SEASONAL OCCURRENCE OF FLEAS AND OTHER ECTOPARASITES ON SMALL MAMMALS AT WATERBERG PLATEAU PARK, NAMIBIA

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ABSTRACT

Fleas and other ectoparasites infesting small mammals were studied from December 2005 to June 2006 at Waterberg Plateau Park, Namibia. The main aim of this study was to investigate seasonal occurrence of fleas and other ectoparasites on small mammals at selected sites at Waterberg Plateau Park. Small mammals were live-trapped, marked and released. Ectoparasites were collected (by brushing) from these small mammals before they were marked and released. Fleas, ticks and lice were stored in 70% ethyl alcohol, whereas mites were stored in Oudeman's fluid before being processed and prepared for identification purposes.

A total of one hundred and seventy nine (179) small mammals belonging to 11 rodent species (*Aethomys namaquensis, Aethomys chrysophilus, Dendromus melanotis, Graphiurus murinus, Gerbirullus paeba, Gerbirullus vallinus, Mus indutus, Mastomys* spp., *Saccostomus campestris, Tatera leucogaster* & *Thallomys nigricauda*) and 1 shrew (*Crocidura hirta*) were captured and examined. A total of one hundred and fourteen (114) fleas belonging to eight (8) species (*Listropsylla aricinae, Listropsylla dorippae, Pulex irritans, Xenopsylla brasiliensis, Xenopsylla cheopis, Xenopsylla nubica, Xenopsylla philoxera* & *Xenopsylla versuta*) and fifteen (15) ixodid ticks belonging to three (3) species (*Haemaphysalis elliptica, Hyaloma truncatum* & *Rhipicephalus neummani*) were recovered. Additionally, three lice (3) and four hundred & sixty nine (468) mites were recovered but could not be identified. During the present study, a larva belonging to a tick species *R. neumanni* was collected for the first time from the wild. Again, a nymph of *R. neumanni* was recorded for only the second time in the wild in whole of Southern Africa. Generally,

prevalence, intensity of infestation, and species diversity of ectoparasites varied among the 5 months, host species and between host sexes. Prevalence, intensity of infestation, and species diversity of ectoparasites was generally higher in December and lower in March; higher in *T. leucogaster* than *Mastomys* spp. & *G. paeba* and no ectoparasites were collected from *C. hirta*, *G. murinus*, *G. vallinus* and *S. campestris*. There was no significant difference in prevalence, intensity of infestation and species diversity of ectoparasites (except in prevalence of mites) between female and male hosts, fleas (prevalence: U=8.0, P=0.347; intensity: U=11.0, P=0.754; species diversity (H'): U=11.0, P=0.754); ticks (prevalence: U=9.0, P=0.465; intensity: U=11.0, P=0.735; species diversity (H'): U=7.5, P=0.296); mites (prevalence: U=2.0, P=0.028; intensity: U=9.0, P=0.465). However, fleas showed evidence of seasonality in the prevalence of infestation (H=5.58, df=4, P<0.001).

DEDICATION

This paper is dedicated to my father, Mr. Joel Uusiku and my mother, Mrs. Aina. N. Uusiku who raised me up, supported me in the best way they could, encouraged and shaped my life in the way I am today. If they were not there for me, I could not be able to produce this paper today. May the Lord always bless them.

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DECLARATION

This is a thesis prepared in partial fulfilment of the requirement for the degree of Master of Science in Biodiversity Management and Research at the University of Namibia in Windhoek, Namibia. This thesis is the original work of the author and it has not been submitted for a degree elsewhere. The views and opinions stated therein are those of the author and not necessarily those of the institution.

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ACRONYMS AND ABBREVIATIONS

A. chrysophilus:	*Aethomys chrysophilus*
A. namaquensis:	*Aethomys namaquensis*
Apr'06:	April 2006
C. hirta:	*Crocidura hirta*
DAAD:	The Deutscher Akademischer Austansch Dienst
D. melanotis:	*Dendromus melanotis*
Dec'05:	December 2005
G. murinus:	*Graphiurus murinus*
G. paeba:	*Gerbillurus paeba*
G. vallinus:	*Gerbillurus vallinus*
H. elliptica:	*Haemaphysalis elliptica*
H. truncatum:	*Hyalomma truncatum*
Jun'06:	June 2006
L. aricinae:	*Listropsylla aricinae*
L. dorripae:	*Listropsylla dorripae*
M. indutus:	*Mus indutus*
Mar'06:	March 2006
Mastomys spp.*:*	*Mastomys* species
May'06:	May 2006
MET :	Ministry of Environment and Tourism
NMS :	Namibia Meteorological Services
P. irritans:	*Pulex irritans*

R. neumanni:	*Rhipicephalus neumanni*
S. campestris:	*Saccostomus campestris*
T. leucogaster:	*Tatera leucogaster*
T. nigricauda:	*Thallomys nigricauda*
UNAM:	University of Namibia
UNESCO:	United Nation Educational, Scientific and Cultural Organization
WPP:	Waterberg Plateau Park
X. brasiliensis:	*Xenopsylla brasiliensis*
X. cheopis:	*Xenopsylla cheopis*
X. nubica	*Xenopsylla nubica*
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CHAPTER 1 INTRODUCTION

Ectoparasites are diverse and highly adapted group of invertebrates that inhabit the external body surface of vertebrates. They may live permanently on their host, or they may occupy the host's nest and immediate environment, and visit the body of the host periodically (Kennedy & Newman, 1986). In either case, there is a close dependency on the host for various life-sustaining resources. The relationship between parasites and hosts is an ancient one, and the mechanisms by which parasites seek, identify and maintain contacts with their hosts are sophisticated and complex (Kennedy & Newman, 1986).

Ectoparasites are extremely well adapted to their way of life and almost any free-living wild animal is permanently infested with a variety of species (Blackmore & Owen, 1968). Some infestations, particularly of blood sucking parasites, tend to be seasonal in their incidence. The type and numbers found depend on a variety of factors, the most important of which are the species of the animal concerned, its' geographical distribution and its general state of health (Blackmore & Owen, 1968).

The majority of mammalian ectoparasites belong to the classes Arachnida and Insecta. The former class contains mites (Acarina: Mesostigmata & Astigmata) and ticks (Acarina: Ixodidae & Argasidae), while the latter contains fleas (Siphonaptera), lice (Phthiraptera: Mallophaga & Anoplura) and parasitic flies (Diptera: Hippoboscidae, Streblidae, Cuterebridae, Gasterophilidae, Hypodermatidae, and Oestridae).

Approximately 2,000 species and subspecies of Siphonaptera (fleas) grouped into about 7 families have been described world wide and the total number of species is estimated to be near 3,000 (Knapp & Scheibner, 1985. In the Southern African sub-continent, Segerman (1995) reported that there are 34 genera representing approximately 110 flea species. Adult fleas are small (2-3mm long), wingless insects highly modified for ectoparasitic life. There are 825 described species of ticks in the world whereas in Africa there are 48 described species (Walker *et al*., 2003). More than 30,000 species of Acarina (ticks & mites) have been described and it has been estimated that perhaps half a million are still undescribed (Borror *et al*., 1989; Miller & Harley, 1992). Over 3,000 species of Phthiraptera (lice) have been described worldwide (Borror *et al*., 1989) and the average length of adults is 2 mm.

The actual significance of any disease of any free-living wild animals is usually considered from one of two basic points of view: firstly, the effect of the disease on the animal itself and the resultant ecological implications and secondly, from the relationship of the disease in the wild species and its infectivity for man or his domesticated animals (Borror *et al*., 1989).

