INFLUENCE OF CATTLE GRAZING AND GLADE AREAS ON INVERTEBRATE ASSEMBLAGES IN A SAVANNA ECOSYSTEM, NORTHERN KENYA

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university

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I dedicate this work to my parents Eva and George Nganga, my brother Collins Mureithi and my sister Ivy Muthoni. God bless you for standing with me throughout this study.

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ABSTRACT

Northern Kenya is a vast semi-arid area where large tracts of land are dedicated to ranching, conservancies and pastoralism. Various studies have been conducted in this region to understand how grazing influences the vegetation patterns, its composition and re-growth characteristics. However, few studies have been conducted on the effect that grazing has on invertebrate assemblages. This study therefore investigated the effect of cattle grazing on invertebrate assemblages within Lewa Wildlife Conservancy, and across glade patches established from areas that held kraals in past years.

Sampling of invertebrates was carried out across seasons over a ten month period using pitfall trap and sweep net methods, at a six-week interval, and the results obtained subjected to analysis of variance. Vegetation data for plant community characteristics and biomass was collected using line intercept method. Soil was collected once during the study period in all treatment sites and tested for soil pH, nitrogen, bulk density and organic carbon. Soil pH was measured using a soil solution ratio of 1:5 (1 part soil to 5 parts 0.01M Calcium chloride), Total Nitrogen was measured using the Kjeldahl method, a soil auger and metal core rings were used to collect disturbed and undisturbed soil samples respectively and Organic Carbon content was measured using the Walkley and Black method.

A total of 339 invertebrate species from 296 families were collected; pitfall trap method accounted for 200 species [59%] and sweep net method had 139 species [41%]. Of this total invertebrate collection, 160 families were from the order Coleoptera [54%] while Orthoptera, Hemiptera, Hymenoptera, Diptera, had 51 [17%], 33, [11%], 32 [11%], 20 [7%] families respectively.

Invertebrate diversity and abundance collected by both sweep net and pitfall trap methods were not significantly different across the three treatments; glades, grazing and control.

Invertebrate species diversity and invertebrate species abundance were not significant at $\alpha \leq 0.05$ for invertebrates collected using sweep net method. Similarly, for invertebrate species collected using pitfall method, invertebrate diversity and abundance were not significant. However, when the collected invertebrates were grouped into their different orders, invertebrate species revealed significant differences in abundance ($\alpha \leq 0.05$). Invertebrate species mean abundance was highest in the order Coleoptera in glades and grazed treatments.

Percentage total invertebrate abundance from glades of the year 2010 was the highest (24%) compared to that of glades established in the other years. Glades from the year 2009 and 2012 had the lowest total invertebrate abundance at 18% while those of the year 2008 and 2011 recorded total invertebrate abundance of 20%. However, these differences in total invertebrate abundance, across the years, were insignificant at $\alpha \leq 0.05$.

Invertebrate species diversity was not significantly different across glades of different years, either by using sweep net or pitfall trap methods. However, an analysis of variance on invertebrates collected across glades of different years, using pitfall method, revealed a significant difference on invertebrate species abundance ($\alpha \leq 0.05$) that was attributed to differences in glades of 2009 and 2010.

Invertebrate species diversity and abundance were significantly different across seasons $\alpha \leq 0.05$ and invertebrate species abundance was higher in the wet seasons than in the dry one. Vegetation biomass was not significantly different across the three treatments but was significantly different across seasons within these treatments ($\alpha \leq 0.05$) with the highest amounts of vegetation biomass occurring in the first wet season and the lowest amounts in the dry season. A negative and significant correlation was established between Diptera species and forbs biomass ($r = -0.29$, $\alpha \leq 0.05$) and between Hemiptera species and perennials biomass ($r = -0.26$, $\alpha \leq 0.05$). Other invertebrate species namely Hymenoptera, Coleoptera and Orthoptera did not significantly correlate to vegetation parameters, showing that vegetation has an indirect effect on these species.

There was a negative and significant relationship between invertebrate species from the order Coleoptera and soil bulk density ($r = -0.52$, $\alpha \leq 0.1$). Soil bulk density was within the ideal range of 1.10 and 1.47 g/cm^3 for plant growth that is linked to increased invertebrate diversity and abundance. Invertebrate species from the other orders, this are, Diptera, Hymenoptera, Hemiptera and Orthoptera, did not give significant correlations with all measured soil attributes, indicating lack of a direct relationship.

From this study, invertebrate species patterns reveal important ecological trends in grazed conservancies and can therefore be used for ecological monitoring. Controlled grazing in such conservancies should be encouraged as it does not affect the ecological integrity for biodiversity conservation. Moreover, in practicing this, these conservancies will meet their corporate responsibility of supporting neighboring grazing communities.

Keywords: kraals, glades, grazing, invertebrates, savanna, cattle

CHAPTER ONE

INTRODUCTION

This chapter introduces the importance of savannas in the world, the sources of livelihoods in them, and more specifically in Northern Kenya. The concept on the use of kraals and subsequent formation of glades is introduced and the effect of this on invertebrate species is discussed. Invertebrate roles, their importance and link to grazing are discussed with a view of understanding the effect of grazing on invertebrate functioning in the ecosystem. The problem statement and the hypotheses for the study are also given at the end of the chapter.

1.1 Background

Two thirds of the world's population inhabits tropical areas while savannas occupy approximately 40% of these lands (Solbrig, 1990). In Kenya, they are mainly found in arid and semi-arid parts of the country in which Lewa Wildlife Conservancy is located. From the National Policy for Sustainable Development of Arid and Semi-Arid Lands in Kenya, the human population of these lands is estimated at 10 million inhabitants, most of who are pastoralists and largely depend on livestock as the main source of livelihood. The arid and semi-arid zones occupy approximately 80% of the country (GoK, 2010).

Lewa Wildlife Conservancy (LWC) is located in the semi-arid part of Northern Kenya and is endowed with vast land standing at approximately 60,000 hectares (Lewa, 2008). The conservancy has large portions of unproductive standing biomass. Therefore, a need arose to control the overly grown grass in other ways rather than burning, to not only enhance the conservancy productivity, but also share the benefits of over-productivity with the community living around this area. This led to the introduction of controlled grazing within the conservancy.

1.2 Grazing History

Under-utilization of the grassland in Lewa led to the area having high biomass of more than 5000 kg/ha with low species diversity mostly dominated by *Pennisetum stramineum* and *Pennisetum mezzianum* grass species (Lewa, 2008). Burning had been used over time to control the grasslands. However, this was abandoned for grazing. Lewa Wildlife Conservancy introduced cattle grazing with the long-term goal of managing the overly dense grass by allowing grazing access to the surrounding community.

Cattle grazing within the conservancy began in 2008, and cattle were grazed intensively in selected areas within the conservancy. At night, the cattle were kept in kraals for a period of five to seven days in the dry season and for one to two days in the wet season to avoid overgrazing and over-trampling in one area (Mwololo, 2012). A kraal is a cattle holding constructed with an approximate diameter of 30 meters and fenced around to form a circular shape and in which cattle rest at night.

Two kraals were used in every area and both held approximately 600 cattle. In the event that rain fell within the time cattle were in a kraal, the cattle were moved the following day to avoid compaction damage to the soil. With this grazing practice, Lewa Wildlife Conservancy sought to know if this introduction of cattle from the community would affect the invertebrate diversity and abundance within the conservancy. It is with this in mind that this study was conceptualized and carried out to inform future grazing practices in the conservancy.

Invertebrates are by far the most abundant and most diverse organisms in ecosystems found in both terrestrial and in aquatic systems (Patrick, 1994). Invertebrates are important in the functioning of the world's ecosystems (Freckman et al., 1997). Invertebrates for example bees and butterflies are beneficial to humans and to the ecosystem through pollination (Roger and Calderone, 2000). A study by Siemann and Weisser (2004), showed that insects play a mediating role between the ecosystem and plant physiology, dynamics and activities.

Soil invertebrates specifically modulate soil temperature, moisture, nutrients, plant species composition, soil compaction, trace gas production, aggregate formation and stability, soil crusting, aeration, runoff, carbon storage, organic matter stabilization, macro-pores, water transport, and microbial community structure to varying degrees (Whitford, 2000). Invertebrates are also important as linkages at critical interfaces: land/air (litter, soil and plant canopies), root/soil, and land/water each invertebrate playing a role in each interface (Coleman and Hendrix, 2000).

Roles played by each invertebrate in this linkage of ecosystem components is critical as some ecological processes depend on invertebrates. Change in distribution of certain invertebrates causes an effect on the response of dependent or competitive invertebrates (Frost *et.al.*,1995).

Grazing and the associated trampling effects have an effect on vegetation productivity and biomass quantity (Kariuki, 2010). Grazing however has been shown to increase plant diversity so long as grazing pressure is kept constant and rotations practiced to avoid overgrazing (McIntyre, Heard and Martin, 2003). Changes in vegetation diversity and structure can affect invertebrate diversity. A study by Murdoch, Evans and Peterson (1972) demonstrated that plant evenness and diversity is positively correlated to insect evenness and diversity respectively.

Biological conservation is one of the core mandates of Lewa Wildlife Conservancy and the institution accords importance to invertebrate survival and conservation. Following the uncertain responses of invertebrates to stress such as grazing, there is need to better understand how the diversity, abundance, and characteristics of invertebrate assemblages is affected by grazing and glades. This will be important in evaluating the effect that introduction of cattle will have on the invertebrates found within the conservancy.

This study documented the specific invertebrate species present and the effect of cattle grazing, glades, seasons and soil attributes on invertebrate species.

1.3 Problem statement

Loss of particular invertebrates can have an adverse effect on the food web as demonstrated by New (1995), where invertebrates were shown to be acting as a link between habitats. A negative change in an organism diversity and abundance consequently affects the food web interactions (Holmquist, 2004). Holmquist (2004) found that the abundance of invertebrates was affected on or close to trails created by anthropogenic disturbance. This suggests that areas trodden upon by cattle as they graze have decreasing invertebrate numbers leading to the underlying hypothesis for this study that disturbed areas such as those under grazing and those areas that previously had kraals have less invertebrates than areas without disturbance.

1.4 Objectives

The primary objective of the study was to investigate the effect of cattle grazing and glades formation on the diversity and abundance of invertebrates in a wildlife conservancy.

The specific objectives were to:

i. Determine the effect of cattle grazing on invertebrate species diversity and abundance.
ii. Determine how invertebrate species diversity and abundance differ on glades of different ages.
iii. Determine the effect of seasons on invertebrate species diversity and abundance and on vegetation characteristics.

iv. Determine the effects of soil properties on invertebrate species diversity and abundance.
v. Develop a reference collection of the invertebrate species found in Lewa Wildlife Conservancy for local and international use.

1.5 Hypothesis

The hypotheses for this study were that:

i. Grazed and non-grazed areas have similar invertebrate species diversity and abundance.
ii. Glades have similar invertebrate species diversity and abundance irrespective of the age of the glade.
iii. Invertebrate species diversity and abundance are similar across seasons and vegetation attributes are similar across seasons.
iv. Soil properties have no effect on invertebrate species diversity and abundance.

1.6 Thesis organization

Chapter one introduces the background of the study, the grazing history, the problem statement and the general and specific objectives. Chapter two contains the literature review covering the importance of grazing and its effects on invertebrate assemblage. This chapter also reviews the effect of kraals and grazing on soil micro-climate and the consequent effect of this on the invertebrates' community. Chapter three discusses the general study area, the climate, vegetation and habitat. Key methods of collection and processing of invertebrate, vegetation and soil samples are discussed. The study layout is also discussed. Chapter four presents the results, interpretations and discusses the main findings. Lastly, Chapter five discusses and summarizes the important findings of the study and presents some key recommendations. This work has a strong bias to land resource management in the wider context of the degree area of land and water management.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews the different work done by scientists on the subjects discussed in this work. The section is divided into sub-sections with each sub-section addressing a specific objective as earlier outlined in Chapter One. The sections discussed cover the effect of grazing on invertebrates, literature on kraals and their importance, effect of seasons on invertebrates, how vegetation and soil affect invertebrate behavior and the ecological importance and functioning of invertebrates in the ecosystem.

2.1 Effects of cattle grazing on invertebrates population

Grazing should generally be prescribed to avoid the adverse effects of overgrazing such as soil compaction, loss of native species and invasion by the exotic species. Grazing has been described as a complex suite of component disturbances including dewatering, trampling, soil compaction, incision and plant biomass removal, all of which have the potential of significantly degrading invertebrate assemblage numbers (Holmquist, 2004).

Cattle's grazing is a necessary activity as it constitutes the source of livelihood for most pastoralist communities. Grazing is a useful method of controlling weeds and invasive species. When properly managed cattle grazing can be used to break up the soil and to incorporate seeds of native plants for the interest of their conservation (McIntyre *et.al*., 2003). Conservation of these native plants is especially important to preserve invertebrates such as grasshoppers, bees, beetles which play a significant role in the food chain, some of which are fed on by birds (McNabb, 2001) and some by other smaller mammals.

Invertebrates such as bees, grasshoppers, beetles and species from the Hemiptera order are dependent on plants as a source of food (Debano, 2006). This then is the reason cattle grazing should be controlled to avoid overgrazing and other adverse effects brought about by overgrazing.

Cattle grazing impacts on the diversity and abundance of many orders of insects; Debano (2006) demonstrated that beetles richness decreased on grazed sites and insects from orders Diptera and Hymenoptera appeared to be less diverse in the grazed than non-grazed areas. Cattle grazing should therefore be held to a level where it does not upset ecosystem balance to the point of causing changes in abundance of organisms that are lower in the food chain (Marsack, 2000) .

Fabricius (2002) showed that grazing and trampling has effects on some invertebrates groups. Holmquist (2004) conclusively stated that un-grazed sites had more total invertebrate numbers than grazed sites. Effect of compaction and trampling are seen on invertebrates that feed on roots. Hunter (2001) reported effects on invertebrates such as mint root borer, mint flea beetle and strawberry root borer, when the root structure failed to fully establish due to soil compaction.

Morris (1967) established that intensive grazing causes a decrease in invertebrate abundance and concluded that a heterogeneous habitat created by rotational grazing was the best way to maximize invertebrate biodiversity. Southwood (1979) and Morris (1981) in other studies, showed that invertebrate abundance and community composition in grasslands is a function of herbaceous vegetation. The vegetation parameters used in Southwood (1979) and Morris (1981) were biomass, plant structural productivity and composition. Halaj (2000) reported grazing as having a profound effect on arthropods.

Most of these past studies demonstrate that invertebrates, with the exception of the tolerant taxa, are negatively affected by grazing as evidenced by the reduction in species richness and abundance in areas where vegetation has been removed through grazing activities. However, cattle grazing are not entirely detrimental as evidenced by Marty (2005) in the study where it was demonstrated that in regions threatened by exotic species invasion and lacking native wild grazers, cattle grazing provides the type of disturbance that helps maintain diverse plant and invertebrate communities.

Grazing has been demonstrated to reduce the complexity of the habitat by reducing the relative vegetation cover (Warui *et.al*., 2005) and consequently having an effect on invertebrates species assemblage. This can be attributed to the way in which different invertebrates respond to grazing pressure. The effect of cattle grazing on each order of insect is dependent on the preferred habitat of that invertebrate species (Debano, 2006) and the means by which it acquires its food.

Lauenroth and Milchunas (1993) established that grazing has a very slight effect on vegetation species composition and on alteration of the dominant vegetation species compared to the effect caused by environmental variables. In this same study it was found that grazing has an effect on the aboveground net primary productivity (ANPP) and on plant diversity. Species composition of vegetation-associated insect communities was shown to differ and was significantly correlated with percent vegetation cover and number of shrubs (Debano, 2006).

A study on the invertebrate community response as seen from Engle (2008) and Fuhlendorf (2004) gave deductions showing similar invertebrate effects arising from areas of transitional grazing and patch burning. These two measures were shown to cause an increase in the total invertebrate numbers compared to areas of current burn. Engle’s study led to deductions that disputed earlier evidence by Hutchinson (1980) that fire and grazing reduce invertebrate numbers. Engle (2008) was able to show that patches recovering from focal burning and grazing contain structure, plant species and resources such as accumulating plant litter. These resources, enhance invertebrate species numbers, and they are absent in areas lacking fire and grazing (Fuhlendorf, 2004).

Swengel (2001) reported that direct invertebrate mortality is what brings about low invertebrate numbers in areas experiencing current burn as opposed to areas recovering from transitional fires. This supported Hutchinson’s (1980) findings that fire and grazing reduce invertebrate numbers during current burn. However, Arnott (2006) explained that removal of vegetation by fire stimulates invertebrate reproduction and multiplication, hence the increase that was observed post burn for many invertebrate studies.

From the above literature the combined effects of cattle grazing and glades on invertebrate diversity have been documented. Therefore this study investigated the effect of controlled cattle grazing and the effect of glades, formed in previously kraaled areas, on invertebrate species diversity and abundance to understand if and which invertebrate species are more vulnerable to grazing effects than others.

The study used both pitfall trap and sweep net to capture both ground living and foliage dwelling invertebrate species respectively. The study aimed at creating a thorough understanding on the effect of foliage removal, caused by grazing, and of glade establishment on invertebrate species diversity and abundance.

2.2 Kraals and glade effect on invertebrate populations

Kraals are described as areas that are used to hold cattle (Borg, 1996) and they can be designed in different ways but are mostly preferred circular to prevent bunching up of cattle in corners as is the case in rectangular kraals. Cattle are led out in the mornings for grazing in surrounding areas and back in the evenings to sleep in the kraals. Kraaled areas have large amounts of cattle dung which greatly increases the soil organic matter and consequently improves the soil structure and water infiltration in the area thereby greatly increasing the soil quality (Asawalam, 2011). This promotes vegetation growth and an enhanced micro climate for invertebrate species.

Kraaled areas are high in nitrogen, potassium and carbon (Young, 1995) owing to the accumulation of defecates and urine deposition during the time the cattle are constrained in that area. This results in the formation of green patches (glades) that indicate areas of vegetation regeneration. The patches created in glades (the area formed on removal of a kraal) control the micro climate and soil factors through the redistribution of organic matter and concentration of limiting resources (Lauenroth *et.al*., 2001).

This concentration of nutrients affects the diversity and abundance of different invertebrate species. Nitrogen loading is known to decrease insect species richness but increases insect abundances (Haddad *et.al.,* 2000). In another study on nitrogen deposition and insect herbivores, it was reported that Nitrogen deposition caused a strong increase in plant production, decreased C: N ratio, increased soil organic carbon and enhanced rates of N mineralization.

The number of cattle held in kraals is controlled because grazing intensity and stocking rate has been demonstrated to decrease the carbon sinks and nitrogen storage found in grassland savannahs (Zhang, 2011). Nitrogen loading is another likely occurrence in kraaled areas and it has been noted to have an indirect effect on the food chain through increase in plant biomass which results in increased insect diversity and abundance (Haddad *et.al.,* 2000).

2.3 Effect of seasons and climate change on invertebrate assemblages

Insects are known to reproduce and breed following different patterns. Some hibernate in the winter seasons and emerge in the summer and owing to the short life cycles of insects and a higher reproductive capacity, insect population increases during the warmer seasons (Greenslade *et.al*., 2012).

Change in season however, not only affects reproductive ability of insects but also brings about a change in the environment and habitats where these insects are found. In mid to high latitude areas, warmer temperatures has been seen to coincide with rapid survival and insect development (Adamo and Lovett, 2011). Warmer periods may also give a cue to insects that depend on onset of warmer periods to begin reproduction (Hoffmann and Frodsham, 1993).

Food resources are depended on by invertebrates therefore changes in environmental conditions indirectly affect invertebrate species (Greenslade *et. al*., 2012). Dawn and Clifford (1988) reported that most invertebrate species abundance increases with increased rainfall amounts and the study showed insects, such as those from the order formicidae, to be favored by hotter drier periods while others, such as those from the order collembola, are favoured by the more moist conditions. This then suggested that factors such as rainfall amounts, soil moisture levels and temperature determine vegetation growth and consequently impact on invertebrate dynamics.

Elevated carbon dioxide concentrations and increased temperatures brought about by climate change have an effect on invertebrate diversity as insects some insects alter how much they eat and others develop more rapidly in response to increased temperatures (Trumble and Butler, 2009). As carbon dioxide levels increase, plant defenses reduce and allow for greater destruction by leaf-eating insects. (Urbana-Champaign, 2008). Elevated temperatures have also been shown to cause early maturity in insects (Masters *et.al.*,1998) which may lead to greater risk from extreme events leading to reduction in adult numbers.

