; silt, pH and phosphorus. These three attributes showed a significant difference only in transects two and three. Electrical conductivity and sand at the sampled transects had no significant difference among the four transects at the ranch.

Table 4.8. Distribution of soil attributes among the four sampled transects (sample size is ten micro–sites per transect; n=10)

Transect	% Clay	% Sand	% Silt	EC (μs)	MgP/kg	pH
T1	28.16±4.29^{b}	50.10±7.49^{a}	21.72±4.71^{ab}	153.10±80.45^{a}	8.64±0.85^{a}	6.59±0.11^{ab}
T2	28.56±4.73^{b}	51.32±6.56^{a}	20.12±4.92^{a}	237.00±143.31^{a}	13.00±2.95^{b}	6.71±0.43^{b}
T3	22.96±2.85^{a}	50.50±4.90^{a}	26.52±4.00^{b}	206.40±110.80^{a}	18.41±2.18^{c}	6.13±0.82^{a}
T4	23.76±5.07^{a}	52.70±7.58^{a}	23.52±6.51^{ab}	170.80±113.85^{a}	18.86±1.79^{c}	6.30±0.30^{ab}

Mean values within a column followed by the same letter are not significantly different by DMR test ($P \leq 0.05$).

CCA results on species–environmental factors relationships during wet and dry seasons showed that, the relationships on species and environmental factors in the CCA triplots were mostly explained by the first two axes. During the wet season, first and second axes of CCA explained species–environmental factors variations of 23.30 % and 18.70 %, respectively (Table 4.9) and during the dry season, of 22.20 % and 16.40 %, respectively (Table 4.10).

Table 4.9. CCA axes variances during the wet season

Axes	1	2	3	4	Total inertia
Eigenvalues	0.31	0.25	0.15	0.13	2.93
Species-environment correlations	0.86	0.88	0.87	0.80	
Cumulative percentage variance of species data	10.50	18.90	24.00	28.40	
Cumulative percentage variance of species-environment relation	23.30	42.00	53.50	63.40	
Sum of all eigenvalues					2.93
Sum of all canonical eigenvalues					1.32

Table 4.10. CCA axes variances during the dry season

Axes	1	2	3	4	Total inertia
Eigenvalues	0.29	0.21	0.15	0.13	2.89
Species-environment correlations	0.89	0.87	0.82	0.91	
Cumulative percentage variance of species data	10.00	17.40	22.50	27.00	
Cumulative percentage variance of species-environment relation	22.20	38.60	49.80	59.90	
Sum of all eigenvalues					2.89
Sum of all canonical eigenvalues					1.30

CCA Monte Carlo results showed that environmental factors which significantly influenced the distribution of species during wet season were; soil depth, percentage of clay in the soil, soil pH and slope direction (Table 4.11), and during the dry season were; soil depth, percentage of clay in the soil, slope direction and boulders (Table 4.12).

Table 4.11. CCA Monte Carlo permutation test results for environmental factors during the wet season with their significant probabilities (P) and F–values

Environmental variable	P	F
Soil depth	0.004	2.290
Amount of clay in the soil	0.002	2.220
Measured soil pH	0.006	1.970
Slope direction	0.050	1.530
Measured soil electrical conductivity (EC)	0.066	1.570
Percentage of sand in the soil	0.106	1.410
Grazing intensity	0.194	1.260
Altitude	0.122	1.400
Depressions	0.434	1.010
Shade	0.314	1.120
Slope gradient	0.592	0.860
Amount of phosphorus in the soil	0.804	0.690
Burning	0.836	0.680
Boulders	0.840	0.650
Termite hills	0.890	0.480
Animal tracks	0.958	0.350

Table 4.12. CCA Monte Carlo permutation test results for environmental factors during the dry season with their significant probabilities (P) and F–values

