

Full Length Research Paper

Land use practices and their implications on soil macro-fauna in Maasai Mara ecosystem

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Accepted 23 April, 2012

The composition, abundance, diversity and species richness of soil macro-fauna communities were assessed in four major land use types present within protected and agricultural landscapes in Maasai Mara savannah ecosystem (MME), Kenya. The four land uses were: natural grassland; woodland, inside and outside protected area; maize mono-cropping and maize-bean intercropping systems in adjacent agricultural farms. Sampling of soil macro-fauna was carried out in November, 2009 (short rain), April 2010 (wet rainy season) and September 2010 (dry season). Hand sorting of soil taken from 25 × 25 × 30 cm monoliths was used to extract all soil macro fauna greater than 2 mm body length. A total of 3,658 individuals comprising of 128 species mainly belonging to Phylum Arthropoda distributed across 3 classes and 13 orders, and Phylum Annelida with one order were collected across the four different land use systems. Termites and ants, and to a lesser extent coleopteran and earthworms were the most abundant groups. Significant effects of land use on macro-fauna abundance and species richness in all cases ($p < 0.001$) were observed. There were significant interaction between Season*Region*Land use ($p < 0.01$), Region*Land use ($p < 0.05$) and Region*Protection*Land use ($p < 0.02$). Grassland and woodland had the highest density (1351.61 vs. 2852.47 individual m^{-2}) of total macro-fauna, whilst the lowest density occurred in agricultural land (205.48 individual m^{-2}). Agriculture altered macro-fauna communities by declining individuals from Order Coleoptera, Hymenoptera and Isoptera by > 50% and eliminating some Orders/Species. Human related disturbances outside protected area network declined macro-fauna density in grassland and woodland in dry region (65.07 vs. 39.74%) but increased the density by 107 vs. 340% in wet region. The study highlights the important effect of agriculture on macro-fauna communities and the need for conservation alternatives in unprotected areas. This study supports conservation of biodiversity beyond protected area network.

Key words: Macro-fauna, grassland, woodland, agriculture, Maasai Mara, land use.

INTRODUCTION

Maasai Mara ecosystems (MME) is in various states of decline, evidenced by soil erosion, low productivity and poor water quality caused by forest clearing, intensive agricultural production, and continued use of land resources for purposes that are not sustainable (Serneels

and Lambin, 2001; Muchai et al., 2007). The biological diversity of these systems has declined drastically over the past decade (Sinclair et al., 2002; Homewood et al., 2007), necessitating urgent alternative conservation measures to curb the decline. Efforts to conserve these ecosystems are currently moving from protected areas into promoting innovative farming practices which sustain biological diversity without compromising food and income needs of the local community (Buck et al., 2001). Identification of such innovations will require wide

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knowledge of all-taxa biodiversity contributing to a sustainable ecosystem, including the diversity of soil macro-fauna.

Soil macro-fauna largely govern ecosystem functioning and are important components of below ground biodiversity accounting for 50 to 75% of the total dry weight of invertebrates in soils (Brown et al., 2001). They include widespread and active taxa of earthworms, ants, termites, millipedes, beetles and flies larvae among others (Kalisz and Powell, 2000). Macro-fauna are important drivers of decomposition of organic matter and help in dispersal of seeds and spores (Harinikumar and Bagyraj, 1994). In addition, they contribute to the physical rearrangement of soil particles, changing the pore size distribution and as a result, improve water and nutrient infiltration and gaseous emission (Paoletti and Bressan, 1996; Lavelle et al., 2001). They are also effective monitors of soil quality and degradation (Paoletti and Bressan, 1996). Soil macro-fauna are significant regulators of nutrient turnover both directly through their feeding activities and indirectly through their influence on soil structure and biological processes (Susilo et al., 2004). Earthworms in particular are powerful regulators of soil processes, participating in the maintenance of soil structure and the regulation of soil organic matter dynamics and are considered as a natural resource of agronomic interest that may be used to increase the sustainability of most production systems (Lavelle et al., 1997). Termites influence crop residue breakdown, soil structure development and fertility, while ants modify the soil physical and chemical activities (de Bruyn and Conacher, 1990). Soil macro-fauna are also known to be important in influencing decomposition and biodegradation of organic residues, as well as breaking down and redistributing organic matter in the soil profile (Lee and Foster, 1991; Lavelle et al., 1992).

Land use can exert a strong influence on the abundance, biomass, diversity and community composition of soil macro-fauna (Decaëns et al., 1994; Barros et al., 2002). When macro-fauna communities of important functional groups are affected by land use, essential ecosystem functions may also suffer (Daily et al., 1997). Soil macro-fauna are also thought to be influenced by unsustainable human disturbances such as overgrazing, fire, deforestation, loss of crop and background biodiversity, pollution, soil erosion, and depletion of fertility (Lavelle et al., 1997; Gillison et al., 2003; Bignellet al., 2005; Moreira et al., 2008). Because soil macro-fauna communities are likely to be dynamic (Decaëns et al. 2002), it is important to sample across seasons and at different successional stages of agricultural use. The influence of soil macro-fauna on soil properties may be particularly important for resource-limited smallholder farmers, who depend on the biological productivity of the soil for their livelihoods (Swift et al., 1994; Giller et al., 1997).

Further research is therefore needed on the effect of land use, season, and human disturbance and protection

status on macro-fauna in order to develop concrete recommendations for development of an abundant and diverse soil macro-fauna, which in turn may assist in the conservation of soil fertility and productivity. The majority of soil macro-fauna studies have been made in temperate habitats, but little attention has been paid to the soil macro-fauna communities in the tropical Africa (Okwakol and Sekamatte, 2007). Very few macro-fauna studies have been conducted in Kenya. Recent work by Ayuke et al. (2009) reported different macro-fauna assemblages in the Coast and Eastern part of Kenya, but no study has been reported in Savannah ecosystems in Kenya. Such studies are needed for better management and sustainability of macro-fauna diversity and maintenance of ecosystems services.

The aim of this study were to compare patterns of abundance, diversity, and community characteristics for soil macro-fauna in the four dominant land use types in MME. We also aimed at characterizing seasonal distribution patterns of soil macro-fauna abundance and diversity in both the dry and wet seasons. In this study, we hypothesized that: (i) Land use strongly influences soil macro-fauna abundance and composition; (ii) a greater number of macro-fauna are found in protected habitats; (iii) soil macro-fauna density is related to season and (iv) human disturbance and agriculture would not favor an abundant and diverse soil macro-fauna. To test these alternatives, we carried out a one year study in MME, Kenya, using a sampling design with four main fixed factors: 1) "land use" (with 4 levels; (i) indigenous woodland, (ii) natural grasslands, (iii) maize mono cropland and (iv) mixed maize-bean intercropland, and 2) "protection" (with 2 levels; inside vs. outside the reserve), 3) "season" (with two levels; wet long rain vs. dry), and 4) "region" (with two levels; wet side vs. dry side).

MATERIALS AND METHODS

Study Area

The study was conducted in Narok and Trans Mara Districts of Kenya which lie between longitudes 34° 42' 26.03" E and 35° 41' 03.41" E; and Latitudes 0° 58' 58.41" S and 1° 57' 16.72" S and covers about 6000 km² (Figure 1). This forms part of the Maasai Mara savannah ecosystem. The area is bounded by the international boundary of Kenya and Tanzania in the south, the Siria escarpment (Esoit Olololo) to the west, agriculture and forest to the north, the Loita plains and hills to the east and the Siana plains and hills to the south-east (Figure 1). The area is mainly composed of *Themeda* grassland, dwarf shrub and *Acacia drapanolopium* grassland and *Croton* bush and other woody species interspersed with grassland (Stelfox et al., 1986).