2.4 Effect of plant cover, plant biomass and soil properties on invertebrate populations

Chappell *et.al*. (1971) demonstrated that abundance and species richness of soil fauna is reduced in systems due to soil compaction. That study showed compacted soils to be less favorable for good plant growth due to restricted supply of air, water and nutrients. The plant therefore fails to get adequate nourishment due to the increased soil density and hardness (Adams, 1998). Plants affected in this way fail to attain the desired height and structure. This directly affects invertebrates that depend on vegetation structure for their habitat (Rypstra, 1999) and plants can therefore not grow in these kind of compacted soils.

Plants richness affected by unsuitable environmental conditions affects insect dynamics and patterns (Knops *et.al.,* 1999). Loss of plant diversity therefore affects insect diversity (Haddad *et.al.,* 2001) and growth of plants, which is the main food resource for invertebrates, and is determined by factors such as the type of soil, the fitness of soil and a soil in good health (Peter and Stephen, 2013). Soils of good health easily retain high moisture levels throughout a season even when rains cease falling (Walker, 1991). This however is only true for soils with a high infiltration capacity.

2.5 Ecological roles and importance of invertebrates on the environment and ecosystem services

Invertebrates, our main study focus, are by far the most abundant of animals in the world ecosystems but poorly understood (Patrick, 1994). In agro ecosystems they perform a variety of ecological services (Freckman *et al.*, 1997) that include recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals among others (Butler 2011).

Invertebrates are also of economic importance as they are regarded as major pests of agricultural plants and products. Invertebrates are important in waste recycling which makes minerals and organic materials available to plants and other animals (Lavelle, 1997). Beetles, for example are known to contribute to soil fertility by returning organic matter back into the soil through several multi-trophic interactions (Borror, 1981). Soil earthworms are equally important as they decompose organic matter and their activities improve soil drainage, aeration and composition of the soil (Edwards, 1998).

Processes such as these promote plant growth creating a habitat structure that is suitable for vegetation associated invertebrates. Some other insects such as bumblebees, honey bees, butterflies are pollinators and plants rely on them to pollinate their flowers so as to complete the plant reproductive cycle. Insects such as these are heavily relied on for food production (McGregor, 1976).

Insects also carry within them a large pool of nutrients and these same insects are part of most food chains with many birds feeding on them as part of their adult diet or for their chicks (McNabb, 2001). Grazing as a practice can therefore be managed to levels where it does not become detrimental to the environment. This has the resultant effect of increasing invertebrate numbers which benefits other small mammals and birds in the food chain (O'leske, 1997).

Invertebrate studies are also important for bio-monitoring because invertebrates are sensitive to a variety of stresses and their population dynamics are easy to monitor, measure and quantify (Holmquist, 2004). Functional roles of invertebrates are easily understood and therefore bio-monitoring can be used to detect disturbances in the ecosystem before major damage occurs (Warui *et.al*. 2005).

Invertebrates such as grasshoppers and spiders can indicate to us the health of our savannas and environment (Warui *et.al*. 2005), much like how aquatic insects and plants indicate water quality. By understanding the distribution patterns of these invertebrate populations in response to various factors including grazing and formation of glades, we can begin to use them as environmental indicators for conservation purposes particularly in such prime conservation areas such as the savanna grasslands and wildlife conservancies.

CHAPTER THREE

MATERIALS AND METHODS

This chapter highlights the general study area in terms of the general location, the type of climate experienced, the vegetation dominating the area and the soil types. The study design used is discussed in detail. The chapter also addresses the different methods used in collecting data for the study parameters; the invertebrates, vegetation and soils. It further discusses the specific indices used to analyze invertebrate data and the data analyses methods and soft-wares used.

3.1 Study Area

A map of the study area is indicated in Figure 3.1 with different shading patterns to illustrate the study area, the national reserves around the area, the forest reserves and major towns, roads and rivers.

3.1.1 Location

This study was conducted at the Lewa Wildlife Conservancy (LWC) (Fig 3.1), which is a wildlife sanctuary incorporating the Ngare Ndare forest and covering 60000 acres North of Mt Kenya (Lewa, 2008). Lewa Wildlife Conservancy lies at an elevation of 1195m with an altitudinal gradient from 1450m in the North to 2300m in the South (Lewa, 2008). The area lies at a longitude of 0°19′35.64″ N and a latitude of 37°31′27.40″ E.

3.1.2 Vegetation and habitats

Lewa Wildlife Conservancy consists of diverse ecosystems mainly open savannah, forest habitat, rocky terrains, acacia woodlands and riverine vegetation (Lewa, 2008). The area is majorly a grassland savanna with tree and shrub cover of slightly more than 20 per cent (Pratt, 1977).

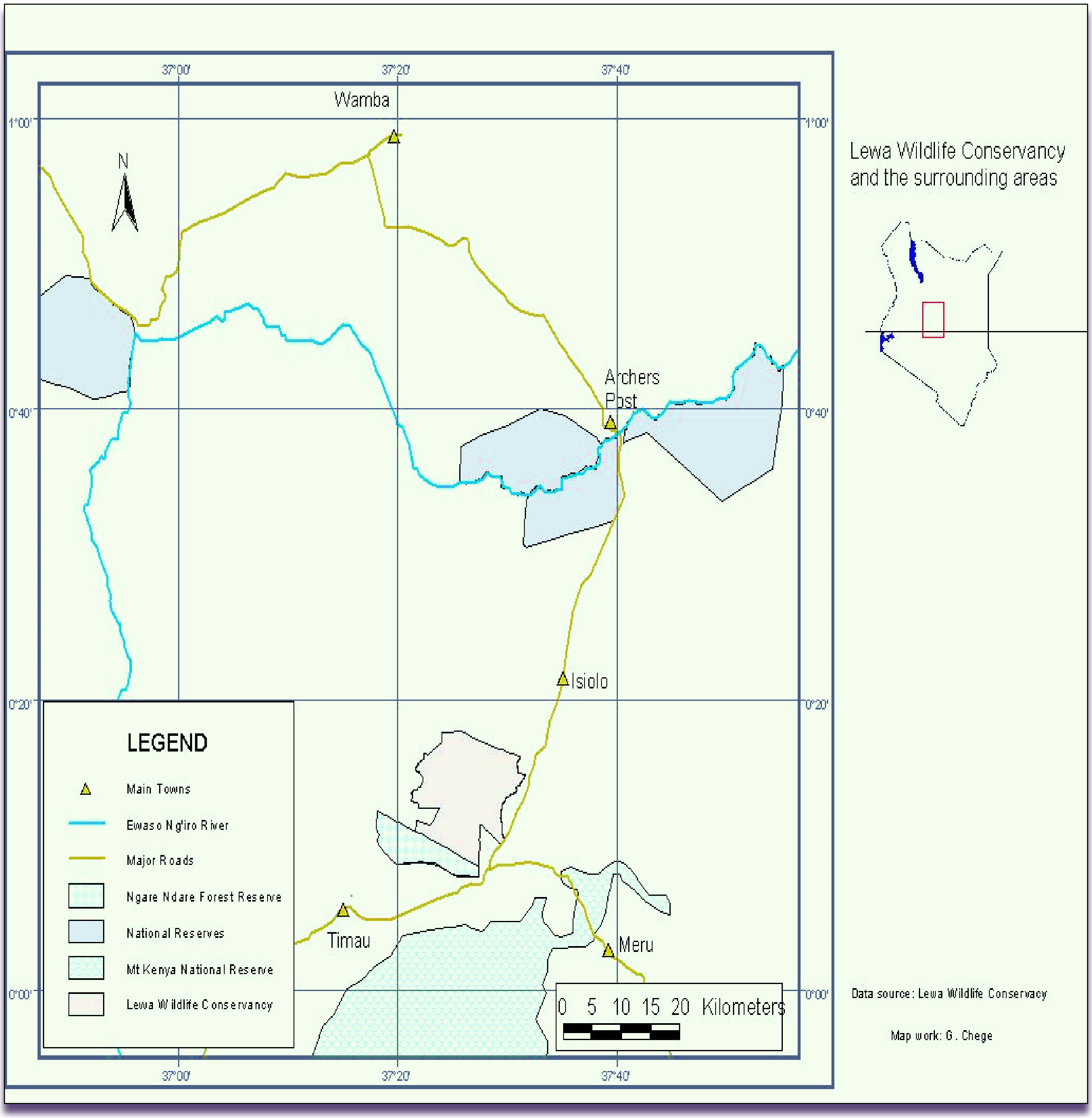


Figure 3 1: Lewa Wildlife Conservancy and the surrounding areas

Lewa vegetation is dominated by *Pennisetum stramineum and Cynodon dactylon* (Lewa, 2008). Herlocker (1979) reported that *Cynodon* increases in areas where *Themeda triandra* has been overgrazed. *Harpachne schimperi* and *Aristida adoensis* represent the unpalatable species. The dominant woody species is *Acacia drepanolobium.* The shorter flat-topped *Acacia drepanolobium* occurs in the drier areas and much taller ones are found in the more fertile soils that remain moist over long periods of time. *Acacia xanthophloea* represent the tall closed woodland occurring in the riverine areas of Lewa Wildlife Conservancy (Lewa, 2008).

3.1.3 Climate

The temperature in Lewa ranges from highs of 32°C to lows of 24°C. The temperature variation is attributed to the transitional climate borrowing from the Eastern Kenya highlands and the much warmer Northern Kenya lowlands. The mean annual rainfall is 667mm with a range of 250-700 mm per annum. The area is characterized by periods of prolonged droughts with the long rains falling from March to May and the short rains from October to December (Lewa, 2008). Fig 3.2 shows rainfall averages over a five-year period.

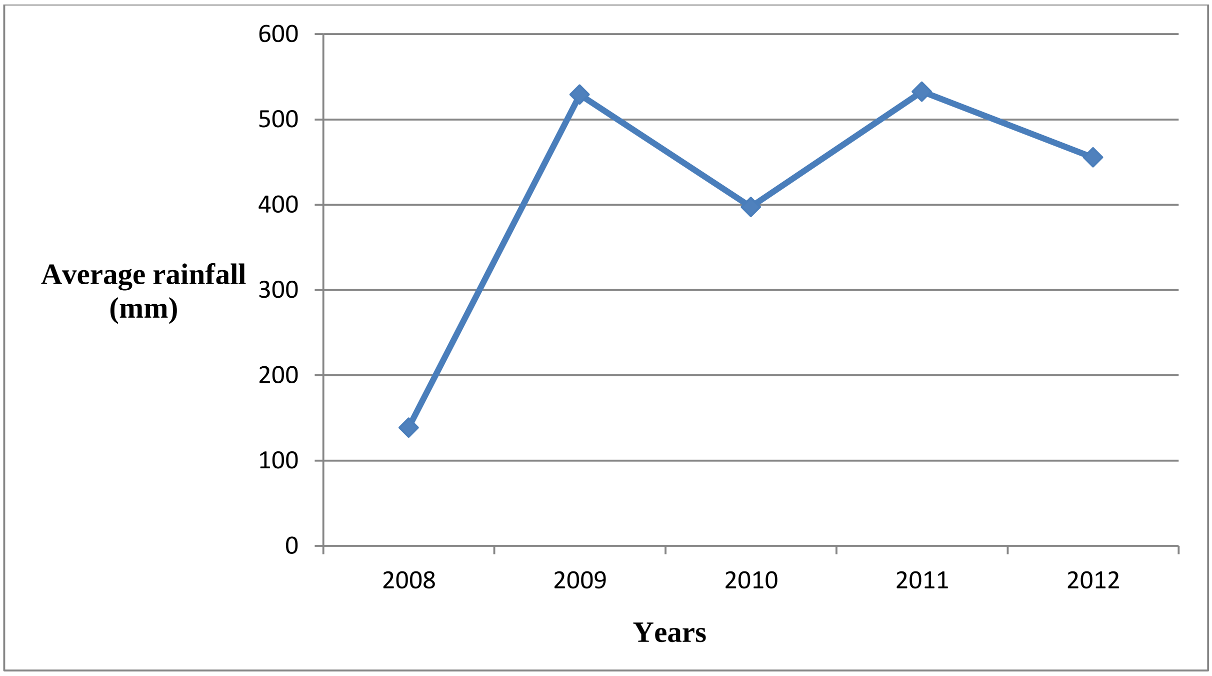


Figure 3 2: Average rainfall patterns (mm) for the years 2008 to 2012 in Lewa Wildlife Conservancy

3.1.4 Drainage and soils

Lewa drainage forms part of the Ewaso Ngiro river basin. Lewa water sources are the Ngare Ndare, Lewa and Ngare Sergoi rivers. The area has a seasonal river Marania, which has its source from the Lolmutunyi spring (Lewa, 2008). The Conservancy has three man-made dams. Fluvisols, Nitisols, Solonetz, Gleysols and Vertisols are the major soil types found in the conservancy. The area is largely dominated by black cotton soils (Vertisols) with some areas having mixed red (Nitisols and Solonetz) and black cotton soils (Vertisols) (Lewa, 2008).

3.2 Study Site Selection

Study sites were selected using a stratified random sampling design and the sampling points randomly selected across Lewa. The study sites were from areas where the 2008 Lewa grazing program had been carried out. Since the areas from which the grazing program was carried out were not evenly distributed across the conservancy, stratification was used to group the glades in close proximity to each other under Northern, Eastern, Western and Southern blocks.

From each block, five sites were randomly selected to give a total of 20 sites. For cost effectiveness, five randomly selected sites were dropped leaving the study with a total of 15 sites, where three sites represented glades from every year beginning 2008 to 2012. Each site had three treatment namely; glades, grazing and control plots. These 15 sites formed the core data collection sites for this study.

3.3 Study Layout

Table 3. 1: Study sites with treatment allocation within the Conservancy

Year of glade establishment	Treatment one **Glades**	Treatment two **Grazing**	No glade & No grazing **Control**
2008	GL AH GL MTI I GL CYS	GR AH GR MTI I GR CYS	C AH C MTI I C CYS
2009	GL MTI II GL CM GL SR	GR MTI II GR CM GR SR	C MTI II C CM C SR
2010	GL MK GL MTA GL MC	GR MK GR MTA GR MC	C MK C MTA C MC
2011	GL MNC GL LS GL LM	GR MNC GR LS GR LM	C MNC C LS C LM
2012	GL AS GL FP GL CS	GR AS GR FP GR CS	C AS C FP C CS

The letter codes represent the sites and the other abbreviations represent the names of all plots sampled and the full names of these plots are listed in appendix 1.

Treatment codes: GL – Glades; GR – Grazing; C – Control

3.4 Data Collection Methods

The study collected data on invertebrates, vegetation and soil parameters. The particular methods used for each of the parameters and the reasons behind the use of the methods, are detailed in this section.

3.4.1 Vegetation sampling

Data collection on vegetation was focused on cover, botanical composition, tree density, frequency and biomass. Sampling was carried out along a 50-meter transect for each of the 45 sampling plots; that is three sampling plots per site for the selected 15 study sites. Vegetation sampling was done every six weeks concurrently with invertebrate sampling.

Line intercept method was used to collect data on vegetation cover, frequency, botanical composition and biomass. This method is best suited for semi-arid bunchgrass and shrub vegetation types (Coulloudon, 1999) since it is simple and rapid. The line intercept and quadrat method has been used previously (Cox, 1990; Knapp, 1984) where a 50 meter tape was marked into intercepts of 1m and the vegetation species encountered after every one meter was recorded (Salem, 2005). A 0.25 square meter quadrat was used to record the vegetation encountered after every 5 meters on the 50 meter tape (Daubenmire, 1959).

Use of quadrats is a sites-less technique and it is an advantageous method since it saves on time and sample sites do not need to be established (Matthew and Robert, 1993). Readings were recorded at 1 metre intervals and used to identify plant species for plant composition and frequency data. Collected vegetation biomass was recorded after every 5 metres. Sampling was repeated for every of the three plots in each of the 15 study sites.

Vegetation biomass was sampled using the line intercept method and vegetation was clipped at 5cm above the ground and weighed to record the field/green weight. Previous studies by Tackenberg (2007) and Mulonda (2011) used this method where after vegetation was clipped and the field weight recorded, the dry weight would be measured after oven drying to a constant weight at 60°C. The biomass was expressed as DM in kg/ha (Stubbendieck and Cook, 1986). The vegetation samples collected for biomass were separated into perennials, forbs and litter. This was done for future studies that may need to better understand the specific correlation between vegetation and different invertebrate groups.

The Point Centre Quarter (PCQ) method was used to estimate tree density (Browser, 1984). For every 20 meters that were covered, a quadrat was laid out and four quarters marked. The nearest tree on each quarter had its species name and distance recorded (Stubbendieck and Cook, 1986). The point center quarter method has previously been used by (Kevin, 2007) as a measure of tree density. Tree density was estimated once during the collection period.

3.4.2 Soil sampling

Soil samples were collected from each of the 45 sampling plots. Soil was sampled for disturbed and undisturbed samples. Disturbed samples were collected at random points in all plots. A soil auger was used to obtain soil from the ground and soil samples collected at a 40 cm depth. These samples were used to analyze for nitrogen, organic carbon and pH. Undisturbed samples were collected using metal core rings that were driven into the ground using a mallet until the ring was flush with the surface. The ring was then excavated, capped and labelled. Samples were used to test for texture, bulk density and porosity, a measure inversely related to bulk density.

Soil pH was measured using a soil solution ratio of 1:5 (1 part soil to 5 parts 0.01M Calcium chloride). A pH probe was immersed into the suspension to measure the pH (Thomas., 1996). pH is an important measure as it has an effect on the solubility and availability of many nutrient elements (Coleman, 1967**)**. Total nitrogen was measured using the Kjeldahl method (Kjeldahl, 1883). Bremner(1960) demonstrated the reliabilty of this method that involves the digestion of the soil sample in hot sulfuric acid which then converts the nitrogen present into NH_4^+. The concentration is recorded and used to estimate the total nitrogen present.

Organic carbon content was measured using the Walkley and Black method (Walkley, 1935). This method is widely and successfully used as demonstrated by Klaus *et.al.,* (2007) and Isabella *et.al.,* (2004), and it provides an accurate estimate of soil organic carbon (Wang *et.al.,* 2012).

3.4.3 Invertebrate sampling

3.4.1.1 Pitfall traps

Yarro (2007) defines a pitfall trap as a plastic container that is sunk into the ground in such a way that the rim of the cup is level with the ground (Plate 1). This causes insects and other arthropods to inadvertently fall into the trap. Pitfall trap is a simple technique widely used in capturing surface active invertebrates and also in examining their spatial distribution patterns and relative abundance (Ward, 2001). These traps are considered to be excellent tools for detecting and monitoring activity of crawling soil and litter arthropods (Southwood, 2000). This method is ideal for sampling ground-dwelling insects and arthropods (Thomas and Raj, 2010) and it has been shown to give a closer estimate of the total number of species in a particular community (Uetz, 1976). In this study the traps used were plastic 250 milliliter cups with a diameter of 7cm and a depth of 11 cm (Plate 1).

Plate 1: Installed pitfall trap half-filled with detergent water (Source: This study)

Four of these traps were laid out along a 50 m transect line, mapped out using a global positioning system (GPS), starting randomly from any point along the line. The four pitfall traps were laid along the transect line with a three meter spacing. 100 milliliters of water containing a sprinkle of locally purchased washing powder was poured into each of the four installed pitfall traps. Traps were left open and specimen collected using a domestic sieve 48 hours after initial installation. Specimens were emptied into containers for sorting in the laboratory. The study had four traps on each of the 45 plots sampled making a total of 180 traps. Sampling was repeated every six weeks over a ten-month period. Identification of invertebrate species was done under a microscope using taxonomic keys.

Despite this being a widely used method, it is difficult to observe the trap throughout to ascertain that insects trapped are those crawling and not flying into the trap. McGavin (2007) indicated that pitfall traps are also used by birds and smaller mammals for a drink especially in drier areas such as open savannas like Lewa wildlife conservancy. Invertebrate activity on the other hand is affected by surrounding vegetation and weather parameters (Greenslade, 1971). In the event of heavy rains or in sloping terrains the traps get flooded. Traps are also non-selective in their collection and they do not prevent trapped invertebrates from preying on each other (Ritcher, 2009).

Nonetheless, the method was used owing to advantages such as efficiency in trapping since pitfall trap is a method that allows for continuous invertebrate trapping (Wraten, 1988). Pitfall traps are also easy to install, cost effective and invertebrate sampling using this method requires very little effort (Hill, 2005). This method has been previously and successfully used in past studies (Uetz, 1976; Greenslade, 1971; Cheli and Corley, 2010)

The invertebrate samples collected were pooled into an air-tight container from the four pitfalls in each of the 45 sites and transferred onto an ordinary sieve. The content was rinsed under running water to get rid of the soil that collects in the traps and to separate the specimens from litter. The specimens were then transferred into vials containing 70% ethanol for preservation before sorting and mounting. Large specimens were pinned on insect mounting boxes with labels containing site names, study area, global positioning systems (GPS) coordinates, treatments used, method of collection, name of collectors and date of collection and. Smaller specimens were transferred into vials with their respective identification labels.