Environmental variable	P	F
Soil depth	0.002	2.290
Percentage of clay in the soil	0.002	2.210
Slope direction	0.004	2.010
Boulders	0.014	1.730
Measured soil pH	0.062	1.490
Grazing intensity	0.214	1.210
Percentage of sand in the soil	0.328	1.120
Amount of phosphorus in the soil	0.374	1.070
Slope gradient	0.598	0.880
Termite hills	0.566	0.880
Measured soil electrical conductivity (EC)	0.686	0.790
Depressions	0.690	0.790
Shade	0.470	0.960
Burning	0.762	0.760
Altitude	0.872	0.670
Animal tracks	0.888	0.570

The CCA correlation matrix between plot scores and environmental factors during the wet season showed that soil depth was positively correlated with first axis, and the second axis was correlated positively with soil pH and clay, and negatively with slope direction (Table 4.13). During the dry season, the CCA correlation matrix results showed; soil depth and slope direction were positively correlated with the CCA first axis, and clay and boulders were correlated positively with the second axis (Table 4.14).

Table 4.13. A CCA applied to the correlation matrix of the environmental factors the during wet season

Environmental factor	Axis	
	CCA 1	CCA 2
Altitude	0.319	0.018
Slope direction	0.309	-0.352
Slope gradient	0.042	-0.266
Boulders	-0.053	0.158
Termite hill	0.191	0.007
Depressions	0.407	0.118
Shade	-0.109	0.108
Animal tracks	0.129	0.083
Burning	0.249	-0.035
Grazing intensity	-0.144	0.208
Soil depth	0.671	0.046
Soil pH	0.293	0.441
Measured soil electrical conductivity	0.162	0.135
Amount of phosphorus in the soil	0.412	-0.342
Percentage of clay	-0.407	0.541
Percentage of sand	0.398	-0.191
Percentage of silt	-0.129	-0.256

Table 4.14. A CCA applied to the correlation matrix of the environmental factors during the dry season

Environmental factor	Axis	
	CCA 1	CCA 2
Altitude	0.213	0.119
Slope direction	0.480	-0.120
Slope gradient	0.019	-0.172
Boulders	0.125	0.261
Termite hills	0.166	-0.003
Depressions	0.253	-0.002
Shade	-0.084	0.199
Animal tracts	0.140	0.059
Burning	0.290	0.139
Grazing intensity	-0.091	0.193
Soil depth	0.548	0.053
Soil pH	0.238	0.278
Measured soil electrical conductivity	0.149	0.142
Amount of phosphorus in the soil	0.343	-0.399
Percentage of clay	-0.340	0.595
Percentage of sand	0.270	-0.277
Percentage of silt	-0.024	-0.204

The wet and dry seasons' CCA triplots (Figures 4.6 and 4.7) showed that the distribution of *Aristida congesta* was positively influenced by soils clay content and negatively by increasing soil depths. *Aristida kenyensis*, during wet season, was positively influenced by soil pH and by boulders during the dry season. *Aristida* *adoensis* during the wet and dry seasons was positively influenced by soil depth and slope direction, and negatively by increasing percentage of clay in the soil.

