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The Ecology and Conservation of Juliana's Golden Mole (*Neamblysomus julianae*)

by

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Submitted in fulfilment of the requirements for the degree
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in the

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Supervisor: Dr M.P. Robertson
Co-supervisor: Prof N.C. Bennett

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I declare that this thesis, which I hereby submit for the degree Master of Science (Zoology) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Craig Ryan Jackson
21 February 2007

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Abstract

Despite an IUCN conservation status of critically endangered, Juliana's golden mole (*Neamblysomus julianae*) has received no ecological research attention to date. The species urgently requires conservation attention, but a poor understanding its biology, ecology and distribution makes effective conservation planning almost impossible. In light of this, a thorough understanding of the habitat requirements for this habitat specific species was needed. Additionally, the cryptic lifestyle of Juliana's golden mole has resulted in very few distribution records for the species. Little was known about the animals' daily and seasonal activity patterns or movement patterns. This study revealed that Juliana's golden mole is range restricted on account of sandy soils that have a uniform particle size distribution. This feature limits substrate compaction, making tunnelling far easier for these small mammals. In comparison to uninhabited areas, occupied habitat had greater vegetation cover provided by trees and shrubs, and this would be expected to provide a cooler and moister microenvironment. The ecological parameters associated with the species presence were then used, in addition to existing GIS data, to predict regions of potentially suitable habitat. This process revealed large potentially inhabitable areas in the northern parts of South Africa. Preliminary ground-truthing has shown the model to be relatively accurate with three potentially new populations having been identified. Contrary to what has been reported in the literature, Juliana's golden mole does not appear to be strictly nocturnal. Instead, an adaptive pattern of activity was observed, governed by soil temperature. Body temperature was found to fluctuate to some degree with that of the soil temperature, but fluctuations were regulated by behavioural thermoregulation. Seasonal activity is highly correlated with rainfall. Rain moistens the soil making it significantly softer and far easier to tunnel through. Using this and other information acquired through the course of the study, the thesis culminates with an evaluation of conservation concerns and proposed conservation management actions.

Keywords

Juliana's golden mole, *Neamblysomus julianae*, Chrysochloridae, habitat requirements, conservation planning, activity pattern, species distribution model, torpor, conservation management plan.

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Foreword

Prior to this project, knowledge about the biology and ecology of Juliana's golden mole was comprised almost exclusively from anecdotal observations. The only aspects investigated rigorously were morphological and taxonomic in nature, although these were based on small sample sizes. Chapter one provides an introduction to the Chrysochloridae (golden moles) and, more specifically, Juliana's golden mole. The three isolated populations from which the species is described are discussed. Soil and vegetation properties at each of the three populations were investigated and presented in Chapter 2. In an attempt to highlight any consistent differences between ecological variables in suitable and unsuitable habitat, sampling design employed a presence-absence approach. The findings were used to reclassify existing GIS layers in Chapter 3. Manipulating these layers produced a map indicating where potentially suitable habitat may be located in the northern parts of South Africa. Insights into daily and seasonal patterns of activity were gained in Chapter 4, and conservation recommendations are presented in the fifth and final chapter.

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Chapter 1

An Introduction to the Ecology and Conservation of Juliana's Golden Mole

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"So much mystery attaches to their [golden moles] habits and the various species show such interesting adaptations, that they must be considered as being amongst the most interesting mammals in the world"

- Dr Austin Roberts -

1.1 Background and Justification

1.1.1 Golden moles

The golden moles (Chrysochloridae) are an ancient group of mammals. They inhabit diverse environments ranging from deserts, grassland and bushveld to coastal dunes and forests (Skinner & Chimimba 2005), varying in altitude from sea level to more than 3250m above sea level (C.R. Jackson Pers. Obs.). Despite this substantial variation in habitat type, all Chrysochlorids are morphologically similar, with adaptations for their specialized subterranean lifestyle that include fusiform bodies, muscular forequarters powering pick-like claws, and an absence of external ear pinnae and tails (Bronner 1997). Their subcutaneous, highly vestigial eyes with degenerate optic nerve, render these animals blind. Their senses are instead well adapted to olfactory and sematosensory cues and are used for hunting their prey comprising various types of invertebrates (Skinner & Chimimba 2005). A hardened, shovel-like nose pad that has a leather-like texture is used to move loose soil during burrowing. Fur colour varies from jet-black to brown and yellow and the name 'golden mole' describes the silver, bronze, green or violet iridescent sheen of the pelage (Bronner 1997). Low metabolic rates are a characteristic feature of subterranean mammals (Bennett & Faulkes 2000) but the golden moles have refined this energy saving mechanism even further and can employ torpor when thermally or energetically stressed (Skinner & Chimimba 2005).

1.1.2 Phylogenetic relationships

The Chrysochloridae have traditionally been grouped with the Insectivora. Based on their unique physical attributes, Broom (1950) placed the family in its own order, the Chrysochloridea, whilst others retained them as part of the Insectivora (Roberts 1951). The order Insectivora has perhaps had the most unstable systematic history of all the mammalian orders. Despite being studied for over 300 years, consensus of the taxonomic relationships between the representatives has still not been reached (Grenyer & Purvis 2003).

Using molecular systematics, a unique supra-ordinal clade of diverse taxa, endemic to Africa, was identified based on amino acid sequencing (de Jong *et al.* 1981). This unique clade, later termed the Afrotheria (Stanhope *et al*. 1998), groups a mixture of African mammals that includes the golden moles (Chrysochloridae), elephant shrews (Macroscelidea), tenrecs (Tenerecidae) with the aardvark (Tubulidentata), elephants (Proboscidea), hyraxes (Hyracoidea) and the sea cows (Sirenia). Although the monophyly of Afrotheria is well supported by recent molecular studies, the interrelationships within afrotherian mammals remains to be clarified (Murata *et al.* 2003). Within the supra-ordinal clade, golden moles and tenrecs were placed into a new order named the Afrosoricida (Stanhope *et al.* 1998). These molecular affinities do not bide well with the traditional phylogenies based on morphological and palaeontological data that instead point towards a closer relationship with the core insectivores (Skinner & Chimimba 2005).

Consensus regarding the structure and composition of the Chrysochloridae is perhaps even more debated than that of the order to which they belong. Several taxonomic revisions have occurred over the past five decades, at both the genus and species levels (Roberts 1951; Skinner & Chimimba 2005). Chrysochlorids are restricted exclusively to sub-Saharan Africa, although southern Africa is the centre of golden mole diversity with 18 of the 21 species from nine genera being represented within the region (Skinner & Chimimba 2005). Golden moles are morphologically very similar to one another and it is very possible that cryptic species are contained within the 21 currently recognised species and nine genera (Maree *et al.* 2003).

In sub-Saharan Africa, the mole-rats (Bathyergidae) are the only other totally subterranean mammalian family (Bennett & Faulkes 2000). Mole-rats are rodents and thus have no strong evolutionary association to the Afrosoricida (de Jong *et al.* 1981; Stanhope *et al.* 1998). Mole-rats make use of powerful extra-buccal incisors to excavate their frequently extensive tunnel systems, while all four limbs are employed to move the loosened soil. Unlike golden moles, mole-rats have small eyes, although highly reduced in both size and function and are only capable of detecting variations in light intensity and day length (Oosthuizen *et al.* 2003). Many mole-rat species are highly social, with a single pair of breeding animals and several other subordinate colony members assisting with routine tasks (Bennett & Jarvis 1988; Bennett 1989).

1.1.3 Life below the soil

Properties of the soil substrate are extremely important for an organism that has a totally subterranean existence and that performs all of its daily activities underground. The entire life history of the golden mole is affected either directly or indirectly by properties of the soil. The insulating property of the soil is a major feature that regulates both temperature and humidity fluctuations on a daily as well as seasonal basis (Brady & Weil 1999; Buffenstein 2000). The microenvironment of the burrow just below the surface is fairly constant and largely protected from environmental extremes (Bennett *et al.* 1988; Roper *et al*. 2001). Although the micro-environmental conditions of the subterranean niche are generally stable, it is an environment characterised by the absence of light, high energetic demands for burrowing, as well as hypoxic (low oxygen) and hypercapnic (high carbon dioxide) atmospheric burrow conditions (McNab 1979; Bennett & Faulkes 2000; Buffenstein 2000). The degree to which gas exchange occurs between the outside environment and the burrow is largely dependent on soil type and moisture (Seymour & Seely 1996). The dry, porous Namib Desert sands, home to the Namib golden mole (*Eremitalpa granti namibensis*), provide high levels of oxygen availability for the sub-surface environment (Seymour & Seely 1996). Golden moles are not found in hard soil substrates but are instead restricted to sandy and more friable soil types that facilitate comparatively easy tunnelling. This phenomenon is the chief factor affecting the Chrysochlorid distribution. Unlike the weak digging golden moles, mole-rats are able to inhabit more compact soils given their chisel tooth digging capabilities.

1.1.4 Threats and Conservation Issues

Due to their subterranean lifestyle and ancient history, the present distribution of the Chrysochloridae is a product of mammalian evolution governed by the underlying geological variations, and consequently the present-day soil types (Skinner & Chimimba 2005). Dependence on these soil types results in several species of golden mole having very restricted distributional ranges (see Fig. 1). Living and moving exclusively below ground negates migration to isolated patches of habitat through hard or otherwise unsuitable soil. Small body size further compounds their poor dispersal capabilities. Confined to their soil-mediated geographical ranges, golden moles are especially prone to the ever-increasing housing and road infrastructure associated with today’s modern societies. Habitat is lost and fragmented in the process and this phenomenon is considered to be the single greatest threat to biodiversity at global and regional scales (Noss and Csuti 1997; Brooks *et al*. 2002) and is indeed the greatest concern for effective long-term golden mole conservation.

The majority of golden mole species are distributed over relatively small geographical areas. When these areas fall prey to urban or industrial developments, the subsequent change in land use makes no provision for golden moles or their ecological requirements. Despite the removal of habitat and reduction in population size, the remaining animals are isolated in patches of various sizes. Studies show that species diversity decreases and extinction rate increases in fragmented habitats (Soulé *et al.* 1992). The size of the resultant islands largely determines its viability to support golden moles.

Small areas are more liable to physical disturbance and edge effects and would support a lower number of individuals. When only a few individuals occupy a patch, natural catastrophes such as fires, droughts or floods could kill off the remaining animals. Local extinction events are also more probable through biotic processes such as disease and predation. Demographic parameters including sex ratio, fecundity, mortality, recruitment as well as progeny and individual fitness are compromised. This, in turn, has genetic consequences and factors such as effective population size, inbreeding, genetic drift, gene flow, genetic bottlenecks, founder effect and genetic diversity become serious concerns that further compromise the population's ability to adapt to changing selection pressures (Bolger *et al.* 2001; Keller & Waller 2002; Epps *et al.* 2005).

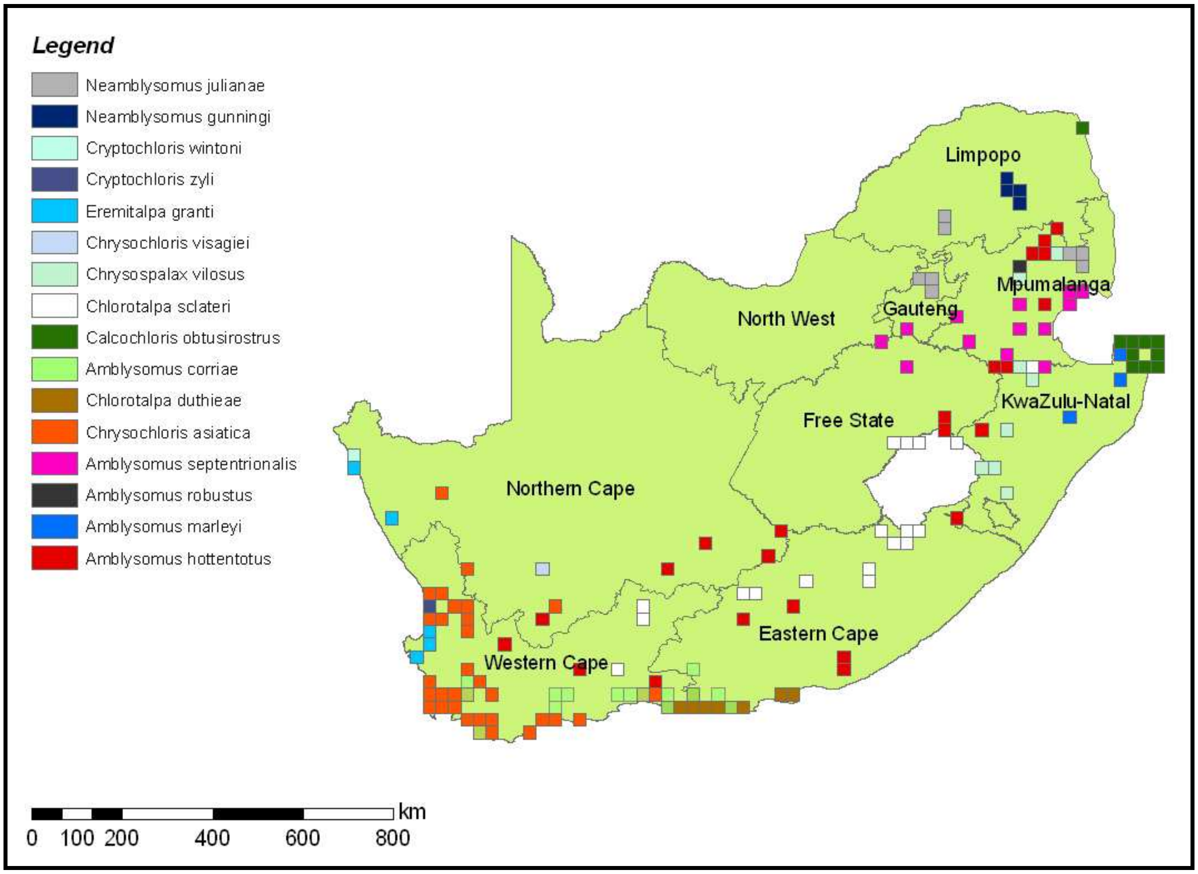

Figure 1. The recorded localities of the 17 golden mole species occurring in South Africa. Data represented in the quarter degree cells (15’ x 15’) are sourced from IUCN conservation assessment for the mammals of South Africa (2004).

Alarmingly, ten of the twenty-one currently recognised species of golden moles have an IUCN-red list status ranging from vulnerable to critically endangered, with another three not assessed due to data deficiencies (Bronner 2006). The five most endangered golden mole species are listed as among the ten most threatened mammals in South Africa (IUCN 2004; Table 1). All five species are poorly studied and occur in a very small area.

Table 1. The ten most endangered mammals in South Africa according to the IUCN red data mammal assessment of 2004.

	Common Name	**Scientific Name**
1	Black Rhinoceros - arid ecotype	*Diceros bicornis bicornis*
2	De Winton's Golden Mole	*Cryptochloris wintoni*
3	Juliana's Golden Mole	*Neamblysomus julianae (Pretoria subpopulation)*
4	Ongoye Red Squirrel	*Paraxerus palliatus ornatus*
5	Rendall's Serotine Bat	*Neoromicia rendalli*
6	Riverine Rabbit	*Bunolagus monticularis*
7	Rough-haired Golden Mole	*Chrysospalax villosus*
8	Short-eared Trident Bat	*Cloeotis percivali*
9	Van Zyl's Golden Mole	*Cryptochloris zyli*
10	Visagie's Golden Mole	*Chrysochloris visagiei*

Despite the endangered status of two-thirds of the golden mole species, there is a dearth of knowledge for the majority of the representatives of the family (Skinner & Chimimba 2005). Indeed, aspects such as basic natural history, distribution, ecology, physiology and taxonomic status are still embryonic. Much of what is known about these species is anecdotal and almost no published quantitative ecological data are available. The Juliana's golden mole (*Neamblysomus julianae*) is an example of such a species and, after only being described less than 35 years ago, it has a very real risk being driven to extinction.

1.2. The Juliana's golden mole (*Neamblysomus julianae*)

1.2.1 Threatened status and biogeography

The Juliana's golden mole is the second most endangered golden mole in South Africa (IUCN 2004). Threats to the species, specifically through anthropogenic activities, have been recognised for some time and when Freitag and van Jaarsveld (1997) prioritised conservation efforts for mammals in north eastern South Africa they awarded this endemic species the highest possible regional score for the then Transvaal province. Their multifaceted assessment incorporated regional occupancy, relative taxonomic distinctness, endemism and vulnerability to evaluate conservation needs of mammal species within the region (Freitag & van Jaarsveld 1997).

Three isolated populations of the Juliana's golden mole are presently recognised. The holotype was collected at the foot of the Bronberg Ridge in the Willows, eastern Pretoria, in 1965 and was subsequently described by Meester in 1972 (Bronner 1997; Skinner & Chimimba 2005). Animals were subsequently located in the Nylsvley Nature Reserve and surroundings environs 120km to the north, and 350km east in the south western section of the Kruger National Park (Skinner & Chimimba 2005).

Morphological (Bronner 1997) and preliminary molecular data (S. Maree, N.C. Bennett, C.R. Jackson*, unpublished data*) indicate each of the currently known populations of Juliana's golden mole form distinct evolutionary lineages. The animals in the Kruger National Park population have an extra tooth in the form of a third molar that is absent in the other populations (Bronner 1997). The statistical support for the molecular findings is very high at more than 90%. The genetic distance of the two specimens from Nylsvley and the Kruger National Park were 0.28% and 0.96%, respectively (S. Maree *et al*. unpublished data). Within the Bronberg population there was no genetic differentiation. The average sequence divergences between the Bronberg population and Nylsvley and Kruger National Park populations were 4.5% and 5.2%, respectively (S. Maree *et al*. *unpublished data*). This is compelling evidence that the three populations represent distinct evolutionary lineages. Based on the amount of sequence divergence, the population in the Kruger National Park could therefore represent a separate species. If the species were split into new or sub-species, each population would then represent the total species' range making the conservation of each population even more critical.

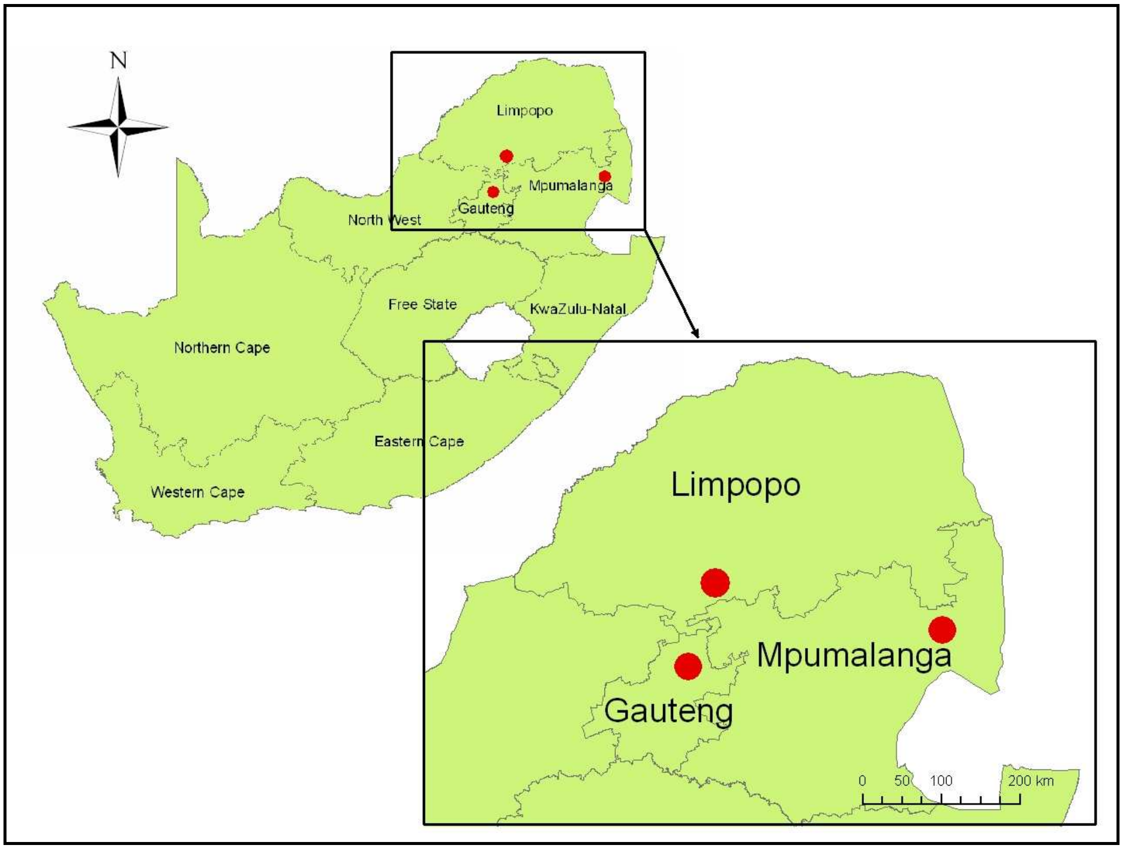

Figure 2. The three isolated populations of Juliana's golden mole; Bronberg Ridge (BR), Nylsvley Nature Reserve (NNR) and Kruger National Park (KNP).

The IUCN currently lists the Bronberg population in Pretoria as Critically Endangered (Bronner 2006). This is the highest category that can be assigned to an extant species and indicates that these animals are facing an extremely high risk of extinction in the immediate future (IUCN 2004). Reasons for this designation are based on its severely fragmented distribution and, given the ongoing habitat loss, predicted continuation of the population decline. Populations on the Nyl flood plain and within the Kruger National Park were listed as vulnerable (IUCN 2004) but have recently been upgraded to endangered (Bronner 2006).

The closest relative of Juliana's golden mole and the only other member of the genus *Neamblysomus* is *N. gunningi*. Similarly, little is known about Gunning's golden mole and it is distributed over a relatively small area in the Magoebaskloof vicinity of Limpopo province. Much of the natural habitat has been transformed into commercial forestry plantations and the species is listed as endangered by the IUCN (Bronner 2006).

1.2.2 Biology and Ecology

The streamlined body of the Juliana's golden mole is covered with a sleek fur, the upper parts of which are cinnamon-brown becoming darker towards the back and paler towards the flanks, with an iridescent sheen. The hair surrounding the muzzle is often lighter in colour (Skinner & Chimimba 2005), even white in some individuals (C.R. Jackson pers. obs.). Juliana's golden mole is a small animal with a mean mass of 35g and a length of around 100mm (Skinner & Chimimba 2005). Anatomically, the Juliana's golden mole shows the highly specialized adaptations to its subterranean lifestyle, such as strong forelimbs, a leathery hardened nose pad and no eyes or external ears.

Figure 3. An adult Juliana's golden mole (*Neamblysomus julianae*) with the pick-like claws and leathery nose pad clearly visible. (Photo: C.R. Jackson)

Neamblysomus julianae is described as a "sand swimming" species (Bronner 1997) since the sandy substrates allow the animal to pull itself through the soil by anchoring its body with sharp forelimbs, pushing upwards with the head, and simultaneously levering the body forward by means of the forelimbs. The hind limbs provide further stability and support during locomotion. These animals are thought to be solitary and forage at night, but recent observations have shown them to be active during the early morning and late afternoon (N.C. Bennett pers. comm.; C.R. Jackson, pers obs). Animals tunnel just below the soil surface in search of prey items and distinctive ridges are produced along the soil surface (Skinner & Chimimba 2005). These slight ridges (Fig. 4) serve as the only evidence of golden mole presence. The depth of the underlying tunnel determines the degree to which the elevation protrudes from the soil surface while they are approximately 50mm in width. As is typical in several other species, deeper, more permanent tunnels could potentially link up with a nest area (Skinner & Chimimba 2005). Although the content of their diet has not been documented, it is thought that these animals feed on a wide variety of invertebrates, ranging from worms and termites to Coleopteran and Lepidopteron larvae (Bronner 1997; Skinner & Chimimba 2005). Talpid moles are known to feed primarily on oligochaetes although their diet is supplemented with both adult and larval forms of insects (Duplaix & Simon 1976). Excess food may be immobilized with a bite and stored for consumption at a later time (N. Williams pers. comm.).

Figure 4. The characteristic foraging tunnels produced by Juliana's golden mole are often difficult to detect. Green arrows indicate the slight cracking and elevation in the soil surface (Photo: C.R. Jackson).

All three populations of the Juliana's golden mole fall within the summer rainfall region characteristic of central and northern parts of South Africa (Low & Rebelo 1996). It is during the wet summer months that golden mole activity is discernable by means of the characteristic sub-surface foraging tunnels (Fig. 4). Soil profiles vary with the local geology and climate, such as rainfall and temperature. Particle size and soil moisture are important determinants of habitat suitability for subterranean organisms and, in combination with seasonal changes in climate, affects the composition of meiofauna and micro-organisms (Brady & Weil 1999; Gullan & Cranston 2000). Activity and behaviour patterns during the dry winter period, when the soil substrate is substantially harder and less friable (see chapter 4), the ambient temperature cooler, and food availability reduced, is not known (Skinner & Chimimba 2005). A seasonal variation in activity thus appears to exist.

1.2.3 Habitat

There is a total lack of detailed ecological and distributional data pertaining to the majority of Chrysochlorid species. The habitat for Juliana's golden mole is described as "sandy soils with rock outcrops" (Skinner & Smithers 1990). This short description is indicative of the limited information available for this species. Even in the Kruger National Park, where most aspects of the savanna landscape have been well studied and documented, a mere eight localities had been recorded (February 2004) where this species is known to occur from a region that covers some

65 000ha. The Nylsvley population is described from the Nylsvley Nature Reserve. The reserve is approximately 4000ha in size but only a narrow strip (*ca*. 800ha) along the south-eastern boundary is sandy and serves as suitable habitat. Very few localities outside of this tiny area have been reported and knowledge of the population distribution is extremely poor. The limited amount of data is probably due to the cryptic nature and subterranean habits of this species.

Unlike mole-rats, golden moles do not have powerful tunnelling abilities and are consequently restricted to the more friable soil types; the Juliana's golden mole is limited to the sandy soil types (Skinner & Chimimba 2005). It is not evenly distributed throughout its geographical range and occupies very specific smaller components of the greater area, even when this appears homogenous. Fine-scale habitat characteristics thus appear to be very important.

Fine scale habitat properties are especially important for the Pretoria population that occurs exclusively along the north eastern slopes of the 20km long Bronberg Ridge. The slopes of the Bronberg Ridge are characterised by a mosaic of rocky regions surrounded by shallow sandy soil. Deeper soils occur along the foot of the ridge. This narrow region does not generally exceed 1km in width, after which there is a rapid transition to hard, uninhabitable substrates (the slope, on average, is 816m wide (Bosch 2004)). The sandy soils are not continuous due to the rocky regions and there are naturally occurring sandy passages that link larger patches. Several of these links have been severed and an extensive road network and housing developments have fragmented the ridge as a whole. This narrow strip constitutes the entire range of the Pretoria population and is consequently extremely prone to further habitat transformation and fragmentation. A relatively small asphalt road transecting the ridge is suspected to constitute an impenetrable barrier for the golden mole. Unlike birds or surface-dwelling mammals that can negotiate small obstacles separating suitable patches of habitat, the golden mole is unable to burrow through concrete or tarmac and as a consequence roads are a major source of habitat fragmentation. Isolation caused by fragmentation can reduce re-colonisation rates and thus erode genetic diversity due to reduced gene flow (Bolger *et al.* 2001).

1.3 Aims of the thesis

The ultimate aim of the thesis was to investigate aspects of the biology of the species so that this could inform the management actions required to conserve the species. This, the first chapter, provides a general introduction and background to the species and the threats that this species faces. A detailed ecological description of each of the three populations and the study sites is provided. Chapter two considers the habitat specificity of the species and presents a thorough investigation of soil and vegetation characteristics associated with the species' presence. Building on the improved understanding of ecological variables that may limit the species distribution, a predictive habitat model was constructed (Chapter three) to highlight other areas that could potentially be inhabited by this cryptic mammal. Chapter four considers the use of torpor in the species as well as daily and seasonal activity patterns. The fifth and final chapter draws upon and interprets the findings in the form of a conservation management plan. Long-term conservation planning is vital for this species, and threats and important considerations are listed and discussed in detail. This has the potential to contribute greatly to the conservation of Juliana's golden mole.

1.3.1 Study Areas

Threats and conservation requirements vary between the three isolated populations. The Bronberg Ridge has, and continues to be, severely degraded by urban activities comprising real estate development and a large opencast quartzite mine (IUCN 2004). Golden moles in the Kruger National Park, Nylsvley Nature Reserve, and greater environs inhabit regions in which the general ecosystem remains pristine due to protected nature reserves or low impact farming and game ranching, thereby limiting the degree of habitat fragmentation and population isolation. Despite these varying threats, the area occupied by each population differs notably in topography, geology, soils, vegetation and general ecology. Rainfall and temperature patterns at each population are shown in Figures 5 and 6. The Bronberg receives the highest rainfall and lowest average temperatures, while the Kruger National Park has the highest average temperatures and second greatest amount of rainfall. Nylsvley Nature Reserve has intermediate values for both average temperature and rainfall when compared to the other two populations.

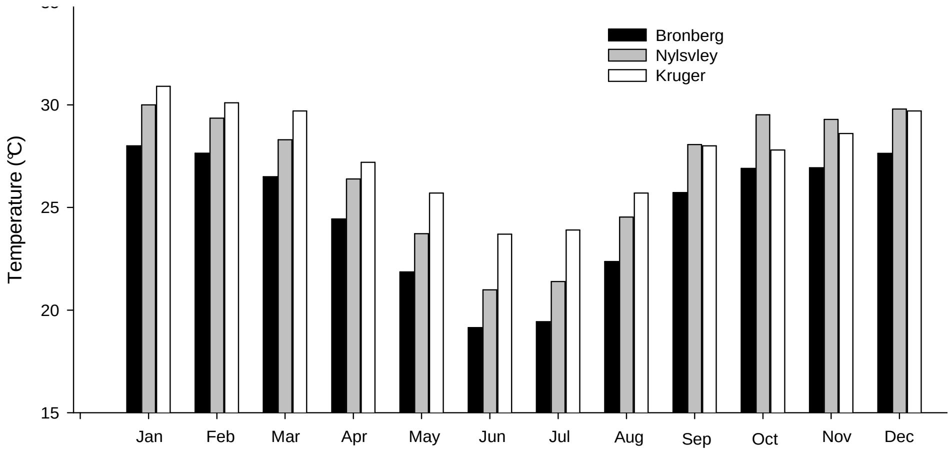

Figure 5. Average maximum temperatures for each of the three populations. Temperatures recorded by the South African Weather Service. Averages calculated from January 1940 to December 2004. Data from weather stations at the University of Pretoria, Bela-Bela (Warmbaths) and Pretoriuskop Camp were used to calculate averages for the respective study areas.

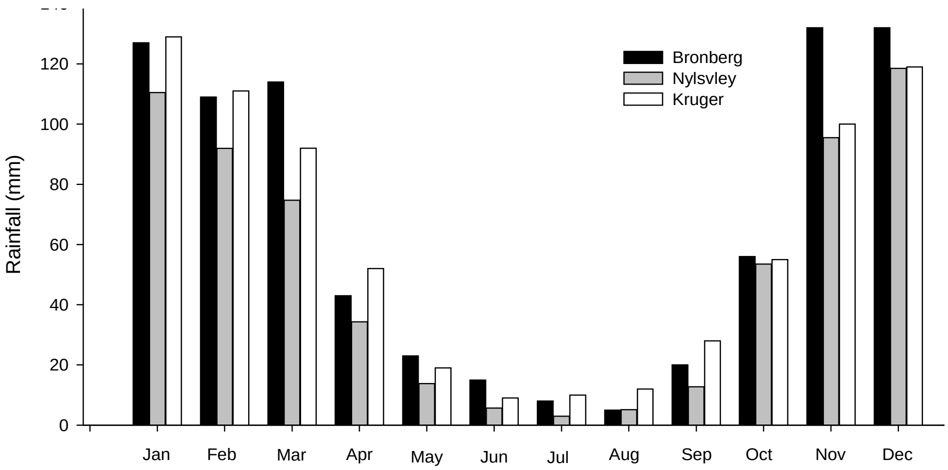

Figure 6. Average monthly rainfall for each of the three populations. Rainfall recorded by the South African Weather Service. Averages calculated from January 1940 to December 2004. Data from weather stations at the University of Pretoria, Bela-Bela (Warmbaths) and Pretoriuskop Camp were used to calculate averages for the respective study areas.

1.3.1.1 Bronberg Ridge (BR)

The Bronberg is a prominent ridge in the residential suburbs of eastern Pretoria, Gauteng Province. It runs south easterly as a low ridge with a small south-western steep slope and a large north-eastern talus slope (Bosch 2004). The ridge changes to a rocky rolling hill west of the R25 road to Bronkhorstspruit. Juliana's golden mole does not inhabit the entire ridge, but is restricted to the sandier northern most section, approximately 15km in length (C.R. Jackson Pers. obs.). Three prominent mountain saddles occur in the Bronberg at Hans Strydom Road, Swavelpoort and Tygerpoort. Drainage patterns resulted in the formation of these saddles and they may serve as natural barriers to golden mole movement along the ridge.