3.4.1.2 Sweep nets

Sweep net is a method where the collector walks at a constant pace while repeatedly swinging a sweep net side to side in a full 180 degree arc (Plate 2). A sweep net has a sack made of durable material and works by dislodging and collecting insects from vegetation. Sweep net is a fast and inexpensive method for sampling arthropods and its portability and ease of use in various habitats makes this method quite preferred (Leather, 2008; Spafford and Lortie, 2013; O'leske, 1997).

Plate 2. A sweep net (Source: This study)

In this study, a sweep net with a 15 inch wide ring and a 1.5 meter long handle was used. 20 sweeps were made along a 50 meter transect line laid out in each of the 45 sites. A sweep harmonization for this study was established at the beginning by having the same person making the sweeps each time to establish consistency and to maintain a consistent height and vigor of the sweep along the transect line (Davíðsdóttir, 2013) though in some sites there was slight interference by the small thorny bushes of *Acacia drepanolobium.*

The contents of the sweep net were emptied into a Ziploc bag and labeled appropriately. The specimens were sorted to remove the grass and other unwanted materials collected along with the insects and larger specimens pinned to mounting boxes. The smaller specimens were transferred to vials with their appropriate labels. Identification of invertebrate species was done under a microscope using taxonomic keys. This process was repeated every six weeks over a six month period. A total of 900 sweeps were done during each sampling period. This collection was done once every six weeks over ten-month duration.

When using sweep nets, one should bear in mind that air temperatures and intensity of solar radiation determine the number of invertebrates present therefore this should be taken into account during analysis (Leather, 2008). In this study therefore, collection time for each sites was recorded to aid in understanding the observations that would later be made during analysis. The sweep net method has been stated to be ineffective in collecting some density of some orders such as Lepidoptera (Mc Gavin 2007).

Mc Gavin (2007) stated that using a sweep net when the vegetation is wet is difficult as invertebrates stick together and become lumped up. Harper (1998) reported that comparison studies were difficult to make when relying on sweeping data from different studies as the sampling efforts differ among studies. However the method was used as it captures much of the vegetation associated insects such as flies, bugs, spiders and small beetles (Sutherland, 2006).

3.4.4 Rainfall Collection

Rainfall was recorded using a standard rainfall gauge situated at different parts within the study area. Rainfall collected in each area was averaged to give the monthly recording. Rainfall recordings were taken monthly before insect collection began, during the collection and a few months after collection was completed. The first season invertebrate collection occurred between November and December of 2012 (Wet Season 1), the second collection occurred between January and February of 2013 (Dry Season) and the final invertebrate collection was done in late March to early May of 2013 (Wet Season 2). The recordings obtained during the study period were used to explain the patterns of invertebrate species and their distribution.

3.5 Data Analyses

Invertebrate data were subjected to analyses using several indices with an aim of establishing significant invertebrate patterns on diversity and abundance.

3.5.1 Species diversity

The Shannon-Wiener index, a popular diversity index in the ecological literature, (where it is also known as Shannon's diversity index, the Shannon-Wiener index, the Shannon-Weaver index and the Shannon entropy), was used to calculate species diversity. It has been shown that this index is based on the weighted geometric mean of the proportional abundances of the types (Clarke, 2001; Whittaker, 1972), and that it equals the logarithm of true diversity.

$$H' = - \Sigma^{R}_{i=1} p_i \log p_i$$

Where P is the proportion of total sample belonging to the i^{th} species

H' represents the index of species diversity

R represents species richness (total of species present)

This index has been widely used in different investigations and although the method is sometimes viewed as having properties that make interpretations difficult (Magurran, 2004) it continues to be a popular diversity index. In this index, the diversity values are seen to increase as richness and evenness increase too. This index provides a simple summary as it combines both aspects of invertebrate species diversity this is species richness and species evenness.

This is however seen as a weakness when it comes to comparing communities whose richness differ greatly (Magurran, 2004). The index has also been seen to have bias when a smaller proportion of species sampling is done (Buckland, 2005). Buckland (2005) reported the decreased sensitivity of the Shannon index to be due to changes in abundances, a parameter that affects dominance in cases of environmental changes. The method has been used by many studies this notwithstanding.

3.5.2 Species richness

Species richness was used to quantify how many different types of specimen the dataset of interest contains. For example, species richness (usually notated *S*) of a dataset is the number of different species in the corresponding species list. The Margalef's index (d) (Margalef, 1958), was the measure of species richness for this study.

$d = (S-1)/ \log N$

Where d is Margalef's index

S is the total number of species

N is the total number of individuals

Richness is a simple measure (Clarke, 2001), so it has been a popular diversity index in ecology, where abundance data are often not available for the datasets of interest.

3.5.3 Species evenness

Species evenness is the probability that two entities taken at random from the dataset of interest represent the same type of entity. The Pielou's evenness index (Pielou, 1966) was used.

$J' = H' \text{ (observed)} / H'_{max}$

Where H'_{max} is the maximum possible diversity which would be achieved if all species were equally abundant (=log S). H' is the species diversity.

3.6 Data Analysis

Invertebrate diversity and abundance measures were calculated using Primer v5: User Manual/Tutorial. Statistica Six Sigma software, Release 7 and IBM SPSS Statistics 20 were used for running analysis of variance, correlations, and for descriptive statistics of the invertebrate species, vegetation and soil data. Separation of means was carried out using Post Hoc Tukey tests.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results and discussions. The tests used are indicated after every set of results with key outcomes being discussed. Results from analysis on invertebrates are presented based on the two different methods used, that is, sweep net and pitfall trap. Also, results on vegetation and soil attributes analyzed are presented and discussed.

4.0 Composition of invertebrates in the study area

A total of 339 invertebrate species were collected; pitfall trap method accounted for 200 species and sweep net accounted for 139 species (See Appendix 2). These species were from five orders. 160 families were from the order Coleoptera [54%] while Orthoptera, Hemiptera, Hymenoptera and Diptera had 51 [17%], 33 [11%], 32 [11%] and 20 [7%] families respectively and their relative proportions are indicated in Figure 4.1. Coleoptera had the highest number of families while Diptera had the lowest number of families.

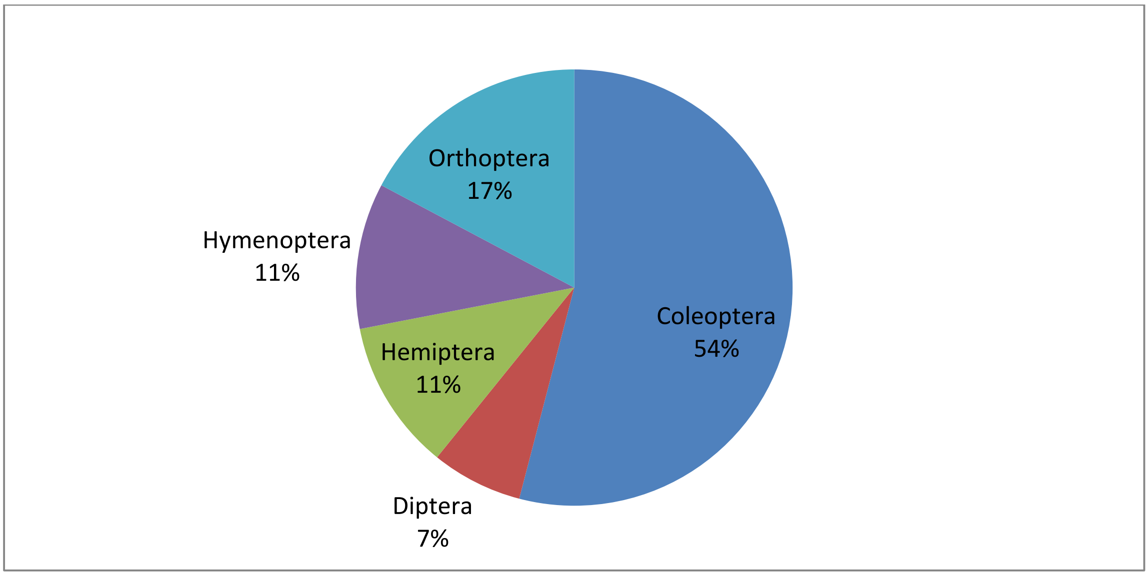


Figure 4. 1: Relative proportion of invertebrate orders in Lewa Wildlife Conservancy

The number of samples collected was substantial resulting in a good sampling effort (Fig 4.2) where the species cumulative count increased at first and gradually leveled off. This curve suggests that most of the invertebrate species in the study area were covered but not exhausted. The samples however, still gave a good representation of the whole population.

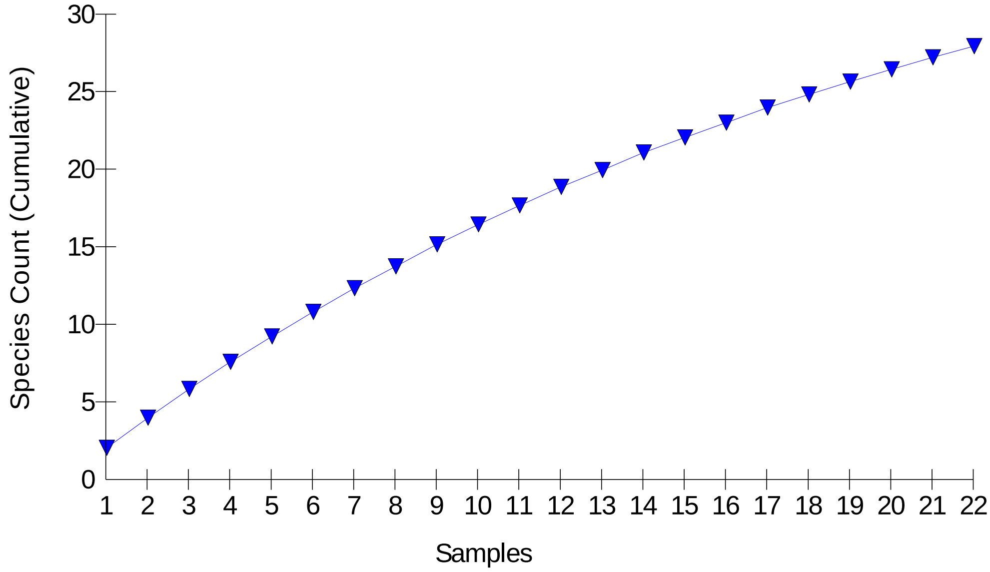


Figure 4. 2: Species area curve calculated from 999 iterations of random samples of the raw data collected from both sweep net and pitfall trap methods in Lewa Wildlife Conservancy

4.1 Effect of grazing on invertebrate diversity and abundance

An analysis of variance carried out on data from both sweep net and pitfall trap methods revealed that invertebrate species abundance and diversity were not significantly different across the three treatments (Table 4.1).

Table 4. 1: Mean invertebrate abundance across the three treatment areas in Lewa wildlife Conservancy

	Sweep net method N (270)	Pitfall trap method N(237)
Treatment	Mean total species (S)	
Glades	1.39 ± 0.31^{a}	4.55 ± 1.22^{a}
Grazing	1.87 ± 0.52^{a}	5.11 ± 2.14^{a}
Control	1.93 ± 0.57^{a}	3.64 ± 0.97^{a}

Rows with different letter superscripts are significant at ά ≤ 0.05

A further analysis of variance on the invertebrate diversity measures (Table 4.2) showed that for all diversity measures analyzed, none was significantly different across treatments for sweep net or pitfall trap methods.

Table 4. 2: One way analysis of variance on the effect of grazing on invertebrate diversity measures

Diversity measure	P-values	
	Sweep net method	Pitfall trap method
S	0.863[a]	0.432[a]
N	0.706[a]	0.344[a]
H'	0.899[a]	0.606[a]
J´	0.901[a]	0.504[a]

Rows with different letter superscripts are significant at $ά \leq 0.05$, df = (2,132)

S-Total invertebrate species numbers   N-Square root transformed abundance

H'-Shannon Weiner diversity index   J́- Pielou's evenness index

Invertebrate data was subjected to analysis of variance at a higher resolution by grouping insects into their specific orders and testing for differences in abundance across treatments. Invertebrate abundance of all orders was not significantly different across treatments but across the five orders insect abundance was found to be significantly different at $p = 0.03$ and invertebrate species from the order Coleoptera showed dominance.

Table 4. 3: Mean abundance of invertebrates belonging to different orders across the three treatments in Lewa Wildlife Conservancy

Treatments	Coleoptera N (135)	Diptera N (19)	Hemiptera N (31)	Hymenoptera N (28)	Orthoptera N (43)
Glades	12.73 ± 6.52[a]	6.95 ± 3.16[b]	3.65 ± 1.11[c]	6.79 ± 3.91[d]	4.21 ± 1.09[e]
Grazing	8.86 ± 4.09[a]	5.26 ± 2.02[b]	7.81 ± 4.59[c]	6.29 ± 3.94[d]	3.65 ± 0.83[e]
Control	8.19 ± 3.65[a]	4.84 ± 1.57[b]	8.00 ± 4.62[c]	4.36 ± 2.41[d]	2.95 ± 0.50[e]

Rows with different letter superscripts are significant at $ά \leq 0.05$

Coleoptera species abundance was highest compared to species abundance of the other orders sampled (Table 4.3). This can be explained by the higher dung accumulation and plant diversity in glades and grazing areas that accomodated a wider variety of beetle families. Glade sites experience nutrient enrichment from dung deposits resulting in new growths and regeneration of plant cover while grazed areas experience defoliation that creates an open structure for growth of plants and regrowth.

Dung nutrient enrichment tends to favor mostly invertebrate species from the order Coleoptera. Invertebrate species from the other orders; Diptera, Hemiptera, Hymenoptera and Orthoptera, exhibited species abundance increases in some treatment areas and decreased species abundance in others, but remained insignificantly different across treatments (Table 4.3).

Invertebrates from the order Orthoptera exhibited a similar pattern as those from the order Coleoptera, increasing in numbers in the glades and declining in numbers as plant cover and biomass increased in the control sites just as is described in Kevan (1982) about hoppers and crickets preference to open meadows and fields. Hemiptera occurred in increased numbers in control sites which had more plants from which the insects could obtain their sap.

Diptera and Hymenoptera invertebrates were found in increased numbers in glades. This can be explained by preference of Diptera species to areas with saturated soil, presence of dung or muddy puddles which supports work by Eaton and Kaufman (2007). Invertebrate species from the order Hymenoptera preferred areas with new growth and emerging flowering plants which supports findings of Klein *et.al.,* (2007). These however were trends observed as analysis of variance did not yield significant differences in species abundance across treatments.

The grazing system practiced was a rotational grazing system and the stocking density of cattle was uniform across all sites for all the five years that grazing occurred, this is from the year 2008 to the year 2012, thereby standardizing the effect that grazing would have had due to varying stocking density (Appendix 5).

Beetles are known to control grass weeds (Biotechnology and Biological Sciences Research Council, 2011) such as *Oxalis stricta* and *Portulaca oleracea* which were found to be common in glades. The effect of this is that by feeding on the weeds, beetles allow for domination of the better preferred and more palatable grass species with higher forage quality such *panicum maximum* and *cynodon spp* which gives cattle better nutrition when grazed in that area.

Beetles especially dung beetles and others from the scarabaeidae family are important in nutrient cycling, introduction of organic matter into the soil, reduction of pasture fouling, improvement of soil structure through tunneling and promotion of forage growth (Bertone, *et. al.)* as they decompose and consume large amounts of animal manure adding nutrients to the soil and providing increased soil aeration.

Beetles are also important in cattle production especially in rangelands as they increase plant recruitment when plant seeds are dispersed by the scarabs; tunnellers and rollers (Kunz and Krell, 2011; Andresen and Feer, 2005). Each of these beetle types has their role in seed dispersal with tunnellers causing a relatively clumped seed distribution and rollers performing higher quality dispersion (Andresen and Feer, 2005).

Ground and tiger beetles are also useful to the ecosystem as they are predatory, consuming a wide assortment of soil-dwelling insects and phytophagous, feeding on plants and the seeds of troublesome weeds (Sunderland, 2002; Tooley and Brust, 2002) and can therefore effectively be used in bio-control.

In the absence of scarabs, dung decomposition would be slowed down inhibiting the benefits of a good nutrient distribution system. Where these beetles are lacking, accumulation of dung occurs leading to rangeland fouling (Bertone, *et. al*.) which reduces the effective land available for cattle foraging as cattle will not forage near dung. Losey and Vaughan (2006) estimated the economic benefit of dung beetles to be at least $380 million annually based on the ecosystem services they provide that in turn increase forage production and decrease livestock pests.

Dung beetles are known for their role in soil bioturbation which is the mixing and redistribution of sediments as they decompose dung and this helps in restoration of disturbed lands and maintenance of the ecosystem services when the system is disturbed (Beynon *et.al.,* 2012) a process that affects soil moisture and soil aeration.

These processes of bioturbation, and nutrient cycling, increases plant productivity and plant growth (Bertone *et.al.,* 2014) explaining why glades; which are areas where these beetles were mostly found, are areas of high forage quality and of increased nutrient enrichment (Young, 1995). This gives the indication of the importance of glade formation in support of the beetle species that bring about positive effects on the lands they are found in.

Also by feeding on manure, scarabs compete with the horn fly for nesting habitats and food resources and the beetles accelerate manure drying creating competition for the larvae of the horn fly (Byford *et.al.,* 1992). This is important because the horn fly is an obligate blood-feeding ecto-parasite (Cupp *et.al.*,1998) which is considered one of the most economically important pests of cattle worldwide. Use of scarab beetles will help reduce the millions spent on insecticides to reduce the horn fly numbers. The more scarab beetles present the less flies are found in an area (Byford *et.al.,* 1992). Dominance of beetles is therefore important based on the roles these insects play.

4.2 Effect of glades on invertebrate diversity and abundance

Invertebrate response to glades formed and the aging effects of these glades on invertebrate species is reported. Invertebrate species were found to be distributed in different proportions in these glade sites as shown in (Fig 4.3). Vegetation in glades was dominated by *Cynodon spp* and underwent succession to *Pennisetum stramineum.*

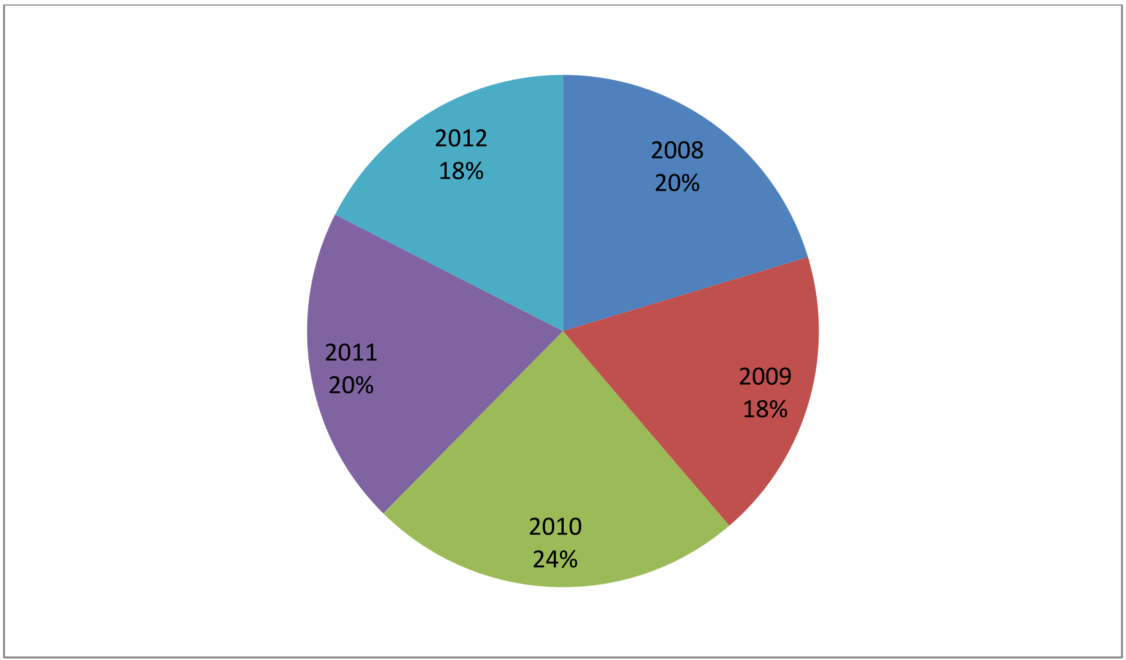


Figure 4. 3: Percentage proportion showing distribution of invertebrate species in glades across different years in Lewa Wildlife Conservancy

The year 2010 glades had the highest invertebrate percentage count (24%) compared to glades of the other four years. The year 2009 and 2012 glades had the lowest invertebrate percentage count at 18% while those of the year 2008 and 2011 recorded similar invertebrate percentage count at 20%.