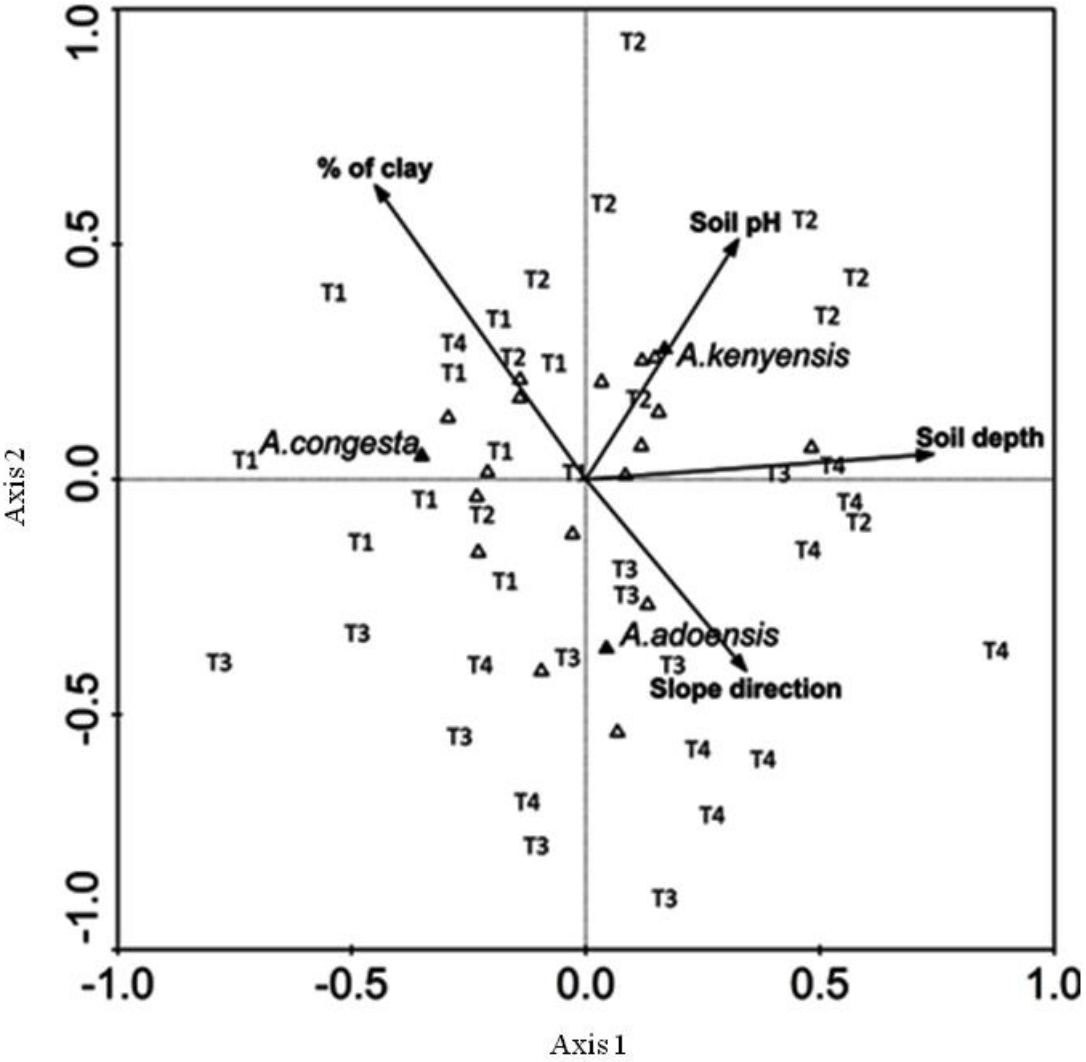

Figure 4.6. A CCA triplot for the wet season. $^{\Delta\ \&\ T}$Symbols in the triplot represent plant species and transect respectively.

