A STUDY ON SOME ECOLOGICAL ASPECTS OF THE GIANT MOLE-RAT *TACHYORYCTES MACROCEPHALUS* (RUPPELL,1842). IN BALE MOUNTAINS, ETHIOPIA

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ABSTRACT

The giant mole-rat (Tachyoryctes macrocephalus) which is endemic to Ethiopia, was studied in two observation areas at Bale Mountains National Park in south eastern Ethiopia. The burrow system excavated revealed extensive underground tunnels, one functional nest per system, one nest entrance, and nesting material consisting exclusively of grasses knitted into a hollow ball. One to several blind tunnels were found filled with foodstores and faeces. The underground tunnel systems were marked by soil mounds, earth plugs, foraging holes and haypiles on the surface. Soil mounds and earth plugs of T. macrocephalus resembled those of pocket gophers.

Mole-rats spent an average of about 70 minutes a day on the surface, mainly foraging but also observing and digging. The time spent on the surface by mole-rats at high altitude was significantly greater than that spent by mole-rats at low altitude. This difference appeared to be related to the difference in vegetation cover.

The population density of mole-rats was estimated to be about 6000 mole-rats per km^2 at Sanetti and 570 mole-rats per km^2 at Badeae. This difference in population density was probably due to differences in soil and vegetation types. Compotion with domestic live stock at lower altitudes might have also contributed.

Mole-rats restricted their activities to the parts of their burrow system at higher ground in the wet season and became frequently active in the tunnels at lower ground in the dry season.

The major predator appeared to be the Simien fox (*Canis simensis*).

Comparison with other rodent moles (Bathyergidae, Spalacidae Geomyidae) showed many convergent characteristics as a result of their subterranean adaptations.

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INTRODUCTION

Tachyoryctes is the only genus that forms a truly subterranean group of the family Rhizomyidae in Africa. There are two important species, one of which is the root-rat *Tachyoryctes s.splendens* (Ruppell, 1835), type locality Gondar, Ethiopia. The other species is the giant mole-rat *Tachyoryctes macrocephalus* (Ruppell 1842), type locality "Shoa, Abyssinia, "but probably not the modern province of Shoa (Yalden et al., 1976; Yalden, 1985).

The two African species of Rhizomyidae are readily identified by size. *T. macrocephalus* is much larger than *T. splendens*, but has a short tail (less than 65mm) which makes even very young specimens readily identifiable (Yalden et al., 1976). The body weight of adult *T. splendens* ranges from 160 to 280 g and its *condylobasal length* is 33 to 50 mm; whereas *T. macrocephalus* weighs 300 to 1000 g and has a condylobasal length which is 51 to 70 mm long (Yalden, 1985). The giant mole-rat is stocky short-limbed cylindrical bodied rodent with a relatively large head. The pelage is generally a pale brown color, with some slight variation to more ginger or more silver shades of brown, and paler ventrally. A conspicuous black patch occurs on the upper eyelid in life. Some individuals have a faint crown and mid-dorsal stripe. Eyes are large; external pinnae are visible although not conspiciuous. The tail is whitish, short, thick at the base and tapers sharply (Yalden, 1975; 1985).

The external appearance of *T. splendens* is basically rat-like, and is the least modified for fossorial life of the. East African mole-rats (Jarvis and Sale, 1971; Kingdom,1974). Afework Bekele (1983a; 1983b) noted that the jaw muscles of T. splendens are large as an adaptation to subterranean existence. Yalden (1985) compared the jaw muscles of T. macrocephalus with that of T. splendens and suggested that T. macrocephalus is less specialized to subterranean life than T. splendens. Nevertheless, T. macrocephalus is specialized for the subterranean niche and shares with other rodent moles such as bathyergids, spalacids and geomyids morphological features like cylindrical body, a truncated skull with large incisors and rostrum, wide strong zygomatic arch, a broad occipital arch and a relatively small brain case (Yalden, 1985). Because Tachyoryctes is less specialized, it is a dominant and a more effective colonizer than the bathyerigid mole-rats (Kingdon, 1974).

T. splendens is widely distributed in East Africa, including Ethiopia, Somaliland, Kenya, Uganda, the Eastern Congo (Ellerman, 1956), Burundi and Tanzania (Kingdon, 1974). Because it is a nuisance in agriculture and gardens and because of its wide distribution, the biology of this species is fairly well known (Jarvis, 1969, 1973a, 1973b; Rahm, 1969; Jarvis and Sale, 1971; Hickman, 1983). The giant mole-rat, however, is confined to the Ethiopian highlands in distribution and the only reliable record for this species is from Bale Mountians. T. macrocephalus is the most poorly known of all rodent moles, the total primary bibliography for the species containing only six references.

According to Yalden (1975) there are two valid subspecies, T.m.macrocephalus (Ruppell, 1842) and T.m.hecki (Neumann and

Rummler, 1928) type, locality of the latter, "Abakkara, about 150 km West of Lake Awasa, in the boundary region between Djamdjam and Arussi Gala, "but west is in error for east." Revised to Abakkara, South of Adaba, Ethiopia, ca 06°50' N, 39°15'E (Yalden et al., 1976).

Although very poorly known the giant mole-rat illustrates interesting ecological phenomena. It is the small mammals, rather than the plants, which are "dominants" of the afro-alpine community and in many places more than 50% of the ground cover is bare soil thrown out by burrowing mammals. *T. macrocephalus* is the most important of these, by virtue of its size as well as its abundance (Yalden, 1975). On the Afro-alpine zone the instability of the soil is made more pronounced by the burrowing of the giant mole-rat, whose activities keep most of the afro-alpine vegetation in a permanent pioneer phase. As a result the afro-alpine vegetation of the area, which otherwise is similar with afro-alpine vegetation of East Africa, has been significantly altered (Hedberg, 1975). The burrowing activity of this animal has also played an important role in chemical and physical processes of soil formation in the moorland zone as suggested by Weinert and Mazurek (1984). The giant mole-rat has also an ecological importance as a source of food for the endangered species *Canis simensis* in Bale Mountains (Morris and Malcom 1977; Yalden, 1985).

A study of the little known giant mole-rat, which plays a peculiar ecological role in the afro-alpine community was necessary and with this in mind this research was conducted. The main objectives of this study were:

To compile ecological data on this endemic mole-rat

To understand the burrowing activity and burrow patterns

To study the feeding activity of the mole-rat

Field observations were carried out on two observation sites. The first was a large plateau called Sanetti about 4000m above sea level (asl) with afro-alpine moorland zone and the second was Badeae, a grassland area with Artemisia afra and Kniphofia foliosa shrubs and Giant Health on well drained areas; the altitude was 3300m asl. Field trips were made irregularly to these areas from August 1984 to May 1986. On both study areas observations were made on the surface (above ground) activities of the animals, the physical characteristics of the exposed part of the burrow systems were measured, and attempts were made to trap the animals using nylon string slipknot and Victor gopher traps. Only one animal was caught with the gopher trap. Another mole-rat was obtained soon after it was killed by a simien fox. Stomach contents, gonads and external parasites were preserved from the two specimens. Internal parasites (Cestodes and Nematodes) were found in the trapped mole-rat. Two more or less complete burrow systems were excavated at lower altitudes, and a portion of a burrow system was excavated at Sanetti.

THE STUDY AREA

The proposed Bale Mountains National Park (BMNP) is situated in the Bale Mountains which form the south-eastern limit of the eastern highlands of Ethiopia (Fig. 1). The major part of the mountain massif which is included in the park is in the form of a plateau with an altitude over 3,500m asl., The mountain slopes down to the north to 3,000m asl., and to the south to 1500m asl (Hillman, 1986a).

The two observation sites for the mole-rat study i.e. Sanetti and Badeae lie within the boundary of the proposed BMNP. (Fig. 2). The park is in south eastern Ethiopia, with an area of 2200 km^2 encompassed by the coordinates N6^{O}29'- N7^{o}10', and E39^{o}28'- E39^{o}57' (Hillman, 1986a).

SANETTI PLATEAU

This is the widest central portion of the park including the main mountain massif at over 3,900m asl which originated from recent lava flows (Hillman, 1986a).

The vegetaion of this area is characteristically afro-alpine moor-land. Plant species diversity is low, and according to Hedberg (1975) the most important vascular plants can be assigned to five main life forms. These are giant rosette plants represented by the Giant lobelia, Lobelia rhynchopetalum; tussock grasses such as Festuca spp; acaulescent rosette plants like Oreophyton falcatum; cushion plants represented by Helichrysum spp and sclerophyllous shrubs represented by Alchemilla spp. The vegetation cover varies from 100 % at the lower end of the altitude range in well sheltered sites, to less than 10% at higher and exposed altitudes (Hillman, 1986a).

BADEAE

This study area lies in the northern part of the park at 3300 asl. According to Weinert and Mazurek (1984) the vegetation of this area is characterized by *Hagenia-Erica* forest, *Hagenia-Juniperus* forest, *Hagenia-Hypericum* forest on rocky and loamy sandy slopes, and secondary *Ferula communis-Artemisia afra* pasture land. The actual study site is grassland surrounded by *Kniphofia foliosa-Artemisia afra* shrub and the giant health in well-drained areas. The grassland becomes inundated during the wet season. Huge numbers of cattle and horses graze in this area every day throughout the dry and much of the rainy season. This has severely affected the vegetation and soil in the grassland.

Climate is highly variable over the park area because of the high range of altitudes (from 1,500 to 4377m asl) and by the very bulk of the mountain massif itself (Hillman, 1986a). The rainfall is characterized by an eight month rainy season (from March to October) followed by a four month dry season (from November to February). This long rainy season is due to the fact that rain is received from both equatorial westerlies and Indian Ocean air streams at different times of the year (Daniel Gamachu, 1977; Hillman, 1986a). The annual rainfall received varies from 600mm to 1000m at lower altitude,

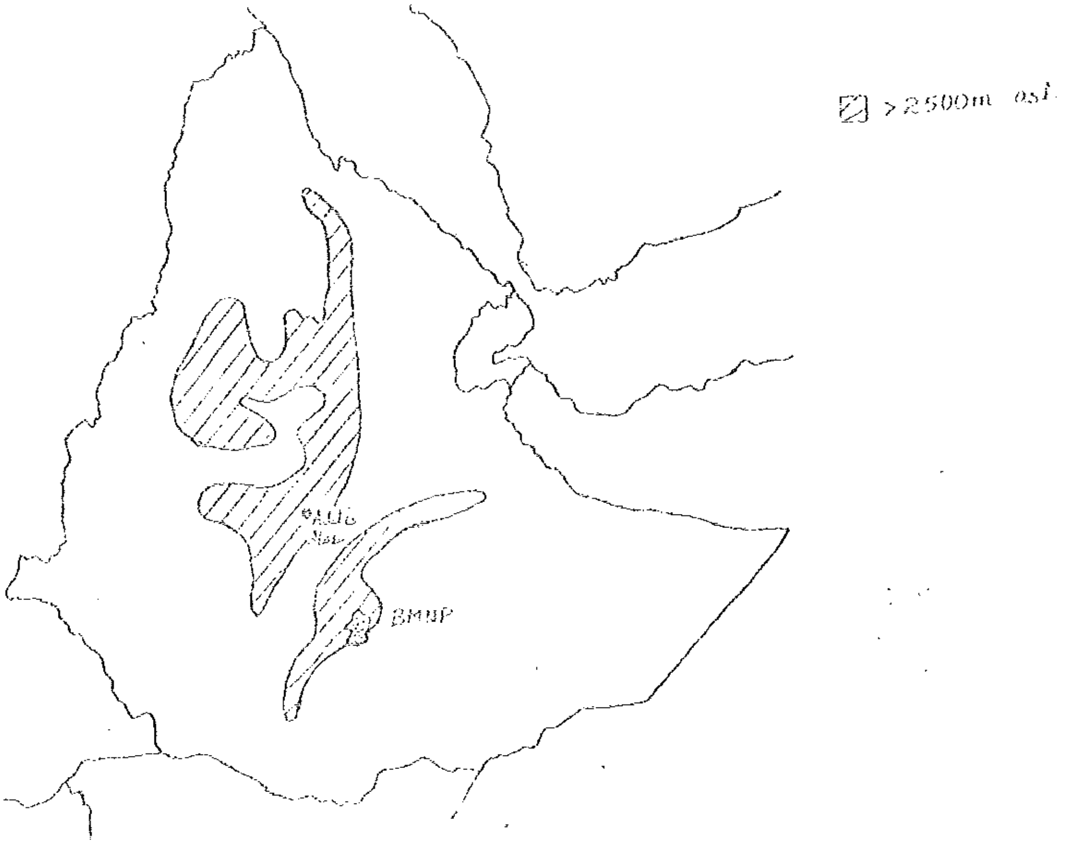


Fig. 1. Map of Ethiopia showing the position of Bale Mountains National Park (BMNP)

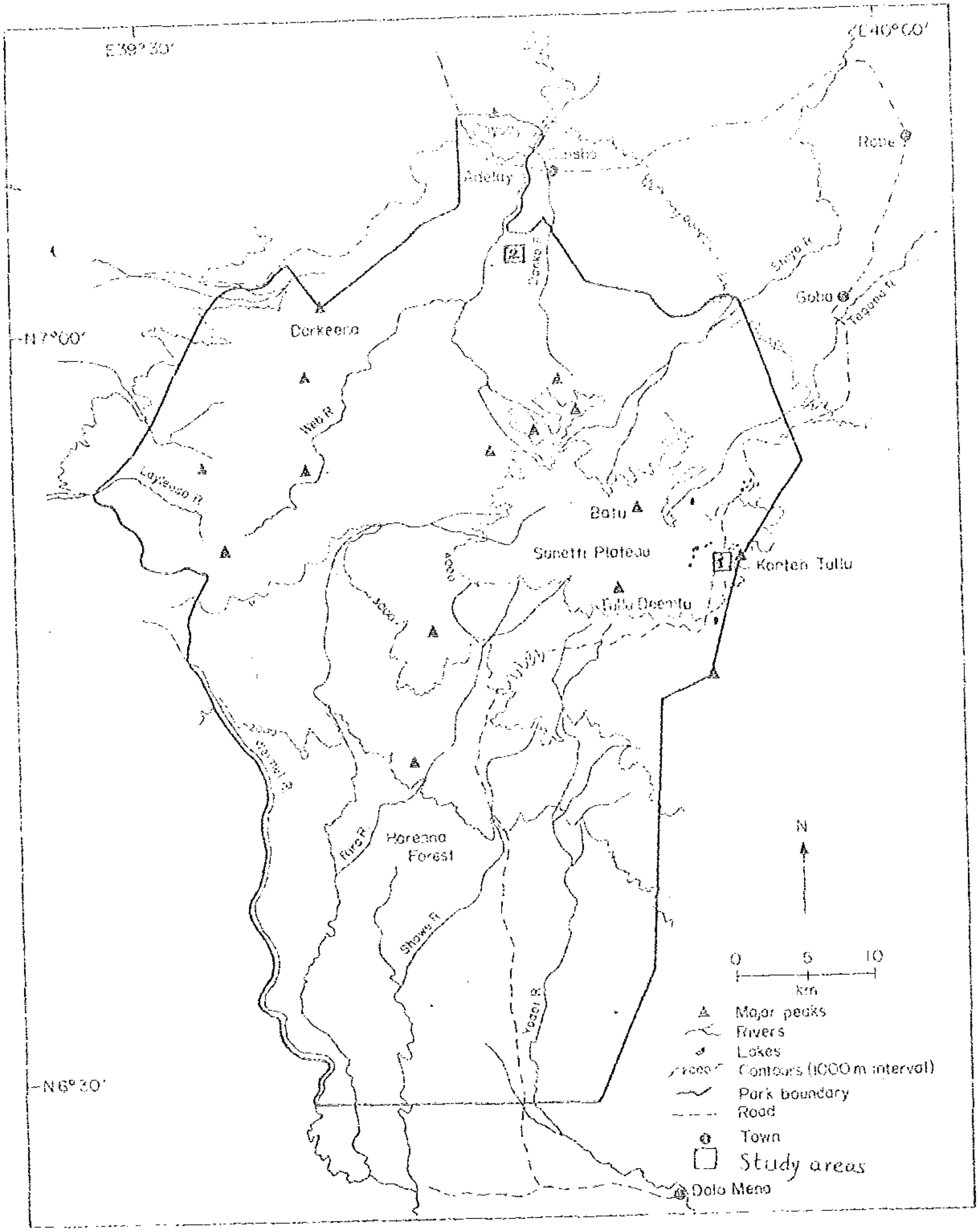


Fig. 2. Bale Mountains National Park and the study areas
1. Senetti.
2. Bedeae.
[illegible]

and from 1000mm to 1400mm at higher altitudes (Daniel Gemechu, 1977) In general, rainfall increases with altitude up unitl 3,850m altitude and begins to decrease above this al altitude (Hillman, 1986a).

