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The Giant Mole Rat, *Tachyoryctes macrocephalus* (Rüppell, 1942) As Ecosystem Engineer, in Sanetti plateau of Bale Mountains National Park, South Ethiopia.



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ABBREVIATION USED

BMNP - Bale Mountains National Park

GMR - Giant Mole Rat

Mm -Mima mound

GI - Grazing Intensity

BD - soil Bulk Density

PD - Soil Particle density

ABSTRACT: Studies on Giant Mole Rats as ecosystem engineers were carried out on Sanetti plateau, Bale Mountains National Park from July 2008 to March 2009 covering both wet and dry seasons. Fifteen 50x50 m² plots of which five with high giant mole rat density and five with low giant mole rat and five with none-giant mole density were selected for the study on factors that influence density and distributions on of giant mole rat and the impact on the environment. In addition to this, ten 50x50 m² plots of which five with high density giant mole at and five with low density giant mole rat were selected for population and co-existence studies. An estimate of 48 maximum and 20 minimum individual giant mole rats were found per-hectare in the present study. A total of 75 kg soil samples were taken from studied plots for soil carbon, nitrogen, phosphorous and particle density study and 225 bags samples were taken for soil bulk density test. The soil samples were tested for required parameters in Addis Ababa National Soil Test. Soil properties, vegetation cover, livestock, grazing season, and slope were factors affect the density and distribution of giant mole rats. The soil factors determine the number of mima mound formation and number of fresh open and closed holes. The mean fresh open and closed holes during dry and wet season were significantly different ($t = -2.743, df = 9; P = 0.013 < 0.05$; $t = 4.300, df = 9, P = 0.00 < 0.05$), respectively. Density and distribution of mole rats were best indicated by the number of mime mound in a given area. The number of mima mound showed statistically significant compared to fresh open and closed holes, old closed holes and grazing intensity ($P = 0.01 < 0.05$). Giant mole rats aid soil formation, hence burrowing and mima mound formation mix soil component. It also aerates and enriches soil with nutrients whereas in other hand it enhances soil erosion by exposing soil to erosion factors. The burrowing pattern of giant mole rats affect Soil carbon by releasing carbon dioxide into atmosphere contributes to climate change. The soil carbon content and soil bulk density in giant mol rat showed significantly different compared to none giant mole rat plots ($F_{2, 72} = 19.1; P = 0.00 < 0.05$; $\chi^2 = 5.699, df = 1; P = 0.017 > 0.005$), respectively. Giant mole rat had mutual way of living with the alpine chat and commensalisms with murid rodents. The maximum number of giant mole rat observed is statistically positively correlated with number of alpine chat ($\alpha = 0.05$; $r = 0.287$) and total number of giant mole rats observed positively correlated with total raptors ($\alpha = 0.05; r = 0.303$) in the studied plots. Combined effect of giant mole rat and livestock would have caused great impact on the ecosystem. Conservation measure aimed at afro

alpine ecosystem of Bale Mountains would take accounts the role of the giant mole rat as ecosystem engineers.

Key words: Bale Mountains National Park, ecosystem engineer, giant mole rat, mima mound, soil Carbon, soil bulk density.

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1. INTRODUCTION

Ethiopia is characterized by diverse climatic conditions and habitat (Leykun Abunie, 2000). The topography of the country ranges from 116 m below sea level up to 4620 m above sea level. This topographic diversity produces a wide range of climatic and ecosystem diversity making Ethiopia a centre of biodiversity and endemism.

The Bale Mountains National Park (BMNP) as part of the highlands of southeastern Ethiopia encompasses a variety of habitats that supports diversity of wildlife species. The habitat type includes forest, grassland, woodland, heather moorland and afro alpine vegetation (Hederg, 1951; Hillman, 1986a; Miede and Miede, 1994; Sillero-Zubiri 1994; Marino, 2003).

In a natural ecosystem wildlife interacts through various functional activities and ecological processes. This maintains wildlife in their natural habitats and promotes a crucial ecological course of action that links them in their ecosystem (Crawley, 1997). Among mammalian species, rodents play important role in the ecosystem by restructuring soil and vegetation (Delany, 1986). The afroalpine rodents show diurnal activities and plug their burrow at night as behaviour adaptation in response to harsh climatic conditions (Hinze, 2005; Hinze and Pillay, 2006). They also exhibit wide array of morphological forms. They are short limed and tailed. The extreme climatic condition in the high land of Bale Mountains determines the structure of the mammalian community (Marino, 2003).

The afroalpine habitat in the BMNP harbours a variety of rodent species (Hillman, 1986b, 1993; Stephens, 1997; Marino, 2003). *Arvicanthis blicki*, *Lophuromys melanonyx* *Stenocephalemys albocaudata* and *Tachyoryctes macrocephallus* are the most common afro-alpine species. Among these rodents, the giant mole rat, *T. macrocephallu* is a major component of the ecosystem supporting the endangered and endemic Ethiopian wolf (Sillero Zubiri, 1994; Sillero Zubiri and Gottelli, 1995). The Giant mole rat is an

endemic mammal of the Bale Mountains occupying afroalpine heath moorland and grasslands (Yalden 1975, 1985; Hillman, 1886b; Shimelis Beyene, 1986; Yalden and Largen, 1992). They have pale brown pelage to silver shades, which is and paler ventrally. It has also short limbs and tail. The body is cylindrical with comparatively large heads. Ears are partially hidden in the hairs, but visible (Mohammed Yaba, 2007).

Soil movement, formation of mima mound (heap of soil formed by giant mole rat) and cropping vegetations makes the giant mole rat dominant micro geomorphic agents in the area. The changes giant mole rat cause in the physical environment, vegetation and soil clearly affect other afroalpine communities. The burrowing activity of the giant mole rat plays a major role in maintaining, supporting, shaping and restructuring of the afro alpine ecosystem. They build their rounded dome shaped mima mound and continually turn over the soil as they forage. They dig out the top soil on the afroalpine plateau resulting in more herbal growth. The herbs are prime habitat for grass rat, mice and shrews which also form food for birds of prey and the Ethiopian wolf (Sillero-Zubiri, 1994).

The high density of rodents has a major effect in the afroalpine ecosystem particularly, the burrows of giant mole rat has a major effect on the vegetation and soil. In the afro-alpine grassland where giant mole rat occurs at high densities, the ground looks like ploughed area due to the extensive burrowing activity (Yalden, 1985).

The study of population of giant mole rats is done largely using indirect methods. Mark and release method can not be used because mole rats are difficult to enter live traps. Yalden (1975) was estimated the population density of giant mole rat by counting the number of animals he observed and found the density to be 63 per hectare. The highest density of giant mole rat density was recorded in Sanetti plateau and Web valley (Shimelis Beyene, 1986).

Any activity that affects vegetation biomass and soil has a potential to sequester carbon or release carbon dioxide into atmosphere contributing to climatic change. Reduction in forest cover and increase in soil disturbance represents losses of Carbon into the

atmosphere and ongoing reductions in carbon sink (Watson *et al.*, 2008). The burrow action of mole rat disturbs soil and affects the vegetation as a result will affect soil organic carbon.

Protected areas expected to play critical role in climate change mitigation by conserving forest, watershed, soil and biodiversity, all of which are large carbon pools and important resources for the livelihood of people. Therefore, examination of the feasibility of payment for ecosystem services especially carbon financing has become an important aspect in protected area management and planning. Soil is a major reservoir of organic carbon. Soil organic carbon is important to soil production and the role in global carbon cycle is a key to life. Because of this, there is a growing interest in the national monitoring protocols for the measurement of soil organic carbon (Rosenberg *et al.*, 1998). Carbon markets are the key components of national and international emission trading scheme which aim to reduce the amount of carbon dioxide in the atmosphere. Although soil carbon is not yet included in the voluntary or compliance carbon market there is speculation that its inclusion will soon arise. Therefore, examining factors that affect soil carbon will be an important attribute when considering soil carbons potential in the global carbon markets.

In addition to, its potential economic value in the form of carbon markets soil is an important indicator of ecosystem health. Thus, this study on the impact of giant mole rat on soil properties provides useful information on the status of the ecosystem health which can be incorporated into the park long term ecological monitoring program. Further, given rodents a fundamental part of the afro alpine ecosystem examining their impact on soil carbon stocks is imperative in order to assess the feasibility of soil carbon trading as means of protected area financing and to help an economic potential estimate in the future.

The giant mole rats also act as a dominant keystone and ecological indicator species existing with afroalpine fauna then, identifying factors influencing their distribution,

understanding their behavior and their interactions with coexisting species and determining accurate methods to determine their population are equally important and hence in the present study planned to study the giant mole rat as ecosystem engineers in the Sanneti plateau of BMNP Ethiopia.

2. LITERATURE REVIEW

2.1. Rodents as ecosystem engineers

Rodents are the dominant groups of mammals. They are well adapted to living in different habitats by feeding on grass, leaves, roots, seeds and fruits. They are also ubiquitous in their distribution. Hillman (1993) noted 70 species of rodents in Ethiopia of which 15 are endemic and 15 are believed to be economically important (Lynwood, 1985). Rodents comprise 25% of the total mammalian fauna of Ethiopia (Afework Bekele and Corti, 1997). Rodents are grouped into 29 living families, 443 genera and approximately 2004 species in the world. In East Africa, they account for nearly 28% of the mammalian species (Kingdon, 1974). Among the 284 mammalian species that occur in Ethiopia 84 are rodents forming 25% of the total mammalian fauna (Yalden and Largen, 1992).

They have high birth rate, which allows them to maintain stable populations, despite predators and natural control measures. Some rodents are specialized for underground life many are terrestrial and still others are arboreal. Some species are climber others can glide and some are adapted for semi aquatic life (Walker, 1975; Nowak, 1999). Rodents are known to have economical, ecological, social and cultural values and also benefit the environment. But, their conservation status is at risk (Singleton *et al.*, 2003). Subterranean rodents, despite their relatively small size are important in controlling the ecosystem structure and development. Rodents can excavate vast burrow systems and deposit soil in abandoned tunnels and on the ground surface altering strongly the soil characteristic in texture and water holding capacity.

Subterranean rodents graze on shoot tissue rather than roots (Churchfield and Brown, 1987). They increase the root weight ratio of plants in both the grassland and meadow. Rodents exert the greatest influence on plant performance, reducing plant biomass by as much as 50%, substantially increasing plant mortality (Hulme, 1996a). The Soil mound of giant mole rat resembles to those of pocket gophers (Shimelis Beyene, 1986).

Recent studies on pocket gophers revealed that their extensive excavation and association impacts generated a dynamic mosaic of nutrients and soil condition that promoted diversity and maintained disturbances in plant communities in the alpine zone of Colorado Front Range (Reichmann and Seabloom, 2002).

The study on the plateau Zokers in the Tibetan plateau, southwest China showed that they have profound impact in afroalpine ecosystem from consuming vegetation to altering the soil physically. The changes that Zokers cause in the physical environment, vegetation and soil clearly affect herbivore food web. Their behavior and population structure influence the ecosystem in diverse ways. Their burrowing activity below ground, foraging and excrements all have direct and indirect effects on other ecosystem components (Zhang *et al.*, 2003). They formed large distinct area within the grassland matrix by burrowing and mound building. The ecosystem processes proceeded at different rate compared to undisturbed area. They use vegetation patches at different temporal scale forming heterogeneity in their influence which is important to community dynamic biogeochemistry and biodiversity influence in the Tibetan plateau ecosystem (Zhang *et al.*, 2003).

The burrowing activities of giant mole rats are the major factors of disturbance in alpine vegetation in the Sanneti plateau (Hedberg, 1962). The soil is constantly turned over and the plants cropped by the activities of these animals resulting in land resembling a ploughed area.

The burrows of giant mole rats enriches the soil with phosphorous. The soil of eastern Sanetti possessed highest content of phosphorus (143 ppm) due to the burrow action of giant mole rat (Weinest and Mazurek, 1984). They play key role in shaping and maintaining the ecosystem by preventing floristic communities not to reach the climax stage by pruning. This keeps the vegetation in a dynamic stage (Miehe and Miehe, 1994).

Burrowing rodents exert their influence not through their trophic interaction but, by causing physical changes in their environment that affect the structure of the community (Purves *et al.*, 1998). Burrowing dramatically alters their environment, for instance, in temperate boreal forest, beaver causing falling of trees by building dams and creating ponds. In so doing, beaver can transform large area of forest into flooded wetland. Species of such kind are called environmental engineers or foundation species. The European beaver, *Castor fiber* acts as ecosystem engineer in temperate boreal forest (Purves *et al.*, 1998). By altering the structure of the environment, ecosystem engineers act as facilitators that have positive effects on the survival and reproduction of other species in the community. Pocket gophers in Colorado Front Range and plateau Zoker in Tibetan plateau are known subterranean ecosystem engineers (Zhang *et al.*, 2003).

Similarly, the giant mole rat also acts as ecosystem engineers in the afroalpine ecosystem of the Bale Mountain National Park. Burrowing of the giant mole rat prevents ecological succession, maintains the afro- alpine landscape and plays pivotal role in ecosystem structure and development. In addition to this, giant mole rats also act as dominant, keystone and indicator ecological species (BMNP, 2007; Sillero Zubiri, 1994; Sillero-Zubiri *et al.*, 1995).

The objective of the present study is to compile information on the impact of the burrowing activities of giant mole rats in maintaining, supporting, shaping and restructuring the ecosystem in particular soil physical and chemical properties. The present study also aims to examine their behaviour interaction with co-existing species in the area, to examine methods of the population study and factor influencing density and distribution in the Sanetti plateau of BMNP.

3. OBJECTIVE OF THE STUDY

3.1. General Objective

To study the role of giant mole rat, *Tachyoryctes macrocephalus*, as ecosystem engineers.

3.2. Specific Objectives

- ☞ To determine the factors influencing giant mole rat distribution and density
- ☞ To examine giant mole rat as environmental engineers and its impact on the soil physical and chemical properties.
- ☞ To suggest best methods of giant mole rat population study.
- ☞ To carry out behavioral study on giant mole rat examining their ecological co-existence with the other fauna
- ☞ To determine the impact of giant mole rats on the soil carbon and its potential on carbon financing.

4. STUDY AREA

4.1. Bale Mountains National Park

The location of the study area is in the afro- alpine belt of the Bale Mountains National Park (BMNP) at coordinates $6^{\circ} 29' - 7^{\circ} 10' \text{ N}$ and $39^{\circ} 28' - 40^{\circ} 57' \text{ E}$. The Bale Mountains National Park occupies an area of 2400 km^2 and is 400 km away from Addis Ababa. The study area includes the major part of the high altitude plateau extending from 3500 - 4377 m asl (Sanetti Plateau) (Figure 1).

BMNP is one of the most important conservation areas of the Ethiopian highlands which have high conservation significance. It is one of the 34 biodiversity hotspots and is currently on the tentative list for World Heritage Site listing. It has economical, ecological and cultural significance (BMNP, 2007). BMNP is also a water tower being the source of major rivers, has critical hydrological importance as it has watershed provide water to millions of downstream users. It has components of diverse ecosystem centre of biodiversity and endemism. It is classified under IUCN listed Protected Area Category II.

4.2. Sanetti Plateau

Sanetti Plateau is the widest central part of the Park including the main mountain massif and largest afroalpine area in Africa. It supports the Ethiopian wolf (*Canis simensis*), giant mole rat (*Tachyoryctes macrocephalus*) and Starki's hare (*Lepus strarki*) (Hilliman, 1986, 1993; Stephen, 1997).

The soils are largely formed from trachytes and basalt rocks, fertile silt loams with reddish brown to black colors. The soil profile has similar soil proportion with clay fraction of silt loam (10-15%) and chlorite dominant (Miehe and Miehe, 1994). The dominant vegetation species in Sanneti plateau includes *Helichrysum* scrubs such as *H. splendidum*, *H. citrispinum*, *H. gofanse*, and herbaceous communities. Short tussock grasses and mosses are the prominent species (Miehe and Miehe 1994; Marino, 2003). In

the main habitat of the giant mole rat and other rodent species, herbaceous communities are largely dominated by *Alchemilla* species (Hillman, 1986a; Sillero Zubiri, 1994).

It is characterized by eight months of rainy season from March to October, followed by a four months dry season from November to February. The highest amount of rainfall is recorded from July to October and also with a relatively lowest peak in April. The dry season temperature is 25 °C during the day and lowest – 15 °C at night (Hillman, 1986).

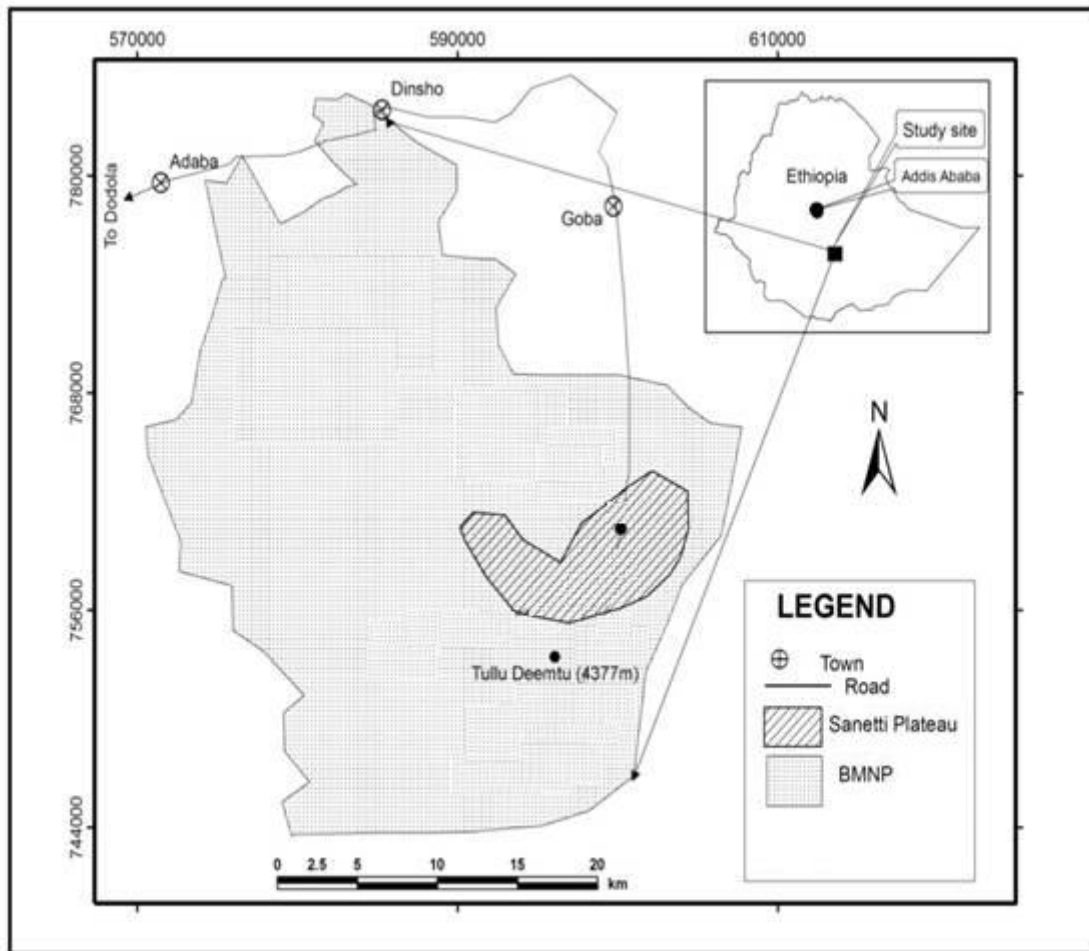


Figure 1. Location of the study area in Bale Mountains National Park, Sannetti Plateau

5. MATERIALS AND METHODS

5.1. MATERIALS

The materials used in the present study include binoculars, compass, 50 cm diameter global positioning system (GPS), thermometer, ruler, clinometers, global soil colour book, plastic soil bags, kelway soil p^H meter, soil Auger, spring balance, pic axe, hammer 50 cm diameter and 10 cm length modified core ring, 50x50 m tape meter, Bamboo marker, 50 cm metal dropper, digging tools, protective gloves, 50x50 nylon rope, digital camera, spade and stop watch.

5.2. METHODS

5.2.1. Preliminary survey

Preliminary survey was conducted during September October 2008. During this period, study sites were surveyed to select study plots. Survey was made starting from Sanetti Ethiopian wolf monitoring camp in eight directions (north, south, east, west, north east, north west, south east, south west) along 10 km transects to identify appropriate plots for further study. In each transect, it was planned to survey 10 plots each 50x50 m with inter- plot distance of 500 m 10 plots per transect. A total of 55 plots were surveyed despite topographic difficulty and bad weather conditions (appendix 1). In each 50x50 plot the number of fresh mound, number of open holes, number of holes fresh closed holes, number of giant more rat observed and the plant species composition were recorded. In addition to this, three special plots with high giant mole rat population were identified.