The entire Mara Ecosystem has been subject to considerable vegetation changes including establishment of dense woodlands and thickets in the Mara Plains due to change in climate, low fire frequency due to recurrent droughts and low animal numbers (Dublin et al., 1990). The Trans Mara naturally supports a mixture of forest and woodland with scattered bushes, but is rapidly being transformed into cultivated land. The main land uses in the area are pastoralism, tourism and agriculture. The Maasai Mara National Reserve (MMNR) is a 1368 km² formal conservation area owned by

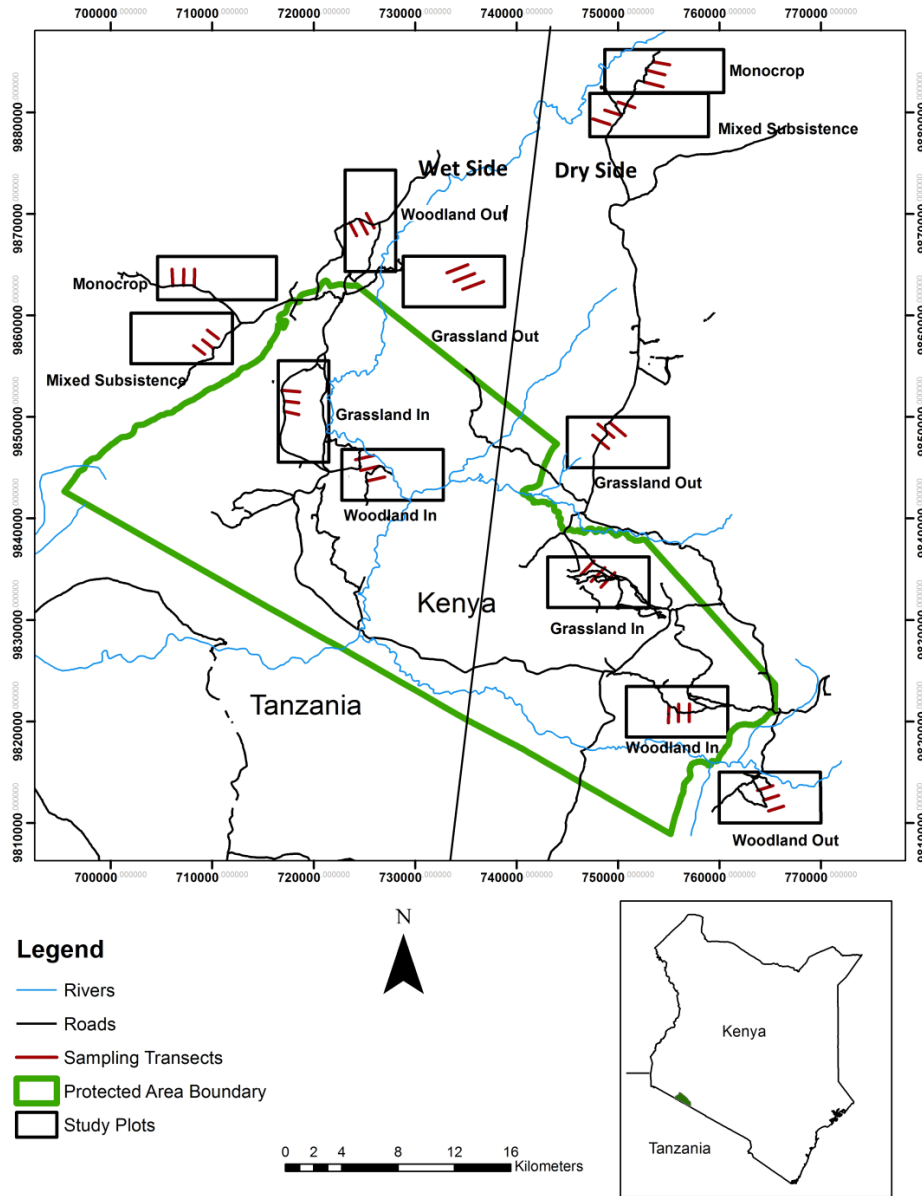


Figure 1. Map showing study area in Maasai Mara, Kenya.

the Government of Kenya and managed by the Narok and Trans Mara District County Councils. Land use within the reserve is restricted to wildlife tourism. Natural woodland and grassland inside the reserve are characterized by minimal human disturbances.

The MMNR is surrounded by group ranches that are under communal or private ownership, either by groups of families (group ownership) or by individual families (individual ownership) where the main land uses are pastoralism and agriculture. Private ownership means individual residents can engage in any or all form of herding, small-scale farming, mechanized commercial farming, and wildlife tourism enterprises. Woodland and grassland outside the park are characterized by heavy human disturbances especially from overgrazing by the cattle and firewood collection. The group ranches contain year-round resident wildlife, but migrants particularly of wildebeests, which help to maintain the grassland vegetation and also spill onto them during the dry season. Wildlife and indigenous people co-existed for many years, usually with limited conflict; but in recent years, the conflict has intensified,

mainly due to increasing human population, changing land use patterns, and altered perceptions of wildlife. Land surrounding the reserve can be divided into two distinct topographic and agro-climatic regions. Land in Trans Mara have high land use potential, high human and livestock population densities, and more development of agriculture. Land in Narok is more arid, have lower human population density and little agriculture, but have high wildlife and livestock population densities.

There have been significant widespread and rapid land-use changes with highly intensive mechanized farming of selected commercial mono-crops such as maize and wheat varieties grown with heavy external inorganic fertilizer inputs around MMNR. Other land changes include the expansion of settlements of small holders, including an increase in the number of Maasai bomas and their associated modifications in vegetation cover, and small-scale subsistence mixed cropping farming, comprising of maize and beans as well as intensive agriculture.

Soil fertility in the agricultural farms in the study area is

maintained mainly by use of inorganic fertilization. Maize mono-cropping was characterized by high inorganic fertilization (annual average of estimates of 30 kg N and P/ha) combined with little farmyard manure as well as pesticides applications. Small-scale maize-bean intercrop was characterized with very low or no inputs inorganic and farmyard manure and pesticide application. The vast majority (95%) of the indigenous Maasai households in the Maasai Mara study sites who are mainly pastoralist derived over two thirds of their income from livestock and very few cultivate their own fields and are not conversant with appropriate crop farming practices. Currently, farmyard manure among small-scale farmers in MME is only applied to fields close to the manyatta (house) or cattle boma (cow kraal). This could be due to unavailability of transport infrastructure and absence of appropriate extension and education on the importance of using manure rather than inorganic fertilizers. The use of green manures, cattle manure, farmyard manure, crop residues and composts manure on farm to enhance crop production is however increasingly gaining importance. Small-scale Maasai subsistence farmers slash and burn with very minimal tillage (with jembes, pangas and hoes) prior to planting while commercial farms clear weeds prior to planting with herbicides and mechanized tillage.

Rainfall in the area is generally influenced by the Inter-tropical convergence zone, but local variations in topography together with orographic and diurnal effects play a major role in rainfall patterns in the study area (Norton-GriYths et al., 1975). The main rain shadow areas encompass the dry south-eastern region, with a mean normal rainfall of approximately 400 mm. There is an overall rainfall gradient from the dry south-eastern plains (500 to 800 mm) to the wet north-west (1200 to 1600 mm) (Sinclair 1995; Hijmans et al., 2005). The rainfall pattern is weakly bimodal, with the 'short rains' occurring within November and December, followed by the main rains from March to May. The main dry season runs from mid-June to mid-October, with sometimes a lesser dry period between January to February. Often, the short and long rains are merged into one season, or the short rains fail completely (Norton-Griyths et al., 1975).