Although ectoparasitism of the skin and gills of fish by *Gylodactylus elegans* (Va Duijn, 1956; Blackmore & Owen, 1968) and heavy infestation of young birds with blood-sucking arthropods can cause death, ectoparasites are seldom a primary or sole cause of death (Blackmore & Owen, 1968). Their pathological significance is therefore more often associated with their capability to act as vectors of other microbial or parasitic diseases, obvious examples being the mosquito as a vector of

malaria, yellow fever and many other diseases, tsetse flies transmitting trypanosomiasis, the rat flea (*Xenopsylla cheopis*) as a vector of bubonic plague and the rabbit flea (*Spilopsyllus cuniculi*) as one of the vectors of myxomatosis.

The potential and need for study of ectoparasites in Namibia are as diverse as the fauna themselves. There is a rich mammal fauna which are reasonably well known, inhabiting a range of widely different habitats and geographic regions. Some of these host species are threatened or endangered where they are currently found in Namibia, and if they disappear there is a good chance that many species of parasites will suffer the same fate. Some ectoparasites are vectors of important human and wildlife diseases such as Plague, or create undesirable dermal immune responses e.g. chigger mite and scabies (Kennedy & Newman, 1986). Ectoparasites have the potential to affect the health and general well-being of wildlife and domestic animal populations, and they may seriously restrict habitat and land resource use because of stress and reduced performance of animals living in a particular habitat. Development and use of land designated for recreational activities may also be affected by the threat of infestation of people and their companion animals by undesirable ectoparasites.

As it would be impossible to attempt to cover the complete subject of ectoparasites of small mammals in the time available, it has been decided to consider only the ectoparasites of Waterberg Plateau Park. Waterberg Plateau Park is regarded as a unique place similar to an island due to its topography, geology and vegetation types of Kalahari dry savannah. Due to the uniqueness of the Waterberg Plateau Park, the mammal fauna in terms of species richness at this place may be different from the

surrounding habitats because of different vegetations, climate and precipitation. Therefore, a unique and diverse ectoparasite fauna is expected. In addition to ectoparasites as vectors of diseases, ectoparasites are important tools in systematics and they can be used to explain the animal fauna at Waterberg Plateau Park.

1.1 Literature review

1.1.1 Fleas

Fleas belong to Order Siphonaptera, which include wingless insects with siphon like mouthparts. On the basis of evolution, it is currently thought that the fleas are closely related to the true flies in the Order Diptera (Knapp & Scheibner, 1985). Fleas are ectoparasites of mammals and birds. About six percent of the flea species known worldwide parasitize birds and the rest are found on mammals (Marshall, 1981; Knapp & Scheibner, 1985), of which most are found in Eurasia (Medvedev, 1989). Among the mammals, rodents are by far the most common hosts with 74% of all known species of fleas (Makundi & Kilonzo, 1994). Fleas rely on animal blood for nutrients and minerals that are essential for their development and reproduction (Eiseb, 2002). In the process of feeding the adult fleas may transmit bacterial, viral, protozoa and other disease to the host (Groepe, 1993).

1.1.2 General morphology of fleas

Adult fleas are small (2-3mm long), wingless insects highly modified for ectoparasitic life. The body is sclerotized, compressed laterally, and armed with numerous bristles and spines arranged in comb like structures (ctenidia) that are present on the head, thorax or in both locations (Knapp & Scheibner, 1985). Most fleas have long legs adapted for jumping, and the legs terminate in a pair of strong claws used for clinging to the host. The head is relatively immobile; eyes may or may not be present depending upon the species. The antennae are short, knobbed and hidden in grooves behind the eyes. Both sexes possess piercing-sucking mouthparts used for obtaining blood meals from the host (Knapp & Scheibner, 1985).

1.1.3 General life cycle of fleas

Fleas mate on the host animal and in most species the female mates only once. Sperm is stored in a spermatheca from which it is drawn as needed during egg laying. A blood meal is prerequisite to production of viable eggs in fleas. Eggs are deposited on the host itself, or in proximate areas and eggs generally detach and fall to the host's bedding or resting area (Knapp & Scheibner, 1985). Although only a few eggs are deposited at a time, as many as 500 may be produced during the female's adult lifespan. A female *Pulex irritans* lay over 400 eggs in her lifetime. Fleas go through a complete metamorphosis during development and are parasites only when adult (Scientific and Industrial Research Organisation: Division of Entomology, 1979).

The incubation period of eggs varies from about 2 to 12 days. Temperatures between 18ºC and 27ºC and relative humidity of 60% to 70% or greater produce conditions amenable to oviposition (Knapp & Scheibner, 1985). Larvae feed on cast exoskeletons and faeces of adult fleas where they obtain their iron (Howard, 1984). At least three instars generally occur during the 1-4 week larval period of most species. Developmental time is influenced by ambient temperature and food availability. Relative humidity of 60% to 80% is required for good larval survival (Knapp & Scheibner, 1985).

1.1.4 Flea-host association

Most larval fleas live mostly in the host's home, while adult fleas vary in their pattern of host associations, from those visiting the host to feed to those that are found permanently upon the host's body (Eiseb, 2002). Chigoe fleas of the genus *Tunga* (Tungidae) which burrow subdermally between the toes and under the toenails are fairly site specific (Marshall, 1981; Smith, 1973). The sticktight flea *Echidnophaga gallinacean* (Pulicidae) is highly host specific and it attaches on the head region of the host body (Hopkins and Rothschild, 1953). However, *Ctenocephalides felis* (Pulicidae) and *Lagaropsylla turba* (Ischnopsyllidae) are found throughout the host pelage (Eiseb, 2002).

Adult fleas are negatively phototatactic and respond to warmth. Host finding in some species e.g. *Ceratophyllus gallinae* have been shown to respond to light and gravity (Howard, 1984). Fleas are attracted by the shadow cast of a potential host and can

locate hosts by visual and thermal cues. Fleas are sensitive to wavelengths between 510 and 550 nm and insensitive to wavelengths between 650 and 700 nm (Price, 1984). Adult fleas are long-lived and may live a year or more; they are able to survive several weeks off the hosts without feeding (Borror & De Long, 1964)

1.1.5 Fleas and diseases

A number of diseases that include Murine typhus and plague are spread or transmitted by fleas. Cat and dog fleas of the genus *Ctenocephalides* act as a vector of the tape worm *Dipylidium caninum* among mostly domestic animals (Walker, 1994).

Murine typhus is a rickettsial disease transmitted to human by fleas (Goddard, 1998). According to Azad *et al.* (1997), Murine typhus is one of the most widely distributed arthropod borne infection endemic to many coastal areas and ports throughout the world. Its outbreaks have been reported from Australia, China, Greece, Israel, Kuwait and Thailand (Azad, 1990). *Murine typhus* is a mild, febrile illness resulting from infections with *Rickettsia typhi*, a small gram-negative, obligate intracellular bacterium (Weiss, 1982). According to Traub *et al.* (1978), Murine typhus is usually transmitted to humans by the contamination of the bite site or skin abrasions with *Rickettsia*-containing flea faeces. Murine typhus is a zoonosis maintained in nature through a cycle involving mainly commensal rodents and their ectoparasites (Eiseb, 2002). The classical transmission cycle for *Murine typhus* is rat-flea-rat and accidentally rat-flea-man (Azad, 1990). The most important components of the

Murine typhus life cycle are commensal rats of the subgenus *Rattus* (*R. rattus* and *R. norvegicus*) and their fleas, especially the oriental rat flea *Xenopsylla cheopis* (Azad, 1990).