According to Hillman (1986a), limited records of temperature in the park area show daily maximum and minimum temperature falling with an increase in altitude. The lowest temperature he recorded, was minus 15°c at Morabowa (3,700 m asl) in February 1984, with plus 26°c. being recorded next day at midday. Lowest temperatures occur at night during the dry season when the sky is clear. The greatest water and temperature stress occur in the dry season (Hillman, 1986a).

DISTRIBUTION AND HABITAT

The giant mole-rat *T. macrocephalus* which is one of the several vertebrate species restricted to high altitude moorland and grassland habitats (Yalden, 1985), is endemic to Ethiopia. Two valid subspecies are known,*T.m.macrocephalus* (Ruppell, 1842) from Shoa, Ethiopia and *T.m.hecki* (Neumann and Rummler, 1928) from Abakkara, Bale, Ethiopia (Yalden, 1975). The type locality of the nominate race is unknown. Although Ruppell described it as Shoa he did not collect animals as far south as the modern Shoa Province and a locality in Begemdir or Wollo seems likely (Yalden et al., 1976).

T.m. hecki is relatively well known and has been collected limited area of Bale provice between 3,2000 to 4,150m asl

(Yalden, 1985). This animal is much more numerous in the moorland zone above about 3900m asl than at lower grassland areas. At high altitude the afro-alpine moorland vegetation dominated by species of Alchemilla, Helichrysum, Kniphofia and Lobelia rhynchopetalum, replaces the giant heath Erica arborea, and extends to the top of the ridges, though the vegetation becomes more sparse with altitude (Yalden, 1975). The giant mole-rat, therefore, is characteristic of the afro-alpine moorland zone, although it is known to extend to heather moorlands (Hillman, 1986a) and grasslands (Yalden et al., 1976) at lower altitudes.

The giant mole-rat occurs abundantly in open grasslands and moorlands, it does not occur in forested areas and in woodlands. In Sanetti the distribution of this mole-rat is associated with large symmetrical mima mounds upto 27m in diameter and 1.5m high. The term "mima mound" was introduced by Dalquest and Sheffer (1942). It refers to the type locality of this terrain, Mima Prairie, Thurston County, Washington, U.S.A. The mima mounds are well formed and numerous in the northern half of Sanetti plateau, where the vegetation is dominated by Alchemilla, particularly on the mounds. Mole-rats occur here at maximum density. The western half of the plateau is dominated by Helichrysum cushions, and very few mima mounds occur with a much lower density of mole-rats. The presence of mima mounds in the giant mole-rat habitat provides support for the Dalquest-Scheffer hypothesis that fossorial rodents produce mima type microrelief.

In the grassland habitat mole-rats appeared to be abundant in short grass grasslands and they tended to be less abundant in tall grass grasslands. In Gaysay, for instance, mole-rat activity was restricted to just outside the fence of the park where the grass was short due to grazing by livestock, whereas there was no fresh sign of mole-rats (though there were old holes and soil mounds) inside the fence, where the grass was tall. The species might be adapted to open habitat, where predators could be easily detected, and reduction in cover might improve survival.

MATERIALS AND METHODS

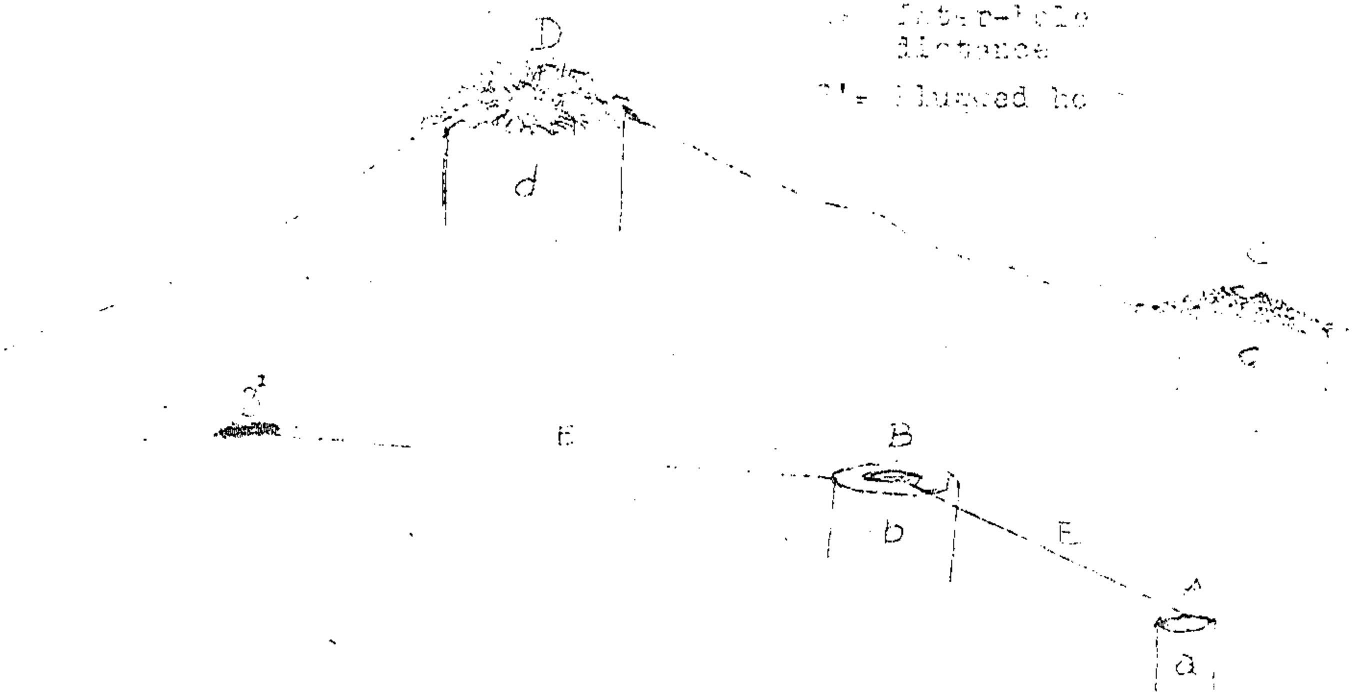
Burrow systems of the giant mole-rat were excavated at Gaysay, Badeae and Sanetti. Excavation sites were selected in areas where barriers such as rocks, and shrubs would not prevent complete excavation. It was not, however, possible to find such an area in Badeae as certain portion of each burrow system were located in the *Kniphofia-Artemisia* shrub.

Before excavation was commenced, the pattern of surface signs, earth plugs, soil mounds and hay piles, was marked. It was, however, difficult to follow lateral tunnels right upto the surface signs, since they were usually plugged for a long distance from the surface back to the main tunnel. Excavation was usually started from active holes, because it was often difficult to locate tunnels starting from soil mounds or earth plugs, because the soil of the plug was packed to the firmness of the surrounding ground. During the excavation tunnels were followed untill they disappeared where they were well plugged, when they became water logged, or rarely up to the surface. The main tunnel ways were not normally plugged and could be followed throughout unless barriers obstructed digging. At Gaysay and Badeae digging was done with picks since the gound was hard, whereas at Sanetti it was possible to dissect tunnels with bare hands. The excavated tunnels were cleaned of excess soil. The pattern of tunnels was then recorded using a tape-meter and compass.

Physical characteristics of exposed parts of burrow systems including feeding hole diameter, foraging area diameter, inter-hole distance, diameter of hay pile and soil mounds (Fig.3) were measured with a tape meter.

The surface activities of mole-rats foraging, observing and digging were recorded on both study areas as categorized by Yalden (1975). The recording of daily mole-rat activities was made from as early as possible in the morning (around 800) up to the end of the day's activity whenever it was possible. During the first half of the study period the total time spent by a mole-rat for a certain activity was recorded in seconds. Although this kind of timing enabled the recording of the actual time spent by a single mole-rat for different activities it was impractical when several mole-rats were simultaneously active. Later during the study period from October 1985 onwards, a standard record sheet was prepared. On this record sheet, activities of five or more animals were recorded even when they were simultaneously active. The activity of each mole-rat was recorded every five minutes. This method of timing actually exaggerated the amount of time spent for various activites specially for observation, since mole-rats normally observe for only a few seconds.

The population density of mole-rats was estimated by counts of surface signs, particularly active foraging holes. These signs were chosen because they represented the activity and



[illegible] hole   a= [illegible]

[illegible] direction   b= [illegible] cratering area [illegible]

[illegible] record   c= [illegible] direction

D= [illegible] pile   d= [illegible] pile [illegible]

E= Inter-hole distance

B'= Plugged ho[illegible]

hence the presence of mole-rats at the time of counting. This method was based on the following assumptions. a) the count was made at about noon because it was assumed that all mole-rats were active by this time b) It was assumed that all the mole-rats had performed half of the day's activity c) It was assumed that once a foraging hole was opened, it remained so until late in the afternoon. The last two assumptions have some drawbacks, for mole-rats could start their activity late in the morning or rarely even in the afternoon. Although one animal could open a second and a third foraging hole before plugging the first one, sometimes the first hole was blocked before the second was opened. The number of foraging holes opened by one mole-rat in a day was on the average 3.4 at Sanetti and 1 at Badeae. Therefore, at Sanetti the number of mole-rats in the sampling areas was the totoal number of active hole counted, divided by 1.7. At Badeae, however, this correction was not important as only one hole was opened by a mole-rat; besides the burrow system of each mole rat could be easily determined.

Estimation of cover-abundance of plants was made in quadrats of 20 x 20 m using a 1-9 modified Braun-Blanquet (1932) scale (van der Maarel, 1979). Quadrats were placed at mima mounds and intermound areas at Sanetti, and at the grassland and *Kniphofia-Artemisia* area to see any differences in the abundance of taxa encountered in the quadrats.

TRAPPING

In July 1984, an attempt was made to trap the animals using Nylon string. The trap was set up by making a loop around an active hole, with a slipknot. The loop was held in position by mud coated match sticks. The other end of the string was held by the observer about 15m away from the hole. It was hoped that pulling of this end of the string while the mole-rat appeared from the hole would tighten the loop and trap the mole-rat. The attempt was not, however, successful at both study areas.

And during the period of 28/9/84-2/12/85, several attempts were made to trap the animals using a Victor gopher trap. But, again it was not possible to trap the animals with this trap, although one animal was caught.

LITERATURE REVIEW

Many mammals live in holes in the ground, dug by themselves or other species, and emerge by night in search of food, but subterranean mammals such as mole-rats have advanced much further towards a completely subterranean existence (Ellerman, 1956). Mole-rats live in extensive underground burrow systems of their own making and spend most of their lives underground, they rarely come above ground (Jarvis and Sale, 1971)

Burrow System

The burrow systems of subterranean mammals consist of a radial or longitudinal superficial net work of feeding tunnels connected to a frequently deeper (Miller, 1964) or shallower (Eloff, 1954; Nevo, 1961; Jarvis and Sale, 1971; Hickman, 1979) central system of chambers used for nesting, food storage, sanitation (Nevo, 1961) and retreat (Jarvis and Sale, 1971). The pattern, extent and depth of these components vary considerably, not only between separate geographic areas, but also with in a single locality, as a result of environmental influences such as temperature, soil moisture and texture, vegetative cover, land contour, availability of food and number of animals occupying one burrow system (Jarvis and Sale, 1971). Hickman (1979) believes, however, discrete variables of the burrow system such as number of nests per system, number of nest ent~~r~~rances and the presence or absence of defaecation chambers, which may be less influenced by the environment, do not vary in different burrow systems. He also suggests that the order of magnitude of continuous variables such as burrow depth and total length of tunnels, which are influenced by the environment, does not vary greatly.

Mole-hill (Soil mound)

All fossorial rodents make open burrows, and hence must transport and dispose of loose soil (Hildebrand, 1982). Mole-rats dig a side branch (lateral tunnels) or reopen an~~d~~ existing branch when they are engaged in extending their burrows (Jarvis and Sale 1971). Once the side branch is opened, the mole-rat pushes loads of excavated soil out of the tunnel entrance on to the surface. The mole-rat repeatedly pushes loads of loosened soil until the side branch is clear. The formation of soil mound begins as the first few loads of excavated soil are pushed out (Jarvis and Sale, 1971). The total number of loads of soil pushed before the mound is completed varies from 16 to 102, where as the total time required to complete the mound varies from 5 to 53 minutes for *Geomys pinetis* (Hickman and Brown, 1973a). The size of a finished mole-hill varies from 15 to 40 cm in diameter and 7 to 15 cm high for *T. splendens* (Jarvis and Sale, 1971) and averages 15 cm in diameter and 20 cm in height, for *Cryptomys hottentotus*, becoming less conical and more flattened with age (Hickmann, 1979). Two types of soil mounds are made by adult *T. splendens*. First, large mounds composed of soil excavated during burrow construction; second, small earth plugs used to plug up holes to the surface made when mole-rats forage above ground. Young animals produce small mounds which can be easily confused with earth plugs made by adult animals (Jarvis and Sale, 1971). *T. macrocephalus* is also known to produce earth plugs (Yalden, 1975).

Haypile

One characteristic feature of *T. macrocephalus* "colonies" is the large hay piles, made up of discarded nesting materials, or perhaps discarded food store, mixed up with old faeces (Yalden, 1975). Jarvis and Sale (1971) have noted that periodically small quantitie of nest material and faeces are thrown up as part of a mole-hill by *T. splendens*, although frequently such materials are accumulated underground. From the quantity of the material ejected, they suggested that the mole-rat is simply disposing of a subsidiary nest when it no longer serves its purpose. Genelly (1965) mentioned that one feature common to the mounds of *Cryptomy hottentotus* was a collection of fragments of the basal sheaths of grasses on which the animals had been feeding.

Foraging tunnels

The foraging tunnels are longitudinal, occasionally branching tunnels with circular cross section and a diameter of 5 to 7 cm for *T. splendens* and ran at fairly constant depth of 19 to 22 cm (Jarvis and Sale, 1971), 10 to 15 cm for *T. macrocephalus* (Yalden 1975); 8 to 20 cm for *Cryptomys* (Genelly , 1965; Hickman, 1979); and 20 cm for *Spalax* (Nevo 1961). Jarvis and Sale, (1971) believe that the depth of these exploratory tunnels is regulated by the root or rhizome level of the plants on which the mole-rats feed, the burrows usually run just below the root level and thus ensure that the food supply remains fresh until it is needed. The depth of the tunnel ways could vary depending on the position of the tunnels in relation to the nest (Hickman, 1979), and the breeding season and waterlevel (Nevo, 1961). Deeper tunnels in Cryptomys burrows were near the proximity of the nest and connected to the shallower tunnels by a series of gradually sloping "ramps" and steep "shafts" (Hickman, 1979). These deeper portions near the nest may serve in protection against potential predators (Jarvis and Sale, 1971).