These results can be explained by the climatic conditions, nutrient enrichment and the carry-over effect since the glades were established. Increase in invertebrate numbers may have been favored by increases in rainfall and nutrient enrichment resulting from the breakdown of dung deposits accumulated from the time kraals were first used in an area. This increased nitrogen deposits from urine and faecal deposits led to the increase in insect abundance as plant productivity increased (Haddad *et.al.*, 2000). Average rainfall amounts for every year, from the year 2008 to 2012 when the study was started, were recorded (Table 4.4), and the results showed highest rainfall amounts occurred in the year 2009 and 2011.

Table 4. 4: Average rainfall amounts in each year over the 5 year period of glade establishment in Lewa Wildlife Conservancy

Year of glade establishment	Average Rainfall (mm)
2008	11.54
2009	44.09
2010	33.11
2011	44.38
2012	37.94

This study was carried out in 2012 and since the glades were formed yearly from the year 2008 onwards, all glades experienced different rainfall effects (Fig 3.2). Glades from the year 2008 experienced two increasing rainfall periods and two decreasing rainfall periods while glades from the year 2009 experienced two decreasing rainfall periods and one increased rainfall period. Glades from the year 2010 had one increasing rainfall period and one decreasing rainfall period while glades of the year 2011 underwent one decreasing rainfall period. Glades of the year 2012 were receiving rainfall during the time of data collection.

These results suggest that it takes glades about three years for the effect of nutrient enrichment from dung deposits to stabilize in order to bring about maximum invertebrate species abundance after which these numbers decline. This is demonstrated from Fig 4.3 where the highest invertebrate counts were recorded in glades that were formed 3 years back;

that is, those of the year 2010. This can be attributed to new vegetation growth that occurs after increased rainfall. This vegetation becomes litter during the drier times. Litter insects, such as those belonging to the order Coleoptera, are known to have a relationship with rainfall (Anu, *et.al.*, 2009).

Invertebrate species diversity was not significantly different across glades of the different years (Table 4.5) and a chi-square analysis on the different proportion of invertebrate species in the glades was also reported as insignificant across the years. However, an analysis of variance on invertebrates collected across the glades, using pitfall method, revealed that invertebrate species abundance was significantly different across glades $F(4,130) = 2.45$, $p = 0.049$* (Fig 4.4). A post hoc Tukey's test revealed that the source of variation was between the year 2009 and 2010 (Table 4.5).

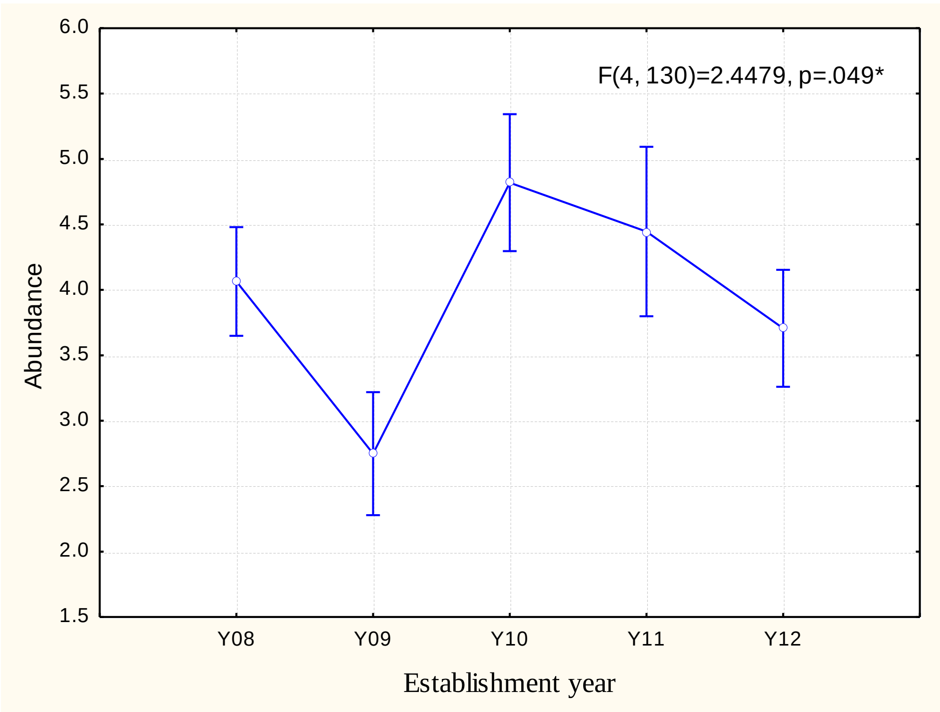


Figure 4. 4: Graphical representation of analysis of variance on glades and invertebrate abundance across the years in Lewa Wildlife Conservancy

Variation in invertebrate abundance between glades formed in the year 2009 and 2010 can be explained by the dependence of invertebrates on vegetation resources (Debano, 2006) where for proper establishment of vegetation, increased rainfall amounts are required for proper growth and flowering. Glades from the year 2009 failed to successfully regenerate like those of 2010 due to a sharp decline in rainfall amounts experienced in the year 2009/2010 (Table 4.4).

Table 4. 5: One way analysis of variance on the effects of aging glades on invertebrate diversity measures

Glade year	Diversity measures	Sweep method	Pitfall method
		Mean total species (S)	
2008	S	2.82 ± 0.46^{a}	6.07 ± 0.93^{a}
	N	8.33 ± 2.32^{a}	21 ± 4.04^{a}
	H'	0.64 ± 0.12^{a}	1.13 ± 0.12^{a}
	J´	0.50 ± 0.08^{a}	0.68 ± 0.06^{a}
2009	S	3.52 ± 0.55^{a}	4.88 ± 0.88^{a}
	N	6.85 ± 1.56^{a}	13.30 ± 4.77^{b}
	H'	0.87 ± 0.14^{a}	1.01 ± 0.16^{a}
	J´	0.60 ± 0.09^{a}	0.61 ± 0.08^{a}
2010	S	3.07 ± 0.37^{a}	7.37 ± 1.20^{a}
	N	11.26 ± 3.34^{a}	30.33 ± 5.83^{c}
	H'	0.75 ± 0.10^{a}	1.26 ± 0.12^{a}
	J´	0.63 ± 0.08^{a}	0.70 ± 0.05^{a}
2011	S	3.44 ± 0.42^{a}	4.33 ± 0.58^{a}
	N	11.11 ± 3.31^{a}	30.67 ± 7.50^{a}
	H'	0.85 ± 0.12^{a}	0.82 ± 0.11^{a}
	J´	0.64 ± 0.08^{a}	0.57 ± 0.07^{a}
2012	S	3.00 ± 0.47^{a}	5.00 ± 0.56^{a}
	N	6.11 ± 1.21^{a}	19.12 ± 4.72^{a}
	H'	0.79 ± 0.13^{a}	1.13 ± 0.13^{a}
	J´	0.62 ± 0.08^{a}	0.71 ± 0.06^{a}

Rows with different letter superscripts are significant at $ά \leq 0.05$,df = (4,130)

Results from Table 4.5 are in line with Anu *et.al.*, (2009) where insect fauna as a whole was reported to show no seasonal variation in insect diversity but a significant variation noted on abundance of certain insect orders. Glades are areas of decreased plant species richness (Veblen, 2012; Walck, 2008) consequently decreasing insect species richness that affects diversity (Haddad *et.al.*, 2000). In this study, species richness was consistently low in glades across years (Table 4.5).

On the other hand, reduced rainfall in 2009 may have likely interfered with dung decomposition resulting in less nutrient accumulation and lower plant re-growth and regeneration rates hence lower invertebrate numbers. A decline in rainfall amounts decreases decomposition rates of vegetation (Salamanca *et.al.*, 2003) and organisms (Archer, 2004). Decreased decomposition leads to decreased N deposition which has been reported to lead to decreased soil organic carbon storage and depressed N mineralization (Throop *et.al*, 2004) all of which affect consumption rates and population dynamics of invertebrates.

Table 4. 6: Mean abundance of invertebrate orders across glades of different years in Lewa Wildlife Conservancy

	Mean total species (S)				
Glade Year	Coleoptera	Diptera	Hemiptera	Hymenoptera	Orthoptera
2008	1.96 ± 0.88^a	0.88 ± 0.34^a	1.85 ± 1.16^a	0.94 ± 0.57^a	0.66 ± 0.21^a
2009	1.81 ± 0.94^a	1.09 ± 0.48^a	0.71 ± 0.32^a	0.99 ± 0.56^a	0.90 ± 0.28^a
2010	2.45 ± 1.32^a	1.77 ± 0.80^a	1.25 ± 0.67^a	1.19 ± 0.74^a	0.70 ± 0.24^a
2011	2.03 ± 1.27^a	0.74 ± 0.38^a	1.54 ± 1.02^a	1.09 ± 0.73^a	0.53 ± 0.20^a
2012	1.53 ± 0.83^a	1.35 ± 0.61^a	1.08 ± 0.82^a	1.63 ± 0.92^a	0.60 ± 0.20^a

Columns with different letter superscripts are significant at $ά \leq 0.05$

Abundance of invertebrate species from the different orders was not significantly different across the glades of different years but species from the order Coleoptera were the most abundant across all glades (Table 4.6).

Generally, kraals established 3 years earlier (glades formed in the year 2010) had the highest invertebrate count suggesting that it takes around three years for the effect of nutrient enrichment in glades to stabilize. Thereafter, a decline in invertebrate numbers is seen as was the case in recently established glades of the year 2011 and 2012 (Table 4.6). Long term glades have been reported to have lower plant species richness leading to low species richness and diversity but higher invertebrate abundance caused by increased grass biomass on the edge of the glades (Carey, 2013) as seen in glades from the year 2008 and 2009, five and four year old glades respectively.

Glades are known for their high vegetation quality and increased levels of nitrogen, potassium and carbon that occur after the cattle have moved from the area and regeneration of high quality vegetation resumes (Young, 1995). These areas are reported by Young (1995) as having low plant species richness and diversity and owing to the unique plant species found in them, an increase in invertebrate abundance is noted (Haddad *et.al.,* 2007; Throop *et.al*, 2004) as seen from this study where glades had highest invertebrate abundance compared to other treatments (Table 4.3).

Invertebrate species diversity was not significantly different across glades $F(4,16) = 2.04$, $p = 0.69$ $ά = 0.05$) but certain invertebrate abundance distribution patterns were noted and are presented in Fig 4.5 to Fig 4.9.

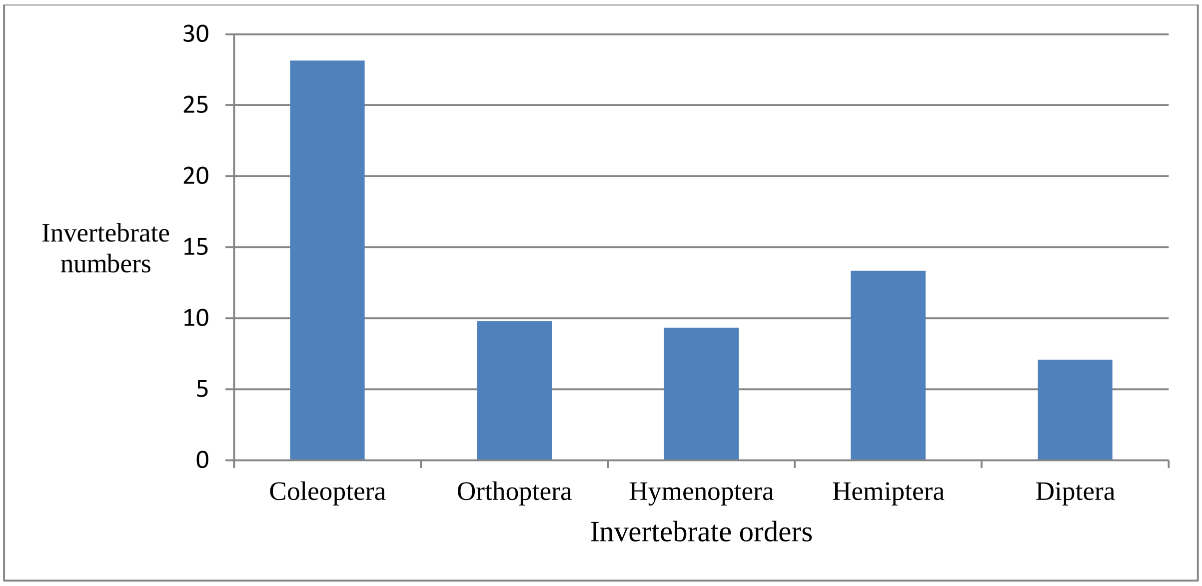


Figure 4. 5: Invertebrate abundance in glades formed in the year 2008 in Lewa Wildlife Conservancy

Except Coleoptera, invertebrates from the order Hemiptera were predominant in the glades of year 2008 (Fig 4.5). Insects belonging to this group include cicadas, aphids, hoppers and water bugs with mouth parts designed for piercing and sucking (Marshall, 2007). Majority of these insects were found in glades from the year 2008, glades which had high biomass quantities and a densely established vegetation that supported survival of these insects. This dense vegetation was also seen to provide a conducive habitat where the parasitic hemiptera, such as those from the Reduviidae family, can hide and attach themselves on the wildlife grazing in those areas.

Glades from the year 2009 had high Orthoptera insect abundance (Fig 4.6). This order comprises of insects such as grasshoppers, crickets and katykids which are well known for their stridulation ability and jumping skills (Hewitt, 1979). Insects from this order are predominantly found in terestrial habitats throughout the world and are often associated with fields and meadows (Kevan, 1982) which was characteristic of glades formed in the year 2009.

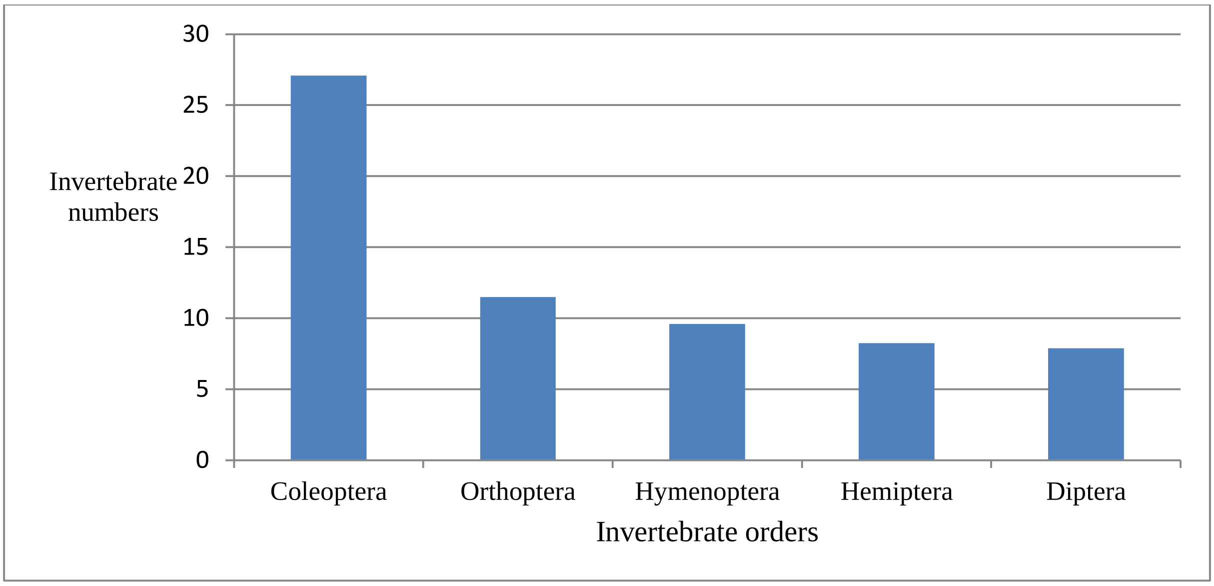


Figure 4. 6: Invertebrate abundance in glades formed in the year 2009 in Lewa Wildlife Conservancy

These glades from the year 2009 attracted and supported a flora and fauna that was unique from the other glades from other years. The array of wild flowers and plants found in these glades were the likely explanation of the high orthoptera numbers.

Insects from the order Coleoptera were present in highest numbers in 2010 glades (Table 4.6 and Fig 4.7). This can be attributed to a stabilized nutrient enhanced effect and a favorable habitat and environment in which their preferred foods were found. Invertebrate species in this order have a wide variety of feeding habits but generally all have mouthparts adapted to feeding and not sucking (Marshall, 2007). Most beetles are herbivores while others are predatory and others are parasitic preferring to live on other insects or mammals (Eaton and Kaufman, 2007).

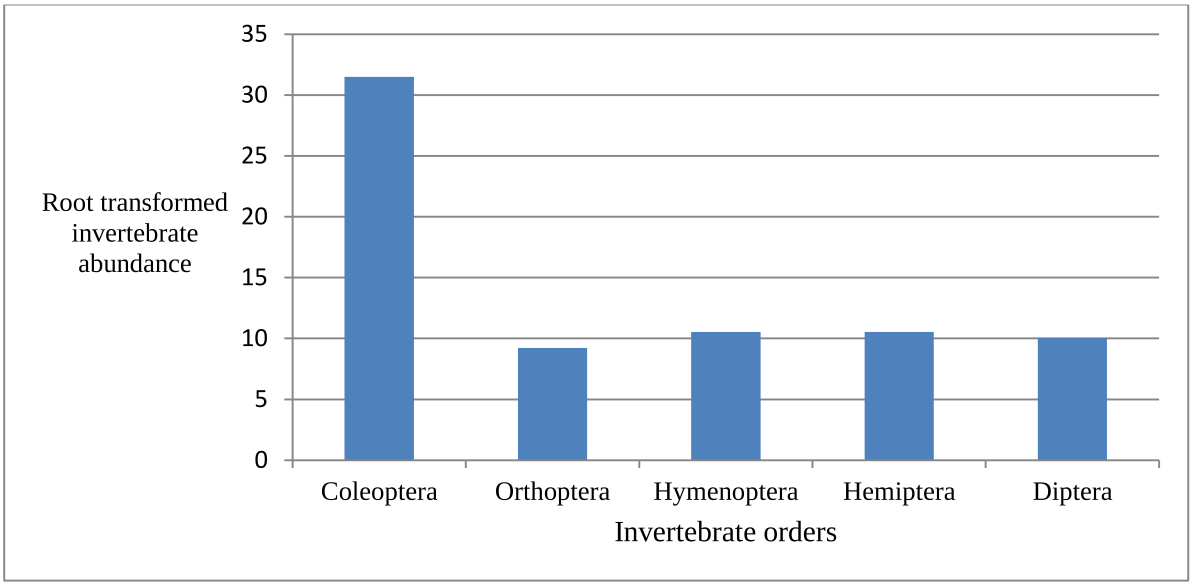


Figure 4. 7: Invertebrate abundance in glades formed in the year 2010 in Lewa Wildlife Conservancy

Glades established in 2010 had plants from families such as *Amaranthaceae*, *Fabaceae* and *Solanaceae*, in higher abundance than in other glades, which when blooming strongly attract beetles. Despite beetle preference to feeding on plants, these insects do not cause damage too adverse to require intervention (Marshall, 2007). Insects from the Hymenoptera order were also highest in 2010 glades than in glades from other years (Table 4.6) and this is attributed to the presence of plants from the family *Fabaceae* and *Malvaceae* in the 2010 glade, plants which bees tend to visit a lot of times.