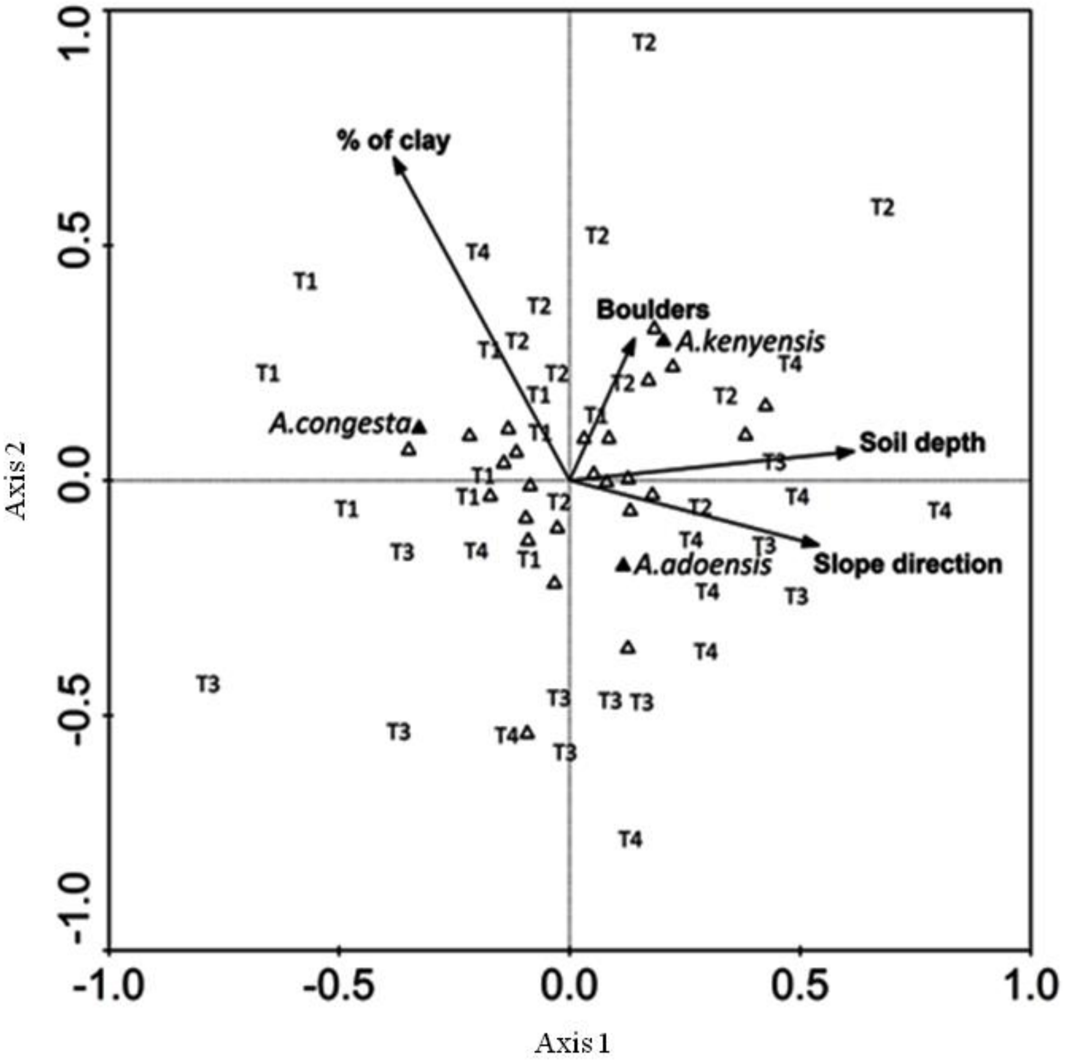

Figure 4.7. A CCA triplot for the dry season. $^{\Delta\ \&\ T}$Symbols in the triplot represent plant species and transect respectively

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Distribution patterns for the three species of *Aristida* at Kifuko ranch

Results of this study on the three species of *Aristida* to spatially isolate into distinct clusters are in agreement with findings reported by Ibrahim and Kabuye (1987). Ibrahim and Kabuye found different species of *Aristida* to occupy distinct habitats. The Results of *A. congesta*, which is a perennial grass, to increase in abundance during the wet season compared to the dry season when it was in low abundance, are in contrast to what one would expect for a perennial grass species. According to Ibrahim and Kabuye (1987) and Agnew (2012), grasses of perennial life form are expected to display almost a constant abundance regardless of seasonality. Recording of more *A. congesta* individuals during the wet sampling season could be attributed to the flowering of *A. congesta* individuals this study may have been missed during the dry season. Grasses without inflorescence look similar to one another and it is likely that during the dry sampling season, some *A. congesta* individuals may have been missed. The results on distributional trends for *A. kenyensis* to increase in abundance during wet season, and of *A. adoensis* abundance to remain constant during wet and dry seasons were expected. These results agree with what Ibrahim and Kabuye (1987) and Agnew (2012) reported for typical annual and perennial grass species.