The total length of foraging burrows ranged from 58 to 340m for Cryptomys (Hickman, 1979), 18 to 52m for T. splendens and is determined by the availability of food, the feeding need of the animal and number of occupants (Jarvis and Sale, 1971). These tunnels are almost always plugged (Hickman and Brown, 1973a; Hickman, 1979) to keep predators out and burrow temperature constant (Jarvis and Sale, 1971) while new ones are constantly dug or reopened in search of food and/or nesting materials (Jarvis and Sale 1971; Jarvis, 1973a; Yalden, 1975).

Nest

Mole-rat burrows contain either one functional nest per system, e.g. cryptomys (Genelly 1965; Hickman, 1979), T. splendens (Jarvis and Sale, 1971) or accessory nest chambers may also be present as in Spalax (Nevo, 1961). Nests are usually situated in raised areas (Eloff, 1954), beneath termite mounds (Hickman, 1979) in mima mounds (Jarvis and Sale, 1971; Gakahu and Cox, 1984) or in specially constructed breeding mounds (Nevo, 1961) and at a relatively shallower depth (Table 1a) to avoid flooding. The diameter of nests varies for different species (Table 1a). This difference appears to be related to the size of the animals, number of occupants and the function of the nest.

Table 1a. Nest dimensions of different mole-rats

Species	Depth	Nest Diameter	Entrance	Source
Tachyoryctes splendens	10-60	23	single	(Jarvis and Sale,1971) (Hickman, 1983)
Cryptomys hottentotus	17	20	multiple	(Hickman, 1979)
Spalax e. ehrenbergi	60-80	20	multiple	(Nevo, 1961)
Heliophobius argentescinereus	30	8-10	-	(Javis & Sale, 1971)
Heterocephalus glaber	-	25	multiple	(Hill et al., 1957)

The nest chamber is primarily a sleeping, resting, and breeding area for Cryptomys (Eloff, 1951a; 1958; Hickman, 1979), Heterocephalus and Heliophobius (Jarvis and Sale, 1971). Spalax is known to construct nests in breeding and resting mounds during breeding and non-breeding seasons respectively (Nevo, 1961). T. splendens, on the other hand, has a large all purpose nest chamber in which feeding, sleeping and defaecation take place (Jarvis, 1973a) and no special nest is built by the pregnant famale (Jarvis and Sale, 1971).

Food store chamber

Fossorial rodents secure food from the ground such as tubers, rhizomes, roots and aerial shoots of plants, and store them in special underground chambers where they are safe from other animals and the weather (Hildebrand, 1982). A special food store chamber is constructed by Spalax (Nevo, 1961), Cryptomys Genelly, 1965), and Heliophobius (Walker, 1964). T. splendens stores food in its nest (Jarvis and Sale, 1971; Jarvis, 1973a). Food storing behaviour seems to have considerable importance in supplying food to the mole-rat during the dry season (Genelly, 1965) to the females during the gestation and lactation period (Nevo, 1961) and the decomposition of store contents may provide warmth (Jarvis and Sale, 1971).

Bolt-hole

T. splendens and Heliophobius (Jarvis and Sale, 1971) and Cryptoms (Hickman, 1979) have a special chamber, the bolt-hole, at the deepest part of the burrow system. It is a blind-ending tunnel which dives down steeply. It is associated with the nest in the burrows of T. splendens (Jarvis and Sale, 1971). When the mole-rat is alarmed, it retreats in to this tunnel and plug up the connection with the rest of the system. It is frequently difficult to locate the bolt-hole, as the escaping animal packs soil between it and the source of danger (Jarvis and Sale, 1971). These investigators noted that, in the field, two month old mole-rats have been found hiding down the bolt-hole of their home burrow, and in young laboratory reared animals, this behavior develops as early as 22 days. Hickman (1977) suggested, however, that this deep tunnel may primarily function to keep humidity high in the burrow system.

Sanitory chambers

Several studies suggested faecal pellets were present only in certain parts of the burrow system of many mole-rats, feeding and resting chambers were devoid of faeces. This has been found for Cryptomys (Genelly, 1965; Hickman, 1979), for Spalax (Nevo, 1961). Genelly (1965) found a single sanitary region in a burrow of Cryptomys which was a 3 ft branch of an active tunnel that had been plugged off from the surface and packed tightly with dried faeces throughout its length. Hickman (1979) has also found tunnels 30 to 40 cm long packed with faecal material in burrows of this species. The sanitory chambers of Spalax were small rooms of approximately 7 cm in diameter; when filled with droppings they were walled up and new ones were formed (Nevo, 1961). The all purpose nest chamber of T. splendens has a sanitory area (Jarvis and Sale, 1971).

Empty chambers

Hickman (1979) found that one to five empty subspherical chambers occured in the burrow system of Cryptomys. They were with one entrance, devoid of contents, and un associated with anastomosis or deep tunnels as were the nests. He suggested that these empty chambers might have been storage chambers, and the absence of food stored in these chambers could be due to the excavation being undertaken at the end of the dry season when the stores would be expended. or they might have functions as resting sites rather than food caches.

ACTIVITY ABOVE GROUND

Mole-rats live in semi permanent burrow systems and rarely come above ground. It will therefore be appreciated that the study of mole-rat populations is hampered by the fact that direct observation is severely limited (Jarvis, 1973b). The problem of subsurface moitoring of fossorial mammals has been approached in a number of ways. The development of radioactive tagging techniques has made it possible to study the activity of subterranean mammals (Jarvis, 1973a). Behavior of mole-rats can also be studied in captivity by keeping the manimals in glass-sided cages filled with moist soil (Eloff, 1958; Genelly, 1965)

In spite of the fact that mole-rats are truly subterranean rodents, many authors report that they are active above ground at night or even during the day. Mature individuals can be seen above ground during autumn possibly searching for a mate (Nevo, 1961). The fresh green food found near the nest of Spalax (Nevo, 1961) and the nesting material in Thomomys (Gettiner, 1975) must have been collected from the surface as the plants are entirely without roots. Young mole-rats of the genus Spalax are frequently found on the surface possibly in earch of their future territory (Nevo, 1961) or when they are flooded or driven out by their parents (Jarvis and Sale, 1971), The rhizomyid mole-rats of Africa are known to forage briefly above ground. This has been found out for Tachyoryctes splendens (Jarvis and Sale, 1971; Jarvis, 1973a) and for T. macrocephalus (Yalden, 1975; 1985). When mole-rats are active above ground their activities can be classified into three catagories, observing, foraging and digging.

Observing

According to Yalden (1975) this behaviour consisted of the animal appearing with its head and shoulders out of its hole, with its body vertical, apparently looking, but perhaps listening, for any danger. Jarvis (1973a) noted that T. splendens, after opening a foraging hole frequently spent 5 or more minutes sniffing the air with only its nose exposed. The animal will disappear completely in response to any loud noise. Similar behaviour was also observed in pocket gophers (Hickman and Brown, 1973 a). Pocket gophers characteristically freeze at their burrow entrances before pushing dirt out. This behavior seems to be an important adaptation promoting survival during the vulnerable period of mound building. A pocket gopher could detect the motion of a predator while only partially exposing itself in the open tunnel. The pocket gopher will disappear into its burrow in an extremely rapid backward lunge, if alarmed (Hickman and Brown, 1973a).

Foraging

Jarvis (1973a) noted that one method of collecting food and nest material by T. splendens was through surface foraging. The animals opened foraging holes to the surface and partly emerged to collect plants above ground. The mole-rats appeared from the hole with short jerky movements and uttering soft snorts. With their hind quarters inside the hole, the mole rats suddenly jerked forwards, siezed a piece of vegetation with their incisors and dart backwards into the burrow. The mole-rats never completely leave the burrow (Jarvis, 1973a). Gettinger (1975) feels that Thomomys talpoides might collect nesting materials from the surface. Yalden (1975) noted that Tachyoryctes. macrocephalus forages above ground in much the same way as T. splendens. During foraging, food is gathered in quick snatches, with the hind quarter remaining inside the foraging hole, only on one occasion, did one animal stretch almost completely out of its hole. The animals retreat backwards into their burrows when alarmed, or when a full load of food has been gathered (Yalden, 1985).

Digging

This surface activity consists of the giant mole-rats shovelling earth out of the foraging holes, and finally blacking them from inside (Yalden, 1975). Jarvis and Sale (1971) noted that, the activity that can be observed on the surface while T. splendens is digging, is the growth of the mole-hill, as the expelled soil is heaving and new partly broken plugs appear near the center of the mole-hill. Similar activity i.e uplifting of soil and/ or the plugging of openings by Spalax were recorded by Nevo et al. (1982).

Feeding

The giant mole-rat T. macrocephalus depends largely on aerial parts of plants for its food (Yalden, 1975) in marked contrast with the root-rat T. splendens, which depends almost exclusively on roots and tubers (Jarvis and Sale, 1971). Yalden (1975) noted that T. macrocephalus gathered indiscriminately whatever vegetation grew around their feeding holes; this was mostly grass and other herbs such as Erigeron sp. and Alchemilla. Stomach content analysis made by Yalden (1975) revealed that the following plants made up the major food items, Festuca abyssinica Poa shimperiana, Agrostis sp, Luzula abyssinica, Veronica cf. ellenbeckii, Helichrysum citrispinum, Erigeron sp and Polygonum sp. Surprisingly enough, "two specimens which came from the same area as the reference material, contained every plant for which reference material was available, except the rather unpalatable-looking Helichrysum" (Yalden, 1975). Other mole-rats also seem to eat what is available. Genelly (1965) noted that Cryptomys hottentotus seemed to prefer the bulb like base of black seed grass. He believes, however, that availability may have been a more important reason for the prominence of this item in the mole-rats diet, since other bulbous plants, although occuring to some extent, are very rare.

Population Density

Mole-rats spend most or all their lives underground (Hildebrand, 1982), and their presence is indicated by fresh mole-hills. The study of mole-rat populations is therefore, hampered by the fact that direct observation is severely limited. Assessment of population density is therefore largely indirect (Jarvis, 1973b). The "mark release" or "Lincoln index" method cannot be used because mole-rats are difficult to live trap repeatedly and also because their discrete burrow systems and solitary nature severely limit the mixing of marked individuals with the rest of the population, and thus the second sample taken from such a population would give a false picture of true population (Jarvis, 1973b). Number of mole-hills has been used by many investigators (Hill et al. 1957 Genelly, 1965; Reid et al., 1966) to express the density of populations of rodent moles. Estimation of population density from counts of mole-hills was unsatisfactory because soil moisture, the availability of food and the sex of the animal all influence the number of mole-hills produced per unit time (Jarvis and Sale, 1971; Jarvis, 1973b). Variation in soil and vegetation results in heterogeneous and variable mole-rat population densities. Thus the number of individuals per unit area varies with in and between species and populations in different habitats (Nevo, 1979) According to Genelly (1965) animals of low mobility such as mole-rats have spotty distributions. Ried et al. (1966) have found a positive relationship between the number of pocket gophers and amount of sign (mole,hills and earth plugs) and concluded that, by recognizing behavioral characteristics and seasonal differences in amount of sign produced by the animals, fresh sign may be employed to approximate population densities.

Yalden (1975) estimated the population density of the giant mole-rat of Urgana Valley, in BMNP, by counting the number of animals he observed and found the density to be 63/ha. He also calculated the biomass and it was 33.6 kg/ha or 3360 kg/km^2.

Predation

One important advantage provided to fossorial mammals by the subterranean niche is protection from potential predators (Hildebrand, 1982). Tachyoryctes differs from many rodents of comparable size in living in a closed burrow system where predation pressures are low (Jarvis, 1973b). This is borne out by the low litter size and number (Jarvis, 1969) and by the low annual recruitment shown by Tachyoryctes populations. Except for a possible vulnerable period when young animals leave or are driven out from the mother's home burrow, to establish an independent burrow system, equal protection is offered by the fossorial habits to all age groups (Jarvis, 1973b). Young animals were found wandering on the surface on very rare occasions, and these occasions were frequently associated with heavy rainfall; this suggests that the mole-rats were flooded out of their burrows and were not voluntarily wandering in search of a place to establish their burrow system (Jarvis, 1973b). Genelly (1965) also found that Cryptomys were forced to surface by burrows flooded during the rainy season.

Predators known to have taken T. Splendens include the domestic dog and cat, jackal, puff adder, mole-snake, augur buzzard, crowned hawk-eagle and Mackinder's owl. Other possible predators include the genet, civet cat, serval cat, caracal, ratel, zorilla, the larger mongooses and birds of prey (Jarvis, 1973)

Honey badgers, foxes, jackals and possibly hyaenas, dig the mole-rats, *Cryptomys* out of their burrows on occasion (Genelly, 1965).

The Simien fox *Canis simensis* is a major predator of *T. macrocephalus* (Yalden, 1975, Morris and Malcolm, 1977;) because a limited sample of Simien fox droppings, collected by these investigators, yielded the remains of 25 individuals of *T. macrocephalus*, representing about 47% by weight of the fox's diet. Yalden (1973) found *T. macrocephalus* from pellets of the long eared owl *Asio abyssinicus*. Other possible predators included various birds of prey such as augur buzzard *Buteo rufofuscus*, lammergeier *Gypaetus barbatus*, cape eagle owl *Bubo capensis* and various eagles were recorded in the giant mole-rat habitat and, at lower altitude, serval *Felis serval* (Yalden 1975, 1985) Hillman, 1986a; 1986b).

RESULTS

The basic structure of the burrow system and patterns of surface activities (discribed below), are two of the most important ecological aspects of the giant mole-rat that have been observed. Other ecological aspects that have been studied included population density, predation, breeding, social structure and seasonal migration of the animal.

TRAPPING

Attempts to trap the mole-rats, using nylon string slipknot victor gopher trap, were not successful although one animal was caught with gopher trap. The main reasons for the failure of trapping appeared to be the following: First, the behavior of the mole-rats; any human activity, especially walking around an active hole by the observe to set up traps, was noticed by the mole-rats, and the mole-rats reacted in the same way as they would react to danger, whenever a trap is setup, either the animals never came back or, more commonly they plugs the tunnels in which the trap was setup. Secondly, the gopher trap was designed to trap pocket gophers which are much smaller than the giant mole-rat. This was confirmed by the fact that traps were triggered several times and later found with fur on the spikes.

BURROW SYSTEM

One complete burrow system (Fig. 9) of *T. macrocephalus* was excavated at Gaysay and in addition burrows were partially excavated at Badeae and Sanetti (Fig. 10 and Fig. 11). The basic burrow pattern consisted of a longitudinal net work of feeding tunnels, with short lateral tunnels filled with food and faeces, radiating from a central nest.

SOIL MOUND Two types of soil mounds are produced by the giant mole-rat. First, large mounds of soil which are conical in shape with a crater-like depression, in the centre of which is the plugged hole through which the soil is ejected.

These type of soil mounds were between 24 and 103 cm in diameter at badeae and between 24 and 62 cm in Sanetti. In general few soil mounds of this type were produced in either of the study areas, although relatively high number of soil mounds observed in Badeae than in Sanetti. Most of these mounds were produced during the dry season.

The second type of soil mounds are earth plugs over old feeding holes (Fig. 4), and are more numerous at higher altitudes. These earth plugs are either surrounded by a zone of grazed vegetation or had channels or grooves dug by the animals on the surface between a hole entrance and a clump of vegetation (Fig. 5). The number of holes opened and plugged per animal per day is on average 3.4 at Sanetti and 1 at Badeae.

HAY PILE Large amounts of dried and/or fresh plant materials mixed up with faeces are periodically discarded through old feeding holes to form hay piles. These piles have a similar shape as the soil mounds as they are ejected in the same way (Fig. 6).

The bases of these haypiles ranged between 59 and 124 cm in diameter. The considerable variation in size is due to the periodic addition of small quantities of hay on already formed haypiles by the mole-rats.