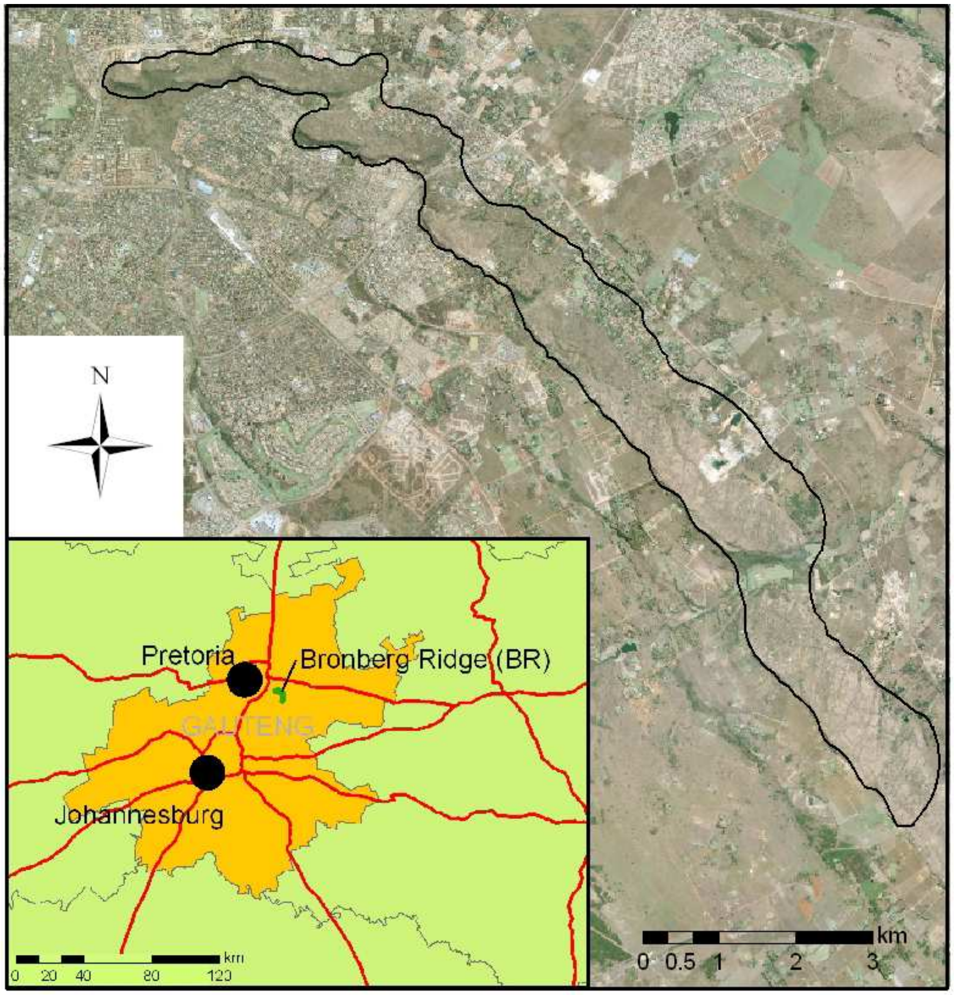

Figure 7. A satellite image of the remainder of the Bronberg Ridge in the eastern suburbs of Pretoria.

The ridge consists of Daspoort quartzite of the Pretoria group (Bosch 2004). Bands of diabase are visible mostly to the south of the ridge. The geological formation consists of a combination of andesite and dolerite that lies adjacent to the quartzite on the northern and southern sides of the ridge (GDACE 2002). The quartzite is underlain with the Silverton shale of the Pretoria Group that can be seen predominantly north of the ridge. The shale has a faster rate of weathering than the other three dominant rock types. The shale weathers into a clayey soil, and the other three rock types into a gravel or sandy soil. The area is covered with large quartzite boulders and extensive sheets of rock. This results in patches of rock surrounded by shallow sandy soils, inhabited by Juliana's golden moles. Recently Bosch (2004) has identified the area as a mountain wetland and suggests that the unique ecosystem associated with wetlands might explain the isolated distribution of the golden mole on the Bronberg and Nyl flood plain.

The Bronberg is located in the greater rocky highveld grassland vegetation unit (Low & Rebelo 1996), but lies in a transitional zone between the grassland biome and savanna biomes. The area includes woody elements that resemble the Waterberg Moist Mountain Bushveld and Mixed Bushveld, also described by Acocks (1988) as the Sour Bushveld.

Figure 8. Part of the Bronberg Ridge showing the slopes that are home to Juliana's golden mole, as well as the ongoing encroachment of housing onto the narrow ridge.

The distribution of the Juliana's golden mole is limited to the north eastern slopes of the Bronberg Ridge region. For the purposes of this study, it was both difficult to find suitably large and pristine properties to facilitate an investigation of ecological factors associated with the mole, which incorporate habitat through the catenal sequence from ridge top down to foot slope. Secondly, gaining access to these properties was often problematic.

1.3.1.2 Nylsvley Nature Reserve (NNR)

The Nylsvley Nature Reserve, approximately 20km southeast of Mookgopong (Naboomspruit) in Limpopo Province, was used as the hub for studies of this population. The original farm was used to farm cattle from the 1920's but was proclaimed as a nature reserve in the early 1970's (Scholes & Walker 1993). The precise distribution of this population is unknown but is thought to be relatively large, possibly similar in size to that of the Kruger population. The areas surrounding Nylsvley are privately owned farms that vary in use from agricultural to game farming.

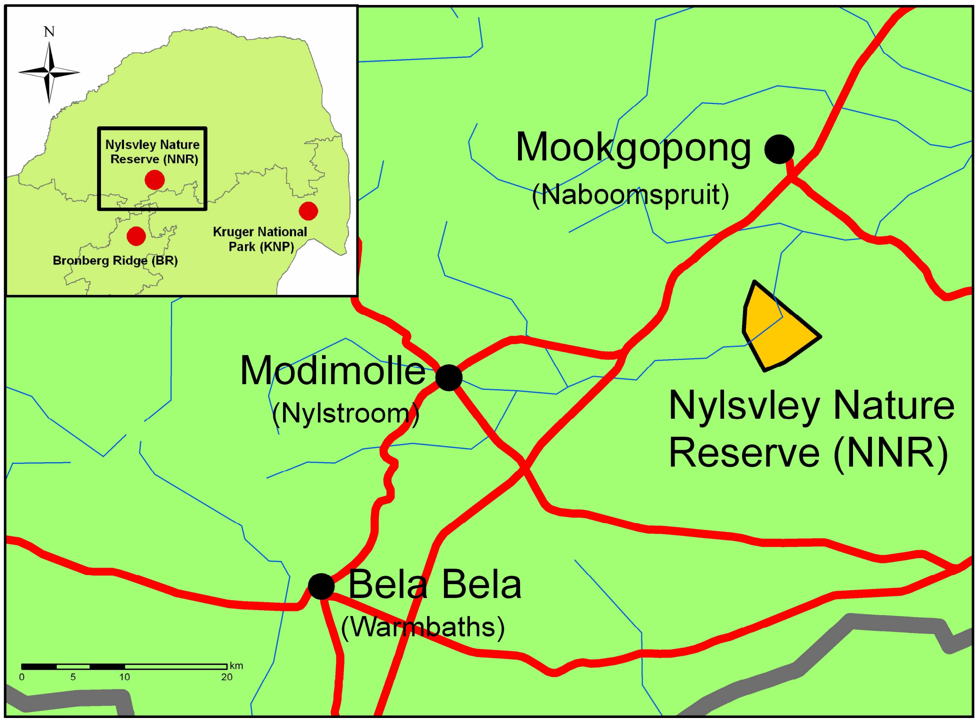

Figure 9. Map showing the location of Nylsvley Nature Reserve (NNR) in relation to the closest towns of Mookgopong, Modimolle and Bela Bela.

Figure 10. Typical suitable golden mole habitat within the Nylsvley Nature Reserve (NNR). The tallest trees are *Burkea africana*, while the lower tree layer is composed of *Terminalia sericea* and *Dichrostachys cinerea*, with the tall grass *Hyperthelia dissoluta* characteristically present on the well-drained sandy soils (Photo: T.H. Setsaas).

Within NNR, golden moles have only been found in the south eastern portion, with the corresponding study area demarcated in Figure 11. This region is located on a remnant of Waterberg sandstone forming the eastern lip of the broad, shallow trough down which the Nyl River flows, before spreading out into the Springbok Flats (Scholes & Walker 1993). Sandy soils derived from sandstone characterise this area and are generally deep, but vary continuously. Due to the low clay content, water moves through the sand until it meets the abrupt unweathered sandstone layer, a poorly permeable substrate, and moves downhill (Scholes & Walker 1993). These seep lines at the bottom of the catena are dominated by *Terminalia sericea*, a usual landscape feature within the African savannas, while the mixed broadleaf woodlands are situated on the nutrient poor uplands. The topography is gently sloping with a few rocky outcrops.

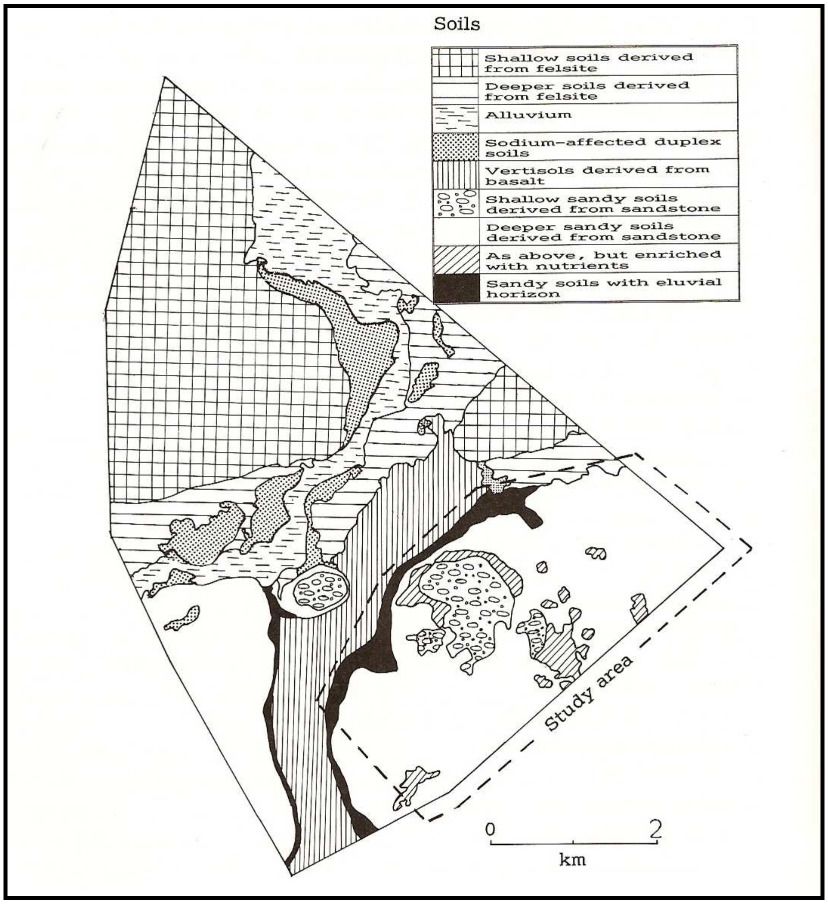

Figure 11. Major soil groups of the Nylsvley Nature Reserve, simplified from Harmse (1977) and published in Scholes and Walker 1993.

1.3.1.3 Kruger National Park (KNP)

The third population of the Juliana's golden mole is situated in the south western section of the Kruger National Park and was originally described from the Pretoriuskop region. The taxonomic similarity between this and the other two populations is questionable (as stated previously) and the ecological features of the habitat also differ from the other populations. Unlike the Pretoria population, this population occupies a far greater range than that of the 20km long section of the Bronberg Ridge. The local distribution extends from just north of the Pretoriuskop camp southwards, in a narrow belt, towards Berg-en-Dal rest camp (Figure 12). Golden mole foraging tunnels were located in Berg-en-Dal camp during a fieldtrip to this area in February 2004. No records from the camp or the immediate vicinity had previously been recorded. Another species has recently been recorded near the town of Malelane and molecular evidence groups these animals most closely to the Robust golden mole (*Amblysomus robustus*) (S. Maree *et al. unpublished data*). Based on golden mole's habitat specificity and the respective similarities between the two proximate species, the animals in Berg-en-Dal camp may well be of the *Amblysomus robustus* genotype. A specimen would be required to resolve the taxonomic status.

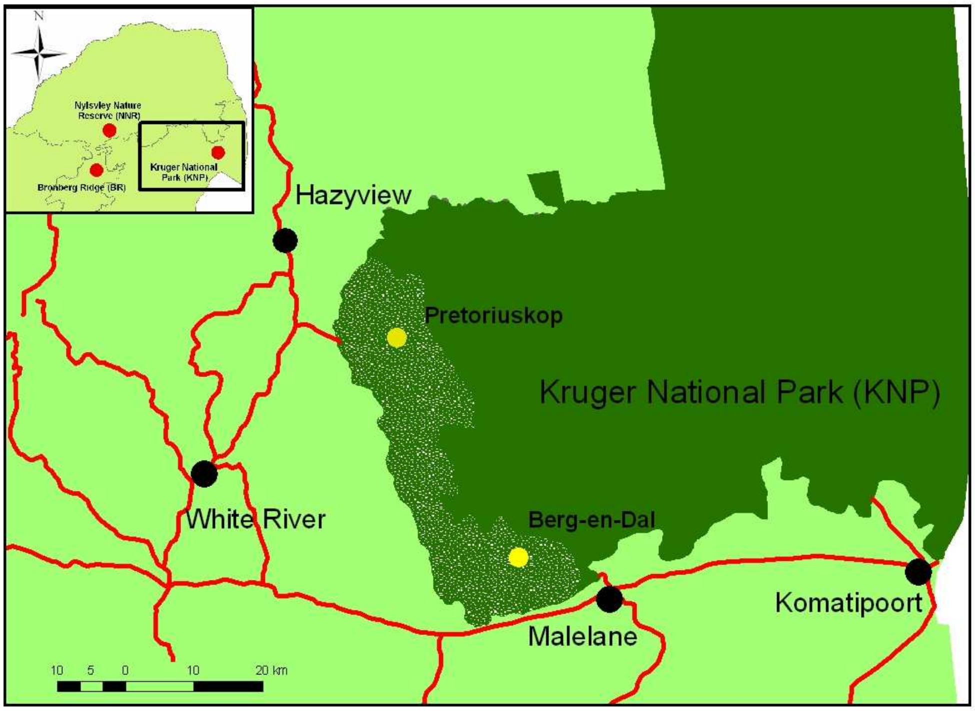

Figure 12. The approximate distribution (white shaded area) of Juliana's golden mole within the Kruger National Park (dark green area). Pretoriuskop and Berg-en-Dal camps are shown, while red lines indicate the main road network between the surrounding towns.

Two distinct ecological landforms are represented within this region and were described by Venter (1990) as the Malelane and Pretoriuskop Landtypes (Figures 13, 14 & 15). The soils of Pretoriuskop land type reflect the relatively high rainfall regime under which they have developed. They are mostly deep (more than one metre), well developed on crests and midslopes, and very often display plinthic subsoil horizons (Venter 1990). The red and yellow apedal soils of crests and upper midslopes (Hutton, Bainsvlei, Clovelly and Avalon forms) occur very low down along hill slopes leaving only narrow, inconspicuous footslopes dominated by duplex soils (Kroonstad and Estcourt forms) along drainage lines. Moderately undulating plains have formed on granite of the Nelspruit Granite suite (Venter 1990) and are a characteristic topographic feature of the region.

The geology of the Malelane landtype is described as banded and layered porphyritic gneiss and migmatite of the Nelspruit granite suite, and schist of the Barberton sequence (Venter 1990). The landform consists mainly of low mountains and hills and this landscape extends westward past the town of Nelspruit. The mountains are highly dissected by several seasonal streams, which are usually characterized by relatively narrow steep-sided valleys that give the area a rugged appearance (Venter 1990). The Nsikazi, Matjulu and Mlambane seasonal drainage channels have formed wider valleys. Shallow lithosolic soils (Mispah and Glenrosa forms) and rock outcrops characterise this region and soils vary from brown or red, apedal, eutrophic loam, to coarse or medium sand, depending on the nature of the underlying granitoid rocks. The majority of the valleys of this land type are relatively narrow and deep and the only deep soils are represented by colluvial accumulations of lithosolic talus along the steep upper footslopes of such valleys (Venter 1990). Shallow to moderately deep, eutrophic, coarse sand occurs only in the larger valleys of the Matjulwana and Matjulu spruits. Golden moles have been located within the Matjulwana and Matjulu valleys in the south of this landtype, and are very difficult to detect (C.R. Jackson Pers. obs.).

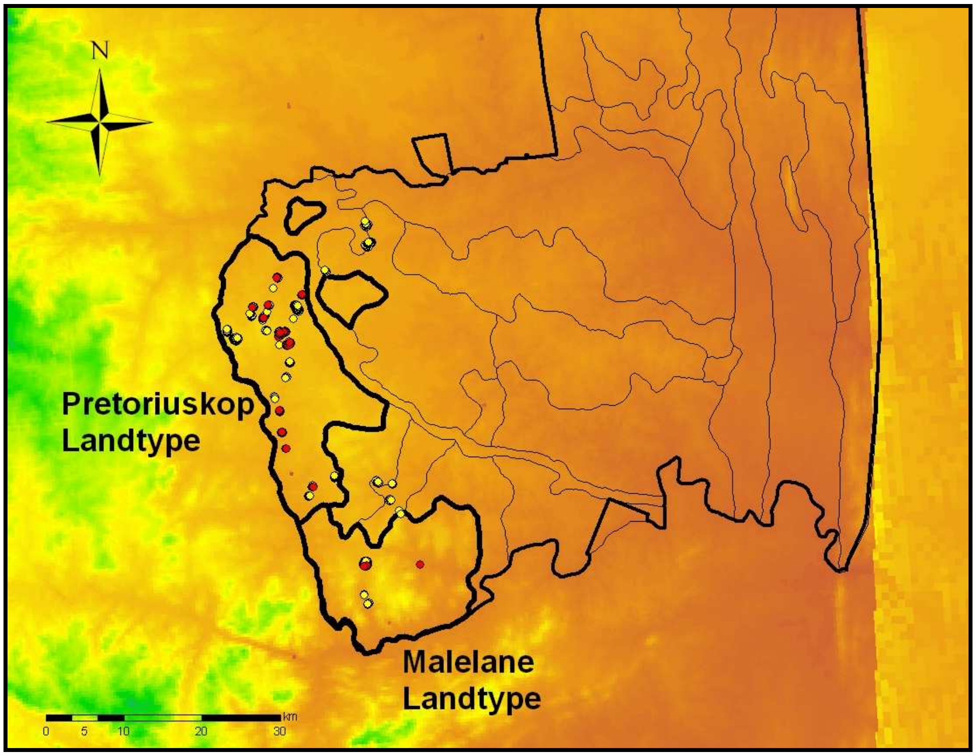

Figure 13. The Landtypes of the Kruger National Park (Venter 1990) shown on a Digital Elevation Model (DEM) of the southern most section of the Park. The Pretoriuskop and Malelane Landtypes are indicated and Juliana’s golden mole appears to be limited to this region. Red points indicate GPS positions where golden mole activity was detected, while no apparent activity was found at the yellow points (survey conducted in February 2004).

Figure 14. Rocky, undulating topography typical of the Malelane landtype.

Figure 15. Stands of *Terminalia sericea*, a characteristic feature of the Pretoriuskop landtype.

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Chapter 2

A Quantitative Habitat Description for Juliana's Golden Mole

For in the end we will conserve only what we love.
We will love only what we understand.
And we will understand only what we are taught.

- Baba Dioum -

2.1 Introduction

Identifying processes that shape the distribution and abundance patterns of species is vital for biodiversity conservation (Caughley & Gunn 1996). Species are unevenly distributed over space since landscapes are naturally heterogeneous, consisting of a mosaic of various habitat types (Mauritzen *et al.* 1999, Sanderson *et al.* 2002). Organisms are faced with habitat patches of varying suitability and accessibility, but most organisms, at one scale or another, depend on heterogeneity for their survival (Pulliam & Danielson 1991, Huston 1994). As a result, people and animals cluster their activities differentially among landscape elements (Huston 1994).

Through evolutionary processes, organisms may respond to this variation by becoming either niche specialists or niche generalists (Elena & Sanjuán 2003; Harmon *et al.* 2005). Highly specialist species occupy narrow niches within a given ecosystem and are often limited to a particular type of landscape, being extremely dependent on the ecological processes associated with it (Harmon *et al.* 2005). Evolutionary biologists have recognised that specialisation in a specific environment is accompanied by a decreased performance in other environments (Elena & Sanjuán 2003, Kneitel & Chase 2004, Harmon *et al.* 2005).

Effective conservation planning thus needs to consider the heterogeneous and dynamic nature of ecosystems (Huston 1994, Koehler 2000) and a species' dependence on particular elements thereof (Caughley & Gunn 1996). Dealing with the special habitat requirements, poor dispersal capabilities, sensitivity to human disturbance, and low detection probabilities typically associated with many rare, habitat specific or cryptic species pose serious challenges to conservation planning (Piggott & Taylor 2003). Most golden mole species are totally fossorial and very difficult to detect in their subterranean niche. Furthermore, they are habitat specific and range restricted on account of their acute adaptations to specific soil conditions (Bronner 1997, Skinner & Chimimba 2005). It is plausible that several golden mole populations and potentially new species are still to be described. Indeed, in the past three years our research team and collaborating organizations have discovered three new populations of golden moles, previously unrecorded (one in Gauteng Province and two in Mpumalanga Province).

The ancient evolutionary adaptations of the Chrysochloridae and subsequent persistence within their subterranean niche threaten them indirectly in today's anthropogenically transformed world. A major threat to wildlife conservation in general, especially in areas of economic importance, is the increasing rate of habitat loss and subsequent modification (Gaylard & Kerley 2001). In recent years, natural ecosystems have been altered, fragmented, and transformed into diverse patches that are interspersed with homes, pastures, roads, and agriculture (Gonzalez 2000, Bolger *et al*. 2001). Habitat destruction is not usually a random process and transforms naturally diverse landscapes into artificial sectors with abrupt borders, each possessing a random collection of the natural fauna and flora (Gonzalez 2000). Some mammal species may be well adapted to these highly fragmented habitats but many are not because of specialised life history traits or poor dispersal capabilities (Terborgh 1974, Barko *et al.* 2003). Golden mole's specialisation makes them susceptible to habitat loss and fragmentation, and it is therefore not surprising that so many species are threatened.

After De Winton's golden mole (*Cryptochloris wintoni*), known from only a few specimens collected more than 50 years ago (Bronner 1997), Juliana's golden mole (*Neamblysomus julianae*) is South Africa's second most endangered golden mole (Pretoria population; Bronner 2006). The dearth of information available for the species is due primarily to its subterranean lifestyle, with major data deficiencies typical for the majority of golden mole species (Skinner & Chimimba 2005). As a consequence of its fossoriality, all aspects of its biology and ecology are directly affected by the properties of the soil substrate. To date, literature pertaining to the species distribution states that the Juliana's golden mole is confined to "sandy soils" (Skinner & Smithers 1990). However, the animals are not uniformly distributed throughout their geographical range and appear to be restricted to particular habitat types (C.R. Jackson Pers. obs.). Sand can be defined as the soil separate consisting of particles ranging from 0.05mm to 2mm in size (Brady & Weil 1999). The relative proportions of the various size classes within a soil sample provide a good indication of a range of functional soil properties (Brady & Weil 1999). Reasons for their disjunct distribution at both local and regional scales have not been studied nor properly understood and particle size distribution (PSD) could thus potentially yield especially relevant information regarding factors affecting soil suitability for golden moles.

The high energetic costs of movement underground have been well documented for subterranean mammals (Nevo 1979, Bennett & Faulkes 2000, Luna *et al.* 2002, Luna & Antinuchi 2006). The relationship between the cost of tunnelling and soil hardness is regarded as one of the most important factors affecting burrowing efficiency in subterranean rodents (Luna & Antinuchi 2006). For example, the digging metabolic rate (DMR) for the 130-gram *Ctenomys talarum* (Ctenomyidae) was found to be 295.9% higher than the resting metabolic rate when digging through relatively soft soil (Luna *et al*. 2002). When confronted with harder soil types the DMR increased by 66% (Luna & Antinuchi 2006). Similar sharp increases in metabolic rate could be expected for Chrysochlorids. In contrast to subterranean rodents, golden moles living in sandy soils are said to “sand swim” since they pull and push their way through the sand without actively chiselling away at a soil surface (true burrowing). The gross energy cost of sand swimming was found to be 26 times more expensive than running on the surface (Seymour *et al*. 1998). Sand swimming through soft sands, however, only incurred energetic costs amounting to less than one tenth of the energy required by mammals tunnelling through compact soils (Seymour *et al*. 1998).

The natural vegetation communities are dictated chiefly by soil and climatic conditions (Kent & Cocker 1995, Bredenkamp & Brown 2001). One of the most conspicuous features of land-surfaces is the presence of vegetation and it is consequently the underlying determining force in ecosystems (Walter 1979). Each plant community has a unique structure and appearance, which is determined by the proportions of the species growing in it and changes from place to place due to the physical environment (Brewer 1994). An analysis of vegetation characteristics, including species and structural composition, in areas with and without golden mole activity could potentially elicit vegetation patterns associated with the presence of Juliana’s golden mole. At a fine scale certain plant taxa could serve as indicator species, while specific plant communities associated with the same habitat as Juliana’s golden mole could be identified at a broader scale.

Given their poor dispersal capabilities, patchy distribution, and susceptibility to habitat fragmentation, conservation efforts are desperately required to address the issue of habitat connectivity and protection. This necessitates a thorough understanding of the species’ ecological requirements and distribution, both at local and regional scales. The objective of this chapter is to classify the habitat utilised by Juliana’s golden mole at the landscape scale by identifying the key ecological features associated with its distribution. This process was conducted in such a way as to facilitate the development of a method by which potentially suitable habitat could be recognised over large areas, and thus detect presently unrecorded golden mole populations (Chapter 3).

Although the availability of food resources is important in limiting species distributions, very little is known about diet of Juliana's golden mole. The composition of an animal's diet is typically determined through gut content analysis (Juen & Traugott 2005). This would entail trapping and killing golden moles. This is not feasible given the trap-shy nature and endangered status of Juliana's golden mole, and was consequently not addressed in this study.

2.2 Methods

2.2.1 Determination of presence/absence status

Habitat requirements were inferred by assessing soil and vegetation properties at sites where signs of Juliana's golden mole were present and at sites where they were absent. Species presence/absence surveys are commonly used in monitoring programs, metapopulation studies and habitat modelling, yet they can never be used to confirm that a species is absent from a given location (MacKenzie *et al*. 2002; Guisan & Zimmerman 2000; MacKenzie 2005). Failure to detect a species' presence in an occupied habitat patch is a common sampling problem when the population size is small, individuals are difficult to sample, or sampling effort is limited (Gu & Swihart 2004). Detecting the presence of *N. julianae* is difficult because of the animal's cryptic ways. Another problem is that not all suitable habitat is always occupied, so this may result in false negative observations (Fielding & Bell 1997).

Only when signs of burrowing are evident can the habitat suitability be known for certain. Ecological data provided for presence sites in this study are therefore guaranteed to be an accurate reflection of habitat conditions associated with the species distribution. Certain plots where the species is considered to be absent may have been patches of unoccupied but suitable habitat or a patch in which the presence of the animal went undetected. However, all plots were carefully searched to ensure that if the animal was present it was detected. Despite certain limitations, this method suffices to highlight habitat preferences of the species thus aiding conservation planning. The likely consequence of false negative errors is to reduce the magnitude of difference observed between habitat that is considered to be suitable and habitat that is considered to be unsuitable.

2.2.2 Vegetation survey

Fresh signs of golden mole activity are only seen after periods of rain, which softens the soil and makes it more cohesive. During the summer rainfall months of February and March 2005, soil, vegetation and general landscape properties were recorded at 48 study plots (NNR: 12, BR: 13, KNP: 23) and incorporated both presence and absence localities for the Juliana's golden mole. The randomly selected study sites were representative of the general biota within the greater area and comprised 5m x 5m plots, a minimum of 100m apart, in which a full Braun-Blanquet vegetation analysis (see Kent & Cocker 1995) was conducted, thereby providing a plant species list (Appendix A) and a relative cover abundance score for each plant species.

Vegetation cover was assessed by calculating the total surface area of the 25m^2 quadrat, expressed as a percentage, that had some form of vegetation cover emanating from it (i.e. not overhanging canopy cover from adjacent trees). Furthermore, the relative cover provided by the individual tree, shrub and herbaceous layers was evaluated. The cumulative value of the percentage of all three vegetation strata classes does, therefore, not equal the overall vegetation cover score. Tree density (individuals greater than 2m in height), average height (to the nearest half-metre) and canopy cover (percentage of total quadrat) was assessed within a greater 10m x 10m area that incorporated the original 25m^2 plot. The larger area provided a more realistic representation of these properties within the general landscape.

2.2.3 Soil properties

At all four corners of a quadrat, soil samples were augured (Johnson's soil augers; bucket 80mm in diameter), soil depth evaluated to a maximum depth of one metre (measuring maximum auger depth), and a static cone-penetrometer (Herrick & Jones 2002) assessment undertaken. Soil samples were transferred directly from the auger bucket into water and airtight plastic bags. In the laboratory soil moisture was determined gravimetrically by drying samples to constant mass at 40°C in an oven. Thereafter, soil texture was ascertained.

Soil texture provides an indication of the relative proportions of the various separates in the soil (Van der Watt & Van Rooyen 1995). A well-graded soil refers to the constituent particles being distributed over a wide range of sizes and, conversely, a uniformly or poorly graded soil refers to the size of particles being distributed over a narrow size range. The grain size distribution or range of particle sizes in a sample influence several soil properties, including compaction and soil permeability to water (Brady & Weil 1999). A representative sub-sample (approximately 500g) was put through a series of nine sieves that ranged in size from 8mm to 0.063mm and were vibrated on an electronic shaker for 10 minutes (Briggs 1977). Individual sieve contents were weighed and the relative proportion of the sample calculated, thereby giving the particle-size distribution of each sample.

The penetrometer (Eikelkamp Agricultural Instruments, Netherlands), consisting of a rigid cone-tipped rod attached to a pressure-measuring device (proving ring), was used to determine the hardness of a soil. This instrument is commonly used by soil scientists and engineers in the characterization of soil hardness or strength (Herrick & Jones 2002, Salako 2003). The cone has a 30° apex angle and is connected to a long steel shaft. During testing the penetrometer is pushed into the ground at a slow, steady speed. As the penetrometer descends into the ground the soil resistance is measured at 50mm intervals beginning at the soil surface. The measure of soil strength (or resistance) is taken directly from the dial on the proving ring and the units of measurement are presented in kN/50mm. These measurements facilitate the quantitative characterisation of soil hardness as this property is thought to be one of the major factors governing soil suitability for golden moles.

2.2.4 Statistical analysis

2.2.4.1 General

Vegetation, soil depth, and penetrometer data were tested for normality using a P-P Plot in SPSS (SPSS Inc. 2005). Data were subsequently analysed to test for significant differences between presence and absence sites using the Mann Whitney U-test for non-parametric data (Zar 1984). Values are represented as median ± standard deviation, with sample size (*n*). A significance level (*P*) of 0.05 was selected for all tests.

A Spearman's rank correlation (Zar 1984) was used to assess whether any ecological variables were inter-correlated. This non-parametric measure of correlation would elucidate any relationships between variables.

2.2.4.2 IndVal Indicator Analysis

The association of specific plant species with golden mole presence or absence was investigated using INDVAL-indicator analysis (Dûfrene & Legendre 1997) programmed in MATLAB® R2006a (The MathWorks, Inc., USA). In total, 245 different plant species were collected from the three study areas.

The indicator value method facilitates the identification of indicator species for *a priori* established groups of samples (in this case presence and absence). The indicator value of a species i in group j is calculated by multiplying its group specificity (A_{ij}) with its group fidelity (B_{ij}). A_{ij} is the mean abundance of the species i in the sites of group j relative to its abundance in all groups considered. Bij is the relative frequency of occurrence of species i in the sites of group j:

$$A_{ij} = (\text{N individuals}_{ij}) / (\text{N individuals}_{i})$$

$$B_{ij} = (\text{N sites}_{ij}) / (\text{N sites}_{j})$$

$$\text{INDVAL} = (A_{ij}) \times (B_{ij}) \times 100$$

The resulting indicator value is expressed as percentage of perfect indication (i.e. when all individuals of a species are found only in one of the *a priori* established groups and when the species occurs in all sites of that group). A species with high specificity and high fidelity will have high indicator values (McGeoch *et al*. 2002)

2.2.4.3 Shannon's Diversity Index

In order to assess the degree of heterogeneity in soil particle-size distributions for presence and absence study sites, Shannon's Diversity index (*H*) was used to assess the heterogeneity of particle size distribution (Smith and Smith 2003). This index accounts for both abundance and evenness of the particle sizes within and between size classes. This index is conventionally used to compare species assemblages (Begon *et al*. 1990). The proportion of particle sizes *i* relative to the total number of particle sizes (p_i) is calculated, and then multiplied by the natural logarithm of this proportion ($\ln p_i$). The resulting product is summed across particle sizes, and multiplied by –1:

$$H = -\sum_{i=1}^{S} p_i \ln p_j$$

A low Shannon's index value would indicate a peak in the soil PSD thus indicating the poorly graded nature of the soil. Shannon's index and soil hardness are presented as median ± SD for presence and absence sites. Non-parametric Mann-Whitney U-tests were used to test for differences between presence and absence sites as regards to soil hardness (penetrometer) as well as Shannon's index. Data was pooled across all three populations for the PSD and penetrometer data analysis.

2.2.4.4 Multiple logistic regression analysis

The presence of the golden mole in a plot can be considered a binominal process; it is either present with a probability of p or absent with a probability of $1 - p$, where var (p) = $p(1 - p)$. Such data is therefore suitable for logistic regression analysis where a generalized linear model is fitted to the data by using maximum likelihood techniques (McCullagh & Nelder 1989). A global model was composed to investigate the relative importance of each explanatory factor (ecological variables). This model applied a multiple regression analysis to the explanatory factors. Eleven alternative and biologically relevant candidate models, all derived from the global model, were analysed. The models incorporated the fact that data were collected from three different populations. Akaike's Information Criterion (AIC; Burnham & Anderson 2002), based on the principle of parsimony, was employed to select the most appropriate model. In particular, the formula

$$AIC_c = -2\log_e(L(\hat{\theta})) + 2K + \frac{2K(K+1)}{(n-K-1)}$$

was used and accounts for low sample sizes. K denotes the number of parameters estimated in the model, and n is the sample size (Burnham & Anderson 2002). In addition, Akaike weights were calculated as:

$$w_i = \frac{\exp(-\Delta_i / 2)}{\sum_{r=1}^{R} \exp(-\Delta_r / 2)}$$

In the AIC sense, this can be interpreted as the probability that a specific model is the best, in that it minimizes the expected Kullback-Leibler (KL) discrepancy, given the data and the set of candidate models (Burnham & Anderson 2002). The model with the highest Akaike weights (ω) consequently explains the most variation using the fewest number of parameters. At the same time the biological relevance of the models must always be carefully considered (Burnham & Anderson 2002). Because all the models had a similar structure and sample size, the respective AIC_C values from the different models were comparable (Burnham & Anderson 2002). In order to calculate the confidence intervals for the coefficients of the best model, the Markov Chain Monte Carlo method was used, which generates a sample from the posterior distribution of the parameters of the fitted model (R Development Core Team 2006). Coefficients were considered significant when confidence intervals did not overlap with zero (Burnham & Anderson 2002).