5.1.2 Plant species associations

In this study, distinct plant species associations for the three species of *Aristida* inhabiting Kifuko ranch were evident. Plant associates and habitats found occupied by *Aristida* species in this study have been earlier reported in other studies. Ibrahim and Kabuye (1987) found species of *Aristida* to associate with plant species of disturbed grasslands and rangelands. Mcintyre and Filet (1997) reported association of *Aristida* species with plant species of deteriorating pastureland. *Evolvulus alsinoides,* which in this study was found associated with *Aristida congesta*, is reported by Agnew (2012) to grow with *Aristida* species on warm tropical regions. *Cymbopogon pospischilii* and *Enneapogon schimperanus* that were highly recorded at clusters of *Aristida* species are reported by Ibrahim and Kabuye (1987) as species of degraded rangeland habitats. According to Ibrahim and Kabuye (1987), *Cymbopogon pospischilii* and *Enneapogon schimperanus* grow on rocky ground in semi–arid grassland. Cerros-Tlatilpa *et al*. (2011) reported that *Aristida* species radiated in Africa in the late Miocene – Early Pliocene, during which time there was climatic changes leading to increased aridity and rainfall seasonality. Aridity and rainfall seasonality are true conditions of Kifuko ranch, and these are the suitable conditions for the listed plant species found associating with the three *Aristida* species.

The high numbers of plant species that were associated with *A. congesta* and *A. kenyensis* during the wet season compared to the low numbers of species associated with *A. congesta* and *A. kenyensis* during the dry season, can be speculated to the increased abundances of *A. congesta* and of *A. kenyensis* shown in this study, during the wet season compared to their low abundances during the dry season. The phenomenon of almost the same species and number of species that associate with *A. adoensis* on the other hand can be speculated to the constant abundances of *A. adoensis,* reported in this study, during wet and dry seasons.

5.1.3 Relationship between *Aristida* species and environmental variables

The environmental variables that significantly influenced the distribution of *Aristida* species in the wet and dry CCA biplots, projected in almost equal lengths. These results showed that these variables were almost of equal importance to the distribution of *Aristida* species at Kifuko. During the wet season, the abundance of *Aristida kenyensis* was positively influenced by soil pH. Soil pH in this study was recorded at about 6.1 to 6.7. Soil pH of 5.5 to 7.0 in presence of soil moisture is reported to aid easy flow of nutrients (Tyler, 1989). Ben-Shahar (1987) reported soil pH to significantly influence distribution of grasses in a moist savanna biome in South Africa. During the dry season, *A. kenyensis* correlated positively with boulders instead of soil pH. These results are in agreement with those of Nobel *et al*. (1992) who reported the role of large boulders in modifying their adjacent habitats and consequently influencing patterning of desert plant species. Boulders in this study therefore might have shielded micro habitats of *A. kenyensis* from the harsh conditions experienced during the dry season and influenced distribution of the species.

The results of the *Aristida adoensis* individuals, which correlated negatively with clay content in the soil, are in agreement with those of Sankaran *et al.* (2008). Sankaran *et al.* (2008) reported a negative relationship between woody cover and clay soil content in African savannas. Individuals of *Aristida adoensis* correlated positively with deep soils and slope direction. Ives (1958) reported a positive relationship among slope direction, drainage channels and soil erosion. Slope direction in this study may have accelerated soil erosion. Clayton (1970) found eroded habitats suitable for *A. adoensis*.

Aristida congesta individuals correlated negatively with plots of deep soils but positively with plots of high clay content. Clayton (1970) reported *A. congesta* to on habitats with gravel substrate. In savanna ecosystems, the concept of resource partitioning along soil depths by plants is well studied (Partel and Wilson, 2002; Holdo and Nippert, 2015). Partel and Wilson (2002) reported significant role of plant root dynamics in influencing plants spatial patterning in prairie and forest. Holdo and Nippert (2015) reported on differential soil moisture availabilities for African savanna grasses and trees. The shallow and fibrous root system of *A. congesta* in this study could be hypothesized to help the species to easily exploit resources of water soil nutrients held at shallow depths of clay soils.