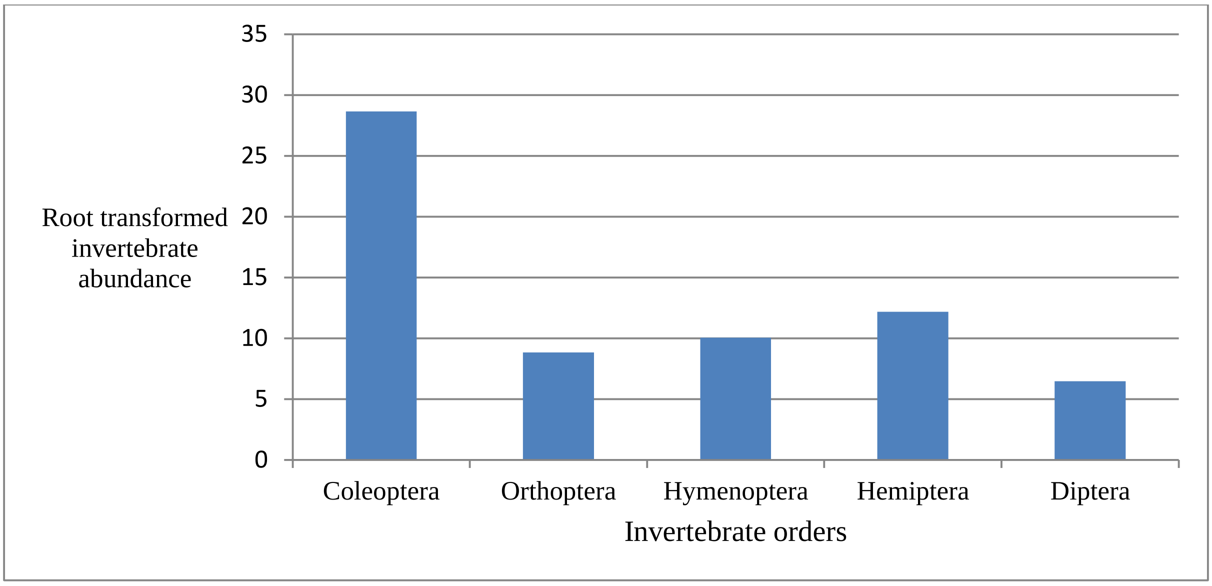


Figure 4. 8: Invertebrate abundance in glades formed in the year 2011 in Lewa Wildlife Conservancy

Glades of 2011 showed no distinct patterns and no order of invertebrates was highest in number for glades established in this year compared to numbers from other years (Fig 4.8).

Kraals set up in 2012 had cattle recently settling in them and consequently, dung was present in high amounts. This explained why invertebrate species from the order diptera were present in higher numbers in glades from the year 2012 than in most of the glades from the other years as shown by Eaton and Kaufman (2007) about predominant presence of flies in areas with manure or areas with any wet decaying matter.

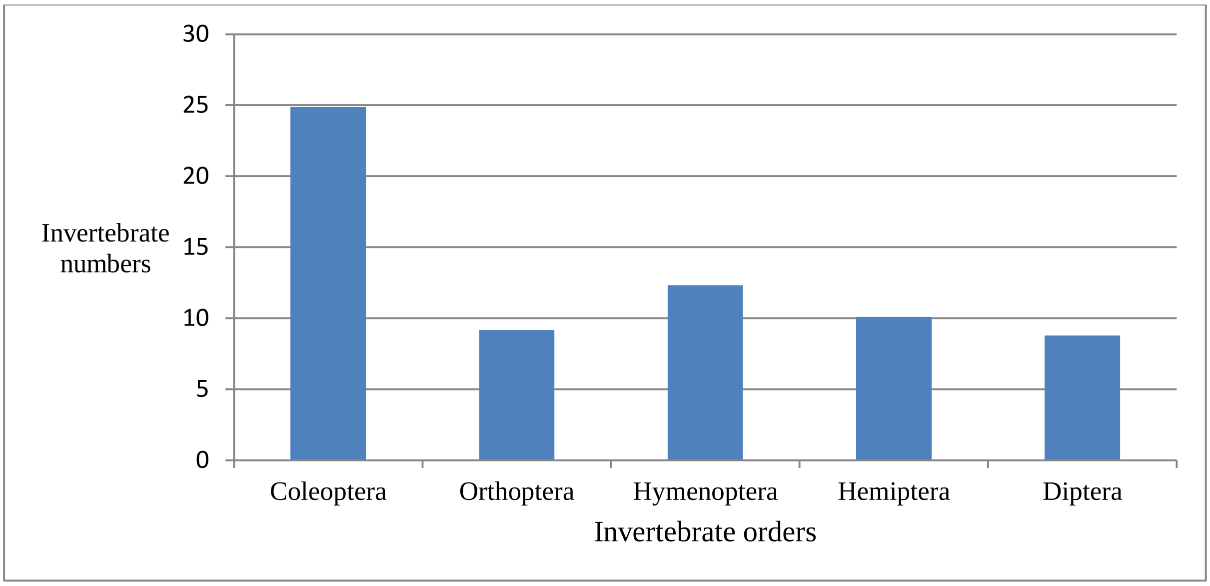


Figure 4. 9: Invertebrate abundance in glades formed in the year 2012 in Lewa Wildlife Conservancy

Except in glades from the year 2010, invertebrate species belonging to the order Diptera and Hymenoptera were found to occur in large numbers in glades of the year 2012. The order Diptera represents the flies and mosquitoes while that of Hymenoptera represents the ants and wasps. Glades from the year 2012 experienced new growth and dominance of *Amaranthus*. Invertebrates species from the order Coleoptera were fewest in numbers in glades formed in the year 2012 with a mean abundance of 1.53 ± 0.83, compared to their abundance in glades of other years (Table 4.6). This is likely due to lack of the preferred beetle plant cover in glades of the year 2012.

The order Hymenoptera, of which bees belong to, was in high numbers in glades from the years 2010 and 2012 (Table 4.6). This can be explained by the behaviours and characteristic of bees which actively pollinate areas with high presence of an array of different flora, as was the case in glades from the year 2010, and areas with emerging flowering plants as was seen in glades from the year the 2012.

4.3 Effect of season on invertebrates and vegetation

4.3.1 Effect of season on invertebrate species diversity and abundance

Invertebrates were collected in three consecutive seasons, two wet and one dry (Fig 4.10). The first wet season run from November to December in the year 2012, the dry season was in the months of January and February in the year 2013 and the second wet season in March and May of the year 2013.

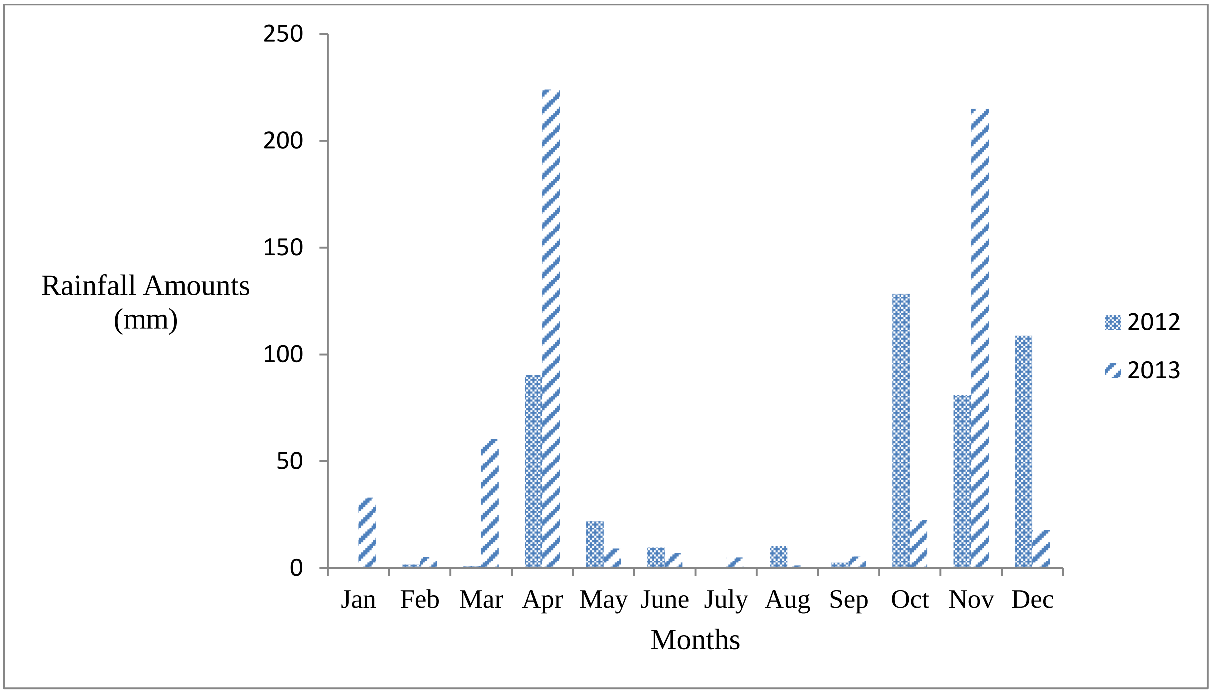


Figure 4. 10: Rainfall amounts recorded during the study period in Lewa Wildlife Conservancy

The wet season had an overall higher count of invertebrate species (Fig 4.11) and these numbers steadily declined with successive seasons. This supports the study by Margaret (1982) where invertebrates were shown to respond positively to increased rainfall.

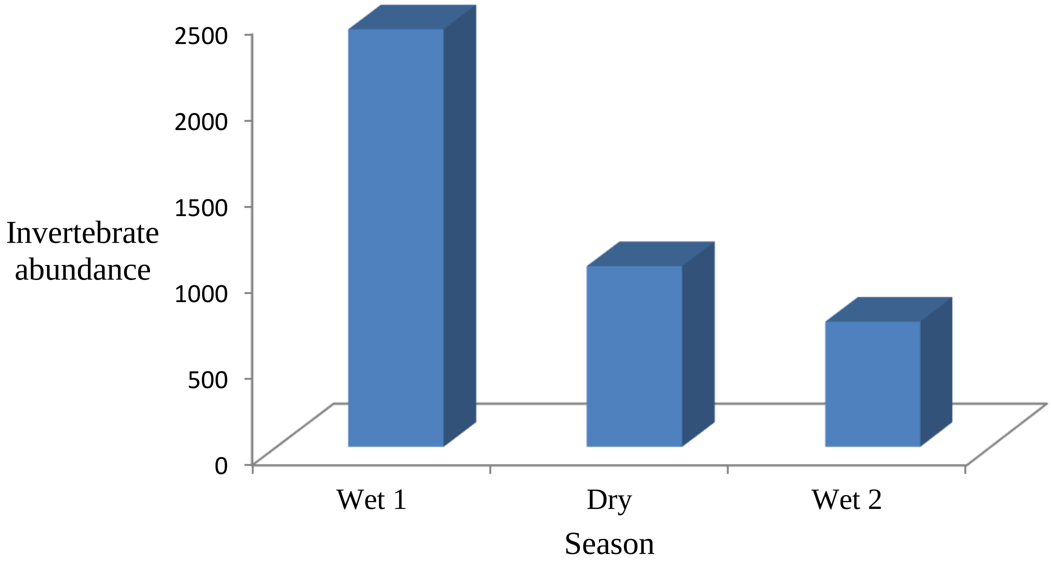


Figure 4. 11: Invertebrate abundance collected in successive seasons in Lewa Wildlife Conservancy

Invertebrates from the five orders increased greatly during the first collection that occurred in the first wet season. This is likely because samples collected in the first wet season were free from prior site disturbance that occurs when traps are being set up in the sites. An increase in rainfall also increased the food reserves and contributed to regeneration of plant cover thus increasing the food resource. Dryer seasons end up with less diversity of plants species (Houston and Melzer, 2012) leading to fewer invertebrates, lower dominance and different invertebrate assemblages arising from loss of sensitive plant and insect species.

Abundance of invertebrate species from the order Orthoptera did not vary across the seasons like the rest of the other invertebrate species from the remaining four orders (Table 4.7). Invertebrates are generally sensitive to loss in vegetation and changes in temperature, rainfall and soil moisture levels (Pellegrino *et.al*, 2013; Ecosystem Ecology, 2007) and loss of vegetation caused by decreased rainfall amounts will likely have an impact on invertebrate reproduction and overall abundance. However, hoppers and crickets, which are the main insects of this order, have the ability to survive in both open habitats and denser vegetation that arise in drier and wetter seasons respectively. Abundance of invertebrates, when compared for the five orders, was not significantly different across seasons (Table 4.7).

Table 4. 7: Mean abundance of invertebrate species spread across seasons in Lewa Wildlife Conservancy

	Mean total species (S)				
Season	Coleoptera	Diptera	Hemiptera	Hymenoptera	Orthoptera
Wet 1	12.63 ± 8.02^a	4.68 ± 1.83^a	11.03 ± 8.41^a	2.45 ± 1.17^a	1.98 ± 0.59^a
Dry	4.96 ± 3.43^a	0.79 ± 0.30^a	3.66 ± 1.35^a	1.58 ± 0.76^a	1.96 ± 0.46^a
Wet 2	3.73 ± 1.63^a	0.74 ± 0.28^a	0.34 ± 0.16^a	0.19 ± 0.09^a	1.9 ± 0.61^a

Rows with different letter superscripts are significant at $ά \leq 0.05$

Invertebrate species from the order Hemiptera require feed from plant sap to survive (Eaton and Kaufman, 2007). Therefore, Hemiptera species numbers were low in the dry season as drier periods means withering and drying up of vegetation leading to low food availability for invertebrate species belonging to this order. On the other hand, invertebrate species from the order Hymenoptera depend on pollen from flowering plants to survive as they pollinate (Klein *et.al.*, 2007). Low rainfall affects flowering and pollen formation resulting in a decline in numbers as some species migrate to more suitable areas and others fail to survive.

Diptera are ordinarily found in damp environments and are termed as the most diverse order of insects in fresh water (Eaton and Kaufman, 2007). Drier seasons inhibit this preferred environment drying up the saturated soils, the mud puddles and available sources of water. This could have caused a reduction in Diptera numbers seen from the results of this study. Coleoptera numbers declined too owing to the decreased perennial grass biomass (Table 4.10).

Invertebrate diversity and abundance were significantly different ($p = 0.00$, α 0.05) across seasons (Table 4.8), with the wet seasons accounting for higher diversity and increased abundance and a post hoc Tukey test showing variation in all the three seasons (Table 4.9).

Table 4. 8: One way ANOVA on effects of seasons on invertebrates collected across seasons in Lewa Wildlife Conservancy

		Mean total species (S)	
Season	Diversity measures	Sweep method	Pitfall method
Wet Ssn 1	S	4.98 ± 0.38^{a}	8.97 ± 0.86^{a}
	N	15.17 ± 2.30^{a}	40.58 ± 5.61^{a}
	H'	1.15 ± 0.09^{a}	1.37 ± 0.12^{a}
	J´	0.73 ± 0.04^{a}	0.64 ± 0.05^{d}
Dry Ssn	S	2.51 ± 0.28^{b}	3.82 ± 0.32^{b}
	N	4.91 ± 0.76^{b}	15.87 ± 3.05^{b}
	H'	0.70 ± 0.09^{b}	0.91 ± 0.08^{b}
	J´	0.58 ± 0.07^{b}	0.67 ± 0.05^{d}
Wet Ssn 2	S	2.24 ± 0.22^{c}	3.89 ± 0.42^{c}
	N	4.04 ± 0.51^{c}	12.08 ± 2.15^{c}
	H'	0.62 ± 0.08^{c}	0.95 ± 0.09^{c}
	J´	0.56 ± 0.07^{c}	0.65 ± 0.06^{d}

Rows with different letter superscripts are significant at $ά \leq 0.05$, df (2,132)

S-Total invertebrate species numbers N-Square root transformed abundance

H'-Shannon Weiner diversity index J´-Pielou's evenness index d- Magurran diversity index

Seasonal changes however did not have a significant effect on Pielou's evenness index [J´] (Table 4.8) for pitfall trap method. This can be attributed to the fact that pitfall trap as a collecting method captures a wide variety of organisms thereby reducing the species evenness. All other indices however were positive and significantly different across the seasons.

Denlinger (1980) indicated that arthropod variability occurs with changes in not only food supplies but also due to environmental changes such as rainfall and temperature increases. Results from this study (Table 4.8) positively affirm Denlinger's findings as invertebrate diversity and abundance changed significantly across the seasons.

A post hoc Tukey test (Table 4.9) showed that significant differences in invertebrate species indices existed between the first wet season and the dry season, and between the dry season and the second wet season. The two wet seasons also showed significant differences ($p \leq 0.05$) where invertebrate abundance was recorded as highest during the long rains of the first wet season and these numbers declined in the second wet season.

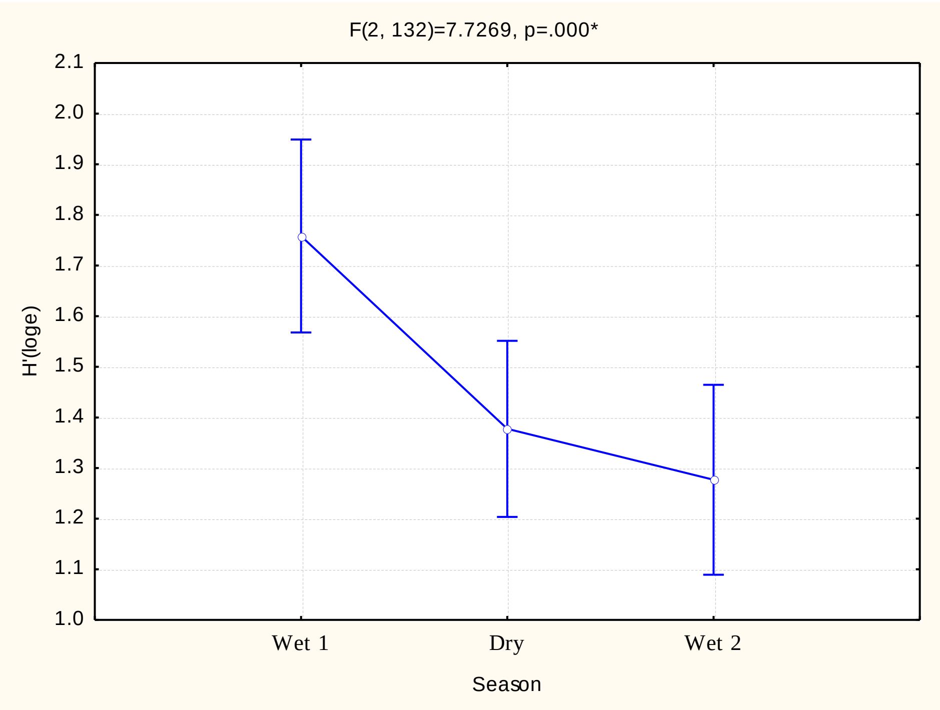
Table 4. 9: Post hoc Tukey test on effect of seasons on invertebrate species abundance in Lewa Wildlife Conservancy

Season	**Wet 1**	**Dry**	**Wet 2**
Wet 1		0.000022*	0.000022*
Dry	0.000022*		0.000022*
Wet 2	0.000022*	0.000022*	

MSE = 13.829, df = 2,132

This is likely because the second wet season recorded lower rainfall amounts compared to the first wet season and this observation was consistent with Denlinger (1980) and Margaret (1982) who both reported that changes in rainfall across seasons causes fluctuations in plant biomass, the main food resource of invertebrates, which can in turn affect their overall reproduction and abundance (Table 4.8).

Insect diversity was highest in the first wet season, it declined in the dry season and experienced a further decline in the second wet season (Fig 4.12). This could be attributed to the in tandem relationship of species evenness and diversity and the reduction in biomass and plant cover in the second wet season. Murdoch *et.al*.,(1972) stated that plant evenness and diversity are highly correlated to insect evenness and diversity. These findings were similar to the results of this study where highest insect diversity was noted in the first wet season which had an increased plant diversity.

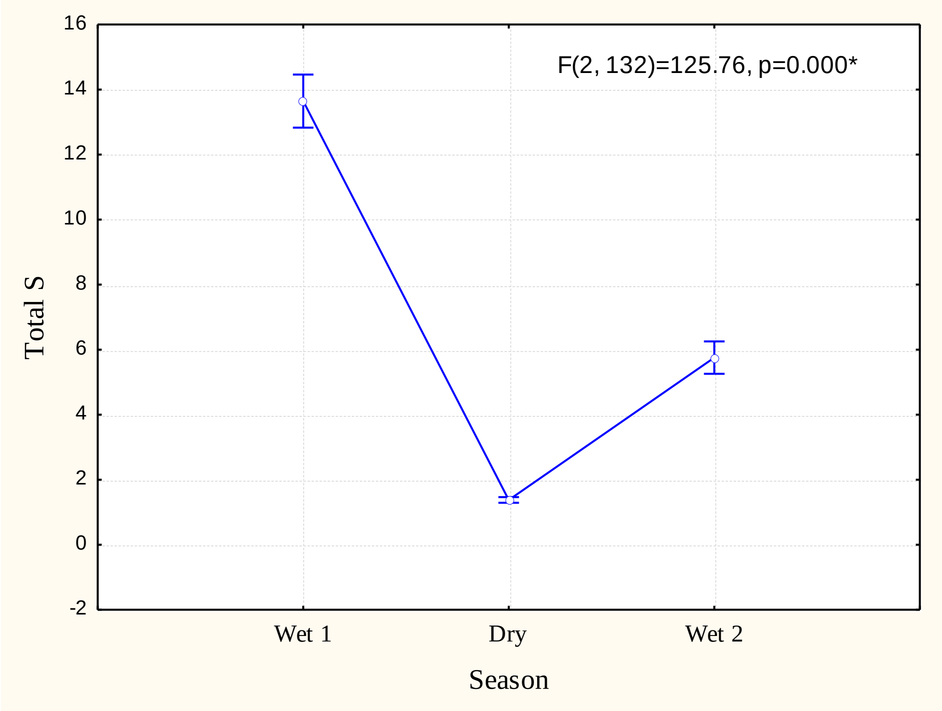


df (2,132)

Figure 4. 12: Shannon Weiner (H') index testing for invertebrate species diversity across seasons in Lewa Wildlife Conservancy

Total invertebrate species richness was highest in the first wet season (Fig 4.13) and this richness steadily declined as the dry season approached. However, an increase in invertebrate species richness was noted as the second wet season began. Species richness was significantly different across the three seasons and as rainfall increased, so did the number of invertebrate species collected. The dry season had fewer invertebrate species unlike the wetter periods when food reserves increased, following re-growth and plant regeneration, which caused an increase in invertebrate species richness.