Study design

A one year study was carried between November 2009 and October, 2010. Sampling of soil macro-fauna was carried out in November, 2009 (short rainy season), April 2010 (wet long rainy season) and September 2010 (dry season) to coincide with the three contrasting seasons in our study system. Soil for macro-fauna study was collected from four main land use types (i) indigenous woodland, (ii) natural grasslands (iii) maize mono cropland and (iv) mixed maize-bean intercropland that represent the management and use of a large percentage (> 85%) of the land area in the region. For each land use, plots of 10 × 5 km were selected inside the park (protected) and outside the park (unprotected) and in agricultural farms. Selected plots were marked using a GPS (Figure 1). Two natural grassland and two indigenous woodland plots were located in protected area (inside the reserve) while two natural grassland and two indigenous woodland plots were located outside protected area (outside the reserve), one each, in both dry and wet region of MME.

Similarly, two maize mono-cropping plots and two maize-bean intercrop plots were selected one each in both dry and wet region of MME (Figure 1). Data was collected along three 1 km long transect in each of the study plots. The three transects were laid out at least 1 km away from each other and 500 m away from the road. In each plot, macro-fauna communities were sampled by excavating five soil monoliths 30 cm deep, and 25 × 25 cm large, placed at random within a circular area of 10 m radius at every 250 m interval along the transect (total 15 monoliths per sampling plot). A total of 540 monoliths cutting across the four different land use systems (four

main land use types) were excavated during the entire study area. Rocky areas were avoided as sampling points. In most cases, soils were not compact, hence, field sorting of soil to extract macro-fauna was very efficient. Any hard compacted soil and cohesive soil cores were carefully broken down into tiny soil particles and the various groups representing the soil macro-fauna hand-sorted.

Collection and identification of macro-fauna

Each sample was taken to the sampling base and hand sorted, removing all the macro-fauna > 2 mm in diameter that were visible to the naked eye (Lavelle et al., 2003). Roots did not affect the volume of soil sorted. The amount of soil moisture did not affect the efficiency of sorting and counting. The sorted macro-fauna were collected, counted and killed in 70% alcohol. Earthworms were first fixed in 70% ethanol before being preserved in 4% formaldehyde. Other macro-fauna were preserved in 70% alcohol. All the macro-fauna were stored in sealed vials before being transported to the NMK's Department of Zoology, Invertebrate Zoology collection laboratory, Nairobi, Kenya, for identification. The soil macro-fauna were identified using appropriate keys contained in Arnett (1993), Barnes et al. (1993), Chu and Cutkomp (1992), Dindal (1990) and Stehr (1991) and reference specimens in the zoological collection of NMK.

The macro-fauna collected were then separated into higher taxa (Family and Order level), and wherever possible, to generic and species level and counted. Fourteen faunal (orders) community variables were described, that is, numbers of Blattaria, Coleoptera, Collembola, Diptera, Geophilomorpha, Hymenoptera, Isoptera, Polydesmida, Spirostreptida, Lepidoptera, Dermptera, Haplotoxida, and the two unidentified morphospecies of the class Chilopoda and Diplopoda were recognized. Colonial macro-fauna occurring in very high numbers, such as ants and termites, were assessed using a 100 mm³ test tube sub-sample and count data for the monolith extrapolated.

Statistical data analysis

The macro-fauna data set was based on the average faunal data for each plot. Five variables were derived from the data collected: (1) the number of taxa per sample, (2) Density (numbers per square meter) of each taxon, (3) density of all macro-fauna, (4) Shannon H index and (5) Evenness index. Levene's test was used to test for homogeneity of variances. All count data were log (N+1) transformed to more closely fit the normal distribution (Sokal and Rohlf, 1995). We had 12 sampling plots with 14 faunal variables. Data collected in November was pooled with data collected in September and treated as dry season. The design therefore included four main fixed factors: 1) "land use" (with 4 levels; i. indigenous woodland, ii. natural grasslands, iii. maize mono cropland and iv. mixed maize-bean intercropland), 2) "protection" (with 2 levels; inside vs. outside the reserve), 3) "season" (with two levels; wet vs. dry), and 4) "region" wet side vs. dry side. This gave us 4 × 2 × 2 × 2 levels = 32 combinations. To be able to say anything about the effects from land use, protection, season and region, and to test for respective influence of all sources of variation, our statistical analysis included all the four factors in our sampling design, and their respective interaction terms (e.g. Protection*Land use, Region*Protection*Land use, etc.).

We therefore analyzed the data using a general linear model. We performed all statistical analysis using the STATISTICA software (StatSoftInc, 2010) unless stated otherwise. Significant levels for statistical tests were set at P < 0.05. Means are presented ± SD. Whenever appropriate, post hoc analysis of the dataset was tested using t-tests and ANOVA. Redundancy Analysis (RDA) was used to investigate the correlative relationships of different land use

Table 1. Selected soil properties for the different land use systems of Embu. Means with the same letters are not significantly different.

Soil properties			pH	N (%)	C (%)	P (ppm)
	IN	Grassland	6.01bc	0.10c	0.71cd	37.33b
		Woodland	6.30ab	0.12c	0.92bc	37.00b
Dry	Out	Grassland	6.42ab	0.13bc	0.84bc	54.33b
		Woodland	6.03bc	0.12c	0.82bc	33.67b
	Agric	Maize	6.05bc	0.11c	0.68d	128.67a
		M/B-S	6.77a	0.25a	1.31a	67.00b
		SED	0.19	0.02	0.11	26.95
		P	0.05	0.03	0.05	0.01
	IN	Grassland	5.76bc	0.17bc	1.26b	74.00a
		Woodland	6.15ab	0.24a	1.57a	48.00abc
Wet	Out	Grassland	6.26a	0.13c	0.83c	46.33bc
		Woodland	6.09ab	0.23a	1.38a	63.67ab
		Maize	5.51c	0.18abc	1.13b	25.00c
	Agric	M/B-S	6.03ab	0.23a	1.32b	53.33ab
		SED	0.22	0.03	0.11	13.17
		p	0.03	0.04	0.02	0.03

systems on macro-fauna communities using Canoco 4.5 program. The macro-fauna datasets, without data transformation, were also submitted to a principal component analysis (PCA) multivariate analysis to explore and separate various faunal variations with land use systems. The PCA was performed on a matrix composed of 24 lines (sampled systems) and 14 columns (for the Order/morphospecies richness and density attributes of macro-fauna communities). The analysis was done with density and morphospecies richness data of the different management land use systems. Analyses of diversity are presented at the ordinal level based on field identification. We calculated community indices including diversity, species richness and evenness in order to identify patterns of community assemblage within each land-use type using Ecological Methodology Program (2nd edition). To calculate Shannon's diversity index (H') we used the formula: $H' = -\sum_{i=1}^s p_i \ln p_i$. Where s is the total number of taxa collected, and p_i is the proportion of individuals that are taxon relative to all individuals from all taxa collected (4). Evenness (J') was calculated as: $J' = H' / \ln s$. To test effect of land use on diversity indices, three-way ANOVA was performed and significant differences tested by Fisher's LSD (Least Significant Difference)

RESULTS

Soil characteristic in MME

Soil chemical characteristics did not differ within site but there were some significant differences in soil properties between sites and land use systems (Table 1). Generally, the soil pH was more less neutral in natural ecosystems (ranged from 5.76 to 6.42) in both grassland and woodland. Disturbed grassland in wet region tended to

have lower pH though not different from protected grassland and woodland. Generally, agricultural systems, in particular maize-mono-cropping recorded lower soil pH in the two regions (5.19 vs. 6.05) compared to natural ecosystems. However, soil pH was similar to that of natural ecosystem in maize-bean intercropping in the two regions (6.03 vs. 6.77). Total N was higher in woodland and maize-bean intercropping in wet region, but in dry region total N was higher in maize-bean intercropping. Levels of carbon were generally lower in maize mono-cropping in dry region, but did not seem to differ in the wet region across the different land uses systems. High available P levels were observed in maize-mono-cropping in the drier side of MME, but lowers levels of available P were observed in maize mono-cropping in the wet region.