The composition of the hay pile refelected the composition of vegetation surrounding the burrow system. In Sanetti, for instance, the hay piles in Alchemilla dominated areas were made up of almost exclusively Alchemilla, while in Badeae grasses were the dominant

Fig.4. The Giant mole-rat makes earth plugs which are old foraging holes filled with fresh soil

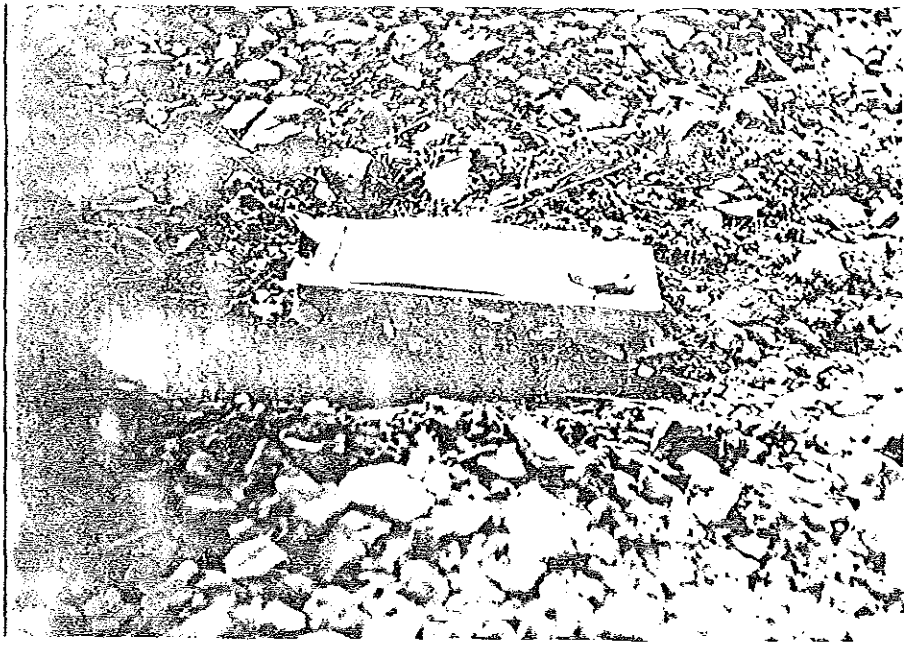


Fig. 5. Surface channels are made to collect plants that grow some distance away from foraging holes

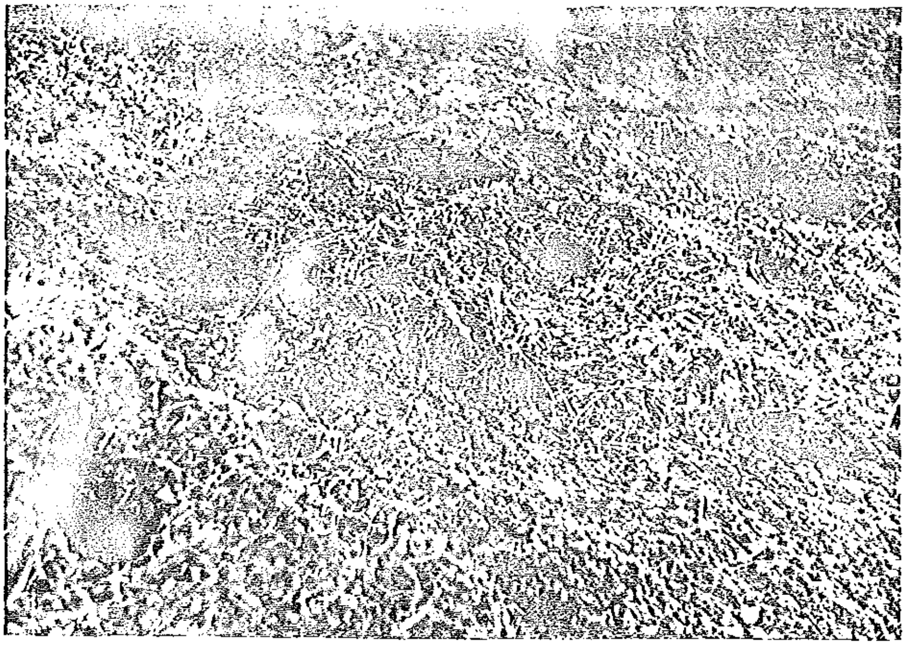


Fig. 6. Hay piles with holes at the centre through which the hay is discarded.

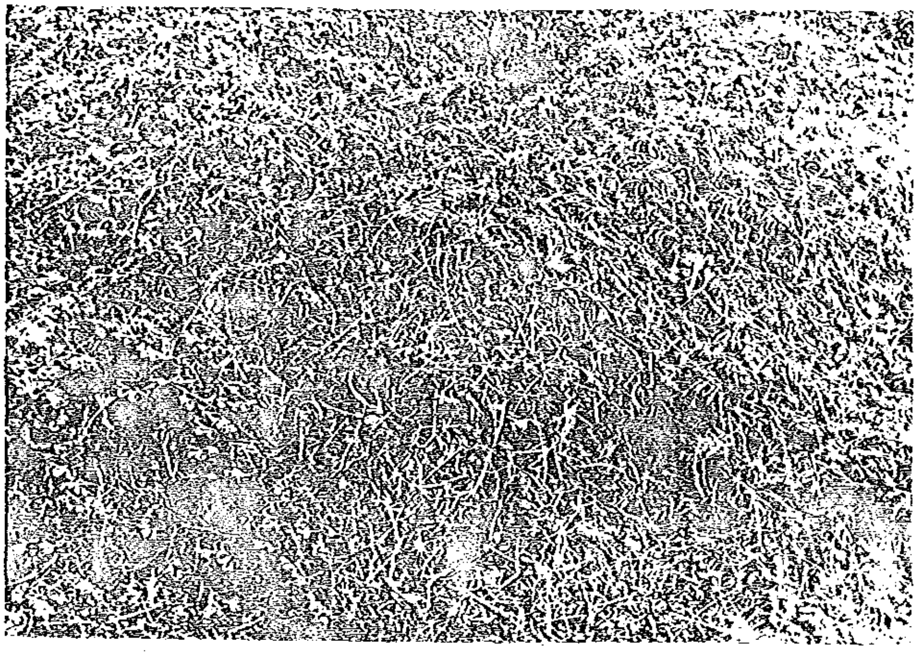


Fig.7. Portion of a hay pile: The composition of hay pile reflects the composition of vegetation surrounding burrow system.

components of the hay pile, although *Alchemilla* and other herbs were also present (Fig. 7).

FORAGING TUNNELS. The main part of the burrow system was composed of two sets of underground tunnels (Fig. 9). One set of tunnels ran at a shallower depth, from about 8 to 26 cm. below the surface, whereas the other set of tunnels ran at a greater depth from 26 to 52 cm. Both sets of tunnels were interconnected by gradually sloping " ramps". The deeper tunnels which constituted only 17.4% of the total tunnel length, were adjacent to, but not connected to the nest which was part of the shallow tunnel system. In general all the tunnels were circular in cross-section with a fairly constant diameter of approximately 14 cm. Branches from the shallower tunnels led to old or active feeding holes on the surface, although the actual routes of these blind tunnels were difficult to locate as the entrance and part of the tunnels had been refilled with soil. The total length of the tunnels ways in the completely excavated burrow was greater than 90 m. These tunnels covered an area of greater than 360 m^2 of which less than 10% was covered by recent soil mounds and earth plugs.

NEST One functional nest was found per burrow system of *T. macrocephalus*. Details of the nest structure are shown in Table 1b. The nests were lined by a hollow ball of nesting materials which was almost exclusively grass. However, only nests from low altitude were examined, where grasses were generally the dominant species and it is probable that at higher altitude other material may be used. The nests were devoid of any faecal material. The nests were normally heavily infested with mites and fleas.

FOOD STORE Short side branches, probably plugged feeding tunnels, were used as storage chambers, and the depths and sizes of the various storage chambers is shown in Table 2. In general, all of the storage chambers were filled with grasses and/or herbs and faeces.

Table 1b. Structure of nests of T. macrocephalus in burrow system I & II (measurements were in cm)

Locality	Burrow system	Nest chamber	Depth from surface	Diameter	Width	Height
Gaysay	I	I/1	20.0	27.0	25.0	19.0
	I	I/2	24.0	30.0	22.0	18.0
Badeae	II	II/1	14.0	29.0	36.0	19.5
	II	II/2	18.0	20.0	37.0	NR
Mean			19.0	26.5	30.0	18.8
Range			14.0-24.0	20.0-30.0	22.0-37.0	18.0-19.0

NR Not recorded

Table 2. Measurements of storage chambers in

Locality	Burrow system	Storage "Chamber"	Depth from Surface	Diameter	Length
Gaysay	I	I/1	35.0	14.0	22.0
Badeae	II	II/1	22.0	12.0	19.0
Sanetti	III	III/1	18.0	13.5	27.0
Sanetti	III	III/2	55.0	17.0	37.0
Sanetti	III	III/3	32.0	14.0	22.0
Sanetti	III	III/4	42.0	14.0	50.0
LOW ALTITUDE	Mean		28.5	13.0	20.5
	RRANGE		22.0-35.0	12.0-14.0	19.0-22.0
HIGH ALTITUDE	Mean		36.8	14.6	34.0
	Range		18.0-55.0	13.5-17.0	22.0-50.0
OVERALL	Mean		34.0	14.0	29.5
	Range		18.0-55.0	12.0-17.0	19.0-50.0

The number of storage chambers was very high in Sanetti. In this area four storage chambers were found in 6m of a partially excavated burrow system. At lower altitude (Gaysay) only one such chamber was found in the whole burrow system of more than 90 m. In addition, at Badeae fresh grasses and herbs were found accumulated in one of the main tunnel ways only 121 cm from an active hole.

EXPOSED PARTS OF BURROW SYSTEM. Measurements made on the exposed parts of the burrow system are show in Table 3. Foraging hole diameter remained constant particularly in the burrow system of one mole-rat, where the range was between 7 and 12 cm. The average diameter of foraging area was slightly greater at high altitudes. This difference might be that at this altitude the foraging areas did not normally have regular circular shape due to the sparse vegetation, and hence only few foraging areas were measured. Whereas in the lower altitudes the circular grazed zones around a foraging hole were clearly defined (Fig. 8).

The distance between holes of similar age, inter-hole distance, was measured. It was intended to measure the distance between holes produced consecutively because there were definate differances in distance between such holes at high and low altitude areas. Otherwise the areas appeared honeycombed with holes, both old and active, particularly at Sanetti. The inter-hole distance were highly variable and ranged between 13 and 340 cm at Sanetti, 12 and 140 cm at Badeae and between 9 and 100 cm at Gaysay. Using the Z test, inter-hole distance at higher altitude was significantly greater than inter-hole distance at lower altitudes.

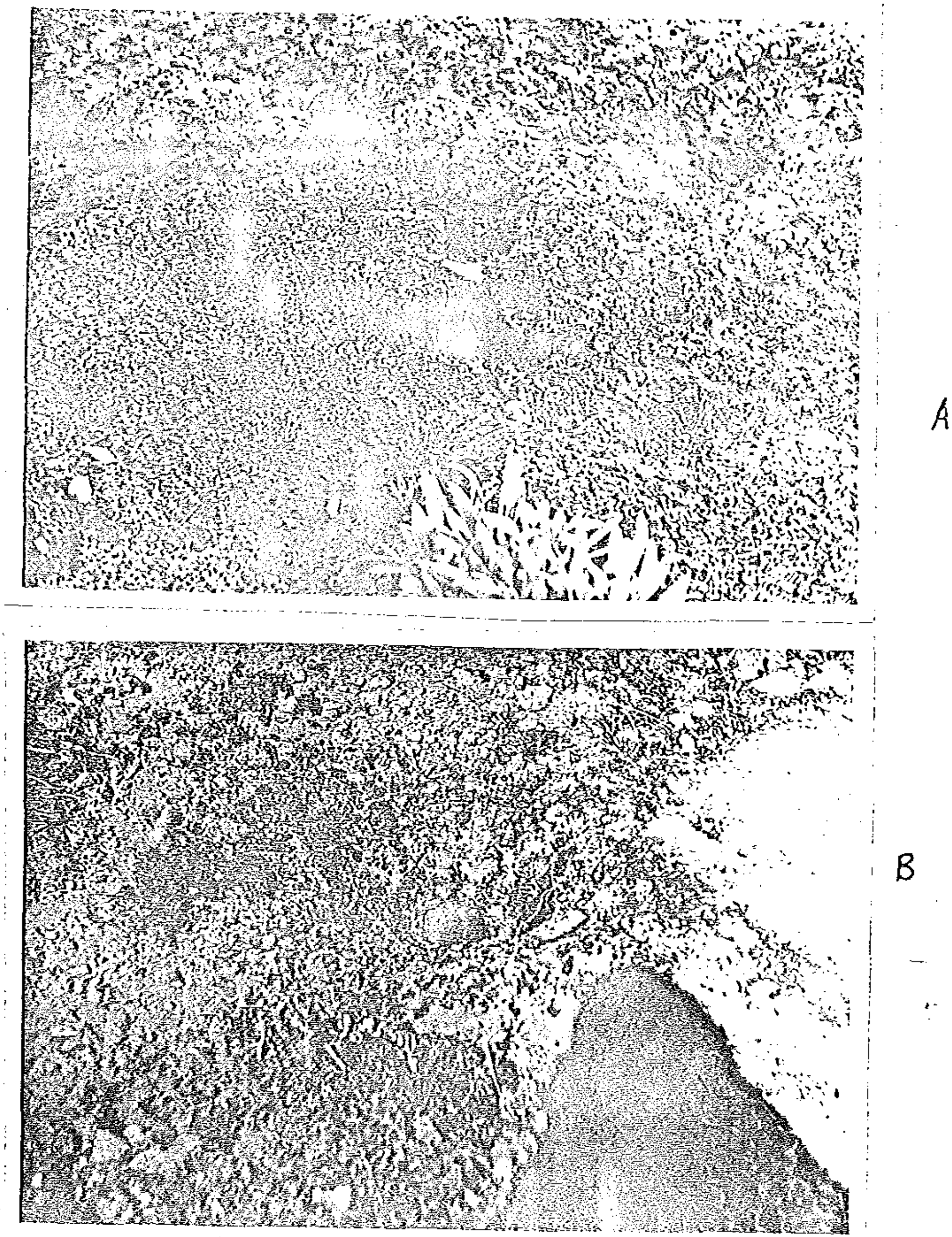


Fig. 8. Active hole Open foraging hole: (A) surrounded by a zone of grazed vegetation (near Badeae), (B) opened on an almost bare ground (Sanetti).