5.2.2. Plot selection

A total of 15 plots were selected from the preliminary study sites of which five were high density giant mole rat five low density and five no giant mole rat finally plots were characterized as high low and none mole rat density by counting the number of fresh mounds (the number of fresh mound was positively correlated to actual number of mound rat seen ($r = 0.058$, $P < 0.05$). Low density plots were considered when the numbers of fresh mounds were below the median number of fresh mounds observed in the preliminary study across all plots, and high density plots when the number of fresh mounds exceeded the median. Once classified using all plots, a ward Hierarchal Cluster analyses was carried out on vegetation species composition, to ensure that high low and no plots selected had the same species composition so that all differences in soil properties could not be attributed to differences in species composition shows that three similar vegetation compositions were identified at third level so that the minimum number of five plots of each density could be selected plots selected are indicated in appendix 2. In addition to this, five high giant mole rat and five low density giant mole rat plots were determined for population and behaviors study which is different from the one used for soil and vegetation analysis.

5.2.3. Data Collection

Data were collected using qualitative and quantitative methods. The qualitative data were collected by ecological observation and recording. The ecological role of giant mole rat in ecosystem shaping, supporting and restructuring, adaptation of giant mole rat to afro alpine ecosystem, ecological interaction and cropping of vegetation were considered. Photographs were taken for further confirmation whereas the quantitative data were collected by measurement. e.g., impact of giant mole rat on soil carbon, the activity of giant mole rat above surface, soil p^H and ambient temperature. The wet season data were collected from October 8 to December 20, 2008 whereas the dry season data were from March 22- April 8, 2009. Soil properties were determined in dry season only and the following variables were assessed. These are Soil temperature, color, texture, pH, bulk

density, carbon, and nitrogen and particles density, behavioral and population data were collected in both dry and wet season.

5.3.2.1. General plot data, placing plot

The GPS coordinate selected or considered to be the south corner of the plot. A tap meter was then laid at 90⁰ angle in north direction for 50 meters and was then pegged. Using a compass layout, the second side at right angle to the first side marked. Using the same procedure the 3rd and 4th side of the plots were established. By measuring the slope on each side were adjusted so that, all sides are measured at length based on the measured angle of the slope ensuring that all corners are at 90 degree. In the five plots where high giant mole rat density and no giant mole rat occurred, metal droppers were placed in each of the four corners to permanently mark the plots for soil erosion purpose. The metal dropper was hammered into the ground to the level of the insulation mark so that change in soil level could be detected later during dry season.

In each of the 50x50 m plot the following data were recorded on the data sheet. the location of the plot, number of giant mole rat slope GPS southeast and South west corner, number of fresh mound, number of fresh open and closed holes, no number of old mound number of livestock dung, grazing intensity and number and size of (base circumference and height) mima mound data collected , grazing intensity data were collected based on scale given in Appendix 3. In each corner of 50 x 50 m plots and in the centre of the plot laying of 5x5 m quadrates were placed and using, the Braun - Banquets scale(appendix 4). The vegetation cover and each of the species in the quadrat identified then Percentage bare ground, rock and grass were recorded on data sheet.

5.3.2.2. Soil physical and chemical properties

Soil color, structure and texture

In each of the 15 plots 1x1 meter hole was dug for soil profiling, this hole was randomly placed but occurred only in an area where no open holes or fresh mounds occurred

Soil horizon is the vertical horizon found in a depth of soil (in this instance 1 cm depth). This can be defined as based on the difference in soil color and texture there can be any amount of horizon in a given depth from 1(A) or more (Figure 3).

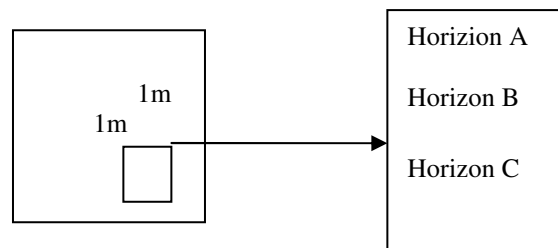


Figure 2. 50 cm pit dug in the study plot for soil profiling

In each horizon, the following information are measured and recorded.

- a) Horizon depth – using a measuring tape
 - b) Soil colour texture, structure was described using a soil globe colour book.
-
- 1 Soil color: a sample of soil was taken from each horizon irrespective of moisture (if dry sprayed with a little bit of water) stand in sun over shoulder and shining on the soil and break pieces compare the color inside with the chart provided. If the soil has two colors these were recorded both indicating which was dominant and which is sub-dominant.
 - 2 The soil texture was described by feeling the soil with finger and following the description in the book.
 - 3 Soil structure was described using the description and diagrams from the book to describe the soil structure

- 4 Lastly the soil lab further identified soil type based on soil texture and color as determined by experts in the laboratory.

Soil temperature, p^H and % saturation

Soil temperature was measured by placing a thermometer horizontal in the soil, then record the soil temperature was taken at 5 cm interval up to a depth of 60 cm (50 cm approximately a maximum depth for giant mole rat burrow). At each interval temperature was recorded on data sheet.

A Kelway soil p^H and % moisture /field capacity/ meter model HB-2, was used to obtained p^H and % moisture by placing the meter from the surface vertically into the soil for a depth of 10 cm reading and recording. In addition, the meter was placed horizontally in the pit wall at 5 cm intervals, up to the depth 50 cm i.e at 15 cm, 20, 25, 30,35,40,45 and 50 cm. data were recorded on data sheet. If soil was hard it was soften initially with pic-axe prior to measuring.

Soil bulk density

Bulk density was recorded at 10 cm intervals to a depth of 50 cm. A 5 cm diametre and 10 cm length modified core ring was used for this at each depth. The core ring was pushed vertically into the ground and removed, leveling at each end. The sample was then placed in a plastic bag and clearly labeled with depth and plot number location and date. Thus, a total of five samples were taken in this instance. Bulk density was calculated after the soil laboratory analysis was completed. Data and sample identifications were recorded on data sheet.

Soil chemical properties

In addition to soil samples and measurements taken from pit, additional samples were taken from other areas of the plots. Three samples were taken directly from old closed holes in the plots and three from area in the plots that have no holes but likely burrow systems might occur underneath. From each of these, 6 sampling points, the following data were taken. Samples were taken using a modified; soil Auger 60 cm x 10 cm which was hammered vertically into the soil to a depth of 50 cm and was removed with the soil in the tube.

Using the p^H moisture meter p^H and percentage saturation were measured from the top of the Auger (0-10 cm) and bottom representing (40-50 cm). A thermometer was also used in this manner to measure soil temperature from the soil sample.

Soil was extracted from the Auger placed on a plastic sheet and mixed thoroughly and a composite sample weighing 1 kg was placed in a plastic soil bag and labeled. These samples were taken to Addis Ababa to the soil laboratory. They were analyzed for soil organic Carbon, total Nitrogen, available Phosphorous and particle density.

Next to where the sample was taken using a core ring bulk density samples were taken at 0-10 cm and 40-50 cm following the method described above. The data and sample identification code was recorded on datasheet. For the purpose of identification, each sample had a code for bulk density. This was the plot number, followed by the area sampled and the number of sample. So if it was taken from sample one from old mound at 0 -10 cm from plot NW_1 , then the identification code would be $NW_1 O_1 A$. If the sample was taken 40 -50 cm from plot NW_1 the sample code was $NW_1 O_1 B$ (Appendices 5 and 6). The same applies for samples for laboratory analyses except in this instance the code would change. These samples were then sent to the laboratory to determined bulk density at 0-10 and 40-50 cm. Thus, a total of 75 kg of soil was taken from 15 plots and sent to laboratory for analysis of soil carbon, nitrogen available phosphorous and particle density (Appendix 7).

In terms of climatic change carbon is traded as ton carbon dioxide in carbon market. The ton of carbon per hectare was determined using the percentage carbon values obtained from the laboratory and placing them in the following equation.

Carbon ton per hectare = ($\%$ /100) x df x depth x 100, where

- $\%$ = percentage of Carbon by weight in fine soil.
- Df = is the density of soil material in grams per cubic centimeter
- Depth = is the soil over which carbon is measured in cm. In the present study depth is 50 cm. in each studied plots

The ton of carbon per hectare is then multiplied by molecular ratio of carbon dioxide to that of carbon (i.e. 44/12) giving ton carbon dioxide per hectare, t CO₂/ha. It is the t CO₂ that are then sold in the market price, in this study price used were \$4, \$6, \$8 (Watson *et al.*, 2008) to determine the economic potentials of soil carbon in BMNP. Using the same equation ton Nitrogen per hectare was obtained then converted into ton carbon dioxide where (1N₂O =310 CO₂). And, then above prices is used to determine the BMNP afro-alpine potential value for soil carbon trading. This study compare the t CO₂/ha between the study (high, low and none) giant mole rat plots to determine the potentials impact giant mole rats on soil carbon and determine the feasibility of the soil carbon trading of the park in afroalpine where burrowing activity of mole rat exist.

5.3.2.3. Giant mole rat population and behavior study

Five high giant mole rat density and five low giant mole rat density (as determined from the site selection study) 50x50 m plots were used in this study. These plots were different to the ones used for soil and vegetation analysis (Appendix 8).

Plots were laid out in similar manner to those described above. However, this time metal droppers were placed in the four corners of all plots so we could monitor soil erosion.

In the morning at approximately 08.00 h the number of fresh mounds, old mounds and open holes were counted within the entire 50x50 m plot by using strip transects 1m wide on each side (Figure 4).

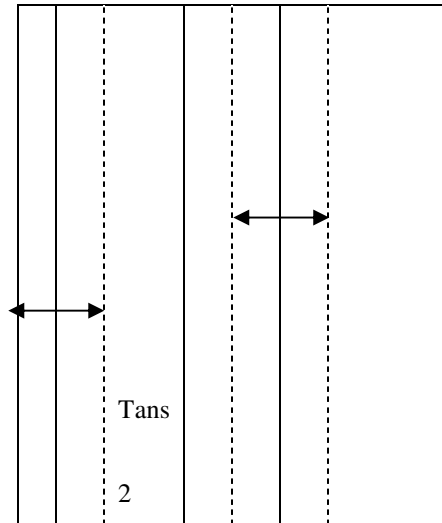


Figure 3. Strip transect to count fresh open holes and fresh closed holes

If the southwest corner is considered 0 metre then, start first transect at 1 m, placing a rope in a straight line from the bottom to the top of the grid so that a 1 m distance between the transect line can be marked out on either side. This was repeated every 2 meters until the last transect at 49 m. Thus, in total 25 transects were walked across the plot. When walking the strip transects all fresh and open holes were marked using bamboo markers (distinguishing among fresh mounds and fresh open and closed holes). This was repeated for each plot.

At 5 pm these transect were then observed again and the additional number of fresh closed and open holes were counted that were not counted in the morning. Once, 1m strip was on each side of transect was marked. walk the transect counting every fresh mound, open hole and old closed mound and place a marker at all fresh and open holes identifying which is which. This was repeated for all the plots.

In addition, between 10 00-11.00 hours observed the plots at least 10 m away using binocular, all giant mole rats appearing at the same time were counted. Thus, in once

sighting perhaps 5 mole rats were observed. In addition, the first giant mole rat that comes above ground, using a stop watch, the length of time and the activity above ground was recorded. Once retreating underground, the cause of retreating was recorded i.e. raptor overhead. Throughout the area, the number and time of raptors, wolves and alpine chats were recorded including any other interesting behavioral observations. Through the hour period the ambient temperature was also noted at 10 minute intervals. This was repeated at 12 .00-13.00 hours and 14 .00-15.00 hours.

This was carried out on all plots repeated for five consecutive days per plot this was repeated during both dry and wet seasons.

5.2.4. Data analysis

Prior to data analysis all proportion of data set was checked to meet the assumption of normality by using Kolmogorov- Smirnov test. The data sets shows that ($P < 0.05$) so, fit the normality assumption. To determine the best factor used to indicate density and distribution of giant mole rat, Poisson Regression Model was used. Comparison between fresh open and closed holes in high and low density plots in dry and wet season was carried out by using t-test. To examine the soil Carbon, Nitrogen, available Phosphorus and soil particle density one way ANOVA was used. Old and no mound soil carbon, nitrogen, available phosphorus and particle density is compared by independent t- test. Kuruskal Wallis test was used to examine soil bulk density, soil p^H , percentage soil saturation, temperature, livestock utilization and gazing intensity. Dunn's Post - Hoc test was used to identify where specific difference was found in the study plots. Parentage of carbon and nitrogen in the soil across the studied plots changed to ton carbon then ton carbon dioxide ($t\ CO_2$) per hectare to see the status of soil carbon emission due to burrowing of giant mole rat and to make rough estimation of soil carbon trading potential of the afroalpine ecosystem where the burrowing of giant mole rat occurs. The measure of central tendency is also used to measure vegetation cover and bare ground in the study plots. To explain the co-existence of giant mole rat with other afroalpine fauna two tailed Pearson Correlation Coefficient was employed. Wilcoxon Signed Rank test was used to examine the population status of giant mole rat in dry and wet seasons. Photographs were incorporated in the text where it is needed. Qualitative data were explained using descriptive statistics. All the data analysis was carried out using SPSS Version 15.

6. RESULTS

6.1. Factors influencing distribution and density of giant mole rat

6.1.1. Percentage coverage of plant species and bare ground

The majority of cover of vegetation in the giant mole rat plots was *A. abyssinica* whereas the none giant mole rat plots it was *Helichrisum* and grass species. The vegetation cover and bare ground in the study plots are given in appendix 9.

Table 1. Analysis of Vegetation cover and bare ground in the study plots

GMR Density	Species	Average	$\pm SD$
NONE	BG	13.64	6.91
	Grass	30.8	9.09
	Rock	8.4	7.74
	A.abby.	4.44	6.46
	H.cit	25.4	12.24
	A.rotti	5.88	7.00
	A.hym	0.64	1.55
	Sensio spp	0	0.00
	H.rupp.	0	0.00
	Others	2.44	1.80
GMR Density	Species	Average	$\pm SD$
LOW	BG	16.56	13.17
	Grass	10.48	9.01
	Rock	11.92	8.34
	A.abby.	28.8	14.09
	H.cit	10.92	10.50
	A.rotti	3.88	5.78
	A.hym	3.36	10.96
	Sensio spp	0.4	2.00
	H.rupp.	0	0.00
	Others	3.88	4.72
GMR Density	Species	Average	$\pm SD$
HIGH	BG	23.92	10.23
	Grass	18.24	13.46
	Rock	13.52	9.82
	A.abby.	24.4	11.93
	H.cit	4.48	5.16

A.rotti	1.8	3.43
A.hym	0.36	1.80
Sensio spp	0.33	1.00
H.rupp.	1.6	4.73
Others	3.44	2.45

N.B.

BG- Bare ground

A.abby - *Alchemilla Abyssinia*

A..rotti- - *Alchemilla rotti*

A.. hym-- *Alchemilla hymones*

H. cis- Helichrysum citrispinium

H. gof- Helichrysum gofanse

H . rupp- Hablocarpal rupellelli

Senecio spp –Senecio species

Other idicated minor plant species in the study plot(Festuca species giant loblia and Trifolium species)

6.1.2. Grazing intensity

Grazing intensity in giant mole rat plots (high, low) compared to none giant mole rat where significantly higher ($\chi^2 = 0.492$, $P = 0.05$; post hoc $P < 0.05$) (Appendix10). Extensive patches of bare ground were observed in high and low density giant mole rat plots. The maximum grazing intensity across the study plots is shown in Figure 5.

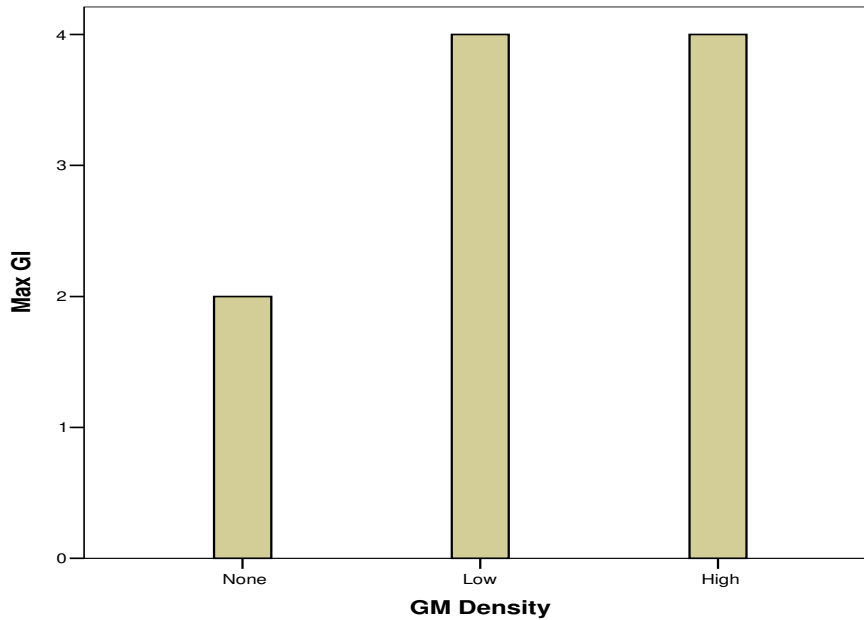


Figure 4. Maximum grazing intensity in study plots

6.1.2. Livestock Utilization

The mean cow dung across high, low and none giant mole rat plots was significantly different ($\chi^2 = 10.204$, $df = 2$, $P = 0.006$) between the different densities, with higher dung counts occurring in high density plots compared to none giant mole rat plots. Fresh cow dung was observed in study plots (Appendix 11).

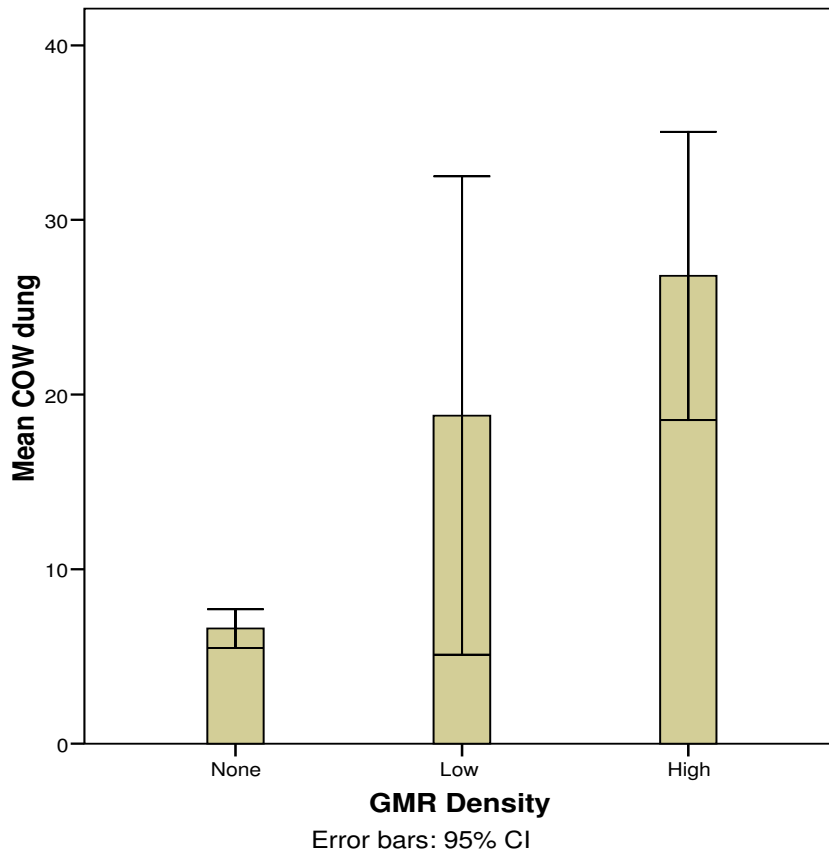


Figure 5. Mean Cow dung across study plots

6.1.3. Seasons

The mean of fresh closed and fresh open holes in the study giant mole rat plots were higher in wet season than dry season. The difference was statistically significant, fresh closed holes ($t = 3.261$, $df = 9$, $p = 0.01 < 0.05$) and fresh open holes ($t = 2.672$, $df = 9$, $P = 0.026 < 0.05$). The mean of fresh closed holes and open holes were greater in wet season than dry season.

6.1.4. The number of Mima mound

The number of mima mound with fresh sign is highly positively correlated to the maximum giant mole rat counted in the study plots, in both wet seasons ($r = 0.91$, $n = 10$, $p < 0.001$) and dry season ($r = 0.93$, $n = 10$, $P < 0.010$). The maximum number giant mole rat counted and the number of mima mound with fresh sign in the study plots in both dry and wet season were given in the Table 2.

Table 2. The number of mima mound with fresh sign across in dry and wet season.

Plots No	No of mima mound with fresh sign		No of Giant mole rat counted		Remark
	wet	dry	Wet	dry	
Site 1	9	15	9	12	Near alpine lake
Site 2	8	8	8	8	
Site 3	9	10	9	10	
W 1	8	8	8	8	
E 2	8	9	17	12	Near alpine lake
NW3	4	4	4	4	
SE 4	4	4	5	5	
SW 5	4	5	5	5	
SW 3	5	7	6	7	Near alpine lake
W5	4	4	5	6	

6.1.5. Soil physical properties (structure and texture)

The structure of the soil in the giant mole rat plots (high and low) was dominantly aggregate or single grained, whereas the none giant mole rat plots are dominantly massive and granular. The soil texture in high and low giant mole rat plots were silt and silt loam whereas the soil texture in none giant mole rat is clay and sandy clay (Table 3).