5.2 Conclusion

- At a local spatial scale, each of the three *Aristida* species recorded at Kifuko distributed distinctively, with *A. congesta*, *A. kenyensis* and *A. adoensis* occupying mainly plots of transects one, two, and three and four, in this respective order. The abundances of *A. kenyensis* and of *A. congesta* increased significantly during the wet season compared to the dry season. The abundance of *A. adoensis* did not show any significant change during the wet season compared to the dry season.
- Each of the three *Aristida* species recorded at Kifuko ranch associated with specific plant species that were mainly of degraded rangelands.

- Distribution of each of the three *Aristida* species recorded at Kifuko was influenced by one or by a set of specific environmental variables. This demonstrated that, apart from the generalized tenet that distribution of all *Aristida* species is influenced by habitat disturbance (Clayton, 1970; Ibrahim and Kabuye, 1987), individual species of the genus at local scale respond to different environmental variations.

5.3 Recommendations

- The ability of the three *Aristida* species to distinctively isolate at localized scale and to associate with specific plant species, mostly species of degraded rangelands, presents these *Aristida* species as suitable candidates for monitoring rangeland conditions. The species of *Aristida* can therefore be recommended to be used by pastoralist communities around Kifuko ranch for monitoring conditions of their rangelands.
- This study recommends *A. kenyensis* to the pastoralist communities living around Kifuko ranch as a source of pasture following the onset of rain season and just after a prolonged drought. *Aristida congesta*, which grows on habitats with shallow soils and high clay content and *A. adoensis*, which grows on disturbed and well drained habitats with deep soils, can be recommended to the pastoralist communities living around Kifuko ranch as suitable pasture grass. These two species can also be recommended as stabilizing grass species of the heavily degraded landscapes around Kifuko.
- This study recommends replication of this study in another part of Northern Kenya to ascertain whether the environmental variables sampled in this study were taken at optimum.

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APPENDICES

Appendix I: Kifuko study sites for transects one, two, three and four

A, site from transect 1 with shallow soil; B, site from transect 2 with relatively deeper soil compared to A; C, site from transect 3 with deep soil and well aerated; D, site from transect 4 with deep soil and well aerated.

Appendix II: Species frequencies and abundances per transect during wet sampling season

	Species frequencies per transect					**Species abundances per transect**				
Species list	**T1**	**T2**	**T3**	**T4**	**#**	**T1**	**T2**	**T3**	**T4**	**#**
Aristida adoensis	5	5	9	9	28	9	8	30	23	70
Aristida congesta	9	3	2	2	16	112	17	23	15	167
Aristida kenyensis	6	6	2	2	16	21	40	19	6	86
Bothriochloa insculpta	5	7	2	4	18	x	x	x	x	x
Cymbopogon pospischilii	3	1	0	0	4	x	x	x	x	x
Cynodon dactylon	0	4	0	2	6	x	x	x	x	x
Enneapogon schimperanus	3	0	0	1	4	x	x	x	x	x
Eragrostis aethiopica	2	5	0	0	7	x	x	x	x	x
Eragrostis superba	0	0	4	2	6	x	x	x	x	x
Evolvulus alsinoides	4	0	1	0	5	x	x	x	x	x
Harpachne schimperi	7	5	7	5	24	x	x	x	x	x
Indigofera circinella	4	0	0	2	6	x	x	x	x	x
Indigofera sp.	3	6	0	0	9	x	x	x	x	x
Microchloa kunthii	1	0	2	2	5	x	x	x	x	x
Polygala stenopetala	2	1	0	1	4	x	x	x	x	x
Rhynchelytrum repens	2	0	5	1	8	x	x	x	x	x
Schkuhria pinnata	3	1	1	0	5	x	x	x	x	x
Sida ovata	1	3	2	0	6	x	x	x	x	x
Sida tenuicarpa	1	4	1	3	9	x	x	x	x	x
Solanum incanum	0	4	0	3	7	x	x	x	x	x
Themeda triandra	6	6	4	6	22	x	x	x	x	x
Aerva lanata*	0	2	0	0	2	x	x	x	x	x
Aspilia mossambicensis*	0	1	0	0	1	x	x	x	x	x
Chamaecrista sp.*	1	0	0	0	1	x	x	x	x	x
Chloris virgata*	0	2	0	0	2	x	x	x	x	x
Commelina Africana*	0	1	0	0	1	x	x	x	x	x
Dichrostachys cinerea*	1	0	0	0	1	x	x	x	x	x
Digitaria abyssinica*	0	0	0	1	1	x	x	x	x	x
Digitaria sp.*	1	0	0	0	1	x	x	x	x	x
Dodonaea angustifolia*	0	0	0	1	1	x	x	x	x	x
Eleusine multiflora*	1	0	0	0	1	x	x	x	x	x
Emilia discifolia*	2	0	0	0	2	x	x	x	x	x
Eragrostis cilianensis*	1	0	0	0	1	x	x	x	x	x
Euphorbia crotonoides*	1	0	0	0	1	x	x	x	x	x
Grewia similis*	0	1	0	0	1	x	x	x	x	x
Gutenbergia cordifolia*	1	0	0	1	2	x	x	x	x	x
Heteropogon contortus*	1	0	0	0	1	x	x	x	x	x
Hibiscus macranthus*	0	1	0	0	1	x	x	x	x	x
Ipomoea mombassana*	1	1	0	0	2	x	x	x	x	x
Leucas mwingensis*	0	1	0	0	1	x	x	x	x	x
Monsonia longipes*	2	0	0	0	2	x	x	x	x	x
Oxygonum sinuatum*	0	1	0	1	2	x	x	x	x	x
Pavonia sp.*	0	1	0	0	1	x	x	x	x	x