Macro-fauna communities within MME

A total of 3,658 individuals were collected across the four different land use systems in MME over the course of the study. Table 2 shows the various groups of macro-fauna and how they were distributed across the two regions in MME. The individuals mainly belonged to Phylum Arthropoda and Annelida, mainly represented by Haplotaxida – the Earthworms). The arthropods were distributed across 3 classes (Insecta, Diplopoda and Chilopoda) and 13 orders namely; Coleoptera (Beetles), Blattaria (Cockroaches), Dermaptera (Earwigs), Diptera

Table 2. Major soil macro-fauna taxa recorded in the two regions (dry and wet) of Maasai Mara Ecosystems.

Class	Order	Family	Genus/spp.	Number of species	Number of macro-fauna in m ²			
					Dry region	Wet region		
Chilopoda	Geophilomorpha	Geophilidae	<i>Geophilidae A-F</i>	6	78.22	16.00		
			<i>Chilopoda A</i>	1	0.00	1.78		
Collembolla			<i>Collembolla A</i>	1	0.00	1.78		
Diplopoda	Polydesmida	Gomphodesmidae	<i>Gomphodesmidae A-C</i>	3	39.11	32.00		
	Spirostreptida	Odontopygidae	<i>Odontopygidae A-C</i>	3	12.44	10.67		
			<i>Diplopoda A-B</i>	2	3.56	12.44		
Insecta	Blattaria	Blattidae	<i>Blattidae A</i>	1	1.78	3.56		
	Coleoptera	Brentidae	<i>Brentidae A</i>	1	1.78	0.00		
		Buprestidae	<i>Buprestidae A-B</i>	2	5.33	0.00		
		Cantharidae	<i>Cantharidae A</i>	1	1.78	0.00		
		Carabidae	<i>Carabidae A-C</i>	3	24.89	10.67		
		Cerambycidae	<i>Cerambycidae A-D</i>	4	8.89	5.33		
		Chrysomelidae	<i>Chrysomelidae A-B</i>	2	8.89	1.78		
		Curculionidae	<i>Curculionidae A-C</i>	3	46.22	21.33		
		Elateridae	<i>Elateridae A-B</i>	2	24.89	8.89		
		Histeridae	<i>Histeridae A</i>	1	0.00	1.78		
		Scarabaeidae	<i>Coprisevanidus</i>	1	0.00	1.78		
			<i>Empecamta sp.1</i>	1	8.89	0.00		
			<i>Onthophagus sp.1</i>	1	5.33	10.67		
			<i>Scarabaeidae. A-M</i>	13	298.78	146.89		
			Staphylinidae	<i>PaederusPaederus</i>	1	0.00	1.78	
				<i>Staphylinidae A-C</i>	3	8.89	28.44	
			Tenebrionidae	<i>Tenebrionidae A-J</i>	10	26.67	17.78	
				<i>Coleoptera. A-D</i>	4	8.89	19.56	
			Dermaptera	<i>Dermaptera A</i>	1	5.33	0.00	
		Diptera	<i>Diptera. A</i>	6	5.33	3.56		
	Hymenoptera	Formicidae	<i>Crematogaster spp1</i>	1	5.33	128.00		
			<i>Dorylus sp.1</i>	1	117.33	64.00		
			<i>Monomorium sp.1</i>	1	1737.78	0.00		
			<i>Odontomachus sp.1</i>	1	1.78	3.56		
			<i>Pachycondyla sp.1</i>	1	10.67	8.89		
			<i>Polyrhachis sp.1</i>	1	1.78	0.00		
			<i>Tetramorium sp.1</i>	1	9172.44	7131.56		
			<i>Tetramorium sp.2</i>	1	0.00	19.56		
			<i>Tetramorium sp.3</i>	1	0.00	5.33		
			<i>Formicidae A-T</i>	20	152.89	312.89		
			<i>Hymenoptera. A</i>	1	0.00	3.56		
			Isoptera	Termitidae	<i>Macrotermes sp.1</i>	1	0.00	1.78
					<i>Microcerotermes sp.1</i>	1	384.00	46.22
					<i>Microtermes sp.1</i>	1	1000.00	0.00
		<i>Odontotermes sp.1</i>	1		106.67	3826.67		
		<i>Pseudocanthotermes sp.1</i>	1		1.78	1.78		
		<i>Soldierless sp.1</i>	1		3828.44	58.67		
		<i>Soldierless sp.2</i>	1		350.22	2728.89		
		<i>Termitidae. A-H</i>	8		1132.44	1090.67		
		<i>Isoptera A</i>	1		0.00	3.56		
	Lepidoptera	Noctuidae	<i>Noctuidae. A</i>		1	1.78	0.00	
Oligochaeta	Haplotaxida		<i>Haplotaxida A-D</i>	4	186.67	430.44		

(Flies), Geophilomorpha (Soil Centipedes), Hymenoptera (Ants), Isoptera (Termites), Lepidoptera (Butterflies and Moths), Polydesmida (Millipedes), Spirosterptida (Millipedes), Collembola (Spring tails) and two orders not identified from class Chilopoda and class Diplopoda (Table 2). Class Insecta was most abundant with 97.5% of arthropod density followed by class Oligochaeta / Clitellata (1.83%), while the others had less than 1%. Order Hymenoptera was the most abundant with 53.16% of the total number of individuals observed, followed by Isoptera (42.27%). The macro-fauna densities in the other orders decreased in the order: Hymenoptera > Isoptera > Coleoptera > Haplotaxida > Geophilomorpha > Polydesmida > Spirosterptida > Diptera > Blattaria. Most of the macro-fauna species could not be identified to species level (due to lack of taxonomic keys). However, those individuals which were morphologically clearly different from the each other in each order/family/genus were maintained as separate morphotypes and were considered to be different species. In total, 128 species which were morphologically different were recorded, and number of species representations in the observed Orders decreased in the order: Coleoptera > Hymenoptera > Isoptera > Diptera > Geophilomorpha > Polydesmida/Haplotaxida > Spirosterptida.

Effect of land use, region, season, protection status

The interaction between land uses, seasons, region and protection status in determining macro-fauna abundance in MME was shown statistically using general linear modeling (GLM). General linear model using four main fixed factors: 1) "land use" with 4 levels; i indigenous woodland, ii natural grasslands iii maize monocropland and iv maize-bean mixed cropland; 2) "protection" with 2 levels; inside vs. outside the reserve; 3) "season" with two levels; i wet long rain, ii dry, and 4) "Region" with two levels; i dry side and ii wet side, revealed significant effects of land use on macro-fauna abundance and diversity in all cases (GLM: $F = 2.968$, $df = 14$, $P < 0.001$), and a significant interaction between Season*Region*Land use ($F = 2.361$, $df = 14$, $P < 0.009$), Region*Land use ($F = 1.841$, $df = 14$, $P < 0.049$) and Region*Protection*Land use ($F = 2.148$, $df = 14$, $P < 0.019$). This model particularly explained significantly the abundance of Hymenoptera, Haplotaxida, Diptera, and un-identified Chilopoda and Diplopoda. Land use was indeed more important in explaining abundance of these macro-fauna in MME. Protection status, season and region did not affect macro-fauna community significantly on their own in this model ($P > 0.05$ in all cases). However, when protection status was removed from the model, GLM on the remaining three factors revealed significant effects of land use, season, region, and an interaction effect of region and land use as shown in the following sequential model (GLM, Land use: $F = 3.339$, df

= 42, $P < 0.0001$, Season ($F = 2.034$, $df = 14$, $P < 0.025$), Region ($F = 2.094$, $df = 14$, $P < 0.021$), and Region*Land use ($F = 1.530$, $df = 42$, $P < 0.026$). This model particularly elucidated significantly, the abundance of Coleoptera, Hymenoptera, Haplotaxida, Isoptera, and un-identified Diplopoda. Again, the importance of land use in explaining macro-fauna abundance in our study systems is clear cut. Table 3 and Figure 2 show results of post-hoc testing of statistically significant relationships between the land use and region variables.