Due to the problem of multi-colinearity in multiple regression analyses, the pairwise correlation between all the variables was evaluated (Table 4). In particular, there was strong inter-correlation among the various tree variables and soil variables. Thus, to avoid multi-colinearity among the explanatory variables in the multiple regression analysis as well as to reduce the number of explanatory factors, the first component from two principal component analyses (PC1-factor; SPSS 2005) was used. For the vegetation variables, the PC1-factor was based on the measurements of tree layer, average tree height, canopy cover and tree density, while the Shannon index (particle size distribution) and soil hardness were included for the soil variables. For the tree measurements, the PC1 accounted for 63% of the total variance of the variables included in the analysis, and was positively correlated with canopy cover ($r = 0.875$, $P < 0.001$), tree layer ($r = 0.841$, $P < 0.001$), average tree height ($r = 0.802$, $P < 0.001$) and tree density ($r = 0.640$, $P < 0.001$). The PC1- factor can thus be interpreted as the physiognomic properties of trees based on the variables included in the principal component analysis, and will hereafter be referred to as the “tree factor”. For the soil measurements, the PC1 accounted for 80% of the total variance of the variables included in the analysis and was positively correlated with Shannon’s index ($r = 0.892$, $P < 0.001$) and soil hardness ($r = 0.892$, $P < 0.001$). The PC1- factor in this principal component analysis can therefore be interpreted as the soil variables governing and describing soil hardness and compaction, and will hereafter be referred to as the “soil factor”.

2.3 Results

2.3.1 Vegetation

Vegetation cover and the relative cover afforded by the individual tree, shrub and herbaceous layers were calculated, as well as canopy cover, tree height and tree density. A summary of statistical results comparing these features in presence and absence quadrats is presented in Table 1.

In the KNP, overall vegetation cover for areas with golden mole activity was approximately three or more times greater than that of BR and NNR. Golden mole presence was associated with significantly higher levels of vegetation cover in comparison to absence plots in KNP, while data from NNR and BR showed an inverse relationship, although this was only significant for BR.

When analysing individual components of the overall vegetation structure, both KNP and BR have significantly greater relative cover provided by the tree layers in presence plots. NNR follows the same trend, but the relationship is not significant. In addition, all three populations showed greater shrub layer cover in presence rather than absence plots, but none differed significantly. In contrast, a lower level of herbaceous cover in presence plots was found in NNR and BR (BR significantly different) while an inverse but non-significant relationship was recorded in KNP. Median values for average tree height were greater in all presence plots, but the KNP was the only population where a significant relationship between presence and absence plots was found to exist.

Presence plots in the KNP (significant) and BR had greater canopy cover, while in NNR the opposite was found. Median tree density values did not differ significantly between presence and absence plots for any of the three populations.

Table 1. Summary of median values of vegetation variables (± SD) and significance values (NS = not significant, $p<0.05$) from Mann Whitney U-test for data from presence and absence plots in Kruger National Park (KNP), Nylsvley Nature Reserve (NNR) and Bronberg Ridge (BR).

	KNP (n=22)			NNR (n=12)			BR (n=13)		
	Absent	Present	*P*-value	Absent	Present	*P*-value	Absent	Present	*P*-value
Vegetation cover (%)	40.00 ± 22.56	87.50 ± 29.34	0.049	60.00 ± 23.35	20.00 ± 23.63	NS	75.00 ± 11.09	30.00 ± 23.29	0.011
Tree layer (%)	10.00 ± 21.79	45.00 ± 18.75	0.049	20.00 ± 20.13	30.00 ± 18.22	NS	0 ± 2.50	10.00 ± 12.81	0.034
Shrub layer (%)	1.00 ± 6.29	7.50 ± 6.77	NS	2.00 ± 2.05	2.00 ± 3.76	NS	0 ± 12.5	5.0 ± 12.81	NS
Herb layer (%)	40.00 ± 20.57	72.50 ± 25.95	NS	60.00 ± 25.25	15.00 ± 23.40	NS	75.00 ± 23.94	15.00 ± 22.75	0.011
Average tree height (m)	4.00 ± 3.00	7.50 ± 2.08	0.011	4.00 ± 0.84	5.00 ± 2.89	NS	1.50 ± 1.73	300 ± 2.37	NS
Canopy cover (%)	15.00 ± 18.11	37.50 ± 16.65	0.027	15.00 ± 11.51	10.00 ± 17.56	NS	0.50 ± 12.34	20.00 ± 23.18	NS
Tree density $(100m^2)^{-1}$	4.00 ± 3.05	4.00 ± 3.27	NS	3.00 ± 1.14	3.00 ± 2.81	NS	0.50 ± 5.85	5.00 ± 3.03	NS

Plant species

The indicator analysis did not yield any species that had both a high specificity and fidelity to presence sites. A subjective benchmark value of 70% IndVal was used to denote an indicator species (McGeoch *et al*. 2002). Only three species emerged at each population that had significant probabilities, but these all had low IndVal values, ranging from 20.00% to 55.56% (Table 2). A list of all plant species recorded, in both presence and absence plots, is presented in Appendix A.

Table 2. Plant species associated with presence sites at each population that had significant probability values. The corresponding IndVal values are presented.

Population	Species	IndVal	Probability
KNP	*Ascolepis capensis*	20.00	0.010
	Helichrysum acutatum	20.00	0.008
	Tristachya leucothrix	20.00	0.006
NNR	*Acacia toritillis*	28.57	0.044
	Dichrostachys cinerea	28.57	0.049
	Justicia flava	28.57	0.043
BR	*Eragrostis trichophora*	55.56	<0.001
	B8-64 (unidentified)	44.44	<0.001
	Combretum molle	33.33	0.015

2.3.2 Soil Properties

2.3.2.1 Particle size distribution (texture)

Data for soil texture was pooled across all three populations for analysis. Shannon's Diversity index showed significantly lower values in sites where the golden mole was found to be present (1.66±0.17) than where it was absent (1.90±0.11; Mann-Whitney U-test, U=62.0, N=44, *P* <0.0001). A considerably higher frequency of particles was distributed in the 0.250mm size class for presence sites, forming a distinct peak in the PSD. This indicates that the soil is more poorly graded in soil types favoured by the mole, i.e. presence sites (Fig. 1).

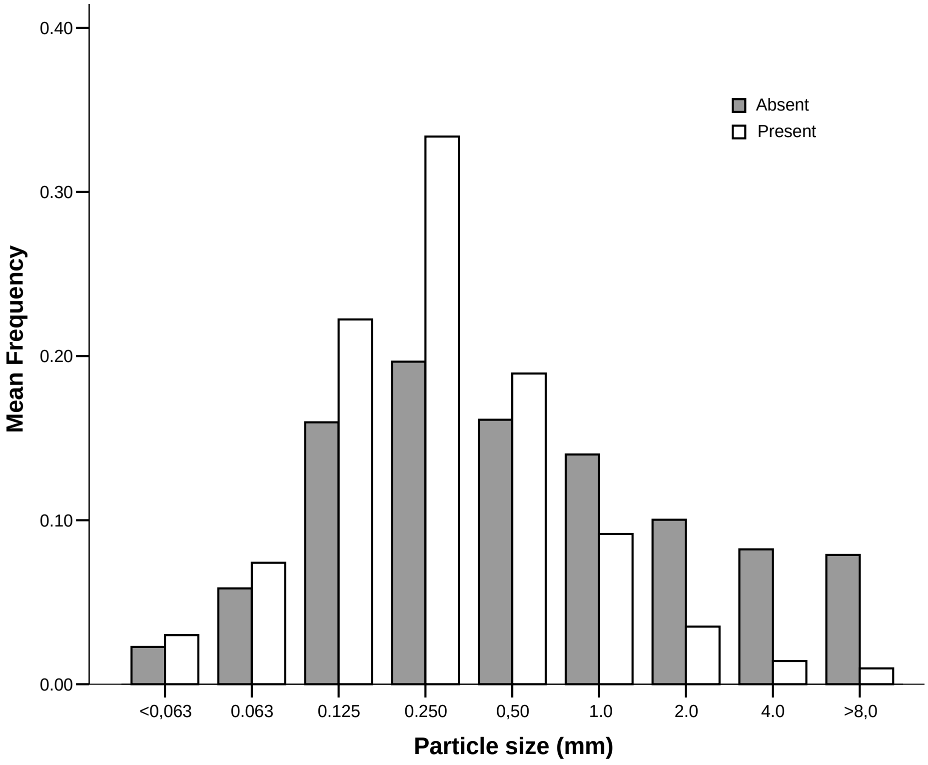

Figure 1. Mean frequency of soil particle-size distributions (all three study areas combined) from soil samples collected where the golden mole was either absent or present. Particle size is measured in millimetres (mm).

2.3.2.2 Soil hardness

The results from penetrometer data, pooled across all three populations, are shown in Figure 2. Soil resistance to the penetrometer probe over the first 100mm of the soil profile was 0.49±0.31 and 1.05±0.48 kN/50mm for presence and absence sites, respectively. The soil was significantly harder for absence sites than presence sites (Mann-Whitney U-test, U=132.0, N=48, *P* =0.001).

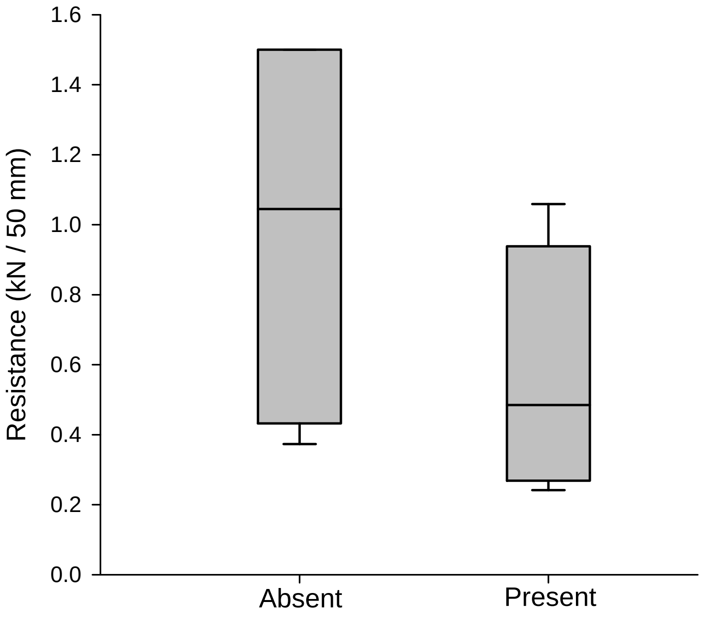

Figure 2. Soil resistance (kN/50mm) for the first 100mm of the soil profile where golden moles were recorded as either absent or present (all three study areas combined). The shaded boxes incorporate the interquartile range, with the whiskers representing the 10th and 90th percentiles, respectively. Median is indicted within box plot.

Distinct variations became evident when analysing soil resistance to the penetrometer probe at the population level (Figure 3 and Table 4). KNP had far harder soil (in both presence and absence plots) in comparison to NNR and BR. The median for the presence localities is by far the greatest in KNP while soil hardness in absence plots closely resembles values for these areas in BR. Values for both presence and absence at NNR had very low values. When comparing presence and absence, NNR and BR populations had values that differed significantly (Mann Whitney U-test: KNP *P* =0.100; NNR *P* =0.040; BR *P* =0.030).

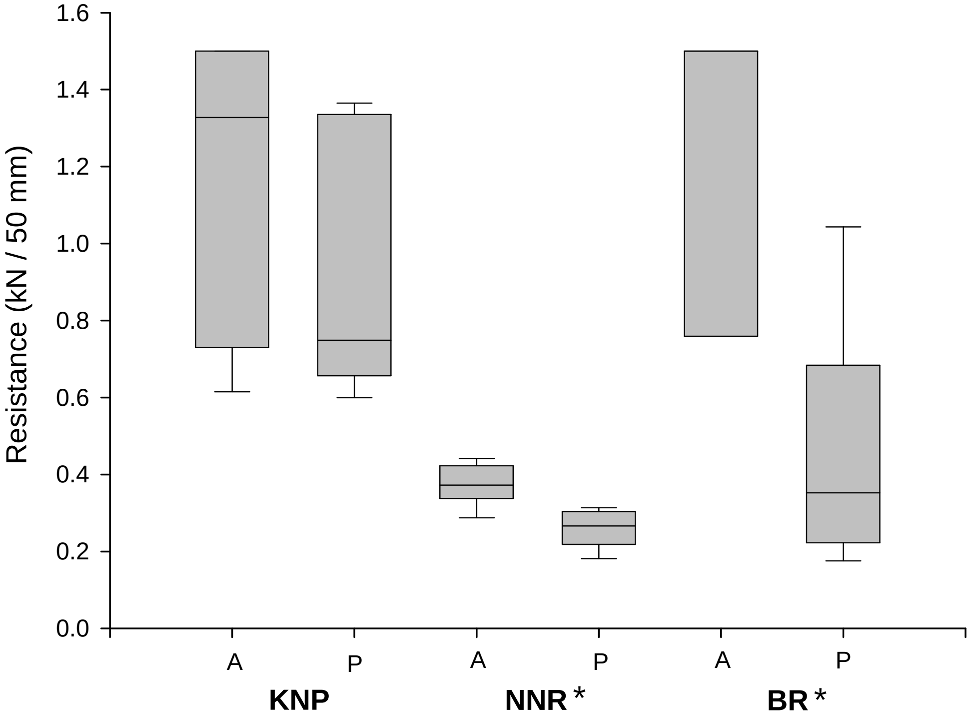

Figure 3. Soil penetrometer readings (kN/50mm) for the first 100mm of the soil profile, where golden moles were recorded as either absent or present. The shaded boxes incorporate the 25th to 75th quartiles, with the whiskers representing the 10th and 90th percentiles, respectively. Median is indicted within box plot, while * denotes significant difference.

Furthermore, a significant positive correlation was found between soil PSD and soil hardness (Spearman Rank correlation, R=0.628, N=44, *P*<0.0001), which indicates that as the heterogeneity in the PSD increases, soil hardness increases.

In an attempt to establish the potential effect of soil moisture and particle size distribution (as analysed using Shannon's index above) on soil hardness, Table 3 presents the mean values for these variables at each of the three populations. When comparing the three populations, KNP has the greatest average soil hardness and Shannon's index, but the lowest moisture content. The NNR has the softest soil and greatest moisture content, but an average Shannon's index slightly greater than that of the BR. Of the three populations, the BR has the lowest Shannon's index but intermediate soil moisture and hardness. From this simple comparison of values, it would appear that in addition to PSD, soil moisture directly affects a soil's hardness (Collis-George 1959).

Table 3. A comparison of average soil moisture, Shannon's index values, and soil hardness values for the Bronberg Ridge (BR), Nylsvley Nature Reserve (NNR), and the Kruger National Park (KNP). Sample sizes shown in parentheses.

	BR	NNR	KNP
Average soil moisture (%)	4.62 (52)	5.92 (48)	2.97 (92)
Average Shannon's diversity index value	1.67 (13)	1.71 (12)	1.86 (23)
Average soil hardness (kN/50mm)	0.69 (52)	0.31 (12)	1.04 (92)

2.3.2.3 Soil depth

The presence of Juliana's golden mole was associated with deep soils in KNP and NNR, but golden mole activity on the BR was located in comparatively shallow soils (Table 4). Soil depth associated with the absence of the species along the BR was comparable to that of KNP and NNR.

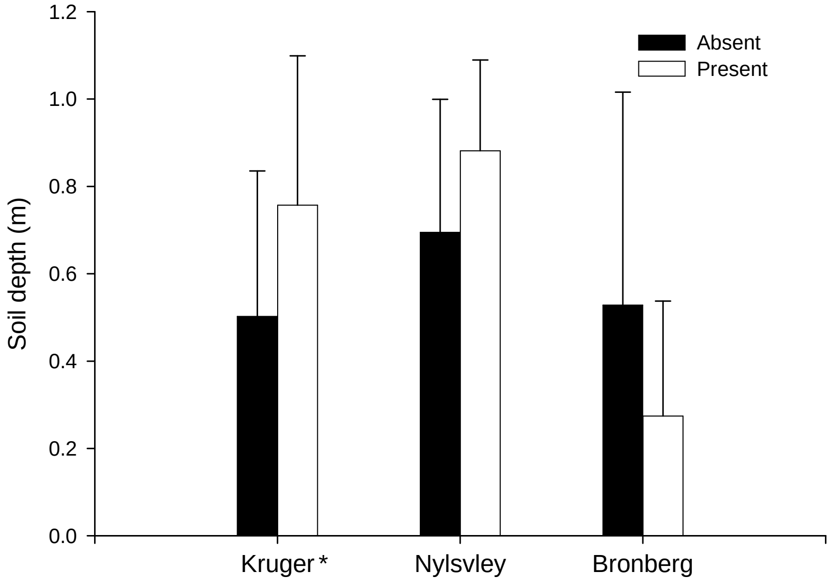

Figure 4. Soil depth (m) in relation to presence and absence of Juliana's golden mole at each population. A significant difference between Absence and presence is denoted by *.

The Spearman's rank correlation (Table 5) revealed several significant relationships. All significant correlations between vegetation variables showed high correlation coefficient values. This intercorrelation is not unexpected given the interrelatedness of many of the vegetation properties. Soil depth and PSD were significantly correlated with certain vegetation characteristics. The soil depth and particle size therefore appear to have a significant contribution to shaping the vegetation structure.

Table 4. Summary of median values of soil hardness and depth (± SD) and significance values (NS = not significant, p>0.05) from Mann Whitney U-test for data from presence and absence plots in Kruger National Park (KNP; n=22), Nylsvley Nature Reserve (NNR; n=12) and Bronberg Ridge (BR; n=13).

	KNP			NNR			BR		
	Absent	Present	*P*-value	Absent	Present	*P*-value	Absent	Present	*P*-value
Soil hardness (kN/100mm)	1.12 ± 0.35	0.96 ± 0.22	NS (0.057)	0.38 ± 0.04	0.26 ± 0.04	0.003	1.50 ± 0.53	0.42 ± 0.17	0.034
Soil depth (m)	0.52 ± 0.33	0.95 ± 0.35	NS (0.057)	0.70 ± 0.30	0.93 ± 0.14	NS	0.53 ± 0.54	0.17 ± 0.27	NS

Table 5. Spearman’s rank correlation showing the correlation coefficient between respective variables. Significant correlations are indicated by asterisks: where * denotes *P* < 0.05 and ** denotes *P* < 0.001

	Soil depth	Soil hardness	Particle size distribution	Vegetation cover	Tree layer	Shrub layer	Herb layer	Average tree height	Canopy cover	Tree density
Soil depth (m)	1.000									
Soil hardness (kN/50mm)	-0.113	1.000								
Paritcle size distribution	0.022	0.628**	1.000							
Vegetation cover (%)	-0.068	0.197	0.304*	1.000						
Tree layer (%)	-0.144	-0.037	-0.056	0.195	1.000					
Shrub layer (%)	-0.312*	-0.014	-0.188	0.002	-0.015	1.000				
Herb layer (%)	0.129	0.245	0.358*	0.908**	0.163	-0.200	1.000			
Avgerage tree height (m)	-0.088	0.046	0.010	0.066	0.724**	0.008	0.105	1.000		
Canopy cover (%)	-0.287*	-0.009	-0.205	0.059	0.709**	0.125	-0.007	0.629**	1.000	
Tree density $(m^2)^{-1}$	-0.340*	-0.111	-0.351*	0.027	0.476**	0.264	-0.068	0.277	0.683**	1.000

2.3.3.4 Multiple logistic regression

The tests presented in the vegetation and soil properties sections above provide an overview of the potential influence of individual variables on the presence or absence of Juliana's golden mole. In contrast, the logistic regression model investigated the relative importance of all the environmental explanatory factors on the probability of finding Juliana's golden mole present in the study plots. Initially, a global multiple regression model was produced that included all explanatory variables, namely: soil factor, tree factor, soil depth, vegetation cover and shrub layer. Then a number of alternative models were run (Table 6). The AIC_C criteria favoured a model that included a significant effect of tree factor and soil factor. The tree factor was positively associated with presence of the mole, indicating that the probability of golden mole occurrence increased as tree factor increased. In light of the variables comprising the "tree factor", this indicates that an increase in tree height, layer, density, and canopy cover increase the habitat suitability for Juliana's golden mole. The soil factor was negatively associated with presence of the golden mole, indicating that occurrence of the mole decreased as soil factor increased. Thus as soil particle size heterogeneity (Shannon's index) increases, resulting in a corresponding increase in soil hardness, the probability of finding Juliana's golden mole decreases.

In contrast to statistical differences with the second best model, statistical support for the chosen model was far more pronounced when compared to the third, fourth and fifth best models, as the two highest ranked models had both a ΔAIC_C less than 2 (Table 6). The Akaike weight criteria suggested that the highest ranked model was 1.66 times more likely to be the KL best model compared to the second ranked model (Table 6), which also included the effect of shrub layer. Accordingly, this indicates that shrub layer, which was positively correlated with the occurrence of the mole, should be considered as a contributing component of the characteristics that determine the habitat suitability for Juliana's golden mole. Table 7 shows the statistical attributes for components incorporated in the best model.

Table 6. The candidate models explaining the probability of finding Juliana's golden mole present in study plots. The models are based on multiple logistic regression analyses and ranked according to descending values of the Akaike weights (ω_i). According to the principle of parsimony, the model with the highest ω_i explains most of the variation using the fewest parameters. K indicates the number of model terms plus one for intercept and error term, AIC_C represents Akaike information criterion corrected for small sample size, and ΔAIC_C denotes the deviance in AIC_C from the model with the lowest AIC_C. The table lists the five best candidate models out of 11 potential models.

Model	*K*	AIC_C	ΔAIC_C	ω_i
Soil factor + Tree factor	3	50.33	0.00	0.335
Soil factor + Tree factor + Shrub layer	4	51.34	1.01	0.202
Soil factor	2	52.46	2.13	0.116
Soil factor + Tree factor + Soil depth	4	52.66	2.33	0.105
Soil factor + Tree factor + Veg. cover	4	52.76	2.43	0.099

Table 7. Factors affecting the probability of finding Juliana's golden mole present in study plots. *β*, SE, t and CI_{min}, CL_{max} denote the regression coefficient, standard error, t-value and 97.5% confidence interval for the coefficients, respectively. Coefficients are considered significant when confidence intervals do not overlap with zero.

Coefficients	*β*	SE	T	CI_{min}, CI_{max}
(Intercept)	1.527	0.088	17.421	1.362, 1.694
Soil factor	-0.334	0.065	-5.174	-0.449, -0.200
Tree factor	0.112	0.057	1.946	0.009, 0.230

2.4 Discussion

Biotic and abiotic elements exert a mutual force on one another and due to this interconnectedness, climate, soil, vegetation, and animal life should not be considered as separate branches of science (Walter 1979). Juliana's golden mole is reliant on both biotic and abiotic elements, as well as the forces acting between these elements. By investigating various habitat components in a presence/absence manner it was hoped that some of the most important variables affecting habitat quality and their patchy distribution would be highlighted.

2.4.1 Vegetation

Climate and substrate are the determining factors for vegetation growth and each ecological region has its own set of unique variables that influence the plant community structure (Bredenkamp & Brown 2001). Few aspects of vegetation structure or composition appeared to be strongly associated with the habitat of the Juliana's golden mole since not many trends emerged that were consistent across all populations. The most apparent and only consistent trend was that the relative cover of tree and shrub layers was greater in presence sites than absence sites for all three populations. This would be expected to have a major influence on microclimatic conditions such as soil temperature and soil moisture. A combination of these two factors, specifically in the relatively hot and dry conditions characteristic of all three populations, would directly affect soil hardness (see Chapter 4) and consequently the optimal microhabitat conditions for the species. In addition, soil moisture and temperature affect the biology of soil micro-arthropods (Choi *et al*. 2002) with moister rather than drier conditions expected to be more favourable for these organisms (Ivask *et al*. 2006). Such conditions would most likely support a greater abundance and diversity of soil invertebrates thus making food acquisition easier for golden moles.

The INDVAL analysis investigated the potential use of sympatric plant taxa as indicator species, but did not yield any associations of great affinity. An important consideration is the size and number of sample plots. A relatively low sample size incorporating 5 x 5m quadrats may not be sufficiently large to capture a large proportion of plant species occurring within the suitable habitat. Species that occur at lower densities within this region may well have only been recorded in a small percentage of sample plots. Their significance could potentially be overlooked or the projected probability underestimated when using the INDVAL analysis. It is thus difficult to interpret the present results of the INDVAL analysis. All species showed low indicator values (<60%), whereas values greater than 70% would typically be required before a species is considered to have a meaningful indicator value (McGeogh *et al*. 2002). The results from this study had values ranging between 20.00 and 55.56%, and thus none of the species recorded can be considered to be reliable indicator species for Juliana’s golden mole habitat.

Dense stands of large (>3m) *Terminalia sericea* are very common in both the NNR and KNP, but are absent from the BR. These species are good indicators of sandy soils and often highlight areas that are inhabited by Juliana’s golden mole (C.R. Jackson Pers. obs.). This species did not feature strongly in the INDVAL analysis, most likely because it does not occur at the BR population. When combining the plant species from all three populations, this would directly affect the INDVAL analysis. Additionally, the subjective placement of the relatively small survey quadrats may have misrepresented the occurrence of these trees. Since this chapter aims to fully describe the habitat utilised by Juliana’s golden mole, it is important to state the nature of this association. Within large parts of the lowveld, *T. sericea* occurs as a shrub-like form. These smaller trees occur on harder granitic soils and would not serve as a good indicator of potential golden mole habitat.

2.4.2 Soil properties

Particle size influences several soil properties including soil bulk density (the mass of dry soil per unit bulk volume; Brady & Weil 1999) and compaction. The PSD data reveals that the sandy soils inhabited by Juliana’s golden mole are poorly graded compared to the sites where golden mole activity was not recorded (Figure 1). Although the relationship between gradation and compaction of a soil is well known for engineering applications (Kurup & Griffin 2006), it has not been documented for soils lacking major anthropogenic disturbance. The significant positive correlation between soil PSD and soil hardness confirms that as the heterogeneity in the PSD increases, soil hardness increases. It is proposed that the difference in PSD between the sites leads to a difference in the natural bulk density of the surface soil horizons and that this difference is significant in determining the distribution of the golden moles. This property is especially relevant given the golden moles' small size (35g) and weak digging capabilities (compared to the mole-rats (*Bathyergidae*), for example; Bennett & Faulkes 2000) that result in their "sand swimming" mode of locomotion (Seymour & Seely 1996). A poorly graded soil (and therefore a soil with a comparatively low natural bulk density) would thus offer less resistance to tunnelling activities and the animals would expend far less energy on this task (see Seymour *et al*. 1998).

The soil penetrometer values provide a clear indication of the variation in soil bulk density. Analysis of these two soil variables clearly shows that Juliana's golden mole favours softer soil substrates that offer significantly less resistance to burrowing activities. Figure 3 clearly indicates that mean penetrometer values for both presence and absence locations were far greater within the KNP compared to the other populations. Data for KNP was collected during the first three weeks of February 2005. Rainfall data collected at various weather stations within the study region show that this was an exceptionally dry month, with the south western parts of KNP receiving only 6 to 54% of the long-term monthly average for the month of February (South African National Parks). This may account in part for the elevated soil hardness values, as can be seen in Table 3. Comparisons of soil hardness within and between populations must therefore take rainfall and soil moisture into account, as this will affect soil hardness.

In addition to soil hardness, the uniformity of grain size influences a soil's drainage potential (Brady & Weil 1999). A granular soil with a wide range of grain sizes (well graded), especially in the finer ranges, will be less permeable than a granular soil with most of the particle sizes within a narrow range. Soils with low permeability drain much slower and this is a potentially lethal phenomenon to any subterranean mammal, from a waterlogging perspective. Shallow soils exacerbate the saturation potential and heavy rainstorms, characteristic of the summer rainfall region of southern Africa, can result in waterlogged conditions forcing golden moles to the surface where they could potentially drown in pools of water, die of exposure to the elements, or be taken by opportunistic predators and scavengers. For example, on two separate occasions (September 2003 and December 2003) Sclater's golden moles (*Chlorotalpa sclateri*) were found dead on the soil surface after heavy rain in the Sani Pass region of the Drakensberg (C.R. Jackson Pers. obs.).

Not all golden mole species inhabit sandy soils (Skinner & Chimimba 2005). A pattern appears to exist between body size and the soil type that golden moles inhabit (Skinner & Chimimba 2005). The species with small body sizes, those that have mean masses of between 15 – 40 grams (for example, *Eremitalpa granti granti, E. g. namibensis*, *Chlorotalpa duthieae, Calcochloris obtusirostris*) inhabit sandy soils. The species with larger body sizes (50 – 500 grams, such as *Chrysospalax trevelyani, C. villosus, Chrysochloris asiatica, Amblysomus hottentotus*) inhabit montane grasslands, forests or fynbos regions. These ecosystems are not characterised by particularly sandy soils (Low & Rebelo 1996). Although no literature was found on the PSD of soils in these regions, it would be expected they would show better gradation than very sandy soil, and could potentially have higher clay contents. This apparent habitat selection based on body size appears to hold true for 16 of the 17 species described in the book, with *Amblysomus marleyi* being the only exception. Reasons for this evolutionary phenomenon could include the fact that the larger bodied animals are stronger and better equipped to tunnel through harder soil types that contain higher clay contents and are potentially better graded. Furthermore, creating tunnels with larger diameters in sandy soil may prevent them from being structurally sound, since the low clay content reduces soil friability (Brady & Weil 1999). Tunnel systems in less sandy soil should also be of a more permanent nature, and this would have implications for energy conservation.

The two Australian marsupial mole species, *Notoryctes caurinus* and *N. typhlops* are convergent with the Chrysochloridae and early descriptions of marsupial moles even suggested that they were Chrysochlorids (see Johnson & Walton 1989). Marsupial moles are the most specialised extant marsupials with respect to morphology and ecology, and like the Juliana's golden mole are confined to sandy areas (Johnson & Walton 1989). The striking morphological and ecological similarities of the two groups, including the range restriction associated with soil types hint at the importance of the soil substrate. Additionally, it is interesting to note that of the 17 species of golden mole that occur within South Africa, nine have distributional ranges that incorporate some part of the coastline (Skinner & Chimimba 2005). Typical beach and coastal dune sand is also poorly graded and will consequently be less prone to compaction, providing similar advantages to these species.

Golden moles were encountered more frequently in shallower soil types on the BR (mean depth 0.27m). In contrast, NNR and KNP had deeper soils associated with the presence of the golden moles (0.88m and 0.76m, respectively). Although the values for BR appear to be very shallow, soil depth patterns vary greatly on the ridge. The weathering rock produces pockets of sandy soils and these can vary greatly in depth (C.R. Jackson Pers. obs.). In presence study sites, soil depth ranged from 0.04m to more than 1m. Veins and pockets of deeper soils are interspersed and the survey technique employed for this study may have largely overlooked these features. These deeper sands may serve as a refuge during the dry months and the importance thereof cannot be overlooked.

The Spearman rank correlation revealed that a number of habitat features were highly correlated with one another (Table 4). Most interesting is the significant correlation between soil depth and relative cover of the shrub layer, canopy cover, and tree density. Furthermore, PSD is significantly correlated with vegetation cover, relative cover of the herb layer, and tree density. The correlation between these two soil properties and the respective vegetation characteristics indicate that the effects of these biotic and abiotic elements are not mutually exclusive, and soil properties appear to play a major role in shaping the general vegetation structure. This in turn has implications for, and lends support to, using general vegetation descriptions for the purposes of describing (or identifying potentially suitable) golden mole habitat. Several vegetation properties were inter-correlated. Due to the similarities between many of these measures, many of the significant relationships are somewhat intuitive. These would include the correlation between average tree height and tree layer cover, canopy cover and tree layer cover, and tree density and tree layer cover.

2.4.3 Multiple logistic regression

The multiple logistic regression revealed that the model including the soil factor (derived from PSD and soil hardness) in combination with the tree factor (derived from tree density, layer, height, and canopy cover) best explained the probability of habitat being suitable for Juliana's golden mole. Additionally, the second best model includes shrub layer with the tree and soil factors. This analysis provides further support of the importance of PSD, but also emphasises the contribution of vegetation structure to habitat suitability. As discussed above, the PSD regulates the ease of tunnelling and consequent energy expenditure. The effect of PSD on vegetation structure would most likely concern soil permeability and associated nutrient status. Poorly graded sandy soils are well drained and as a consequence soil nutrients leach out as the water descends through the soil profile (Scholes 1990) making soils acidic and infertile (Low & Rebelo 1996). Plants growing on these soils are well adapted to nutrient poor soils and form distinct "sourveld" communities (for example, sour mixed bushveld, Low & Rebelo 1996). Characteristic tree species that are frequently associated with well-drained sandy soils in the north eastern parts of South Africa are *Terminalia sericea* and *Burkea africana* (Low & Rebelo 1996). These broadleaved species have large spreading canopies that provide shade and are frequently encountered in Juliana's golden mole habitat (C.R. Jackson Pers. obs.).

Both the Mann-Whitney tests on vegetation variables and the logistic regression indicate the importance of tree and shrub cover. Shaded areas would greatly influence microclimatic variables such as soil moisture and temperature, as well as potentially affecting invertebrate abundance. Limiting the amount of direct sunlight on the soil surface would keep the soil moist for longer periods and the soil temperature lower. Chapter 4 highlights the importance of these variables for both daily and seasonal activities. Poorly graded sandy soils with a very sparse vegetation cover may thus not provide microclimatic conditions required by Juliana's golden mole. It is interesting to note that the median vegetation cover value for KNP (87.50%) was three to four times greater than of NNR or BR. The KNP has the hardest soil type (based on both PSD and penetrometer values) as well as the hottest average annual temperatures (see Chapter 1). The larger amount of vegetation cover would maintain lower soil temperatures in comparison to areas devoid of vegetation and consequently reduce evaporative water loss from the soil, keeping it softer for longer periods. Soil temperature is of vital importance to daily activity patterns and foraging (please refer to Chapter 4), and shaded soil surfaces would be especially important in the very hot and relatively dry climate of the KNP.

2.5 Conclusion

In quantifying the habitat variables associated with the presence of Juliana's golden mole, PSD appears to have a strong effect on habitat suitability. Direct influences concern the soil hardness, with poorly graded sandy soils offering far less resistance to movement. Although most likely not of primary importance to Juliana's golden mole, PSD also affects water retention and soil permeability. The poorly graded soils are well drained and this prevents long-term over saturation after heavy rain. The rapid draining of the soils leaches out nutrients, resulting in a characteristic, well adapted plant community in these ecosystems. The PSD was strongly correlated with vegetation cover, tree density and herb layer, with the golden mole favouring regions with greater tree and shrub layers. Increased vegetation cover limits evaporative water loss from the soil, retaining soil moister for longer periods. Increased soil moisture keeps the soil softer and also provides favourable microclimatic conditions for soil invertebrates, the golden moles food source.