Table 3. Soil structure, texture and color among study plots

Plot no	GMR Density	Horizon	Depth (cm)	Color	Texture	Structure
N2	Low	A				
		B			Water table & Rock	
		C			Layer difficult to dig	
N4	Low	A	0-20	10 YR 4/4	Silty loam	Single grained
		B	20-45	7.5 YR 4/4	silty clay	Platy
		C	45-70	7.5 YR 7/8	clay	Massive
NW ₃	Low	A	0-20	10YR 5/4	silty	single grained
		B	20-35	10YR 4/4	silty clay	platy
		C	30-50	10YR 4/4	sandy clay	granular
NW ₂	Low	A	0-20	7.5 YR 3/4	silty loam	single grained
		B	15-30	7.5 YR 5/4	silty clay	platy
		C	30-50	7.5 YR 4/5	sandy clay	Blocky
SE ₃	Low	A	0-20	10YR 4/3	loam	Aggregate
		B	20-45	10 YR 5/4	silty loam	Aggregate
		C	45-60	10 YR 7/4	clay	platy
	NE3	A	0-20	7.51/2 4/2	silty loam	single grained
		B	20-35	10YR 4/3 45 1/2 7/2	silty clay	granular
		C	35-55	7.5YR 8/2	clay	massive
SW2	High	A	0-20	10 YR 4/2	Silty loam	Aggregate (single grained)
		B	20-35	10 YR 4/1	silty clay	Platy
		C	35-68	10 YR 2/2	clay	Massive

E5	High	A	0-15	10YR 4/2	silty Loam	single grained
		B	15-30	7.5 YR 4/2	silty clay loam	single grained
		C	35-45	10 YR 8/4	clay	massive
		D	40-50	4.5 YR 7/8	sandy clay	granular
NE2	High	A	0-15	2.5 YR 5/2	silty loam	single grained
		B	20-50	2.5 YR 4/2	silty clay	single grained
W3	High	A	0-20	7.5 YR 4/2	silty clay loam	single grained
		B	20-50	10 YR 7/1	silty clay	massive
E6	None	A	0-20	5 SR 5/4	clay loam	massive
		B	20-50	4 YR 4/6	sandy clay	Granular
E7	None	A	2.00E-01	7.5 YR 4/3	sandy clay	Granular
		B	20-35	7.5 YR 2.5/2	sandy clay	Granular
		C	35-50	7.5 YR 6/8	sandy	Blocky
Sw8	None	A	0-15	10 YR 3/6	clay loam	massive
		B	15-40	10 YR 4/6	sandy clay	Granular
		C	40-55	1.5 YR 3/2	sandy	Blocky
Sw9	None	A	0-20	7.5 YR 4/1	sandy loam	granular
		B	25-45	7.5 YR 2.5/1	sand clay	massive
		C	45-60	7.5 YR 4/2	sandy	single grand
Sw10	None	A	0-20	5YR 5/4	sandy loam	Granular
		B	20-45	5 YR 4/6	sandy clay	Granular
		C	45-60	2.5 YR 3/2	sandy	Granular

6.1.7. Soil particle density and Soil bulk density

Soil particles density in study giant mole rat plots show statistically no significant difference ($F = 0.851$, $df = 72$, $P = 0.431 > 0.05$) (Figure 6) (Appendix 12). The pit soil bulk density in non giant mole rat plots is lower than giant mole rat plots This was statistically significant at ($\chi^2 = 5.699$, $df = 1$ $P = 0.017 > 0.05$). However, no difference

was observed in old mound and no mound soil (0-10 cm) and (40-50 cm) bulk density in high and low density giant mole rat plots (Figure 7)(Appendix 13 a and b).

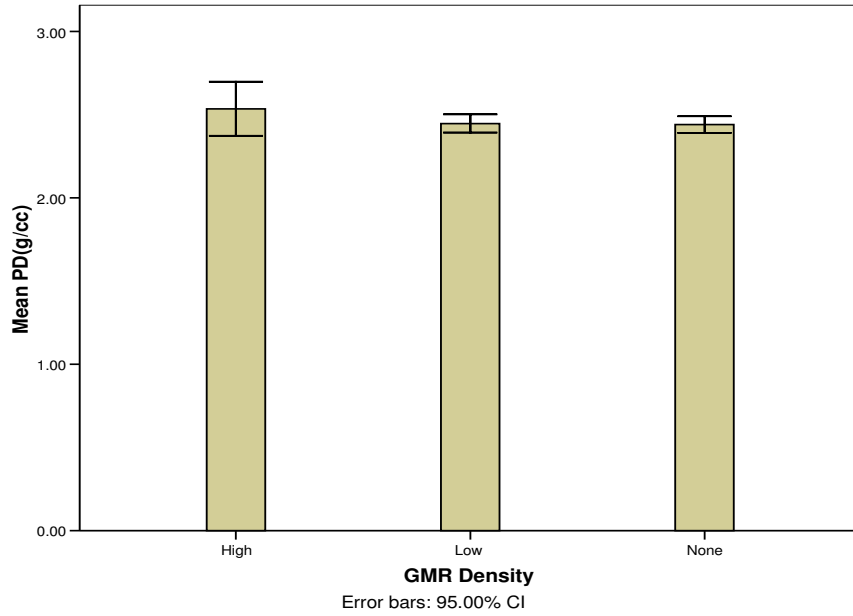


Figure 6. Soil particle density across the study plots

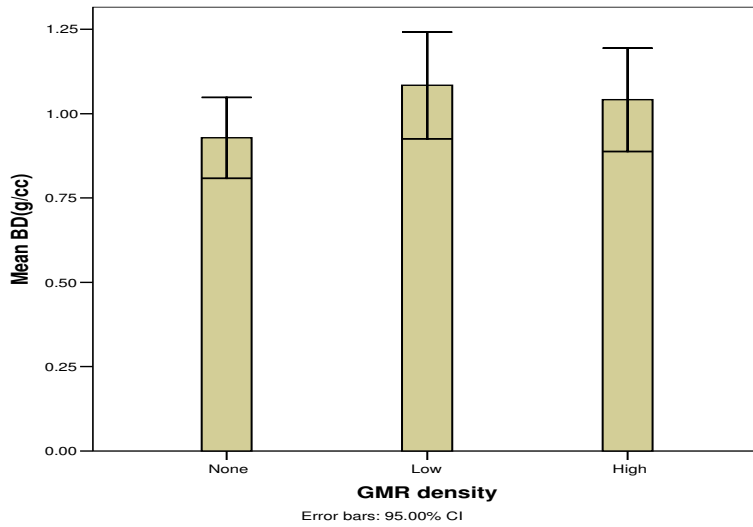
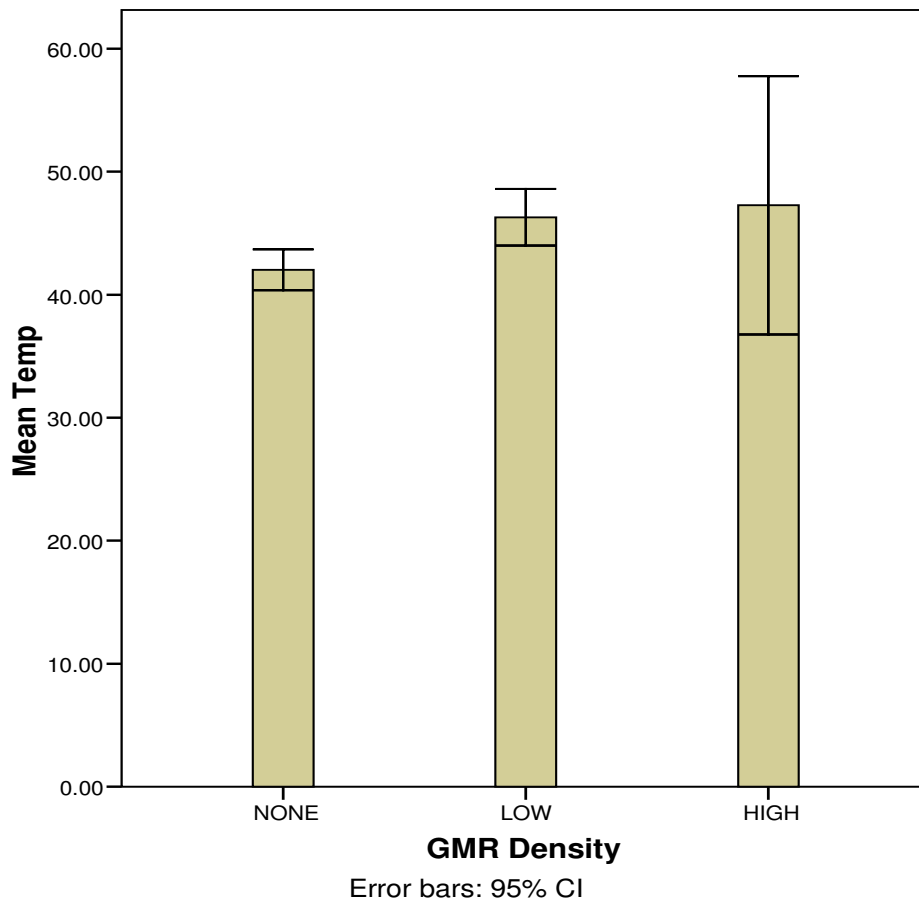


Figure 7. Soil bulk density across the studied plots

6.1.8. Soil pH, Percentage saturation and soil Temperature

The soil pH, percentage saturation and soil temperature at 50cm depth show statistically no significant difference among the studied high, low and non giant mole rat plots. All the parameters were statistically insignificant at soil Temperature ($\chi^2 = 3.479$, $df = 2$, $P = 0.76$) (Figure 8) pH ($\chi^2 = 2.722$, $df = 2$, $P = 0.256$) (Figure 9) percentage saturation ($\chi^2=1.00$, $df=2$, $P = 0.607$) (Figure 10) (Appendix 14).



NB Temp = Soil Temperature

Figure 8. Soil mean temperature across the studied plots

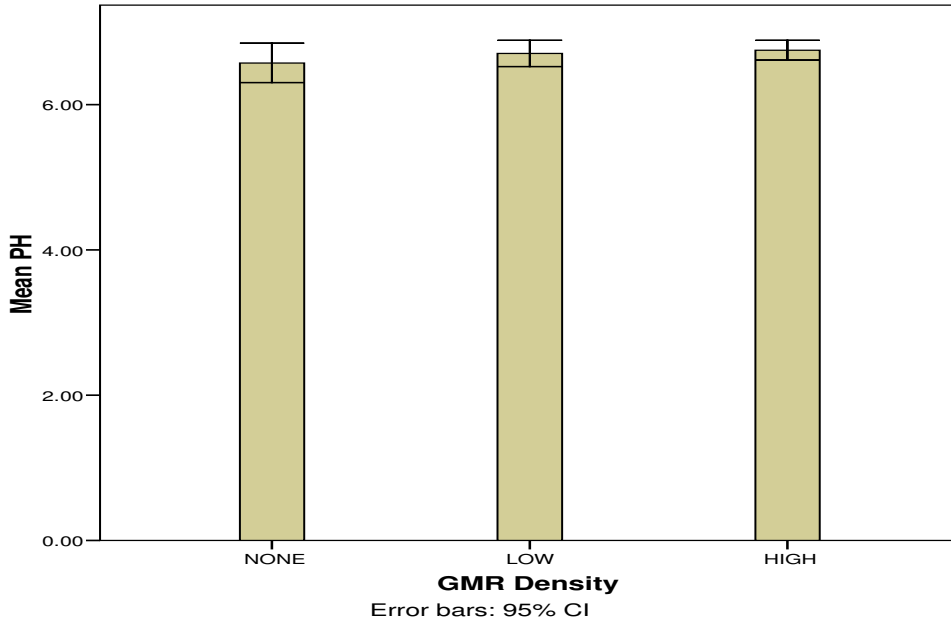
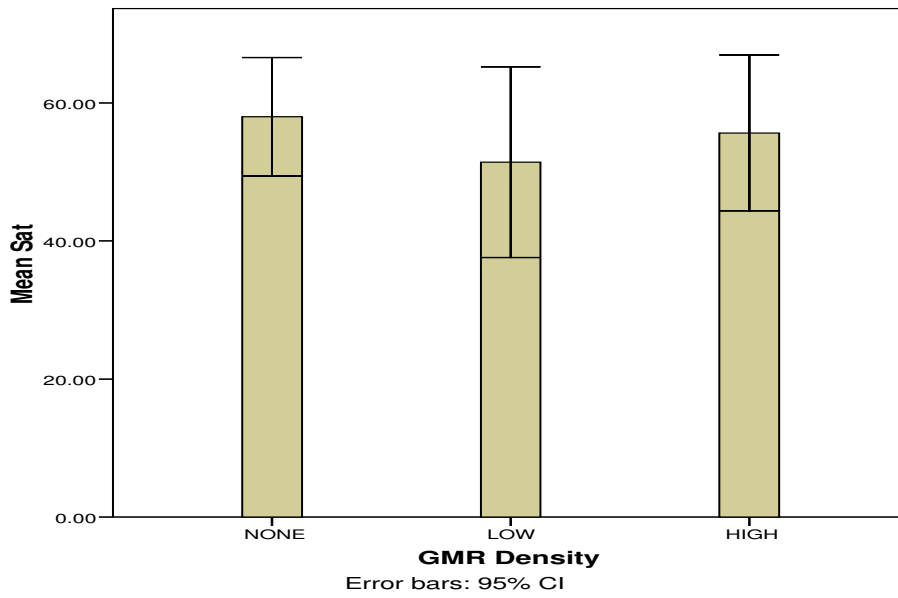


Figure 9. Soil Mean pH across the studied plots



NB. Sat - Saturation , GMR- Giant Mole Rat

Figure 10. Soil Mean percentage saturation across the studied plots

6.1.9. The best factor determine distribution and density of giant mole rat

Poisson regression (Table 4) shows that the number of mima mounds is a better indicator of giant mole rat density compared to fresh signs such as open holes and freshly closed hole, old closed holes and grazing intensity (Wald statistic = 5.87 ; P = 0.01 < 0.05).

Table 4: Poisson Regression Model

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.432	.7509	-1.039	1.904	.332	1	.565
fresh Closed mound	-.009	.0254	-.058	.041	.112	1	.738
fresh Open mound	.061	.0812	-.098	.221	.571	1	.450
Old mound	-.008	.0044	-.016	.001	3.082	1	.079
N ₀ Mm	.649	.2677	.124	1.174	5.872	1	.015
GI (Scale)	-299 1 ^a	.2609	-810	.213	1.312	1	.252

6.2. Giant mole rats as environmental engineers

6.2.1. Soil Carbon, Nitrogen and Available phosphorous

The mean of soil carbon and nitrogen across high low and non giant mole rat studied plots show statistically significant difference in percentage of carbon ($F_{2,72} = 1.91$, $df = 72$, $P = 0.00 < 0.05$) (Figure11) and nitrogen ($F_{2,72} = 6.941$, $df = 72$, $P = 0.002 < 0.05$) (Figure 12) with plots with no mole rats having statistically higher values however, no difference was observed between the plots in available phosphorus ($F_{2,72} = 1.323$, $df = 72$, $P = 0.275 > 0.05$) (Figure13 (Appendix 15)). The difference lies between high density mole rat plots and none mole rat plots and low density mole rat plot and non mole rat plots (Table 10).

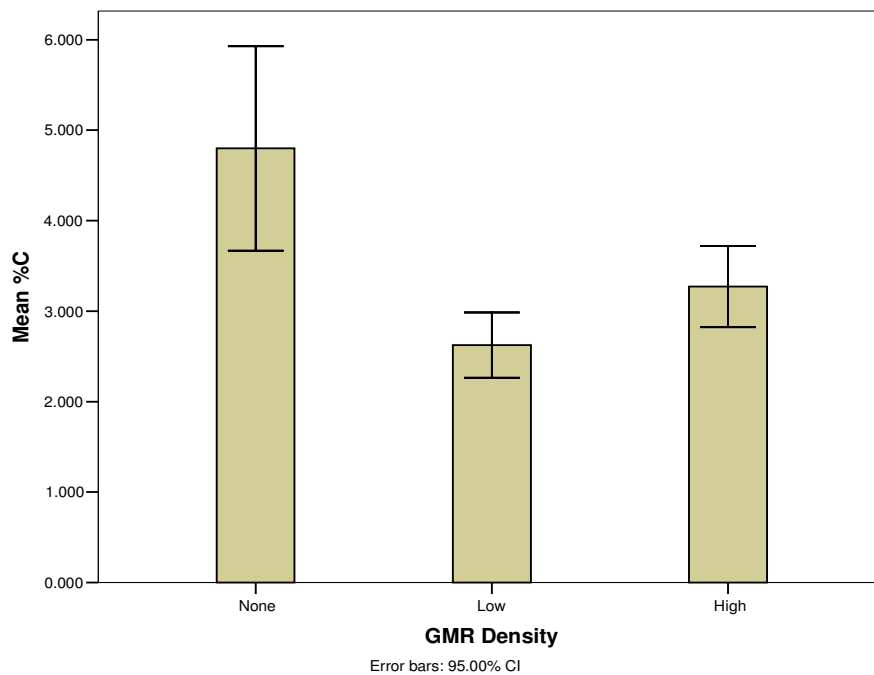


Figure11. Mean % Carbon per the study plots

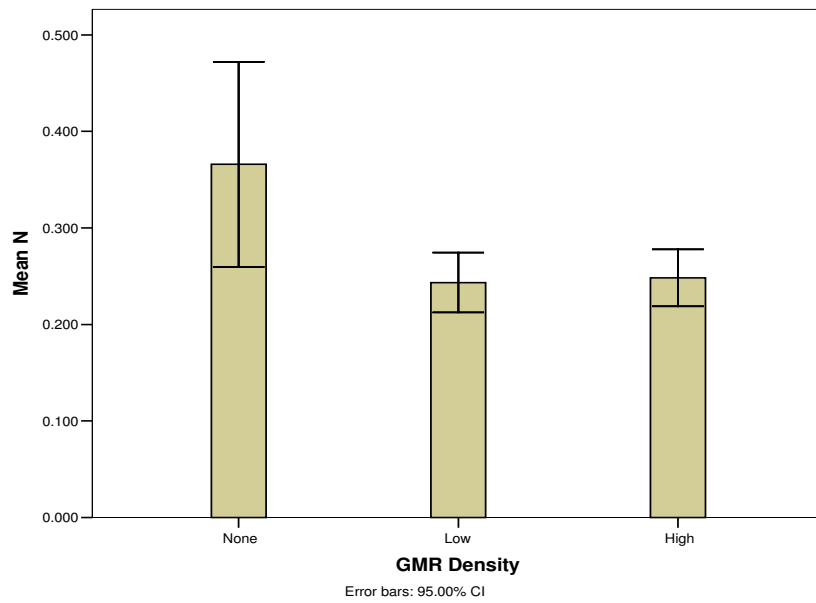
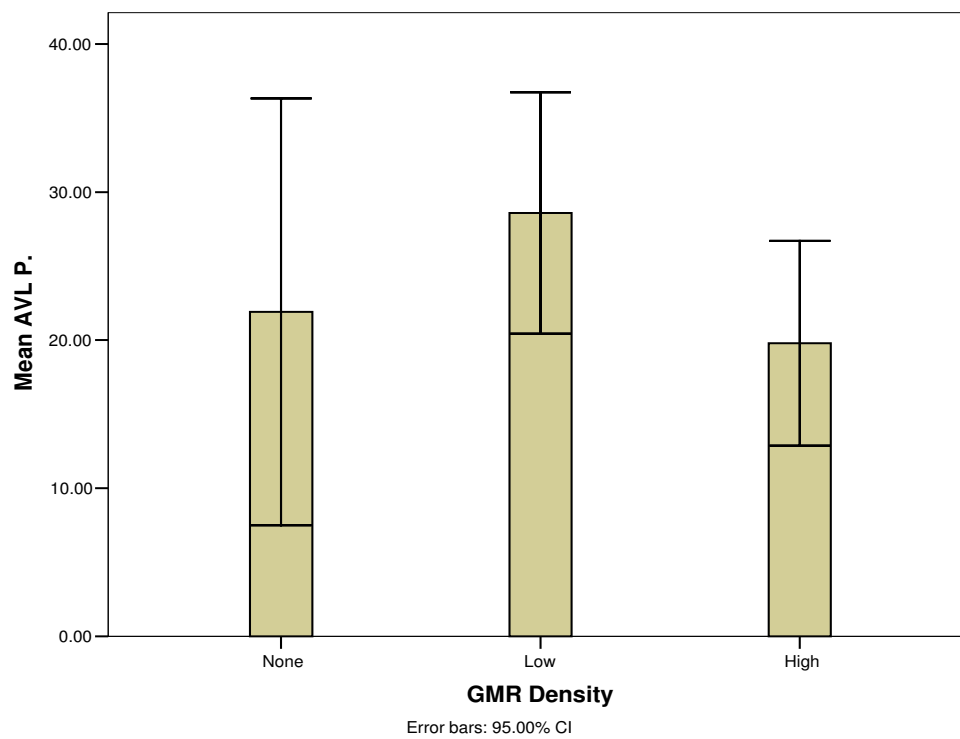


Figure12. Mean % Nitrogen per the study plots



N.B.GMR-Giant mole rat

AVL.P – Available Phosphorus

Figure 13. Mean Available Phosphorus (AVL.P.) per the study plots

Table 5. Soil carbon, nitrogen and available phosphorus Post-Hoc test

Multiple Comparisons

LSD

Dependent Variable	(I) GMR density	(J) GMR density	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Carbon	None	Low	2.44467*	.39931	.000	1.6487	3.241
		High	1.89680*	.39931	.000	1.1008	2.693
	Low	None	-2.44467*	.39931	.000	-3.2407	-1.65
		High	-.54787	.32603	.097	-1.1978	.1021
	High	None	-1.89680*	.39931	.000	-2.6928	-1.10
		Low	.54787	.32603	.097	-.1021	1.198
Nitrogen	None	Low	.12233*	.03528	.001	.0520	.1927
		High	.11740*	.03528	.001	.0471	.1877
	Low	None	-.12233*	.03528	.001	-.1927	-.0520
		High	-.00493	.02881	.864	-.0624	.0525
	High	None	-.11740*	.03528	.001	-.1877	-.0471
		Low	.00493	.02881	.864	-.0525	.0624
Available phosphorous	None	Low	-6.67667	6.79347	.329	-20.2192	6.866
		High	2.11200	6.79347	.757	-11.4305	15.65
	Low	None	6.67667	6.79347	.329	-6.8659	20.22
		High	8.78867	5.54684	.117	-2.2688	19.85
	High	None	-2.11200	6.79347	.757	-15.6545	11.43
		Low	-8.78867	5.54684	.117	-19.8461	2.269

*. The mean difference is significant at the .05 level.