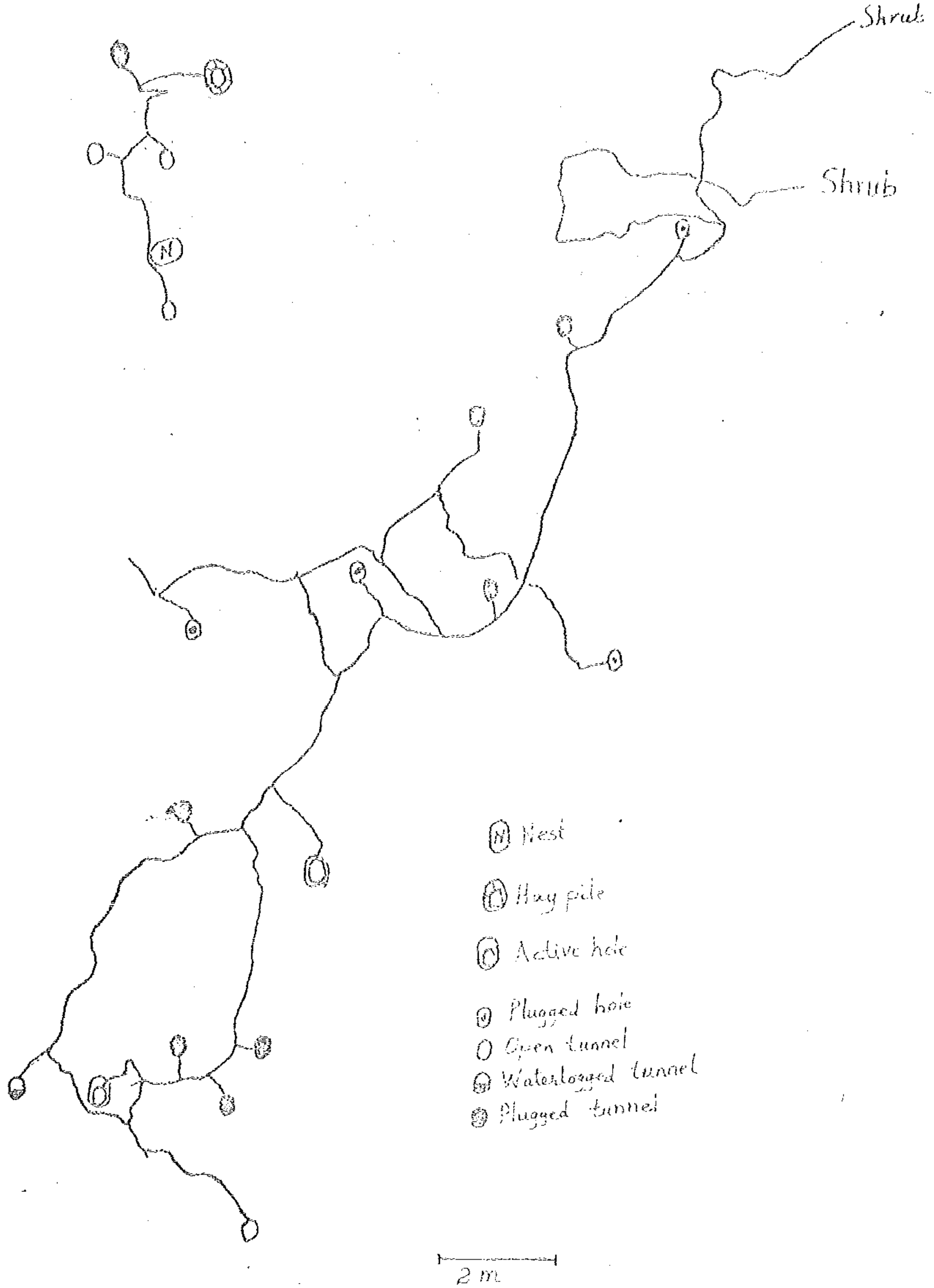


Fig.10. Top view of a partially excavated burrow system at Badeae. (Burrow System II)

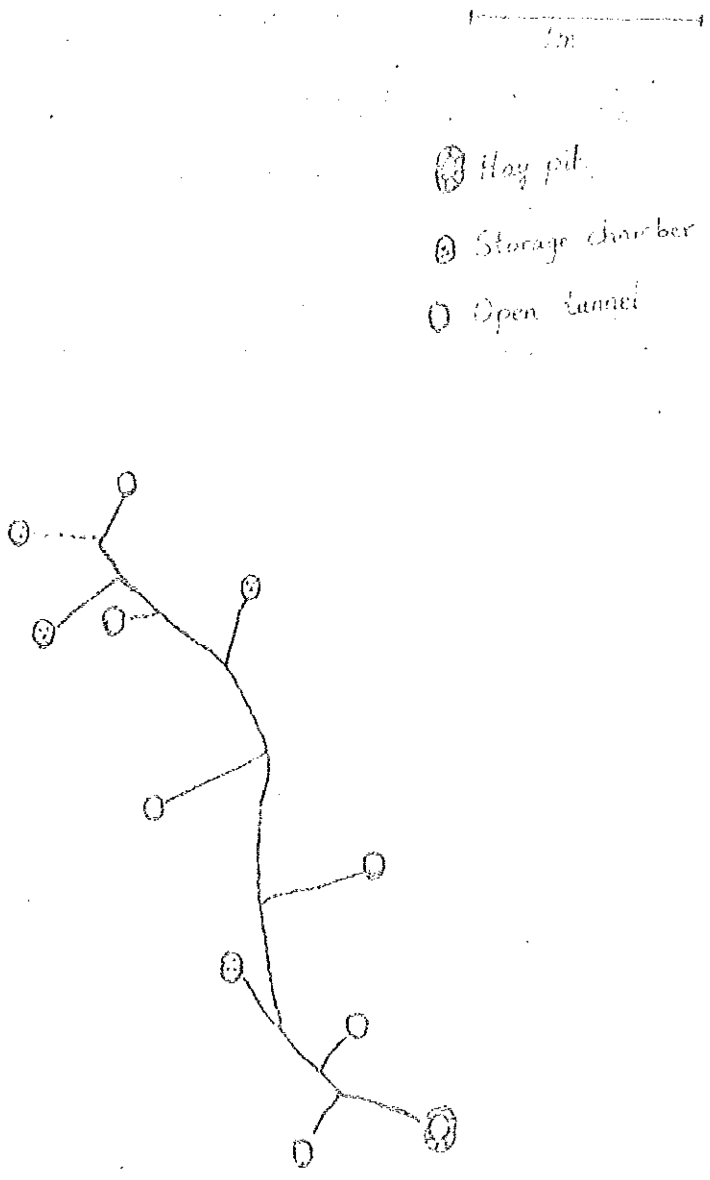


Fig.11. Top view of a partially excavated burrow system at Sanetti. (Burrow System III)

Table 3. Physical characteristics of surface parts of burrow system (measurements in cm except altitude)

Locality	Altitude	Hole-diameter	Foraging area diameter	Inter-Hole distance	Haypile diameter	Soil mound diameter
Gaysay	3000m	10.5±1.1(n=24)	29.0±3.7(n=8)	48.0±29.5(n=22)	NR	NR
Badeae	3300m	8.9±1.0(n=21)	25.0+5.3(n=20)	42.4±22.6(n=36)	87.0±9.9(n=2)	71.5±20.5(n=15)
Sanetti	4050m	9.6±1.2(n=24)	30.6±8.7(n=15)	85.3±82.7(n=36	94.9±63.5(n=25)	39.5±15.4(n=14)

(NR= not recorded

ACTIVITY ABOVE GROUND

Giant mole-rats (T. macrocephalus) came out of foraging holes and spent brief periods of activity on the surface of the ground almost everyday at both observation areas. The activities performed on the surface were classified into three catagories (a) observing (b) foragin, (c) digging.

OBSERVING The activity consisted of the giant mole-rat appearing out of its hole and freezing for a few seconds, looking and listening for any danger in the surrounding area. Whenever a mole-rat comes out to the surface through a foraging hole, it first observes the surrounding area before it starts other activities. When mole-rats appear for the first time, they make a relatively long period of observation (30 seconds or more).

The duration and frequency of observation is higher when the mole-rat is disturbed by humans or other animals and when it suspects danger, for example, when it is aware of the observer.

Mole-rats have acute sight and sense of hearing. When they are on the surface they will readily respond to a flying Augur buzzard, and even slight movement of an object such as humans or cattle. Mole-rats are extremely sensitive to sound, all will retreat into their burrows in response to human conversation from more than a hundred meters away, even when the source of the sound is not visible to them.

FORAGING The activity classified as foraging represents the gathering of plant shoots (grasses and herbs) from around a feeding hole by the mole-rat. In general, the animals come out of the hole, seize the vegetation with their incisors and pull of a piece of vegetation. The mole-rats make from one to several snatches and when the mouth is full they retreat into their burrows. On rare occassions mole-rats masticate while on the surface.

Mole-rats normally forage while their hind quarters are still inside the foraging hole when the hole is surrounded by a good mat of food plants. At higher altitudes, however, they usually come out of their burrows or even moved a distance of about a meter or more from the foraging hole to gather the scattered vegetation. In Sanetti many feeding holes are usually opened on to bare soil, and the animals have to make surface channels to a near by cluster of vegetation. These channels enabled the mole-rats to find the feeding holes while retreating backwards.

An actively foraging mole-rat will repeatedly come out of its holes and gather the vegetation and dart back into the hole. While vigorously foraging, the time spent under ground between each appearance is usually only a few seconds (typically 3 to 8 secs). This vigorous foraging lasts from 1.5 to 16 min (Average 4.5 min) and is then followed by the disappearance of the mole-rat, for from a few to several minutes. The animal then may resume its foraging activity, until apparently the vegetation around the feeding hole is cleared or becomes difficult to pull off, or when the animal is disturbed.

In the lower altitude grassland areas mole-rat preferably gathered grasses, even though they also collected other herbs. In Sanetti, however, mole-rats gathered indiscriminately any vegetation found close to their feeding hole.

DIGGING The activity termed digging represented mainly the process of plugging old foraging holes. During this activity mole-rats did not usually come to the surface; rather the activity became evident when the observer saw the soil that was being pushed from inside to block the hole. Occasionally mole-rats might push excess soil out of the holes before they actually plugged the holes. In most cases, this activity went unnoticed by the observer as only small amounts of soil were pushed out.

The actual time mole-rats spent in blocking old feeding holes was greater than that recorded on Table 4. This was because, whenever the vegetation around a foraging hole was cleared or when the mole-rats were disturbed, they accumulated loose soil until the tunnel just behind the entrance was filled, then pushed the soil out through the hole. It was only this final process that could be timed.

In both observation sites mole-rats were observed while extending the process of plugging of old foraging holes. The animals repeatedly brought out loose soil through the holes, and each time they pushed the soil a few centimeters away from the holes in every direction, with the sides of their heads. As a result crater-like soil mounds were formed. The holes were then finally plugged.

Table 4. Time (in minutes) spent by T. macrocephalus on different activities. and their percentage of the total observation period in parenthesis.

Locality	Date	Mole-rat	Foraging	Observing	Digging	Total activity	Total observation period
Sanetti	20/6/84	A	80.5(15.9)	17.7(3.5)	0	98.2(19.4)	505.0
Sanetti	20/6/84	B	85.0(16.8)	3.7(0.73)	0	98.7(17.5)	505.0
Badeae	22/6/84	A'	31.3(19.5)	2.7(1.7)	0	34.0(21.2)	160.0
Badeae	20/8/84	A'	16.0(41)	0.5(0.1)	0	16.5(4.2)	390.0
Badeae	20/8/84	F'	14.0(3.6)	1.4(0.4)	0	15.4(3.9)	390.0
Badeae	20/8/84	F''	47.0(12.0)	3.1(0.8)	0	50.1(12.8)	390.0
Sanetti	29/9/84	A	61.0(16.9)	1.0(0.3)	0	62.0(17.2)	360.0
Badeae	1/10/84	E'	24.0(5.0	3.0(0.6)	0	27.0(5.6)	480.0
Badeae	1/10/84	F'	11.0(2.3	1.5(0.3)	12.0(2.5)	24.5(5.1)	480.0
Sanetti	29/10/84	A	60.0(18.0)	30.0(9.0)	5.0(1.3)	95.0(28.6)	332.0
Sanetti	29/10/84	B	55.0(16.6)	0	0	55.0(16.6)	332.0
Sanetti	29/10/84	C	65.0(19.6)	0	0	65.0(19.6)	332.0
Sanetti	29/10/84	D	75.0(22.6)	20.0(6.0)	0	95.0(28.6)	332.0
Sanetti	29/10/84	E	40.0(12.0)	20.0 (6.0)	0	60.0(18.0)	332.0

Table 4 continued

Locality	Date	Mole-rat	Foraging	Observing	Digging	Total activity	Total Observation period
Sanetti	28/12/84	D	75.0(20.2)	20.0(5.4)	10.0(2.7)	105.0(28.3)	370.0
Sanetti	28/12/84	E	25.0(6.7)	10.0(2.7)	10.0(2.7)	45.0(12.0)	370.0)
Badeae	31/12/84	A'	20.0(4.3)	10.0(2.2)	0	30.0(6.5)	465.0
Badeae	31/12/84	B'	85.0(18.2)	15.0(3.2)	0	100.0(21.5)	465.0
Badeae	26/3/85	A'	55.0(10.5)	20.0(3.8)	0	75.0(14.4)	520.0
Badeae	26/3/85	B'	75.0(14.4)	20.0(3.8)	5.0(1.0)	100.0(19.2)	520.0
Badeae	26/3/85	C'	20.0(3.8)	10.0(1.9)	0	30.0(5.8)	520.0
Sanetti	21/12/85	A	80.0(16.7)	10.0(2.1)	10.0(2.1)	100.0(20.8)	480.0
Sanetti	21/12/85	B	105.0(21.8)	20.0(4.2)	5.0(1.0)	130.0(27.0)	480.0
Sanetti	21/12/85	C	60.0(12.5)	10.0(2.1)	75.0(15.6)	145.0(30.2)	480.0
Badeae	24/12/85	A'	75.0(12.5)	10.0(1.7)	5.0(0.8)	90.0(15.0)	600.0
BADEAE	MEAN		39.4(8.1)	8.1(1.7)	1.3(0.4)	49.3(10.1)*	488.3
	RANGE		11.0-85.0	0.5-20.0	5.0-12.0	15.4-100.0	160.0-600.0
SANETTI	MEAN		66.7(16.6)	12.5(3.1)	8.9(2.2)	88.0(21.9)*	400.8
	RANGE		40.0-105.0	0-30.0	0-75.0	45.0-145	332.0-505.0
OVERALL	MEAN		53.6(12.7)	10.4(2.4)	5.4(1.3)	69.4(16.4)	423.6
	RANGE		11.0-105.0	0.5-30.0	0-75.0	15.4-145.0	160.0-600.0

* A t-test shows that there is a significant difference in the total time spent aboveground by mole-rats at Sanetti and Badeae.

In Badeae a mole-rat was found digging on a big soil mound. The animal was completely out of the hole and was shovelling the soil with its muzzle in every direction. It did not bring out loose soil from the burrow but pushed the soil away from the hole, that was already there. A similar observation was made at Sanetti, but here the mole-rat was shovelling hay in an old hay pile. These activities showed that formation of big haypiles and soil mounds were probably long processes taking months or even years.

TOTAL ACTIVITY. The total time spent by mole-rats for different activities is shown in Table 4. The total period of surface activities represented from 3.9 to 21.5% (average 10.1%) at Badeae and from 12 to 30.2% (average 22.5%) at Sanetti, of the total observation period. The total activity period varied considerably between different mole-rats on both study areas (Table 4). The total period of surface activity at Sanetti was significantly greater than the total period of activity at Badeae.

On average foraging activity contributed about 77%, observing about 15% and digging about 8% of the total period of activity. The distribution of these activities are shown in Fig 12 for individual mole-rats and Fig. 13 for groups of mole-rats in both observation sites. Surprisingly enough, there was no significant difference between wet and dry season surface activities.