Appendix II (continued)

	Species frequencies per transect					**Species abundances per transect**				
Species list	**T1**	**T2**	**T3**	**T4**	**#**	**T1**	**T2**	**T3**	**T4**	**#**
*Pennisetum mezianum**	0	2	0	1	3	x	x	x	x	x
*Setaria pumila**	2	1	0	0	3	x	x	x	x	x
*Sida rhombifolia**	0	0	1	0	1	x	x	x	x	x
*Tephrosia sp.**	0	1	0	0	1	x	x	x	x	x
*Tragus berteronianus**	0	0	0	1	1	x	x	x	x	x
*Urochloa sp.**	0	1	0	0	1	x	x	x	x	x

*Species were not used in the analysis because they did not meet threshold of occurring ≥ 4 times out of the 10 sampled micro – sites per transect. Sign x denotes species abundance data was not collected. Sign # denotes Totals.

Appendix III: Species frequencies and abundances per transect during dry sampling season

	Species frequencies per transect					Species abundances per transect				
Species list	**T1**	**T2**	**T3**	**T4**	**#**	**T1**	**T2**	**T3**	**T4**	**#**
Aristida adoensis	5	6	9	9	29	10	13	30	23	76
Aristida congesta	8	2	2	2	14	108	13	23	15	159
Aristida kenyensis	4	4	1	1	10	9	18	8	3	38
Bothriochloa insculpta	7	5	2	6	20	x	x	x	x	x
Chamaecrista sp.	4	0	0	0	4	x	x	x	x	x
Commelina sp.	1	2	0	2	5	x	x	x	x	x
Cymbopogon pospischilii	4	1	4	2	11	x	x	x	x	x
Cynodon dactylon	0	3	1	2	6	x	x	x	x	x
Digitaria abyssinica	0	1	1	2	4	x	x	x	x	x
Enneapogon schimperanus	4	0	1	0	5	x	x	x	x	x
Eragrostis sp.	6	4	3	6	19	x	x	x	x	x
Eragrostis superba	0	0	5	2	7	x	x	x	x	x
Euphorbia sp.	1	7	1	1	10	x	x	x	x	x
Evolvulus alsinoides	6	1	1	0	8	x	x	x	x	x
Harpachne schimperi	7	4	9	6	26	x	x	x	x	x
Helichrysum nandense	1	1	2	0	4	x	x	x	x	x
Heteropogon contortus	0	0	2	2	4	x	x	x	x	x
Hibiscus macranthus	1	3	0	0	4	x	x	x	x	x
Indigofera circinella	2	2	1	2	7	x	x	x	x	x
Indigofera sp.	3	4	2	0	9	x	x	x	x	x
Microchloa kunthii	2	0	2	2	6	x	x	x	x	x
Pennisetum mezianum	1	4	0	1	6	x	x	x	x	x
Rhynchelytrum repens	3	0	3	1	7	x	x	x	x	x
Schkuhria pinnata	3	1	1	0	5	x	x	x	x	x
Sida massaica	2	3	1	3	9	x	x	x	x	x
Sida ovata	1	3	3	0	6	x	x	x	x	x
Solanum incanum	0	3	0	3	6	x	x	x	x	x
Themeda triandra	8	7	4	7	26	x	x	x	x	x
*Sida rhombifolia**	2	0	0	0	2	x	x	x	x	x