Plague is a highly infectious disease caused by a small gram-negative bacillus *Yersinia pestis* (Eiseb, 2002). In Namibia, plague was first noticed in the northern part of the country in 1931 (Groepe, 1993). This outbreak started in Northern Cape Province of South Africa and crossed into the central regions of Namibia from which it moved gradually to the northern areas where it became stabilized (Shangula, 1998). According to Shangula (1998), plague disease maintained foci in two districts, namely Engela and Onandjokwe in northwest Namibia, covering an area of 2000km^2. Shangula (1998) further reported that transmission is believed to be through flea bites or through the ingestion of infested animal tissue as mouse meat was considered a delicacy in this area. The number of plague cases recorded in Namibia between 1983 and 1997 are as follow: cases (3316), confirmed (645), deaths (128) with an average case-fatality rate of 3.86 (Shangula, 1998). According to Eiseb (2002), most laboratories confirmed cases occurred in the 9-10 years age group, followed by the 0-9 year age group.

1.1.6 Mites and ticks

Mites and ticks are arachnids and they are ectoparasites that belong to Order Acari (Borror *et. al.*, 1989). According to Miller & Harley (1992) and Borror *et. al.* (1989), more than 30,000 species have been described and it has been estimated that perhaps

half a million more are still undescribed. Acari occur in practically all habitats in which animals are found and rival the insects in their variations in habits and life histories. Acari are more abundant in soil and organic debris. Many are parasitic, at least during part of their life cycle, and both vertebrates and invertebrates serve as hosts. Most of the parasitic forms are external parasites of their hosts Borror *et. al.,* (1989).

Many of the Acari free living forms are predacious, some are scavengers, some of the parasitic forms are pests of humans and animals, causing damage by their feeding and sometimes serving as vectors of diseases (Borror *et. al.,* 1989). The Order Acari is divided into two suborders, Mesostigmata (mites) and Ixodida (ticks). Mesostigmata is a largest suborder of the parasitiformes and includes predacious, scavenging and parasitic forms. The parasitic mites in this group attack birds; bats, small mammals, snakes, insects and rarely humans, but the chicken mite *Dermanyssus gallinae* (De Geer) can cause dermatitis in man. Two families of Ixodida occur in the world and in Namibia as well, the Ixodidae (hard ticks) and the Argasidae (soft ticks). Ticks are larger than most other Acari and are parasitic, feeding on the blood of mammals, birds and reptiles. Those attacking man are annoying pests and some species serve as disease vectors (Borror *et. al.,* 1989).

1.1.7 General morphology of ticks

As members of the subphylum Chelicerata, ticks have chelicerae as the primary mouthpart structure (Teel, 1985). The major body region of a tick is fused and the

abdomen lacks the apparent segmentation. The tick body plan includes two main regions: the anterior mouthparts (capitulum or gnathosoma) and the general body region that bears the legs and unsegmented abdomen (idiosoma). The basis capituli form the ring like foundation for the capitulum and from its anterolateral margins arises a pair of four segmented palps (Teel, 1985). The chericerae and palps are borne on the capitulum. The dorsal chelicerae are two-segmented, tube-shaped appendages housed in cheliceral sheaths, and are capable of anterior-posterior motion. The distal end of each chelicera has a sclerotized, toothlike digit which moves laterally to cut the host's skin during attachment (Teel, 1985). The idiosoma bears six legs in the larva and eight legs in nymph and adult forms. The six leg segments are all capable of considerable articulation and usually have paired claws and a padlike pulvillus distally (Teel, 1985).

1.1.8 General life cycle of ticks

Tick life cycle includes four stages: eggs, six-legged larva, eight-legged nymph, and adult (Teel, 1985). The Argasidae may produce from 2 to 7 nymphal instars, depending on species, host and environmental conditions. Sexual dimorphism is generally not evident until the adult stage, with immature ixodids looking like small females without genital openings. Life cycles are categorized according to the number of host utilized for blood meals, or the sequence of feeding and off-host periods required to produce each generation.

One-host ticks e.g. *Rhipicephalus (Boophilus) annulatus* attach to the host as larvae and through three separate blood feedings on this single host, complete metamorphosis to nymph and engorged adult. Generally, one-host ticks remain attached to the host between feedings. A two-host tick life cycle may be found among Ixodidae e.g. *Rhipicephalus evertsi*, where larvae and nymphs utilize a single host with engorged larvae remaining attached between feedings. The three-host ticks e.g. *Amblyomma americanum* utilize a separate host for each stage. The host association in this cycle is interrupted at the completion of each blood feeding when the engorged tick larva, nymph, or adult drops to the ground to molt, or in the case of adult females, oviposit. Mating occurs on the host except in some specie of *Ixodes* (Teel, 1985). The multihost life cycle is exhibited by the majority of argasids. The sequence requires a separate host for the larvae, each nymphal instar (2 to 7), and each adult feeding. Unlike most ixodids, mating occurs off the host for argasids (Teel, 1985).

1.1.9 Tick-host association

Although ixodid ticks are not host specific, they are not indiscriminate in the host they parasitize. A few show an extremely wide range and these are often of economic importance, but most occur on a limited range of hosts which they parasitize with varying intensities (Kettle, 1992). Some hosts are commonly and heavily infested and others within the same population may be infrequently and lightly infested (Kettle, 1992). Each species is adapted to its hosts, concentrating on particular parts of the host's body and adjusting its seasonal and daily activity cycles to the host's

behaviour and availability (Kettle, 1992). To overcome adverse conditions or times when the host is not present, diapause may occur at any stage of the life cycle and both pre- and post-feeding (Kettle, 1992).

According to Teel (1985), the feeding begins with an incision in the host's skin made with the chelicerae. As the incision is made, the hypostome is inserted and the palps are spread on the surface of the host, perpendicular to the axis of the hypostome. All stages of ixodid ticks, as well as some larval and nymphal argasid species, require long feeding periods of between 2 to 14 days. By contrast, most adults and many immature argasids complete the process within minutes or a few hours (Teel, 1985).

1.1.10 Ticks and diseases

Ticks are most important vectors of diseases to domestic animals and second only to mosquitoes as vectors of diseases to human-kind (Borror *et. al.,* 1989). Certain ticks, especially engorging females feeding on the neck or near the base of the skull of their host, inject venom that produces a paralysis; paralysis may be fatal if the tick is not removed. The most important tick borne diseases are Rocky Mountain Spotted fever, relapsing fever, Lyme disease, tularaemia and many others (Borror *et. al.,* 1989).

1.1.11 General morphology of mites

The body form of most mites is saclike with no obvious segmentation. A distinct head is lacking, and the cephalic region is termed gnathosoma. The remainder of the body is the idiosoma (Hall, 1985). In common with many other members of the class

arachnida, mites generally possess four pairs of legs in the nymphal and adult stages and three pairs as larvae. The mouthparts are quiet variable; however, chelicerae are commonly present in many parasitic species and are used to penetrate host skin. Mites lack the recurved hypostomal teeth that permit firm attachment by ticks (Hall, 1985). Most species exhibit a tracheated respiratory system, with a few smaller forms relying on cuticular oxygen exchange. Generally, true eyes are absent and may be represented by simple visual receptors (Hall, 1985)

1.1.12 General life cycle of mites

The life cycle of most mites follows the same general pattern. The majority of species are oviparous, with exceptions apparent where motile larvae, or in some cases e.g. *Pyemotes*, adults are produced. Eggs hatch into six-legged larvae, which usually molt rapidly to the nymphal stage. Nymphs progress through a series of molts, depending on species, with the resultant forms termed protonymphs, deutonymphs, or tritonymphs, according to the stadium involved. Four pairs of legs are generally apparent with the initial nymphal stage. Sexual differentiation is generally not obvious until the adult form is reached. Mating behaviour in most species remains largely unknown (Hall, 1985; Kettle, 1992).