6.2.2. Old mound and No mound soil

There was no difference between old mound and no mound soil samples in high and low density giant mole rat plots in mean carbon, Nitrogen, available phosphorus and particle density (carbon: $t = -0.074$, $df = 58$ $P = 0.942$; Nitrogen; $t = 0.071$, $df = 58$, $P = 0.578$; available phosphorous $t = 0.560$ $df = 58$, $P = 0.57$; particle density: $t = 0.020$, $df = 58$) (Appendix 16a). Similarly no difference was observed in old mound soil samples between high and low density mole rat plots in soil carbon, Nitrogen, available phosphorus and particle density ($t = -0.033$, $df = 28$ $P = 0.0869$, $t = -0.537$, $df = 28$ $P =$

0.7892 $t = 0.051$ $df = 28$, $P = 0.755$, $t = -0.505$ $df = 28$ $P = 0.082$), respectively (Appendix 16b)(Table 6, and figure 14). However, there was a significant difference in carbon nitrogen, phosphorus between high and low density plots where comparing samples from no mounds (carbon: $F_{2,42} = 9.677$, $P = 0.00 < 0.05$); Nitrogen ($F_{2,42} = 3.548$, $P = 0.38 < 0.05$) and available phosphorus ($F_{2,42} = 3.548$, $P = 0.38 < 0.05$). However, no significant difference in particle density ($F_{2,42} = 2.258$ $P = 0.117 > 0.05$) (Figure 15) (Table 7).

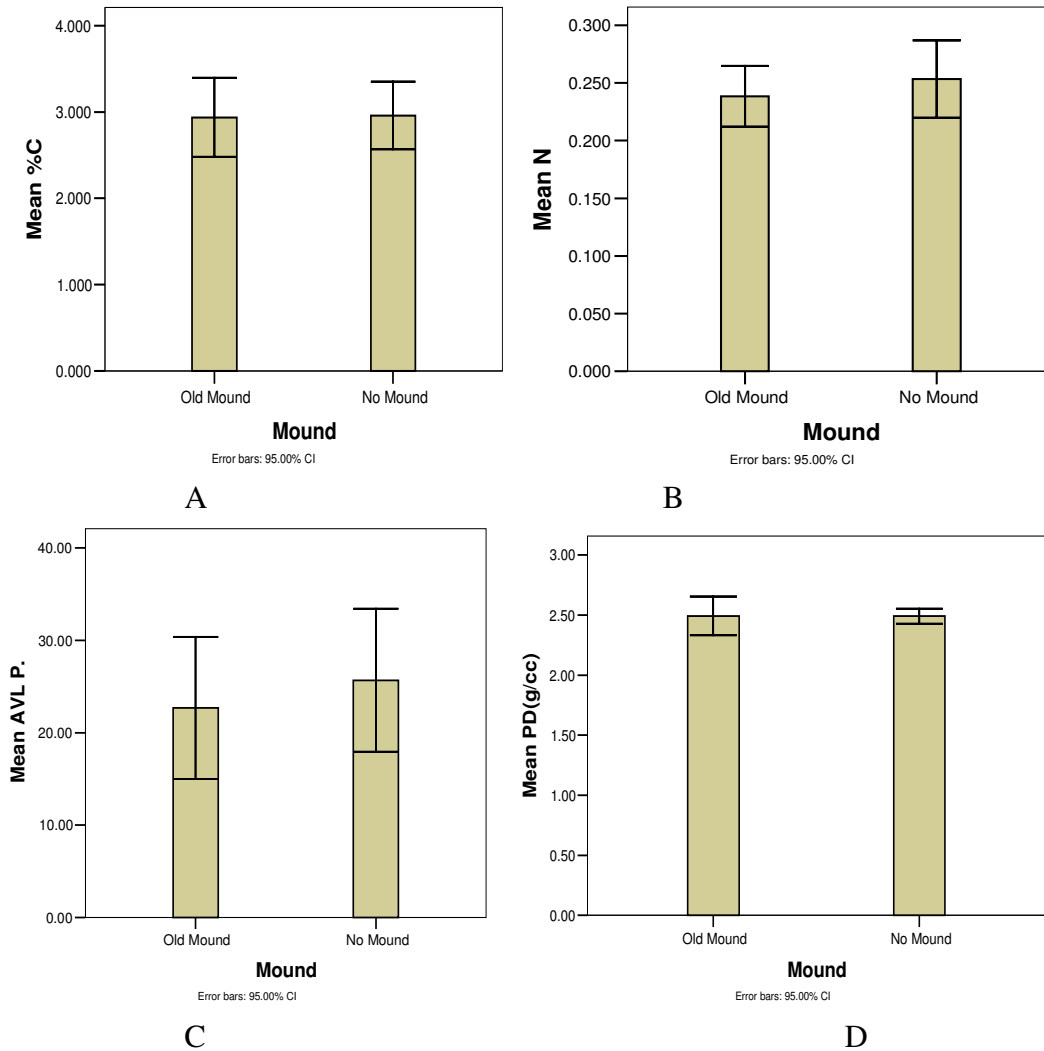


Figure 14. The mean + 95% confidence intervals for A) soil carbon (B) nitrogen (C) available phosphorus (D) particle density for old mound soil in high and low giant mole rat in carbon, Nitrogen, available phosphorus and particle density

Table 6. Independent t-test old mound soil in high versus low density mole rat plots

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
%C	Equal variance assumed	.028	.869	-1.033	28	.310	-.460667	.445802	.373851	.452518
	Equal variance not assumed			-1.033	27.977	.310	-.460667	.445802	.373885	.452552
N	Equal variance assumed	.077	.783	-.537	28	.596	-.014000	.026092	-.067447	.039447
	Equal variance not assumed			-.537	27.996	.596	-.014000	.026092	-.067448	.039448
AVL P.	Equal variance assumed	.100	.755	.051	28	.960	.38800	7.65756	5.29781	6.07381
	Equal variance not assumed			.051	27.959	.960	.38800	7.65756	5.29883	6.07483
PD(g/cc)	Equal variance assumed	3.266	.082	-.505	28	.618	-.08067	.15977	-.40795	.24661
	Equal variance not assumed			-.505	14.446	.621	-.08067	.15977	-.42236	.26102

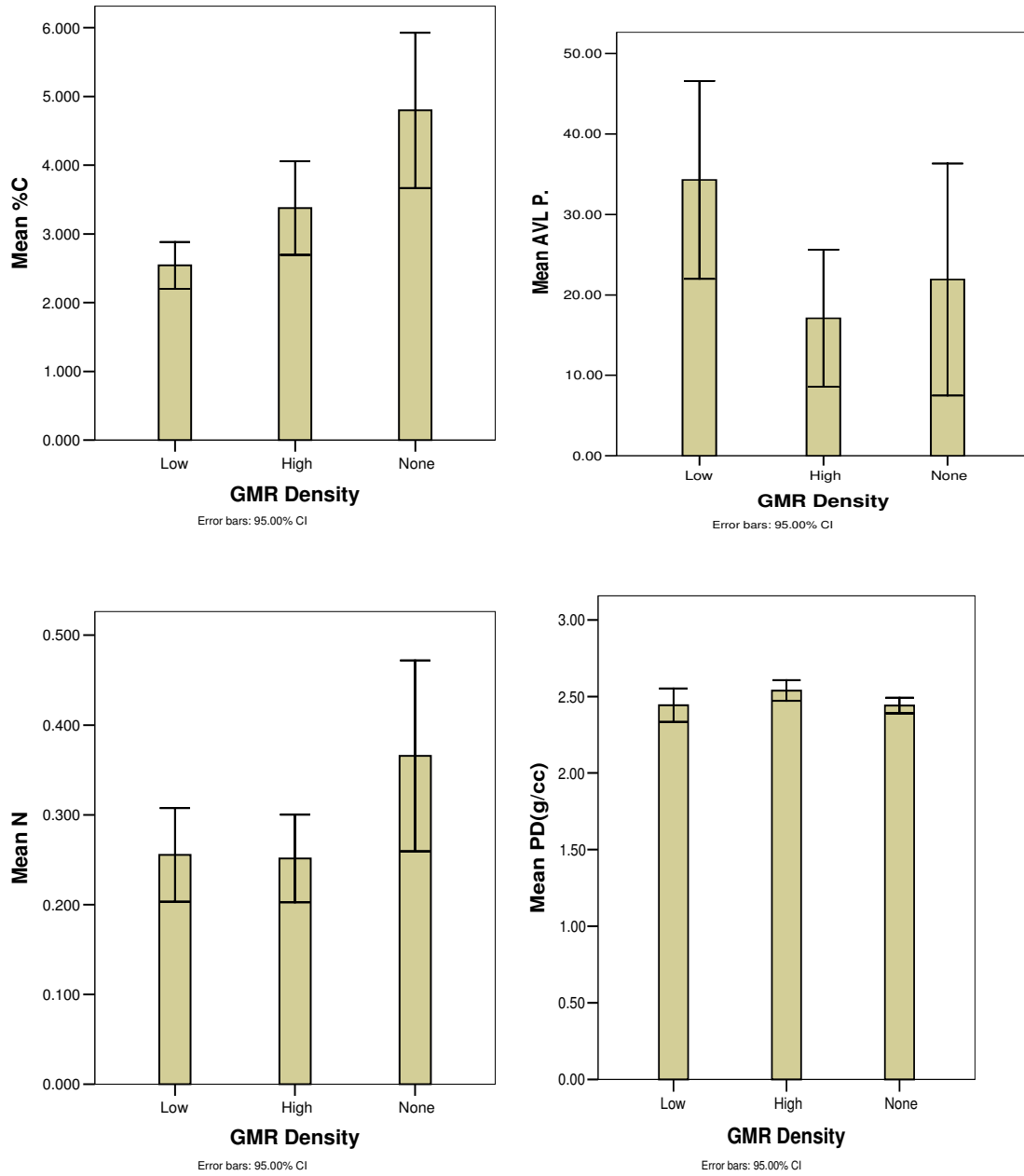


Figure 15. The mean + 95% confidence intervals (A)) soil carbon (B), nitrogen (C) available phosphorus D) particle density , no mound soil in high low density mole rat plots versus no mound soil non giant rat plot

Table 7. Post - Hoc test no mound soil in high and low density mole rat plots versus non giant mole rat plots

Multiple Comparisons

LSD

Dependent Variabl	(I) GMR Densit	(J) GMR Densit	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
%C	None	Low	2.257467*	.518632	.000	1.21083	3.30411
		High	1.422400*	.518632	.009	.37576	2.46904
	Low	None	-2.257467*	.518632	.000	-3.30411	-1.21083
		High	-.835067	.518632	.115	-1.88171	.21157
	High	None	-1.422400*	.518632	.009	-2.46904	-.37576
		Low	.835067	.518632	.115	-.21157	1.88171
N	None	Low	.110333*	.048749	.029	.01195	.20871
		High	.114467*	.048749	.024	.01609	.21285
	Low	None	-.110333*	.048749	.029	-.20871	-.01195
		High	.004133	.048749	.933	-.09425	.10251
	High	None	-.114467*	.048749	.024	-.21285	-.01609
		Low	-.004133	.048749	.933	-.10251	.09425
AVL P.	None	Low	-12.37067	7.91270	.125	-28.3391	3.5978
		High	4.81867	7.91270	.546	-11.1498	20.7871
	Low	None	12.37067	7.91270	.125	-3.5978	28.3391
		High	17.18933*	7.91270	.036	1.2209	33.1578
	High	None	-4.81867	7.91270	.546	-20.7871	11.1498
		Low	-17.18933*	7.91270	.036	-33.1578	-1.2209
PD(g/cc)	None	Low	-.00133	.05253	.980	-.1073	.1047
		High	-.09733	.05253	.071	-.2033	.0087
	Low	None	.00133	.05253	.980	-.1047	.1073
		High	-.09600	.05253	.075	-.2020	.0100
	High	None	.09733	.05253	.071	-.0087	.2033
		Low	.09600	.05253	.075	-.0100	.2020

*. The mean difference is significant at the .05 level.

6.2.3. Relevance of giant mole rats on carbon trading potential

6.2.3.1. Ton carbon and ton carbon dioxide per hectare

The old mound soil ton carbon (t C) and ton of cabondioxide (t CO₂) per hectare in high and low density giant mole rat plots were statistically insignificant ($t = 0.077$, $df = 24$ $P = 0.032 > 0.05$) whereas the no mound soil high density and low density and non giant mole rat plots statistically significant ($F_{41} = 4.502$, $df = 41$, $P = 0.017 < 0.05$). The difference exists between the high density mole rat plots and none giant mole rat plots but, there is no difference between low density mole rat plots and none giant mole rat plots.

6.2.3.2. Ton Nitrogen in old mound and no mound soil

Comparison between no mound soil in ton nitrogen in high density versus low density giant mole rat statistically insignificant ($t = 1.445$, $df = 28$ $P = 0.715 > 0.05$). The same is true for old mound soil in high density versus low mole rat plots in ton carbon. It is statistically insignificant ($t = -0.058$, $df = 24$, $P = 0.450 > 0.05$) however, no mound soil in high density plots versus non giant mole rat plots statistically significant at ($t = -2.488$, $df = 28$ $P = 0.019 < 0.05$) the difference lie between giant mole rat plot and none giant mole rat plots.

6.2.3.3. Mean carbon and ton carbon dioxide per hectare

Ton carbon and ton carbon dioxide per hectare across high low, and none giant mole rat plots statistically significant ($F_{2, 72} = 6.202$, $P = 0.03 < 0.05$). Mean carbon and ton carbon are positively correlated across studied plot. The non giant mole rat plots have high mean ton carbon and ton carbon dioxide. Thus, high soil carbon trading potential (Figure 11).The ton nitrogen in the giant mole rat study plots is also statistically significant ($F_{2, 72} = 6.941$, $P = 0.02 < 0.05$).

Table 8. Mean carbon and ton Carbon per hectare Post Hoc Tests in studied Plots

Multiple Comparisons

(I) GMR Density	(J) GMR Density	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower	Upper
Low	High	-79.850	69.234	.253	-218.08	58.38
	None	-285.337(*)	81.339	.001	-447.74	-122.94
High	Low	79.850	69.234	.253	-58.38	218.08
	None	-205.487(*)	82.423	.015	-370.05	-40.92
None	Low	285.337(*)	81.339	.001	122.94	447.74
	High	205.487(*)	82.423	.015	40.92	370.05

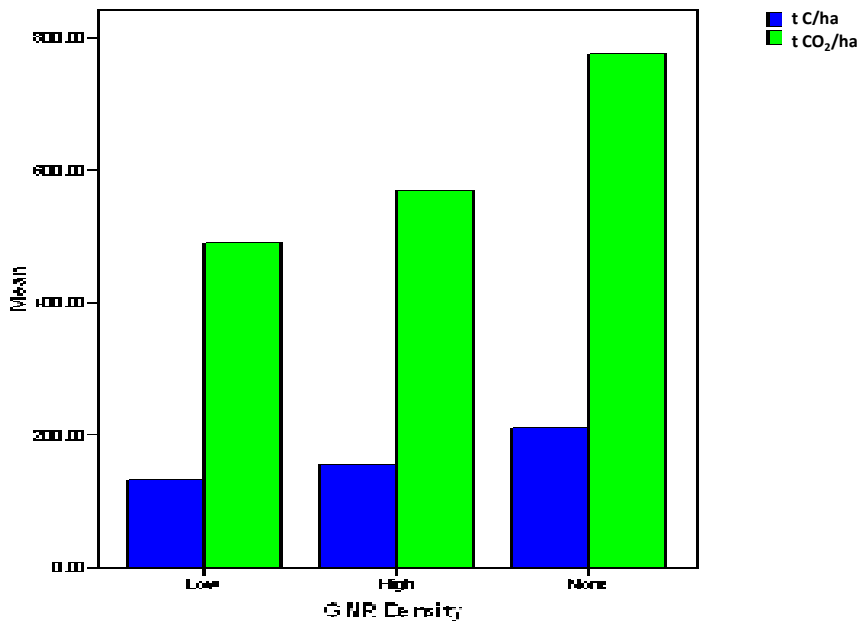


Figure 16. Mean carbon and ton carbon dioxide per hectare

6.2.3.4. The soil Carbon economics

There is a lower ton CO₂ per hectare in high and low density mole rat plots compared to no mole rats (Figure 17). This is also true for ton nitrous oxide (Figure 18). The occurrence of mole rats has the potential to reduce the economic potential available form of soil carbon. Equation of soil carbon economics shows burrowing of giant mole rat affect soil carbon and emit CO₂ in to air. The soil carbon will include in carbon trading in terms of ton CO₂. If ton CO₂ is sold 4 dollars 6 dollars and 8 dollars in average 38827.05 dollars 27032.17 dollars 25249.61 dollars are obtained in none, low and high-density giant mole rat, respectively (Table 8 and 9). To see the effect in the presence and absence of the giant mole rat, it considered the average of low and high and obtained the difference between absence and presence of the animal. Therefore, from the difference there is 12686.16 dollars that can be obtained from afroalpine soil carbon trading is lost due to the presence of giant mole rat. This was assuming that all burrowing rodents have similar impact and given that at least 50% (approximately 50,000 ha) of the afro alpine has burrowing rodents.