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Appendix A: Plant species lists for the Bronberg Ridge, Nylsvley Nature Reserve, and Kruger National Park study areas. The occurrence of a plant species in a presence or absence study quadrat is designated by †. Specimen codes are provided for species that were not successfully identified in the herbarium, and are listed at the bottom of each list.

Table 1. Plant species recorded in presence and/or absence study quadrats on the Bronberg Ridge, Gauteng Province, South Africa.

Species name	Presence	Absence
Acacia sp.	†	
Acalypha angustata	†	
Acalypha villicaulus	†	
Adenia glauca	†	
Aloe sp.	†	†
Argyrolobium pauciflorum		†
Aristida adscensionis	†	
Aristida congesta	†	
Aristida transvallensis		†
Asparagus africanus	†	
Athrixia elata	†	
Barleria sp.	†	†
Berkheya seminivera	†	
Bidens pilosa	†	
Brachiaria serrata		†
Burkea africana	†	
Canthium gilfillanii	†	
Canthium mundianum	†	
Cheilanthus hirta	†	
Cleome maculata	†	†
Combretum molle	†	
Commelina africana	†	
Cryptolepis oblongifolia	†	
Cymbopogon plurinodis	†	
Dichoma zeyheri		†
Diheteropogon amplectens	†	†
Elephantorrhiza burkei	†	
Elephantorrhiza elephantina		†

Eragrostis curvula	†	
Eragrostis gummiflua		†
Eragrostis trichophora	†	†
Eustachys paspaloides	†	
Foeniculum vulgare		†
Hebenstretia angolensis	†	
Helichrysum rugulosum	†	†
Hibiscus trionum	†	
Hypharrenia filipendula	†	
Indigofera hilarus	†	†
Justicia anagalloides	†	†
Leonotis sp. 1	†	
Loudetia simplex	†	†
Melinis nerviglumis	†	
Melinis repens	†	†
Ochna pulchra	†	†
Oldenlandia corymbosa	†	†
Opuntia ficus-indica	†	
Parinari capensis	†	
Pearsonia sessilifolia	†	
Pellaea calomelanos	†	†
Rhynchosia caribaea	†	
Rhynchosia minima		
Rhynchosia nitens	†	†
Rhynchosia totta	†	
Senecio inornatus	†	†
Senecio macrocephalus		†
Senecio sp. 1		†
Setaria sphacelata	†	†
Strychnos pungens	†	
Tagetes minuta	†	
Tephrosia sp.	†	
Themeda triandra	†	†
Tristachya biserata	†	
Urelytrum agropyroides	†	†

Vernonia staehelinoides	†	
Xerophyta retinervis	†	†
B11-77		†
B11-79		†
B11-81		†
B12-86	†	
B1-3	†	†
B13-88	†	
B1-4	†	
B16-94	†	
B2-28	†	†
B4-38	†	
B5-44		†
B5-46		†
B5-48		†
B8-64	†	

Table 2. Plant species recorded in presence and/or absence study quadrats in Nylsvley Nature Reserve, Limpopo Province, South Africa.

Species name	Presence	Absence
Abutilon angulatum		†
Acacia karroo		†
Acacia toritillis		†
Achyranthes aspera		†
Aerva leucura		†
Aristida congesta	†	†
Aristida diffusa	†	†
Asparagus africanus	†	†
Blepharis integrifolia		†
Burkea africana	†	
Carrisa bispinosa		†
Chaelanthus costatus	†	
Cleome maculata	†	
Combretum molle	†	
Commelina africana	†	†
Crabbea acaulis	†	
Dactyloctenium aegyptium		†
Dichrostachys cinerea	†	†
Digitaria eriantha	†	
Diheteropogon amplectens	†	
Diospyros lycioides		†
Eragrostis curvula	†	†
Eragrostis gummiflua		†
Eragrostis sp. 2	†	†
Eragrostis trichophora		†
Euclea crispa		†
Euclea natalensis	†	
Eustachys paspaloides		†
Grewia flava		†
Grewia monticola	†	
Gymnosporia sp.		†
Hermannia sp.	†	

Hermannia sp. A		†
Hermannia sp. B		†
Hermannia sp. C	†	
Ipomoea sinensis	†	
Isoglossa grantii		†
Justicia flava		†
Kohautia virgata	†	
Lannea discolor	†	
Lobelia sp.	†	
Melinis repens	†	
Oldenlandia corymbosa	†	
Panicum maximum	†	†
Perotis patens	†	
Rhus dentata	†	
Rhynchosia totta	†	
Sida cordifolia		†
Solanum delagoensis	†	†
Strychnos madagascariensis	†	
Strychnos pungens	†	
Tephrosia polystacha	†	†
Terminalia sericea	†	†
Themeda triandra	†	
Urelytrum agropyroides	†	
Waltheria indica	†	
Ziziphus mucronata		†
N10-74	†	
N10-78	†	
N10-80	†	†
N1-1	†	
N1-10	†	
N1-16	†	
N11-84		†
N12-88		†
N14-100		†
N14-99		†

N1-9	†	
N2-19	†	
N2-20	†	
N2-22	†	
N2-25	†	
N2-26	†	
N3-34	†	†
N3-36	†	
N3-38	†	
N7-55	†	
N7-59	†	
N7-61	†	
N8-63	†	
N8-64	†	
N8-67	†	
N9-73		†

Table 3. Plant species recorded in presence and/or absence study quadrats in the Kruger National Park, Mpumalanga Province, South Africa**.**

Species name	Presence	Absence
Acacia swazica		†
Achyropsis avicularis	†	
Aeschynomene micrantha	†	
Agathesanthemum bojeri	†	†
Alysicarpus rugosus subsp. perennirufus	†	†
Andropogon schirensis	†	†
Argyrolobium sp.	†	
Argyrolobium speciosum	†	
Argyrolobium transvaalense	†	
Aristida congesta		†
Ascolepis capensis		†
Balanites maughamii		†
Barleria gueinzii	†	†
Barleria sp.	†	†
Bidens bipinata		†
Bothriochloa insculpta		†
Brachycorythis pleistophylla	†	
Cassia abbreviata	†	†
Chamaechrista plumosa	†	†
Combretum apiculatum	†	†
Combretum collinum	†	†
Combretum molle	†	†
Combretum zeyheri		†
Commelina africana	†	†
Commelina benghalensis	†	
Commelina eckloniana	†	
Cucumis zeyheri	†	†
Dalbergia melanoxylon		†
Dicerocorym seneliodes	†	
Dichrostachys cinerea	†	†
Digitaria eriantha	†	†
Dioscorea sylvatica	†	

Eragrostis superba	†	†
Euclea natalensis	†	
Evolvulus alsinoides	†	
Gladiolus dalenii		†
Gloriosa superba var. superba	†	
Grewia monticola		†
Gymnosporia buxifolia	†	
Helichrysum acutatum	†	
Hermannia sp. A		†
Hermannia sp. B	†	†
Heteropogon contortus	†	†
Hibiscus engleri	†	†
Hibiscus micranthes	†	
Hyperthelia dissoluta	†	†
Indigofera delagoensis	†	†
Jasminium fluminense	†	†
Justicia flava	†	
Lipocarpha chinensis	†	
Lotononis laxa		†
Melhania prostrata		†
Melinis repens	†	†
Panicum maximum	†	†
Pellaea calomelanos		†
Peltophorum africanum		†
Pentanisia angustifolia		†
Perotis patens	†	†
Philenoptera violacea		†
Phyllanthus cedrelifolius	†	†
Phyllanthus incurvus	†	
Phyllanthus reticulatus	†	
Pogonarthria squarrosa	†	†
Pterocarpus angloensis	†	
Pterocarpus rotundifolia		†
Rhoicissus tridentata	†	†
Rhus dentata	†	

Rhus gueinzii		†
Rhus pyroides	†	†
Rhus sp.		†
Rhynchosia minima		†
Rhynchosia totta	†	†
Schmidta pappophoroides		†
Schotia brachypetala	†	
Setaria sphacelata	†	†
Setaria16	†	†
Sida acuta		†
Solanum delagoensis	†	†
Solanum panduriforme		†
Sphedamnocarpus pariens	†	
Sporobolus afrincanus		†
Stachys natalensis	†	
Strychnos gerrardii	†	
Strychnos henningsii	†	†
Stylochiton natalense	†	†
Tephrosia polystacha	†	†
Tephrosia sp.	†	†
Terminalia sericea	†	†
Themeda triandra	†	†
Tristachya leucothrix		†
Urochloa mosambicensis	†	†
Vernonia natalensis	†	
Vigna unguiculata	†	
Vitex harveyana		†
Zanthoxylum capense	†	
K1-10		†
K11-103		†
K13-110	†	
K13-112	†	
K14-119	†	
K17-143	†	
K18-145		†

K18-147		†
K19-150	†	
K20-160	†	†
K20-163	†	
K22-180		†
K22-181		†
K22-185		†
K23-188		†
K23-189		†
K23-190		†
K23-194		†
K23-195		†
K25-206	†	
K25-210	†	
K25-212	†	
K25-213	†	†
K25-214	†	
K26-218		†
K26-219		†
K26-221		†
K6-51		†

Chapter 3

Predicting the Potential Distribution of Juliana's Golden Mole

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"Look and you will find it… what goes
unsought will go undetected…"

- Sophocles -

3.1 Introduction

Most biogeographical research is concerned with the structure and dynamics of geographical ranges (Brown *et al*. 1996). A species' distribution is determined by various factors acting at different scales and intensities (Pearson & Dawson 2003) and is a complex expression of its ecology and evolution (Brown *et al*. 1996). Biologists have long sought explanations for how plants and animals are distributed spatially and temporally across the earth's surface (Guisan & Thuiller 2005). The earliest biogeographers, including de Candole, Wallace, Hooker and Darwin, were concerned with factors that limited distribution and influenced species composition and diversity, but rarely focused specifically on geographic ranges (Brown *et al*. 1996). Studies during the twentieth century focused on environmental factors limiting particular species distributions and, despite a long history of biogeographical studies, most investigations of the characteristics of geographical ranges have only been done within the last 25 years (Brown *et al*. 1996).

Earliest ecological modelling techniques utilised correlations between species distributions and climate, such as Johnston (1924) (cited in Mack 1996), who predicted the spread of an invasive cactus species in Australia. Computer-based modelling originated in the mid-1970's with the first attempt at modelling a species distribution by Nix *et al*. (1977). In the last two decades, however, interest in species distribution models has grown considerably, and new approaches have largely been supported by the parallel developments of computer and statistical sciences (Guisan & Thuiller 2005). Consequently, the number of scientific publications has increased significantly since the early 1990's, with reviews on the rapidly advancing field appearing regularly for the past decade (see, for example, Franklin 1995; Austin 1998; Guisan & Zimmermann 2000; Scott *et al*. 2002; Guisan & Thuiller 2005). Advances have resulted in species distribution models (SDMs) becoming a powerful tool to address various issues in ecology and biogeography, but more recently in climate change research and conservation biology (Rushton *et al*. 2004, Araújo & Guisan 2006).

SDMs are now seen with increasing frequency throughout ecology and conservation biology (Vaughan & Ormerod 2005). They are, by definition, empirical models that relate data obtained in the field to environmental predictor variables, based on statistically or theoretically derived response surfaces (Guisan & Zimmermann 2000). Landscapes are naturally heterogeneous and give rise to spatially structured populations of organisms (Szacki 1999) with climatic and physical factors, at certain scales, profoundly affecting the distribution (Soberón & Peterson 2005). Physiological adaptations to a limited range of environmental conditions are thus the ultimate barriers restricting species distribution, since neighbouring habitats comprise different biotic and abiotic variables (Cox & Moore 1993). Species thus have specific environmental requirements, referred to as their ecological niche, and SDMs are characteristically reliant on the niche concept to provide spatial predictions (Guisan & Zimmermann 2000).

The ecological niche, as defined by Hutchinson (1957), can be separated into the fundamental (FN) and realised niche (RN) concepts. The FN is the ‘n-dimensional hypervolume’ where species S_1, in the absence of competition with species S_2, is able to persist indefinitely. The region of FN where S_1 is not absent due to competition with S2 is recognised as species S_1’s RN. FN is therefore essentially a function of an organism’s physiology and ecosystem constraints, while RN additionally includes biotic interactions and competitive exclusion (Guisan & Zimmermann 2000). Most ecological modellers use Hutchinson’s framework although there is conflict as to what the models genuinely represent (Guisan & Zimmermann 2000, Pearson & Dawson 2003, Soberón & Peterson 2005, Araújo & Guisan 2006). Furthermore, the niche concept focuses primarily on competition whilst ignoring positive biotic interactions that may be as important for a species’ persistence (Araújo & Guisan 2006).

The FN, for the purposes of approximating species’ distributions, has been estimated in one of two ways (Soberón & Peterson 2005). The mechanistic approach to model building (Guisan & Zimmermann 2000) uses a direct method that evaluates how well the target species responds to different physical parameters, such as temperature and humidity, for example (Soberón & Peterson 2005). Inferred fitness values associated with various parameters are transferred to the GIS interface, from where geographic regions of positive fitness are displayed. The second approach makes use of presence data and relates this to corresponding ecological dimensions in the form of GIS layers (Soberón & Peterson 2005). Combinations of environmental variables most closely linked with the observed distribution of the species are thereby identified and mapped to identify appropriate regions. Several different algorithms have been used in this step of the model building process (see Guisan & Zimmermann 2000, Guisan & Thuiller 2005) in an attempt to statistically extrapolate from the associations between occurrences and various environmental parameters (Soberón & Peterson 2005).

Most SDMs are developed from statistically or theoretically derived response surfaces. The relationship between the environment and the observed distribution is therefore presumed to be in equilibrium and the resultant SDM is said to be “static” in nature (Guisan & Zimmermann 2000). In contrast, dynamic SDMs are able to provide a more complex simulation but these require extensive knowledge of the species involved and are thus usually limited to well-studied species and habitats (Guisan & Zimmermann 2000). Environmental predictors are either proximal or distal (Austin 2002). Proximal and distal refer to the position of the predictor in the series of processes that connect the predictor to its effect on the organism. Most proximal predictors will be the causal variable determining the response of the organism (Austin 2002).

When attempting to assess the geographical range of rare species, insights from SDMs provide an effective alternative to other approaches such as ground surveys. Spatial predictions from distribution models can be used to stratify sampling efforts thereby considerably increasing the efficiency of such exercises (Guisan *et al*. 2006). Despite their potential in conservation management, to date most predictive models have been developed for common plants and animals or biodiversity (Guisan *et al*. 2006), with relatively few models having been applied to rare or endangered species (Engler *et al*. 2004). This is due primarily to data deficiencies for many such species. Knowledge of a species’ geographical distribution and habitat preferences are central to the conservation and population management of threatened species (Guisan *et al*. 2006). Species habitat models are often the best method to facilitate identification and subsequent protection of these important habitats (Rushton *et al*. 2004, Carter *et al*. 2006).

For many taxa, habitat protection will necessitate the creation of a reserve or reserve network (Guisan & Thuiller 2005). Various tools and methods have been developed within the realm of conservation planning to design protected areas such that biodiversity is adequately represented and protected within the confines of the reserve. Criteria used for reserve establishment typically attempt to maximise areas of high quality habitat for all elements of biodiversity, with particular reference to rare and endangered species, as well as those with special habitat requirements (see Pearce & Ferrier 2001). SDMs provide a mechanism by which sensitive and important habitat for one or many species can be identified, at different scales, and subsequently incorporated into reserve or protected area networks (Wilson *et al*. 2005).

Juliana's golden mole (*Neamblysomus julianae*) is extremely habitat specific and particularly difficult to detect due to its subterranean lifestyle. Despite occurring less than 15km from the centre of South Africa's capital city Pretoria, the species was only described in 1972 (Bronner 1997). The species is presently described from the Bronberg Ridge (BR) in eastern Pretoria, the Nylsvley Nature Reserve (NNR) and immediate surroundings, and the south western Kruger National Park (KNP). Distribution records within these regions are scant, and the habitat specificity of the species results in an uneven distribution throughout the landscape. The small size and fossorial lifestyle results in the golden mole having poor dispersal capabilities and in modern environments, intertwined with roads and infrastructure, they are very prone to habitat fragmentation.

Conservation planning thus needs to address the interconnectedness of the species' geographical range at a local (landscape) and regional scale. The species is presently described from a few scattered, isolated localities. The first step would therefore be to fully understand the extent of the species distribution. Ground surveys would be required to search for the characteristic foraging tunnels evident during the summer rainfall period. Finding suitable habitat would be especially difficult (time consuming and expensive) since the three isolated populations are spread out over a large portion of north eastern South Africa (Fig. 1). Simple computer based modelling techniques were employed to produce a SDM that could be used to identify potentially suitable habitat. These areas could then be targeted by field surveys, saving time and money while still potentially revealing presently unrecorded populations of golden moles.

In addition to gaining a better understanding of the species distribution, an accurate SDM can be used to assess what conservation efforts are required to protect areas of suitable habitat at different scales. Given the poor dispersal capabilities of this species, gaps in or patchiness of habitat can be identified and the effect of present day land use assessed within the proposed geographical distribution. Several conservation actions could come to the fore by assessing the distribution, connectedness, and condition of suitable habitat.

3.2 Methods

3.2.1 Conceptualisation

Understanding the mechanism that underlies a species' distribution is vital for conservation and management (Rushton *et al*. 2004), yet researchers often focus purely on the prediction and do not attempt to gain a greater understanding of the mechanism of habitat selection (Fielding & Bell

1997, Guisan & Zimmermann 2000). An adequate knowledge of the species-habitat relationship is required to ensure that the overall approach is not weakened (Carter *et al*. 2006). Neglecting such ecological knowledge has been identified as a limiting factor in the application SDMs in ecology and conservation planning (Austin 2002). Ecological theory should therefore be used more systematically at all stages of the model building process (Guisan & Thuiller 2005). The SDM for Juliana's golden mole relies heavily on the ecological findings presented in chapter 2. Data was collected in such a way so as to facilitate the identification of potentially suitable habitat over large areas. Statistical models are based on correlation between a species presence and certain biotic and abiotic elements. It is consequently not possible to determine causation from correlation (Austin 2002) when attempting to understanding reasons for a given distribution. Thorough field investigations identified the most proximal factors thought to limit the distribution of Juliana's golden mole. The main factor was shown to be the poorly graded, sandy soils. Austin (2002) comments on the difficultly of providing GIS coverage for most proximal variables and they would therefore be impractical for modelling applications. Given that several basic soil properties can be mapped relatively accurately, and the species dependence on some of these properties, our model could fully exploit the availability of good quality GIS soil data.

Additionally, a full vegetation assessment provided an overview of plant species and communities associated with the species' distribution. Theoretically, vegetation features are amongst the best predictors for vertebrates since habitat selection, at one level or another operates on vegetation structure (Carter *et al*. 2006). Personally collected presence records were used as an additional interface between ecological information obtained in the field and specific GIS-based environmental predictors. Environmental predictors were mapped by other organisations and agencies making selection of specific attributes or categories within predictors potentially difficult. Presence records allowed the corresponding elements of predictor variables to be selected, if not already identified by the ecological investigations. Due to the problem of collecting false-absence data during presence-absence sampling exercises (See Chapter 2: Methods), only presence records are guaranteed to provide an accurate reflection of a species' presence/absence status and therefore absence data was not used in model development. During October 2004 a new population of golden moles (species status still unknown) was recorded approximately 25km east-north-east of Bronkhorstspruit, 60km east of BR on the boundary between Gauteng and Mpumalanga Provinces. This location was also taken into consideration when developing the model. Most SDMs utilise some statistical method (see Guisan & Zimmermann 2000) but these approaches rely on several distribution records for the entire area of interest. Insufficient records were available for Juliana's golden mole and a simple overlay model was used.

The accessibility of habitat to dispersal and the evolutionary capacity of the species to adapt to new conditions are important when attempting to distinguish between the potential and actual distributions (Guisan & Thuiller 2005, Soberón & Peterson 2005). Dispersal capabilities and historical distribution are especially important considerations for Juliana's golden mole. They are very poor dispersers due to their small size, subterranean lifestyle and dependence on soil properties and consequently cannot be expected to move great distances between isolated areas of suitable habitat. Furthermore, Chrysochlorids are an ancient mammalian family and their present distribution depends largely on past environmental changes in habitat type (mostly soils) and general environmental conditions (Skinner & Chimimba 2005). Certain habitat patches may thus appear suitable but do not support any animals due to ancient geological and climatic perturbations.

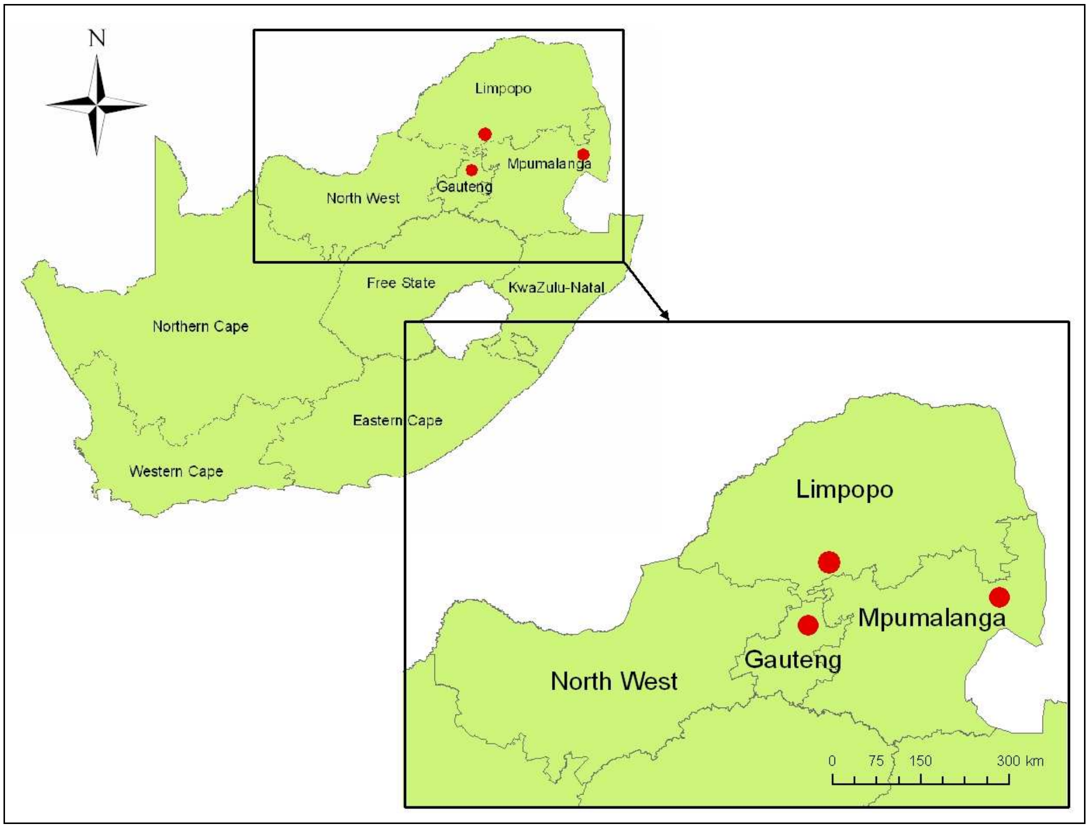

Figure 1. The geographical extent covered by the model incorporated the four northern-most provinces of South Africa and encompassed the three described populations along the Bronberg Ridge (BR), in and around Nylsvley Nature Reserve (NNR) and the south western portion of the Kruger National Park (KNP).

Current information indicates that Juliana's golden mole is restricted to the savanna regions of South Africa (Bronner 1997). This biome occurs in the north-eastern part of South Africa (Low & Rebelo 1996) and the geographical extent of the model thus targeted this region. Environmental predictors with the best possible spatial resolution (grain) were utilised since the species would be susceptible to landscape-level variations in ecological variables.

3.2.2 Data preparation

The Environmental Potential Atlas (ENPAT) series is a collection of environmental, social and economic Geographic Information System (GIS) data sets on national and provincial levels. These datasets are the property the Department of Environmental Affairs and Tourism (South Africa) and may be used freely for educational or non-profit purposes.

Three ENPAT GIS layers, namely clay content, soil types and a national vegetation map, all mapped at a scale of 1:50 000, were incorporated into the model (Table 1). Since the target species is only found in sandy soils, which are characteristically composed of a very low percentage of clay particles (Brady & Weil 1999), the lowest clay category (<15%) was selected to represent suitable soil conditions for the target species. Based on soil analyses in the lab and presence localities, four soil types were selected as being suitable for the target species over the map region (Table 1). An additional soil map was obtained from Gauteng Department of Agriculture, Conservation and Environment (GDACE). The only feature selected was “rock with limited soils” as this accurately describes the range of the BR population.

Table 1. Environmental predictors used in the species distribution model (SDM). Data sourced from Environmental Potential Atlas (ENPAT) and Gauteng Department of Agriculture, Conservation and Environment (GDACE).

Environmental Predictor	Data Source	Attributes selected
Soil type	ENPAT	1. Glenrosa and/or Mispah forms (other soils may occur), lime rare or absent in the entire landscape 2. Plinthic catena: dystrophic and/or mesotrophic; red soils not widespread, upland duplex and margalitic soils rare 3. Red-yellow apedal, freely drained soils; red, dystrophic and/or mesotrophic 4. Red-yellow apedal, freely drained soils; red, high base status, > 300 mm deep (no dunes)
	GDACE	5. Rock with limited soils
Vegetation type	ENPAT	1. Bankenveld 2. Lowveld 3. Lowveld Sour Bushveld 4. Mixed Bushveld 5. Sour Bushveld 6. Sourish Mixed Bushveld
Clay Content	ENPAT	1. <15%

Six vegetation types of the vegetation map were found to overlap with the presence records (Table 1). These vegetation types were classified as being suitable for the target species. All the “sour bushveld” vegetation types are characteristic of well-drained, nutrient poor, sandy soils (Low & Rebelo 1996). The Bankenveld vegetation type is a transitional vegetation type between the grasslands of the high interior plateau and the bushveld of the low interior plateau, characterised by rocky hills, ridges, plateaux and plains (Low & Rebelo 1996).

3.2.3 Modelling methods

The predictor variable layers were reclassified in ESRI® ArcMap™ 9.1 (ESRI Inc., USA) by assigning a value of one to the categories (listed in Table 1) that were considered to be suitable for the target species and a zero to the remaining categories. Since the ENPAT data is supplied separately for individual provinces, this process was completed individually for the North West Province, Limpopo Province (referred to as Northern Province in dataset), Mpumalanga Province and Gauteng Province. The resultant binary datasets for each environmental predictor were then multiplied with one another using the Spatial Analyst tools in ArcMap™. The end product of this model therefore presents a habitat suitability map where the selected criteria for all three environmental predictors must be met before a specific area will be highlighted as potentially suitable habitat.

3.2.4 National Land Cover Map

The SDM map does not assess the present land use of potentially suitable habitat. Given Juliana’s golden mole’s habitat specificity and predisposition to habitat loss and fragmentation, it is important to consider the present state habitat identified as potentially suitable. To establish the extent and nature of disturbance to these areas, the National Land Cover Map (NLCM) was utilised (Fairbanks *et al*. 2000). The NLCM was produced by reclassifying Landsat satellite images and categorises land use for the entire South Africa into 49 separate classes. Transformed habitat can then be removed from the SDM output and a comprehensive assessment of present-day habitat can be obtained. Incorporating these incompatible land uses into the model would provide important insights for conservation management. For the purposes of the present SDM, the 49 categories were reclassified into 13 categories in ArcMap™. Table 2 shows the 13 reclassified classes. Roads pose direct threats to golden mole habitat continuity and the ENPAT national roads GIS layer was added to the NLCM. From personal observation this layer does not depict all the roads in the NNR and KNP regions.

Table 2. The 13 reclassified categories of the National Land Cover Database (2000).

	Definition of class
1	Natural vegetation
2	Planted grassland
3	Forest plantations (man-managed)
4	Water bodies
5	Wetlands
6	Bare rock and soil (natural)
7	Bare rock and soil (erosion)
8	Degraded vegetation
9	Cultivated land
10	Urban/built-up (residential)
11	Urban/built-up (small holdings)
12	Urban/built-up (commercial)
13	Mining and quarries

3.2.5 Model evaluation

The best way to evaluate the predictions of the model would be to undertake an extensive ground truthing exercise to assess classification accuracy using an accuracy measure that is based on data from a confusion matrix (Fielding & Bell 1997). Such an exercise is both time-consuming and expensive to undertake and was beyond the scope of the project. However, there was limited funding available for a ground-truthing field trip.

The model was created at the end of the 2005-2006-rainfall season and only a single day (4 April 2006) was used to ground-truth the model, as conditions were already relatively dry. When the soil is dry new foraging tunnels are seldom encountered, thus providing no evidence of the presence of the species. Only a comparatively small area of the predicted distribution was covered and efforts were directed mostly at the north-western section of the study area. Heading west from Pretoria, we travelled towards Rustenberg and then north-east in the general direction of Modimolle (Nylstroom). Travelling east, the area in the vicinity of Nylsvley Nature Reserve was inspected before turning back to Pretoria. Further field assessments of the model will be needed after sufficient rains have fallen.

3.3 Results

3.3.1 Areas of potentially suitable habitat

The SDM revealed areas of potentially suitable habitat (Fig. 2) that ranged in size from extremely small (± 2km^2) to very large (±2000km^2). Most of these areas are relatively far from the three presently described populations of Juliana’s golden mole. A Narrow belt of habitat extends south west from Pretoria, passing just north of Krugersdorp, after which it continues in a north westerly direction passing between Zeerust and Mafikeng. An additional strip is located just north of Pretoria but extends westward just north of Rustenberg. A large but discontinuous region to the west of Polokwane, between Alldays, Ellisras, Thabazimbi and NNR is highlighted as potentially suitable. A smaller section is found not far away, approximately 70km east of NNR between Polokwane and Groblersdal. Small patches are seen in the north east of South Africa with the majority of these occurring along the Soutpansberg mountain range. To the east of Bronkhorstspruit lies a medium sized portion of potentially suitable habitat that includes the new population found in this vicinity. The KNP population appears to be limited to a relatively small triangular shaped area between Hazyview, Nelspruit and Malelane.

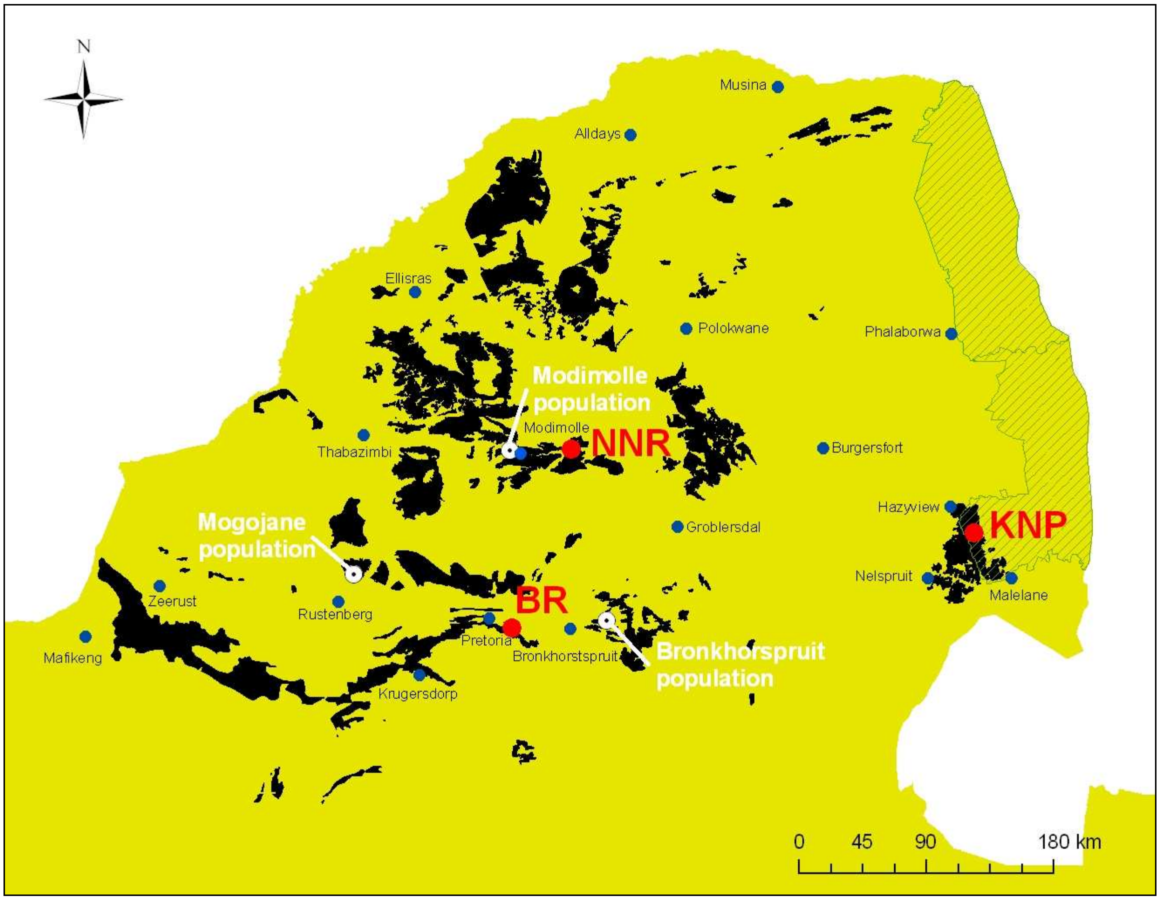

Figure 2. The habitat map produced by the species distribution model is shown in black. The three described populations occurring in the Kruger National Park (KNP), Nylsvley Nature Reserve (NNR) and Bronberg Ridge (BR) are indicated in red, along with the three new or potentially new populations in white. The green-hashed lines show the boundaries of the Kruger National Park.

The predicted distribution closely matches the distribution records (presence and absence), even at a fine scale (Fig. 2 and 3). The model also correctly predicts the areas near Bronkhorstspruit as being suitable, where the new population was discovered (Fig. 2).