1.1.13 Mites and diseases

Although many of the larger parasitic species are external, various other types exist as intradermal inhabitants, parasite within lungs, air sacs, various body canals, or within tissue proper. Mites have inimical effects on the health of humans and animals

and these effects have been grouped in 4 general categories: production of dermatitis or similar tissue damage, exsanguinations or feeding on other body fluids, transfer of pathogens as vectors or developmental hosts and production of allergic reactions in host or associated animals (Hall, 1985). In Asia and Australia, man becomes infected by *Scrub typhus* when they enter an area infested by rodent and mites. Mite *Liponyssoides sanguineus* spread *Rickettsial pox* to man in urban areas of North America and Russia, but similar diseases occur in non-urban areas of South America and Korea where the reservoir hosts are voles (Cox, 1979).

1.1.14 Lice

Lice are wingless, dorsoventrally flattened, obligate ectoparasites belonging to Class Insecta and Order Phthiraptera (Miller & Harley, 1992). Over 3,000 species of lice have been described. Order Phthiraptera is divided into two suborders, Mallophaga (chewing or biting lice) and Anoplura (sucking lice) (Borror *et al*., 1989; Miller & Harley, 1992). The chewing lice feed on bits of hair, feathers or skin of the host. The sucking lice feed mainly on blood.

The chewing lice are considered to belong to two suborders, the Amblycera and Ischnocera. These insects feed upon feathers of birds or on hair and skin scales of other animals. They are important pests of domestic fowl and animals, but they do not live on man. The chicken head louse, *Cuclotogaster heterographus* (Nitzsh) (Phthiraptera; Ischnocera: Philopteridae) is an example (Miller & Harley, 1992).

1.1.15 General morphology of lice

Anoplura are small flat, wingless, parasitic insects ranging from less than 0.5 mm to 8 mm in the adults and 2 mm would be an average length. The mouthparts are formed for piercing and sucking. Legs and antennae are short. The antennae are usually 5-segmented. The eyes are reduced and usually absent and there are no ocelli. The head is prognathous with the mouth opening terminal. The highly specialised mouthparts are not visible externally and there are no palps (Kettle, 1992).

Immature stages resemble the adults except for size. The three thoracic segments are fused. There is only a single tarsal segment and a single claw. When the claw is retracted it makes contact with a thumb-like process on the tibia, the enclosed space having the diameter of the hairs of the host, and enables the louse to maintain itself on an active host. There is one pair of spiracles, the mesothoracic, on the thorax, and six pairs on segments 3-8 of the abdomen. The abdomen has nine visible segments.
The sexes can be easily distinguished (Kettle, 1992). The sclerotised genitalia of the male are prominent posteriorly in the midline, and the female has two pairs of lateral gonopods and the sternal plate of the eighth segment sclerotised to varying degrees (Kettle, 1992)

1.1.16 General life cycle of lice

Lice deposit their eggs on the hair or feathers of the host. The life cycle of all lice are very similar with the duration of the egg stage being one to two weeks, the nymphal stages occupying one to three weeks, and the total time from egg to egg being three

to five weeks (Kettle, 1992). Adults probably live for up to a month, although Benbrook (1965) considers that the normal life span of lice on poultry is several months.

1.1.17 Lice-host association

Anoplura are found commonly on domestic animals, but not on birds. The human louse belongs to this suborder. They feed by sucking blood and are important pests of domestic animals and man (Miller & Harley, 1992). Phthiraptera are wingless, dorsoventrally flattened, obligate ectoparasites, spending all their lives on their hosts (mostly birds and mammals) and lacking any free living stage. Lice are highly host specific and many species even prefer specific sites on their host's body. Extensive surveys, such as one concerning the lice of neotropical birds that showed an average of 1.1 lice species per bird species across 127 species and 26 families of birds, indicate that lice are highly moxenous (restricted to one host species). A high level of coevolution between louse and host might be expected and in general, related animals have related lice (Borror *et. al.,* 1989).

1.1.18 Lice and diseases

These insects are irritating pests that can be carriers of disease. Only the sucking lice contain members that attack humans (Miller & Harley, 1992). The human body louse has been responsible for millions of human deaths through the centuries. They spread the organism causing epidemic typhus from one person to another. The hog louse,

Haematopinus suis (Linnaeus) (Phthiraptera; Anoplura: Haematopinidae) is an example (Miller & Harley, 1992).

1.1.19 Previous studies on ectoparasites

In France, a long-term comparative study of infestation patterns by *Ixodes* ticks in urban and rural populations of the common Blackbird *Turdus merula* was carried out by Gregoire *et al.* (2002). This study examined the prevalence and intensity of infestation by Ixodid ticks between birds living in rural vs. urban habitats. The overall prevalence of ticks was significantly higher in the rural habitat where 74% of individuals (n=130) were infested. This contrasted markedly with the situation in the urban habitat where less than 2% of individuals (n=360) carried ticks. There was no significant effect of sex of the host on the intensity or prevalence of tick infestations, but there was a significant effect of age of the host on tick infestations essentially due to the absence of ticks on nestlings (Gregoire *et al.*, 2002).

A study conducted by Durden (1986) on ectoparasites and other arthropod associates of Tropical Rainforest mammals in Sulawesi Utara of Indonesia revealed that lice are highly host specific and usually, just one louse species infested any individual host at one time but in a few cases two louse species may be present on the same animals.

Durden (1986) also reported that no louse species infested more than three different (but closely related) host species and they tend to prefer specific sites on their host's body. In the study, lice were located principally on the head and dorsal body of the

host whereas louse eggs (nits) were confined largely to pelage on the medial dorsal body Durden (1986). Blackmore and Owen (1968) conducted a study on the significance of ectoparasites in British wild rodents and their study revealed a rigid host preference by lice while certain species of mites can infest almost any mammal. Ticks were much less host specific than lice.

Makundi and Kilonzo (1994) reported a seasonal change in the abundance of fleas which is generally common especially in areas with pronounced seasonality in temperature and rainfall. A study in the Lake Nakuru National Park in Kenya, Schwan (1986) reported seasonal variations in the abundance of fleas infesting rodents. Makundi & Kilonzo (1994) reported that similar observations have been made in Java (1972), Hawaii (1955), Vietnam (1969), and the United States of America (1940, 1955 & 1963). Some climatic influence on flea populations was also recorded in Taiwan (Murrel & Cates, 1970).

In a preliminary study survey of microparasite communities of rodents of Kahawa in Kenya, Oguge *et al.* (1997) have indicated that distribution of microparasite in rodents depends to a great extent on the species and the microhabitat. The two factors were also important for ectoparasite diversity and mean intensity on hosts and such variation in the parasite community composition in different microhabitats and host species is due to ecological characteristics such as diet.

In Tanzania, fleas are of considerable medical importance due to occurrence of plague outbreaks; Some studies reported a seasonal pattern in occurrence of fleas

(Makundi & Kilonzo, 1994). Kilonzo *et al.* (1981) reported the seasonal fluctuations of rodents and their ectoparasites which were noted in north-eastern Tanzania. Another study in the western Usambara Mountains in northeastern Tanzania, confirmed a seasonal pattern of rodent and flea populations and the occurrence of plague outbreaks among human populations (Njunwa *et al.*, 1989).