In general, activity usually began in the morning at about 8:00 and ended around 18:00 in the evening on both observation

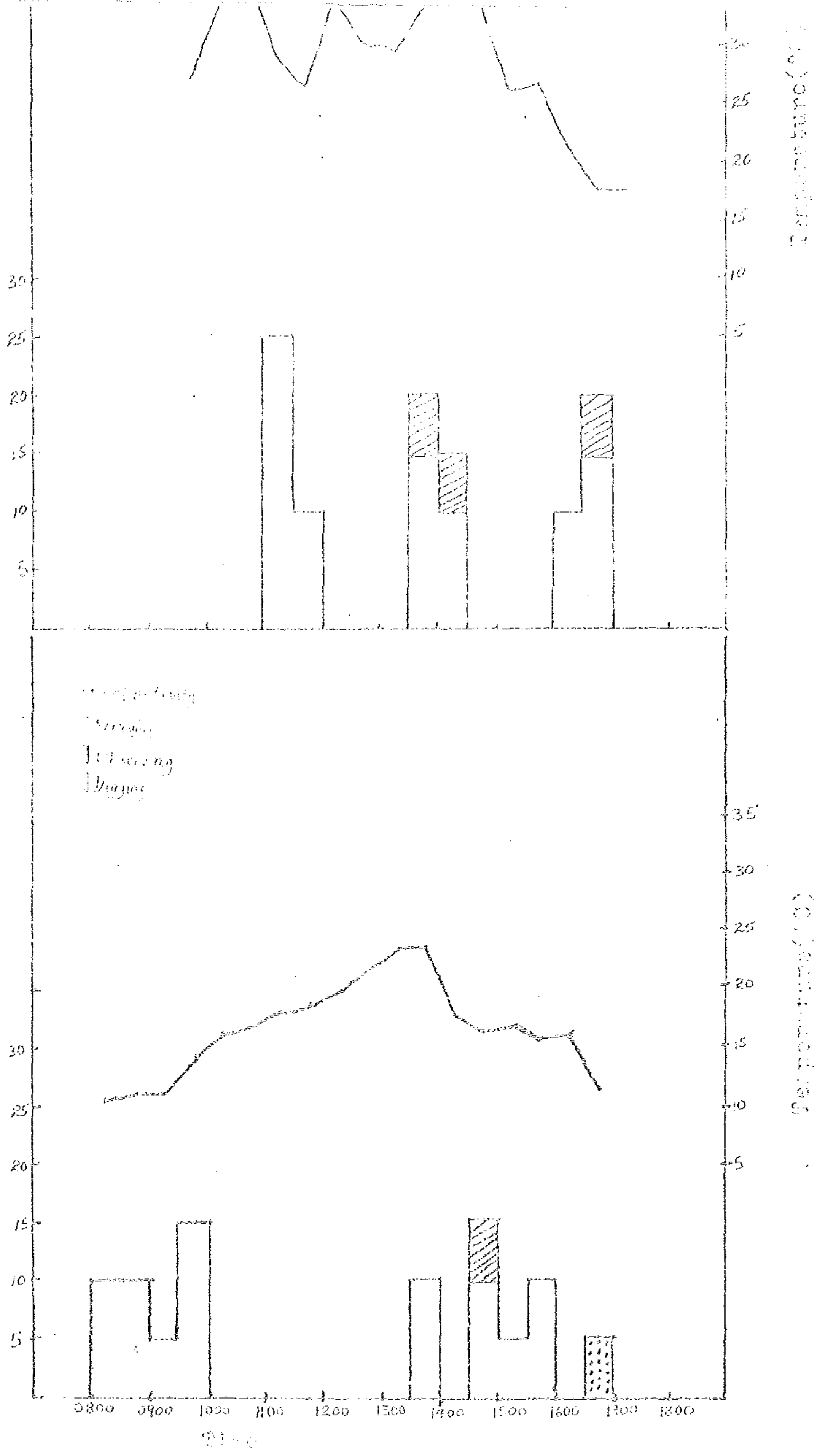


Fig. 12( ) Aboveground activity recorded for individual

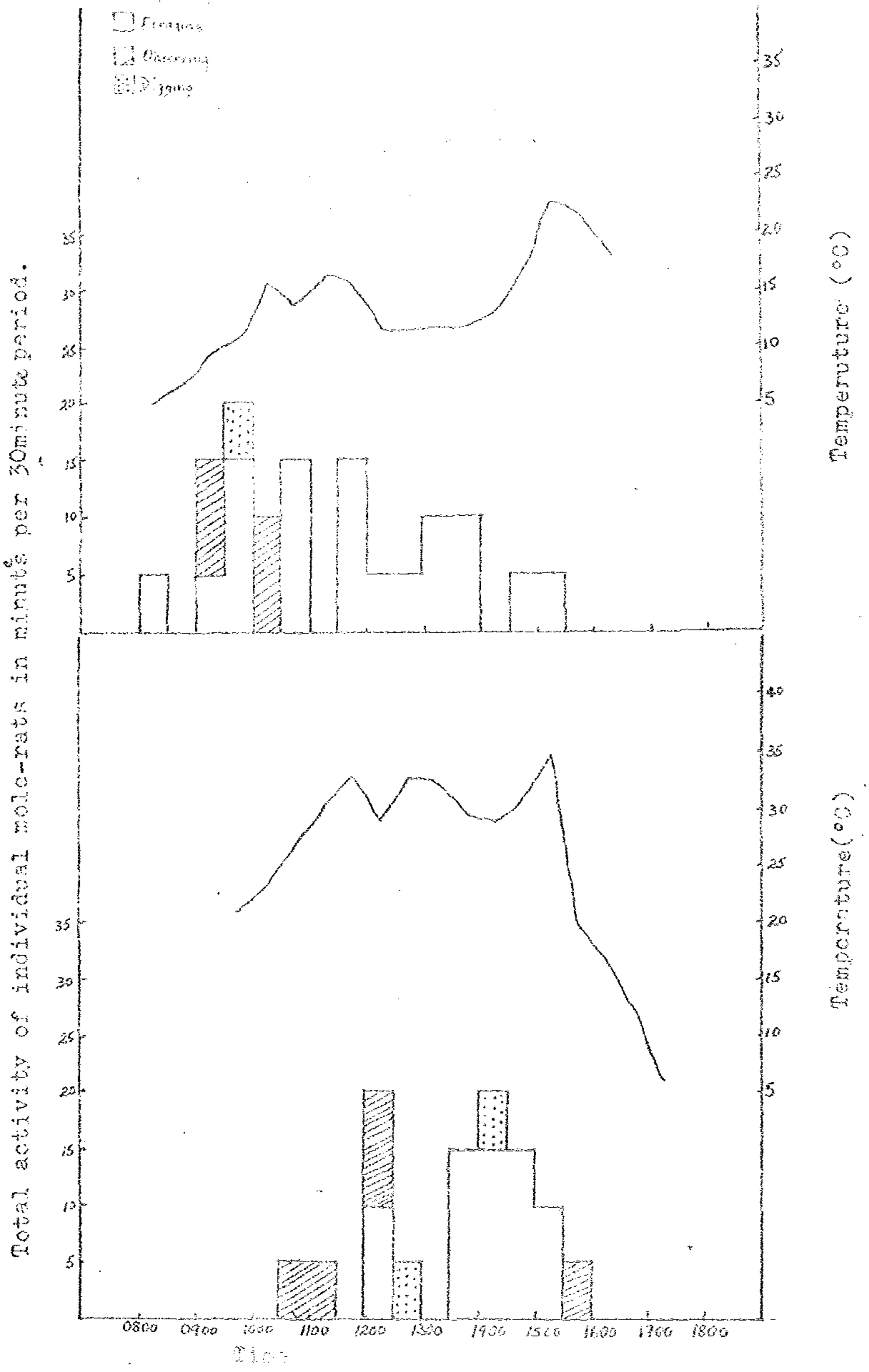


Fig. 12(b) Aboveground activity recorded for individual mole-rat at [illegible].

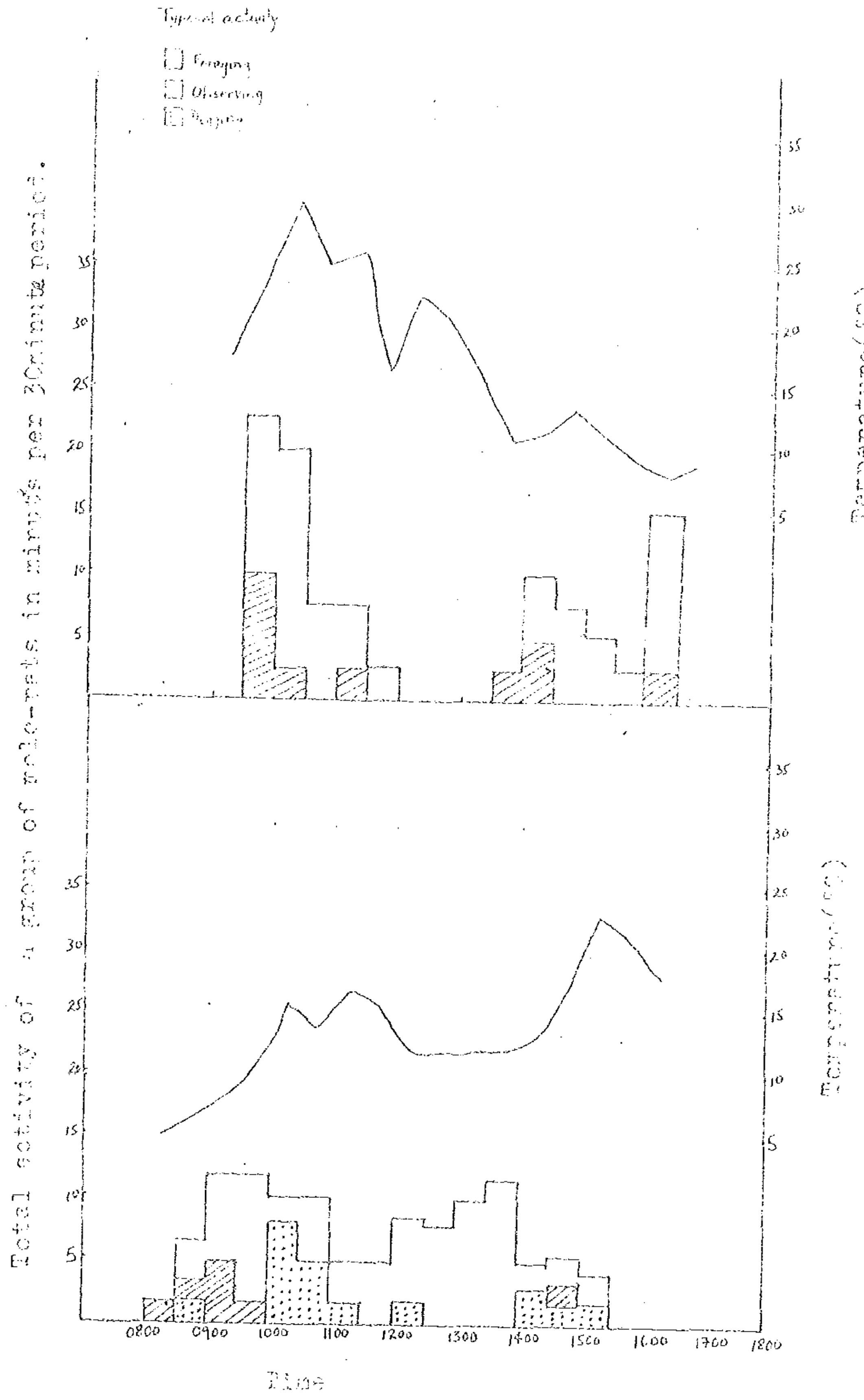


fig. 13. Above ground activity recorded for a group of mole-rats
(a) Activity of mole-rats at Bodone
(b) Activity of mole-rats at Sanetti

sites, although individual mole-rats could start activity late in the morning or even at midday. Normally, mole-rats that started activity late ended their activities late in afternoon. The beginning and ending of activities were clearly noticed by the opening and blocking of foraging holes in the morning and in the dusk respectively.

The relationship between air temperature and mole-rat activities is shown in Figures 12 and 13. Air temperature and mole-rat activities do not seem to have direct correlation, although the mole-rats restrict their surface activities from about 8:00 in the morning to about 18:00 in the afternoon in order to avoid extremely cold temperatures.

POPULATION DENSITY

The population densities of the giant mole-rat were estimated on both study areas by counting fresh signs, active holes, in a belt transect of 4000m^2 (see materials and methods). The density of population was estimated to be 1 mole-rat per 167m^2 or 5988 mole-rats per km^2 area at Sanetti and 1 mole-rat per 1333m^2 or 570 mole-rats per km^2 area at Badeae.

PREDATION

The most important predator of T. macrocephalus was the Simien fox, (Canis simensis), particularly at higher altitudes. In Sanetti foxes were regularly seen hunting for mole-rats and other rodents (Fig. 14). On one occasion a fox was seen eating a mole-rat. In this area many of the mole-rat burrows had been dug, presumably by Simion fox, since there was no other digging predator in the area.

Augur buzzar (Buteo rufofuscus) were frequently observed in Sanetti and between 3 and 8 were recorded each day (Fig. 15). The fact that mole-rat eyes are located at the top of the head indicates that aerial enemies are important, though eyes in this position are also advantageous to look in every direction while foraging.

BREEDING

Disappointingly little information was obtained on breeding. One juvenile mole-rat was seen in September 1984 at Sanetti. This suggested that breeding may occur towards the end of the rainy season. This was further supported by the fact that the rate of soil mound formation was high during the dry season, possibly when the juveniles were making their own burrow system.

SOCIAL ORGANIZATION

All observations made during this study suggested that T. macrocephalus is solitary. One mole-rat almost always occupied one burrow system, although the burrows of two mole-rats could be close enough, so that mole-rats could appear from two holes as close as 7m. apart. In Sanetti, each mima mound appeared to be occupied by a single mole-rat. However, on two different occasions and locations two mole-rats were observed on one mima mound. One juvenile and one adult were seen on the

Fig. 14. Simien fox (*Canis simensis*) hunting.

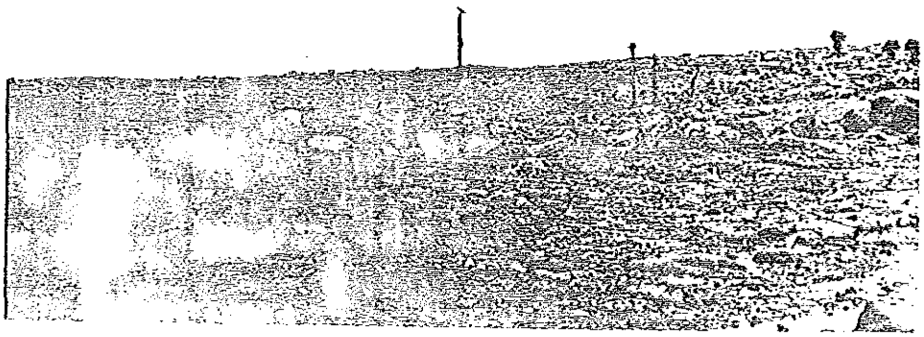


Fig. 15. The Giant lobelia (*Lobelia rhynchopetalum*) serves as a look-out perch for the Augur buzzard (*Buteo rufofuscus*)

same mound in September 1984, and two adult-sized mole-rats were observed on one mima mound in December 1985.

SEASONAL MIGRATION

Mole-rats were observed to make seasonal movements within their burrows. At Badeae for instance, part of the burrow system of each mole-rat was found to be within the raised areas of <u>Kniphofia-Artemisia</u> shrub, where as the main part was located in the lower ground grassland. During the rainy season, the grassland became swampy and all mole-rat activity was restricted to the higher ground in the shrub. Few tunnels were dug in the <u>Kniphofia-Artemisia</u> area, as the number of soil mounds observed were very few. This indicated that this part of the burrow was a permanent system which was more frequently used during the wet season, because of its more favourable moisture conditions. As the swampy grassland began to dry up towards October, the mole-rats moved slowly down the grassland by excavating new tunnels or reconstructing the old ones. When mole-rats followed old tunnels, as indicated by the appearance of active holes near old soil mounds of the previous year, little soil was ejected onto the surface. However, when mole-rats followed new underground routes, by excavating new tunnels, the amount of soil ejected and the number of soil mounds produced were very high.

This kind of restriction of mole-rat activities to raised areas, during the rainy season, was also observed at Gaysay and Sanetti. At Gaysay, deep tunnels and even shallow tunnels in the low level ground, were waterlogged in the wet season. During this period mole-rat activity was restricted to the shallow tunnels in higher ground. At Sanetti, in areas with well formed mima mounds, mole-rat activities were restricted to the top of the mounds specially when the intermound areas became inundated. In areas with seasonally flowing streams, mole-rat opened foraging holes right up to the stream bed during the dry season and restricted their activities to higher grounds during the wet season.