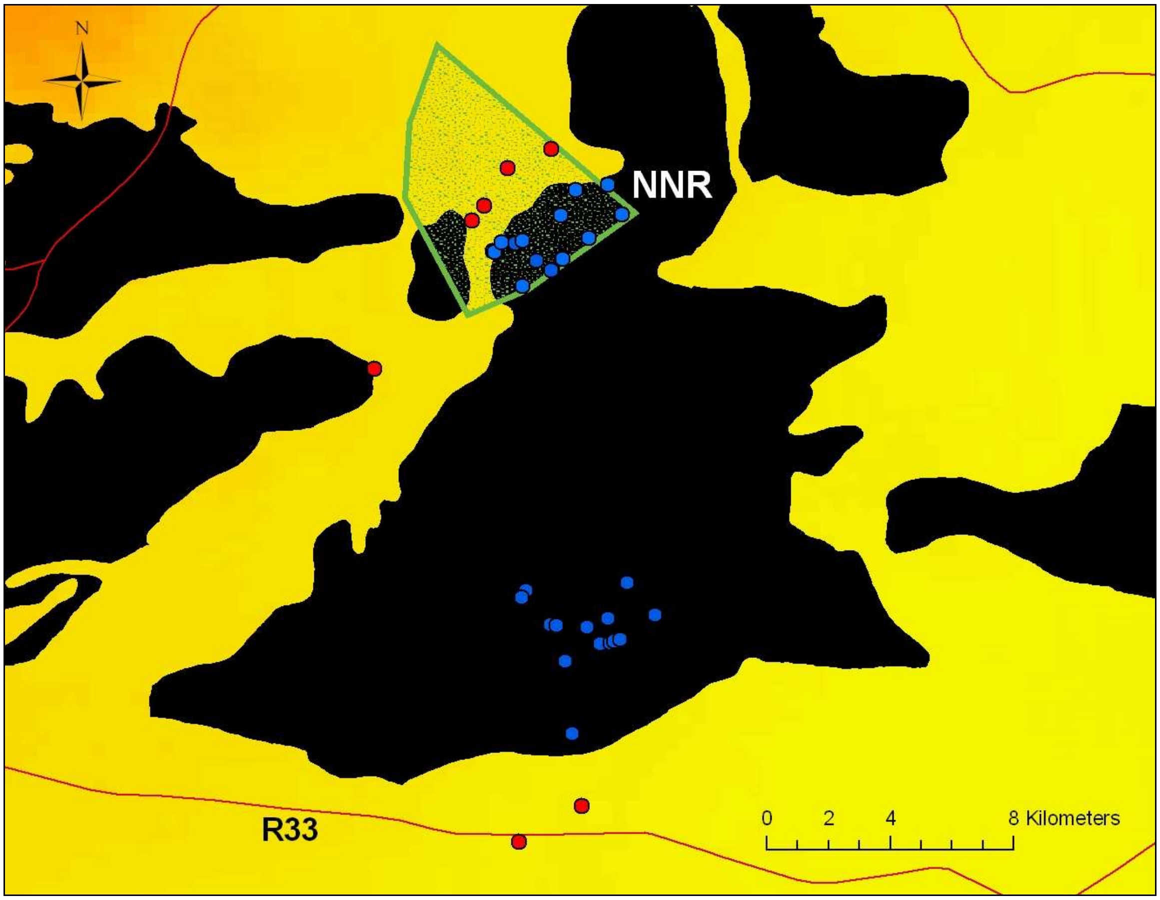

Figure 3. Predicted habitat patches surrounding the Nylsvley Nature Reserve (NNR), shown in green. The blue dots are personally recorded sites where golden moles activity was detected, while red dots indicate areas of absence recorded in particularly unsuitable habitat.

3.3.2 Ground-truthing

The fieldtrip undertaken to evaluate the model revealed another two areas that may support populations of Juliana’s golden mole. The first is situated 110km north west of the BR in the Ga-Mogojane community (Fig. 2). The settlement is characterised by a homestead-type layout, with many households having small patches of maize or other crops growing in their gardens. After assessing some disturbances in the soil thought to be from golden moles, we questioned a local resident about golden moles. When presented with a photo he immediately recognised the animal and told us that he had killed one in February 2006. The animal was reportedly found on the soil surface at about 22:00 after heavy rain. Thinking that it was a mouse, the person killed it but then noticed that it was in fact a golden mole. He was able to accurately describe the basic morphological features as well as distinguish between the animal he had killed (golden mole) and a mole-rat (Bathyergidae). This is an important fact since most people would not know the difference between a mole-rat and a golden mole and usually confuse members of the two very different mammalian families. The fact that it was found on the surface after heavy rain also provides strong evidence that it was indeed a golden mole. Despite searching the immediate vicinity for foraging tunnels, we could not find any signs of the golden moles.

The second site is situated 35km west of NNR (“Modimolle population” in Fig. 2) and was visited whilst ground-truthing the SDM. The visit followed a report of golden mole occurrence from a resident at a retirement home on the outskirts of Modimolle (Nylstroom). This report was not received until after the model was complete. The locality falls within a region that was predicted to be suitable for the target species. The resident was not home at the time of our visit so could not show us where the animals had been seen. Despite walking around the area, no golden mole trails were found. Several habitat characteristics in undisturbed sections, such as the presence of *Terminalia sericea*, were very similar to the Nylsvley population 35km away.

3.3.3 Present land use within regions of potentially suitable habitat

The 13 redefined land cover classes (Table 2) were used to evaluate the condition of the potentially suitable habitat identified by the SDM. When viewing Figures 4 – 6, the nature of land use must be viewed specifically within the boundaries of the potentially suitable habitat. The extent of remaining natural vegetation and the degree of fragmentation thereof are the most important considerations when assessing the condition of a population’s habitat. The BR population is recognised as the most threatened population due to incompatible development activities within the restricted region and the NLC clearly illustrates this (Fig. 4). The NLC is several years old and there has been extensive development along the Bronberg during this period, further impacting on the population. Due to less intensive development within the NNR and KNP regions, these populations have been recognised as less threatened (Bronner 2006). Insights from the NLC provide an accurate assessment thereof and show that much of the habitat connected to the NNR is either cultivated or degraded to some degree. The KNP is well protected within the Park boundaries but is highly urbanised and cultivated outside of this area. Within KNP, an extensive and potentially detrimental road network (mostly management roads) is evident.

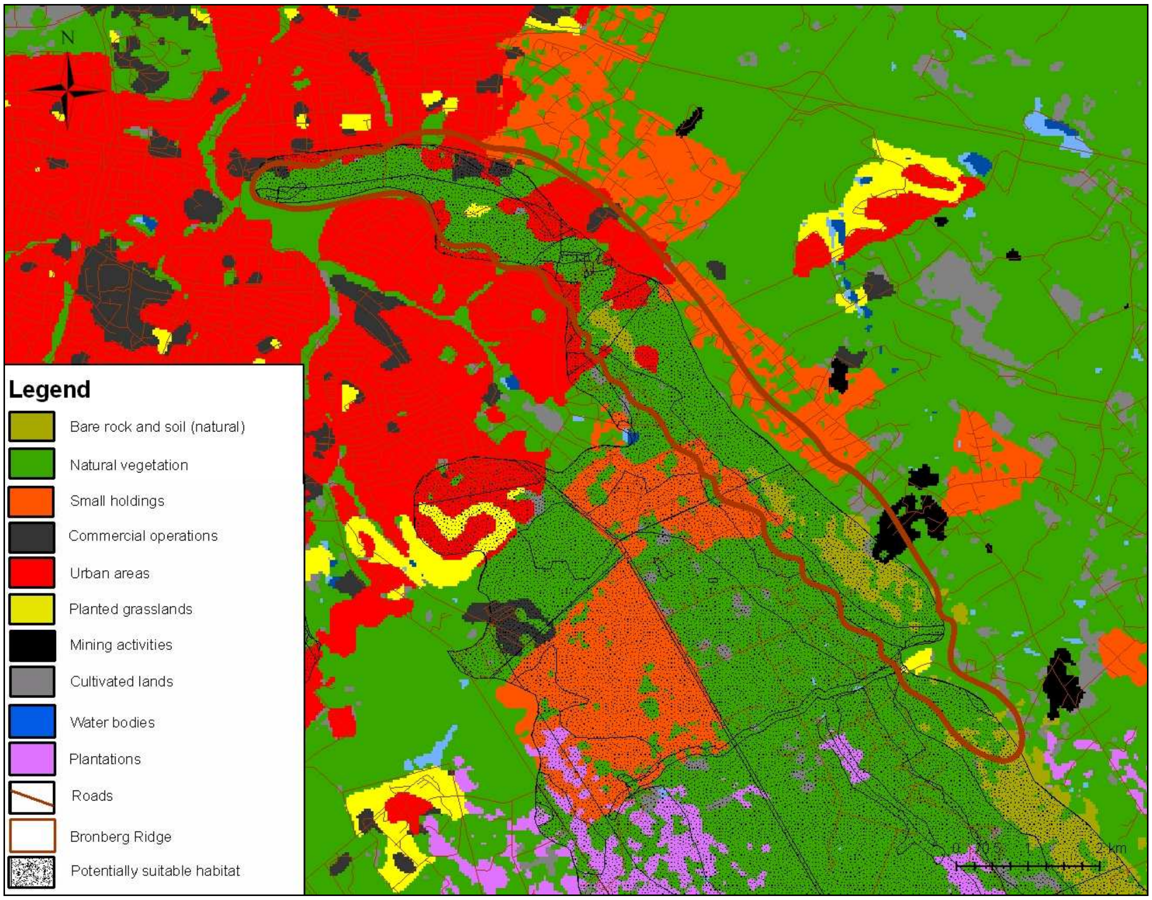

Figure 4. Land use and roads in the vicinity of Bronberg Ridge, Gauteng Province. Land use classes were reclassified from the National Land Cover Database (2000).

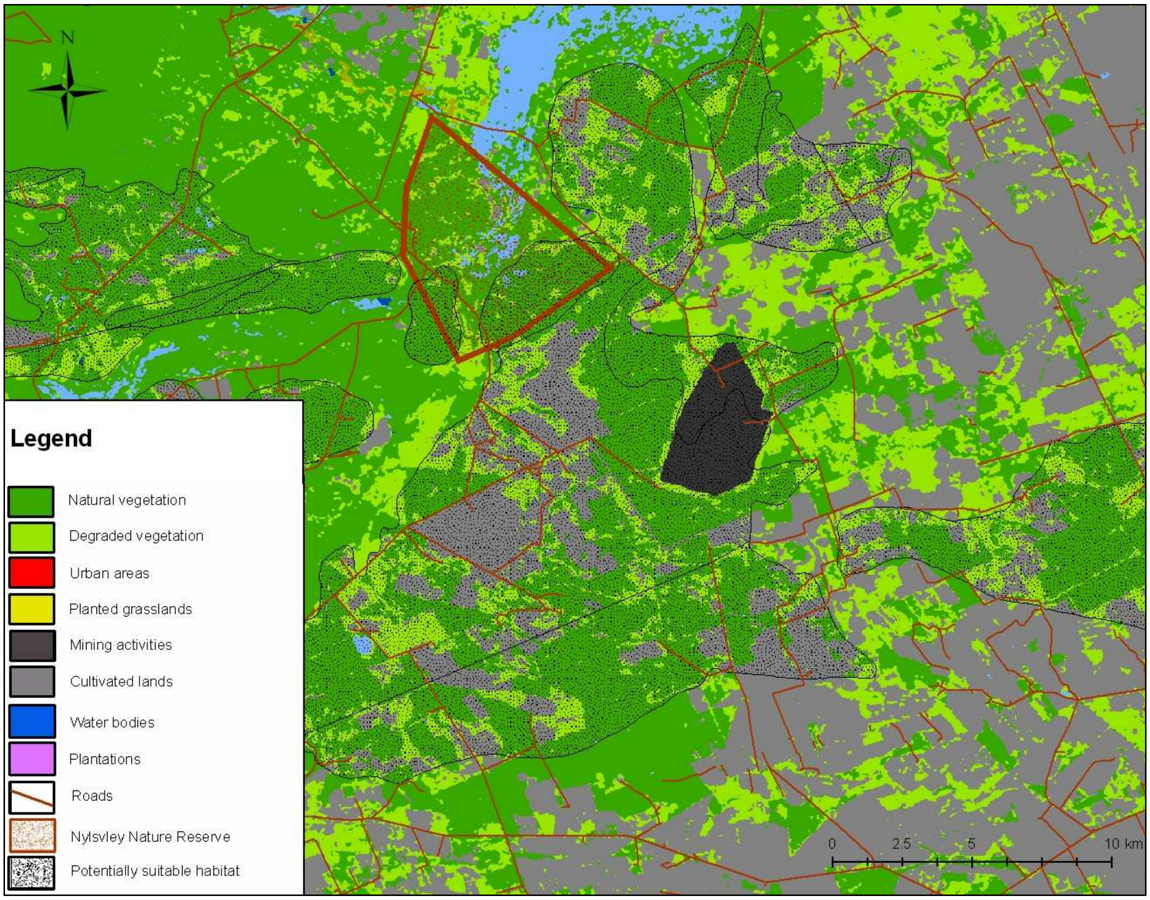

Figure 5. Land use and roads in the vicinity of Nylsvley Nature Reserve, Limpopo Province. Land use classes were reclassified from the National Land Cover Database (2000).

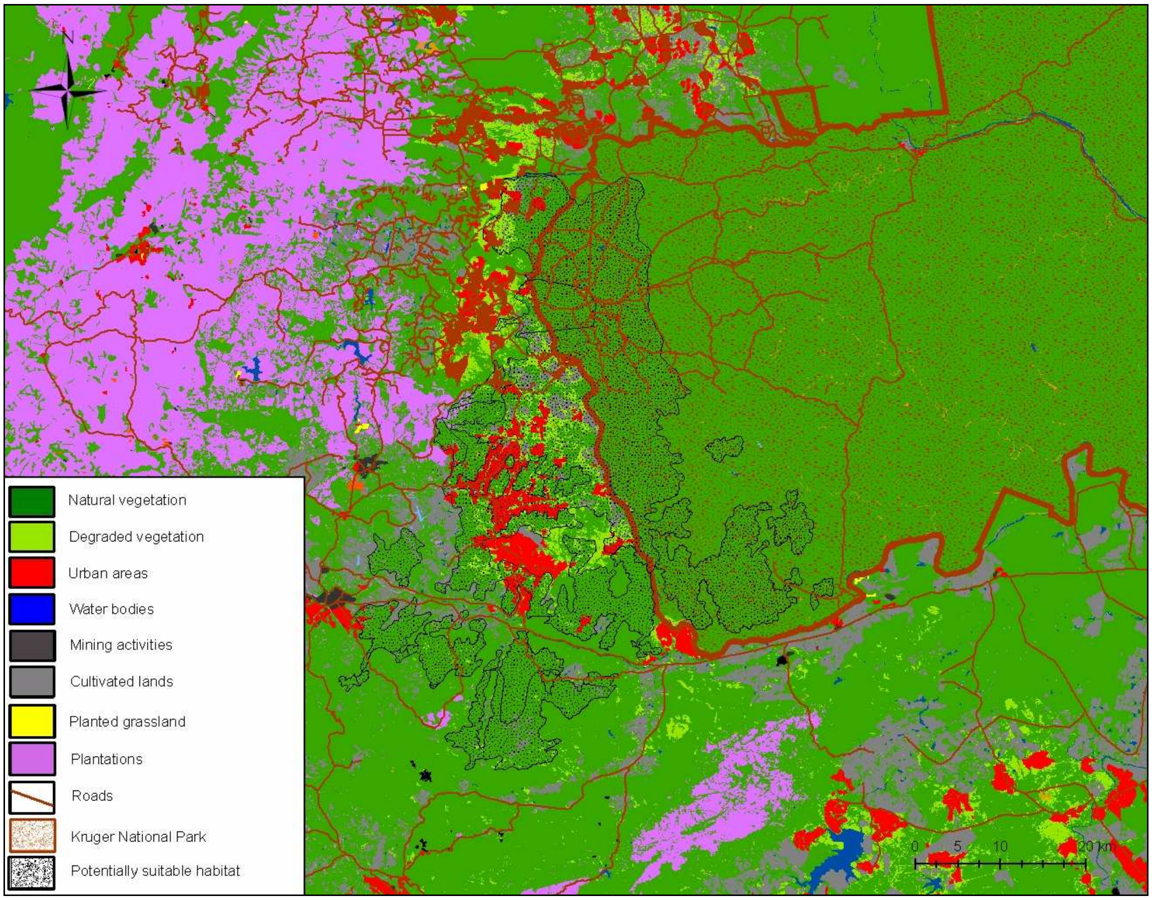

Figure 6. Land use and roads in the vicinity of the south western Kruger National Park, Mpumalanga Province. Land use classes were reclassified from the National Land Cover Database (2000).

3.4 Discussion

Most predictive models have been developed for common plant and animal species, with relatively few successful applications of SDMs for rare or threatened taxa (Guisan *et al*. 2006). Accurate habitat predictions are essential for species of great conservation interest and are often the most important element that needs to be conserved in an attempt to conserve a species (Guisan *et al*. 2006). Detecting other presently unrecorded populations of Juliana's golden mole is vital for conservation efforts. An accurate knowledge of the species distribution is required to implement conservation management. Furthermore, additional populations would have direct impacts on the IUCN red list status of Juliana's golden mole. The distribution of Juliana's golden mole appears to be well described by a limited number of variables. The fossorial lifestyle and habitat specificity of the Juliana's golden mole to sandy soils with low clay content allowed a predictive model to be created using only three layers of ecological data. Given the simplicity of the ecological model, the results yielded a surprisingly accurate prediction, based on preliminary field assessments. There was a close match between sites that were known to be suitable and the area predicted as potentially suitable. The model was able to distinguish between suitable and unsuitable habitat at a very fine scale (Fig. 3) and furthermore incorporates three potentially new populations. Large areas have not been visited and further visits to these areas will be required to fully assess the accuracy of the model.

One potential false positive prediction occurs within Gauteng Province. Unlike NNR and KNP, the BR population occurs along a ridge characterised by comparatively shallow soils and several rocky features. An additional soil property, namely “rock with limited soils”, had to be added for Gauteng Province to adequately represent the BR population. This has resulted in a prediction that includes a narrow strip extending in a west and south westerly direction from the Bronberg Ridge. This belt of shallow soil occurs along the Magaliesberg mountain range. From personal observation, the soils in the central region of the mountain range are probably too shallow and sparse to support golden moles. The ridge is relatively steep in several places and is characterised by a large proportion of rocks with very little soil. Except for the north western most section (with no golden moles), the Bronberg Ridge is characterised by a relatively gradual slope with large pockets of sand (Bosch 2004). Through processes of weathering and natural soil erosion (not human induced), the footslopes of the ridge have especially deep sands. Generally, the Magaliesberg does not have great quantities of soft sand, even along the footslopes (C.R. Jackson Pers. obs.). The western portions of the ridge have not been visited and a field visit is thus required to ascertain the status of these soil features.

The naturally discontinuous nature of the suitable habitat patches is apparent when viewing Figures 2 and 3. This has very serious conservation implications for the species. In addition to the naturally patchy distribution of habitat, more recent anthropogenic changes have further compromised the structural integrity of the habitat by fragmentation and destruction of habitat. Natural vegetation is transformed to make way for agriculture, housing and mining. An extensive road network fragments even historically small habitat patches into still smaller portions. The SDM does not assess the present land use within the areas that are predicted to be suitable for the species. Applying the national land cover map data to the SDM provides a more holistic view of the present day potential distribution of the species.

Large parts of the potentially suitable habitat have been transformed by urban development in the Gauteng region. The major threat outside of this province is from roads and farming practices that destroy and transform natural habitat. The Nylsvley region has several farming enterprises including cattle and game ranching, and a large variety of vegetable and crop production. The various land uses of these respective enterprises will have wide ranging effects on Juliana’s golden mole but would be expected to substantially reduce the areas of continuous, suitable habitat. Ascertaining the state of these areas when viewing current land use is extremely beneficial for the purposes of updating the IUCN red list status of each population. Most conservation action is based on the red-list status of a species, making an accurate assessment and listing of vital importance (see Chapter 5: IUCN status).

An accurate map of the potential distribution provides an overview of the interconnectedness of known populations and facilitates the investigation of other highly suitable regions. Conservation actions can be assisted by such information. For example, the population described from the NNR has only recently been listed as endangered (Bronner 2006). Based on the present understanding of the population's distribution, the entire portion of habitat that could support this population (not excluding transformed habitat) is only a maximum of ±250km^2. The NLCM shows that approximately 35% of this area is cultivated, 2.5% is mined, and 15% of the natural vegetation is degraded. Basing IUCN red list status on accurate habitat availability would most likely see this population elevated to critically endangered.

Another important consideration is the genetic distinctness within and between populations. Preliminary molecular evidence shows that distinct genetic differences are apparent between each of the three currently recognised populations (S. Maree *et al*. *unpublished data*). The KNP population differs greatly from NNR and BR. Molecular data indicates that Gunning's golden mole (*Neamblysomus gunningi*) is in fact more closely related to the NNR and BR populations than the KNP population is to them (S. Maree Pers. comm.). The SDM provides a good indication of how isolated animals from various populations might be. No other potentially suitable habitat is found close to this population, and could be seen as complementing molecular findings indicating the genetic distinctness of the KNP population. Ecological barriers, primarily in the form of hard soil types, have resulted in the respective populations being isolated from one another for an extremely long period of time.

Genetic variation may also occur at the population level. Natural features such as rivers or rocky ridges may act as impenetrable barriers for the golden moles. Today the greatest barriers are roads and patches of transformed habitat. Serious genetic bottlenecks may thus result, reducing the viability of individual fragments even more. Moreover, patches identified as suitable habitat may well be naturally discontinuous, with fine-scale variations in habitat continuity overlooked when mapping landscape features at a scale of 1:250 000.

The population dynamics can be strongly influenced by the abundance and location of suitable habitat (Pulliam & Dunning 1997). The relatively small size and current land use of several habitat patches identified as potentially suitable may give rise to source-sink population dynamics. The death rate within a "sink" habitat exceeds the birth rate but animal numbers within these areas can be maintained via a process of immigration from “source” habitat (Pulliam 1988). Whilst this concept usually revolves around the concept of inter-specific competition, alternative events may give rise to differential birth and death rates within Juliana’s golden mole populations. The structural differences between isolated habitat fragments and the surrounding matrix do not only entail isolation, but also result in edge effects on habitat patches (Noss & Csuti 1997). The outer boundary of a patch represents a zone of influence that varies in width depending on what is being measured (Noss & Csuti 1997). These peripheral zones may serve as sinks for many reasons. These might include increased predation, modified microclimate or being killed by vehicles.

Half of the currently recognised golden mole species are listed as vulnerable, threatened, endangered or critically endangered by the IUCN (Bronner 2006). Information on the distribution of several other golden mole species’ distributions is urgently required (Bronner 2006) with several species known from less than five specimens (Skinner & Chmimba 2005). SDMs thus hold great promise to highlight the potential habitat and distributions of other Chrysochlorids. Subsequent field surveys can target specified regions, thereby proving far more efficient (quicker and cheaper) than unaided survey methods. Many of the threatened golden mole species occur in close proximity to centres of human activity but their cryptic nature renders populations, especially those in rural regions, undetected. Timeous detection of species’ distributions are required should the golden moles be incorporated into long-term conservation plans. These conservation plans can then aim to maintain habitat connectivity and integrity between various parts of a species geographical distribution. The BR population of the Juliana’s golden mole is an example of a golden mole species that did not receive adequate protection from long-term conservation planning, due to various reasons. Conservation efforts for the now critically endangered population primarily attempt to curb property development and further fragmentation of the rapidly declining population, estimated to have decreased by 80% (Bronner 2006).

3.5 Acknowledgements

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Chapter 4

Body temperature fluctuations and patterns of daily and seasonal activity in Juliana’s golden mole

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> **“Research is to see what everybody else has seen,**
> **and to think what nobody else has thought”**
>
> **- Albert Szent-Gyorgyi -**

4.1 Introduction

To successfully negotiate fluctuating biotic and abiotic environmental parameters, animals require compensatory strategies in order to maintain physiological homeostasis. Over evolutionary time these mechanisms shape a species’ adaptations to a given ecological niche (Humphries *et al*. 2003). Species-specific responses to climatic and environmental variables employ both behavioural and physiological mechanisms to circumvent specific ecological adversities that may include resource limitations and extreme ambient temperatures (Wang 1989). Such adaptations are especially important in harsh or unpredictable environments where ecophysiological adaptations may limit the extent of the distribution of a species (Bozinovic & Rosenmann 1989), particularly for small mammals with poor dispersal capabilities (Brown 1995). An understanding of the physiology, behaviour and energetic status of unrestrained organisms in their natural environment is fundamental to basic and applied ecology (Cooke *et al*. 2004).

Most homeotherms maintain a relatively stable core body temperature despite large daily and seasonal fluctuations in ambient conditions (Refinetti 1999). Body temperature stability is attained by heat loss and heat production (Aschoff 1982, Shido *et al*. 1986, Bakko *et al*. 1988). Core body temperature is subject to oscillation even in stable conditions and a daily body temperature rhythm has been observed in all species studied to date. Body temperature fluctuations evolved as an adaptation to cyclic variations in environmental conditions (Refinetti & Menaker 1992). A study of the amplitude of the daily rhythm of body temperature in eleven small mammal species (Refinetti 1999) revealed that those from temperate environments and those that are nocturnal have lower amplitudes of daily rhythm. Generally a mean amplitude greater than 2°C will exceed the limits of variability traditionally associated with homeothermy (Bligh & Johnson 1973).

Many mammals and some bird species lower their body temperature (T_b) set point and metabolic rate (MR) to offset the energetic costs of thermoregulation during periods of cold ambient temperature (T_a) and or food shortage (Wang & Wolowyk 1988). This heterothermic energy saving mechanism, known as torpor, can save animals up to 99% of their daily energy requirements and is thus of great importance for both short and long-term energy budgets (Wang 1989). Hibernation refers to torpor when used over several days, while daily torpor is only used within the time frame of a single circadian cycle (Geiser & Ruf 1995). Daily torpor occurs in at least six avian and nine mammalian orders (Geiser & Ruf 1995, Geiser 1998). Avian torpor is more common in recent lineages whereas it is a feature associated with the older mammalian lineages (Geiser 1998). Although torpor appears to be an ancestral trait in mammals, it is not necessarily functionally primitive since it enables animals to accurately regulate body temperature, thereby minimising energy expenditure (Geiser 1998).

High energetic costs in endotherms are particularly pronounced in small-bodied species because the mass-specific basal metabolic rate (BMR) increases steeply with decreasing body mass (Louw 1993). Torpid individuals benefit from significant energy savings relative to individuals that maintain high body temperatures (Geiser 1993; Song & Geiser 1997) and even small reductions in T_b may result in substantial energy savings (Studier 1981; Webb *et al*. 1993). These minor reductions in T_b, while an animal remains active, are referred to as shallow torpor (Lausen & Barclay 2003). Although frequently overlooked by physiologists, shallow torpor is likely of greatest energetic and ecological importance, since initial reductions in T_b save animals more energy than reductions of the same increment at lower T_b (Willis & Brigham 2003).

Almost all studies on daily torpor in mammals have been conducted in laboratories under constant environmental conditions (Körtner & Geiser 2000). Laboratory studies have often produced findings that do not occur under natural conditions, perhaps because the stress and conditions in captivity alter the natural pattern of torpor and arousal (Thomas 1995). It is therefore important to understand the patterns of torpor and arousal under natural conditions, but this type of information is lacking for most hibernators (Park *et al*. 2000, Lausen & Barclay 2003).

The temporal organization of behaviour has profound implications for the survival and reproduction of animals (Daan and Aschoff 1982), and a temporal niche of a species may be as important for survival as its geographical niche (Daan 1981, Refinetti 2004). The ecology and behaviour of a species is fundamentally affected by its activity rhythm (Erkert & Kappeler 2004). Time must be allocated to different activities within a 24-hour cycle and most mammals are either diurnal or nocturnal, restricting activity to the light or dark phase of the photoperiod, respectively

(Ashby 1972). A third group is crepuscular, displaying bimodal activity peaks occurring during the light/dark transition periods at dawn and dusk. Several peaks of activity during a 24-hour cycle are referred to as ultradian, polyphasic, or cathemeral and this is the most uncommon activity pattern (Tattersall 1987, Halle 2006). The species-specific patterns of activity result from the interaction of the animal's endogenous rhythm, entrainment mechanisms (e.g. photoperiod), and the masking effects of certain environmental cues (Fernandez-Duque 2003).

Besides variations in short-term behaviour patterns, abiotic and biotic factors can vary seasonally and generate seasonal patterns of animal activity (Romañach *et al*. 2005). Many mammals are confronted with seasonal changes in food availability. Large animals with their low mass-specific metabolic rate are able to sustain their energy demands during times of food shortage by metabolizing body fat stores (Körtner & Geiser 1998). In contrast, small mammals with their high mass-specific metabolic rate, unfavourable surface to volume ratios and small fat stores can only sustain normal metabolism for short periods (Geiser 1993, Körtner & Geiser 1998). To overcome these energetic constraints, many small mammals (<10 kg) employ hibernation as an energy-saving strategy (Wang 1989, Geiser 1993, Körtner & Geiser 1998).

4.1.1 Ecophysiological adaptations of golden moles

Although a subterranean lifestyle affords golden moles a more stable microenvironment (Nevo 1979, Bennett *et al.* 1988; Roper *et al*. 2001), life below the soil surface presents its own unique set of challenges. Locomotion by means of tunneling is energetically expensive (Seymour *et al*. 1998), respiration occurs in a hypercapnic and hypoxic atmosphere (Boggs *et al*. 1984, Seymour & Seely 1996) and food resources may be hard to acquire and vary in both abundance and distribution (Narins *et al*. 1997, Scantlebury *et al*. 2005). Energy constraints and challenges posed by atmospheric conditions are consequently a major factor driving the ecophysiological adaptations of Chrysochlorids (Scantlebury *et al*. 2005). Furthermore, the relative constancy of the microenvironment should promote specialisation (i.e. narrow niches) in these environments (Nevo 1979).

A typical physiological trait of subterranean mammals such as golden moles is a low and labile body temperature that fluctuates according to the surrounding microclimatic burrow conditions (Bennett & Faulkes 2000). Golden moles may also be expected to have large amplitudes of daily rhythm due to their use of torpor (Kuyper 1979, Fielden 1990, Bennett & Spinks 1995). Data for the Namib desert golden mole (*Eremitalpa granti namibensis*), Hottentot golden mole (*Amblysomus hottentotus*) and Cape golden mole (*Chyrsochloris asiatica*) show that mean T_b, recorded within animal's thermoneutral zones (TNZ), measured 34.7°C, 33.5°C and 32.9°C, respectively (Kuyper 1979, Fielden 1990, Bennett & Spinks 1995). The same authors recorded torpor in these three species. This work was conducted in the laboratory where, in some instances, ambient temperatures were decreased to extreme temperatures (Kuyper 1979) but this may not be experienced in the wild since the animal may employ other behavioural thermoregulatory means.

In addition to low T_b's, golden moles have extremely high levels of thermal conductance (Bennett & Spinks 1995). This adaptation to subterranean life has been ascribed to preventing overheating in the closed tunnel system where evaporative water loss and evaporative cooling play a minor role in thermoregulation, and to energy conservation (see Bozinovic *et al*. 2005 for review). The Cape golden mole (*Chrysochloris asiatica)*, for example, has a thermal conductance 178% greater than would be expected for an insectivorous mammal of equal size (Bennett & Spinks 1995). Golden moles are consequently very sensitive to temperature fluctuations outside of their TNZ.

Metabolic studies on these three species also consistently show that golden moles have low metabolic rates (Bennett & Spinks 1995, Seymour *et al*. 1998) that may also fluctuate seasonally (Scantlebury *et al*. 2005). Based on allometric predictions for 26 insectivorous mammals, the resting metabolic rate (RMR) of *E. g. namibensis* and *C. asiatica* is only 22% and 68% of what would be expected, respectively (Bennett & Spinks 1995, Seymour *et al.* 1998). Although metabolism was not measured in this study, work on other species by Kuyper (1979), Fielden (1990), Bennett & Spinks (1995), Scantlebury *et al*. (2005) suggests that Juliana's golden mole might similarly exhibit low RMR values.

In addition to ecophysiological traits, patterns of animal movement can provide useful information on migration, dispersal, homing activity and habitat utilisation (Eggert 2002). European moles (Talpidae) follow 3-4 hour bouts of activity and rest (Duplaix & Simon 1976). Juliana's golden moles do not produce foraging tunnels during the dry winter months. This has been attributed to the dry hard soil conditions characteristic of this period (Skinner & Chimimba 2005). The subterranean nature of golden moles makes them difficult to study and there are no field records accurately documenting activity rhythms in these Afrotherians. Anecdotal observations on daily and seasonal activity patterns form the basis of available information for Juliana's golden mole, while no studies have been undertaken to investigate physiological characteristics.

Expectations of torpor, daily activity pattern, and body temperature characteristics in Juliana's golden mole are based on the studies by Kuyper (1979), Fielden (1990), Bennett & Spinks (1995), and Scantlebury *et al*. (2005). However, all data on torpor were collected in the laboratory under controlled conditions. So, what are conditions like in the field and what responses are used to cope with conditions that compromise an animal's state of physiological homeostasis? Additionally, when does daily and seasonal activity peak in this species?

The intention of this chapter was to firstly investigate patterns of seasonal activity, and secondly gain an insight into daily activity patterns. We documented seasonal variation in activity in relation to rainfall, soil moisture and soil hardness. We expected that foraging tunnels would be far more abundant after rainfall, as this would increase soil moisture making the soil softer and tunneling much easier. Secondly, an implantable temperature-sensing transmitter was used to monitor daily activity, movement patterns and fluctuations of body temperature in relation to activity and ambient soil temperature. Based on the limited information on other Chrysochlorids, we expected T_b to be lower during the day and higher at night when active. Furthermore, hourly observations revealed whether the animal was moving or stationary, and its position recorded. Animals should select microclimates that suit their physiological needs and knowing the animal's exact position allowed us to evaluate the potential use of behavioural thermoregulation (such as moving to shaded area), another aspect frequently overlooked in laboratory studies (Lausen & Barclay 2003).