According to Trpis (1994), the host specificity, ecology, and geographical distribution of fleas have been studied by medical entomologists and parasitologists in various European countries. Trpis (1994) further reported that one small mammal species may host several species of fleas and a lack of host-specificity in some species of fleas may increase the potential for acquisition and interspecific transmission of pathogens among wild animals.

In the Southern African sub-continent, Segerman (1995) reported that there are 34 genera representing approximately 110 flea species. Forty-eight species of rodents representing 9 families are regarded as the most important hosts for fleas in Southern Africa (De Mellion *et. al.*, 1961; Segerman, 1995; Zumpt and Haeselbarth, 1966).

Braack *et. al*., (1996) undertook a study to determine the species composition and infestation intensity of ectoparasites infesting the two rodent species *Aethomys chrysophilus* and *Tatera leucogaster* in the Kruger National Park, South Africa. This study revealed that fleas differentiated between the two hosts, *Xenopsylla brasiliensis* occurring only on *A. chrysophilus* and *Xenopsylla frayi* only on *T. leucogaster*. The study of Braack *et al*. (1996) further revealed that mites were harboured by all

individuals of both host species whereas only one louse of the 46 *A. chrysophilus* hosted lice, a male which yielded 79 *Hoplopleura patersoni*, but was otherwise not unusually heavily infested with other arthropod parasites. In contrast, 72% of the *T. leucogaster* had lice, varying between 2 and 80 per infested host, indicating a strong host-specificity in lice.

Another study on ectoparasites was carried out in the northern part of Namibia during a plague outbreak. A trapping programme for rodents was carried out on a monthly basis to monitor the population size of the rodents (Shangula, 1998). Rodents found in the plague focal area were: *Rhabdomys pumilio*, *Mastomys* species and *Tatera leucogaster.* The commonest fleas collected were *Xenopsylla philoxera, Xenopsylla versuta* and *Xenopsylla brasiliensis*.

A study on small mammal ectoparasites in Namibia was carried out at Nabaos and Gellap-Ost farms by Eiseb (2002). The two farms are located in the southern part of the country in the Keetmanshoop district. This particular study investigated species composition of fleas inhabiting small mammals that are occurring at heavily degraded farmland (Nabaos) and undergraded farmland (Gellap-Ost) and also seasonal changes in species composition of fleas. The study revealed that small mammal and flea species composition were higher at Gellap-Ost than at Nabaos. This may be due to more grass cover and diverse plant species at Gellap-Ost. According to Eiseb (2002), dense grass and vegetation cover provide more diverse habitat for small mammal for nesting and feeding. The dense vegetation cover may also assist the small mammals to hide from predators thus enhancing their chances of

survival at Gellap-Ost than at Nabaos. He further reported that conditions at Gellap-Ost could also contribute to the abundance of small mammals and to the species richness of fleas. With regard to season, the number of fleas was higher in August than in May and February at both farms. Many parasitologists believe that habitat selection of a particular parasite is related to a host, which provides its parasites with place to live, forage and mate (Price, 1977 & 1990; Kuris *et al.*, 1980; Kennedy, 1990). With regard to age and body weight, the adult hosts were dominant (141) whereas only 26 juveniles were examined during the study at Gellap-Ost and Nabaos.

Amutenya (2004) carried out a study to compare the diversity, prevalence and intensity of infection of fleas of small mammals in selected sites in Namibia: Gross Hertzog farm, University of Namibia and Gamsberg. This study found that prevalence, species diversity and intensity of fleas of small mammals varied between sites due to differences in vegetation cover and plant species diversities.

Kangombe (2005) carried out a study to infer host specificity of fleas of small mammals based on prevalence, intensity of infestation and species diversity of fleas in selected sites around Windhoek. This study found that prevalence of fleas differed among different host species and between male and female hosts due to behavioural differences of flea species, and particular odours executed by the hosts. The intensity of infestation and species diversity of fleas did not vary between small mammal species and between male and female hosts.

1.2 Justification of the study

The knowledge of ectoparasites of small mammals in Namibia is limited and little attention has been given to this particular field. Apart from ectoparasites as transmitters of diseases, little attention has also been given to their ecology and taxonomic knowledge. In Namibia, fleas play an important role in the transmission of the plague which occurs naturally in wild small mammals in Engela and Onandjokwe districts of Ohangwena and Oshikoto regions of northern Namibia (Shangula, 1998). Other ectoparasites such as mites, lice and ticks do also cause diseases, but it is not yet confirmed in Namibia.

Waterberg Plateau Park is regarded as a unique place similar to an island due to its topography, geology and vegetation types of Kalahari dry savanna. It is the only place in Namibia with such unique area with both tree savanna and dry wood forest (Zeller pers. comm, 2005). Due to the uniqueness of the Waterberg Plateau Park, the mammal fauna in terms of species richness at this place is regarded as different from the surroundings because of different vegetations, climate and precipitation. Therefore, a unique and diverse ectoparasite fauna was expected.

According to literature, not all species of ectoparasites infest all species of small mammals and because small mammal fauna at Waterberg Plateau Park are diverse, it was necessary to investigate to find out whether this is reflected also in the species composition of ectoparasites. According to five of the workers at Waterberg Plateau Park (pers.comm), small mammals at WPP are becoming pests in their houses, moving in and out and destroying some of their properties while at the same time

they might carry the harmful non-host specific ectoparasites to humans. This is one of the reasons why the study was conducted at the Park.

It is also essential for the Waterberg Plateau Park management to know the ectoparasite species present on small mammals. This will facilitate effective and successful Natural Resources Management (NRM), where the understanding and management of the inter-linkage of biodiversity is needed rather than understanding and managing just a component of biodiversity. High load of ectoparasites (ticks & fleas in particular) on individual host (small mammal) may cause anaemia and other diseases which will result in death and decline in small mammal populations and low seed predation and dispersal rate. Due to the ability of some ectoparasites to infest a wide range of hosts, as soon as the fleas detect a drop in blood temperature of the dead host, ectoparasites will look for other hosts including big mammals, pets and humans where they may also transmit diseases and cause death (loss in biodiversity). Therefore, knowledge of seasonal variation in abundance of ectoparasites is essential to understand the potential future outbreaks of ectoparasite-related diseases and their implications for small mammals in the park.

1.3 Aims and objectives of the study

1.3.1 Aim

The main aim of this study was to investigate seasonal occurrence of fleas and other ectoparasites on small mammals at selected sites at Waterberg Plateau Park.

1.3.2 Objectives

1) To determine and compare the seasonal variations in species diversity and abundance of fleas and other ectoparasites on small mammals.
2) To determine and compare the seasonal variation in the intensity of infestation of fleas and other ectoparasites on different species of small mammals
3) To determine and compare the seasonal variation in the prevalence of fleas and other ectoparasites on different species of small mammals
4) To compare the seasonal variation in intensity, prevalence and species diversity of fleas and other ectoparasites between infested male and female small mammals.

1.4 Key questions

1) What is the species diversity of fleas and other ectoparasites on small mammals at Waterberg Plateau Park?
2) How does the species diversity and abundance of fleas and other ectoparasites of small mammals vary with season?
3) Are there differences in the intensity of infestation of fleas and other ectoparasites among small mammal species in different seasons?
4) Does prevalence of fleas and other ectoparasites differ between different species of small mammals in different seasons?
5) Do different species of small mammals harbour different species of fleas and other ectoparasites?

6) Does sex of small mammal host affect species diversity, intensity and prevalence of fleas and other ectoparasites?

1.5 Hypotheses

1) High diversity of fleas and other ectoparasites is expected on small mammal at Waterberg Plateau Park due to the expected uniqueness of the small mammals found on the Plateau compared to those outside.