Seasonal effects on Macro-fauna communities

Seasonal variation was observed in macro-fauna density and species richness as well as densities of individuals from Order Diplopoda, Spirosterptida and Diptera ($p < 0.05$ in all cases). Higher density and species numbers were observed in dry than in wet season, 7178.21 vs. 887.62 individuals (m^2); 9.78 vs. 4.93 species; $P < 0.05$ in all cases). Similarly, higher densities of order Spirosterptida were observed in dry than in wet season (4.57 ± 3.36 vs. 0.76 ± 1.07) while individuals from order Diptera were higher in dry than in wet season (1.90 ± 1.63 vs. 0.38 ± 0.77). Individuals from order Lepidoptera, Blattaria, Collembola, and Dermaptera were only observed during the dry seasons while individuals from un-identified Chilopoda and Diplopoda were observed only in the wet season.

Regional effect on Macro-fauna communities and diversity

The overall macro-fauna total densities were not different across the two region of MME (t-test, $df = 2$, $p > 0.05$, data not shown), but individuals from Order Coleoptera were higher in dry region than in the wet region (91.43 ± 49.35 vs. 31.24 ± 15.53 individuals m^{-2} $p < 0.02$). Individuals from order Haplotaxida were on the other hand significantly higher in wet region than in the dry region (t-test; 8.00 ± 24.15 vs. 15.24 ± 14.32 , $p < 0.001$). Table 4 shows how species diversity index, evenness index and species richness varied across different land use systems and regions in MME. Shannon H index was also significantly higher in wet region than in dry region ($p = 0.03$), but species richness and evenness index were not different in the two region ($P > 0.05$) (Table 4).

Effect of land use on Macro-fauna density, species richness and diversity

Macro-fauna total density was significantly affected by different land use systems across MME. The abundance of macro-fauna differed significantly between the four woodland types (ANOVA: $F = 3.29636$, $df = 42$,

Table 3. Density (number of individuals' log (N+1)/m²) of the various invertebrate groups across different land use systems in dry and wet regions of Maasai Mara region. Macro-fauna mean densities between the different land use categories during the study period. Land use comprised of grassland, woodland, maize mono-cropping (MMonocrop), maize-bean intercropping systems (M-BMixed).

Groups	Grassland	Woodland	t-value	df	P
Earthworm	1.29 (0.98)a	0.80 (0.86)b	2.28	70.00	0.03
Termites	1.30 (1.40)b	1.97 (1.43)a	-1.99	70.00	0.05
Millipedes	0.14 (0.47)b	0.49 (0.72)a	-2.48	70.00	0.02
	Grassland	MMonocrop	t-value	df	P
Beetles	1.45 (0.88)a	0.65 (0.76)b	3.31	52.00	0.00
Ants	1.68 (1.25)a	0.00 (0.00)b	5.65	52.00	0.00
Termites	1.30 (1.40)a	0.33 (0.77)b	2.75	52.00	0.01
	Grassland	M-BMixed	t-value	df	P
Beetles	1.45 (0.88)a	0.61 (0.80)b	3.43	52.00	0.00
Earthworm	1.29 (0.98)a	0.54 (0.71)b	2.92	52.00	0.01
Ants	1.68 (1.25)a	0.62 (0.92)b	3.17	52.00	0.00
	Woodland	M-BMixed	t-value	df	P
Beetles	1.31 (1.00)a	0.61 (0.80)b	2.58	52.00	0.01
Ants	2.06 (1.18)a	0.62 (0.92)b	4.54	52.00	0.00
Termites	1.97 (1.43)a	0.61 (1.13)b	3.51	52.00	0.00
	Woodland	MMonocrop	t-value	df	P
Beetles	1.31 (1.00)a	0.65 (0.76)b	2.46	52.00	0.02
Ants	2.06 (1.18)a	0.00 (0.00)b	7.39	52.00	0.00
Termites	1.97 (1.43)a	0.33 (0.77)b	4.53	52.00	0.00
	M-BMixed	MMonocrop	t-value	df	P
Millipedes	0.14 (0.40)a	0.00 (0.00)a	1.46	34.00	0.15
Centipedes	0.39 (0.66)a	0.00 (0.00)b	2.51	34.00	0.02
Earthworm	0.54 (0.71)b	1.24 (0.89)a	-2.62	34.00	0.01
Ants	0.62 (0.92)a	0.00 (0.00)b	2.85	34.00	0.01

Within row, means followed by the same letters are not statistically significantly different at $p < 0.05$. Values in parentheses are standard deviation (SD).

$P < 0.0001$). Overall macro-fauna abundance was lowest in agriculture land (maize mono-cropland and mixed maize-bean cropland), intermediate in grassland and highest in woodland (Figure 2). Agriculture significantly affected the composition of Macro-fauna community (RDA, $F = 25.17$, $p = 0.005$) and explained 39% of total variation in data set (Figure 3). Agriculture significantly declined the density of individual belonging to Order Coleoptera by 87.9%, Hymenoptera by 70.5% and Isoptera by 82.9% (Figure 4). Four orders (Blattaria, Dermaptera, Collembola, and un-identified Chilopoda) observed in grassland and woodland was not found in cultivated soils. Among the land uses systems, woodland (RDA, $F = 7.53$, $p = 0.005$) and grassland (RDA, $F = 16.01$, $p = 0.004$) affected macro-fauna community and explained 16 and 24% of total variation in data set,

respectively (Figure 3).

High densities of individuals from Order Coleoptera, Hymenoptera and Isoptera were observed in woodland and grassland compared to extremely low densities in mono-cropping and intercropping systems (Figure 4). Human disturbances outside the reserve declined macro-fauna density and species richness in grassland and woodland by 65.07 and 39.74% in the dry region, and increased macro-fauna density and species richness in grassland and woodland by 107 and 340% ($p < 0.05$ in all cases). Extremely low macro-fauna density and species richness were observed in cultivated soil, with both mono-cropping (maize) and inter-cropping (maize-bean intercrop) systems resulting into > 10 times lower densities than natural grassland and woodland in both dry and wet region, $P < 0.05$ in all cases (Figure 2 and

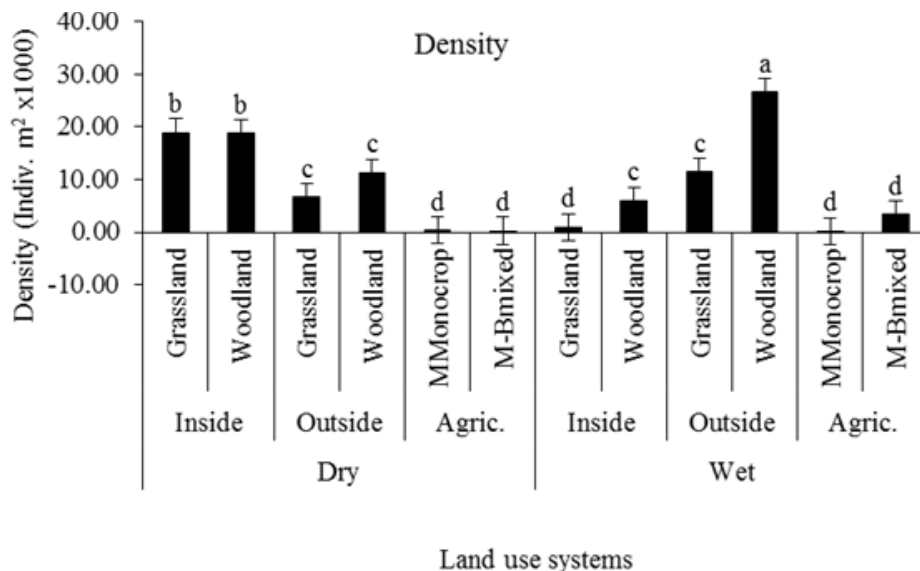


Figure 2. Macro-fauna density (individuals/m²) across different land use systems in dry and wet regions of Maasai Mara region. Land use comprised of grassland, woodland, maize monocropping (MMonocrop), maize-bean intercropping systems (M-BMixed). Inside = inside the park, Outside = outside the park. Errors bar is the standard error of the difference (SED).