4.2 Methods

4.2.1 Seasonal activity pattern

Five transects, each consisting of six quadrats at least 20 metres apart, were identified on the Bronberg Ridge at the beginning of July 2005. Each quadrat measured 5 x 5 metres and transects were separated by a distance of between 1km and 3.5km. Furthermore, each transect was placed up the slope of the ridge so as to incorporate any variation between the top, middle and lower reaches of the ridge. A rain gauge was placed in the middle of each transect and emptied monthly. Rainfall, soil hardness, soil moisture, and new signs of golden mole activity were recorded within each quadrat during monthly visits. After each visit all foraging trails within a quadrat were flattened to facilitate the re-evaluation of activity during the following visit. Monitoring the production of foraging tunnels does not permit an assessment of the level of activity. Consequently, only the presence or absence of these structures was recorded. Seasonal activity in the context of this study refers to any visible signs of activity, which would be confined to subsurface foraging tunnels. The study commenced during the dry winter month of July 2005 and continued until after the first good summer rains in December 2005, thereby spanning the change in seasons and amount of rainfall.

Soil samples were extracted by means of an auger (80mm in diameter) and placed directly into a water and airtight plastic bag. Soil water content was determined gravimetrically in the laboratory. Soil hardness was evaluated using a penetrometer (Eikelkamp Agricultural Instruments, Netherlands). This instrument consists of a rigid cone-tipped rod attached to a pressure-measuring device and was used to determine the strength of a soil. During testing the penetrometer was pushed into the ground at a slow, steady speed and measurements were recorded at 50mm intervals beginning at the soil surface, measured in kN/50mm.

4.2.2 Daily activity and radio-telemetry

During October and November 2005, a three-week field trip to Nylsvley Nature Reserve was undertaken to trap (with permit from Limpopo Tourism and Parks) and implant a Juliana's golden mole with a temperature-sensing transmitter. Only 8mm of rain had fallen since 20 April 2005 and the Reserve was extremely dry. No fresh foraging tunnels were found and even when tunnel systems were opened up, no blocking occurred. A second attempt was made during February 2006. Sufficient rains had fallen and several new tunnels were apparent. Rain fell every day during the first week of our visit and appeared to alter the animal's activity patterns in that they became active at all hours and did not adhere to a nocturnal activity pattern.

Juliana's golden mole is not successfully trapped without physical injury using any mechanical trapping device. As a result, fresh tunnel systems need to be opened and exposed to ambient atmospheric conditions. When active in the vicinity of the disturbed tunnel, animals sense the disturbance and attempt to block the exposed hole. By sitting and waiting at such a position, animals can be removed from the shallow soil sand when attempting to reconstruct their tunnel system. Between two and four people were placed at different tunnel systems during the trapping process. After several hours spent sitting in front of excavated tunnels, and one 17 hour marathon sitting, an animal was eventually caught on the eleventh night (16 February 2006 at 23:10). This animal was caught after approximately 230 man-hours of trapping effort. It was immediately transferred into a large plastic container (900mm x 500mm x 500mm) along with soil and grass clumps collected from the capture site.

The animal was transported to Bela Bela (Warmbaths) early the following morning. Arrangements had been made with Dr Marius du Toit at the Warmbaths Animal Clinic to operate on the animal and insert the small transmitter. The transmitter (PIP2: Biotrack Ltd, UK) is coated in silicone (RTV3140) that renders it biologically inert. The transmitter is less than 10mm in diameter, spherically shaped and is temperature responsive requiring calibration prior to implantation. Pulse rates of transmitted signals (150.575MHz) increase or decrease with temperature fluctuations. An increase in T_b produces a corresponding decrease in the transmitter pulse rate. The calibration process entails placing an individual unit in a water bath at varying temperatures and recording the corresponding pulse rate. Once implanted, a given pulse rate then accurately corresponds to the internal body temperature. To complement T_b data, three temperature logging iButtons

(Dallas Semiconductor, USA) were programmed to take readings every 15 minutes (accurate to 0.5°C) and placed in existing foraging tunnels, approximately 40mm below the soil surface. Burrow temperature for subterranean mammals is analogous to ambient air temperature for surface dwelling species and consequently referred to as ambient temperature (T_a) from here on.

The animal was anaesthetised using Isofor™ (isoflourothane) controlled through an Ohmeda Isotec 3 (BOC health care) vaporising unit. Initial dosage was set to 5 on the control dial, the maximum concentration per unit oxygen, and as soon as the animal was anaesthetised the dosage was lowered to 2 and this allowed a perfect plane of anaesthesia to be maintained. A hot water bottle was placed under the animal to provide a source of heat and served to keep the animal warm. A small section of fur on the abdomen was shaved and the skin sterilized. The transmitter was sterilized, rinsed in saline, and a small incision made into the peritoneal cavity through which the calibrated unit was inserted.

Three small sutures were placed in the muscle lining and three in the outer layer of skin. This was further sealed by Histoacryl® (skin glue) to prevent any soil entering the wound. This worked very effectively and very neatly sealed the site of insertion. The animal was anaesthetised for 35 minutes in total and the anaesthesia was well controlled at all times. When undisturbed the animal respired 20 times per minute, but any noise or handling resulted in a rapid increase.

Upon completion of the operation the animal was placed under infrared lights (heat source) and allowed to recover completely from the effects of the anaesthetic. The animal showed no adverse signs to the operation and moved around without any apparent difficulty after less than five minutes. It was then transferred back into the soil-filled container and transported back to Nylsvley Nature Reserve. It was placed in an unused room (quiet), allowed to recover, and later released at 19:00 (same day) at the place of capture. Five hours prior to release recording of body temperature commenced using an Alinco DJ-X10 receiver (Alinco Inc., Osaka, Japan) and large (4 bar) antenna. This was recorded every hour and was continued after release for a total of six full days in the field (149 hours in total). For analysis of movement and body temperature, the first five readings were omitted and only 144 recordings were utilised. This consequently excluded readings that may have been affected by anaesthesia or the immediate effects of surgery.

During the intensive hourly monitoring of the animal, the pulse rate of the transmitted signal was recorded by using a stopwatch and counting the number of pulses within a one-minute interval. Additionally, the animal’s spatial position was marked with numbered flags. The positions of each flag were later recorded with a Trimble Differential GPS (Trimble, Ca., USA), providing accurate mapping of each point within approximately 50mm. The small size of the transmitters renders them relatively weak and this facilitated an accurate determination of the animal's position to within approximately 300mm. Care was taken not to step on the animal or the tunnel system, but several parts of the tunnel system were not visible and some tunnels were accidentally trodden on. Straight-line distances between points were measured but these values only provide a minimum distance that was covered by the animal. In reality these distances may have been greatly underestimated in several instances due to the typical zig-zagging nature of foraging tunnels. For the purposes of analysing activity patterns over the six-day period, an activity unit is defined as a movement from one spatial position to another. Since the animal's position was determined at hourly intervals, a maximum of 24 activity units would thus be possible within a day. Torpor was defined using the concept of "active temperature" (T_{act}) that generates an individual-specific definition of torpor based on T_b recorded in the field (Barclay *et al*. 2001). Body temperature is recorded daily at a time when an animal is assumed to be active and this temperature is then considered to be the threshold below which an individual is assumed to be torpid. This method does therefore not overlook the potential occurrence of shallow torpor.

4.2.3 Statistical Analysis

Pearson's Rank correlation was used to assess the relationships between rainfall, soil moisture and penetrometer readings. Data were collected over six months from 30 sample sites and consequently n = 180 for all statistical analyses. A Mann Whitney U-test was used to test seasonal differences between golden mole activity and rainfall, as well as between golden mole activity and penetrometer values. A significance level of 0.05 was used for all tests.

To analyse daily activity pattern, the total number of activity units recorded at a specific time of day or night was divided by the total number of activity units and multiplied by 100. This provides a percentage of the total activity that occurred at the specific times of the day or night. This was used to establish whether the animal displayed a set activity pattern over the six-day period. To analyse the effects of T_a on activity, the number of activity units occurring at each recorded T_a was divided by the total number of activity units and multiplied by 100. This quantified the percentage of total activity occurring at each T_a.

To estimate the potential energy savings from entering shallow torpor, the difference in energy expended on thermoregulation between an animal which had a minimum stable T_b which was indicative of no torpor (33^{o}C), and an animal that utilised the observed amount of torpor in the present study was calculated. This made use of the mean daily observed T_b averaged over the six days of measurements (31.5^{o}C). Assuming the animal was in heat balance with the soil (mean soil T_a was 28.97°C), then the quantity of heat that must be produced by the animal to keep temperature constant can be determined by the following equation:

$$Q = W \times C\ (T_b - T_a) \qquad (1)$$

(Schmist-Nielden, 1997, pg. 254) where W is the mass of the animal (g); C is the thermal conductance of the animal; T_b and T_a are body temperature and ambient temperatures respectively. We used the thermal conductance of a Namib golden mole (Seymour *et al*., 1998) for the region of 30-33°C (=0.40 $mlO_2/g.h.^oC$).

The area covered by the golden mole over the six days of tracking was determined using the minimum convex polygon approach. This was calculated in ArcMap using the Hawth's Analysis Tools software (Beyer 2004).

4.3 Results

4.3.1 Seasonal activity

The six-month study on the Bronberg Ridge showed that golden moles were active in more plots after periods of rain (Mann Whitney U-test, U = 2626.0, n = 180, $P < 0.0001$). Figure 1 presents the relationship between monthly rainfall and golden mole activity. There was a significant positive correlation between rainfall and soil moisture content (Spearman Rank, R = 0.544, n = 180, $P < 0.0001$). There was a significant negative correlation between soil moisture and soil hardness (Spearman Rank, R = -0.221, n = 180, P = 0.003, Fig. 2). Consequently, golden moles were active in more quadrats when moisture levels were high (Mann Whitney U-test, U = 3030.0, n = 180, P = 0.051, Fig. 3).

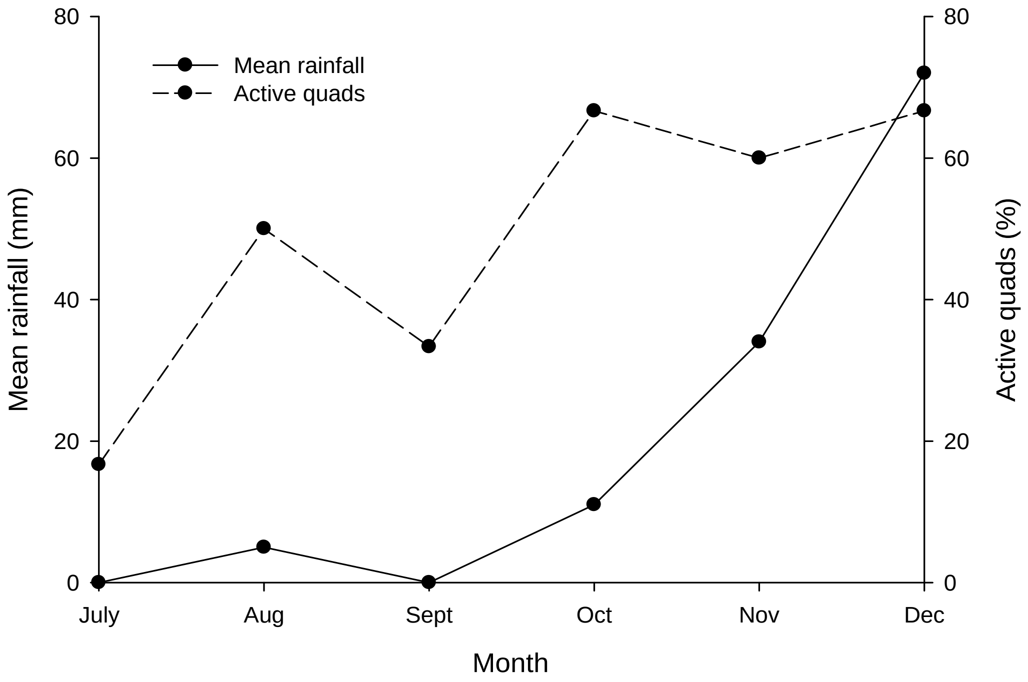

Figure 1. The effect of rainfall (mm) on golden mole burrowing activity (percentage of active quadrats).

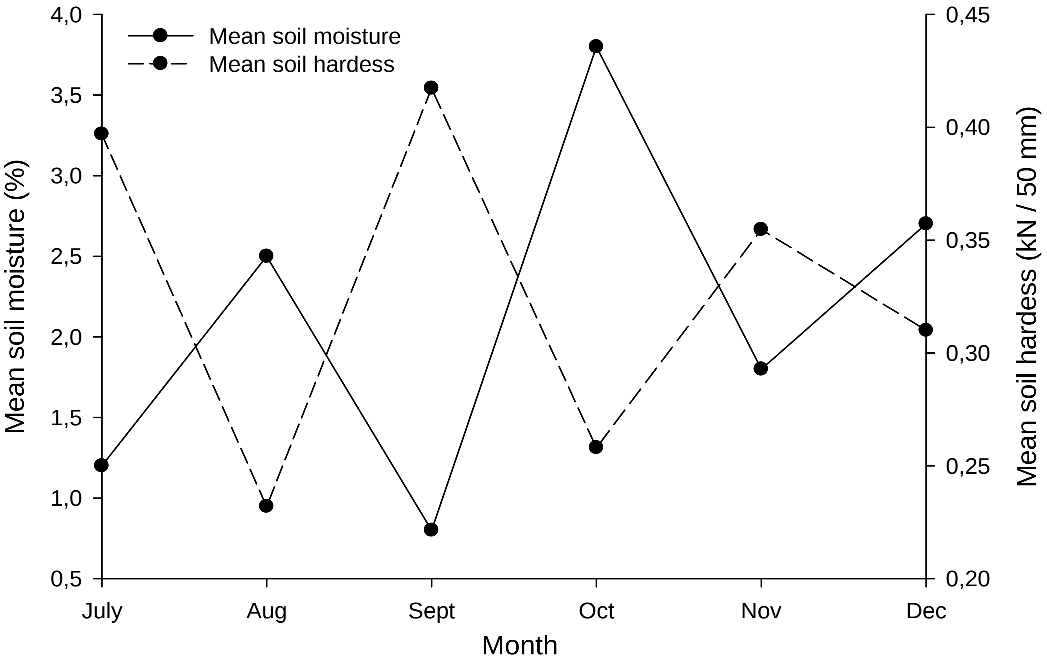

Figure 2. The relationship between mean soil moisture (%) and mean soil hardness (kN/50mm).

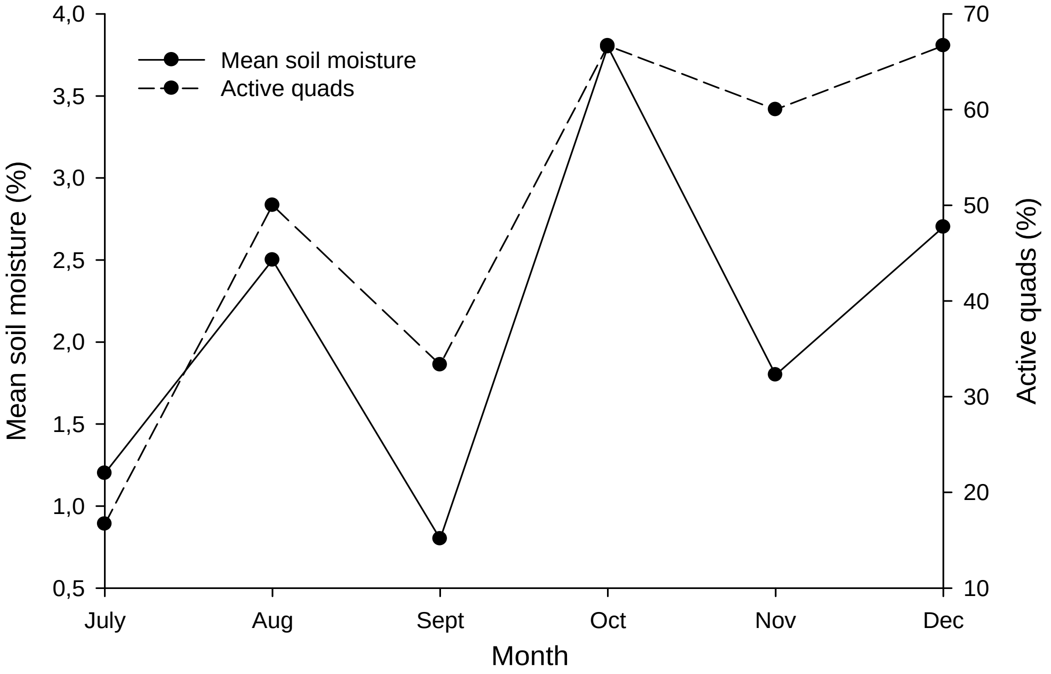

Figure 3. Trends in Juliana's golden mole burrowing activity (percentage of active quadrats) and mean soil moisture (%).

4.3.2 Telemetry

Body temperature and geographical position of the implanted golden mole were monitored hourly. Soil temperature and body temperature of the golden mole for the six-day study period are shown in Figure 4.

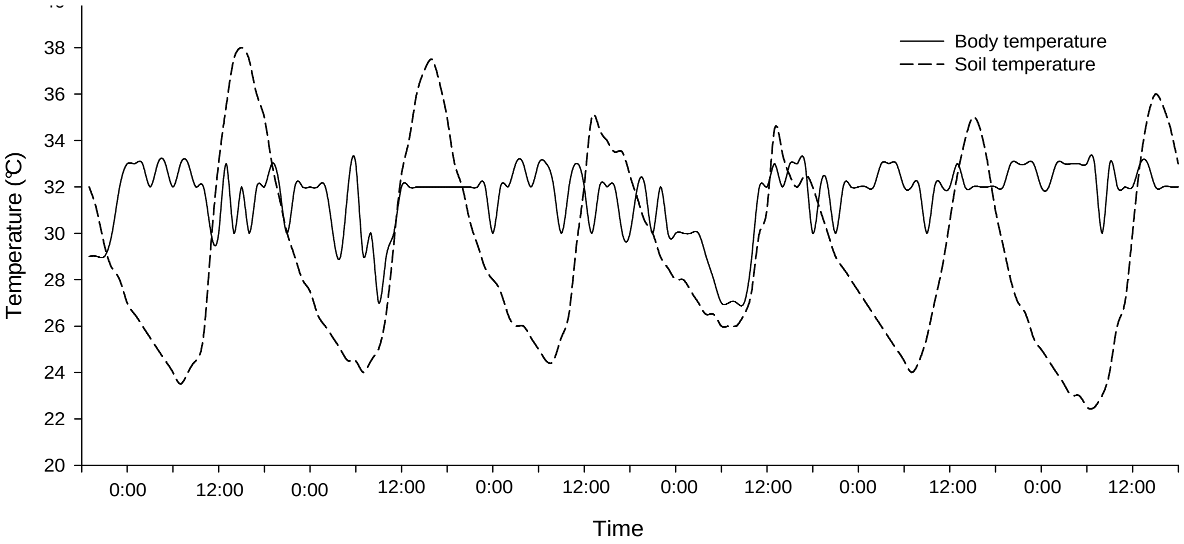

Figure 4. Body temperature of the tagged animal in relation to burrow temperature recorded in close proximity to the monitored animal.

Core body temperature ranged from 27 – 33°C, while the burrow temperature (mean temperature from three sites) ranged from 22.5 – 38°C. Body temperature appears to be regulated so that it does not exceed an upper limit of 33°C and T_{act} was thus set at 33°C, with lower T_{b}s considered as torpid (shallow). Using 33°C as the normothermal T_{b} below which normal activity ceased, and a mean T_{a} of 28.97$^{\mathrm{o}}$C, the amount of energy expended on thermoregulation in a 24 h period would be 27.77kJ./day (Equation 1 above). By comparison, if we use the mean measured body temperature of the animal over the 6-day measurement period (31.5$^{\mathrm{o}}$C) (which includes periods in which the animal allowed its body temperature to fall), then the amount of energy expended on thermoregulation would be 17.44 kJ/day. Hence, allowing T_{b} to fall by 1.5$^{\mathrm{o}}$C results in an energy saving of approximately 10kJ/day.

Subterranean mammals have low and labile body temperatures and in several instances the animal's temperature closely followed the change in the surrounding burrow temperature (Fig. 5). To illustrate potential body temperature fluctuations with soil temperature and potential behavioural thermoregulatory mechanisms, selected portions of Figure 4 are presented at a finer scale in Figures 5 and 6.

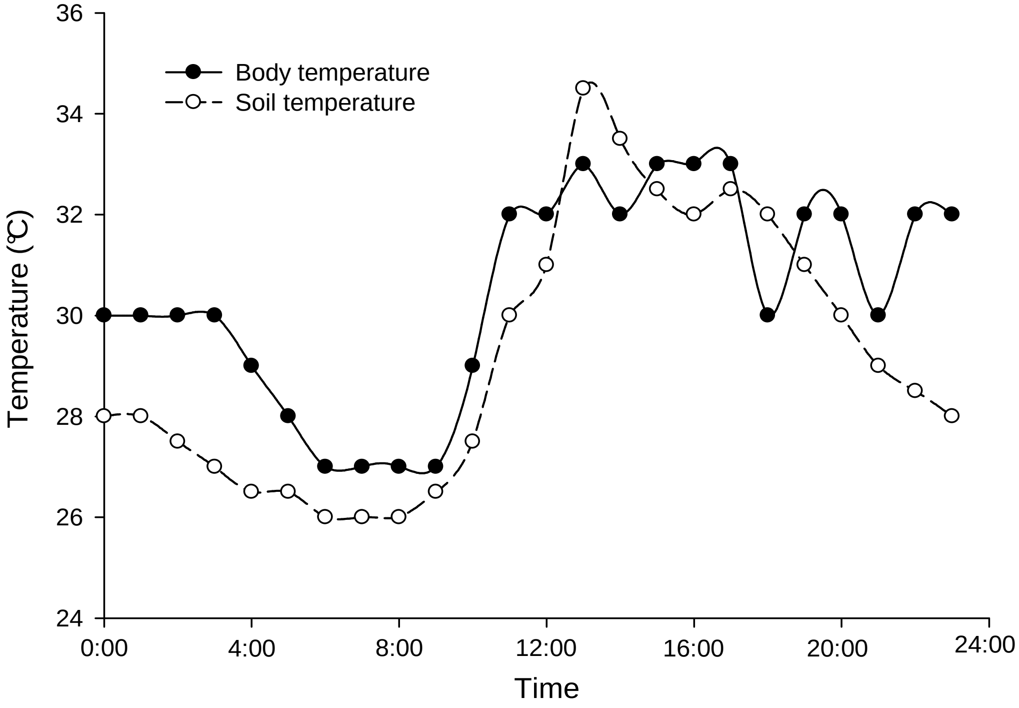

Figure 5. An extract from 21 February 2006, showing body temperature fluctuation (passive heating) in relation to ambient soil temperature.

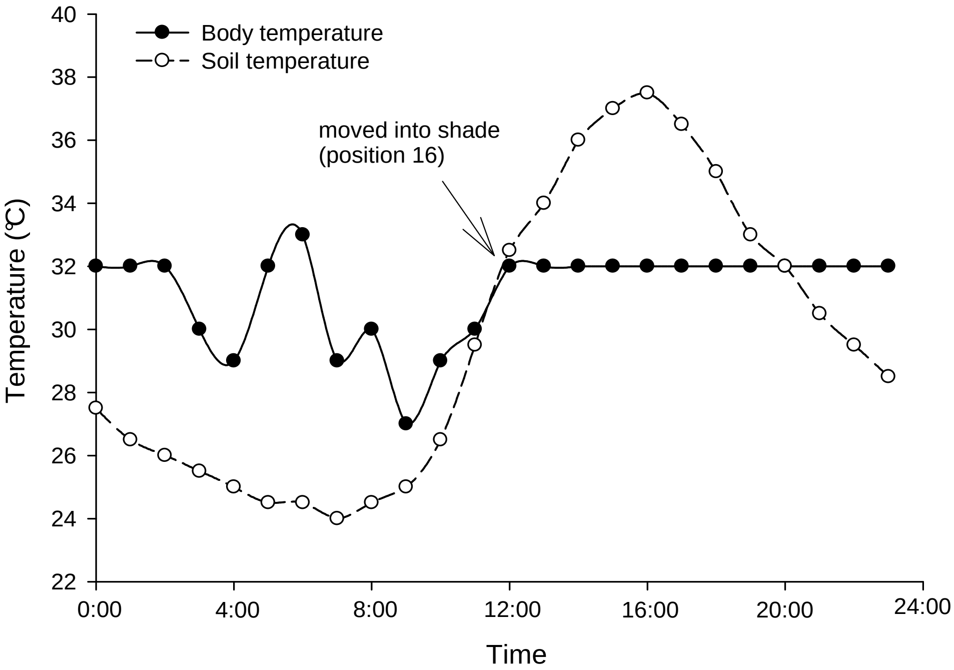

Figure 6. An extract from 19 February 2006, showing body temperature in relation to soil temperature, and when the animal moved into a shady area.

It was found that on hot days, when soil temperatures measured 38°C, the golden mole would move into a shady position as soon as the soil temperature approached 33°C (Fig. 6). This occurred on the four hottest days (the remaining two days were overcast and cooler) and on two consecutive days (19 and 20 February 2006) the animal moved to position number 16 (Fig. 9). Position 16 is directly under a small silver cluster leaf (*Terminalia sericea*) of approximately 3.5m in height, with shade-providing branches extending upwards from 500mm above the soil surface. This patch was thus well protected from direct sunlight. The effective use of such shady patches is clearly seen in Figure 6. After T_b fluctuated extensively during the cooler morning hours, the animal moved into a shaded area when T_a exceeded T_{act}. This allowed the animal to maintain a perfectly constant temperature despite a high T_a. A decreasing T_a in the early evening appears to trigger the onset of nocturnal activity since the animal became active everyday before T_a dropped below 31°C.

4.3.3 Animal movement

After releasing the golden mole, it remained active for four hours (covering 66.30m, measured over three activity units) and then remained at the same position for a period of 11 hours. This location (position 4) was frequented during the six days and the animal was recorded here on 37 occasions (25.69% of the time). At the end of the study a hole was dug at this site that revealed a tunnel spiralling downward to a depth of approximately 400mm below the surface. No chambers were uncovered.

Activity rhythms, using the defined term of activity units, revealed two peaks in daily activity (Fig. 7). These peaks centred around 11:00 and 21:00 and when analysing the distance moved during the period of two hours before until two hours after each peak (i.e. 9:00 – 13:00 and 19:00 – 23:00), a total of 303.83 metres was covered (measured from 35 activity units). The 17 activity units recorded during the midday activity period accounted for 38.74% of this distance, while the 18 nocturnal units accounted for 61.26%. Furthermore, ten bouts of activity that lasted between three to five hours in duration were recorded.

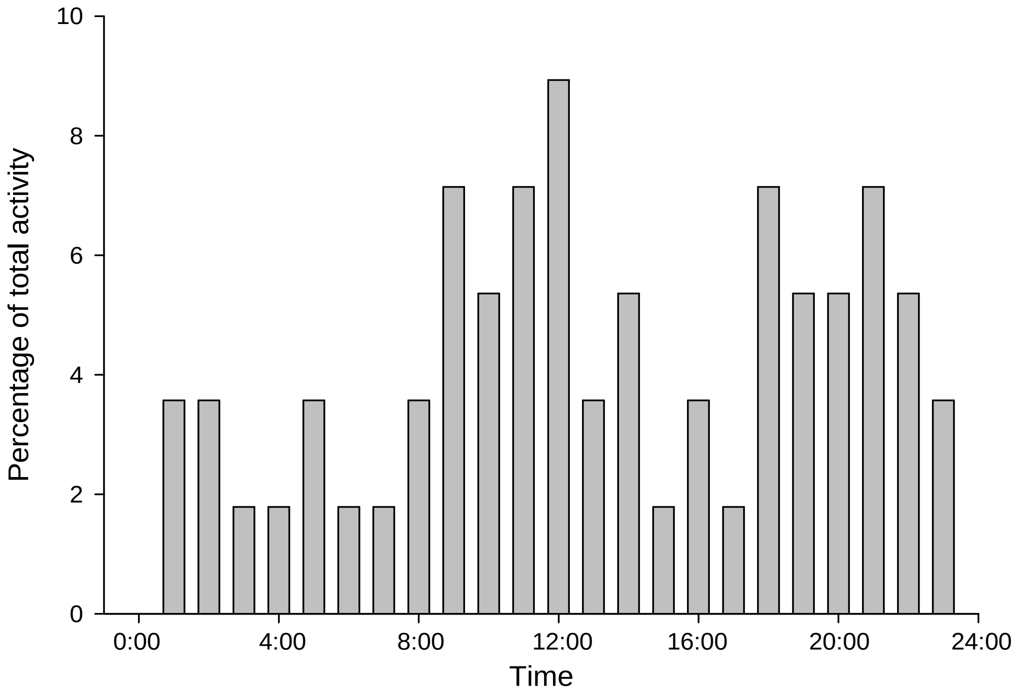

Figure 7. Percentage of activity units recorded at specific times of the day or night. A total of 144 observations were used, of which 61 recordings reported movement (41.67%).

A lack of distinct periods of inactivity prompted an alternative analysis of the data set. When viewing the percentage of total activity that occurs at specific soil temperatures (Fig. 8), a distinct pattern emerges with 96% of activity coinciding with T_a not exceeding 33.5°C. The corresponding position of the animal was recorded and this allowed us to remove five activity bouts that occurred under apparently high temperatures, when in reality the animal was moving about in the well shaded clumps of vegetation where T_a would be expected to be a couple of degrees lower. The iButtons were not placed in shaded areas and thus in no way represent climatic conditions within shaded refuges. The true effects of T_a on activity would have been slightly obscured without the insights gained from the positional observations. Activity when T_a measured 30°C or less accounted for 77% of all the activity.

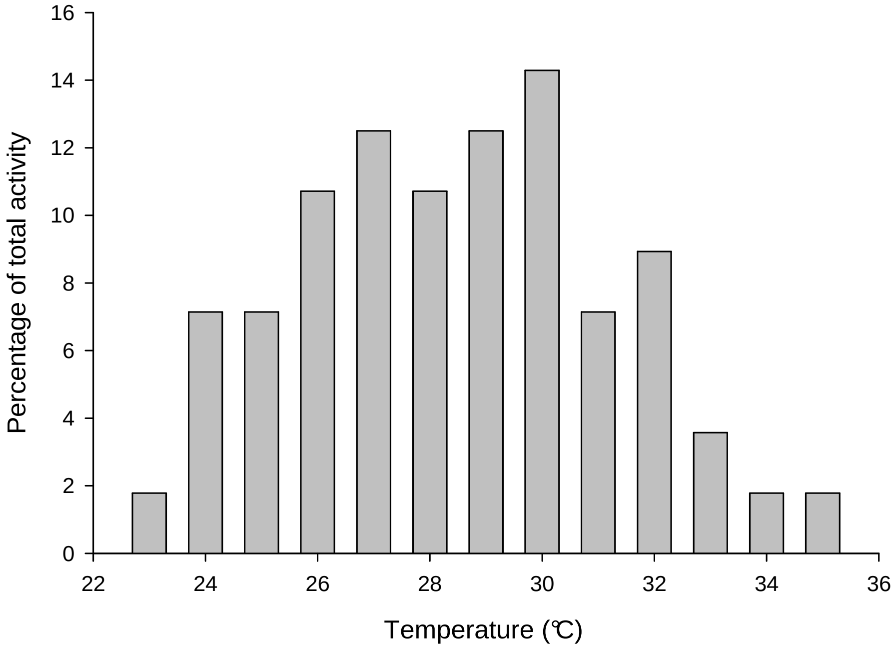

Figure 8. Percentage of total activity occurred at the different soil temperatures recorded during the six-day study period. (Five observations that occurred at temperatures of 34-36°C were removed from the data since the animal was within its frequented shady refuge, where the temperature would have been far cooler).

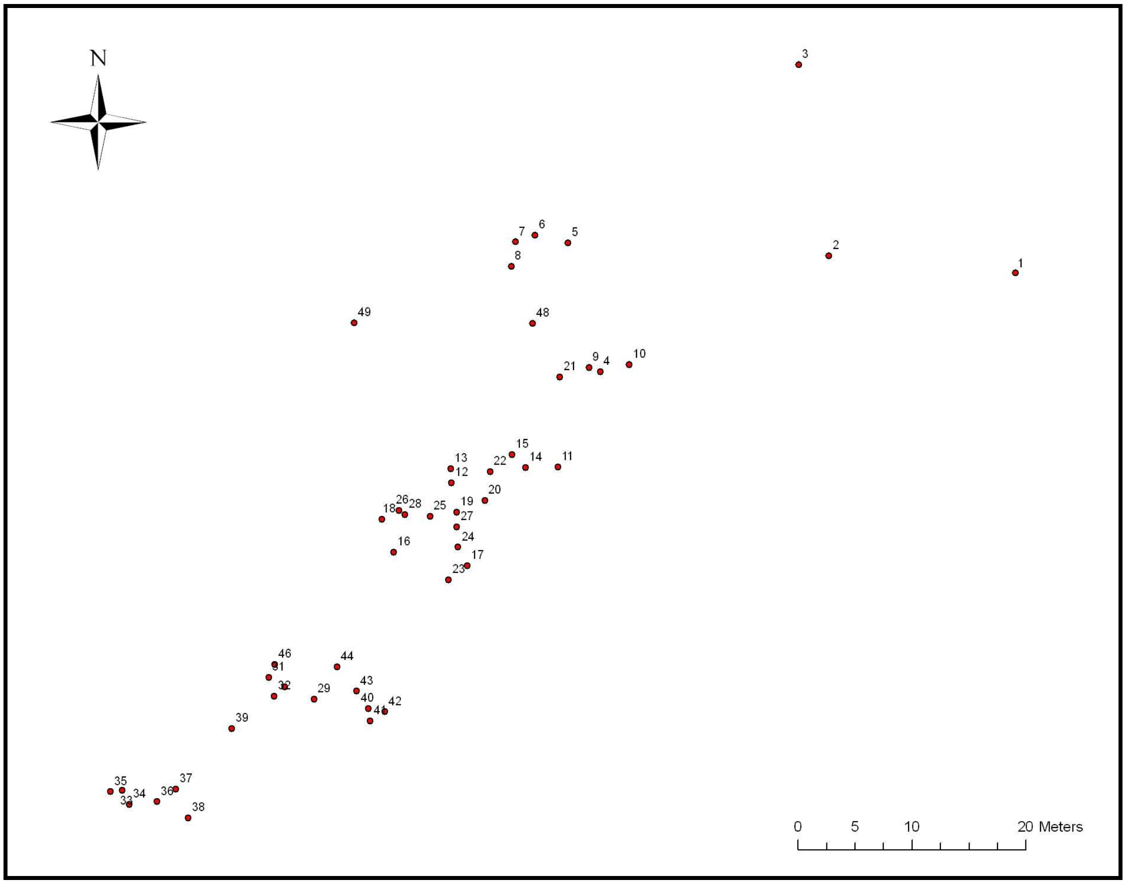

Figure 9. GPS points of the golden mole’s positions recorded over the six-day period.