2) Based on the objectives of this study, it is hypothesized that seasons play a role in the foraging and reproduction of small mammal communities due to the changes in precipitation and temperature as different species may act better in a certain time of the year than in other times of the year. The same applies to the fleas and other ectoparasites because they depend on the hosts for living, foraging and mating (Price, 1977, 1990; Kuris *et al.*, 1980; Kennedy, 1990). Species diversity and abundance of fleas and other ectoparasites of small mammals at Waterberg Plateau Park is expected to be higher in the dry season than in the wet season because of susceptibility of fleas and other ectoparasites to fluctuations in temperature and moisture.

3) The intensity of fleas and other ectoparasites among small mammal species is expected to be higher in dry season than in wet seasons because of susceptibility of fleas and other ectoparasites to fluctuations in temperature and moisture.

4) Prevalence of fleas and other ectoparasites on different species of small mammals is expected to be higher in dry season than in wet season as some small mammal species may not be preferred hosts of certain ectoparasite species during wet season. Any host is a habitat of an individual ectoparasite and this determines the structure of parasite communities as it provides the flea and other ectoparasites with a place to live, forage and mate.

5) Different small mammal species are expected to harbour different species of fleas and other ectoparasites as some of the ectoparasites may prefer only certain species of small mammals as suitable hosts.

6) Higher prevalence, intensity and species diversity of fleas and other ectoparasites is expected to be found on male small mammals than on female small mammals because males appear to move greater distances than females and thus, some ectoparasite species may favour males to maximize dispersal distances and minimize inbreeding (Wells-Gosling and Heaney, 1984; Walter & Proctor, 1999).

CHAPTER 2 MATERIALS AND METHODS

2.1 Description of the study area

The study was carried out at Waterberg Plateau Park (WPP). Waterberg Plateau Park (Proclamation 49 of 1972) was declared as a game reserve on 16 June 1972 (MET, 1986). The main objective of WPP is to develop a rare and endangered species breeding area to provide stock for the reintroduction of species within areas of Namibia where they formerly occurred (Du Preez, 2000).

2.1.1 Location and size

WPP is located in north, central Namibia, between 20°30´ S and 17°15´ E (Figure 1) Approximately 70 km east of Otjiwarongo. The Park is 50 km on its longest axis and 16 km on its broadest axis, with a total area of 40 545 ha (Figure 2.1 (a)) of which 40 000 ha is situated on the plateau, where the small mammals were trapped. Location of the four study grids in relation to Waterberg plateau Park is shown in Figure 2.1(b).

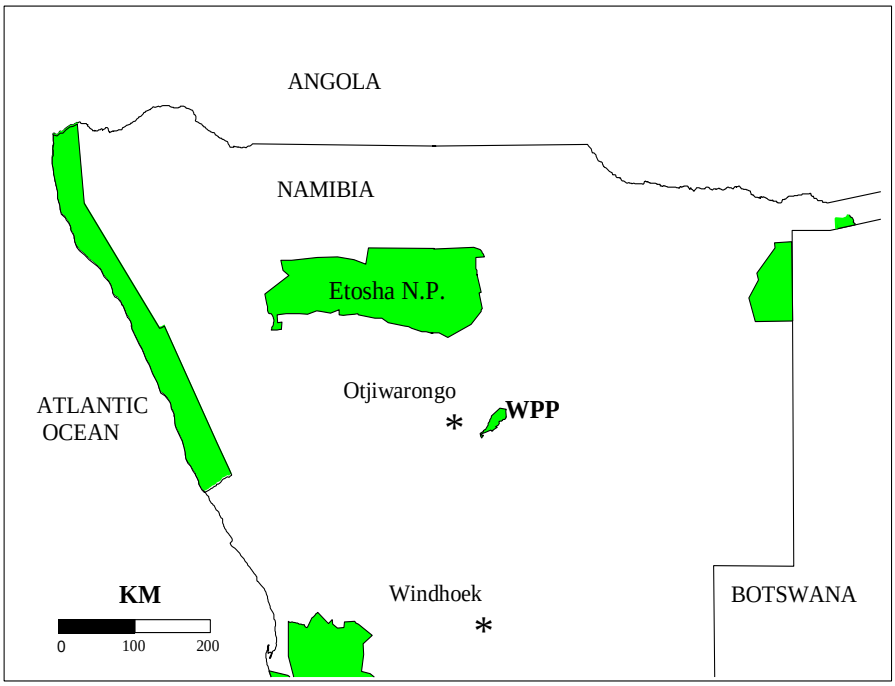

Figure 2.1(a) Location of Waterberg Plateau Park (WPP) in relation to central and northern Namibia (MET, 1986; Du Preez, 2000).

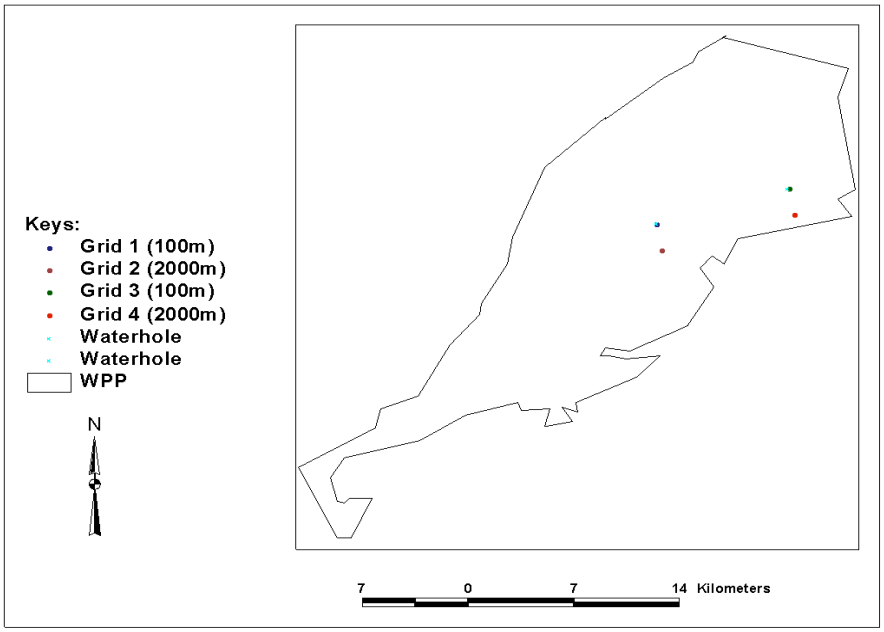

Figure 2.1(b) Location of study grids (within the park) in relation to Waterberg Plateau Park (WPP). In the keys of the Figure, 100m and 2000m indicate the distance of trapping grids from the waterholes.

2.1.2 Climate

According to the Köppen system of classification, the WPP falls into the "Hot Steppe" climatic zone and the area's climate is influenced by different factors. During the winter months (May to August) high-pressure cells move south and lead to the formation of the Kalahari high-pressure system over Botswana. As a consequence, there is no prevailing humid air that flows into northern Namibia, with rain during these months being an exception on WPP (Van der Merwe, 1983; Du Preez, 2000). The topography of the WPP is an important determining factor in the local climate of the plateau. The plateau is 150m higher than the surrounding areas and is within the 500-600mm rainfall isohyet (Figure 2.2).