Table 4. Indices of faunal diversity in different land-use systems in Maasai Mara Ecosystem. Species richness (number of species), Shannon’s index ($H = -\sum p_i \log p_i$, $P_i = n_i/N$, n_i = number of individuals for each order, N = number of total individuals). Evenness ($e = H/\log S$, H = Shannon’s index, S = number of order). Protection included natural ecosystem inside and outside the park and agricultural land. Land use comprised of grassland, woodland, maize mono-cropping (MMonocrop), maize-bean intercropping systems (M-BMixed).

		Species richness	Shannon H	Evenness (e ^H /S)
Region	Dry	13.44 (1.05)	0.94 (0.21)b	0.39 (0.06)
	wet	14.39 (1.05)	1.56 (0.21)a	0.47 (0.06)
	<i>F</i>	0.50	5.43	0.74
	<i>p</i>	0.49	0.03	0.40
Protection	Agriculture	5.67 (1.29)	1.08 (0.26)	0.68 (0.08)
	Inside	17.33 (1.29)	1.50 (0.26)	0.36 (0.08)
	Outside	18.75 (1.29)	1.17 (0.26)	0.24 (0.08)
	<i>F-value</i>	0.61	0.83	1.35
	<i>p-value</i>	0.44	0.37	0.26
Land use	Grassland	15.67 (1.29)a	1.25 (0.26)	0.33 (0.08)
	Woodland	20.42 (1.29)a	1.42 (0.26)	0.27 (0.08)
	MMonocrop	5.00 (1.82)b	1.00 (0.37)	0.62 (0.11)
	M-BMixed	6.33 (1.82)b	1.17 (0.37)	0.74 (0.11)
	<i>F-value</i>	6.55	0.16	0.45
	<i>p-value</i>	0.02	0.86	0.64
ANOVA				
Region*Protection		p = 0.23	p = 0.19	p = 0.06
Region*land use		p = 0.24	p = 0.63	p = 0.30
Protection*land use		p = 0.35	p = 0.19	p = 0.59
Reg*Prote*Land use		p = 0.68	p = 0.47	p = 0.64

Within column, means followed by the same letters are not statistically significantly different at $p < 0.05$. Values in parentheses are standard of the mean (SE).

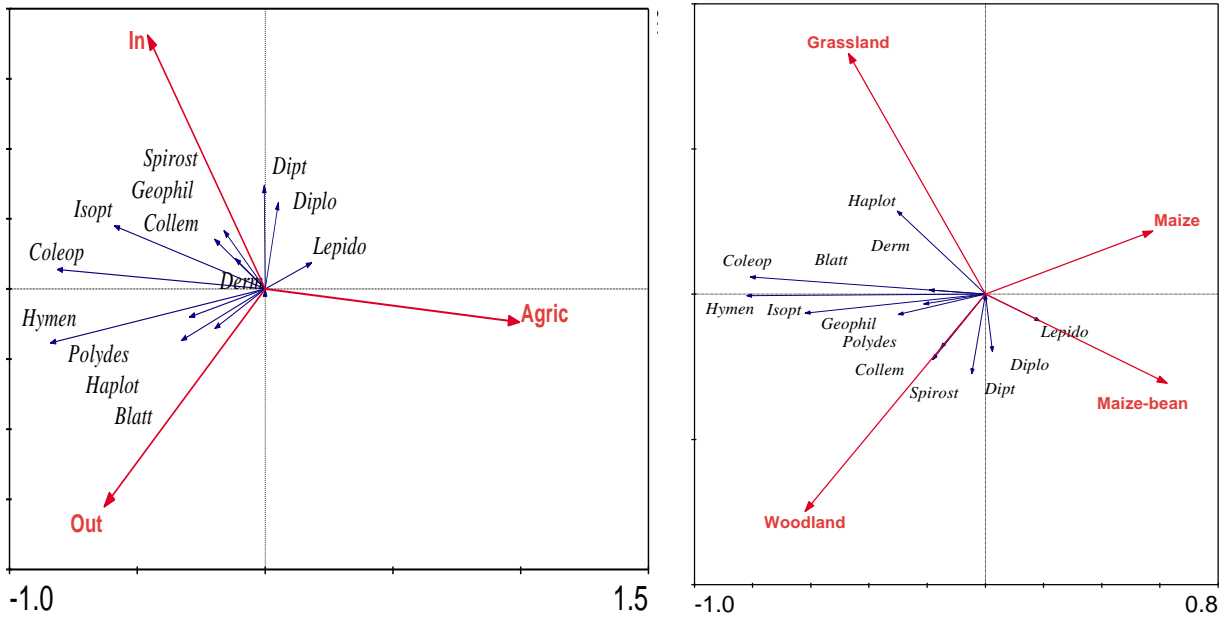


Figure 3. Redundancy analysis (RDA) bi-plot showing correlation of macro-fauna density and land use systems. Individuals are from Orders Hymenoptera (Hymen), Isoptera (Isopt), Coleoptera (Coleop), Haplotaaxida (Haplot), Geophilomorpha (Geophil), Polydesmida (Polydes), Spirosterptida (Spirost), Diptera (Dipt), Blattaria (Blatt) and classes Diplopoda (Diplo) and Collembola (Collem).

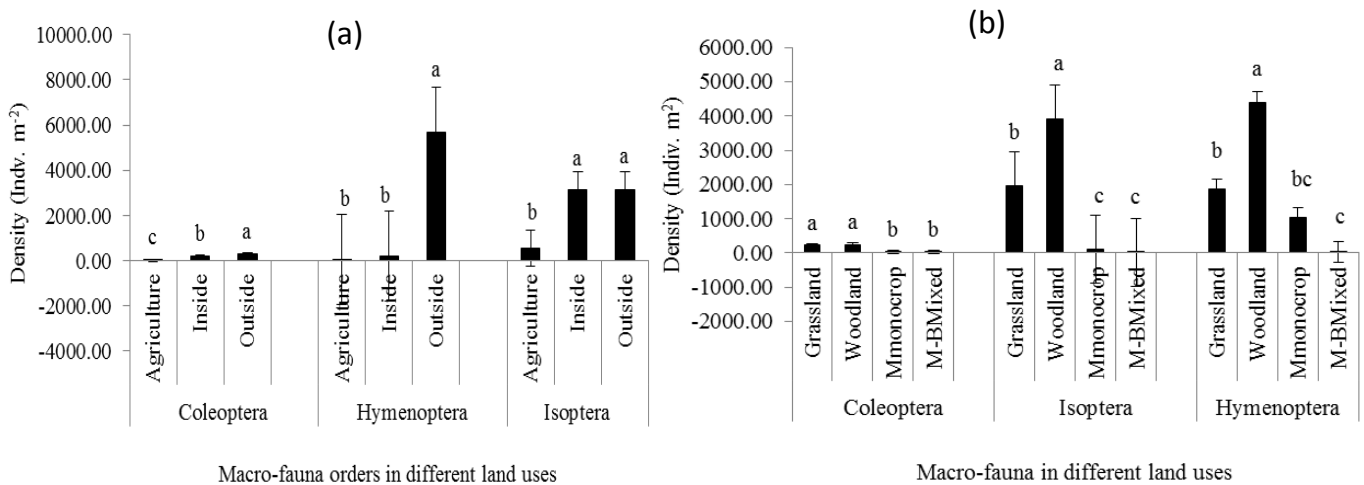


Figure 4. Effect of disturbance and Land use systems (grassland and woodland, Maize monocropping, small-scale maize-bean intercrop) on density of various groups of macro-fauna (Coleoptera, Hymenoptera and Isoptera) in Maasai Mara Ecosystems. Error bar is the standard error of the differences (SE). Bars followed by same letter per given Macro-fauna group are not statistically different at $p \leq 0.05$.