*Acacia sp.**	1	0	0	0	1	x	x	x	x	x
*Dichrostachys cinerea**	1	0	0	0	1	x	x	x	x	x
*Ipomoea sp.**	1	1	0	0	2	x	x	x	x	x
*Oxygonum sinuatum**	1	0	0	0	1	x	x	x	x	x
Acacia kirkii *	1	0	0	0	1	x	x	x	x	x
*Leucas sp.**	1	1	0	0	2	x	x	x	x	x
*Monsonia angustifolia**	0	1	0	0	1	x	x	x	x	x
*Aerva lanata**	0	1	0	0	1	x	x	x	x	x

Appendix III (continued)

	Species frequencies per transect					**Species abundances per transect**				
Species list	**T1**	**T2**	**T3**	**T4**	**#**	**T1**	**T2**	**T3**	**T4**	**#**
*Aspilia mossambicensis**	0	1	0	1	x	x	x	x	x	x
*Grewia similis**	0	1	0	0	1	x	x	x	x	x
*Amaranthus hybridus**	0	2	0	0	2	x	x	x	x	x
*Tragus berteronianus**	0	2	1	0	3	x	x	x	x	x
*Polygala erioptera**	0	2	1	0	3	x	x	x	x	x
*Acacia drepanolobium**	0	1	0	0	1	x	x	x	x	x
*Pentanisia ouranogyne**	0	1	0	0	1	x	x	x	x	x
*Tephrosia sp.**	0	0	2	0	2	x	x	x	x	x
*Tinnea aethiopica**	0	0	1	0	1	x	x	x	x	x
*Sonchus sp.**	0	0	1	0	1	x	x	x	x	x
*Dodonaea angustifolia**	0	0	1	1	2	x	x	x	x	x
*Gutenbergia cordifolia**	0	0	0	1	1	x	x	x	x	x
*Sporobolus sp.**	0	0	0	1	1	x	x	x	x	x

*Species were not used in the analysis because they did not meet threshold of occurring ≥ 4 times out of the 10 sampled micro – sites per transect. Sign x denotes species abundance data was not collected. Sign # denotes Totals.

Appendix IV: Structured field data sheet used to collect environmental data for the study

Site Description			
Date: ---------------			
Transect No: -------	Plot No:------------	Latitude/Longitude: ------------	Elevation: -------(m)

Parameter	**Attributes**	**Codes**
A) Slope direction	South	1
	South West	2
	East	3
	North East	4
	North	5
	North West	6
	West	7
	South Eest	8
B) Slope gradient	1—5 %	1
	6 —10 %	2
	11—15 %	3
C) Soil depth	Shallow	1
	Deep	2
D) Boulders	Present	1
	Absent	0
E) Shade	Present	1
	Absent	0
F) Animal tracks	Present	1
	Absent	0
G) Termite hills	Present	1
	Absent	0
H) Depressions	Present	1
	Absent	0
I) Burning	Present	1
	Absent	0
J) Animal bomas	Present	1
	Absent	0
K) Grazing intensity	Minimal	1
	Moderate	2
	High	3