In the wetter seasons, environmental conditions were found to be favorable to invertebrate species causing an increase in their numbers. Katherine *et.al*.(2001) found that invertebrate species richness was positively correlated to high plant biomass. This is similar to findings of this study where species richness increased during the wetter seasons (Fig 4.13) in tandem with increased plant biomass that was experienced in the wetter seasons (Table 4.10).



df (2,132)

Figure 4. 13: Seasonal species richness (S) across all study sites using data from both sweep net and pitfall trap methods in Lewa Wildlife Conservancy

4.3.2 Effect of seasons on vegetation cover and biomass

Glades had higher vegetation biomass during the rainy seasons than in the dry season (Table 4.10). This can be explained by the favorable conditions such as increased rainfall which favored increased food reserves and consequently plant re-growth and regeneration (Doris & Julia, 2006). During the dryer season, growth in glades is not supported causing the new growth to wither and die off and this becomes litter.

An analysis of variance revealed that vegetation biomass was not significantly different across treatments but it was found to be significantly different across seasons F (2, 16) p = 0.001 ά = 0.05 (Table 4.10)

Table 4. 10: Seasonal biomass (kg/ha) across treatment and across seasons in Lewa Wildlife Conservancy

		Mean total species (S)		
Treatment	Vegetation type	Wet Ssn 1	Dry Ssn	Wet Ssn 2
Glades	Litter	443 ± 79^a	233 ± 46^b	141 ± 30^c
	Perennial	3061 ± 396^a	1785 ± 232^b	2223 ± 276^c
	Forbs	365 ± 65^a	223 ± 166^b	244 ± 72^c
Grazing	Litter	738 ± 84^a	416 ± 60^b	231 ± 41^c
	Perennial	3068 ± 327^a	2387 ± 296^b	2249 ± 174^c
	Forbs	294 ± 42^a	168 ± 44^b	208 ± 32^c
Control	Litter	592 ± 69^a	431 ± 75^b	293 ± 45^c
	Perennial	3079 ± 372^a	2513 ± 268^b	2540 ± 186^c
	Forbs	337 ± 61^a	192 ± 35^b	217 ± 50^c

Rows with different letter superscripts are significant at $ά \leq 0.05$

Control and grazing plots had higher vegetation cover throughout the different seasons but did not show a positive response towards increased rainfall like glade plots which experienced increases in vegetation cover following the rains (Fig 4.14). The grazed and control plots had similar plant cover with slight increases during the wet seasons and more litter in the dry season. Dry periods are characterized by withering of plants which then increases the litter biomass.

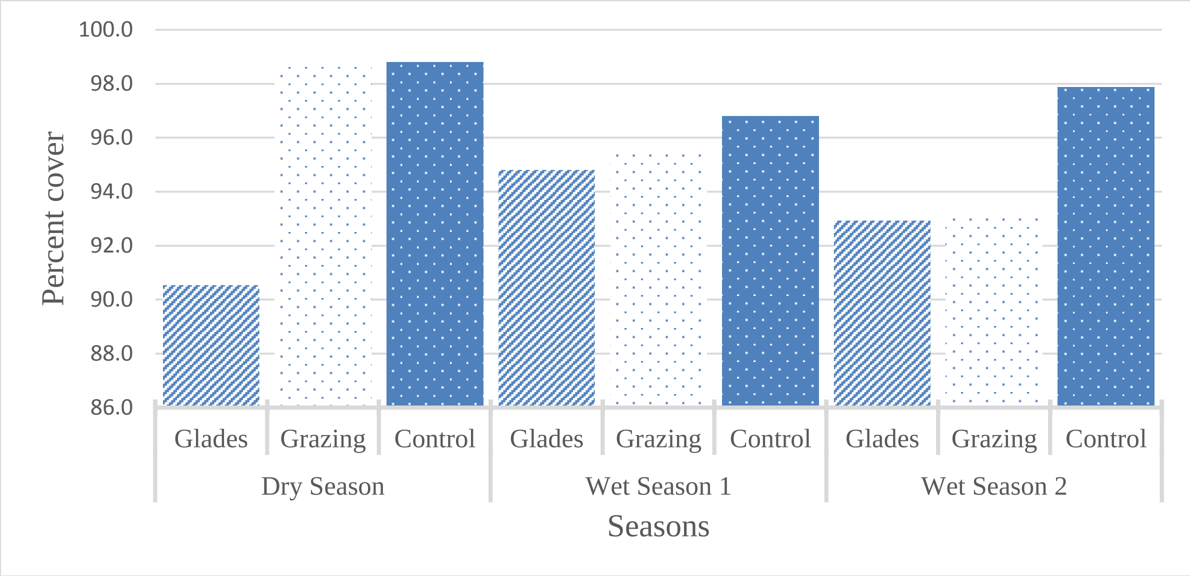


Figure 4. 14: Percent vegetation cover patterns across seasons in Lewa Wildlife Conservancy

Control sites had more plant cover due to their undisturbed state (Fig 4.15). Grazed sites had experienced defoliation hence the lower plant cover and plant biomass. Glades had little or no vegetation cover due to increased grazing pressure and trampling that occurred when the cattle rested in these sites. Glades however, eventually experience regeneration and new growth of higher quality vegetation than the grazed or control sites.

Litter had highest biomass in the first wet season and the quantities declined in the dry season and further in the second wet season (Table 4.10, Fig 4.15). This was because the first wet season was preceded by a long period that lacked rainfall causing plants that grew in previous months to wither and die off. Perennials biomass responded positively to increased rainfall across the seasons while forbs biomass seemed fairly similar for all treatments across the seasons. Grazing and control sites had similar and higher perennial biomass compared to glade sites. This followed assertion by Doris and Julia (2006) that vegetation responds positively to increased rainfall.

4.3.3 Correlation analysis between invertebrate species and vegetation biomass

Plant biomass is known to have a strong and positive correlation to increased insect abundance (Haddad., 2001). A Pearson correlation was carried out to establish if there is a direct relationship between vegetation parameters assessed in the study and invertebrate species. Diptera species and forbs and Hemiptera species and perennials demonstrated a negative and significant relationship where r = -0.289 and r = -0.258 respectively (Table 4.11).

Table 4. 11: Correlation analysis (r2) between vegetation biomass in (kg/ha) and invertebrate species in the study area

	Litter	Perennial	Forbs
Coleoptera	-0.059	0.027	0.174
Diptera	-0.061	0.128	-0.289*
Hemiptera	0.008	-0.258*	0.009
Hymenoptera	-0.15	-0.137	-0.204
Orthoptera	-0.244	-0.184	-0.102

(*) Correlation is significant at 0.05 level

This correlation supports work by Debano (2006) and Warui *et.al*.,(2005) that vegetation associated insects depend on the habitat structure created and would therefore be most likely affected by changes in the vegetation. The relationship demonstrated between these invertebrates and the vegetation biomass shows the dependance of these insects on the vegetation.

However, these results differed with Murdoch, Evans and Peterson (1972) and Southwood *et.al.*,(1979), studies which reported that insect species richness increases with increasing plant species richness due to the increased diversity of resources. This could however be attributed to the different orders sampled in the other studies.

4.4 Effects of soil properties on invertebrate species diversity and abundance

In this study, soil pH, organic carbon, nitrogen and bulk density were measured. Investigation was done to find out the invertebrates response to soil pH, organic carbon, nitrogen and bulk density. Soil properties largely influence the type of invertebrates present, their numbers and preferred food type which is determined by the specific plant supported by that soil. Jones (2001) stated that the nutrients found in soil largely determine the kind of plant that specific soil is capable of supporting, which in turn influence invertebrate diversity and abundance.

A Pearson correlation was carried out to establish if there was a relationship between soil properties and invertebrate species and correlation was established for Coleoptera species and bulk density (Table 4.12) where r = - 0.517 significant at 0.05.

Table 4. 12: Correlation analysis between soil attributes and invertebrate species in the study area

	pH	Organic carbon	Nitrogen	Bulk density
Coleoptera	0.089	0.096	0.043	-0.517**
Diptera	-0.053	0.084	-0.019	0.139
Hemiptera	0.089	0.074	0.237	0.044
Hymenoptera	0.194	-0.171	-0.181	0.081
Orthoptera	-0.161	0.227	0.206	0.010

(**) Correlation is significant at 0.1 level

4.5.1 Soil pH

Soil pH was not significantly different across treatments (Fig 4.15) but it was noted that soil pH was lowest in glades compared to the grazing and control plots. This may likely be attributed to the presence of high faecal deposits and high urea concentrations deposited by cattle resting in these plots similar to findings by Ali (1998).

In grazed sites, faecal deposits and urea were widely dispersed therefore minimizing their effect on soil pH. Soils of lower pH, such as in glades, support particular kinds of plants which in turn influence the likely insects found in the area thus causing an indirect effect on invertebrate species.

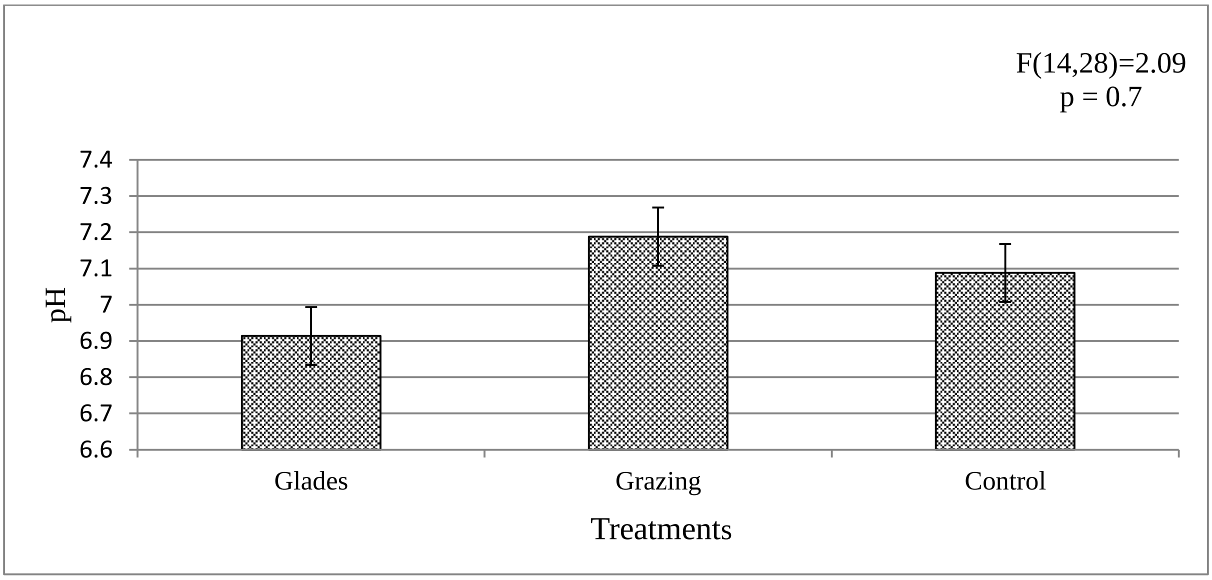


Figure 4. 15: pH values across treatments in Lewa Wildlife Conservancy

In this study, the link between soil pH and invertebrate species was demonstrated by plants of *solanaceae* family. Plants from the family *solanaceae* grow in a wide range of soils but do better in sites rich in organic manure, an environment ably provided by glade sites. Beetles, which belong to the order Coleoptera and bees from the order Hymenoptera respectively, feed from and pollinate plants of this family hence the link of invertebrate species to soil pH. This relationship was however not significant as reported in Table 4.12.

Similarly, plants from the family *fabaceae* were observed in the areas of low pH. This is because plants from this family have the ability to convert nitrogen present in the air, from the urea and faecal deposits, to nitrogen in a form usable by the plants through nitrogen-fixation. Plants from this family provide food for beetles and during flowering, bees and wasps are likely to visit for pollination purposes, partly explaining the high counts of Coleoptera and Hymenoptera in glades.

4.5.2 Soil organic carbon

Organic carbon is derived from animal and plant residue, synthesized by micro-organisms or decomposed when the environmental conditions are favorable (Sommers, 1982). The decaying materials contribute to carbon cycling and increased biological activity. Products released from this cycling are carbon dioxide, water, energy, plant nutrients and other re-synthesized organic carbon compounds (Bauer and Black, 1994). In this study, it was revealed that soil organic carbon was not significantly different across treatments (Fig 4.16).

Grazed plots had higher amounts of organic carbon (Fig 4.16) while control plots had the lowest organic carbon amounts. High organic carbon amounts were found to increase the water-holding capacity and structural stability of the soil similar to findings from UNEP (2012). This supports high numbers of burrowing and ground walking invertebrates such as beetles (Table 4.2). High amounts of organic carbon are also known to act as a soil buffer to changes in soil pH (Paterson and Hoyle, 2011), thus explaining why grazed sites had a relatively neutral pH (Fig 4.15).

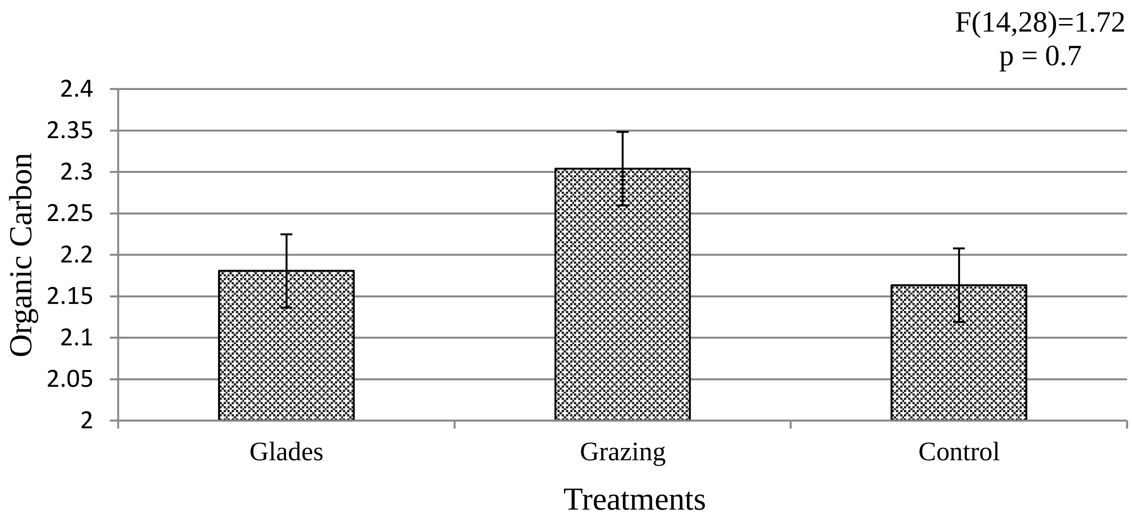


Figure 4. 16: Concentration of Organic carbon mg/kg across treatments in Lewa Wildlife Conservancy

The result of successive decomposition is that the overall soil cation exchange capacity (CEC) increases and so does soil aggregation and aggregate stability. This decomposition contributes nutrients such as nitrogen and phospohorous creating a microclimate suitable for increased plant productivity and consequently higher invetebrate species numbers in grazed than in control areas (Table 4.1).

4.5.3 Soil nitrogen

Nitrogen was not significantly different across treatments but was highest in glades due to increased faecal deposition at the beginning of glade formation. Glade and grazing sites had high amounts of nitrogen (Fig 4.17) which according to Wilsey and Gray (2007) increases the plant biomass and consequently the insect abundance (Table 4.1).

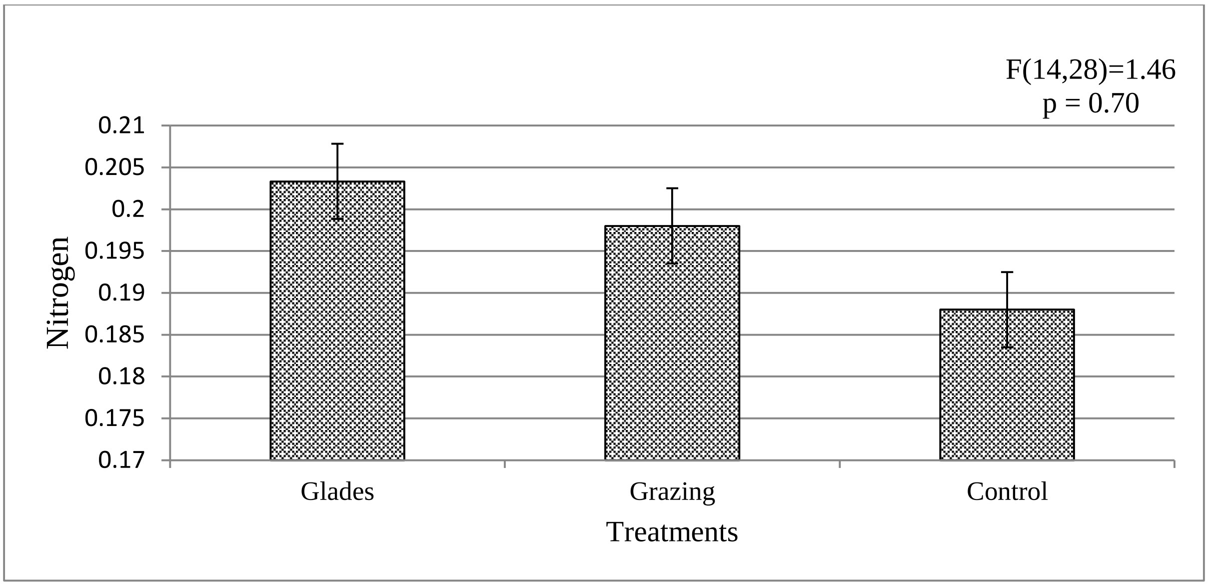


Figure 4. 17: Nitrogen levels across treatments in Lewa Wildlife Conservancy

Nitrogen is an important nutrient in ensuring plant productivity and an essential element of all amino acids which are the protein-building blocks of plant tissues. Nitrogen also makes a component of chlorophyll, required for photosynthesis. Through mineralization, organic N is broken down by a group of soil microorganisms and converted to plant available inorganic forms (Bartholomew and Clarke, 1965). This allows for increased plant productivity and improved plant quality thereby attracting invertebrates in large numbers in glades and grazed sites.

4.5.4 Soil bulk density

Glades and grazed sites had lower bulk density that was not significantly different from the control sites as shown by an analysis of variance (Fig 4.18). Bulk density was however higher for control sites but generally within the ideal range across all treatments, a range of between 1.10 - 1.47 g/cm^3 for clayey soils as stated in USDA (2008).

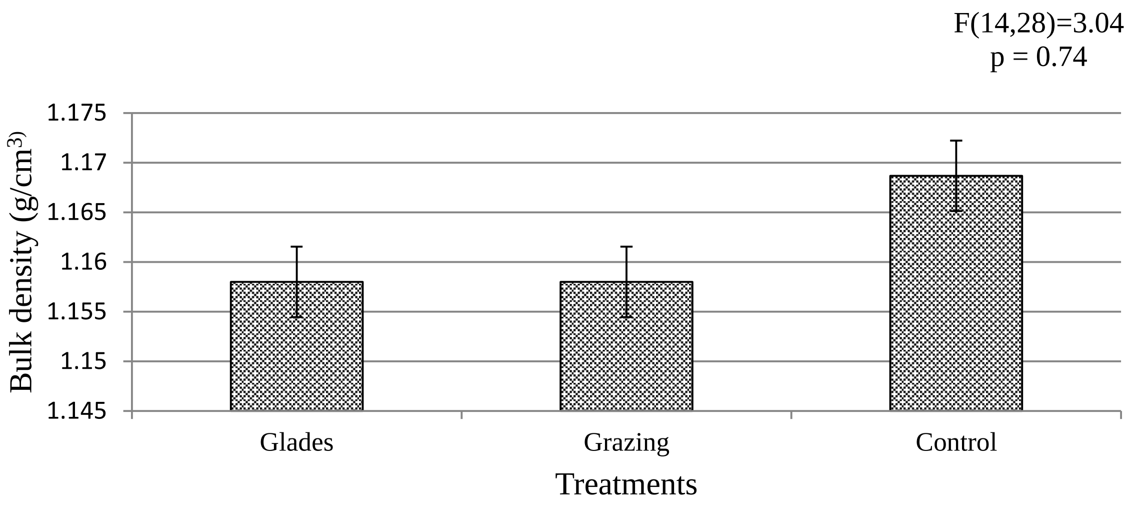


Figure 4. 18: Bulk density of treatments across sites in the study area

Soils from all treatments had a strong structure hence allowing water and solute movement. These soils were also well aerated due to presence of evenly distributed pore space within the soil which supported free movement of invertebrates. Ideal bulk density ranges, such as those reported in this study, enhance soil porosity and penetration of the plants roots leading to better plant growth which is closely linked to invertebrate diversity and abundance.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study investigated the effect that cattle grazing has on invertebrate assemblages in a savanna ecosystem where controlled grazing is practiced and kraals are used to create glades.