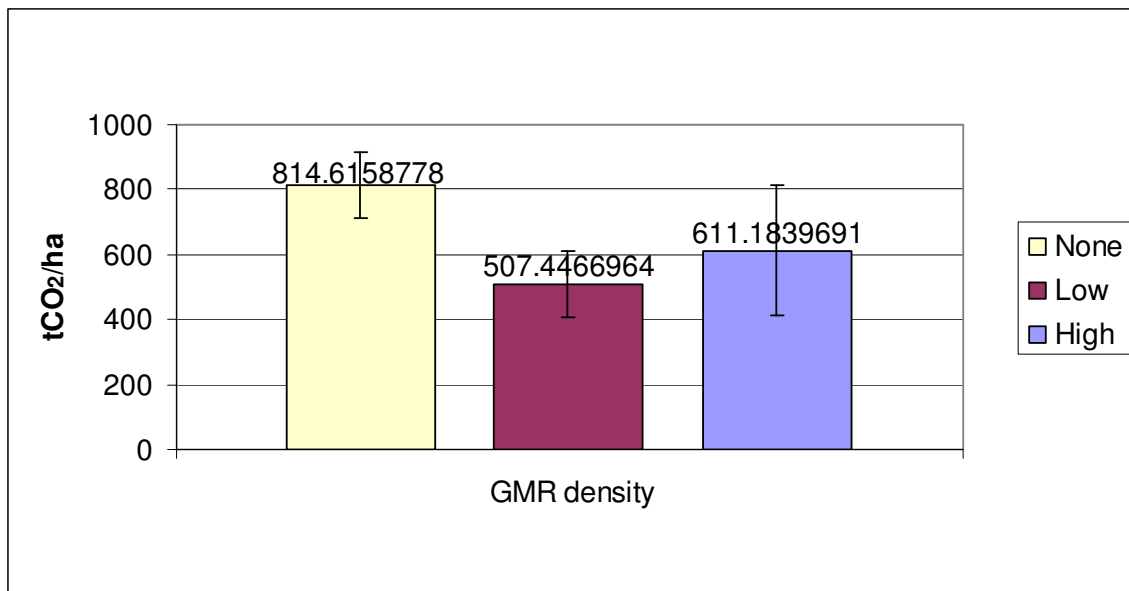


Figure 17. Ton carbon dioxide per hectare in the studied plots

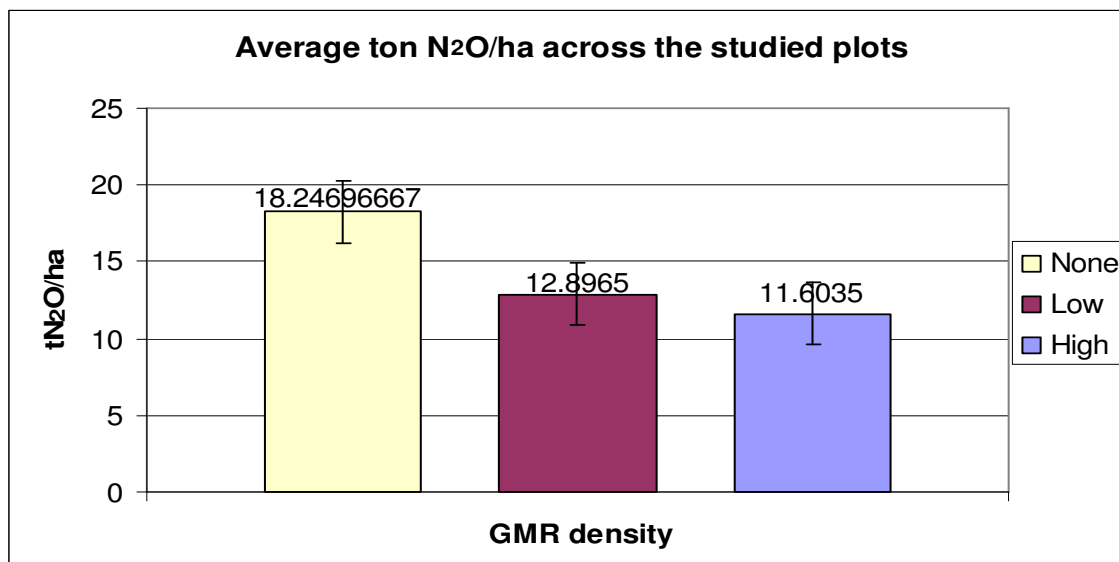


Figure 18. Ton nitrous oxide per hectare of the studied plots

Table 9 Economic value of ton CO₂ sold in different price

Category	Difference in Economic value/ha		
	\$4	\$6	\$8
High-Low	-1188.3709	-1782.556364	-2376.741818
Low-None	-7863.2554	-11794.88309	-15726.51078
High-None	-9051.6263	-13577.43945	-18103.2526

Table 10. Cumulative Economic impact of giant mole rat on soil carbon market

GMR density	tC/ha	Total		\$4	\$6	\$8	Average
		tCO ₂ /ha	tCO ₂ /ha				
None	222.168	814.615878	6471.18	25884.7	38827.05	51769.4	38827.05
Low	138.3946	507.446696	4505.36	18021.45	27032.17	36042.89	27032.17
High	166.6865	611.183969	4208.27	16833.08	25249.61	33666.15	25249.61
Absence of MR					38827.05		
Presence of MR					26140.89		
Difference					-		12686.16127

6.3. Giant mole rat population study

6.3.1. Giant mole rat counts

Direct observation of giant mole rats above ground resulted of a maximum 12 and a minimum of 4 individual giant mole rats observed per hour at any one time. By making use of the Wilcoxon sign ranked test ($Z = -1.342$, $P = 0.18 > 0.05$) (Appendix 17). The maximum seen giant mole rat in the wet season showed no significant difference with maximum number of mole rats seen in the dry season.

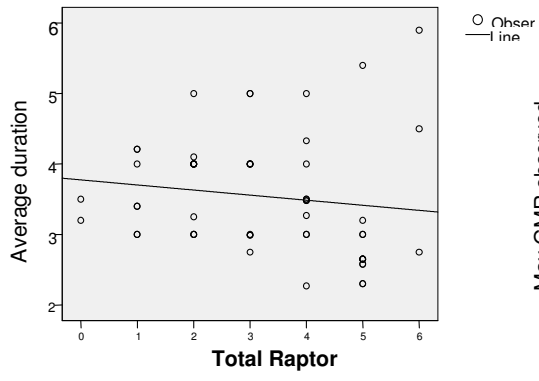
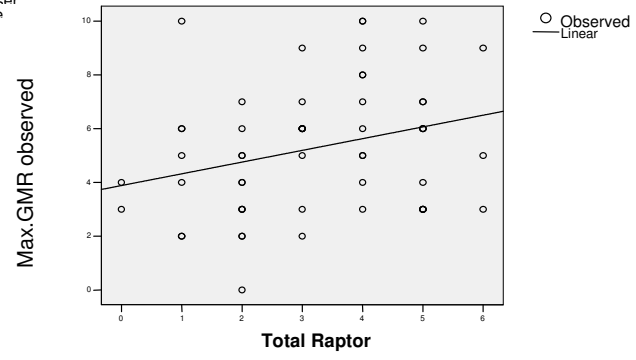
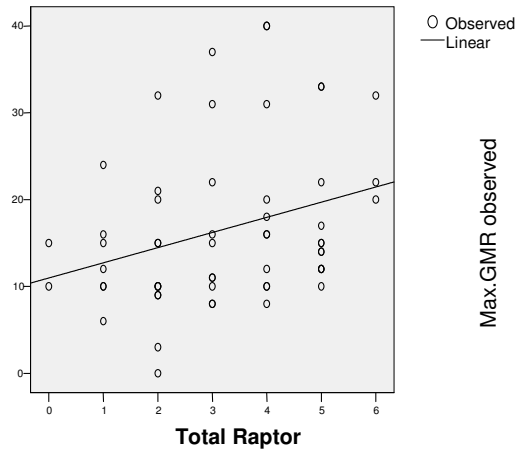
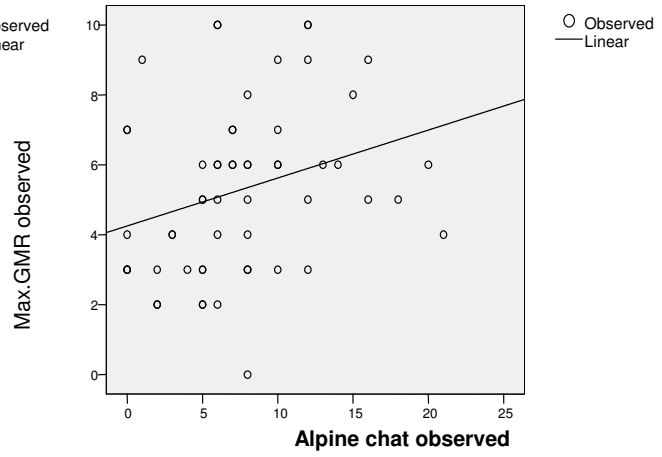
6.3.2 Fresh signs (Fresh open and closed holes)

The mean of fresh open and closed holes per plots in high and low density giant mole rat plots show statistically significant difference at ($t = 2.548$, $df = 1.9$ $P = 0.020 < 0.05$). The mean fresh open hole and closed holes were higher in high giant mole rat plots. During wet season, the mean fresh open and fresh closed holes in high density giant mole rat plot is significantly different from low density giant mole rat plots (open: $t = 2.742$, $df = 18$; $P = 0.00 < 0.05$; closed: $t = 4.300$ $df = 18$, $P = 0.00 < 0.05$). Fresh open holes were greater than in wet season compared to the dry season ($t = -2.321$, $df = 18$, $P = 0.032 < 0.08$) (Appendices 18 and 19).

The maximum number of giant mole rat showed a statistically significant positive correlation open holes in the morning positive correlation with fresh open in the afternoon statistical significant at ($\alpha = 0.01$, $r = 0.490$) However, a negative correlation was observed between the mean of fresh holes in the morning and the amount of fresh closed holes in the afternoon ($\alpha = 0.05$, $r = 0.455$). in other words as the number of fresh open holes increased in the mornings the number of fresh closed holes the afternoon decreased. Fresh open hole in the afternoon statistically significant positive correlation with fresh open in the morning ($\alpha = 0.01$, $r = 0.787$) whereas fresh closed holes in the afternoon statistically significant positive correlation with fresh open in the after noon ($\alpha = 0.01$, $r = 0.569$).

6.4. Ecological interaction- species coexistence.

The two tailed Pearson correlation shows of giant mole rat average duration above ground is weak negatively correlated with the total raptors. This was statistically insignificant ($r = - 0.140$) (Fig 19A). The maximum number of giant mole rats and total number of giant mole rat observed in the study showed significant positive correlations with total number of raptors observed ($\alpha = 0.05$, $r = 0.285$, $r = 0.303$) (Fig 19B and C), respectively. The total number of giant mole rat observed showed a statistically significant positive correlation with the total number of Ethiopian wolf that visited the study plots per day with ($\alpha = 0.05$, $r = 0.268$). Similarly, the total number of Alpine chat significantly positively correlated with maximum number of giant mole rat observed in the study plots ($\alpha = 0.05$, $r = 0.287$) (Fig.19D) (Appendix 20).

A**B****C****D**

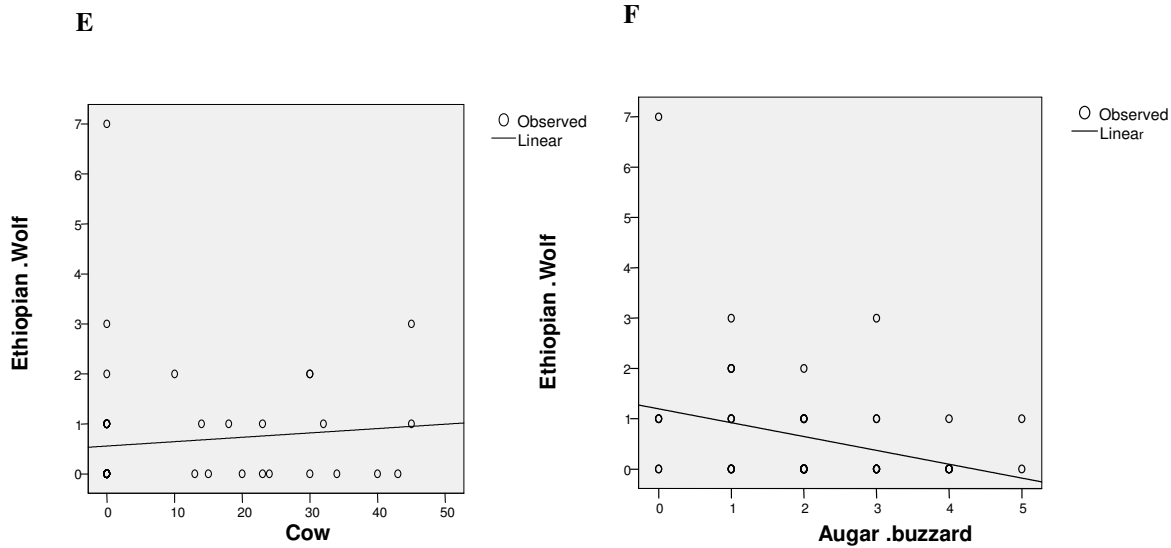


Figure 19: Scatter plots of giant mole rat with other afro alpine fauna in Sanetti plateau

6.5. Giant mole rat behavioral study

Giant mole rats spent a mean of 3.59 ± 0.91 minutes above ground at any one time. During this time above ground the mole rats were observed basking, foraging and digging. The amount of time the giant mole rat spent above ground was positively correlated to the mean ambient temperature. Giant mole rats were observed above ground for a minimum of 2.00 minutes and maximum of 6.14 minutes. However, mean temperature of air and mean duration above ground of giant mole rat statistically insignificant ($r = 0.79 > 0.05$). Similarly the maximum number of giant mole rat seen did not increase as mean ambient increased. ($r = 0.171 > 0.05$) (Appendix 21). Figure 21 shows the maximum giant mole rat seen the mean ambient temperature of air.

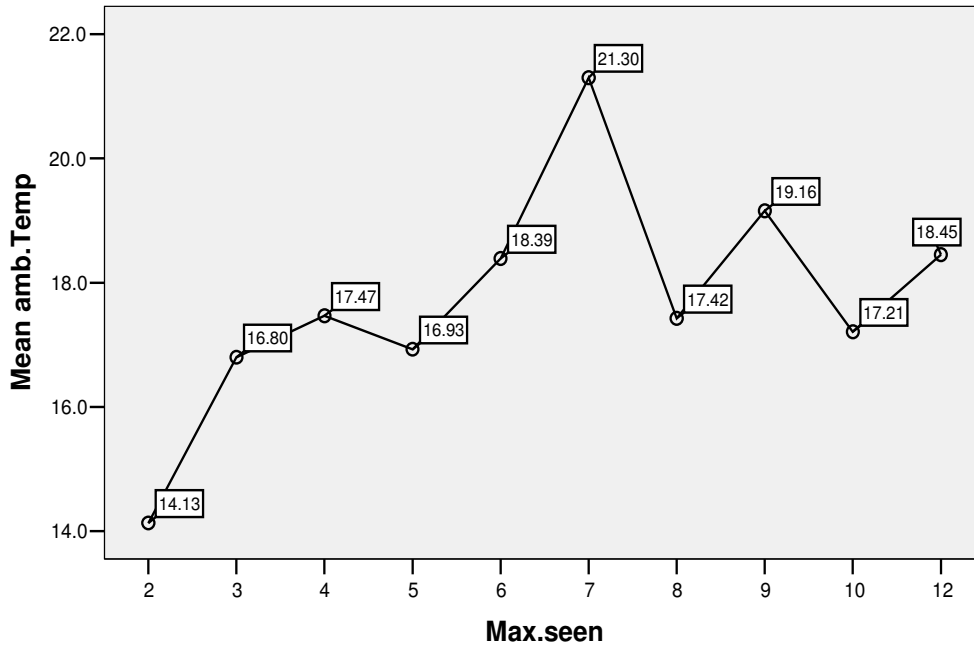


Figure 20. Mean ambient temperature and maximum giant mole rats seen

The mole rat retreats in to the burrow by self or if it recognizes the potential predators (raptors Ethiopian wolf, and domestic dog). The percentage of the retreat by self is greater than retreat due to predators. The frequency of retreat due raptors is greater than due to Ethiopian wolf. The percentage of retreat by self is 54.4% due to raptors 27.1% due to Ethiopian wolves 16.1 and due to domestic dog is 1.9 (Figure 21). In the total frequency of sightings of giant mole rat a total of 9 Ethiopian wolf, 89 alpine chats and 52 raptors of which 30 is auger buzzard were counted in the vicinity at the same time. The frequency of interaction between giant mole rat and raptors is stronger than Ethiopian wolf whereas the frequency of interaction between giant mole rat and alpine chat is the strongest.

Reason for Retreating Giant mole rat

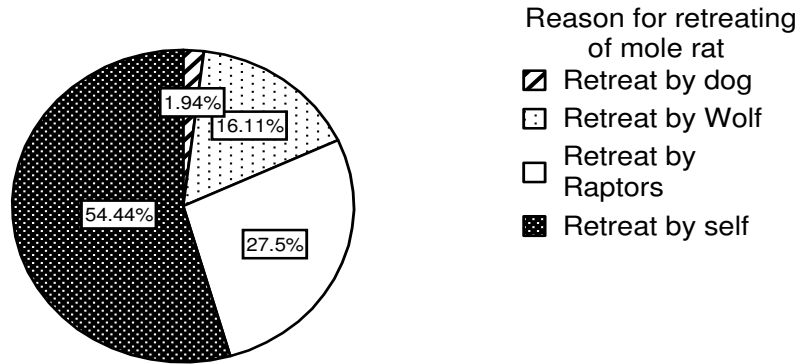


Figure 21. Percentage of retreat of giant mole rat

6.6. Qualitative Data

The burrow of giant mole rat is branched in to multi direction. The eye of the giant mole rat is on the top of the head. It only forages at the periphery of the burrow entry point and retreats into the burrow backwards. It also forages while in side the burrow Ethiopian wolf fail to dig out the giant mole rat from such depth once it retreat to the burrow. Giant mole rat does not stay above the ground for along time. It sustains surface activity if and only if the area is quiet and free form potential predators. It is also vigilant observer in between it pulls pieces of vegetation and does not chew vegetation cut by protruding incisor above the ground. In addition to wolves, domestic dogs were also observed while hunting the Giant mole rats in Sanetti plateau.

7. DISCUSSION

The distribution and density of giant mole rat in the Sanetti plateau is influenced by different factors. Of these, soil factors, vegetations cover, livestock utilization, season and grazing intensity were examined in the present study.

Soil is a restrictive environment for most burrowing animals. Relatively little food and oxygen is available and movement through densely packed sand rocky, gravel and organic debris is difficult. The giant mole rat digs a burrow up to 50 cm for thermoregulatory function (Sillero Zubiri, 1994). So, the soils that cannot be easily excavated to make burrow affect the distribution and density of the giant mole rat. Soil structure, texture, moisture and depth determine the burrow construction, the soil mound and mima mound formation. Soil that contains large amount of gravel is not suitable for giant mole rat for digging. From the present study, in Sanetti plateau near Tuluu Deemtu, the soil contains large gravel and sand dominated by *Helichrysum* and grass species. Giant mole rats are absent in this area because, the burrowing is difficult in such area. If the particle is packed tightly together in clay soil, it also makes burrowing difficult. Burrowing requires 300 - 400 times more energy than required for moving similar distance across the surface (Vieck, 1971; Jarvis and Bennetti 1991). Thus, the burrow systems of giant mole rat are short but intricate (Shimelis Beyene, 1986).

The metabolic energy conservation is important to overcome the cold afroalpine climate (Hinze and Pilley, 2006). Burrow construction is an important component of subterranean animal activity, which influences the distribution. Soils that contain large amount of gravel are difficult to make burrow.

Soil texture in giant mole rat plots is dominantly silt and loam and single grinded structure because; it easily burrowed by soil fauna. Soil moisture content also is an important factor determining the suitability of an area for the giant mole rat (Shimiles Beyene, 1986). Clay sticks to one another in moist. The greater water contents the smaller volume of soil air depletes the oxygen quickly during respiration. The activity of soil fauna is influenced by the supply of oxygen (Wild, 1993). Due to physiological limitation and energy conservation, giant mole rats

prefer silt or aggregate structure whereas none giant mole rats plots are dominated by sand and clay with massive and granular structure. Single grained loam with single grained structure is easily workable. Subterranean rodent tends to live in a porous soil with at least well drained poor water holding capacity (Rickman and Brown, 1972).

Since, digging requires high demand of oxygen for metabolic energy production. The soil pH, percentage saturation and temperature should be expected to influence the distribution and density of giant mole rat, but in the present study there is no significant difference in soil pH percentage saturation and temperatures in the studied plots.

During, the present study, large numbers of giant mole rats are observed in swampy shore during the dry season due to migration because; the soil is well drained and soft during the dry season. This also goes in line with other studies Yalden (1975) and Sillero Zubiri (1994) who have observed high density of giant mole rats along seasonally water logged swamp shores.

In the cliffy rocky area, the number of soil mound and mima mound decreases. Giant mole rats dig burrow up to 50 cm for thermoregulatory purposes. On steeply cliffy area soil depth is short and is not suitable to burrow up to 50 cm. So, mole rat distribution is restricted by thermoregulatory and burrowing requirements. Sillero - Zubiri, 1994 also confirmed that field signs were most abundant where soil depth was greater than 50 cm. So, soil type influences the distribution and number of giant mole rats. However, soil p^H, % moisture and soil temperature factors likely to influence species composition shows no difference between the plots,

Vegetation cover also affects the distribution and density of giant mole rats. Giant mole rats are numerous in moorland above 3000- 4000 m asl. The afroalpine moorland vegetation is dominated by *Alchemilla*, *Helichysum* and giant lobelia (Yalden, 1975, 1985; Yalden and Largan, 1992; Nauka, 2001). Food is the limiting factor of rodent of population distribution (Hansson, 1979). The major food items of giant mole rats are *Alchemila abyssinica* and *Festuca* species (Mamahamed Yaba, 2007). From the present study, *A. abyssinca* is a dominant species in high and low giant mole rat plots where as grass species and *H ciferspinum*. Are dominant in none giant mole rat plot. Sillero Zubiri (1994) confirmed that the old mima mound left by giant mole rat trigger the growth of *A. abyssica* which is favoured by murid rodents. Low density

giant mole rat occurs in *Helichyrsom* dwarf scrub dominated area at Tullu deemtu. In the present study, plots where mole rats were absent. The giant mole rat is also absent where giant heath *Erica* shrub is observed. Meihe and Meihe (1994) confirmed that limited or no giant mole rat is present in area covered by *E. arboria* shrub. Because, the *Erica* vegetation covers is edaphically unsuitable for burrowing. Thus, vegetation cover influences the density and distribution of mole rats.

The mean of soil mound (fresh open and fresh closed hole) were different during dry and wet seasons in the giant mole rat plots. The number of soil mound depends on the soil factors, availability of food and sex of the animal (Hensan and Beck, 1968; Jarvis, 1973b). Thermoregulatory benefits of the hole also determine the number of fresh open and closed holes (Sillero Zubiri, 1994). The number of fresh open and closed holes is abundant on mima mound. However, this does not necessarily mean that there is more number of mole rats on mima mounds because, mole rat is a solitary rodent live on discrete burrow system on mima mound. In addition to this, in some studied plots due to heavy grazing intensity it is difficult to count fresh sign.