Table 4). Maize-bean intercropping systems did not support higher macro-fauna communities than monocropping systems. Earthworms were more dominant in grasslands (Figure 2). Macro-fauna communities in grassland systems were rather similar to the woodland. Species diversity (H index) was also lower in agricultural farms, though not statistically different ($p > 0.05$) (Table 4). Evenness index did not reveal any differences in the

different land use systems although tended to be higher in agricultural systems than natural systems ($p > 0.05$) (Table 4).

PCA on macro-fauna variables

Four factors explained 60% of the variance, F1 (21.7%),

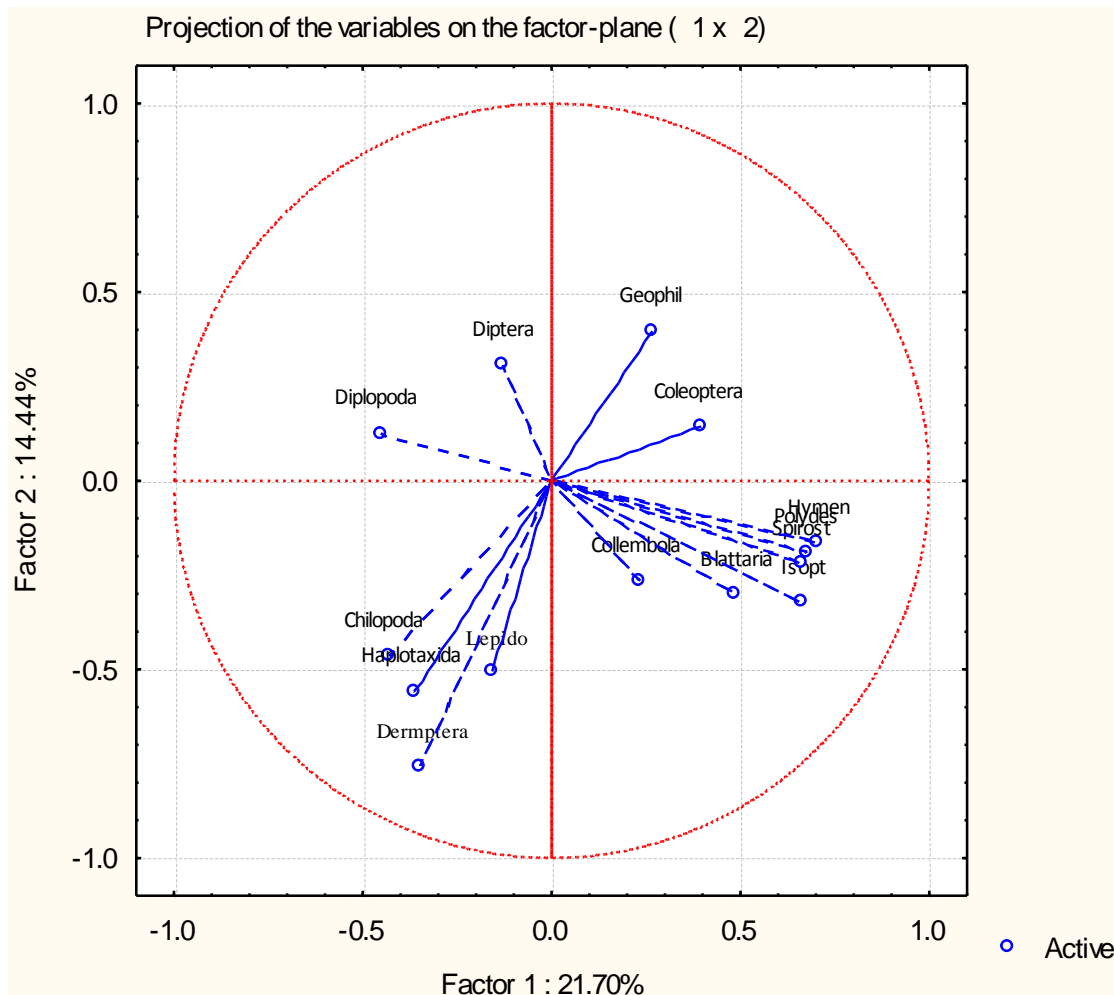


Figure 5. PCA analysis of macro-fauna abundance cross land use systems in Maasai Mara. The first two axis explained 36.14% of the total variance- axis1 (21.7%) and axis2 (14.44%). Axis1 distinguished communities with soil litter fauna dominance represented by Coleoptera, Diplopoda, Hymenoptera, Spirosy, (and other litter-dwelling macro-fauna) from those with a moderate density of these groups (haplotaxida, chilopoda). Axis2 separated the systems characterized by Haplotaaxida, Diptera and similar from those with greater abundance of Isoptera.

F2 (14.4), F3 (12.4) and F4 (11.4). Factor 1 distinguished communities dominated by earthworms and isopteran from those dominated by Coleoptera. It separated the systems with a high total density of fauna, large populations of ants and other litter-dwelling soil macro-fauna, and a high richness from the systems with a high abundance of earthworms, Homoptera and Gastropoda (Figure 5). According to the PCA analysis of macro-fauna density, the first two axis explained 36.14% of the total variance, axis1 (21.7%) and axis2 (14.44%) (Figure 5). Axis1 distinguished communities with soil litter fauna dominance represented by Coleoptera, Diplopoda, Hymenoptera, Spirosy, (and other litter-dwelling macro-fauna) from those with a moderate density of these groups (Haplotaaxida, Chilopoda). Axis2 separated the systems characterized by Haplotaaxida, Diptera and similar from those with greater abundance of Isoptera.

DISCUSSION

Macro-fauna community in MME

The macro-fauna densities recorded in this study is within the range of what has been observed in different habitats in Savannah region and some of the moist tropical habitats (Dangerfield, 1997; Leakey and Proctor, 1987; Ayuke et al., 2009) and Mediterranean arid ecosystems (Doblas-Miranda et al., 2007). Individuals belonging to order Hymenoptera and Isoptera dominated these regions with high localized populations being observed. Our results are in accordance with previous studies which have documented the dominances of ants, termites (especially fungus growing termites) and beetles larvae in Savannah regions (Dangerfield, 1997). Recent studies in other parts in Kenya have also documented high

densities of Hymenoptera and Isoptera (Ayuke et al., 2009).

Individuals from order coleopteran were third largest represented group in MME, and had the highest species representation. Several studies have reported large number of species of beetles especially scarab beetles and their larvae (white grubs) in native forests and grasslands as well as in agricultural land (Brown et al., 2001). Earthworms (order Haploxitada) were fourth largest group in MME, and their occurrences were low compared to what have been reported in moist climate (Ayuke et al., 2009).