Grazing had an effect on invertebrate species abundance. However, in this study, invertebrate species abundance was initially not significantly different across treatments but when analyzed at a higher resolution, this is by grouping them into their different orders, a significant difference on invertebrate species abundance was revealed and species from the order Coleoptera were found to be the most dominant in all treatment sites.

Aging of glades has an effect on invertebrate species abundance with highest species abundance occurring three years after kraal movement. Glades are areas of low plant species richness and low plant species diversity which consequently decreases invertebrate species diversity. Glades are also areas of high vegetation quality and areas with increased levels of nitrogen and organic carbon. Glade establishment is a positive management strategy with long term benefits and should continue being practiced as it allows for open habitats and plant regeneration, both of which are beneficial to crawling insects.

There is a direct and positive relationship between seasons, vegetation cover and vegetation biomass. The abundance of vegetation associated insects is determined by presence or absence of vegetation cover and vegetation biomass. However, ground crawling insects do not have a direct relationship with vegetation cover or biomass, suggesting that vegetation indirectly supports habitats for crawling invertebrates.

Ground crawling insects have a negative relationship with increased soil bulk density as their movement and habitats are affected and changed in the presence of increased stocking density and grazing intensity.

Invertebrates respond positively to changes in micro climate provided by increased litter fall occurring in areas of high vegetation biomass and increased nutrient levels in the glades where nitrogen and organic carbon were found in high amounts. Both nitrogen and organic carbon are important in providing a favorable habitat and litter brings a suitable micro-climate that promotes increased plant biomass and consequently increased insect abundance.

Soil properties analyzed were not significantly different across treatments. This is likely attributed to the similarity of the soils in the study area. Nitrogen, pH and organic carbon levels were in adequate levels for crop growth and the bulk densities tested for all sites indicated no restriction for growth of roots or pore space for aeration and movement of invertebrates.

This study revealed that invertebrate species diversity and abundance are influenced by grazing, seasons, glades, vegetation biomass and soil properties such as bulk density. Invertebrate responses are central to ecological monitoring in conservancies and Lewa wildlife conservancy will benefit from bio-monitoring which will guide in selection of management strategies that will preserve the conservancy’s ecological integrity.

5.2 Recommendations

From the findings of this study, the following recommendations can be drawn, that

1. Further research should be carried out where specific invertebrate families will be analyzed in tandem with particular vegetation species known to support them to better the management practices used and for better conservation efforts of both the vegetation and invertebrates. For studies on beetles, it is recommended that the study focuses on the type of beetle for instance dwellers, tunnelers and rollers; to provide sufficient evidence of which type are more dominant and in this way provide an insight on the ecological role that is most promoted.

2. Soil properties should be regularly tested as an indicator of soil health. Such tests will also be an indicator of constraints to soil invertebrate movement. A soil in good health is useful in enabling proper plants growth and it provides a suitable habitat and food resource for the invertebrates.

3. Grazing and establishment of glades should be encouraged as they are mutually beneficial management strategies that improve existing habitats by doing away with unproductive vegetation biomass which consequently improves vegetation distribution for the benefit of the invertebrates. Allowing grazing in the Conservancy also favors the surrounding communities as their main source of livelihood is pastoralism. This allows Lewa Conservancy to meet its twin mandate to conserve biodiversity and its corporate responsibility of supporting the pastoral livelihoods of the surrounding community.

4. The current practice of keeping cattle in kraals for not more than ten days should continue as it prevents excessive nitrogen loading which would reduce plant biomass and consequently decrease insect abundance. Movement of cattle, to kraals in different areas as soon as unexpected rainfall is experienced, is an important strategy that prevents excessive trampling, compaction and damage to the soil.

5. The effect of treatments on invertebrate guilds should be evaluated to provide information on management strategies that will enhance invertebrate guild associations.

5.3 Study challenges

In this study a few challenges were faced in particular the availability of lab equipment in the field to process the invertebrate and vegetation samples collected and the long distance between sampling sites which slightly varied the invertebrate sampling schedules. This however did not affect the sampling efforts or sampling time adversely.

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APPENDICES

Appendix 1: Study site abbreviation list

The letter code refers to different study sites where;

AS- Air Strip
FP- Fumbi Plains
CS- Corner Safi
MTI II – Mlima Tim II
AH – Anna's Hse
MNC – Mnanda Chali
LM – Laga Mwangi
MTA – Mlima Tatu
CM – Corner Mbuni
MTI I – Mlima Tim I
LS – Luai Sambara
MK – Mlango Kiboo
MC – Mlima Choroa
SR – Simba Ridge
CYS – Chini Sambara

Appendix 2: A checklist of invertebrates collected from Lewa Wildlife Conservancy

Sweep species

GENUS SPECIES	FAMILY	ORDER	COMMON REFERENCE
Psammodes castanopterus	Tenebrionidae	Coleoptera	Darkling beetle
Adesmia abbreviata	Tenebrionidae	Coleoptera	Darkling beetle
Himatismus trivialis	Tenebrionidae	Coleoptera	Darkling beetle
Zophobas morio	Tenebrionidae	Coleoptera	Darkling beetle
Chlaenius sp3	Carabidae	Coleoptera	Ground beetle
Sepidium sp1	Tenebrionidae	Coleoptera	-
Melyris parvula	Melyridae	Coleoptera	Soft-winged flower beetle
Calosoma chlorosticum	Carabidae	Coleoptera	Ground beetle
Zophosis abbysinica	Tenebrionidae	Coleoptera	Darkling beetle
Cypholoba caillaudi	Carabidae	Coleoptera	Ground beetle
Chilanthia cavernosa	Carabidae	Coleoptera	Ground beetle
Chlaenius notabilis	Carabidae	Coleoptera	Ground beetle
Chlaenius coecus	Carabidae	Coleoptera	Ground beetle
Chlaenius sp1	Carabidae	Coleoptera	Ground beetle
Chlaenius angustatus	Carabidae	Coleoptera	Ground beetle
Cybister regimbarti	Dytiscidae	Coleoptera	-
Disphericus sulcostriatus	Carabidae	Coleoptera	Ground beetle
Disphericus sp1	Carabidae	Coleoptera	Ground beetle
Aprosterna sp1	Scarabaeidae	Coleoptera	Dung beetle
Laccoptera cicatricosa	Chrysomelidae	Coleoptera	Leaf beetle
Apophylia sp1	Chrysomelidae	Coleoptera	Leaf beetle
Apophylia sp2	Chrysomelidae	Coleoptera	Leaf beetle

GENUS SPECIES	**FAMILY**	**ORDER**	**COMMON REFERENCE**
Onthophagus nigricomis	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus gazella	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus liopterus	Scarabaeidae	Coleoptera	Dung beetle
Copris lunaris	Scarabaeidae	Coleoptera	True dung beetle
Harpalus asemus	Carabidae	Coleoptera	Ground beetle
Tanymecus sp1	Curculionidae	Coleoptera	Leaf weevil
Lema rubricollis	Chrysomelidae	Coleoptera	Leaf beetle
Lema nitidus	Chrysomelidae	Coleoptera	Leaf beetle
Lema cyanella	Chrysomelidae	Coleoptera	Leaf beetle
Lema melanopa	Chrysomelidae	Coleoptera	Leaf beetle
Chrysochus auratus	Chrysomelidae	Coleoptera	Leaf beetle
Aulacophora hilaris	Chrysomelidae	Coleoptera	Pumpkin beetle
Onthophagus rangifer	Scarabaeidae	Coleoptera	Dung beetle
Pseudocolapsis sp2	Chrysomelidae	Coleoptera	Leaf beetle
Megalognatha sp1	Chrysomelidae	Coleoptera	Leaf beetle
Tetralobus sp1	Elateridae	Coleoptera	Click beetle
Pseudocolapsis sp3	Chrysomelidae	Coleoptera	Leaf beetle
Monolepta sp1	Chrysomelidae	Coleoptera	Red shouldered leaf beetle
Curculionidae sp1	Curculionidae	Coleoptera	Bark beetles
Maacoccus bicruciatus	Coccidae	Coleoptera	Soft scale insects
Monolepta signata	Chrysomelidae	Coleoptera	Flea leaf beetle
Copa nigripennis	Scarabaeidae	Coleoptera	
Monolepta sp2	Chrysomelidae	Coleoptera	Red shouldered leaf beetle
Clytrinae sp1	Chrysomelidae	Coleoptera	Leaf beetle
Adolocera sp1	Anthribidae	Coleoptera	Click beetle
Elateridae sp3	Elateridae	Coleoptera	Click beetle
Elateridae sp4	Elateridae	Coleoptera	Click beetle
Adolocera sp2	Anthribidae	Coleoptera	Click beetle
Melitonoma sp1	Chrysomelidae	Coleoptera	Leaf beetle
Closteromerus tenuis	Cerambycidae	Coleoptera	Long horn beetle
Melitonoma sobrina	Chrysomelidae	Coleoptera	Leaf beetle
Deinacrida rugosa	Stenopelmatidae	Coleoptera	-
Elateridae sp2	Elateridae	Coleoptera	Click beetle
Paussus sp1	Carabidae	Coleoptera	Ground beetle
Blepisanis sp1	Cerambycidae	Coleoptera	Long horn beetle
Heteroderes sp1	Elateridae	Coleoptera	Click beetle
Lagria purpurascens	Tenebrionidae	Coleoptera	Darkling beetle
Lagria hirta	Tenebrionidae	Coleoptera	Darkling beetle
Megaleruca sp1	Chrysomelidae	Coleoptera	Leaf beetle
Megalognatha meruensis	Chrysomelidae	Coleoptera	Leaf beetle

GENUS SPECIES	FAMILY	ORDER	COMMON REFERENCE
Mylabris oculata	Meloidae	Coleoptera	Blister beetles
Alticinae sp1	Chrysomelidae	Coleoptera	Flea leaf beetle
Saprinus sp1	Histeridae	Coleoptera	Clown/Hister
Lagria cuprina	Tenebrionidae	Coleoptera	Darkling beetle
Schizonycha sp1	Scarabaeidae	Coleoptera	Dung beetle
Hister sp2	Histeridae	Coleoptera	Clown/Hister beetle
Hippodamia variegata	Cicadellidae	Coleoptera	Leafhoppers
Micraspis vincta	Coccinellidae	Coleoptera	Striped ladybird beetle
Cheilomenes lunata	Coccinellidae	Coleoptera	Ladybird
Hister tropicus	Histeridae	Coleoptera	Clown/Hister beetle
Cardiophorus samburensis	Elateridae	Coleoptera	Click beetle
Mylabris sp1	Meloidae	Coleoptera	Blister beetles
Mylabris phalerata	Meloidae	Coleoptera	Blister beetles
Mylabris variabilis	Meloidae	Coleoptera	Blister beetles
Epicauta alboritta	Meloidae	Coleoptera	Blister beetles
Epicauta hirticornis	Meloidae	Coleoptera	Red-headed slender oil beetle
Epicauta velata	Meloidae	Coleoptera	Blister beetles
Epicauta vittata	Meloidae	Coleoptera	Blister beetles
Ceroctis sp2	Meloidae	Coleoptera	Blister beetles
Dromica erlangeri	Carabidae	Coleoptera	Ground beetles
Metacatharsius sp1	Scarabaeidae	Coleoptera	Dung beetle
Epicauta cotinis	Meloidae	Coleoptera	Margined blister beetle
Crepidogaster sp1	Carabidae	Coleoptera	Ground beetles
Adoretus uncifer	Dytiscidae	Coleoptera	-
Brachinus sp1	Carabidae	Coleoptera	Ground beetles
Sisyphus seminulum	Scarabaeidae	Coleoptera	Dung beetle
Sisyphus nodifer	Scarabaeidae	Coleoptera	Dung beetle
Neosisyphus tibialis	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus sp1	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus sp2	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus sp3	Scarabaeidae	Coleoptera	Dung beetle
Oniticellus sp1	Scarabaeidae	Coleoptera	Dung beetle
Othophagus sansibaricus	Scarabaeidae	Coleoptera	Dung beetle
Othophagus bellus	Scarabaeidae	Coleoptera	Dung beetle
Harpalus sp1	Carabidae	Coleoptera	Ground beetle
Harpalus sp2	Carabidae	Coleoptera	Ground beetle
Harpalus jeanneli	Carabidae	Coleoptera	Ground beetle
Abacetus nitidulus	Carabidae	Coleoptera	Ground beetle
Gonocephalum simplex	Tenebrionidae	Coleoptera	Darkling beetle
Heliocopris sp1	Scarabaeidae	Coleoptera	Dung beetle
Anthaxia kheiliana	Buprestidae	Coleoptera	Jewel beetle

GENUS SPECIES	FAMILY	ORDER	COMMON REFERENCE
Copris typhoeus	Scarabaeidae	Coleoptera	Dung beetle
Acmaeodera sp2	Buprestidae	Coleoptera	Jewel beetle
Acmaeodera sp1	Buprestidae	Coleoptera	Metallic wood boring beetle
Elateridae sp7	Elateridae	Coleoptera	Click beetle
Anomala bottae	Scarabaeidae	Coleoptera	Dung beetle
Cardiophorus suhmaculatus	Elateridae	Coleoptera	Click beetle
Elateridae sp5	Elateridae	Coleoptera	Click beetle
Elateridae sp6	Elateridae	Coleoptera	Click beetle
Lycus sp1	Lycidae	Coleoptera	Net-winged beetle
Tanymecus falsus	Curculionidae	Coleoptera	Leaf weevil
Lema sanguinicollis	Chrysomelidae	Coleoptera	Leaf beetle
Hydrophilus senegalenis	Carabidae	Coleoptera	Ground beetle
Acmaeodera virgo	Buprestidae	Coleoptera	Metallic wood boring beetle/Jewel beetle
Anthaxia sp2	Buprestidae	Coleoptera	Jewel beetle
Anthaxia sp1	Buprestidae	Coleoptera	Jewel beetle
Dicladispa armigera	Chrysomelidae	Coleoptera	Rice hispa
Nematocerussp1	Curculionidae	Coleoptera	Cashew weevil beetle
Nematocerus sp2	Curculionidae	Coleoptera	Cashew weevil beetle
Chaetocnema sp1	Chrysomelidae	Coleoptera	Flea beetle
Pseudocolapsis sp1	Chrysomelidae	Coleoptera	Leaf beetle
Aphodius sp1	Scarabaeidae	Coleoptera	Dung beetle
Copris mesacanthus	Scarabaeidae	Coleoptera	Nursing dung beetle
Copris fallacious	Scarabaeidae	Coleoptera	Dung beetle
Sympectrum fonscolombii	Libellulidae	Odonata	Red-veined dragonfly
Trithemis arteriosa	Libellulidae	Odonata	Red-veined dropwing
Orthetrum caffrum	Libellulidae	Odonata	Two striped skimmer/White-lined skimmer dragonfly
Xiphydria longicolli	Xiphydriidae	Hymenoptera	Wood wasps
Melanostoma scalare	Syrphidae	Diptera	Hoverfly
Haematobia irritans	Muscidae	Diptera	Horn fly
Phenacephorus auriculatus	Diapheromeridae	Phasmatida	Stick insects
Archimandrita tessellata	Blaberidae	Blattodea	Giant leaf roach
Cataloipus oberthuri	Acrididae	Othoptera	Grasshopper

GENUS SPECIES	**FAMILY**	**ORDER**	**COMMON REFERENCE**
Tenodera angustipennis	Mantidae	Mantodea	Narrow winged mantis
Sphenarches anisodactylus	Pterophoridae	Lepidoptera	Geranium plume moth
Cisseps fulvicollis	Arctiidae	Lepidoptera	Yellow-collared scape moth
Borbo sp1	Hesperiidae	Lepidoptera	African swift butterfly
Precis limnoria	Nymphalidae	Lepidoptera	White spotted commodore butterfly
Junonia oenone	Nymphalidae	Lepidoptera	Blue pansy butterfly
Junonia hierta	Nymphalidae	Lepidoptera	Yellow pansy butterfly
Spialia sp1	Hesperiidae	Lepidoptera	Skipper butterfly
Hesperiidae sp1	Hesperiidae	Lepidoptera	Skipper butterfly
Hypolimnus missipus	Nymphalidae	Lepidoptera	
Acraea natalica	Nymphalidae	Lepidoptera	Scarlet butterfly
Phalanta phalanthus	Nymphalidae	Lepidoptera	Sun loving butterfly
Astictopterus sp1	Hesperiidae	Lepidoptera	Grassland fairy/Spangled skipper
Pieridae sp1	Pieridae	Lepidoptera	White and Yellow butterfly
Belenois sp1	Pieridae	Lepidoptera	White and Yellow butterfly
Belenois sp2	Pieridae	Lepidoptera	White and Yellow butterfly
Acraea sp1	Nymphalidae	Lepidoptera	Brush-footed butterfly
Acraea neobule	Nymphalidae	Lepidoptera	Wandering donkey butterfly
Colotis aurigineus	Pieridae	Lepidoptera	African golden/Arab veined butterfly
Byblia ilithyia	Nymphalidae	Lepidoptera	Spotted joker butterfly
Catopsilia florella	Pieridae	Lepidoptera	African migrant butterfly

GENUS SPECIES	FAMILY	ORDER	COMMON REFERENCE
Bicyclus sp1	Nymphalidae	Lepidoptera	Squinting bush brown butterfly
Saturniidae sp1	Saturniidae	Lepidoptera	Emperor moths/ Giant silkworm moths
Hesperiidae sp2	Hesperiidae	Lepidoptera	Skipper butterfly
Vanessa cardui	Nymphalidae	Lepidoptera	Painted lady butterfly
Papilio demodocus	Papilionidae	Lepidoptera	Citrus swallowtail butterfly
Nymphalidae sp1	Nymphalidae	Lepidoptera	-

Pitfall species

GENUS SPECIES	FAMILY	ORDER	COMMON REFERENCE
Psammodes castanopterus	Tenebrionidae	Coleoptera	Darkling beetle
Brachinus sp1	Carabidae	Coleoptera	Ground beetles
Adesmia nigrogemmata		Coleoptera	
Himatismus trivialis	Tenebrionidae	Coleoptera	Darkling beetle
Lema sanguinicollis	Chrysomelidae	Coleoptera	Leaf beetle
Hydrophilus senegalenis	Carabidae	Coleoptera	Ground beetle
Tanymecus sp1	Curculionidae	Coleoptera	Leaf weevil
Tanymecus sp2	Curculionidae	Coleoptera	Leaf weevil
Lema rubricollis	Chrysomelidae	Coleoptera	Leaf beetle
Elateridae sp5	Elateridae	Coleoptera	Click beetle
Lycus sp1	Lycidae	Coleoptera	Net-winged beetle
Adolocera sp1	Anthribidae	Coleoptera	Click beetle
Lagria purpurascens	Tenebrionidae	Coleoptera	Darkling beetle
Heteroderes sp1	Elateridae	Coleoptera	Click beetle
Chlaenius sp3	Carabidae	Coleoptera	Ground beetle
Sepidium sp1	Tenebrionidae	Coleoptera	Darkling beetle
Sepidium sp3	Tenebrionidae	Coleoptera	Darkling beetle
Melyris parvula	Melyridae	Coleoptera	Soft-winged flower beetle
Calosoma chlorosticum	Buprestidae	Coleoptera	Jewel beetle
Zophosis abbysinica	Tenebrionidae	Coleoptera	Darkling beetle
Cypholoba caillaudi	Carabidae	Coleoptera	Ground beetle
Chilanthia cavernosa	Carabidae	Coleoptera	Ground beetle
Chlaenius notabilis	Carabidae	Coleoptera	Ground beetle
Chlaenius coecus	Carabidae	Coleoptera	Ground beetle
Chlaenius sp1	Carabidae	Coleoptera	Ground beetle
Chlaenius angustatus	Carabidae	Coleoptera	Ground beetle
Cybister regimbarti	Dytiscidae	Coleoptera	-