Maximum grazing intensity in high and low density giant mole rat is different from none giant mole rat plots. The mean cow dung in giant mole rat plots are also higher than none giant mole rat plots. However, it is not appropriate to determine density of giant mole rat since, cattle and other murid rodents also graze on the same plant item that the giant mole rat feed on.

Soil factors, vegetation cover, the number of mima mound, grazing intensity, slope and season are the main determinants of mole rat distribution. Although, there were many variables that differed between the plots, for example livestock presence, the number of mima mounds, soil bulk density and soil physical properties and vegetation composition, it is likely that soil physical properties and vegetation types are the main influencing factors that determine the presence or absence of mole rats the area. Difference due to livestock is more likely attributed to the difference seen in vegetation rather than a direct link to the mole rats. Similarly, mima mounds are found from the burrowing of giant mole rat and so do not determine their distribution but rather are a result of their distribution. Although, bulk density was different between the plots,

there was no difference in bulk density between old and no mounds suggesting that again these differences are not directly linked to mole rat but rather soil properties.

The number of mima mound is the best indicator of the density of giant mole rat in a given area. The justification for this is the giant mole rat is a solitary rodent that lives in a discrete burrow system on mima mound. The number of mima mound is a function of mole rat density.

In the northern half of Sanetti, well formed and numerous mima mounds are found because, giant mole rats occur here at a higher density. From field observation, the Ethiopian wolves are frequently seen here while hunting. Wolf density is positively correlated with giant mole rat density (Sillero Zubiri, 1994).

The determination of mole rat density by the number of mima mound goes in line with Deliquet and Schaffer (1942) hypothesis that fossorial rodents produce mima mound which produces mima type of micro relief. There is one functional nest per the burrow system of mole rats. The functional nesting system of mole rat usually present beneath or in mima mound (Gakahu and Cox, 1984). The nesting site mainly used for sleeping, resting and breeding (Jarvis, 1973a). In addition to this, Mima mound found in raised area than the surrounding. Thus, it avoids the mole rat from flooding. If the burrow system is the territory of giant mole rat then, one can consider mima mound as home range. Sillero Zubiri (1994) also found that the presence of mima mound was strongly correlated with the mean number of fresh signs (fresh open and closed hole) per transect point Therefore, the density and distribution of mole rat is best determined by mima mound. Thus it appears that soil type and vegetation covers are good predictors of mole rat distribution where as mima mounds are the best potential indicator of mole rat density in the area (Plate 1).



Plate 1. Mima mound of giant mole rat in Sanetti plateau, October 2008 (Photo by Abiyot G)

Soil is an important indicator of ecosystem health. Soil organic carbon is an important constituent of soil. Soil organic carbon interacts with soil components and influences soil the chemical physical and biological properties. Soil properties are the function of soil organic carbon (Wild, 1993). Because of this, soil organic carbon is the best available indicator for evaluating state of soil quality, soil condition, soil erosion potential, productivity and ecological function (Sokora and Sotti, 1996). Soil organic carbon is a major pool that impacts the global carbon cycle. Increasing soil organic carbon is desirable in improving soil fertility. Understanding the present pattern of soil carbon content is essential for projecting future change (Rossenberg, *et al.*, 1988). So, examining factors that affect soil carbon will be an important attribute when considering soil carbon potential in the global carbon market. Carbon market is an important policy instrument aims to reduce green house gas emission. It is a market based instrument provides economic incentives for ecosystem payment in which carbon is traded in ton cabondioxide equivalent (Watson *et al.*, 2008). Any activities that affect vegetation biomass and soil have potential to sequester carbon or release carbon dioxide into atmosphere. Reduction in forest cover and increase in soil disturbance represent losses of carbon into atmosphere and, causes on going reduction of carbon sink (Schlamadinger and Marland, 2000). Burrowing

rodents disturb soil and affect vegetation hence affect soil organic carbon. The disturbance of carbon store in the ecosystem is not recommended in the time of global warming, rather there is a growing interest in the sequestration of carbon. Giant mole rats affect soil organic carbon as burrowing action, release carbon dioxide into atmosphere thus, contribute to climate change.

The clean development mechanism which enables the international trade of carbon credit currently does not allow trading of existing or protected ecological carbon stores despite growing threats they face globally. Conservation of existing carbon stores has become more widely recognized for its importance in mitigating the effects of climate change globally. There is a need for protected areas to begin examining carbon store baseline for their potential in carbon trading.

The mean soil carbon and nitrogen in high and low density giant mole rat plots significantly lower than none giant mole rats. The present studies go in line with other studies conducted in Tibet highland. Soils in zoker mound differ in mean soil organic carbon and nitrogen with surrounding undisturbed soil (Zhang *et al.*, 2003). The old mound soil in giant mole rat plots significantly lowers in mean organic carbon and available nitrogen content than none giant mole rat plots. This verifies that, burrowing of giant mole rat reduces soil carbon since, burrowing releases carbon dioxide into the atmosphere. The most conspicuous effect of giant mole rat on soil arises from burrowing and mima mound formation.

The ton of CO₂ and soil carbon in high and low density giant mole rat plots is lower than none giant mole rat. This is also true for nitrogen.

Soil carbon trading is often excluded from carbon project due to the complexity of determining the predicting the rate of carbon loss from soil with change in land use. In this study the evaluation is used based on the following assumption:

Soil carbon will still occur in soil even disturbed by mole rat.

Carbon credit can be generated from the amount of soil carbon that would have been lost if the area was disturbed by mole rat for a long time.

Decrease in disturbance by mole rat in the afro alpine will result in soil carbon conservation.

Undisturbed soil will continue to sequester carbon over long period of time

Soil continue to be disturbed by mole rat will continue to loss carbon over time

There is low soil carbon decomposition and nutrient recycling as a result of cold temperature of afroalpine. Based on the above assumption actual economic value of soil carbon loss significantly higher due to burrowing of giant mole rat Soil organic carbon released by giant mole rat contributes to climate change. If the soil carbon trading is included in carbon trading approximately 12686.16 US dollar that can be obtained from soil carbon trading is lost due to burrowing giant mole rat.

This was also true for nitrogen, when carbon is affected nitrogen is also affected. Nitrogen is also converted to ton nitrogen per hectare then to ton equivalent CO₂ and traded in soil carbon trading however; its economic value is not indicated in the present study. Hence its conversion is complicated.

So, increase in population number of rodents is a threat to ecological carbons store. Burrowing of rodent facilitates the decomposition of soil organic matter by soil microbes. . Although, soil carbon is not yet a feasible option for carbon trading currently much talk surrounds its inclusion into the voluntary carbon market. Thus, examining its economic feasibility of soil carbon potential in the afro-alpine can help management make decisions in terms of developing carbon projects.

The carbon and nitrogen content of old mound soil and no mound soil in giant mole plot is the same because once soil is disturbed by giant mol rat it takes long time to sequester carbon whereas the undisturbed no mound soil in non giant mole rat will continue to sequester carbon over along period time

The mean of Carbon and Nitrogen in soil occurs in none giant mole rat plots are significantly higher than giant mole rat plots. From the present study, two important things can be justified; in terms of carbon and climate change. First, it is unlikely that afroalpine habitats where high level of burrowing giant mole rats exist will not be viable option for generating income through carbon trading and the second is most predatory animals living on Sanetti plateau relies

mainly on the rodent communities. Therefore, wolves and raptors play important roles in mitigating climate change as they keep rodent numbers down.

Interestingly, these results may also bring Ethiopian wolves into the climate change spotlight further providing evidence of the need for conserving the Ethiopian wolf as important climate change mitigations.

Soil bulk density is a variable property affected by soil organic matter, cultivation and compression by animals. From the present study, the burrowing of mole rat affects soil organic carbon. Soil organic carbon is inversely related to soil bulk density. When soil organic carbon is disturbed by burrowing of giant mole rat, the soil bulk density increases because, the organic matter used as binding soil particle decrease as a result the volume of soil increase. Soil bulk density in giant mole rat plots is higher than none giant mole rat plots. Soil with lower contents of carbon organic carbon tends to have higher bulk densities (Huntington *et al.*, 1989). The increase in the soil bulk density affects soil pore space (porosity). Soil pore space determines soil erosion potential and water holding capacity because, the smaller soil pores space the smaller the infiltration and percolation. Therefore, as impact of disturbance of soil organic carbon by mole rat continues, the soil bulk density increases as result, soil pore space decrease. The smaller infiltration and percolation enhance surface run off. Thus, high erosion potentiality and loss of water holding capacity of soil as a result much water removed as surface runoff instead of being stored in water table. This will decrease the hydrology and ecosystem functionality of Sanneti plateau.

In the present study soil phosphorous negatively correlated with the mean of carbon and nitrogen. The available phosphorus content in soil is significantly high in low giant mole rat plot. The burrowing of giant mole rat enriches soil with phosphorus dioxide Because, once nutrient poor soil is deposited on the ground surface, the temperature of soil found in fresh mound increases leading to concomitant promotion of mineralization of organic phosphorus and Nitrogen in the abundance of soil microorganism. The mean of Phosphorus in high giant mole rat plots is lower than low giant mole rat density plots since most of the soil mound in high density giant molerat plots is fresh. This goes in line with other studies conducted in eastern Sanetti plateau that the soil possessed highest content of phosphorus (143 ppm) due to the

burrow action of giant mole rat (Weninerit and Muzuerk, 1984). In this regard, giant mole rats act as micro - geo nutrient recycling agent.

Soil particles density did not show statistical significant difference across the study plots. This is because, rodent do not appear to have impact on soil particles density. Soil particle density largely depends on cation exchange capacity and pH (wild, 1993).

Soil pH is affected by soil organic carbon. The most desirable pH ranges for organic soil from 5.0 to 5.5 (Hazelton and Murph, 2007). The pH result among the study plots also shows no significant difference across the studied plots. This may be due to that in afro - alpine ecosystem the change in pH is not considerable due to leaching.

Besides, their direct influence through burrowing, giant mole rats are indirectly affected by opening the ground to climatic and geomorphic influences as rain splash, erosion and exposure of sediment especially in the afroalpine zone result in low herbaceous cover. This goes in line with other studies in the Tibet and Lesotho highlands, the vast burrow system made by subterranean rodents significantly accelerate soil erosion (Kevin *et al.*, 1999). One of the most important factors contributing for soil erosion is loss of vegetation cover. Vegetation cover is an important for regulating soil moisture content and suitability as it promotes infiltration of water into soil and reduces surface flow. The roots of plants take some water for photosynthesis. Vegetation cover also minimizes the hitting impact of rain drop thereby reducing the break down and erosion of top soil. Intensive foraging by herbivorous rodents in combination with burrowing activity contributes to a loss of vegetation cover leading to large scale vegetation damage and thus erosion (Kinlaw, 1999; Zhang *et al.*, 2003). They reduce plant biomass by as much as 50% and substantially increase plant mortality (Hume, 1994). This trend is also observed on the Sanetti plateau. High density of giant mole rats causes the removal of plant cover and result in heavy bare ground. In the western part of Sanetti plateau where there is high density of giant mole rats the land looks like ploughed area due to extensive burrows of the giant mole rats (Plate 2).



Plate 2. Extensive burrow of giant mole rat in Sanetti plateau, March 2009 (Photo by Abiyot G).

Giant mole rats contribute to a loss of ground cover and disturb the top soil making it more vulnerable to erosion. The physical burrow system also enhances erosion, and the burrow system made by the giant mole rat is used as water tunnel during rainy season thus, enhancing soil erosion by increasing the speed of surface run off. This goes in line with other studies burrowing can have tremendous impacts on the landscape integrity by accelerating soil erosion (Hall *et al.*, 1999; Kinlaw, 1999; Gabet, 2000). Rodents that forage under ground produce vast load of sediment that are easily transported by shallow surface water flow (Kinlaw, 1999; Meentemeyer *et al.*, 1998). In the present study, soil erosion data are not analyzed because it has high number of zero values. In addition to this, soil erosion takes long time to be detected.

Giant mole rats also benefit the environment their behavioural activities burrowing, cropping vegetation and formation of mima mound causes physical change in the environment. It has a pronounced effect in soil dynamic and formation. The burrowing makes soil structure very loose.

This facilitates movement of air in the soil freely and increases infiltration of water into the ground. The availability of air and water in the soil improves the habitat quality for plant root and soil microbes (Wild, 1993).

The burrowing and formation of mima mound change soil carbon content and above ground plant biomass. Giant mole rats alter the environment through their behavioural or by virtue of large collective biomass. It causes physical change in the environment that affects the structure of afro alpine communities. The burrowing action and cropping of vegetation prevent ecological succession and maintains the afro- alpine ecosystem.

Giant mole rat is an important animal in ecosystem structure and development. It acts as a facilitator, positive effects on the survival and reproduction of some of the other species in the afro -alpine communities. It affects the dynamic of biological communities, direction of succession, micro- geomorphic change and biogeochemistry cycling in afro-alpine ecosystem. Therefore, giant mole rats act as environmental engineer or foundation species (Plate 3).



Plate 3. Giant mole rat foraging in Sanetti plateau, March 2009 (Photo by Abiyot G)

Population studies of giant mole rat are largely dependent on indirect method (Jarvis, 1973b). The mark and release method can not be used because giant mole rats are difficult to trap repeatedly and lives in discrete burrow system. Different methods can be used for giant mole rat count. These are soil mound count, fresh sign counts (open hole, closed hole) count, mima mound count and counting giant mole rat emerging in a given plot over a period of time. In the present study, all approaches were used to determine the best method of giant mole rat population study.

The maximum giant mole rat counted is significantly positive correlation with morning fresh closed holes and afternoon open holes. The number of fresh closed holes and open holes is used to indicate the density of mole rat. However, it is not good parameter for population study because, number of fresh open and closed holes depends on soil moisture, availability of food, season. The numbers of fresh closed and open holes were greater in wet season than dry season. Therefore, this does not necessarily mean that the number of mole rat is large during wet season. The number of fresh sign (closed and open holes) is numerous on mima mounds than other places.

Mole mound (old closed hole) count is good to study the population of mole rat because, soil moisture, the availability of food and sex of the animal influence the number of soil mound produced per unit time (Jarvis and Sale, 1971; Jarvis 1973b). In the present study, in some study plots, it was very difficult to count soil mound due to heavy disturbance by cattle. Its presence was only noticed by fresh open hole on bare ground (Plate 4).



Plate 4. Giant mole rat fresh hole on bare ground in sanetti plateau, March 2009 (Photo by Abiyo G).

The number of closed holes in the afternoon has negatively related the number of open hole in the morning because to conserve metabolic energy, giant mole rats close only few holes that have thermoregulatory benefit. So, low number of closed holes does not necessarily mean that the number of giant mole rat present is low.

Studies by Yalden (1975) and Shimelis Beyene (1986) shown maximum number of giant mole rat is 40 and 60 per hectare, respectively. The present study result shows that counting fresh open holes in the morning is better indicator of giant mole rat number. Based on the maximum number of giant mole rat seen at any one time ($n = 12$, $n = 4$ in 50 x 50m plots). This study predicts that 48 occur per hectare in high density area and 16 in low density areas. This estimate is lower than pervious estimates by Yalden and Shemilise. The decline in the number may be due to the methodological difference and severe anthropogenic impact on the Sanetti plateau. Anthropogenic disturbance limit the population density of rodent (Zhang *et al.*, 2003). Form the present study it was found that heavy competition with domestic livestock is the likely cause for the decline of the number. The giant mole rat count method is better than the fresh sign count but, it is not the best because, the same giant mole rat comes out through different openings.

Because of this, there is a probability of counting the same animals more than once. In addition to this, two giant mole rats can be counted due to overlap of the burrows

All giant mole rats can not start surface activity late in the morning or even the midday. As , the count is in limited hours of the day, there is a probability to miss some of the animal. Giant mole rats disappear completely for a long time in response to any strange sound or disturbance around their habitat.

Mima mound count can also be used for population estimate. From factor analysis; the density and distribution of giant mole rat is best determined by the number mima mound in the given area. Therefore, this method is better than old soil mound count and fresh sign count. However, this method has also the following limitations: On one mima mound more than one giant mole rat can be present at the same time. From ecological observation, two giant mole rats were observed while foraging nearby 50 cm, 20 cm and 10 cm apart at different time. Giant mole rat is a solitary rodent. Combination of mima mound count and giant mole rat counts is found to be the best methods in the giant mole rat population study because, it minimizes the limitations.

Population study of giant mole rats is very important to develop conservation models based on trends in population size and change in habitant availability and to investigate the impact of mole rat on ecosystem. Species with few individuals confined to small geographic ranges are at risk of extinction because they can easily be eliminated by sudden local disturbance such as unusual weather, disease and predator and thus, information on the population of giant mole rat is also useful for proper management and sustainable development of afroalpine ecosystem, any change in population of giant mole rat can affect the biological communities of afroalpine ecosystem. Giant mole rats through, their prime ecological function, behaviour, and trophic interaction exerts a control over the afro alpine communities. Thus, the destruction causes cascade effect.

Giant mole rat behaviour and tropic interaction are vital for ecological co existence with other fauna. In Sanetti plateau there exists a complex ecological interaction between the giant mole rat with afroalpine fauna. This coexistence of ecological interaction is grouped into prey predatory, mutualism, commensalisms and competition.

The prey-predatory interaction helps to regulate population size of rodents. Ethiopian wolf is the main specialist solitary hunter of rodents. In the Bale Mountains mole rat forms large parts of the diet of the Ethiopian wolf. An estimated 40% of wolf diet by weight is the giant mole rat. Giant mole rat is roughly six times the size of the other rodent prey in the area. Ethiopian wolf significantly prefers mole rat to alternative rodents (Sillero Zubiri, 1994). The wolf densities were greatest in habitats with high mole rat population. This study result confirms giant mole rat density is found to be a good indicator of the suitable habitat of the Ethiopian wolf in afro-alpine ecosystem. In addition to this, its wide range of adaptation to afro-alpine ecosystem, giant mole rat can serve as indicator species.

Ethiopian wolf is a specialist predator of rodent. In this study, the following hunting strategies were observed: The Ethiopian wolves use cattle as a hiding ground. Giant mole rats do not retreat to burrow when cattle graze near its burrow. Following the cattle foot step enables wolves to catch the giant mole rat. Because, the movement and sound are not easily recognized by the mole rat

Wolf listens on burrow hole and quickly digs the burrow. In this strategy the wolf insert its long snout into the burrow l hearing to some sort of sound of rodent is heard, it digs quickly into the burrow to dig out the rodent. In central Sanetti, wolf scratches were seen in many places due to this strategy. This indicates that wolves also cause some disturbance of on giant mole rat niche while hunting (plate 5 and 6).



Plate 5. The disturbed plots by Ethiopian wolves in Sanetti plateau October, 2008



Plate 6. Wolf digging on giant mole rat burrows in Sanetti plateau, October 2008 (Photo by Abiyot G)

Raptors and other predators largely depend on giant mole rat in afro alpine ecosystem. During the study, it was observed that Augur buzzard, *Buteo rufofucus*, towny eagle, *Aquila rapa*, steepy eagle, *Aquila nepalensis* and lammergeyer, *Gypaetus barbatus* are the potential avian predators of the giant mole rats. Augur buzzard was frequently observed while hunting. In the present

study, the giant mole rat above surface duration was positively correlated to the number of raptors because as the number of giant mole rat above surface increases, the number of raptor hunting on giant mole rat increases.

The cost of living is very high for giant mole rat in afro-alpine ecosystem because of many potential predators. The giant mole rat is very vigilant on above ground activities. In addition to having subterranean niche for protection from predators giant mole rats have many anti-predator devices and escaping mechanism. During the observations the following anti-predator devices and escaping mechanism were noticed: Giant mole rat burrow system is branched multi directionally. This increases the escape potential. Ethiopian wolves made frequent attempt to dig the giant mole rat out from its burrow. The wolf failed to identify the exact burrow channel in which the giant mole rat moved as the burrow channel leads to multi-direction. It is very difficult for the Ethiopian wolf to dig out giant mole rat from 50 cm depth once it retreat into the burrow. In addition to this, it forages at the periphery of the burrow entry and retreat backward unlike other rodents. This saves time of escaping from potential predators.

The eyes of giant mole rat are located on top of the head. Some subterranean mammals have degenerated eye due to their stay for long period of time in the dark. The giant mole rats have acute sense of sight, and response to slight movement of object near the burrow hole (Mohammed Yaba, 2007). It is also vigilant observer in between it pulls pieces of vegetation and does not chew the vegetation by its protruding incisor above surface.

Giant mole rat and alpine chat had mutualism way of living. When giant a mole rat excavates the burrow and pulls out the soil, some worms are exposed to alpine chat feeds on such worm. When a predator approaches to hunt, the alpine chat gives alarm calls (Ti, Ti) and flies away. During this time, the giant mole rat retreats to its burrow and escapes from potential enemies. When the area becomes safe, alpine chat returns to burrow sites while the giant mole rat comes out to ground and sustains its above ground activity. Giant mole rat uses the alarm of alpine chat to retreat when wolf and raptors approaches its burrow sites. From frequency of sighting in 100 observation of giant mole rat 89 alpine chat were seen with giant mole rat. This is strong frequency of interaction between giant mole rat and alpine chat confirms mutualistic way of living (Plate 7).