ESTIMATION OF COVER ABUNDANCE OF PLANTS

The cover-abundance of the plant genera was estimated at Sanetti and Badeae. Six 20 X20m quadrats were sampled at Sanetti. Three of those quadrats were placed on mima mounds and the other three on intermound areas. Three quadrats were sampled at Badeae. Two of these were sampled on the grassland and the other in the *Kniphofia-Artemisia* shrub.

Table 5a and 5b indicate the plant genera encountered in the sampling areas and their cover percentages. The data in Table 5a show that, at Sanetti, the percentage of plant cover is much smaller (about 10%) on mima mounds than on intermound areas where vegetation cover is greater (about 20%). This difference in vegetation cover appears to be related with mole rat activity. Mole-rats are more frequently active on mima mounds than on intermound areas. As a result much of the ground cover (about 90%), on mima mounds, is bare soil thrown up by the mole-rats.

The data in Table 5a indicates also that Alchemilla spp. are the dominant herbs on mima mounds contributing about 95% the ground covered by plants. Alchemilla is characteristically the dominant genus on mima mounds at Sanetti. It can, therefore, be inferred that species of Alchemilla are well adapted to colonize the soil heaps thrown up by the giant mole-rat.

The data on Table 5b indicate that at Badeae the ground is well covered by vegetation at the grassland. This appears to be related to mole-rat densities. The mole-rat density here is so low that mole-rat activity does not seem to have influence on the vegetation.

On both observation areas mole-rats were observed to gather vegetation indiscriminately around their foraging holes. Thus, duration of the time spent on the surface and number of holes produced by mole-rats was probably related to the percentage of plant cover. In areas of high plant cover such as Badeae mole-rats spent short periods in surface activities and opened few foraging holes per day.

Table 5a. Cover percentage of the plant genera at Sanetti

Genus	Mima mound	Inter-mound
Alchemilla-1	0.9%	1.7%
Alchemilla-2	5.0%	0.8%
Alchemilla-3	3.3%	-
Haplociadum sp.	0.1%	-
Galium sp.	0.1%	-
Pancium sp.	0.1%	-
Festuca sp.	0.10%	8.75%
Helichrysum-1	0.07%	5.0%
Helichrysum-2	0.01%	1.7%
Cynotis sp.	0.03%	-
Trifolum sp.	0.01%	0.07%
Romulea sp.	0.01%	0.01%
Un identified-1	0.01%	-
Un identified-2	0.03%	-
Thymus sp.	-	0.8%
Helichrysum-3	-	0.9%
Helichrysum-4	-	0.03%
Luzula sp.	-	0.01%
Swertia sp.	-	0.03%
Unidentified 3	-	0.01%
Unidentified 4	-	0.03%
Total	9.7%	19.92%
Total average	14.8%	

Table 5b. Cover percentage of the plant genera at Badeae

Genus	Grasland	Kniphofia-Artemisia
Cotula sp.	18.75%	-
Alchemilla-4	11.88%	-
Alchemilla-5	2.50%	-
Alchemilla-6	-	5.00%
Cyperus sp.	2.50%	0.10%
Ranunculus sp.	1.35%	-
Trifolium sp.	1.30%	-
Poa sp.	4.38%	-
Kniphofia	-	8.75%
Artemisia	-	0.10%
Urtica	-	0.10%
Echinops sp	-	0.10%
Unidentified-1	-	0.10%
Total	42.66%	14.25%
Total average	28.46%	

DISCUSSION

Burrow System

Complete and partially excavated burrow at Gaysay, Badeae and Sanetti revealed that Tachyoryctes macrocephalus burrow system has remarkable similarities with and some differences from the burrow system of other fossorial rodents.

SOIL MOUND The two types of soil mounds produced by T. macrocephalus are strikingly similar in shape to large soil mounds which are concentric piles of crumpled cores of soil, and earth plugs of the mountain pocket gopher (Thomomys talpoides) described by Reid et al. (1966). Other pocket gophers are also known to produce similar earth plugs (Hansen and Ward, 1966; Hickman, 1977). The giant mole-rat, however, does not produce winter casts which are characteristic of pocket gophers. This is because Tachyoryctes macrocephalus lives in tropical highlands where little or no snow is formed during the dry season. T. splendens also produces two types of soil mounds (Jarvis 1973a). However, the large soil mounds of this species are conical unlike the crater-like mounds of T. macrocephalus . This discrepancy is due to the manner in which the soil is pushed out. T. splendens ejects loose soil while it is inside the tunnel while T. macrocephalus comes out of a hole and shovels loose earth.

The formation of two types of soil mounds appears to be associated with different activities. Large soil mounds are thrown up when mole-rats are engaged in excavation, and earth plugs are produced when mole-rats block up foraging holes

(Jarvis, 1973a; Yalden, 1975). Earth plugs may also be produced when extremely shallow tunnels are excavated or during the dry season when mole-rats redistribute loose soil (Hickman, 1977).

The fact that few soil mounds are produced in the giant mole-rat habitat particularly at high altitudes, may indicate that a burrow system is used for a longer period of time probably by a series of generations. Young mole-rats can accept an abondoned burrow and repair it (Hickman and Brown, 1973b). The greater number of soil mounds produced at Badeae during the dry season may be due to extension of tunnels towards the grassland as far down as the soil moisture permits; however it may also be related to breeding. Miller and Bond (1960) suggest that the rate of mound formation is more affected by seasonal change in feeding habit and breeding than by precipitation.

The use of small number of holes to eject large amount of soil and hay (large soil mounds and hay piles are produced due to periodic addition of small quantity of soil or hay through the same hole) has the advantage of minimizing the amount of energy needed to excavate additional tunnels.

HAY PILE Hay piles mixed up with faeces are characteristic of the giant mole-rats burrow system (Yalden, 1975). Similar piles of vegetation are also produced as part of soil mound *T. splendens* (Jarvis and Sale, 1971) *Cryptomys hottentotus* (Genelly, 1965) and *Pappogeomys castanops* (Hickman, 1977).

Yalden (1975) suggests the source of these haypiles to be food storage and nesting materials. The present study, however, indicates that food stores are the main and probably the only source of hay piles. Old nests were found at Gaysay and Badeae with nesting materials being decomposed. If nesting materials were discareded as hay piles, as Yalden (1975) suggested, these decomposed nesting materials would not be found. Besides, all nesting materials examined were devoid of faeces. If nesting materials were the main sources of hay piles, faeces would not be found mixed up with the hay. Secondly, hay piles are not always made up of dried vegetation, but can also be composed of fresh grasses and herbs. In fact, towards the end of the rainy season, vegetation added to hay piles are usually fresh. All this shows that hay piles are discarded food materials, the sources of which are the storage chambers that are found filled with fresh and dried vegetation mixed up with faeces.

FORAGING TUNNELS Hickman (1979) noted that deep and shallow tunnels occured in the burrow of *C. hottentotus* and the deep tunnels were located near the proximity of the nest and connected to the shallow tunnels by gradually sloping ramps and steep shafts. Similar pattern of tunnels were observed in this study although steep shafts were not found. Anastomosis (which enables mole-rats to by pass each other in the burrow) and spiral tunnels (which enable mole-rats to escape from predators without losing secure footing) which were characterstic of the burrow of *Cryptomys* (Eloff, 1951a); Genelly, 1965; Hickman, 1979) were not found in this study. The, former may be relatedto the solitary nature, of T. macrocephalus and the latter to minimum underground predator pressure in the giant mole-rat habitat. The foraging tunnels of the giant mole-rat, however, were usually branched into two or three branches, just a short distance behind a foraging hole. This might be a significant anti-predator device, particularly for Simien fox which frequently attempts to dig the mole-rats out.

The foraging tunnels of T. macrocephalus were circular in cross section like tunnels of other substerranean rodents. The average diameter of these tunnels was, however, very much higher than the tunnels of T. splendens reported by Jarvis and Sale (1971). This was probably due to the size of the giant mole-rat. The depth of the foraging burrows of the giant mole-rat was variable (range 8-52 cm) unlike tunnels of T. splendens (Jarvis and Sale, 1971) and Spalax (Nevo, 1961). The depth of the tunnels of T. macrocephalus reported by Yalden (1975) was much smaller because he excavated small portions of differnt burrow systems. Jarvis and Sale (1971) suggested that depths of foraging tunnels are regulated by the level of roots of food plants. The level of rhizomes and tubers, however, does not seem to influence the depth of tunnels of T. macrocephalus because this species feeds largely on aerial shoots of plants (Yalden, 1975). The importance of having a variable burrow depth in this species may be associated with temperature regulation in addition to protection from predators. The micro-environment of a closed burrow system is very stable, unlike the variable and cyclic terrestrial situations (McNab, 1966; 1979; Gettinger, 1975; Taylor et al., 1985). McNab (1966) noted that the daily temperature fluctuation in the burrow of *Geomys* was inversely related to depth, there was little fluctuation at deeper tunnels. Mole-rats therefore, could move to parts of the burrow with favourable temperature (Jarvis, 1978). They can move to deeper burrows if the superficial burrows become too cold or too hot (Gettinger, 1975). This behavioural thermoregulation may be important in the giant mole-rat habitat where air temperature fluctuation is extremely high (Hillman, 1986a) particularly during the dry season. During this period the deeper burrows can be used since they will be dried up. Deep tunnels besides offering protection against predators and extreme~~s~~ temperatures, may also maintain the burrows at higher levels of humidity as they are close to the water table (Hickman 1977).

Spalax is also know to construct shallow breeding mounds during winter and to renew construction of the deep tunnels during the dry season, so that they accommodate the animals during the hot and dry summer climate (Costa and Neve, 1969).

The total length of tunnels recorded in this study was much higher than that suggested by Yalden (1975) and greater than that recorded for T. splendens (See Jarvis and Sale 1971). In the fully excavated burrow system the area covered by recent (about one month old) surface signs such as soil mounds and earth plugs was 8.3% of the total area covered under ground by the net work of tunnels. This extensive underground tunnel system appeared to be the means to exploit the habitat maximally. It covered wide areas for feeding and facilitated seasonal migration to different parts of the burrow system. The area had a 4° slope; thus all the tunnels were not located at the same level. During the wet season, the mole-rats could move to parts of the burrow at higher levels and restrict their activities there and during the period of minimum rainfall, when rain was not sufficient to make the area swampy, the animals could move to burrows at lower levels and feed. This seasonal movement of mole-rats to raised parts of their burrow system during the rainy season was observed at Badeae and Sanetti. In Sanetti, mole-rat activities were restricted to the top of mima mounds during the wet season particularly in areas where the lower intermound areas were inundated. Similar abbreviation of burrow system as a result of flooding was reported for T. splendens (Hickman, 1983; Gakahu and Cox, 1984) Thomomys talpides (Hansen, 1962) and other pocket gophers (Scheffer, 1958).

Extensive underground tunnel system can be a means by which solitary animals such as mole-rats communicate for the purpose of mating (Hickman, 1977) although some mole-rats can migrate over land either to establish a new burrow system or to search for a mate (Nevo, 1961; Hickman and Brown, 1973b).

NEST AND NESTING MATERIALS In this study one functional nest per system was found. A similar finding was reported for *Cryptomys* (Genelly, 1965; Hickman, 1979) and *Tachyoryctes splendens* (Jarvis and Sale, 1971). Nests of *T. macrocephalus* were located at relatively shallower depths from 18 to 24 cm below the surface, as were nests of *T. splendens* (Jarvis and Sale, 1976) *Cryptomys* (Hickman, 1979). The average diameter of nests of *T. macrocephalus* is similar to the diameter of nests of *T. splendens* and *Heterocephalus glaber* (Jarvis and Sale, 1971) and is greater than the diameter of nests of *Cryptomys* (Hickman, 1979) and *Spalax* (Nevo, 1961). This differences in size of the nest can be related to size of the animals. The giant mole-rat is greater in size than many fossorial rodents (Table 6), and hence has to construct relatively bigger nests. The similarity in size between nests of *T. macrocephalus*, and nests of *T. splendens* is probably due to the fact that nest of the latter are multipurpose. The similarity between nests of *T. macrocephalus* and *H. glaber*, despite the enormous difference in size between the two (Table 6), is related to the social structure. *H. glaber* is a colonial rodent and thus has to constuct a bigger nest to accommodate several individuals.

The nesting material of *T. macrocephalus* in common with other mole-rats, was composed of grasses made into a hollow

Table 6 Some fossorial rodents of the world

Genus	Common name	Family	Distribution	Body Rody weight	References
Geomys	Pocket gopher	Geomyidae	E.N.America	Upto 450g	Walker (1964)
Thomomys	Pocket gopher	Geomyidae	W.N.America	Upto 141g	Turner (1974)
Spalax	Blind mole-rat	Spalacidae	Middle East	Upto 295g	Walker (1964)
Cryptomys	Blesmol	Bathyergidae	E&S. Africa	200g	Kingdon(1974)
Heliophobius	Blesmol	Bathyergidae	E. Africa	160g	Kingdon(1974)
Heterocephalus	Naked mole-rat	Bathyergidae	E. Africa	Upto 80g	Kingdon(1974)
Tachyoryctes	Root rat	Rhizomyidae	E. Africa	Upto 300g	Yalden (1985)
Tachyoryctes	Giant mole-rat	Rhizomyidae	Ethiopia	1000g	Yalden (1985)

ball. Even the unrelated insectivore moles use grasses and other vegetation as nesting materials (Armsby et al., 1966). The most important advantage of such material is in increasing insulation and decreasing the rate of heat loss. The insulation provided by the nest of *Peromyscus leucopus* was found by Glaser and Lustick (1975) to retard the loss of metabolic heat and effectively raise the temperature surrounding the mice at lower ambient temperature. Survival of small mammals during periods of cold weather and minimum activity is very much influenced by the degree of protection offered by the nest (Sealander, 1952). Thermal insulation is as important in tropical lowlands as it is in the cold temperate regions, where successful utilization of habitiat includes the ability to circumvent prolonged exposure to extremes of climatic conditions (Taylor et al., 1985).

T. macrocephalus is a highland species as is *T.splendens* and apparently needs the warmth generated from the decompositon of faeces, food store and nesting material. Nests of *T. macrocephalus* were devoid of faecal pellets unlike the nests of *T. splendens* reported by Jarvis and Sale (1971).

FOOD STORE Burrows of T. macrocephalus consist of special food storage chambers as do burrows of *Spalax* (Nevo, 1961), *Heliophobuis* (Walker, 1964) and *Cryptomys* (Genelly, 1965). However incontrast to the storage chambers of these mole-rats, the storage chambers of *T. macrocephalus* contain faecal pellets mixed up with food items. The presence of faeces in storage chambers is probably due to the fact that the mole-rats spend relatively longer period of time feeding in these chambers and may defecate there. The contamination of stored food with faeces is probably the main reason for the frequent ejection of contents of storage chambers as hay piles. Further research is, , however, needed in captive conditions before one could fully conclude on such reasoning.

T. macrocephalus frequently discards contents of storage chambers as haypiles in contrast to T. splendens which accumulates such materials in the nest to get the warmth generated from decomposition. The advantage gained from decomposition of store contents might be offset by the expenditure of energy needed to construct new store chambers particularly in view of the fact that numerous storage chambers occur in burrows of the giant mole rat at high altitudes. The importance of having high numbers of storage chambers at high altitudes where the vegetation cover is only about 15% of the ground may be related to the availability of food. Storing greater amounts of food is important to supplement the limited amount available on the surface seasonally Besides, having small size but numerous storage chambers than few bigger ones reduces the amount of food that is contaminated with faeces during feeding and hence the amount of food that is discarded.