Observations made on a single individual over a period of six days are not sufficient to draw any conclusions regarding spatial movement patterns for this species. The area utilised during this period (Fig. 9) was relatively small and using a minimum convex polygon (MCP) method was calculated to be 3940m^2.

4.4 Discussion

4.4.1 Seasonal activity

Prior to this study, no quantitative data on seasonal activity patterns had been recorded for this species and reports of seasonal activity were anecdotal. Soil hardness was suspected to be the primary factor limiting surface burrowing activity and rainfall was in turn suspected to influence soil hardness. The results from this study confirm that surface activity is highly correlated with rainfall patterns, as this increases soil moisture that in turn softens the soil, making burrowing easier.

Measurements of rainfall in the rain gauges accumulated over 30 days, but the soil moisture and corresponding penetrometer values do not represent average values for an entire month. This is because values for these variables vary with proximity of rainfall to sample collection. Comparison of these two variables for the month of November (Fig. 2 & 3) revealed that despite good rains the soil was relatively hard and soil moisture low. This suggests that the 60mm of rain fell soon after the October site visit and then the summer heat gradually dried out the soil until the monthly site inspection in November. The use of rainfall in combination with soil moisture and hardness was important for interpreting trends between all variables.

Behaviour of Juliana's golden mole during the drier winter period is not known, but as the six-month study shows, fresh surface activity is extremely low during periods of low rainfall. Any rainfall event measuring 5 – 10mm or more triggers the production of new tunnels. Most mammals do not forage continuously but need to store energy for periods when foraging is not possible. Little or no sign of the animals are observed at the surface during the drier periods and the golden moles could potentially move lower down into the soil profile. During July 2006 a Juliana's golden mole was dug up at a depth of approximately 500mm below the soil surface during excavation on the Bronberg Ridge (M. Robertson pers. comm.). Reports have not documented tunnels at this depth for Juliana's golden mole but this observation suggests that they do burrow to greater depths than subsurface burrows. Seasonal vertical migrations of soil invertebrates have been reported from several different ecosystems around the world (Bezkorovainaya & Yashikhin 2003, Frouz *et al*. 2004, Choi *et al*. 2006). These movements within the soil profile may be used to ensure suitable microclimatic conditions for the soil invertebrates that primarily involve moisture and temperature (Choi *et al*. 2006). If deeper tunnels do indeed exist, they are likely to be of a more permanent nature and link specific patches of resources for easy access during resource-limited times. It is also possible that the observed patterns in seasonal surface activity of the Juliana's golden mole is influenced by the vertical migration of meiofauna.

Anecdotal evidence suggests that the Juliana's golden mole may hoard food. A golden mole burrow was found on the Bronberg Ridge under a large (±20kg) stepping stone that contained a little food store consisting of unconsumed invertebrates (N. Williams pers. com. 2003). European moles (*Talpa europeae*) store earthworms in underground food hoarding chambers (Duplaix & Simon 1976). They decapitate a worm, push the remainder of the worm into the soil wall, and store worms in this manner for long periods of time. The worm stays alive but cannot move and thus stays fresh for several months. Over a kilogram of worms can be stored in this way by one individual mole, providing an important energy reserve (Duplaix & Simon 1976).

Several invertebrates pupate or over winter as adults in the soil (Gullan & Cranston 2000). These invertebrates would provide an ideal food source for golden moles. Since this foraging activity would occur well below the soil surface, it would go unnoticed to the human observer. The apparent inactivity during the dry months may in fact not be true, with an unseen vertical shift in activity occurring instead. During the wet summer months the invertebrates emerge at the soil surface, resulting in a depleted food source lower down in the soil profile. Golden moles then forage near the surface, producing the characteristic foraging tunnels, after which they return to greater depths triggered by the drying out of the soil and corresponding vertical migration of soil invertebrates.

The southern African dung beetles (Scarabaeidae) can be divided into seven functional groups based on their habits of dung utilisation (Doube 1991). A general feature of regions with deep sandy soils, both in grassland and savanna, is the numerical (up to 80%) and biomass (up to 65%) dominance of the functional groups described as “large rollers” and “fast-burying tunnelers” (Doube 1991). Members of both these groups are large and have simple or compound subterranean nests with brood balls (Doube 1991). In the summer rainfall region of southern Africa, most species emerge in abundance after the first spring rains during September-October. They are active throughout the wet summer months, become scarce during autumn, and then rare during winter and the early, dry part of spring (Halffter & Edmonds 1982). This seasonal activity pattern mirrors that of Juliana’s golden mole closely. Furthermore, beetle activity is affected by short-term fluctuations in temperature and rainfall (Doube 1991). *Kheper nigroaeneus*, for example, is a species that prefers softer soils and spends the cold, dry winter months underground as an adult in reproductive diapause. Rainfall triggers the end of the diapause and sparks the emergence of the species. The number of individuals trapped on a day following 10mm of rain may increase two to threefold (Doube 1983).

Most scarabs pupate underground, at depths of 0.2 – 1.3m (Halffter & Edmonds 1982). The larval forms, especially of the species occupying sandy habitats, are often large and juicy, providing a potentially substantial energy source for a 35g golden mole. Furthermore, in certain species one or both of the adults stay with the brood ball (Doube 1991, Halffter & Edmonds 1982), providing even more food for a golden mole should they be encountered. Golden moles, using their highly enlarged malleus, would be able to detect vibrations of tunnelling dung beetles when burying a brood ball at some distance or could encounter the relatively large tunnels excavated when the brood ball is buried and use it to direct them to the food source. Elytra from a large dung beetle species has been found in a Juliana’s golden mole foraging tunnel in NNR, indicating that it was most likely consumed by the mammal (C.R. Jackson Pers. obs.). Interestingly, small sections of scarab tunnels may run parallel to and just below the soil surface, before dipping steeply downwards. These sections of tunnel may closely resemble the foraging tunnels produced by Juliana’s golden mole (Fig. 10).

Figure 10. A section of dung beetle tunnel running just below the soil surface prior to dipping steeply downwards. Excavation of this tunnel revealed the host, shown in the inset. Photo's: C.R. Jackson.

4.4.2 Insights gained through radio telemetry

A sample size of one facilitates a novel study but prevents any conclusive deductions from this study. It has, however, provided meaningful insights into activity and T_b patterns of the critically endangered Juliana's golden mole. The approach is a first for the entire family of Chrysochlorids, and given the physiological similarities between almost all the golden mole species many aspects would most likely be applicable to other taxa. The findings are thus a useful point of departure for future work on golden mole ecophysiology and conservation. Additionally, the anaesthetic and surgical procedures proved successful and serve as an important basis for similar work that may be conducted in the future. One challenge to such future work is successfully trapping an adequate number of animals. Other species such as *Amblysomus hottentotus* can be trapped using tunnel traps and are not as trap-shy.

Radio telemetric analysis of movement and body temperature, in combination with soil temperature loggers, provided insights into the species' behaviour in the field. These included the fluctuating T_b and control thereof using behavioural thermoregulation. Behaviour plays a central role in the physiological ecology and thermoregulation of ectothermic reptiles and amphibians (Belliure *et al*. 1996). Comparatively little is known about the role of behaviour in these same processes in endothermic mammals (Gordon *et al*. 1986). Small mammals are more susceptible than large mammals to rapid changes in body temperature because of high body surface area to volume ratios, less insulation, and rapid rates of heat exchange with the environment (Schmidt-Nielsen 1997). The thermal environment can influence the time available for foraging in thermally stressful environments and results in trade-offs between energy intake and increased costs of thermoregulation (Gordon *et al*. 1986).

A high thermal conductance, characteristic of golden moles (Bennett & Spinks 1995), results in T_b closely following T_a in many instances (see Fig. 5, for example). Since heat is readily exchanged between golden mole and soil, actively selecting thermally appropriate areas would serve as an energy efficient form of thermoregulation. Although buffered from large scale and rapid temperature fluctuations, the subsurface soil microenvironment varies at a fine scale. This depends largely on the surrounding vegetation structure and soil temperature can vary greatly over the space of a few metres. Changes in the animal's spatial position clearly indicated how favourable microclimatic environments were exploited, especially utilising well-shaded areas during the hottest part of the day (Fig. 6). On four of the six days the animal was recorded moving into shady patches when the soil temperature approached 33°C. Here the animal was able to maintain a constant temperature of 32 -33°C during the hottest period of the day when soil temperatures reached 38°C. Exploiting shaded areas during the heat of the day allowed the animal to circumvent thermal stress without having to employ any energy-requiring physiological mechanisms.

Subterranean mammals inhabit energy-restricted environments. Allowing T_b to follow *T*a during the coolest parts of the day prevented the expenditure of energy to maintain a set T_b. When becoming active or elevating the T_b to T_{act}, passive heating was employed (Fig. 5). The animal thus allowed the heat of the soil to warm it instead of utilising any physiological means such as non-shivering thermogenesis. Conserving habitat structure and thereby the resultant microhabitat would thus be of great importance given the use of behavioural thermoregulation for this species.

Classical studies of torpor often focus on species inhabiting cold and resource restricted environments. In these situations there is typically a large degree of variation between T_a and T_{act}, resulting in deep bouts of torpor. In the present study, T_a only varied between 22.5 and 38°C thereby not pushing the use of torpor to the limits. Body temperature was 27°C at its lowest and all torpor bouts must therefore be described as being shallow in nature. This represents a potentially major energy saving since initial reductions in T_b would save the golden moles more energy than reductions of the same increment at lower T_b (Willis & Brigham 2003). Torpor reduced the energy expended on thermoregulation from 27.77 kJ/day to 17.44 kJ/day, which is a saving of 10.33 kJ/day. Given that a related species of African golden mole, *Ambysomus hottentottus longiceps,* expends on average approximately 100 kJ/day (Scantelbury *et al*., 2005), a conservative estimate of the daily energy expenditure of Julaina's golden mole at half the body mass would be 50 kJ/day. Hence, a reduction of daily energy expenditure by some 10 kJ/day by the use of torpor represents an energy saving of approximately 25%.

Previous observations have intimated that Juliana's golden mole is nocturnal (Skinner & Chimimba 2005). The bimodal activity rhythm occurs at two time points, 11:00 and 21:00. During these periods, 58.33% of the total distance moved occurred during the evening, while the remaining 41.67% occurred during the midday bout. This suggests that more foraging may occur during the night while the earlier peak in activity may involve movement for thermoregulatory reasons. No distinct periods of inactivity emerged and movement was recorded at all hours of the day and night except for midnight.

Temperature is an important cue affecting the activity patterns of several taxa ranging from beetles and lizards to ground squirrels and echidnas (Foa & Bertolucci 2001, Brice *et al*. 2002, Nisimura *et al*. 2005, Váczi *et al*. 2006). During the intensive trapping effort to capture an individual for the telemetry it was noted that when weather conditions were overcast and cool, especially after rain, animals showed highly unpredictable bouts of activity. On such days the soil temperature are far cooler, allowing them to be active within their TNZ. Analysis of the percentage of activity that occurred at specific temperatures (Fig. 8) reveals that 96% of activity occurred at temperatures lower than T_{act}. This provides strong evidence for an adaptable activity pattern based on T_a and it appears that this species, and possibly other golden moles, have no strict activity period. Subsurface foraging during daylight hours on hot, clear days is probably not possible due to the very hot soil temperatures that may easily exceed 40°C (C.R. Jackson pers. obs.). This would necessitate restricting activities to the evenings, nights, and early mornings when T_a does not exceed 33°C. During periods of rain or cooler spells, activity would be possible for most of the day and night. This flexible behaviour was recorded during the 6-day period, as two of the days were cooler with some rainfall.

This insight into daily activity patterns is complemented by recent work by Rathbun and Rathbun (2007) on the activity of the Namib Desert golden mole. Using small radio transmitters glued into the animal's fur, they monitored activity and movement of individual animals at sunrise, midday and sunset. Previous studies had indicated nearly exclusive nocturnal activity (Fielden *et al*. 1992) in the species, yet the authors recorded both nocturnal and diurnal activity. Their study was conducted during the winter of 2005 when even midday soil temperatures falls within their TNZ, thereby permitting diurnal activity. During the summer months, a shift towards a more nocturnal activity pattern could be expected, but ultimately daily climatic conditions would be expected to govern activity.

Soil temperatures during the early morning hours dipped into the low twenties. Animals would most likely either have to expend energy to generate heat or become torpid. Entering torpor is also associated with energetic costs (Song & Geiser 1997). However, if the animal chooses to forage during this period it will generate body heat by tunnelling through the soil as well supplementing its energy reserves with invertebrate prey items that it encounters whilst doing so. It is interesting to note that 77% of activity occurred at or below a T_a of 30°C. After frequently remaining relatively inactive during the later afternoon, the animal initiated activity every evening just before T_a dropped below 31°C. This may be a cue that triggers the onset of activity on warmer days when foraging is restricted to the cooler hours. Ten bouts of activity ranging in duration from three to five hours were recorded. Since the animals appear to be dependent on the ambient conditions, this may be an adaptive strategy used to cope with the unpredictability of when the next foraging bout might take place.

This study shows how behaviour, in addition to shallow torpor, can greatly limit energy expenditure by an animal occupying an energy-restricted and thermally stressful habitat. Aspects of this study on Juliana's golden mole would be expected to be relevant to the majority of the golden mole species due to their physiological and ecological similarities. Recent literature has called for applied behavioural studies to complement and work in conjunction with conservation ecologists (Caro 1998; Sutherland 1998; Gosling & Sutherland 2000; Linklater 2004). Since conservation efforts are urgently required for Juliana's and many other golden mole species, the findings from this study have direct implications for issues such planning should address.

Such considerations would specifically include the importance of a natural and heterogeneous habitat structure. This is required to provide microclimatic gradients used in daily thermoregulation. Canopy cover from trees and shrubs would also keep the soil cooler thereby retaining soil moisture for longer periods. In contrast to absence sites, chapter 2 showed that the presence of Juliana's golden mole at all three populations was recorded in areas with greater tree and shrub layers. In sub-Saharan Africa, 2.3 million hectares of land is deforested annually, primarily for firewood (Reddy & Goldemberg 1990; Dang 1993). Grasslands devoid of trees would have significantly higher soil temperatures and evaporation, making soils far hotter and harder. The homogeneous nature of such a landscape limits the variability and availability of microclimatic gradients. Increased temperatures would limit the periods of activity for the species on a daily basis, while harder soil surfaces would link in with the seasonal activity patterns of this species. Failing to address apparently unimportant aspects such as vegetation structure could have serious consequences for a population's persistence as it directly affects vital elements of the species' biology.

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Chapter 5

Recommendations and Conclusions

“Integration of science, law, and policy too often exists merely as a normative reference in professional journals rather than as a guiding principle of on-the-ground management or a subject of serious research”

- Rohlf & Dobkin 2005 -

Preface

This chapter identifies threats to Juliana’s golden mole and makes recommendations as to how these threats can be minimised. A document of this nature would typically start with a comprehensive introduction to the target organism. To circumvent needless repetition of information within the framework of this thesis please refer to chapter one for the general introduction to the biology and ecology of Juliana’s golden mole. Several biological and ecological insights have been gained during the course of this study. These additions to the general understanding of the species, as well as other introductory topics relevant to this chapter, are presently provided in the introduction. These are important additions since many aspects thereof require consideration in view of successfully conserving the species. These issues are briefly reviewed here since they are thoroughly discussed in the respective chapters. Please refer to the individual chapters for full details.

5.1 PART I – OVERVIEW

5.1.1 Habitat Preferences (Chapter 2)

Little was known about the habitat preferences of Juliana's golden mole prior to this study. The species was described as occurring in sandveld areas, in certain instances with rocky ridges in close proximity (Skinner & Smithers 1990). The patchy distribution within these regions suggests that they are habitat specific and select, at a finer scale, a more refined microenvironment. A study of the habitat focused on soil and vegetation properties.

5.1.1.1 Soils

The distribution of Juliana's golden mole is associated with sandy soils (Skinner & Smithers 1990). The relative proportion of different particle sizes within a soil governs its properties (Brady & Weil 1999). The functional properties of a sandy soil can vary greatly as its constituent particles can range in size from 0.5 – 2mm (Brady & Weil 1999). Juliana's golden mole shows a preference for soils with a predominance of one or two particle sizes. This type of soil is referred to as a poorly graded soil whereas a well graded soil describes a soil that is well represented in several particle size categories. For a poorly graded soil compaction is low due to the limited number of particle sizes required to interlock with the dominant particle size. Suitable habitats with poorly graded soils have a relatively soft substrate and this makes burrowing far easier for these 35g animals. Furthermore, soil moistened by rainfall is more friable than dry soil, creating seasonal variation within regions comprising suitable habitat.

5.1.1.2 Vegetation

Vegetation characteristics are population specific and vary between the three locations. *Terminalia sericea* and *Burkea africana* are tree species that are specifically associated with sandy soils. The presence of large (> 4m) trees of these two species often serve as a good indicator of sandy soil that is potentially suitable for Juliana's golden mole (C.R. Jackson pers. obs.). When comparing vegetation in the presence and absence study plots, occupied habitats were found to have greater cover of tree and shrub layers in comparison to those of unoccupied areas. This would have direct effects on the microenvironment. Soils would remain moist and softer for longer periods in a shaded microclimate. Activity is affected by soil temperature (chapter 4) and lower ambient temperatures would make a greater period of potential activity possible. No plant species was found to have a high indicator value by which the habitat suitability for Juliana's golden mole could be judged.

5.1.2 Distribution (Chapter 3)

Juliana’s golden mole is described form the Bronberg Ridge (BR) in Gauteng, the Nylsvley Nature Reserve (NNR) in Limpopo Province and the south western Kruger National Park (KNP). Given the cryptic nature of these animals, however, the distribution may be far more extensive than presently recorded. A species distribution model (SDM) predicted potentially suitable habitat across the north eastern region of South Africa. Several large areas of potential occurrence were identified, and preliminary ground-truthing has revealed potentially two new populations in addition to a new one (species status unknown) already discovered close to Bronkhorstspruit. Figure 1 shows the potentially suitable habitat highlighted by the SDM. Extensive ground-truthing is required to fully assess the potential occurrence of the species within these regions.

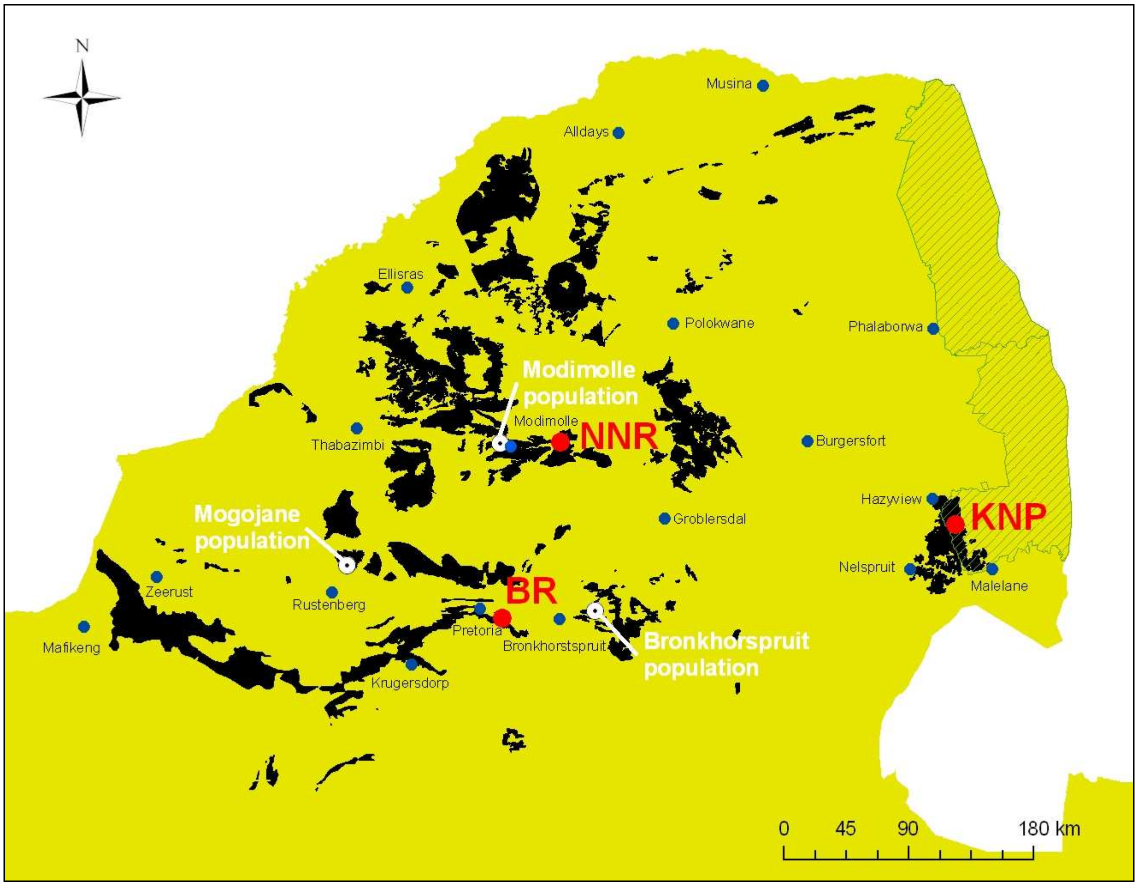

Figure 1. The habitat map produced by the species distribution model is shown in black. The three described populations occurring in the Kruger National Park (KNP), Nylsvley Nature Reserve (NNR) and Bronberg Ridge (BR) are indicated in red, along with the three new or potentially new populations in white. Green-hashed lines designate the boundaries of the KNP.

5.1.3 Body temperature (Chapter 4)

The body temperature of Juliana’s golden mole was found to be low, labile and prone to fluctuate with that of the ambient soil temperature. This phenomenon is common in most subterranean mammals (Bennett & Faulkes 2000). Behavioural thermoregulation is an energy efficient means of thermoregulation often overlooked in laboratory–based physiological studies (Lausen & Barclay 2003). Golden moles have poor thermoregulatory abilities (Bennett & Spinks 1995) and behavioural thermoregulation appears to be an important element of the species' daily activity. Microclimate varies at a very fine scale and moving small distances allows an animal to exploit more favourable microclimatic conditions.

5.1.4 Daily and seasonal activity pattern (Chapter 4)

Juliana's golden mole was previously documented as nocturnal (Skinner & Chimimba 2005). Based on limited data, daily activity appears to be governed by the ambient soil temperature and no specific activity pattern is strictly adhered to. Animals minimise activity at soil temperatures above 31°C, with almost no activity recorded above 33°C. Daily weather conditions largely dictate when subsurface foraging is physiologically feasible. Soil temperatures are far cooler when overcast or during rain and this permits a prolonged potential period for foraging. On hot summer days the soil may only have cooled sufficiently to allow the golden mole activity two hours after sunset. By midmorning soil temperatures once again become too hot for activity. Activity will therefore be restricted to cooler hours after 20:00 and before 10:00.

Fresh subsurface foraging tunnels are not seen during the dry winter months. This visible form of activity has been shown to be highly dependent on rainfall. Rainwater moistens the soil, making it softer and more cohesive for tunnelling. A significant positive correlation was found between soil moisture and soil hardness. Summer rains are also associated with a peak in invertebrate activity. These meiofauna are preyed on near the soil surface during this period. Activity during the dry winter months has not been recorded. It is possible that animals feed lower down in the soil profile and/or store food for these resource-restricted periods.

5.1.5 Movement and Migrations

Golden moles are slow, clumsy and vulnerable above ground (Skinner & Chimimba 2005) and it is unlikely they would travel far. Most golden moles are only encountered above ground when attempting to traverse a physical barrier in the soil (i.e. a road or swimming pool) or during extremely hard rainfall that floods shallow soils (C.R. Jackson pers. obs.). As a result of poor aboveground mobility, dispersal in Juliana's golden mole would in all likelihood occur underground and therefore require suitable sandy habitat.

5.1.6 Predators

Golden moles are prone to predation whilst excavating their shallow foraging tunnels. Natural predators would thus likely include common mammalian species such as jackal (*Canis* *mesomelas*) and caracal (*Felis caracal*). Remains of a Namib golden mole (*Eremitalpa grantii*) was found in an owl scat in the Namib Desert (IUCN 2004) and that of a Juliana's golden mole in an owl scat 25km from NNR (IUCN 2004). Predation by snakes is not documented but is to be expected. Unlike the deeper, more permanent tunnel systems constructed by mole-rats (Bathyergidae), the shallow, temporary nature of the predominant foraging tunnels of the Juliana's golden mole probably limits the predation by snakes. There are several instances of predation by dogs and cats that have been reported in urban environments.

5.1.7 Ecological Role

Juliana's golden mole is primarily a predator of soil dwelling invertebrates (Skinner & Chimimba 2005), but the dynamics of this interaction are not understood although they may be useful in controlling numbers of these invertebrates. Foraging tunnels frequently target the root region of grass clumps and shrubs (C.R. Jackson Pers. obs.), so the role of these animals removing potentially detrimental plant pests cannot be ruled out.

Small mammal perturbation has a variety of impacts on soil properties and processes. Generally, porosity is enhanced resulting in increased water infiltration and evaporation while soil nutrients, litter decomposition rate, mineral concentration, and rates of mineralization tend to increase in small mammal perturbated soils (Whitford & Kay 1999). In addition to the removal of plant feeding invertebrates, golden mole tunnels are likely to increase aeration of the soil, aid nutrient recycling and drainage of rainwater. Bioperturbation also influences vegetation dynamics including structure and composition, seed dispersal and plant distribution (Campos *et al*. 2001). Antelope and other small to medium sized mammals trample old tunnel systems, resulting in shallow depressions (±50mm) from the hooves. During the summer rainfall period these may be repaired, but once the soil starts drying out the decreased golden mole activity results in an accumulation of these small pits. At the end of the dry season this is particularly evident in an intact ecosystem such as NNR. Dry season in the savanna biome is associated with an increased leaf litter layer from trees and shrubs following autumn period. These small depressions could thus potentially assist with decomposition of plant material and the success of seed regeneration since plant seeds would also be deposited in these cavities.

5.2 PART II – CONSERVATION ISSUES

5.2.1 Biology and ecology relevant to threatening processes

5.2.1.1 Dispersal capabilities

Frequently local extinctions occur that can be compensated by colonisation from the greater population (Oborny *et al*. 2005). This depends directly on the target organism's dispersal capabilities. The Juliana's golden mole is small, totally fossorial and has very poor dispersal capabilities. Suitably sandy soils are required for these animals to move from point A to point B. Roads and discontinuous natural habitat present major obstacles to golden mole movement. As a result, populations are easily fragmented resulting in isolated patches of individuals.

5.2.1.2 Population densities

Unlike the many social species of mole-rat (Bathyergidae), all species of golden mole are reported to be solitary (Skinner & Chimimba 2005). In prime habitat, a maximum of two to three Juliana's golden mole may be found per hectare (Bronner 2006). The Bronberg ridge offers pockets of sandy soil immersed in a matrix of unsuitable habitat comprised mostly of sheet rock. The patchiness of the habitat would result in a lower density of animals compared to the NNR and KNP populations and population densities may be half of that which is expected in prime habitat.

5.2.1.3 Body temperature

Golden moles have a high thermal conductance and poor thermoregulatory capabilities (Bennett & Spinks 1995). Their body temperature fluctuates in accordance with that of their surrounding soil microclimate. The transformation of natural vegetation into artificial types has direct effects on soil moisture and temperature, and probably the invertebrate food source. For example, golden moles are frequently encountered in gardens that are well vegetated and watered frequently. Habitat that is transformed into agricultural lands may have little vegetation cover and consequently have higher soil temperatures and evaporation rates compared to the original habitat. The interrelationship of these soil variables may adversely affect the ecophysiology of Juliana's golden moles.

5.2.1.4 Seasonal activity and soil hardness

Very little subsurface foraging appears to take place in the dry months of May to September. Environmental impact assessments aim to establish the status of golden mole presence or absence on a given property so that subsequent management actions may incorporate the ecological requirements of the species. Inspecting areas for signs of golden moles during the dry months may be misleading, as no foraging tunnels may be evident. Suitably experienced persons should carry out such assessments after good rainfall.

5.2.1.5 Climate change

Climate change at global and regional scales is expected to alter the distribution and abundance of several species (McLaughlin *et al*. 2002). General predictions include an increase in temperature and decrease in precipitation (IPCC 2001). The ecophysiological characteristics of the Juliana's golden mole make it prone to temperature and soil moisture fluctuations. Increased soil temperatures combined with lower levels of precipitation would also dehydrate the soil substrate with direct effects on the animal's physiology and potentially its invertebrate prey source. Hard dry soil means the animals cannot successfully create foraging tunnels and an increase in soil temperature would result in the animals having to either be active at temperatures above the preferred thermoneutral zone of 33°C or remain torpid.

5.2.2 Populations and areas under threat

With an estimated loss of more than 80% and a continued population decline (IUCN 2004), the BR population of the Juliana's golden mole is now listed as the third most endangered mammal in South Africa (IUCN 2004). The species occupies less than 10km^2 (IUCN 2004) along the narrow, elongated ridge ecosystem. The ridge is only 816m wide on average (Bosch 2004) and has been exploited by a rapid growth of upmarket housing developments over the past 10 - 20 years. The consequential loss of limited habitat for the golden mole, combined with other associated activities such as roads and pipelines, have created a fragmented patchwork of remaining habitat.

The semi-rural setting in the vicinity of the NNR is thought to limit the immediate threat to the population. The population is described from the reserve, with additional records from outside NNR being very sparse. Suitable sandy soils within the reserve only cover some 800ha and golden moles do not inhabit all of this area. The NNR population is described from a very small area with an assumption that they are more widespread.

The KNP population enjoys the greatest protected area of all three populations, but an additional area of golden mole habitat, approximately 25% the size of the protected area, occurs outside of the western boundary of the Park. Most of this area is now covered by rural settlements and the state of the environment in this neighbouring region is unknown. Within the KNP, roads are the only major concern at present, since they have the potential to act as barriers to golden mole movement.

5.2.3 Specific threats

5.2.3.1 Urbanisation, habitat destruction and fragmentation

The culmination of various threatening processes makes each population, and especially subdivisions thereof, more prone to specific local extinction events. Urbanization is a dominant demographic trend and an important component of global land transformation (Picket *et al*. 2001). In general, habitat destruction is a random process that results in a mosaic of fragmented habitat patches that formerly constituted a single, continuous landscape (Simberloff & Cox 1987; Gonzalez 2000). Destruction of natural landscapes is now thought to have increased the frequency of local extinctions so drastically that these extinctions are now occurring at a rate 100 000 times greater than the background extinction rate (Gonzalez 2000). Modification of natural habitat can cause the death of individuals either directly during the clearing process, or indirectly through the destruction of essential resources (Simberloff & Cox 1987). The remaining population and smaller habitat fragments are likely to be isolated from other fragments and located in a matrix of greatly modified habitat (Saunders *et al*. 1991).

Habitat fragmentation is considered to be one of the principle threats to biodiversity (Noss & Csuti 1997). Large areas of continuous habitat are reduced to several smaller patches with a net loss of viable habitat. Opening up core areas drastically increases edges that expose the population to a varied microclimate, increased levels of predation and invasion by generalist species (Simberloff & Cox 1987). Islands of original habitat remain with an isolated subset of the ecosystem’s biota. Certain faunal groups, for example birds (Soulé *et al*. 1988), are more adept at traversing expanses of inhospitable terrain surrounding suitable habitat patches in the mosaic like landscape. For many species, such as golden moles, even small habitat discontinuities may prove to be a serious hindrance to dispersal and free movement (Bennett 1990).

5.2.3.2 Inbreeding depression and population genetics

Population size within an isolated fragment is of greatest concern as this affects several other factors. If populations remain small and isolated for several generations, they face two genetic threats. Genetic drift results in alleles becoming fixed or lost within the population, and levels of quantitative genetic variation necessary for adaptive evolution erode (Lande 1995). Selection is less effective in small populations so deleterious mutations tend to accumulate. This could eventually lead to a ‘mutational meltdown’ for populations with an effective size (*N*e) of <100 (Keller & Waller 2002). By restricting opportunities for mating, small populations foster inbreeding via mating among relatives. Such inbreeding results in the reduction in fitness, termed inbreeding depression (O’Grady *et al*. 2006). Although any of these genetic mechanisms could threaten population persistence, inbreeding poses the most immediate risk (Keller & Waller 2002; O’Grady *et al*. 2006).

A population harbouring a limited number of individuals, regardless of genetic integrity, is confronted with stochastic processes that could either further reduce the limited number of individuals or kill all remaining individuals (Simberloff & Cox 1987). These stochastic events could be in the form environmental catastrophes such as floods, droughts or wild fires. Diseases, predators and food availability are examples of biotic elements that could have similar effects on the population size.

5.2.3.3 Corridors

Most species, until recently, lived in well-connected habitats but anthropogenic activities have severed natural linkages, resulting in isolated subsets of the original biota. The concept of habitat corridors received a great deal of attention in the literature from the mid-1980s to mid-1990s (for example, Forman & Baudry 1984; Noss & Harris 1986; Simberloff & Cox 1987; Soulé *et al*. 1988; Saunders *et al*. 1991; Vermeulen 1994). Corridors are thought to provide increased movement of biota between isolated habitat patches (Saunders *et al*. 1991). The resultant faunal interchange increases the conservation status of the landscape by firstly reducing the risk of the isolated population from stochastic extinction events, demographic fluctuations or genetic deteriorations. Secondly, should any extinction event occur, re-colonisation is facilitated (Soulé *et al*. 1988; Bennett 1990). Corridors may also have negative effects and might facilitate the spread of disease, pests and fire, increase predation and often have high edge to area ratios (Simberloff & Cox 1987). Edge effects may adversely affect these corridors and may in fact turn into a population sink (Bolger *et al*. 2001).

Two types of corridors can be differentiated (Bolger *et al*. 2001): habitat linkages and movement corridors. A habitat linkage provides all resources required for reproduction and survival by the focal species. A movement corridor on the other hand does not have to support the permanent occupation by the animal but merely allow movement between suitable fragments.

Due to golden moles poor dispersal capabilities and susceptibility to fragmentation, corridors providing linkage between larger regions of habitat may be of importance. This is especially true for the BR population, since the narrow strip of habitat has been highly fragmented. Corridors are sometimes made to sound like artificial additions to the natural landscape when in fact they are the last remaining portions of natural habitat that link two or more sections of habitat.