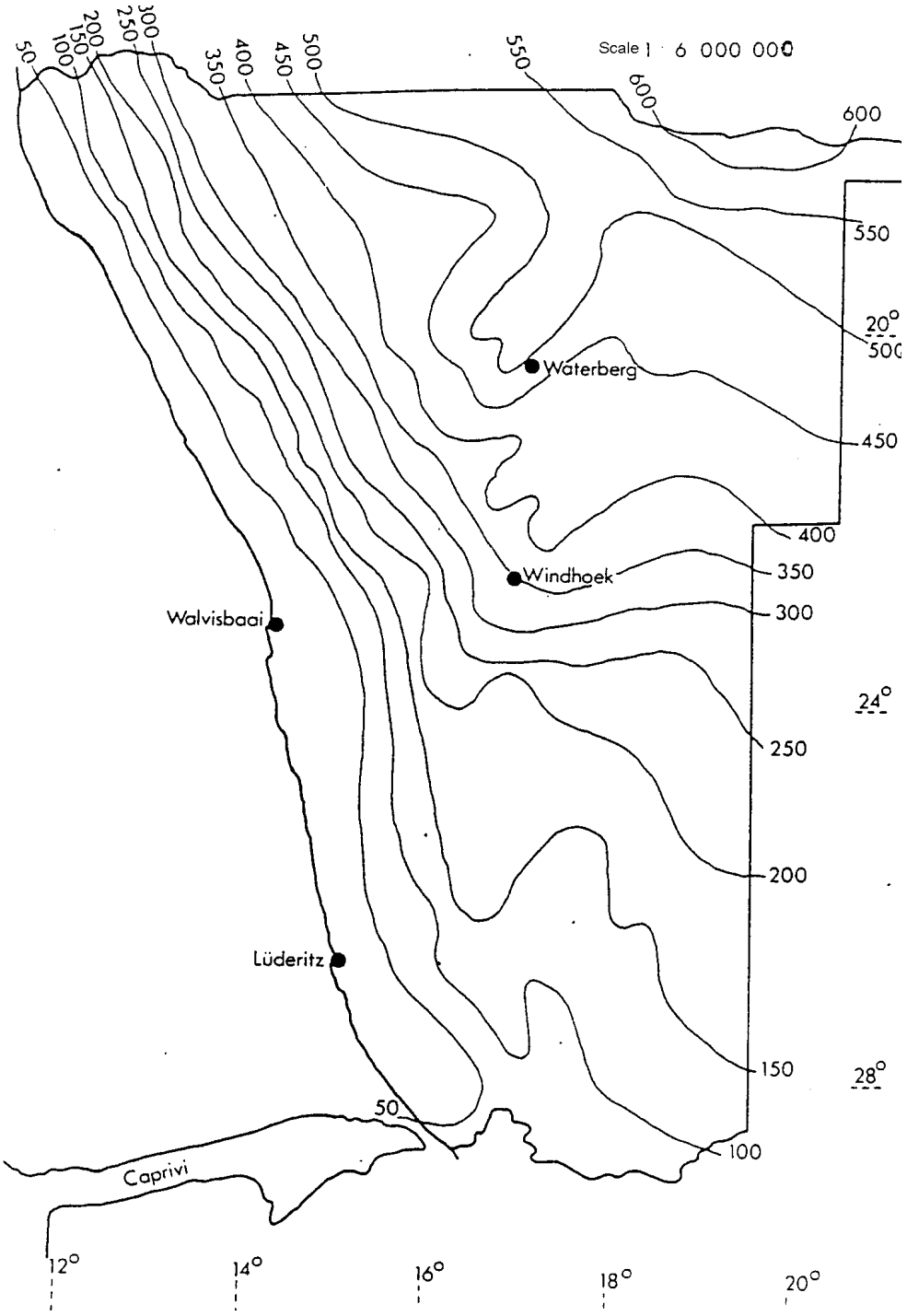

Figure 2.2 Rainfall isohyets of Namibia illustrating the effect of the Waterberg Plateau on the local climate (Du Preez, 2000; NMS, 2006).

2.1.3 Geology

The Waterberg is a table mountain topped by a plateau, which is slightly inclined towards the east and northeast. Consequently its highest point, at 1930m above sea level, lies on the "Klein Waterberg", an isolated outlier (inselberg) about 7 km south-west of the "Groot Waterberg". On three sides, viz. the northwest, southwest and southeast, the mountain is surrounded by steeply rising slopes. To the east and northeast its altitude decreases gradually due to the dip of the plateau in these directions and the mountain merges with the flat landscape of the Kalahari "sandveld" in the east (Hegenberger, 1990).

The Okarukuvisa Mountains are situated along the northwestern edge of the Waterberg plateau and are nearly 200m higher than the plateau. These mountains protect the area in the southeast against erosion (Du Preez, 2000).

The Waterberg is situated on the western side of the Kalahari Basin, just east of the watershed between this depression and the Atlantic Ocean, an area that is prone to denudation. The formation of the mountain went together with the stepwise shaping of the present landscape by weathering and erosion. Several cycles of erosion have affected southern Africa and the records of these are remnants of old, flat erosion surfaces such as the elevated plateaus of the Etjo and the Waterberg Mountains (Lüdtke, 1979).

Wind-blown Kalahari sand, up to several meters thick, covers large tracts of eastern Namibia including parts of the Waterberg plateau, resulting in a typical Kalahari-

type landscape and vegetation. In the high-lying western and northwestern areas of the park, these sands have already been removed by erosion or were never deposited. Looking at the overall geology one could get an indication of the availability of minerals in the specific overlying soils (Grant, 1989; Hegenberger 1990; Du Preez, 2000).

2.1.3.1 Soil

The texture of the soil on the WPP is a sandy loam, which forms 89.4% of the A and B horizons of 225 samples taken by Jankowitz (1983). The clay content of the sand on the plateau is relatively low, 93% of 225 samples had clay contents of less than 20%. The pH ranges between 3.6 and 6 with an average value of 4.4 (Jankowitz, 1983).

Jankowitz (1983) found the following values for some soil nutrients from 77 samples analysed on WPP:

Phosphate (P) - For A and B horizon he found that in 80.0% and 96.6% respectively, the phosphate values were lower than 15 parts per million (ppm). Only 5.7% of all samples analysed were higher than 40 ppm.

Potassium (K) - The potassium values in the A and B horizons were also low with 89.8% in the A horizon and 9.6% in the B horizon.

Calcium (Ca) - For 81.2% in the A and 91.4% in the B horizon Ca values of all samples were below 200 ppm (Du Preez, 2000).

2.1.4 Temperature

Temperature curves follow the typical summer high and winter low pattern of the Southern Hemisphere. According to Du Preez (2000), the warmest months of the year are October, November, December and January. Du Preez further stated that according to Sachse and Bonthuys (1990), temperatures over November and December might reach 40º C in Otjiwarongo.

The most recent temperature data (Sachse and Bonthuys 1990; Du Preez, 2000; NMS, 2006) which gave an indication of the expected temperatures on WPP were for Grootfontein (1968 till 1985) which is approximately 70 km to the northeast of WPP and for Otjiwarongo (1907 till 1982) which is approximately 70 km west of WPP.

2.1.5 Wind

The wind regimes are determined by the high and low-pressure systems. North, northeast and east winds are predominant throughout the year with the windiest time between June and December. During April and October the north winds turn to west winds in the late afternoons, and south and southeast winds blow usually during September and October. Rain occurs usually with the north, northeast and east winds, which brings humid air from those directions (Jankowitz, 1983; Du Preez, 2000).