This is probably because of prevalence of dry conditions in MME, whereas earthworm prefers moist conditions. Millipedes, dung beetles, termites, and roaches, like earthworms, are shredders, and springtails are grazers. They speed decomposition of organic matter, distribute nutrients through the soil, aid in dispersal of arbuscular mycorrhiza spores and enhance soil aggregation. Ants, centipedes and ground beetles, on the other hand, are predators. Their role, while important, is secondary to that of the shredders and grazers.

Seasonal effects

A pronounced seasonality effect on macro-fauna communities was observed in this study. Effect of seasonality on soil macro-fauna has been widely reported, with wet seasons recording high densities and species than dry seasons (Cepeda and Whitford, 1989; Reddy and Venkataiah, 1990). However, contrary to our expectations most individuals were observed during the dry season than in the wet season. We attribute this to effect of climate change which caused unexpected heavy rainfall during the dry season, and unexpected dry spells during the wet season. Effect of heat during dry seasons causes vertical migrations of some groups to the deeper layers in search of moisture (Hassall et al., 1986), changes in micro-climate especially temperatures and moistures, behavioral responses and feeding activities (Dangerfield, 1997).

Some organisms such as earthworm can only tolerate a certain range of temperature and dryness (Martinson et al., 2008), explaining the wide occurrences of such organism in wetter season than in the drier season. Increased soil moisture during the rainy periods also increases availability of organic matter through litter decomposition and greater root biomass (Pauli et al., 2011). Indeed, we found more earthworms in monoculture maize plantations that were regularly irrigated. Order Hymenoptera and Isoptera were more abundant in the beginning of dry (September, 2010) season. This is in line with other studies which have reported increased densities in the dry season (Pauli et al., 2011; Brown et al., 2004), probably due to their low preferences of wet litter habitat conditions (Brühl et al., 1999).

Land use effects

Our study shows that soil macro-fauna were sensitive to land use and management. Woodland systems had higher abundance and diversity than any other type of land use. Our results are in support of other studies that have shown that land use can exert a strong influence on the overall abundance, diversity and community composition of soil macro-fauna (Barrios et al., 2005) as well as soil physical, chemical and biological properties and processes (Six et al., 2004; Barrios, 2007).

Human related disturbances in natural ecosystems did not have pronounced effect in total species richness and composition of macro-fauna communities, but declined the density in dry region and increased it in the wet region. Lack of strong effects of human disturbances in species richness, composition and density (wet region) is in line with various studies which have shown minimal effect of human disturbance on individual macro-fauna taxa (Eggleton et al., 1996; Okwakol, 2000), especially when moisture is not limited. Less extreme disturbances associated with foraging and hunting by local people, selective logging and grazing may produce smaller effects on species numbers and composition. Some macro-fauna species especially individuals from Order Hymenoptera and Isoptera have ability to build nest below ground which shelter them from effect of environmental changes (Okwakol, 2000) and can survive for a number of years after disturbance (Eggleton et al., 1996, 1997). Native earthworms have been shown to be favoured by the presence of cattle (Decaëns et al., 2004). Our result suggest that disturbance levels in unprotected grassland and woodland especially in wet region MME are still moderate and may not have reached noticeable changes in levels of Macro-fauna. However, there may be turnover of species with a tendency for some wood-feeding forms to replace soil-feeders. Further studies along disturbance gradients comparing light and heavily disturbed areas and targeting individuals Orders/Genus may be helpful to further understand effect of human disturbance.

Decline of macro-fauna densities in dry region following disturbances shows aggravated effect of human disturbances in regions with extreme variations of temperature and low water availability. Human disturbances open gaps in natural ecosystems which in return increases soil surface temperature. In absence of inadequate moisture, decomposition of organic material is minimal, grass and other plants dry up and this may cause low food resources and food quality. Infact, low ground cover by vegetation was reported in disturbed grassland and woodland in dry areas of MME, suggesting declining food resources and food quality. Food resources are important factors determining the distribution of macro-fauna in semi-arid areas, and are associated with observed population dynamics. Our results demonstrate that human disturbances are an important factor influencing macro-fauna community under extreme climatic

condition. Alternative conservation measures and management practices that may minimize the level of human disturbances (reduced overgrazing) outside the protected core of MME are desirable in this area to counter diversity decline.

Extremely low densities and species numbers were observed in cultivated soil. Similarly, agriculture negatively altered macro-fauna communities by declining individual belonging to Order Coleoptera, Hymenoptera and Isoptera by > 50% and eliminating some Orders, Genus and/or Species. Mixed cropping systems representing less intensified systems did not seem to either increase macro-fauna density or species number. Agriculture has previously been shown to negatively affect macro-fauna communities (Lavelle et al., 1992; Roper and Gupta, 1995; Brown et al., 1996; Ayuke et al., 2009; Ayuke et al., 2011a, b). This loss of biodiversity can result in reduction in ecosystem services such as pest control, nutrient cycling and maintenance of soil structure. These changes are associated with destruction of nesting habitats, modification of soil micro-climate within cultivated soils, removal of substrate, low diversity and availability of food as well as physical destructions of macro-fauna individuals with management practices such as use of agrochemicals (Roper and Gupta, 1995; Swift et al., 1996). In addition, annual cropping systems decrease the diversity and abundance of soil fauna communities due to soil disturbance and the absence of a permanent soil cover (Barros, 2002).

Disappearance of some species following agricultural activities could be attributed to lack of recovery of population after disturbances. Our result supports previous studies showing agriculture as main threat to soil macro-fauna communities in MME. The relatively low abundance of soil macro-fauna noted within the agricultural land may result from the use of certain agricultural pesticides and chemical inputs suggesting that technological intensification may result in complex natural soil macro-fauna communities being replaced by less diverse systems with frequent disturbances (New 2005). The long-term consequences of this are reduced soil function which in return reduces agricultural productivity. Modifications of macro-fauna communities are known to have potential negative effects on soil functioning and on the sustainability of ecosystems (Decaëns et al., 2004). More detailed studies are needed in this area to identify the other best cropping systems that can sustain sufficiently abundant and diverse communities to optimize the effects of these beneficial organisms.

Conclusions

This study has demonstrated that Savannah ecosystems such as MME is endowed with high diversity of macro-fauna which vary across different land use systems, depending on the level of human disturbances. The study

highlights the important effects of agriculture on macro-fauna communities, and the potential risks of soil quality that threaten cultivated soil in Savannah ecosystems. Identification of sustainable cropping systems that maintain acceptable levels of macro-fauna densities and diversity to optimize soil macro-faunal activities and their impacts on soil fertility are needed in this region. Cropping systems that mimic original natural ecosystem (such as agro-forestry systems) should be given most priority since the current cropping systems, particularly plantation mono-cropping are threat to macro-fauna community. Such land use systems would have a favorable effect on the development of an abundant and diverse soil and macro-fauna, which in turn may assist in the conservation of soil fertility and productivity. Research on how such systems can be improved to reach ecological plasticity of soil macro-fauna is urgently needed. In addition, this study supports conservation of biodiversity beyond protected areas (PAs) and the emerging paradigm of eco-agriculture that focus on the potential of PAs to contain agricultural areas, and the potential of agriculturally-dominated landscapes to include biodiversity conservation. More detailed studies are also needed to identify the best possible combination of land use and agro-diversity (the varying management practices in different land) to allow optimal macro-fauna sustainability.

ACKNOWLEDGEMENTS

This study was supported by Association for strengthening Agricultural Research in Eastern and Central Africa (ASARECA). We thank our colleagues, especially Lukelysia Nyawira and Emma Kibiro of the National Museums of Kenya who assisted in macro-fauna collection and identification.

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