5.2.3.4 Roads

Few ecologists recognise the “sleeping giant” of road ecology (Forman & Alexander 1998) and the threatening effects of road networks are very real for all three populations of Juliana’s golden mole. Within a given landscape, ecological processes affect and are affected by landscape patterns (Turner 1989). Roads are anthropogenic disturbances that impose distinct patterns on landscapes and influence a wide range of ecological processes (Forman & Alexander 1998; Hawbaker *et al*. 2004; Ramp *et al*. 2006). At the local scale, individual road segments change the physical and chemical environment, thereby causing habitat destruction or alteration, increasing the abundance of invasive species, interrupting hydrologic flows, and presenting barriers to species movements (Forman & Alexander 1998). At the landscape scale, roads cause fragmentation by removing habitat, creating high contrast linear edges, and subdividing otherwise continuous habitat (Miller *et al*. 1996; Hawbaker *et al*. 2004). Development and changes in land use near road corridors often cause further fragmentation (Hawbaker et al. 2004). Furthermore, fatalities occur when vehicles collide with animals (Ramp *et al*. 2006). Road ecology and its applications to planning, conservation, management, design, and policy are great challenges for science and society (Forman & Alexander 1998).

Given the effects of roads, the NNR population is very prone to fragmentation by an extensive road network interlinking the farming community. Many of the broad roads are compacted and often topped with a coarse gravel-like substrate, making them very hard. Moving across these barriers would, most probably, necessitate aboveground movement that may well result in golden moles being preyed upon (owls, snakes, jackals (*Canis mesomelas*), caracals (*Felis caracal*), amongst others, are commonly encountered in this area). Traffic levels are low but animals may be killed by motor vehicles. In 2004 an adult Juliana's golden mole was killed on a small road on a private farm approximately 15km from NNR (F. van der Walt, pers. comm.). The habitat of the BR population has been reduced, surrounded and subdivided by an extensive urban road network. Roads alone have subdivided the narrow strip of habitat into three isolated units with housing exacerbating the situation by further impeding movement between areas. Major long-term effects of fragmentation could include inbreeding depression and localised stochastic extinction events, as discussed above.

5.2.3.5 Noise pollution

Several ecological studies have shown that animals avoid large road areas due to noise. In the Netherlands, for example, bird density is 60% lower near highways with species richness declining with proximity to the road (Reijnen *et al*. 1996). The effect distances were also found to vary with traffic density and road-side habitat properties. Speed limits of 120km/h with high traffic volumes are more detrimental and effect distances are greater in grassland than in wooded areas, for example (Reijnen *et al*. 1995). Many plausible explanations exist for the effects of traffic noise on birds and other animals. Likely hypotheses include hearing loss, increase in stress hormones, altered behaviours, interference with communication during breeding activities, differential sensitivity to different frequencies, and deleterious effects on food supply or other habitat features (Forman & Alexander 1998, and references therein).

Susceptibility to noise pollution differs among species. Songbirds appear to be sensitive to very low noise levels, similar to those in a library study room (Reijnen *et al*. 1996). All golden moles species studied to date (members of the genera *Chrysospalax*, *Eremitalpa*, *Chrysochloris* and *Cryptochloris*) have extremely large ossicles (also referred to as the malleus). When compared to body mass, golden moles have the largest ossicles of all mammals for which data exists (von Mayer et al. 1995; Mason 2001). These ossicles appear to have thus been adapted for the detection of substrate vibrations. The mean mass of this tiny bone in the Namib golden mole (*Eremitalpa granti namibensis*) is 45.1mg but only 27.5 mg in *Homo sapiens* (von Mayer *et al*. 1995) despite the golden mole only weighing about 1/3500th of an average human's mass. This species makes good use of these adaptations to home in on scattered grass clumps dispersed over the desert dunes by detecting vibrations from the grass moving in the wind (Narins *et al*. 1997). Once closer to the clump, it can accurately locate its termite food source using the same specialised ear structures.

The high density of traffic in the Bronberg area may thus further contribute to unfavourable ecological effects for the already critically endangered species. Roads surround the entire ridge with especially high traffic volumes along Lynnwood and Hans Strydom Roads. With hearing that is potentially capable of detecting termites 20m away (Narins *et al*. 1997), it is difficult to attempt to comprehend the effects of blasting on individual animals surrounding the Willow's Quarry open cast mine.

5.2.3.6 Land use

Farming practices in the NNR region could also affect and modify the continuity of suitable habitat. Historically, many of the farms have been used for extensive cattle ranching (Scholes & Walker 1993). This practice tends to alter the tree-grass ratio, often allowing invasive bush species such as the sickle bush (*Dichrostachys cinerea*) to become far more dominant (Bothma 2001). The resultant bush encroachment would not be expected to have direct impacts on the golden mole (but see "*fire regime*" below). Cattle may trample tunnel systems, but this happens in a natural setting to a greater or lesser extent with various types of antelope instead. Other farming practices plough up vast tracts of land and transform them into a monoculture of sorts. Removing native vegetation and replacing it with crop species with differing architecture and phenology alters the radiation balance by increasing the solar radiation reaching the ground surface during the day, changing the albedo, and increasing re-radiation at night (Saunders *et al*. 1991). This would be expected to be far more threatening than bush encroachment since the immediate microenvironment is totally transformed and this would affect soil properties (such as temperature and moisture content) and food availability. Furthermore, farmers make use of insecticides, indiscriminately killing off invertebrate food items, with a potential build up of toxins in the upper soil layer. Ploughing up fields would also kill any animals that happened to be in the path of the plough.

Most urban gardens bordering the Bronberg Ridge are highly transformed and covered with exotic vegetation. Based on personal observations, grassy lawns with well-watered flowerbeds may in fact be beneficial to the species. This would create a favourable microclimate where soils would be moist year round, with an assortment of plant species attracting invertebrates. There are tradeoffs in this regard since many of these family homes have dogs and cats. These are a major cause of mortality and several instances have come to our attention over the past few years. Furthermore, the layout of the property and associated features such as driveways, brick walls around the property's perimeter, swimming pools and buildings often isolate individual animals. Over time the garden will no longer be inhabited since re-colonisation and dispersal are not possible. Although only a splinter of its former size, the ridge is relatively undisturbed in many places. Several alien plant species are found all along the ridge but these species do not hold any apparent threat to the conservation of the Juliana's golden mole in the short-term.

5.2.3.7 Fire regime

The savanna biome of South Africa receives frequent fires and fire is often used as a management tool in rangelands and conservation (Tainton 1999). The response of vegetation to a burn depends on the intensity of the fire and the extent of physical damage, but may also depend on how soil properties have been altered. The few centimetres below the soil surface have a disproportionately larger effect on ecosystem functioning by influencing the rate of infiltration and mineralisation of soil organic matter (Mills & Fey 2004). Frequent fires have been shown to increase rainwater runoff and crusting (Mills & Fey 2004). Soil compaction may be 2.5 times higher in frequently burnt areas (Snyman 2002). Furthermore, soils in these areas contain less organic material resulting in higher soil temperatures and an increased rate of desiccation (Snyman 2002). Crusting occurs due to several biochemical processes manipulated by frequent fires (see Mills & Fey 2004). A crust as thin as 0.1mm can reduce infiltration by a factor of 1800 (McIntrye 1958). In semi-arid and arid regions the decreased infiltration can affect re-sprouting and recruitment of plants (Mills & Fey 2004). This would most likely have a negative effect on Juliana's golden mole. Subsurface foraging will be made difficult and energetically more costly. Invertebrates may not be able to penetrate the surface and this would lead to reduced food availability. The layer can be quite extensive. The photograph in Figure 3 was taken in the experimental burn plots in the Numbi area of KNP (in Mills & Vey 2004). Juliana's golden moles occur in this area and the heavy crust visible in the figure would represent a serious problem to the animals.

Figure 2. A broken soil crust on an experimental plot burnt annually in the southern Kruger National Park. The crust was broken using a geological hammer. Photograph from Mills & Fey (2004).

Vegetative biomass accumulates when vegetation is not burnt for an extended period of time and, upon ignition, this provides an extremely hot fire due to the high fuel load (Tainton 1999; McKenzie *et al*. 2004). This could affect golden moles directly, since shallow soils (such as on the Bronberg) may not provide sufficient shelter from an intense fire. A burnt golden mole specimen in the Skukuza Museum bears testimony to this (C.R. Jackson pers. obs.).

There is a potential for a fuel load accumulation on Bronberg since the vegetation is not grazed and browsed as it would historically have been. Its proximity to human settlement and the illegal squatters that it harbours leads to accidental fires (GDACE 2002). The KNP attempts largely to control when and where fires range within the Park's boundaries. The population of Juliana's golden mole occur in the south western parts of the Park. This region receives the highest rainfall in the Park and the sandy soils are well drained, leaching minerals and nutrients useful to plants. The tall grass (*Hyperthelia dissoluta*), characteristic of these "sour veld" regions (Low & Rebelo 1996), in addition to common species of shrubs and trees such as the silver cluster leaf (*Terminalia sericea*), sickle bush (*Dichrostachys cinerea* subsp. *nyassana*) and several bush willow species (*Combretum spp*), make for a large fire if not regularly burnt. Plant species in these areas are less palatable and more nutrient poor resulting in a lower density and diversity of herbivores. The golden mole habitat in the NNR is very similar to that of the KNP. The full effect of fire on the Juliana's golden mole can only be speculated at this stage but since reserve management largely controls fire-frequency for both the NNR and KNP it is an important consideration for further research.

The KNP has a series of experimental burn plots located in different vegetation types throughout the Park and the effects of different fire regimes have been studied in this ongoing experiment since 1954. Several variations of fire frequency exist with approximately 12 different plots in each experimental “string”. Control plots are also included and in these instances the bush has not been burnt for 50 years. These experimental plots would be ideal for studying habitat selection in relation to fire and vegetation structure, and four different strings are situated in the Pretoriuskop vicinity.

5.2.4 Role of protected areas in the conservation of Juliana’s golden mole

Fragmentation and loss of habitat by roads and other hard infrastructure are the major threat to the fossorial Juliana’s golden mole. Protected areas are extremely valuable for golden mole conservation since they typically attempt to limit the extent of the human disturbance. Large areas of land would facilitate dispersal and re-colonisation. The NNR presently protects only about 800ha of golden mole habitat (about three times that remaining on the Bronberg Ridge). The NNR alone will not suffice as the only refuge for animals in this population, and connectivity among neighbouring private land would need to be investigated. Establishing a conservancy between game farms in the vicinity would be a great advantage for nature conservation in general. The KNP harbours a far larger area and would suitably qualify as a safe haven for this potentially new species or subspecies of golden mole. It is unfortunate that it is no longer possible to create a protected area of any meaningful size along the BR. Land is privately owned and very little of the original ridge remains intact.

5.3 PART III – RECOMMENDATIONS FOR CONSERVATION MANAGEMENT

“Integration of science, law, and policy too often exists merely as a normative reference in professional journals rather than as a guiding principle of on-the-ground management or a subject of serious research” (Rohlf & Dobkin 2005). Successful long-term conservation of the golden moles will need a multifaceted approach, incorporating different organisations and expertise. Many biological and ecological aspects pertaining to the conservation of the Juliana’s golden mole require further investigation. Prior to this study, no empirical ecological data was available for the species. The present study thus had to start with very basic but vital aspects. Future research can build on the foundation that has been set. Based on this study, certain management actions are required to address issues that emerged as important threats.

Unlike elephants and lions, golden moles cannot be reintroduced to areas once they have been lost through development. Nor can individuals be relocated to alternative regions to make way for development. They are too habitat specific. Conservation efforts for Juliana's golden mole essentially need to manage the remaining habitat as carefully as possible. There is no turning back if habitat is degraded or transformed. The following Action Plan lists management and research priorities that directly affect the conservation of Juliana's golden mole. Many of the actions are relevant to all three population but certain issues are population specific.

5.3.1 IUCN status and associated conservation issues

5.3.1.1 IUCN categories and discussion of criteria

The IUCN (World Conservation Union) red list Categories are intended to be an easily understood system for identifying and classifying species at high risk of global extinction (IUCN 2004). Red Data books are widely used internationally to direct conservation attention to species listed within the three categories of threat: vulnerable, endangered and critically endangered (Keller *et al*. 2005). Accurate evaluation of a species' conservation status is consequently important to ensure that it receives adequate conservation attention.

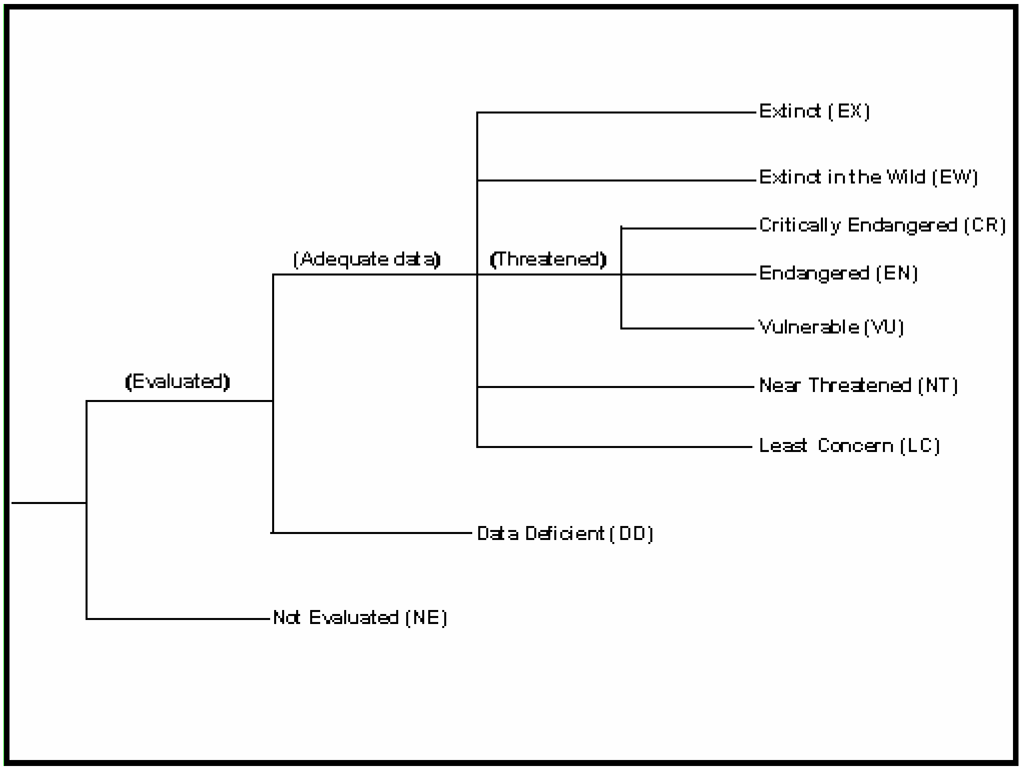

Figure 3. Structure of the IUCN conservation categories used to evaluate a species' expected persistence in the wild.

The latest IUCN red lists are based on a set of criteria (IUCN Categories and Criteria version 3.1 2001) fully evaluating various aspects potentially threatening a particular species or population of a species. A taxon is regarded as Critically Endangered when the best available evidence indicates that it is facing an extremely high risk of extinction in the wild within the foreseeable future. Endangered status is assigned to species considered to be facing a very high risk of extinction, while those facing a high risk of extinction in the wild are classed as Vulnerable.

5.3.1.2 Conservation status

An accurate IUCN-assigned status of threat is of vital importance as this directly affects the conservation attention that a species receives. The IUCN currently lists the BR population as Critically Endangered (A2c, B1ab(i-v)+B2ab(i-v)). This is the highest category of threat that can be assigned to a species and indicates that these animals are facing an extremely high risk of extinction in the immediate future (IUCN 2004). The A2c designation indicates that the population has declined by more than 80% due to habitat loss. The B1ab(i-v)+B2ab(i-v) classification refers to the fact that the population occurs over a severely fragmented area and that a continued decline in suitable habitat and or population size is projected. The NNR and KNP populations are listed as Endangered (IUCN 2004).

Threats to the species, specifically through anthropogenic activities, have been recognised for some time. Freitag and van Jaarsveld (1997) prioritised conservation efforts for mammals in north eastern South Africa and assigned this endemic species the highest possible regional score for the then Transvaal province. Their multifaceted assessment incorporated regional occupancy, relative taxonomic distinctness, endemism and vulnerability to evaluate conservation needs of mammal species within the region (Freitag & van Jaarsveld 1997).

5.3.1.3 Analysis of present species and conservation status listings

There has been much discussion by conservationists as to the level of the taxonomic hierarchy at which efforts to preserve natural diversity should commence (Schreiber *et al.* 1989, Green 2005). This discussion has mainly been elicited by the question of whether to include subspecies in conservation planning or not. The Pretoria population is dealt with separately in the latest IUCN assessment (2004) due the extreme degradation and reduction of the limited area of suitable habitat. When a species is comprised of distinct, geographically isolated populations that are yet not distinct enough to constitute separate species, the term subspecies is employed (Keller *et al*. 2005). No differentiation is made between the three populations despite the fact that morphological and preliminary genetic evidence exists to show that the KNP animals should at least receive subspecies status. The molecular findings also show that, compared to individuals from KNP, Gunnings golden mole (*Neamblysomus gunningi*) is more closely related to the NNR and BR populations. This serves as additional evidence of the genetic divergence of the KNP population and more reason why it should receive separate species status.

A more thorough evaluation of the potential population size, reduction and fragmentation of suitable habitat, and area of occupancy may raise the status of the NNR population from endangered to critically endangered. In 1996 all three populations were listed as critically endangered. A regional assessment in 2002 changed the KNP and NNR to vulnerable (IUCN 2004). The assessors justified the lower status because they believed that these two populations "are protected to some degree by the Kruger National Park and the Nylsvley Nature Reserve" (IUCN 2004). The KNP is more accurately represented in the endangered category, based primarily on the protection it receives from inhabiting the National Park. The narrow belt of habitat along the south western section of the KNP, however, makes this population prone to fragmentation by tar roads. If this population were classified as a separate species in the future, then the conservation status would have to be re-evaluated, as the new species would have an extremely small range.

Since a census of population size is not viable, the condition of golden mole habitat needs to be used as a surrogate measure to estimate population trends. Simply assuming that more golden moles are located in areas surrounding NNR is not sufficient. Aerial photography and/or satellite images should be used to view the extent and position of areas of habitat relative to one another. Figure 4 shows the area adjacent to NNR. The degree of habitat modification and fragmentation is clearly visible. Utilising images will result in objective and more realistic assessments of conservation threat. A revision of IUCN red list status should therefore utilise an updated species classification and recent aerial photographs or satellite images.

Figure 4. Nylsvley Nature Reserve (NNR) is shown by the black line, with the extent of suitable golden mole habitat shown in red (approximately 800ha). The extent of habitat transformation in the greater area is clearly visible when using satellite imagery. Source: Google Earth™.

5.3.2 Ground-truthing of the Species Distribution Model

5.3.2.1 Action 1: Distribution and relative abundance

To successfully conserve golden moles, a thorough understanding of their distribution is required. For example, the NNR population is essentially described from the reserve itself but the surrounding environment has not been surveyed. If a portion of the distribution goes undetected golden moles will go unprotected. When they are eventually detected it may well be too late and any conservation actions may then be practically impossible due to habitat loss and fragmentation.

After gaining a better understanding of species habitat requirements, predictive modelling can be utilised to highlight potential species distribution. This reduces the area that requires field visits thereby saving time and money. The SDM built in Chapter 3 can now be thoroughly evaluated in an attempt to map known population distribution, and find new populations. Intra-population genetic diversity is an important consideration for long-term conservation of the species. A good understanding of the species distribution will facilitate an insight into habitat fragmentation and potential isolation of animals based on regional land use patterns.

Ground-truthing of the SDM should also attempt to make use of local knowledge wherever possible. People living and working in rural or farming communities often spend large periods of time in the field. Using photographs of the foraging tunnels and the golden mole may be useful to make use of the local knowledge, especially if language is a barrier to efficient communication.

5.3.3 Population Monitoring

5.3.3.1 Monitor population trends

Effective means to recognise and assess the conservation status of endangered species is vital for conservation management (Green 2005, Staples *et al*. 2005, Joseph *et al*. 2006). Conservation status is usually evaluated by assessing the population size and geographic distribution of the organism, but this alone may not provide sufficient information on the risk of extinction. Assessments need to be scientifically sound, consistent and defensible (Green 2005). Protection of threatened taxa invariably depends on their conservation status, making accurate evaluation thereof vital (Staples *et al*. 2005). Time series data, often incorporating ecological variables possibly driving the trend, are a preferred method for evaluating threat (Abrams 2002).

Many sophisticated methods are available to study and quantify the abundance of specific animal species (e.g. mark-recapture studies) but these vary in suitability depending on the biology and ecology of the species of concern (Pollock 2006). Selecting an appropriate monitoring technique for conservation purposes is an important consideration. Decisions must often be taken whether to monitor trends in population size with abundance estimates or simply track changes in occupancy or distribution using presence-absence surveys (Joseph *et al*. 2006). Selecting one of these two methods depends on how abundant, widespread and detectable the target species is, as well as the resources available to implement the program. For the purposes of monitoring population fluctuations of the cryptic Juliana’s golden mole, a presence-absence survey method is proposed. Presence-absence survey methods have received criticism in the literature, largely because they are often not amenable to standard statistical tests (Pollock 2006). Recent evaluations have, shown the efficiency of this cost effective technique for monitoring species that are difficult to detect and occur over large areas (Joseph *et al*. 2006, Pollock 2006). Furthermore, results can be accurate enough to assign IUCN red list categories to the threatened species (Joseph *et al*. 2006).

A successful monitoring program firstly depends on the distribution being well mapped out, as stated in Action 6.2. This will allow permanent monitoring points to be identified at regular intervals throughout the population. The size of the spatial distribution and continuity of habitat will determine the number and distance between monitoring points. For example, along the Bronberg Ridge the intervals between monitoring points will be small compared to those employed in the far more extensive KNP population.

Many of the IUCN criteria used to assign a specific degree of threat to a taxon are based on either total population size (i.e. Rule A2b) or area of occupancy and or extent of occurrence (i.e. Rule A2c). Fossorial habits prevent counting individual golden moles. The state of the habitat occupied by golden moles is thus used to evaluate how threatened a species or population might be. The pattern of population trends at different points within a geographic distribution are important to identify potential regions that may function as a population “source” or “sink” (see Pulliam 1988). Strategic positioning of monitoring stations throughout a population is consequently of vital importance.

Monitoring points will need to target both central and peripheral regions of a population. This will help to identify where (and consequently why) the population is declining. Monitoring solely in the core of a population may well overlook population declines towards the peripheries. When assessing trends it may also be useful to distinguish between these two zones, as monitoring in larger populations would have several points towards the core of the distribution and if data from all monitoring points are pooled for analysis trends in the peripheral regions may become obscured.

When monitoring stations are established, they should be placed in area where golden mole activity is apparent. This exercise will therefore need to be conducted after good summer rainfall. A belt transect could be employed whereby a fixed distance, for example 100m, is walked between two GPS points. Each transect could be divided into ten metre blocks, extending 5m to either side of the transect (Fig. 5). A 100m transect will thus consist of ten 10 x 10m quadrats. Based on experience from monitoring seasonal activity over six months on the BR using 5 x 5m quadrats, ten 10 x 10m quadrats will be of a suitable size to detect the presence localised activity. Presence or absence of foraging tunnels can then be recorded in each of the sampling blocks. This would not facilitate the estimation of population size, but will detect any area-specific decreases in population numbers, as well as overall population trends.

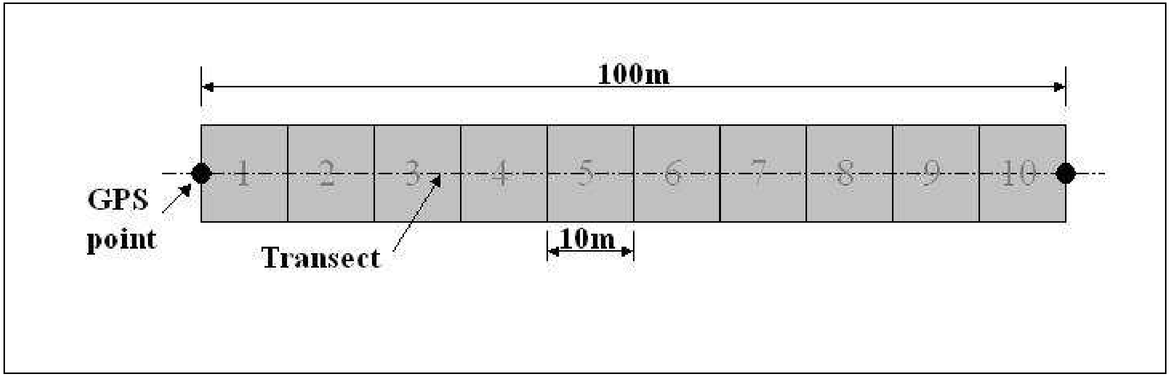

Figure 5. The design of proposed transects that would be used to monitor trends in Juliana's golden mole populations.

The greatest costs involved with this monitoring system would be the vehicle and fuel costs used to access the designated transects. A very important and positive aspect to this technique is the limited time required per transect. Golden mole activity is difficult to detect and they would not be expected to be active in exactly the same quadrat year after year, even if the population numbers are stable. The limited time required per transect allows several to be established. The greater the number of transects the more accurate estimates of population trends would be, since a large sample size would not be affected by chance events in the same way that a small sample size would be. Populations dispersed over a small geographical area, such as the BR, can be sampled more intensively than larger populations such as KNP. For the BR, where there is approximately 250ha of habitat remaining, one transect per five hectares (i.e. 50 in total) would be both feasible and produce enough independent observations from which trends could be monitored. Within NNR that has approximately 800ha of potentially suitable habitat, one transect per ten hectares (i.e. 80 in total) would prove useful while in the KNP and even lower density would be required. These figures are based on personal acquaintance with the study areas and a pilot study determining the exact number of transects and quadrats per transect would be of great value to the success of a monitoring programme.

Since the foraging tunnels are seasonal in nature, the monitoring of populations should ideally be conducted towards the end of the summer rainfall period. February or March would typically be the best time but this will vary slightly between years. Additionally, sampling must not be undertaken soon after heavy rain, as this will eliminate most of the signs of activity. Rainfall events four weeks prior to monitoring should be recorded and presented along with the activity count. This may be useful and necessary to explain particularly high or low counts. Since rainfall can vary at a fine scale, measurements should be recorded from the closest and most relevant weather station.

An additional means of collecting distribution data could be employed within the KNP. Field rangers patrol the bush on a daily basis and make use of GPS units with CyberTracker software. This programme allows the rangers to record observations, including animal species, veld condition and poaching activity, which are later downloaded and stored in a computer database. Species-specific icons are pre-programmed into the software and these are then clicked on to record the presence, location and number of specific taxa. Rangers could record the presence of golden mole tunnels whenever encountered with the simple addition of a golden mole icon to the software package. The staff, resources and infrastructure are already in place; the golden mole must simply be given equal conservation attention. Rangers patrol all reaches of the Park and data collected in this way would prove invaluable in mapping the population’s distribution. Although survey effort will not be the same from year to year, and different areas would be covered, collecting data in this way would be very useful in mapping the species distribution within the KNP.

5.3.4 Further research requirements

5.3.4.1 Biology

Knowledge on the general biology of Juliana’s golden mole is very poor. It is not sufficient to merely preserve habitat in an attempt to conserve Juliana’s golden mole. More information on the species’ diet, social structure, reproduction and activity during winter is required. Fossorial habits render the acquisition of such information incredibly difficult. Innovative techniques will, in many instances, need to be devised if such information is to be revealed. Difficulties associated with trapping the animals will also need to be overcome to facilitate the capture and study of these animals. A greater understanding of the animal’s biology, specifically lifespan and fecundity, will facilitate other conservation evaluations, such as minimum viable population (MVP) estimates.

5.3.4.2 Assess threats imposed by land use

Each population is surrounded, to varying degrees, by a mosaic of land uses. The effect of each on the existence of Juliana’s golden mole would be expected to vary greatly. Certain farming practices, such as cattle farming, may not adversely affect the species. Monocultures would most likely be incompatible. Understanding the effects of the various land uses adjacent to the existing populations would be important. This information would be especially important when re-evaluating the species’ IUCN threatened status. An improved knowledge of the effects of fire on the ecosystem would also be beneficial. This would include its effect on vegetation, soil, invertebrates and the golden mole directly. Experiments would need to be conducted to establish just how a great a barrier to movement asphalt and dirt roads are. Land use on the BR would need to include the predation threat imposed by dogs and cats as well as the pitfall-trap effect of swimming pools.

5.3.4.3 Resolve taxonomy

There is strong evidence suggesting that the KNP population is in fact a separate species. This needs to be clarified urgently. If indeed listed separately, Juliana's golden mole will only occur along the Bronberg Ridge and in the vicinity of NNR. The BR population is restricted to approximately 250ha, while 800ha of habitat occurs within the NNR. More suitable habitat is located outside of the NNR, but farming has drastically reduced the remaining area of viable habitat. The amount of suitable habitat identified by the SDM that is linked to and includes the NNR is approximately 25km^2. Much of this area is no longer in its natural condition and has been rendered as unsuitable habitat.

5.3.5 Legislation and conservation

5.3.5.1 Environmental Impact Assessments

In addition to national legislation in South Africa, legislation affording sensitive ecosystems and endangered organisms protection varies regionally according to provincial regulations. One of the most progressive organisations in this regard is the Gauteng Directorate of Nature Conservation, within the Gauteng Department of Agriculture, Conservation and Environment (GDACE). The three isolated populations of Juliana's golden mole occur in three separate provinces in South Africa. Of these, only GDACE has implemented significant measures in an attempt to curb further population decline.

Two policies offer the population on Bronberg Ridge some level of protection. The first is the Ridge Policy of 2001. Due to the sensitive nature and unique ecosystems associated with ridges, it was realised that development along these geological features needed to be controlled (Pfab 2001). Since Juliana's golden mole is restricted to the Bronberg Ridge in Gauteng, conservation of the narrow ridge is of vital importance to the population. This policy has, to some degree, limited the development of the ridge.

Additionally, the province provides special conservation attention to red data species. As a result, any development within the Bronberg Ridge region requires an EIA by a "specialist" whose task it is to evaluate the habitat suitability for, and the potential occurrence of the Juliana's golden mole. The purpose of a "specialist assessment" is defeated when people with no experience of the species' biology, ecology and habitat preferences are allowed to make recommendations regarding developments that potentially threaten the golden mole. Poor judgements and recommendations may result, thereby defeating the purpose of the EIA process. Many environmental consulting companies choose to do the specialist assessment using their own staff instead of sub-contracting specialists to do the evaluation. This is an ongoing practice in Gauteng, especially amongst the smaller consulting companies (C.R. Jackson pers. obs.).

Certain developments, despite recommendations to the contrary, still proceed. Poorly conducted EIAs, as well as the failure to enforce Record of Decision (RoD) conditions, defeat the purpose of such assessments and seriously compromise the conservation of the species.

Despite being established with good intentions and as a means to conserve the golden mole, the EIA process in its present form will not successfully conserve Juliana's golden mole on the Bronberg Ridge from extinction. Given the high level of urban development in the region, threats entail far more than future development on the ridge. A comprehensive conservation management plan, now commissioned in 2006, is long overdue. Long-term planning, in addition to implementing other measures in the interim, is vital for conservation given the ridge's limited area and urban setting.

Limpopo Parks and Tourism need to become aware of the serious conservation status of the NNR population. Presently the species receives no specific conservation attention. The mandatory use of an EIA process for all sensitive areas would be especially useful. Reports submitted to the Provincial Department would then enable the Department to control the nature of developments where necessary.

5.3.5.2 Economic Implications of Conservation

Successful conservation of the Bronberg population of Juliana's golden mole would have major economic implications. The majority of the land is privately owned yet land use and connectivity would need to be strictly regulated along the ridge to ensure long-term gene flow. There is little hope of conserving this population in the long-term if the existing development and fragmentation processes are allowed to continue. There is typically a stark contrast between conservation requirements and landowners' economic priorities, making these two approaches to land use incompatible. Developing vacant land into real estate is extremely profitable for landowners but this practice destroys and fragments the small remaining sections of golden mole habitat.

In comparison to the BR, the NNR is located in a far more rural setting with less direct pressure from housing. Only a very small part of the NNR serves as suitable golden mole habitat and protecting suitable habitat in neighbouring areas is vital. Land use on the surrounding farms, such as various types of monocultures, are not necessarily compatible with golden mole habitat requirements and would need to be regulated. This would have direct financial implications for either farmer or conservation department since the farmers earn an income from the land.

Economic implications for conserving the KNP population could potentially include limiting tourism activities within the region of suitable habitat adjoining the Parks south western boundary. This would specifically include the controlled development of new rest camps and the associated road networks

5.3.6 National Working Group

5.3.6.1 Co-ordinate & Manage the Action Plan process

At a national scale, no organisation is actively monitoring and co-ordinating conservation initiatives for golden moles. A committee specifically addressing these issues for all the Chrysochlorids would be of great value. The group’s major role would be to actively drive research and conservation of golden moles in southern Africa. This group could make contact with different provincial conservation departments and make recommendations for species occurring within respective provinces. This would include mapping distributions and monitoring trends in habitat quality and population size. A national committee would also have the capacity to establish and manage a database of distribution records.

5.4 PART IV – CONCLUSION

Juliana’s golden mole is habitat specific and extremely cryptic with poor dispersal capabilities that makes it particularly sensitive to habitat fragmentation. The lack of long-term conservation planning for the species needs to be rectified urgently. Conservation management would need to fully describe the distribution of the species as this knowledge is required for habitat protection. A poor understanding of biological aspects such as lifespan, fecundity and reproduction limits the evaluation of extinction risks and should receive research attention in the near future. Since much of the original habitat has been transformed, the effects of the various land uses within these regions needs to be assessed. The taxonomic distinctness of each population needs to clarified after which the IUCN conservation status of the species needs to be re-evaluated. This assessment should also make use of the national land cover map to accurately document the amount and connectivity of remaining habitat. The IUCN conservation status has direct effects on conservation attention the species may receive and an accurate assessment is thus of vital importance.

The red list criteria also make use of population trends and monitoring of each population is of vital importance to detect changes. Environmental impact assessments should be conducted for any change in land use within the vicinity of any population and must be carried out by suitably experienced persons. A national golden mole conservation committee, whose task it would be to create awareness and prioritise research and conservation activities for Chrysochlorids, would be extremely beneficial given the lack of knowledge and attention currently received by the group. Without well-coordinated conservation planning the fate of Juliana's golden mole, as well as the many other endangered golden mole species, remains uncertain.

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