Plate 7. Alpine chat and giant mole rat mutualistic way of living in Sanetti plateau, October, 2008(Photo by Abiyot).

Giant mole rats and murid rodents have commensalism. The old burrows left by the giant mole rat were colonized and occupied by murid rodents. When the giant mole rat leaves the burrow mound, the soil is triggered for the growth of *Alchemilla abyssinica*. This is ideal habitat for murid rodents (*Lophoromus melanonyx* and *Arvicanthis blicki*). The murid rodent depends on the burrows that are made by giant mole rat for nesting and to reduce the risk of predators. The giant mole rat shows aggressive behavior when murid rodent approaches its burrow area. However, it dart back into the burrow when it hears their alarm sound (Plates 8 and 9).



Plate 8. Old burrow system occupied by murid rodents in Sanetti plateau October 2008 dominated by *Alchemilla abyssinica* (Photo by Abiyot G.)



A

B



C



D



E

Plate 9. Some of afro alpine muried rodents from Sanetti plateau October 2008 (Photo Abiyot G)

Cattle and giant mole rats have competitive ecological interaction. Herds of 30-50 cattle visited the study plots. Giant mole rats and cattle were the main grazers in afro alpine habitat competing with each other. *A. abyssinica* and *Festuca* grass species, the herb which is highly consumed by the giant mole rat is also highly grazed the cattle. In addition to this, cattle disturb the ecological niche of giant mole rat while walking on the burrow by trampling it. Cattle grazing near the burrow of giant mole rat provide hiding ground for wolves to hunt on the giant mole rat. Cattle grazing on Sanetti plateau will be threat to the ecosystem in the future (Plate 11). Cattle grazing on the ecosystem affect the water holding capacity of the land. In Sanetti plateau, water flows from *Festuca* grass species to the wetlands. The study in Fynbos watershed vegetation in South Africa Cape of Good Hope Nature Reserve decreased when exotic species invaded the area resulting in a decrease of the indigenous vegetation biomass (Purves, *et al.*, 1998). Therefore, as the *festuca* grass species are grazed by the cattle and rodents in the Sanetti the grass biomass will decrease causing a decrease in stream flow. The grazing by giant mole rat and cattle removes the vegetation cover this results bare ground. More bare ground was observed in the Senetti plateau due to combined effect of the giant mole rats and livestock. Bare sediments, mounds and ground patches are vulnerable to erosion. The cattle grazed on grass namely, *Festuca abyssinica* and *Festuca margima* is leading to bare ground in the wetland ecosystem. This goes in line with other studies. Overgrazing in afro- alpine ecosystem enhances soil erosion (Tyson 1999; Kirkpatrick *et al.*, 2002). Therefore, most of the water is removed as surface run off instead of being stored in the water table. This makes hydrology dsyfunction. Sanetti is the source of many rivers and streams. If the disturbance continues, hydrological significance of the area will be lost.



Plate 10. Cattle grazing on Sanetti plateau: Threat to the ecosystem, March 2009
(photo by Abiyot G)

The other competitive interaction observed in Sannetti is the ecological interaction of Ethiopian wolf and raptors. Ethiopian wolf chase the raptors away while hunting. Because, raptors compete with wolves for food by hunting on rodents none compete the other. Because, when the giant mole rat recognizes the sound of raptors flying over head, particularly the auger buzzard above surface activity is limited. This decreases hunting success for the wolf.

The giant mole rat spent a maximum 6.11 and minimum of 2.00 minutes above ground per ten minutes. It emerges to above activity for a very short period of time. In the present study, mole rat spent above ground on an average 3. 59 minute and retreat into the burrow from time to time by self or when it recognizes the potential predators. However, the frequency of retreat by self is greater than retreat due to predators. This would be anti predator device behavior that reduces perdition as staying for along period above ground exposes to risk of perdition.

The number of fresh open holes in the morning is negatively correlated with the number of fresh closed holes in the afternoon. To conserve metabolic energy, giant mole rats do not close all fresh open holes in the morning during the night time. Only those holes that have thermo regulating benefits are closed because closing all the holes needs extra energy demand.

Shimelies Beyene (1986) observed a minimum of three and a maximum of eight augur buzzard per day hunting giant mole rat. During the present study Augur buzzards were frequently observed while hunting on giant mole rat. The number of auger buzzard positively correlated with maximum number of giant mole rat observed above ground per hour in the studied plots. However, giant mole rat is a very vigilant observer while sustain above ground activities. It immediately notices the raptor over head and dart backward into burrow. From field observation it is highly recognized the (Aa. Aa...) sound of Augur buzzard. Air temperature and mole rat activities do not have direct correlation, although mole rats restrict their activities from 08.00 hour to about 18:00 hour in the afternoon (Shimelies Beyene, 1986). But, from field observations wet season this will show the activities of giant mole rat above ground completely restricted till snow melts away.



Plate 11. An augur buzzard waiting for rodent prey in Sanetti

During the present study from the total Frequency of sighting a total of 52 raptors of which 30 auger buzzards attempted to hunt giant mole rats (Plate 11). The retreat due to raptor is 27.5%, the retreat by self 54.44% and retreat by wolf 16.11%.

8 .CONCLUSIONS AND RECOMENDATIONS

8.1. Conclusions

From present study giant mole rats play crucial ecological role in afroalpine ecosystem of Bale Mountains. Its distribution and density are influenced by soil factors, vegetation cover, grazing intensity and season, however density and distribution of giant mole rat is best determined by the number of mima mound in given area. Soil factors and thermoregulatory benefits of the hole determine the number of fresh open and closed holes.

Like other subterranean rodents the giant mole rats have profound influence in afroalpine ecosystem in diverse ways. These are through foraging, burrowing and trophic interaction. They affect the environment particularly when population density is very high in a given area. It causes soil erosion by removing the above ground biomass resulting in bare ground. The burrowing action excavates soil and bulldozes to the surface and exposes it to erosion factors. Burrowing pattern decreases the carbon reservoir in the soil by disturbing soil organic carbon and emits carbon dioxide into the atmosphere contributing to climatic change. Thus, it makes the afro- alpine ecosystem unfeasible for soil carbon trading. Giant mole rats also cause physical change in the environment, which affects the structure of the communities. This makes the giant mole rats the environmental engineers. It benefits the environment in soil formation, aeration and biogeochemistry of nutrient cycling.

It acts as facilitators and improves the habitat quality for other fauna in the area. Giant mole rats are also the important component in the diet of Ethiopian wolf and many avian predators. The change in population number of giant mole rat causes cascade effect in afroalpine of Bale Mountains. In the afroalpine ecosystem giant mole rats are dominant grazers, keystone, indicators and foundation species. Therefore, giant mole rats should be managed properly to ensure ecological equilibrium and preservation of native biodiversity as well as the long-term sustainable use of the afroalpine ecosystem of Bale Mountain National Park.

8.2. Recommendations

Based on the present study, the following points are recommended:

Further study on the ecology of giant mole rat is important to widen the ecological knowledge because, giant mole rats are major source of diet for the Ethiopian wolves and its importance as environmental engineers should not be underestimated.

Examining soil carbon store potential in the afroalpine Bale Mountains where burrowing of mole rat occur is important to assess feasibility in soil carbon trading. Special conservation action has to be taken for the giant mole rat because it is liable to deterministic and environmental stochastic extinction. Study on population assessment of the giant mole rat is very important for sustainable development of the afroalpine ecosystem. Any anthropogenic intervention to afro- alpine habitat of Bale Mountains should be curtailed.

The Park should be gazetted for effective sustainable development and management. Further study on the giant mole rat as ecosystem engineers is important to know how giant mole rats affect the spatial and the temporal patterns of nutrient cycling in the soil. Giant mole rats have to be considered as flagship species to develop the conservation concept in the already fragile afro-alpine ecosystem of the Bale Mountains.

Bale Mountains National park should have to get recognition by UNESCO as, it fulfils the criteria required for World Heritage Site to attract attention of world communities in its conservation programme.

Bale Mountain National Park is IUCN listed protected area category II, which is mainly used as ecosystem protection and recreation. Thus, using afroalpine ecosystem as rangeland should be banned in due time.

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10. APPENDICES

Appendix 1. Surveyed and unsurveyed plots

Transect No	Direction	No. of plot surveyed	No. of plot not surveyed	Reasons for not surveying
1	North	4	6	Deep gorge unable to cross (Togona valley)
2	South	10	0	
3	West	7	3	Big River unable to cross
4	East	8	2	Huge Cliff and valley
5	Northeast	6	4	Big cliff and gorge
6	South east	5	5	Big Gorge
7	Southwest	10	3	
8	Northwest	5	5	Batu Mountains steepy cliff
TOTAL		55	25	

Appendix 2. Selected plots for the study of factors influencing density and distribution of giant mole rats

Plot Number	GMR Density	SE UTM _x	SW UTM _y	SE UTM _x	SW UTM _y
E6	None	399824	756036	599774	756106
Sw10	None	593550	756036	593500	753904
Sw8	None	594404	753904	594351	754495
Sw9	None	594002	754414	594952	754114
E7	None	600333	755831	690881	753827
N2	Low	597337	758016	597296	758017
N4	Low	597155	759359	597096	759349
Nw3	Low	596181	757790	596130	757791
SE2	Low	597945	756669	597895	756669
SE3	Low	598384	756290	598333	756290
NE2	High	597521	757281	597472	757281
NE3	High	598621	757449	598559	757439
Sw2	High	596962	756774	595913	756759
W3	High	596138	757148	596087	757147
E5	High	599368	756429	599318	756427

N.B. GMR- giant mole rat, SE UTM and SW UTM are the GPS reading of plot corners south east and south west

Appendix 3. Grazing intensity scale used to collect data on livestock utilization

Grazing/browsing intensity	Soil indicators	Vegetation structure indicators	Vegetation composition indicators
None(0)	No herbivore dung ,bare ground ort rack present	As for light but no browse on the shrub layer; no or few sapling where there has been no grazing for many years no browsed shoots on or very few seedlings	Extensive mono specific mats of Vigorous ground layer species may occur on some sites
Light (1)	Dung bare ground and tracks of grazing animals hard to find	Well developed shrub layer with no obvious browsing a lush ground vegetation in place where the shrub layer cover no more than 30 -50 % of the ground	Shrub layer dominated by grazing sensitive species ground mosses un common and consisting of few species
Moderate(2)	Patches of bare soil small and rare dung from grazing animals	Patchy shrubs showing evidence of pruning or browse line grounds vegetation variable in height up to 30 cm and showing direct evidence of browsing	Ground vegetation compressing a mixture of grasses hers or dwarf shrubs including some of the more grazing sensitive specie of herb wide range of moss species
	Few	Shrub absent or moribund	Grasses and mosses

Heavy(3)	patches of bare soil abundant dung from grazing	topiary effects on remaining shrubs a browse line on mature trees ground vegetation <20 cm trees seedlings not projecting	dominating ground vegetation; surviving herb species usually dominated by unpalatable species.
Very heavy(4)	Extensive patches of bare soil	No shrub layer; obvious browse line on mature trees ;ground vegetation <3 cm tall and of trampling down of ground flora suppression of growth and killing of seedling.	Grass and mosses per dominating ground vegetation ;surviving herbs species usually dominated by unpalatable species ; very abundant dung from grazing animals mosses scarce or absent the more palatable species

N.B Table Continued

Appendix . Buran –Bunquet scales used to collect data on vegetation cover and bare ground

Value	Braun-Blanquet scale (% cover)
5	76-100%
4	51-75%
3	26-50%
2	6-25%
1	1-5%
0	<1%

Appendix 5. Soil bulk density samples identification code

SAMPLE ID	Depth collected (cm)	Location in plot
Plot No. P 1	0-10	Pit
Plot No. P 2	10-20	Pit
Plot No. P 3	20-30	Pit
Plot No. P4	30-40	Pit
Plot No. P 5	40-50	Pit
Plot No. O1A	0-10	Old mound sample 1.
Plot No. O1B	40-50	Old mound sample 1.
Plot No. O2A	0-10	Old mound ample 2.
Plot No. O2B	40-50	Old mound sample 2.
Plot No. O3A	0-10	Old mound sample 3.
Plot No. O3B	40-50	Old mound sample 3.
Plot No. N1A	0-10	No mound sample 1.
Plot No. N1B	40-50	No mound sample 1.
Plot No. N2A	0-10	No mound sample 2
Plot No.N2B	40-50	No mound sample 2
Plot No.N3A	0-10	No mound sample 3
Plot No.N3B	40-50	No mound sample 3

Appendix 6. Laboratory soil samples identification code for Carbon test

SAMPLE ID	Depth (cm)	Collected	Location in plot
Plot No. 01	0-50		Old mound sample 1
Plot No. 02	0-50		Old mound sample 2
Plot No. O3	0-50		Old mound sample 3
Plot No. N1	0-50		No mound sample 1
Plot No. N2	0-50		No mound sample 2
Plot No. N3	0-50		No mound sample 3

Appendix 7. Soil Carbon, Nitrogen, Available Phosphorous and Particle density laboratory result

GMR				Dept	Sample					PD(g/
Density	Date	UTMx	UTMY	h	IDS	%C	N	C/N	AVL P.	cc)
Low	Oct2/2008	597337	758015	0-50	N2O1	2.694	0.293	9	5.14	2.39
Low					N2O2	3.619	0.321	11	4.88	2.46
Low					N2O3	1.548	0.172	9	70.02	2.42
Low					N2N1	2.814	0.515	5	29.06	1.79
Low					N2N2	2.734	0.273	10	36.34	2.45
Low					N2N3	2.573	0.227	11	62.56	2.44
Low	Oct3/2008	597155	759359	0-50	N4O1	3.297	0.249	13	11.36	2.36
Low					N4O2	3.619	0.272	13	9.60	2.32
Low					N4O3	1.809	0.206	9	54.94	2.62
Low					N4N1	2.734	0.263	10	76.72	2.41
Low					N4N2	2.151	0.223	10	47.46	2.42
Low					N4N3	2.884	0.228	13	58.82	2.45
Low	Oct4/2008	596181	757790		NW3O1	1.372	0.146	9	18.42	2.50
Low					NW3O2	1.260	0.160	8	17.98	2.51
Low					NW3O3	4.984	0.328	15	54.86	2.42
Low					NW3N1	2.520	0.323	8	18.00	2.56
Low					NW3N2	3.136	0.211	15	16.70	2.49
Low					NW3N3	1.344	0.132	10	14.30	2.55
Low	Oct5/2008	597945	756669		SE2O1	2.240	0.196	13	21.12	2.48
Low					SE2O2	1.876	0.148	9	21.52	2.55
Low					SE2O3	1.232	0.132	10	21.38	2.50
Low					SE2N1	1.540	0.151	12	39.14	2.50
Low					SE2N2	2.436	0.195	15	60.82	2.49
Low					SE2N3	1.712	0.378	12	16.38	2.37
Low	Oct6/2008	598384	756290		SE3O1	3.388	0.287	12	5.10	2.45
Low					SE3O2	2.800	0.232	15	4.60	2.39
Low					SE3O3	4.872	0.330	14	22.46	2.41
Low					SE3N1	2.912	0.210	13	16.56	2.68
Low					SE3N2	3.276	0.240	13	15.84	2.60

Low				SE3N3	3.360	0.263	13	5.50	2.44
High	Oct7/2008	597521	757281	E5O1	3.892	0.307	13	5.08	2.63
High				E5O2	3.444	0.305	11	5.20	2.17
High				E5O3	3.276	0.258	13	4.88	2.58
High				E5N1	4.368	0.349	13	5.64	2.59
High				E5N2	3.248	0.283	11	19.36	2.48
High				E5N3	4.480	0.388	12	11.10	2.45
High	Oct8/2008	596138	757148	W3O1	2.100	0.160	13	30.54	2.47
High				W3O2	2.716	0.200	14	11.44	2.52
High				W3O3	2.160	0.160	14	12.22	2.61
High				W3N1	2.380	0.199	12	24.14	2.59
High				W3N2	1.708	0.167	10	19.20	2.63
High				W3N3	1.811	0.137	13	35.82	2.54
High	Oct9/2008	596962	756774	SW2O1	5.460	0.357	15	11.36	2.57
High				SW2O2	2.563	0.186	14	26.86	2.76
High				SW2O3	1.839	0.141	13	42.14	2.54
High				SW2N1	3.844	0.252	15	57.94	2.63
High				SW2N2	2.340	0.164	14	5.30	2.49
High				SW2N3	3.018	0.202	15	33.26	2.52
High	Oct10/2008	598607	757449	NE3O1	3.566	0.255	14	20.90	2.27
High				NE3O2	1.017	0.375	16	16.02	2.46
High				NE3O3	2.451	0.200	12	63.24	2.48
High				NE3N1	1.504	0.141	11	5.50	2.61
High				NE3N2	5.794	0.349	17	15.44	2.25
High				NE3N3	3.733	0.235	16	11.26	2.76
High	Oct11/2008	597521	757281	NE2O1	3.844	0.239	16	72.44	4.34
High				NE2O2	4.791	0.294	16	10.46	1.23
High				NE2O3	4.401	0.245	18	4.78	2.36
High				NE2N1	4.401	0.281	16	3.88	2.37
High				NE2N2	4.067	0.221	18	3.46	2.57
High				NE2N3	3.956	0.402	10	5.06	2.60
None	Oct12/2008	599824	756036	E6N1	5.014	0.365	14	7.12	2.47
None				E6N2	5.349	0.329	16	7.46	2.52
None				E6N3	5.126	0.533	10	6.58	2.53
None	Oct13/2008	600333	755831	E7N1	6.560	0.568	12	10.60	2.34
None				E7N2	6.960	0.602	12	5.54	2.34
None				E7N3	7.200	0.710	10	5.54	2.26

None	Oct14/2008	594404	754495	SW8N1	3.080	0.266	12	80.18	2.32
None				SW8N2	2.280	0.221	10	46.22	2.52
None				SW8N3	3.400	0.315	11	28.90	2.47
None	Oct15/2008	660333	754114	SW9N1	7.504	0.588	13	10.38	2.46
None				SW9N2	2.034	0.138	15	79.68	2.54
None				SW9N3	3.343	0.232	14	10.38	2.52
None	Oct16/2008	393550	753904	SW10N1	7.588	0.112	14	3.36	2.52
None				SW10N2	4.600	0.375	12	17.36	2.39
None				SW10N3	1.950	0.133	15	9.34	2.42

N.B Table Continued

Appendix 8. Giant mole rat population and behavior study plots

Plot No.	GMR Density	SW UTM _X	SW UTM _Y
Site 1	High	5985200	756819
Site 2	High	595596	757168
Site 3	High	598465	755521
W1	High	597266	757236
E3	High	598348	756829
NW3	Low	596181	757790
SE4	Low	598796	755910
SW5	low	595808	755643
SW3	low	596508	756363
W5	Low	595061	7569353

Appendix 9. Braun-Banquet Scale- vegetation cover and bare ground in the study plots

Plot number	GMR density		Q1	Q2	Q3	Q4	Q5	Total	Average
E6	None	BG	10	5	10	10	10	45	9
E6	None	Grass	15	30	40	35	50	170	34
E6	None	Rock	0	0	5	5	5	15	3
E6	None	A.abv.	0	10	0	5	5	20	4
E6	None	H.cit	20	10	30	20	5	85	17
E6	None	H.gof.	0	15	15	10	15	55	11
E6	None	A.rotti	0	0	0	0	0	0	0
E6	None	A.hym	50	25	0	10	5	90	18
E6	None	Sensio spp	0	0	0	0	0	0	0
E6	None	H.rupp.	0	0	0	0	0	0	0
E6	None	Others	3	3	4	0	3	13	2.6
		total	98	93	99	100	98	488	97.6
SW10	None	BG	20	15	7	10	15	67	13.4
SW10	None	Grass	20	20	30	40	35	145	29
SW10	None	Rock	0	0	0	0	0	0	0
SW10	None	A.abv.	5	5	0	0	30	40	8
SW10	None	H.cit	40	30	50	30	15	165	33
SW10	None	H.gof.	0	23	0	15	13	51	10.2
SW10	None	A.rotti	0	0	0	0	0	0	0
SW10	None	A.hym	0	0	0	0	0	0	0
SW10	None	Sensio spp	0	0	0	0	0	0	0
SW10	None	H.rupp.	0	0	0	0	0	0	0
SW10	None	Others	3	1	5	5	1	15	3
		total	98	94	95	100	98	485	97
SW9	None	BG	7	10	25	5	30	77	15.4
SW9	None	Grass	40	40	25	40	25	170	34
SW9	None	Rock	15	15	25	10	15	80	16
SW9	None	A.abv.	10	10	0	0	0	20	4
SW9	None	H.cit	30	20	20	40	25	135	27
SW9	None	H.gof.	0	0	0	0	0	0	0
SW9	None	A.rotti	0	0	0	0	0	0	0
SW9	None	A.hym	0	0	0	0	0	0	0
SW9	None	Sensio spp	0	0	0	0	0	0	0