GENUS SPECIES	**FAMILY**	**ORDER**	**COMMON REFERENCE**
Disphericus sulcostriatus	Carabidae	Coleoptera	Ground beetle
Disphericus sp1	Carabidae	Coleoptera	Ground beetle
Aprosterna sp1	Scarabaeidae	Coleoptera	Dung beetle
Laccoptera cicatricosa	Chrysomelidae	Coleoptera	Leaf beetle
Apophylia sp1	Chrysomelidae	Coleoptera	Leaf beetle
Apophylia sp2	Chrysomelidae	Coleoptera	Leaf beetle
Onthophagus liopterus	Scarabaeidae	Coleoptera	Dung beetle
Harpalus sp1	Carabidae	Coleoptera	Ground beetle
Copris sp1	Scarabaeidae	Coleoptera	Dung beetle
Dromica erlangeri	Carabidae	Coleoptera	Ground beetles
Crepidogaster sp1	Carabidae	Coleoptera	Ground beetles
Metacatharsius sp1	Scarabaeidae	Coleoptera	Dung beetle
Sisyphus seminulum	Scarabaeidae	Coleoptera	Dung beetle
Sisyphus nodifer	Scarabaeidae	Coleoptera	Dung beetle
Neosisyphus tibialis	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus sp1	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus sp2	Scarabaeidae	Coleoptera	Dung beetle
Onthophagus sp3	Scarabaeidae	Coleoptera	Dung beetle
Pseudocolapsis sp2	Chrysomelidae	Coleoptera	Leaf beetle
Tetralobus sp1	Elateridae	Coleoptera	Click beetle
Pseudocolapsis sp3	Chrysomelidae	Coleoptera	Leaf beetle
Monolepta sp1	Chrysomelidae	Coleoptera	Red shouldered leaf beetle
Curculionidae sp1	Curculionidae	Coleoptera	Bark beetles
Onthophagus rangifer	Scarabaeidae	Coleoptera	Dung beetle
Copa nigripennis	Scarabaeidae	Coleoptera	Dung beetle
Clytrinae sp1	Chrysomelidae	Coleoptera	Leaf beetle
Adolocera sp1	Anthribidae	Coleoptera	Click beetle
Melitonoma sp1	Chrysomelidae	Coleoptera	Leaf beetle
Closteromerus tenuis	Cerambycidae	Coleoptera	Long horn beetle
Elateridae sp2	Elateridae	Coleoptera	Click beetle
Elateridae sp 6	Elateridae	Coleoptera	Click beetle
Elateridae sp 7	Elateridae	Coleoptera	Click beetle
Paussus sp1	Carabidae	Coleoptera	Ground beetles
Blepisanis sp1	Cerambicydae	Coleoptera	Long horn beetle
Cardiophorus samburensis	Elateridae	Coleoptera	Click beetle
Cardiophorus suhmaculatus	Elateridae	Coleoptera	Click beetle
Adolocera sp2	Anthribidae	Coleoptera	Click beetle
Megalognatha meruensis	Chrysomelidae	Coleoptera	Leaf beetle
Alticinae sp1	Chrysomelidae	Coleoptera	Flea leaf beetle
Saprinus sp1	Histeridae	Coleoptera	Clown/Hister beetle
Lagria cuprina	Tenebrionidae	Coleoptera	Darkling beetle
Hister sp2	Histeridae	Coleoptera	Clown/Hister beetle
Hippodamia variegata	Cicadellidae	Coleoptera	Leafhoppers
Cheilomenes lunata	Coccinellidae	Coleoptera	Ladybird

GENUS SPECIES	FAMILY	ORDER	COMMON REFERENCE
Micraspis vincta	Coccinellidae	Coleoptera	Striped ladybird beetle
Hister tropicus	Histeridae	Coleoptera	Clown/Hister beetle
Ceroctis sp2	Meloidae	Coleoptera	Blister beetles
Epicauta alboritta	Meloidae	Coleoptera	Blister beetles
Mylabris sp2	Meloidae	Coleoptera	Blister beetles
Mylabris sp3	Meloidae	Coleoptera	Blister beetles
Mylabris sp4	Meloidae	Coleoptera	Blister beetles
Tanymecus falsus	Curculionidae	Coleoptera	Leaf weevil
Copris mesacanthus	Scarabaeidae	Coleoptera	Nursing dung beetle
Oniticellus sp1	Scarabaeidae	Coleoptera	Dung beetle
Othophagus sansibaricus	Scarabaeidae	Coleoptera	Dung beetle
Othophagus bellus	Scarabaeidae	Coleoptera	Dung beetle
Harpalus sp1	Carabidae	Coleoptera	Ground beetle
Harpalus sp2	Carabidae	Coleoptera	Ground beetle
Harpalus jeanneli	Carabidae	Coleoptera	Ground beetle
Abacetus nitidulus	Carabidae	Coleoptera	Ground beetle
Gonocephalum simplex	Tenebrionidae	Coleoptera	Darkling beetle
Heliocopris sp1	Scarabaeidae	Coleoptera	Dung beetle
Acmaeodera sp1	Buprestidae	Coleoptera	Metallic wood boring beetle
Anthaxia kheiliana	Buprestidae	Coleoptera	Jewel beetle
Copris typhoeus	Scarabaeidae	Coleoptera	Dung beetle
Acmaeodera sp2	Buprestidae	Coleoptera	Metallic wood boring beetle
Acmaeodera virgo	Buprestidae	Coleoptera	Metallic wood boring beetle/Jewel beetle
Anthaxia sp1	Buprestidae	Coleoptera	Jewel beetle
Anthaxia sp2	Buprestidae	Coleoptera	Jewel beetle
Dicladispa armigera	Chrysomelidae	Coleoptera	Rice hispa
Nematocerus sp1	Curculionidae	Coleoptera	Cashew weevil beetle
Nematocerus sp2	Curculionidae	Coleoptera	Cashew weevil beetle
Chaetocnema sp1	Chrysomelidae	Coleoptera	Flea beetle
Pseudocolapsis sp1	Chrysomelidae	Coleoptera	Leaf beetle
Tenodera angustipennis	Mantidae	Mantodea	Narrow-winged mantis
Archimandrita tessellata	Blaberidae	Blattodea	Giant leaf roach
Sympectrum fonscolombii	Libellulidae	Odonata	Red-veined dragonfly
Trithemis arteriosa	Libellulidae	Odonata	Red-veined dropwing

GENUS SPECIES	**FAMILY**	**ORDER**	**COMMON REFERENCE**
Orthetrum caffrum	Libellulidae	Odonata	Two striped skimmer/White-lined skimmer dragonfly
Cataloipus oberthuri	Acrididae	Othoptera	Grasshopper
Cisseps fulvicollis	Arctiidae	Lepidoptera	Yellow-collared scape moth
Vanessa cardui	Nymphalidae	Lepidoptera	Painted lady butterfly
Byblia ilithyia	Nymphalidae	Lepidoptera	Spotted joker butterfly
Papilio demodocus	Papilionidae	Lepidoptera	Citrus swallowtail butterfly
Catopsilia florella	Pieridae	Lepidoptera	African migrant butterfly
Phalanta phalanthus	Nymphalidae	Lepidoptera	Sun loving butterfly
Astictopterus sp1	Hesperiidae	Lepidoptera	Grassland fairy/Spangled skipper
Pieridae sp1	Pieridae	Lepidoptera	White and Yellow butterfly
Borbo sp1	Hesperiidae	Lepidoptera	African swift butterfly
Precis limnoria	Nymphalidae	Lepidoptera	White spotted commodore butterfly
Junonia oenone	Nymphalidae	Lepidoptera	Blue pansy butterfly
Nymphalidae sp1	Nymphalidae	Lepidoptera	
Junonia hierta	Nymphalidae	Lepidoptera	Yellow pansy butterfly
Spialia sp1	Hesperiidae	Lepidoptera	Skipper butterfly
Hesperiidae sp1	Hesperiidae	Lepidoptera	Skipper butterfly
Acraea sp1	Nymphalidae	Lepidoptera	Brush-footed butterfly
Acraea neobule	Nymphalidae	Lepidoptera	Wandering donkey butterfly
Acraea natalica	Nymphalidae	Lepidoptera	Scarlet butterfly
Colotis danae	Pieridae	Lepidoptera	Crimson-tip butterfly
Colotis aurigineus	Pieridae	Lepidoptera	African golden/Arab veined butterfly
Hypolimnus missipus	Nymphalidae	Lepidoptera	Danaid eggfly butterfly
Hesperiidae sp1	Hesperiidae	Lepidoptera	Skipper butterfly
Hesperiidae sp2	Hesperiidae	Lepidoptera	Skipper butterfly

GENUS SPECIES	FAMILY	ORDER	COMMON REFERENCE
Bicyclus sp1	Nymphalidae	Lepidoptera	Squinting bush brown butterfly
Saturniidae sp1	Saturniidae	Lepidoptera	Emperor moths/ Giant silkworm moths
Apis mellifera	Apidae	Hymenoptera	Bee
Amegilla sp1	Apidae	Hymenoptera	Blue-banded bee
Megachile sp1	Megachilidae	Hymenoptera	Leaf-cutter bee
Megachile sp2	Megachilidae	Hymenoptera	Leaf-cutter bee
Systropha sp1	Apidae	Hymenoptera	Spiraled-horned bee
Heriades sp1	Megachilidae	Hymenoptera	Mason bee
Macrogalea candida	Apidae	Hymenoptera	Bee
Steganomus sp1	Halictidae	Hymenoptera	Sweat bee
Lipotriches australica	Halictidae	Hymenoptera	Nomia bee
Ceratina viridis	Megachilidae	Hymenoptera	Small carpenter bee
Seladonia sp1	Halictidae	Hymenoptera	Sweat bee
Patellapsis sp1	Halictidae	Hymenoptera	Sweat bee
Lassioglosum sp1	Halictidae	Hymenoptera	Sweat bee
Lipotriches sp1	Halictidae	Hymenoptera	Nomia bee
Bombus chinensis	Apidae	Hymenoptera	Bumblebee

Appendix 3: A checklist of plant species recorded at Lewa Wildlife Conservancy

Forbs species	Woody species	Grass species
Pupalia lappacea	*Acacia drepanolobium*	*Pennisetum stramineum*
Commelina benghalensis	*Acacia seyal*	*Pennisetum mezianum*
Conyza floribunda	*Acacia xanthphloea*	*Digitaria scalarum*
Bidens ugadensis	*Acacia tortilis*	*Digitaria macroblephara*
Pollichia campestris	*Acacia mellifera*	*Digitaria velutina*
Monechma debile	*Acacia nilotica*	*Themeda triandra*
Barleria acanthoides	*Lycium europeaum*	*Setaria pumila*
Justicia exigna	*Hibiscus aponeurus*	*Setaria veticilata*
Asystacia schimperi	*Hibiscus parvifolia*	*Cynodon dactylon*
Portulaca oleracea	*Boscia mossambiscensis*	*Dactyloctenium aegyptica*
Amaranthus hybridus	*Achyranthus aspera*	*Sorghum purpureo-setaceaum*
Amaranthus lividus	*Cardia ovatis*	*Aristida keninesis*
Medicago sativa	*Lippia ukambensis*	*Aristida adscensionis*
Abutilon mauritanium	*Lantana verbunoides*	*Sporobolus pyramidales*
Sida ovata	*Asparagus falcatus*	*Sporobolus filipes*
Blepharis integrifolia	*Grewia similis*	*Sporobolus discosporus*
Hypoestes verticilaris	*Grewia bicolor*	*Panicum maximum*
Ipomea mombassana	*Boscia angustifolia*	*Chrysopogon plumosus*

Forbs species	**Woody species**	**Grass species**
Convolvulus farinosus	*Omocarpum trachycarpum*	*Enneapogon cenchrus*
Tagetes minuta	*Commiphora schimperi*	*Cenchrus ciliaris*
Commicarpus stellatum	*Rhus natalensis*	*Cynodon plectostachyus*
Oxygonum sinuatum	*Scurtia myrtina*	
Aerva lanata		
Pentanisia ouranogyne		
Indigofera spicata		
Indigofera schimperi		
Cassia mimosoides		
Justicia striata		
Leucas glabrata		
Leucas pododiskos		
Ocimum bacilicum		
Chenopodium ambrosioides		
Digera muricata		
Bothriocline somalensis		
Leucas martinicensis		
Cochorus olitorus		
Triumfetta flavescence		
Solanum incanum		
Alyscarpus rogusus		
Phyllanthus maderaspatens		
Osteospermum vailantii		
Tephrosia pumila		
Polyghala sphenoptera		
Elvolvulus alsinoides	*Capparis tomentosa*	*Lintonia nutans*
Crotalaria incana		
Centemopsis rubra		
Achyranthus aspera		
Cucumis dipsaceus		
Oxalis stricta		

Appendix 4: List of soil properties across treatments in the study area at Lewa Wildlife Conservancy

Site	Glade year	Treatment	pH	Organic carbon	Nitrogen	Bulk density
Airstrip	2012	Glades	6.4	2.44	0.15	1.25
Airstrip	2012	Grazing	6.3	2.85	0.21	1.32
Airstrip	2012	Control	5.9	1.36	0.17	1.27
Anna's Hse	2008	Glades	7.2	1.5	0.21	1.06
Anna's Hse	2008	Grazing	6.4	2.17	0.25	1.12
Anna's Hse	2008	Control	8.4	2.23	0.2	0.93
Chini mlima sambara	2008	Glades	7.4	1.13	0.14	1.18
Chini mlima sambara	2008	Grazing	7.6	2.03	0.17	1.05
Chini mlima sambara	2008	Control	7.6	2.03	0.17	1.25
Corner Mbuni	2009	Glades	7.3	3.52	0.28	1.0
Corner Mbuni	2009	Grazing	6.5	2.71	0.2	1.04
Corner Mbuni	2009	Control	7.6	2.68	0.18	1.12
Corner Safi	2012	Glades	6.5	2.36	0.27	1.02
Corner Safi	2012	Grazing	8.1	1.77	0.15	1.2
Corner Safi	2012	Control	7.7	1.72	0.17	0.99
Fumbi plains	2012	Glades	8.4	2.32	0.25	1.09
Fumbi plains	2012	Grazing	8.6	2.19	0.2	1.15
Fumbi plains	2012	Control	7.0	1.66	0.28	1.16
Laga mwangi	2011	Glades	7.4	1.66	0.28	1.16
Laga mwangi	2011	Grazing	7.5	1.39	0.14	N/A
Laga mwangi	2011	Control	7.4	1.66	0.28	1.16
Luai sambara	2011	Glades	6.9	2.61	0.21	0.61

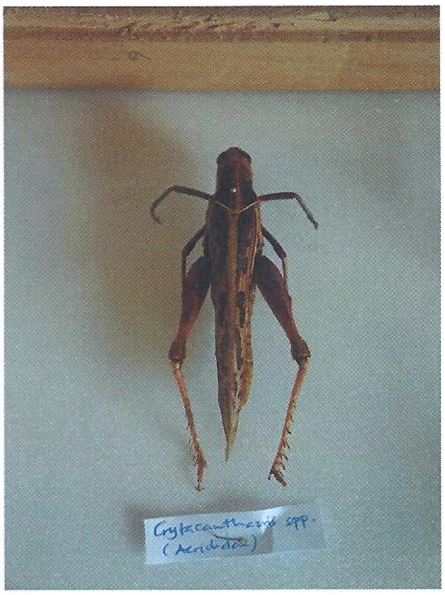
Site	Glade year	Treatment	pH	Organic carbon	Nitrogen	Bulk density
Luai sambara	2011	Grazing	7.1	1.52	0.13	0.91
Luai sambara	2011	Control	7.8	1.83	0.18	0.96
Mlango kiboo	2010	Glades	7.5	3.29	0.22	1.11
Mlango kiboo	2010	Grazing	3.7	2.85	0.18	1.24
Mlango kiboo	2010	Control	6.3	2.27	0.2	1.42
Mlima choroa	2010	Glades	7.5	2.71	0.11	1.31
Mlima choroa	2010	Grazing	7.1	2.24	0.2	1.04
Mlima choroa	2010	Control	6.2	1.75	0.25	1.22
Mlima tatu	2010	Glades	6.6	2.5	0.2	1.46
Mlima tatu	2010	Grazing	6.2	2.64	0.2	1.25
Mlima tatu	2010	Control	6.3	2.47	0.2	1.26
Mlima Tim I	2008	Glades	7.5	2.6	0.25	1.17
Mlima Tim I	2008	Grazing	9.8	2.01	0.2	1.2
Mlima Tim I	2008	Control	7.8	3.6	0.3	1.34
Mlima Tim II	2009	Glades	6.8	2.2	0.2	1.12
Mlima Tim II	2009	Grazing	5.5	3.19	0.25	1.17
Mlima Tim II	2009	Control	6.2	2.64	0.24	1.13
Mnanda chali	2011	Glades	6.1	2.57	0.25	1.2
Mnanda chali	2011	Grazing	7.7	1.93	0.15	1.39
Mnanda chali	2011	Control	6.2	2.3	0.18	1.2
Simba ridge	2009	Glades	7.6	1.11	0.11	1.12
Simba ridge	2009	Grazing	7.5	2.49	0.11	1.26
Simba ridge	2009	Control	7.3	1.04	0.13	1.23

Appendix 5: Cattle stocking density as calculated for all sites grazed in past years in Lewa Wildlife Conservancy

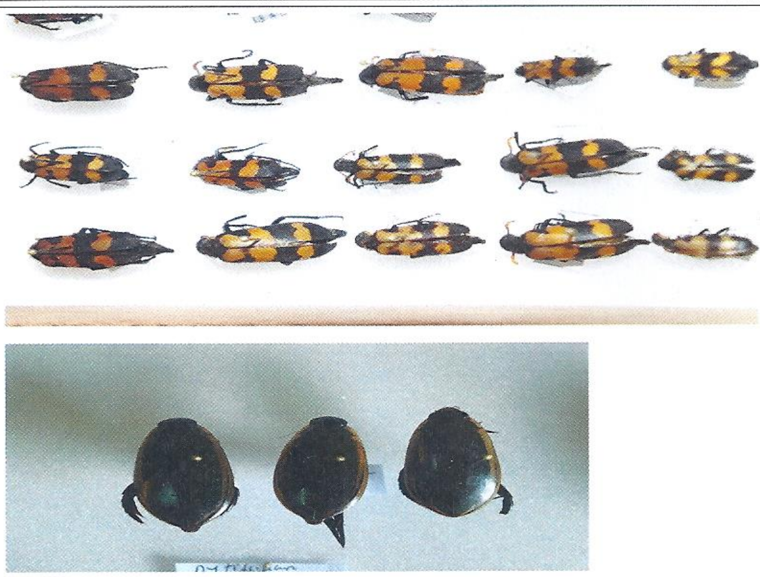
SITE NAME	YEAR OF GRAZING	NUMBER OF CATTLE	AREA (ha)	STOCKING DENSITY
Anna's Hse	2008	300	0.035	8493
Chini Mlima Sambara	2008	600	0.071	8493
Mlima Tim I	2008	600	0.071	8493
Corner Mbuni	2009	200	0.026	7549
Mlima Tim II	2009	600	0.071	8493
Simba Ridge	2009	300	0.035	8493
Mlango Kiboo	2010	300	0.035	8493
Mlima Choroa	2010	1200	0.141	8493
Mlima Tatu	2010	1200	0.141	8493
Laga Mwangi	2011	1200	0.141	8493
Luai Sambara	2011	800	0.097	8235
Mnanda Chali	2011	600	0.071	8493
Air Strip	2012	300	0.035	8493
Corner Safi	2012	500	0.062	8088
Fumbi Plains	2012	1200	0.141	8493

Appendix 6a: Pictures of insects from the various orders, collected from Lewa Wildlife Conservancy

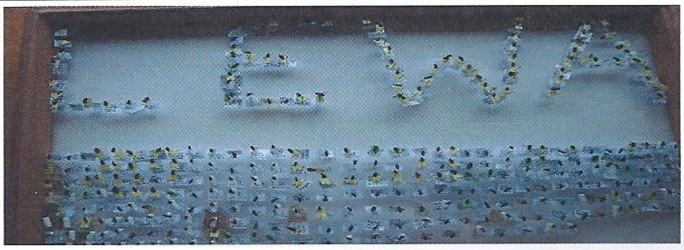
Hymenoptera: Bees and wasps family



Orthoptera: The grasshopper family



Coleoptera: The beetle family



Diptera: Family of flies

Appendix 6b: Pictures of insects from the various orders, at high resolution from literature

Coleoptera: Beetle family

Orthoptera: Grasshoppers

Hemiptera: Bugs family

Hymenoptera: Bees and wasps

Diptera: Flies