BOLT-HOLE Bolt hole which is characteristic of the burrows of T. splendens and Heliophobius (Jarvis and Sale, 1971) and Cryptomys (Hickman, 1979) was not discovered in this study. It seems probable that the burrow of T. macrocephalus also has bolt-hole, but was overlooked during excavation, since

EXPOSED PARTS OF BURROW SYSTEM. The extensive underground tunnel systems of mole-rats are usually marked by earth plugs and/or soil mounds over each entrance on the surface. Table 3 shows that there is a difference between the magnitude of surface signs at high and low altitudes specially with regard to inter-hole distance. The inter-hole distance at high altitude (Sanetti) is significantly greater than that at lower altitude (Badeae). This appears to be related with the vegetation cover. In Sanetti quiet a considerable portion of the ground cover (about 85%) is bare boil. On many occassions, therefore, the mole-rats have to move some distance from their foraging holes, to collect the scattered vegetation which is not uniformly distributed around the hole as in Badeae where bare soil covers only 15% of the ground. In areas where the vegetation is sparse, it is important to have the feeding holes far apart since it provides a wider foraging area and increases the chance of getting food plant between two foraging holes. In Badeae and Gaysay however, the ground is almost completely covered by vegetation and hence distance between foraging holes are smaller. The higher number of foraging holes produced by each animal per day at high altitudes is also related to vegetation cover. At Sanetti, where vegetation cover is extremely low, the amount of vegetation required per day by a mole-rat can be gathered from 3 or more foraging holes, where as at Badeae the vegetation around one foraging hole suffices. As a result higher numbers of foraging holes are produced by a mole-rat per day at higher altitude than at lower altitudes.

ACTIVITY ABOVE GROUND

Subterranean mammals such as mole-rats spend their lives essentially underground and rarely come above ground. Some mole-rats are so specialized to underground life that their eyes are degenerated (Eloff, 1951a; 1951b; 1958; Nevo, 1961). On rare occasions, mole rats may briefly appear on the surface searching for a mate (Nevo, 1961); to collect nesting materials (Gettinger, 1975)and food materials (Jarvis and Sale, 1971; Yalden, 1975) or when their burrows are flooded (Hickman, 1978; Hickman et al., 1983). The giant mole-rat, however, is a more frequent visitor of the surface than other African mole-rats, as it largely feeds on aerial shoots of plants. This behavior has made the recording of aboveground activities such as observing, foraging and digging possible.

OBSERVING When mole-rats appear on the surface either to forage, dispose of loose soil or for any other activity, they invariably make some kind of observation to detect any potential predator that may be present around their burrow systems. This behavior has been recorded for T. splendens (Jarvis and Sale, 1971) T.macrocephalus (Yalden, 1975) and for pocket gophers (Hickman and Brown, 1973a). Mole-rats become vulnerable to predators when they leave their protected underground burrows and the ability to detect predators during this vulnerable period is an important behavioral adaptation promoting survival (Hickman and Brown, 1973a). T. macrocephalus, which is the least specialized mole-rat for subterranean life (Yalden, 1985) has well developed senses of sight and hearing which enable it to detect the motion and sound of predators effectively.

The extended period of observation made by the giant mole-rats, whenever it comes out of a foraging hole for the first time or when it suspects danger, indicates that the animal carefully surveys the environment before it engages in other activites and becomes susceptible to predators.

FORAGING Fossorial rodents collect aerial shoots of plants for nesting material (Gettinger, 1975) and feeding (Nevo, 1961; Jarvis 1973a; Yalden, 1975; 1985) T. macrocephalus spends more time foraging above ground, because it feeds largely on aerial shoots of plants (Yalden, 1975). One important advantage of surface foraging is to minimize energy expenditure. The giant mole-rat can harvest vegetation in an area of about 500 cm^2 by opening only one foraging hole, thus reducing the amount of energy that would be needed to extend foraging tunnels, if it fed only from underground.

Yalden (1975) analyzed stomach contents of giant mole-rats from both high and low altitudes. Specimens collected from high altitudes fed entirely on aerial shoots of plants while the two specimens which included roots and grit were from lower altitude grassland areas. These differences might suggest that the availability of tubers and bulbs was limited at high altitude.

T. splendens feeds largely on tubers and bulbs, although it sometimes surface forages (Jarvis and Sale, 1971) unlike

T. macrocephalus. T. macrocephalus being a highland animal has higher energy requirements and has to consume more food than animals of lower altitudes such as T. splendens. The giant mole-rat appears to have succeeded in obtaining more food by the behavioural modification of extended above ground foraging, although a detailed study of the physiology of this species and the aboveground and belowground productivity of its habitat is important to support this explanation.

DIGGING Most of the digging activity that can be observed at the surface is mainly blocking up of old foraging holes although uplifting of loose soil and hay are also conspicuous. Mole-rats constantly open new holes in search of food and plug up old holes to keep predators out and the micro-climate of the burrow constant.

While on the surface, T. macrocephalus pushes loose soil usually with its muzzle and at times with the sides of its face. This is slightly different from the way T. splendens transports soil (Jarvis and Sale, 1971) in that, when T. macrocephalus uses the side of its face the corresponding fore foot does not seem to be involved.

Modification of the upper lip, which meets behind the protruding incisors, and the well developed incisors suggest that T. macrocephalus in common with East African mole-rats (Jarvis and Sale, 1971), digs with its incisors.

TOTAL ACTIVITY The total periods of surface activities recorded in this study are much higher than those recorded by Yalden (1975) especially at higher altitude. This discrepancy is probably due to differences in habitat and method of recording. Yalden (1975) observed mole-rats at Urgona Valley (BMNP) where the vegetation cover appears to be better (50% of the ground cover) than at Sanetti where the vegetation cover is only about 15%. At lower altitude, in fact, the average total activity period recorded in this study is lower than the average total period of activity recorded by Yalden for adult mole-rats. The method of timing used in this study specially towards the latter half of the study period, increased the time spent by mole-rats for various activities (see materials and methods).

Of the total time spent on the surface 77.2% was spent on foraging, 14.9% on observing and 7.9% on digging. It is not surprising to see that more time was devoted for foraging because all other activities were performed primarily for the purpose of feeding. Nevo (1979) noted that all the activities of subterranean mammals were linked with feeding periods.

Surprisingly enough the pattern of surface activity recorded in this study is very similar to the activity patterns of T. splendens and more or less so with the activity patterns of Heliophobius (Jarvis, 1973a) and Spalax (Nevo, et al. 1982), although nothing is known about the subsurface activities of the giant mole-rat. T. macrocephalus restricts its period of surface activity to a clearly defined time of the day as does T. splendens (Jarvis, 1973a). Jarvis (1973a) suggests that the distinct daily activity pattern is triggered by exposure to light when the mole-rats forage above ground.

Endogenous rhythmicity appears to be synchronized with, and selected by, the environment as an adaptive strategy (Enright, 1970). The surface activity pattern of T. macrocephalus has adaptive value to conserve metabolic energy and promote survival. The mole-rats become active, on the surface, during the day when the air temperature is fairly high. This diurnal activity reduce the amount of energy needed to maintain body temperature in contrast to nocturnal activity, when night temperatures normally dip below freezing. In addition the giant mole-rat can clearly detect the presence and approach of predators on the surface during the day because of its well developed sense of sight. The restriction of above ground activities during the day is, therefore, an adaptive strategy.

POPULATION DENSITY

Subterranean rodents live in a closed burrow system, their presence is thus indicated by surface signs such as soil mounds and earth plugs. Because of their subterranean existence, population densities of mole-rat are usually estimated indirectly (Jarvis, 1973b). The number of surface signs and the rate of their production have been used to estimate population density (Hill et al., 1957; Genelly, 1965; Hansen and Ward, 1966 Reid et al., 1966). Nevo (1961) Jarvis and Sale, (1971) and Jarvis (1973b) believe, however, that estimation of population density from counts of surface signs are unsatisfactory because environmental variations in soil moisture and texture and vegetation influences the number of surface signs produced. More accurate estimation of population density of subterranean rodents can be gained by trapping out all rodent moles in a unit area. Hansen and Ward (1966) and Reid et al. (1966) have found a positive relationship between number of pocket gohpers trapped and surface sign counts.

In this study population density of the giant mole-rat was estimated based on surface sign method, active holes were counted to estimate mole-rat numbers. The population density was estimated to be about 6000 mole-rats per km^2 at Sanetti and 570 mole-rats per km^2 at Badeae. The population density at high altitudes was similar to the density of population estimated by Yalden (1975) but, contrasted with the mole-rat density suggested by Hillman (1986a). This discrepancy is probably related to the specific area where the density was estimated, although the methods of estimation used might also have contributed to the difference in the estimated densities. Neither Yalden (1975) nor Hillman (1986a) used counts of active holes to estimate Mole-rat densities.

The difference in population density between the two observation sites, Sanetti and Badeae, may be due to differences in vegetation and soil types. Although the vegetation cover is very high at lower altitude, the area covered by prefered food plants is actually small. Besides severe competion appears to occur between the mole-rats and domestic livestock at lower altitude. Hansen and Ward (1966) suggest that population densities of pocket gophers cannot be predicted by the availability of food, even though high population densities may depend, in part, on large amounts of available food. This may well be true for the giant mole-rat. Although the availability of food seems to be small from the vegetation cover, large amounts of food can be harvested and stored underground during the growing season. From the higher number of storage chambers and higher number of large hay piles at Sanetti, it appears that food is not a limiting factor at high altitude.

Though the soil types of the two observation sites are similar chemically (Weinert and Mazurek, 1984), they are not physically so. The soil at Sanetti is so soft that it collapses under the foot at nearly every step, whereas at Badeae the soil is very compact, and cattle and horses graze in this area, which may help in compacting. The difference in mechanical properties of the soil at the two observation sites, may also have contributed to the difference in population densities. mole-rats expend energy during excavation and the amount of energy expended to excavate a unit length of tunnel depends on the nature of the soil. It is, therefore, obvious that at Sanetti where the soil is soft and easly workable; mole-rats expend far less energy in digging than at Badeae. Detailed vegetation and soil studies are necessary before the factors that contributed differences in population densities are fully understood.

Predation

Subterranean rodents, such as mole-rats, that live in closed burrow systems are effectively protected from potential predators (Hildebrand, 1982; Jarvis, 1973b). Mole-rats become vulnerable to predators when they come to the surface either to forage (Jarvis & Sale, 1971; Jarvis 1973a) or when the young disperse to establish their own burrow systems (Jarvis 1973b) or when they are driven out by flooding (Genelly, 1965, Jarvis, 1973b) T. macrocephalus seems to be more vulnerable to predators because it spends more time on the surface than other African mole-rats. However it has a well developed sense of sight and hearing which enable it to detect predators more effectively than other mole-rats.

The data in this study and in the literature suggest that the most important predator of T. macrocephalus is the Simien fox (Canis simensis) (Yalden, 1975; Morris and Malcolm 1977; Hillman, 1986a; 1986b). The Simien fox and the giant mole-rat both occur at higher density in the afro-alpine zone. Other mammalian predators that may feed on mole-rat are Zorilla (Ictonyx striatus) (Hillman, 1986b) and Serval (Felis serval) (Yalden, 1975). Various birds of prey have also been recorded in the mole-rat habitat (see Yalden, 1975; Hillman, 1986a) although Augur buzard (Buteo rufofuscus) is the most frequent and probably the most important avian predator. Further work, however, is needed to understand the effect of predation in regulating mole-rat densities and the influence of mole-rat population on the population of the endangered Simein fox (Canis simensis)

BREEDING

Nothing is known about the gestation period and litter size of the giant mole-rat nor is the breeding season well known. Litter size is very low in subterranean mammals (Nevo, 1979). The litter size of T. splendens is usually one, although on rare occasions it can be two or more (Jarvis, 1969; Rham, 1969; Jarvis 1973b). A similar pattern has been found for Bathyergus (Jarvis, 1969), Spalax (Nevo, 1961) and for pocket gophers (Hansen and Bear, 1965). One juvenile observed in this study and one immature observed by Yalden (1975) indicate that litter size of T. macrocephalus is also small, probably one. These juveniles were observed in September and January, and this may indicate that breeding occurs towards the end of the rainy season or possibly throughout the year.

The gestation period of T. splendens ranges from 40 to 48 days (Jarvis, 1969; Rham, 1969). Since T. macrocephalus is a larger mole-rat the gestation period might be expected to be a little longer.

SOCIAL ORGANIZATION

Observations made in this study suggest that T. macrocephalus is solitary, as is T. splendens (Jarvis and Sale, 1971; Hickman, 1983). However, Yalden (1975) described the group of individual mole-rats he observed as a colony although, he presented no evidence to support this contention. There was in the present study, however, good evidence to show that the giant mole-rat is solitary, as there were no foraging holes that had been used by more than one mole-rat. At Sanetti each mima mound was occupied by a single giant mole-rat similar to that described for T. splendens (Gakahu and Cox, 1984) and Thomomys talpoides (Hansen, 1962). On two different occasions, however, two mole-rats were observed on one mima mound. On the first occasion one of the mole-rats was juvenile, and on the second both mole-rats appeared to be adults. These plural occupancies of a burrow system were probably related to breeding. During the breeding season territorial behavior becomes subordinate to reproductive instincts and male and female may tolerate each other. This has been described for other solitary mole-rats such as Spalax (Nevo, 1961) and pocket gophers (Hansen and Miller, 1959).

SUMMARY AND RECOMMENDATIONS

This study provides information on burrow structure, patterns of the surface activities, population density, social structure and seasonal movements of the giant mole-rat (Tachyoryctes macrocephalus Ruppell, 1842) on the basis of field observations in Bale Mountains National Park. This species is endemic to Ethiopia and found only in Bale Mountains as far as is known.

Extensive network of underground tunnels, marked by soil mounds, earth plugs and hay piles on the surface, are dug by this animal. A portion of this tunnel system occurs at greater depth about 50cm from the surface, and remains waterlogged during the wet season. The burrow system contains one to several blind tunnels serving as food caches. The food store is normally contaminated with faeces. One functional nest per burrow system appears to be characteristic.

Mole-rats spend brief periods of time above ground collecting plants, shovelling earth and observing. An individual mole-rat spends, on the average, 54 minutes foraging, 10 minutes observing and 5 minutes plugging up old foraging hole, shovelling earth or hay a day.

The population density of mole-rats was estimated to be 1 mole-rat per 167 m^2 area at Sanetti and 1 mole-rat per 1333m^2 area at Badeae.

The giant mole-rat is a solitary rodent. It makes seasonal movements with in its burrow system.

Simien fox (*Canis simensis*)appears to be the major predator.

Based on this study it is recommended that:

a) Studies of the giant mole-rat in captivity will provide information on subsurface activity of the mole-rat which is totally unknown, breeding biology such as gestation period, litter size and sexual behavior. Important physiological studies can also be made on captive mole-rats.

b) Many more burrows have to be excavated over large areas to determine variability of burrow structure and factors that influence the construction of burrows.

c) Studies on the vegetation types at different altitudes, and their above-ground and below-ground productivity are necessary to understand factors that affect mole-rat's feeding habit.

d) Studies on physical and chemical properties of soil at different habitats are neccessary to understand the impact of these factors on mole-rat densities.

e) The effect of livestock grazing on mole-rat population is not well known at lower altitude. A detailed study of hthis will be important to regulate mole-rat densities. At Sanetti, however, cattle grazing will have adverse effect on mole-rat populations. Very high numbers of cattle are now grazing on Sanetti plateau due to a recent settlement in Rira. This heavy cattle grazing will have detrimental impact on mole-rats not only due to competition for food plant but also due to trampling as the cattle walk on the extremely soft soil.

f) Study of population dynamics of the giant mole-rat is important to the conservation of the endangered Simen fox as the mole-rat is its major prey

g) The giant mole-rat is not only endemic to Ethiopia, but occurs in limited areas in Bale Mountains. It is, therefore, important to visit other highland areas of Ethiopia which seem to harbor this species to determine its range and distribution.

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