SW9	None	H.rupp.	0	0	0	0	0	0	0
SW9	None	Others	0	3	5	5	0	13	2.6
total			97	98	100	100	95	490	98
E7	None	BG	15	10	15	15	30	85	17
E7	None	Grass	25	40	25	20	20	130	26
E7	None	Rock	5	15	20	15	20	75	15
E7	None	A.abby.	10	3	5	0	0	18	3.6
E7	None	H.cit	25	10	20	20	20	95	19
E7	None	H.gof.	0	10	5	10	5	30	6
E7	None	A.rotti	3	0	3	5	3	14	2.8
E7	None	A.hym	20	0	0	5	0	25	5
E7	None	Sensio spp	0	0	0	0	0	0	0
E7	None	H.rupp.	0	0	0	0	0	0	0
E7	None	Others	5	2	2	0	0	9	1.8
total			98	93	95	100	98	484	96.8
SW8	None	BG	20	15	7	10	15	67	13.4
SW8	None	Grass	20	30	30	40	35	155	31
SW8	None	Rock	15	0	5	10	10	40	8
SW8	None	A.abby.	5	5	0	0	3	13	2.6
SW8	None	H.cit	40	30	50	30	5	155	31
SW8	None	H.gof.	0	3	0	0	3	6	1.2
SW8	None	A.rotti	0	0	0	0	0	0	0
SW8	None	A.hym	0	0	0	0	0	0	0
SW8	None	Sensio spp	0	0	0	0	0	0	0
SW8	None	H.rupp.	0	0	0	0	0	0	0
SW8	None	Others	3	2	5	0	3	13	2.6
total			93	95	97	100	92	477	95.4
N4	Low	BG	15	10	20	10	10	65	13
N4	Low	Grass	5	5	2	10	10	32	6.4
N4	Low	Rock	25	15	15	10	5	70	14
N4	Low	A.abby.	20	35	20	0	20	95	19
N4	Low	H.cit	10	10	13	45	20	98	19.6
N4	Low	H.gof.	20	20	20	25	25	110	22
N4	Low	A.rotti	0	0	0	0	0	0	0
N4	Low	A.hym	0	0	0	0	0	0	0
N4	Low	Sensio spp	0	0	0	0	0	0	0
N4	Low	H.rupp.	0	0	0	0	0	0	0

N4	Low	Others	3	3	2	3	2	13	2.6
		total	93	98	92	93	92	468	93.6
N2	Low	BG	20	10	10	30	20	90	18
N2	Low	Grass	30	0	10	13	5	58	11.6
N2	Low	Rock	5	20	20	20	15	80	16
N2	Low	A.abby.	20	30	30	20	40	140	28
N2	Low	H.cit	5	20	20	0	10	55	11
N2	Low	H.gof.	20	5	10	10	40	85	17
N2	Low	A.rotti	0	10	0	5	10	25	5
N2	Low	A.hym	0	0	0	5	5	10	2
N2	Low	Sensio spp	0	10	0	0	0	10	2
N2	Low	H.rupp.	0	0	0	3	0	3	0.6
N2	Low	Others	0	0	0	0	0	0	0
		Total	100	99	95	100	90	484	96.8
NW3	Low	BG	60	30	0	20	0	110	22
NW3	Low	Grass	5	10	20	10	5	50	10
NW3	Low	Rock	20	0	10	10	0	40	8
NW3	Low	A.abby.	5	50	25	25	25	130	26
NW3	Low	H.cit	5	5	5	15	35	65	13
NW3	Low	H.gof.	0	4	0	20	0	24	4.8
NW3	Low	A.rotti	0	0	10	10	5	25	5
NW3	Low	A.hym	0	0	0	10	0	10	2
NW3	Low	Sensio spp	0	0	0	0	0	0	0
NW3	Low	H.rupp.	0	0	0	0	0	0	0
NW3	Low	Others	5	0	0	0	0	5	1
		total	100	95	95	100	90	480	96
SE3	Low	BG	5	30	10	4	5	54	10.8
SE3	Low	Grass	20	7	0	10	40	77	15.4
SE3	Low	Rock	10	20	3	3	2	38	7.6
SE3	Low	A.abby.	25	25	60	30	25	165	33
SE3	Low	H.cit	10	3	3	10	15	41	8.2
SE3	Low	H.gof.	10	3	7	10	9	39	7.8
SE3	Low	A.rotti	10	0	0	0	0	10	2
SE3	Low	A.hym	0	0	0	10	0	10	2
SE3	Low	Sensio spp	0	0	0	0	0	0	0
SE3	Low	H.rupp.	0	0	0	0	0	0	0
SE3	Low	Others	5	10	15	15	0	45	9

		total	95	95	98	98	91	477	95.4
SE2	Low	BG	40	20	10	10	15	95	19
SE2	Low	Grass	15	8	10	10	10	53	10.6
SE2	Low	Rock	10	5	5	5	25	50	10
SE2	Low	A.abby.	10	50	30	50	30	170	34
SE2	Low	H.cit	10	0	0	0	0	10	2
SE2	Low	H.gof.	0	5	0	0	15	20	4
SE2	Low	A.rotti	5	2	15	20	0	42	8.4
SE2	Low	A.hym	0	0	0	0	0	0	0
SE2	Low	Sensio spp	0	0	0	0	0	0	0
SE2	Low	H.rupp.	0	0	0	0	0	0	0
SE2	Low	Others	5	2	7	3	2	19	3.8
		total	95	92	97	98	97	479	95.8
E5	High	BG	30	15	20	15	15	95	19
E5	High	Grass	3	10	10	45	3	71	14.2
E5	High	Rock	30	5	15	15	30	95	19
E5	High	A.abby.	10	20	35	10	20	95	19
E5	High	H.cit	10	10	10	0	0	30	6
E5	High	H.gof.	2	20	5	0	0	27	5.4
E5	High	A.rotti	10	0	0	0	0	10	2
E5	High	A.hym	0	0	0	0	0	0	0
E5	High	Sensio spp	0	0	0	0	0	0	0
E5	High	H.rupp.	0	0	0	0	20	20	4
E5	High	Others	5	10	5	5	3	28	5.6
		total	100	90	100	90	91	471	94.2
NE3	High	BG	45	45	30	15	30	165	33
NE3	High	Grass	10	20	20	10	15	75	15
NE3	High	Rock	5	10	15	20	20	70	14
NE3	High	A.abby.	25	15	20	15	15	90	18
NE3	High	H.cit	0	0	0	5	3	8	1.6
NE3	High	H.gof.	0	0	0	15	5	20	4
NE3	High	A.rotti	3	0	0	0	0	3	0.6
NE3	High	A.hym	0	0	0	0	0	0	0
NE3	High	Sensio spp	0	0	0	0	0	0	0
NE3	High	H.rupp.	0	0	0	10	0	10	2
NE3	High	Others	2	0	5	5	3	15	3
		total	90	91	90	95	91	457	91.4

NE2	High	BG	10	35	10	20	335	410	82
NE2	High	Grass	50	5	10	10	25	100	20
NE2	High	Rock	5	30	3	15	0	53	10.6
NE2	High	A.abby.	15	20	50	20	5	110	22
NE2	High	H.cit	15	3	0	25	20	63	12.6
NE2	High	H.gof.	0	0	0	0	0	0	0
NE2	High	A.rotti	0	0	0	0	10	10	2
NE2	High	A.hym	9	0	0	0	0	9	1.8
NE2	High	Sensio spp	0	0	5	0	0	5	1
NE2	High	H.rupp.	0	0	0	0	0	0	0
NE2	High	Others	3	5	6	0	3	17	3.4
		total	98	98	99	96	98	489	97.8
SW2	High	BG	40	20	15	20	35	130	26
SW2	High	Grass	15	45	35	10	15	120	24
SW2	High	Rock	15	0	25	10	10	60	12
SW2	High	A.abby.	25	10	10	45	25	115	23
SW2	High	H.cit	0	15	5	0	10	30	6
SW2	High	H.gof.	0	0	0	0	0	0	0
SW2	High	A.rotti	0	5	5	0	0	10	2
SW2	High	A.hym	0	0	0	0	0	0	0
SW2	High	Sensio spp	0	0	0	0	0	0	0
SW2	High	H.rupp.	0	0	0	0	0	0	0
SW2	High	Others	2	5	1	2	2	12	2.4
		total	97	100	96	97	97	487	97.4
w5	High	BG	20	20	20	20	20	100	20
w5	High	Grass	35	20	10	10	15	90	18
w5	High	Rock	0	15	30	5	10	60	12
w5	High	A.abby.	30	45	30	45	30	180	36
w5	High	H.cit	0	0	5	5	10	20	4
w5	High	H.gof.	0	0	0	0	0	0	0
w5	High	A.rotti	0	0	5	10	5	20	4
w5	High	A.hym	0	0	0	0	0	0	0
w5	High	Sensio spp	0	0	0	5	0	5	1
w5	High	H.rupp.	10	0	0	0	0	10	2
w5	High	Others	5	5	3	3	5	21	4.2
		total	100	95	93	93	95	476	95.2

N.B Table Continued

Appendix 10. Kruskal wallis - test for grazing intensity in the study plots

Test Statistics^{a,b}

	GI
Chi-Square	10.492
df	2
Asymp. Sig.	.005

a. Kruskal Wallis Test

b. Grouping Variable: GM Density

Appendix 11. Kruskal Wallis Test mean cow dung

	Cow dung
Chi-Square	10.204
df	2
Asymp. Sig.	0.006

Appendix 12. Soil particle density ANOVA table

PD(g/cc)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.147	2	.074	.851	.431
Within Groups	6.231	72	.087		
Total	6.378	74			

Appendix 13 a: 50 cm pit Soil bulk density Kurskal - Wallis test

Test Statistics^{a,b}

	BD(g/cc)
Chi-Square	5.699
df	1
Asymp. Sig.	.017

a. Kruskal Wallis Test

b. Grouping Variable: GMR density

Appendix 13 b. Old mound and no mound soil for soil bulk density for 0-10cm and 40-50 cm depth independent t-test

Independent Samples Test

		Levene's Test for quality of Variance		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
BD	Equal variance assumed	.387	.536	.705	63	.483	.04237	.06011	-.07775	.16249
	Equal variance not assumed			.625	32.547	.536	.04237	.06777	-.09557	.18031

Appendix 14. The pit soil p^H , percentage saturation and temperature Kruskal Wallis-test across study plots

	p^H	% Saturation	Temperature
Chi. square	2.722	1.000	3.479
Df	2	2	2
Asymp.sign	0.256	0.667	0.176

Appendix 15. Soil organic carbon, nitrogen and phosphorous ANOVA table among study plots

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Carbon	Between Groups	61.047	2	30.524	19.1	.000
	Within Groups	114.801	72	1.594		
	Total	175.849	74			
Nitrogen	Between Groups	.173	2	.086	6.941	.002
	Within Groups	.896	72	.012		
	Total	1.069	74			
Available phosphorous	Between Groups	1221.118	2	610.559	1.323	.273
	Within Groups	33228.869	72	461.512		
	Total	34449.987	74			

Appendix 16a. Old mounds and no mound soil carbon, nitrogen, available phosphorus and Particle Density independent t -test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
%C	Equal variance assumed	1.575	.215	-.074	58	.942	-.021600	.293648	-.609400	.566200
	Equal variance not assumed			-.074	56.638	.942	-.021600	.293648	-.609701	.566501
N	Equal variance assumed	.481	.491	-.717	58	.476	-.014933	.020825	-.056620	.026753
	Equal variance not assumed			-.717	54.979	.476	-.014933	.020825	-.056669	.026802
AVL P.	Equal variance assumed	.212	.647	-.560	58	.578	-2.98733	5.33541	3.66731	7.69264
	Equal variance not assumed			-.560	57.998	.578	-2.98733	5.33541	3.66731	7.69265
PD(g/cc)	Equal variance assumed	1.269	.265	.020	58	.984	.00167	.08464	-.16775	.17109
	Equal variance not assumed			.020	37.622	.984	.00167	.08464	-.16973	.17306

Appendix 16b. Old mound and no mound soil independent t-test for soil bulk density.0-10cm and 40-50 cm depth

Independent Samples Test

		Levene's Test for quality of Variance		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
BD	Equal variance assumed	.387	.536	.705	63	.483	.04237	.06011	-.07775	.16249
	Equal variance not assumed			.625	32.547	.536	.04237	.06777	-.09557	.18031

Appendix 17. Wilcoxon Signed Rank test for maximum mole rat seen in wet saand dry season

Ranks

		N	Mean Rank	Sum of Ranks
Max seen in Wet - Max seen in dry	Negative Ranks	0 ^a	.00	.00
	Positive Ranks	2 ^b	1.50	3.00
	Ties	8 ^c		
	Total	10		
FC Wet - FC Dry	Negative Ranks	1 ^d	2.00	2.00
	Positive Ranks	8 ^e	5.38	43.00
	Ties	1 ^f		
	Total	10		
FO Wet - FO Dry	Negative Ranks	7 ^g	6.93	48.50
	Positive Ranks	3 ^h	2.17	6.50
	Ties	0 ⁱ		
	Total	10		

- a. Max seen in Wet < Max seen in dry
- b. Max seen in Wet > Max seen in dry
- c. Max seen in Wet = Max seen in dry
- d. FC Wet < FC Dry
- e. FC Wet > FC Dry
- f. FC Wet = FC Dry
- g. FO Wet < FO Dry
- h. FO Wet > FO Dry
- i. FO Wet = FO Dry

Test Statistics^c

	Max seen in Wet - Max seen in dry	FC Wet - FC Dry	FO Wet - FO Dry
Z	-1.342 ^a	-2.429 ^a	-2.145 ^b
Asymp. Sig. (2-tailed)	.180	.015	.032

a. Based on negative ranks.

b. Based on positive ranks.

c. Wilcoxon Signed Ranks Test

Appendix 18. Mean fresh open holes and closed holes in high and low giant mole rat plots independent t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Fresh Open holes	Equal Variances Assumed	1.214	0.285	-2.743	18	0.013	-22.8	8.31237	-40.264	-5.3364
	Equal Variances not assumed			-2.743	17.445	0.014	-22.8	8.31237	-40.304	-5.2964
fresh closed holes	Equal Variances Assumed	1.355	0.26	4.300	18	0.00	22.1	5.13993	11.3014	32.8986
	Equal Variances not assumed			4.3	13.924	0.001	22.1	5.13993	11.0703	33.1297

Appendix 19. Mean open hole and closed hole independent t-test in high and low giant mole rat plots
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Fresh open holes	Equal Variances Assumed	10.689	0.004	- 2.609	18	0.018	-22.00000	8.43129	89.7135	- 4.2865
	Equal Variances not assumed			- 2.609	12.514	0.022	-22.00000	8.43129	40.2869	- 3.7131
fresh closed holes	Equal Variances Assumed	0.063	0.805	- 2.321	18	0.032	-14.0000	6.42019	28.3883	- 1.4117
	Equal Variances not assumed			- 2.321	17.774	0.032	-14.9	6.42019	28.4006	- 1.3994

Appendix 20. Correlation matrix for giant mole rat ecological interactions with afro alpine avifauna

Correlations

	ve. duratio	ve.temp	total Rap	A.buzz	T.eagle	s.eagle	Lamggey	A.chat	R.r.chat	Eth.Wolf	D.Dog	Cow	Sheep	total seen	Max.seen	
Ave. dura	Pearson Correl	1	-.177	-.140	-.192	.144	-.176	-.061	.153	-.139	.085	-.031	.123	.059	-.087	-.240
	Sig. (2-tailed)		.185	.300	.153	.285	.191	.652	.257	.301	.529	.817	.364	.660	.518	.072
	N	58	58	57	57	57	57	57	57	57	57	57	57	57	57	57
Ave.temp	Pearson Correl	-.177	1	.053	.062	-.050	.107	-.087	.234	.409*	.181	.246	.252	.060	.006	.241
	Sig. (2-tailed)	.185		.696	.649	.709	.430	.520	.080	.002	.178	.065	.058	.660	.966	.070
	N	58	58	57	57	57	57	57	57	57	57	57	57	57	57	57
Total Rap	Pearson Correl	-.140	.053	1	.725*	.518*	.219	.147	.004	.163	-.044	-.051	.010	-.104	.303*	.285*
	Sig. (2-tailed)	.300	.696		.000	.000	.102	.276	.978	.225	.743	.704	.944	.442	.022	.031
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
A.buzz	Pearson Correl	-.192	.062	.725*	1	.035	-.113	-.131	.052	.179	-.296*	.018	.102	.115	.181	.308*
	Sig. (2-tailed)	.153	.649	.000		.796	.404	.331	.700	.182	.026	.893	.452	.394	.179	.020
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
T.eagle	Pearson Correl	.144	-.050	.518*	.035	1	-.254	-.107	-.074	-.093	-.061	-.032	-.002	-.234	.228	.009
	Sig. (2-tailed)	.285	.709	.000	.796		.056	.427	.585	.491	.650	.812	.990	.079	.088	.945
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
s.eagle	Pearson Correl	-.176	.107	.219	-.113	-.254	1	.395*	.112	.107	.298*	-.066	-.124	-.075	-.036	.058
	Sig. (2-tailed)	.191	.430	.102	.404	.056		.002	.409	.428	.024	.628	.358	.581	.789	.669
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Lamggey	Pearson Correl	-.061	-.087	.147	-.131	-.107	.395*	1	-.196	.087	.434*	.244	.050	-.014	.100	.006
	Sig. (2-tailed)	.652	.520	.276	.331	.427	.002		.145	.520	.001	.067	.709	.916	.460	.962
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
A.chat	Pearson Correl	.153	.234	.004	.052	-.074	.112	-.196	1	.336*	-.188	.241	.106	.141	-.124	.287*
	Sig. (2-tailed)	.257	.080	.978	.700	.585	.409	.145		.011	.161	.071	.432	.297	.359	.031
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
R.r.chat	Pearson Correl	-.139	.409*	.163	.179	-.093	.107	.087	.336*	1	.119	.128	.093	.152	-.004	.024
	Sig. (2-tailed)	.301	.002	.225	.182	.491	.428	.520	.011		.379	.341	.490	.260	.978	.862
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Eth.Wolf	Pearson Correl	.085	.181	-.044	-.296*	-.061	.298*	.434*	-.188	.119	1	-.174	.107	-.119	.268*	.203
	Sig. (2-tailed)	.529	.178	.743	.026	.650	.024	.001	.161	.379		.194	.429	.379	.044	.131
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
D.Dog	Pearson Correl	-.031	.246	-.051	.018	-.032	-.066	.244	.241	.128	-.174	1	.130	.103	-.001	.080
	Sig. (2-tailed)	.817	.065	.704	.893	.812	.628	.067	.071	.341	.194		.333	.445	.994	.556
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Cow	Pearson Correl	.123	.252	.010	.102	-.002	-.124	.050	.106	.093	.107	.130	1	.280*	.005	.104
	Sig. (2-tailed)	.364	.058	.944	.452	.990	.358	.709	.432	.490	.429	.333		.035	.971	.442
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Sheep	Pearson Correl	.059	.060	-.104	.115	-.234	-.075	-.014	.141	.152	-.119	.103	.280*	1	-.261*	-.089
	Sig. (2-tailed)	.660	.660	.442	.394	.079	.581	.916	.297	.260	.379	.445	.035		.050	.508
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Total seen	Pearson Correl	-.087	.006	.303*	.181	.228	-.036	.100	-.124	-.004	.268*	-.001	.005	-.261*	1	.628*
	Sig. (2-tailed)	.518	.966	.022	.179	.088	.789	.460	.359	.978	.044	.994	.971	.050		.000
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
Max.seen	Pearson Correl	-.240	.241	.285*	.308*	.009	.058	.006	.287*	.024	.203	.080	.104	-.089	.628*	1
	Sig. (2-tailed)	.072	.070	.031	.020	.945	.669	.962	.031	.862	.131	.556	.442	.508	.000	
	N	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Legend : Abbreviation used in matrix

A. Buzz –Auger buzzard

T.eagle – Towny Eagle

Lammggey – lammergeyer

A.chat -alpine chat

R.r . chat Ruppell robine chat

Eth. wolf - Ethiopian wolf

D. dog –Domestic dog

AVE. Duration - Average duration

T raptor – Total raptors

Ave .temp.- Average temperature

Max. Seen – Maximum seen giant mole rat

Appendix 21. Correlation between ambient temperature and average duration above ground of giant mole rat

	Amb.Temp	Ave.Dur.
Amb.Temp Pearson correlation	1	.035
Sig.(2-tailed)		.791
N	60	60
Ave.Dur. Pearson correlation s	.035	1
Sig .(2-tailed)	.791	
N	60	60

Appendix 22 Photograph taken during study period (by Abiyot .G and Hussen. S)

A



Afro alpine habitat covered by giant lobelia and *helichrysum*

B



Alpine chat in the study plots

C

D



Cattle grazing in the study plots.

Protected area or range land?

E



Fresh Cow dung in the study plots

F



Taking soil samples from non- giant mole rat where grass and helichrysum dominating present near Tulu Deemetu



Measuring ambient temperature of Plots the area surrounding while mole rat foraging



G

Measuring soil p^H on old soil mound of giant mole rat