2.1.6 Evaporation

The mean evaporation is the lowest in May to July (151mm June) and the highest in September to December (364mm October). Evapotranspiration exceeds rainfall with an average of 217mm each month throughout the year. The standard deviation is estimated to 75mm (Figure 2.3)

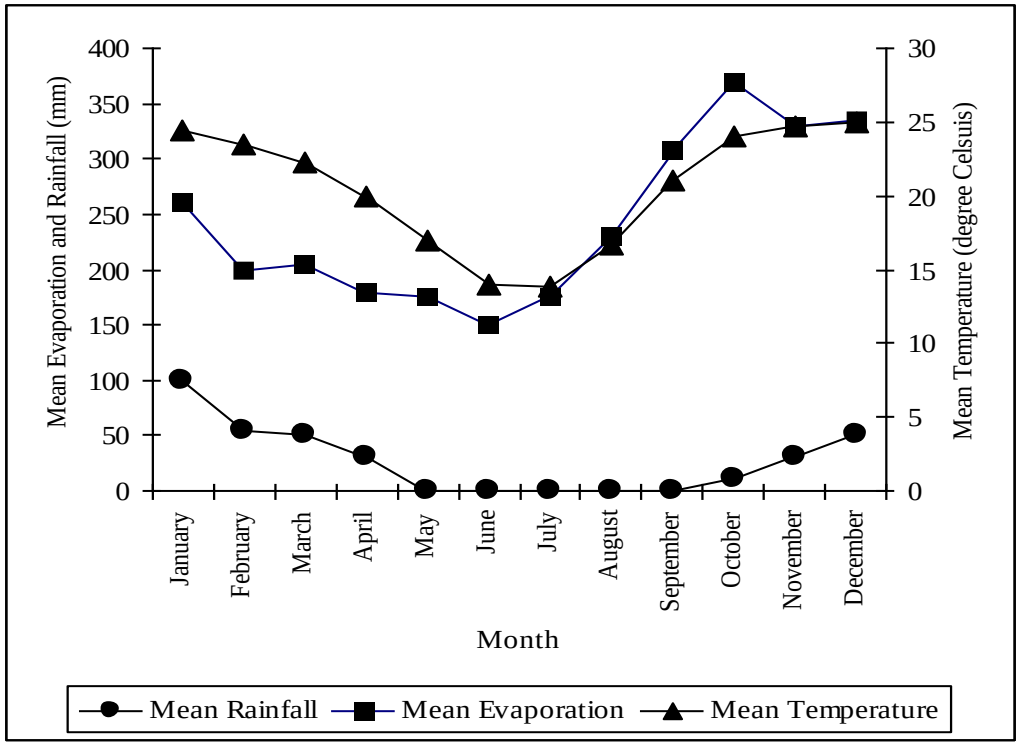

Figure 2.3 Mean monthly evaporation (mm), mean monthly temperatures (°C) and the mean monthly rainfall (mm) at Onjoka - WPP (Jankowitz 1983; Erb 1993; Du Preez, 2000; NMS, 2006).

2.1.7 Vegetation

The vegetation on main plateau is dominated by different vegetation types including *Terminalia sericea – Thesium megalocarpum* (tree/ shrub savanna), *Terminalia sericea –Melhania acuminata* (tree/ shrub savanna) and *Anthephora pubescens* –

Eragrostis superba (grass savanna) and *Peltophorum africanum* (rock communities) (Jankowitz, 1983; Jankowitz & van Rensburg, 1985; Jankowitz & Venter, 1987; Erb, 1993).

The vegetation types on the main plateau are associated with vegetation in the Kalahari basin (Erb, 1993), which only occurs in north-eastern Namibia and north-western Botswana (Zeller, pers. comm., 2005), while the vegetation below the plateau is of the common thorn bush savanna, dominated by *Acacia mellifera, Dichrostachys cinerea and Acacia erioloba* (Jankowitz, 1983; Jankowitz & Van Rensburg, 1985; Jankowitz & Venter, 1987). However, the vegetation at the study sites dominated by *Terminalia sericea, Grewia flavescens, Ziziphus mucronata, Burkea africana, Philenoptera nelsii, melhania acuminate, Blepharus intergrifoluris, combretum collinum and Ochna pulchra.*

2.1.8 Precipitation

During the summer and autumn, dew and mist do occur (Du Preez, 2000). In the absence of statistics on the amounts of rainfall, it is difficult to assess the influence of precipitation on the plant communities. According to Du Preez (2000), frost occurs in the winter months with a definite influence on the structure of the plant communities. Frost is strongly correlated with the topography of the mountains with a higher incidence of lower temperatures in the more low-lying areas. Jankowitz (1983) recorded temperatures at as low as – 9.5ºC, the lowest ever recorded.

2.2 Field trapping of small mammals

2.2.1 Introduction

The study sites were selected on top of the plateau. The study was carried out on plots designed in collaboration with another study which was looking at the population dynamics of small mammals and the effects of disturbance of herbivores on the species diversity of small mammals.

2.2.2 Method of sampling

Two waterholes were selected for the study. Two grids were established at each waterhole: the first grid at 100m and the second one 2000m away from the waterhole. Each sampling grid consisted of 100 small mammal Sherman-live traps placed in 10 rows and 10 columns spaced at 10m intervals and in an area of 10 000m^2 (1hectare). Within one metre of each grid point a Sherman live-trap baited with a rolled mixture of oats and peanut butter was placed in order to catch small mammals. This bait mixture is known to attract a variety of small mammal species (Jones *et al.,* 1996; Zeller *et al.,* 2001).

Active burrows and faeces were the most common signs of small mammal activity. All traps were covered with carton boxes to prevent the animals from dying from heat and cold while confined in the traps. Traps were set (baited and opened) in the late afternoon from 1600hrs and were inspected the next morning from 0700hrs to catch both diurnal and nocturnal small mammals. Every afternoon, the old bait in each trap was replaced with fresh ones.

During a grid check (Table 2.1), all traps were examined and for each animal caught, the following information was recorded: location of capture, species, sex, reproductive status (Appendix 14 & 15), body mass (using a Pesola scale), individual mark and the presence or absence of ectoparasites. The mass of the small mammals were measured using a high precision ±3% Pesola® spring balance. The scales were calibrated for a capacity of 0 to 300 grams. The host animals were individually ushered into a transparent plastic bag which were attached to a scale and the mass were recorded to the nearest gram. Because of the sensitivity of the scale (Pesola® spring balance) to the wind, the scale was shielded from the direct wind effect in each case.

Table 2.1 Number of days and trap nights spent at WPP during the study period in December 2005, March, April, May and June 2006.

Date of trapping	Months 2005-2006	Number of days	Number of traps	Number of trap nights	Number of grid checks
7-23	Dec	16	100	1600	16
12-27	Mar	16	100	1600	16
12-27	Apr	16	100	1600	16
12-27	May	16	100	1600	16
12-27	Jun	16	100	1600	16

All small mammals caught were individually marked for identification during later captures by injecting them with different colour combinations of dyes under the skin of the tail base.

The small mammal trapping and collection of ectoparasites were undertaken over 4 consecutive nights from each sampling grid in December 2005, March, April, May and June 2006. December represented summer, March and April; autumn while May

and June; winter. Each individual small mammal (new or recapture) caught was only examined for ectoparasites once in a month.

2.2.3 Collection of ectoparasites from hosts

Small mammals were removed from the traps and placed in a clear plastic bag. Each animal was individually manipulated to enter a Perspex tube head first. Upon restraint, the host was partially removed from the Perspex tube to allow examination of the posterior half of the body (belly, back, side, rump, hind legs, tail and genitalia of host body). Ectoparasites were obtained by gently brushing (using a tooth brush) the whole body of the live animal. Animals were brushed over a light coloured basin containing 70% ethyl alcohol to dislodge all ectoparasites as far as possible. Ectoparasites were also picked with forceps while carefully examining the pelage and skin. The plastic bags were examined for remaining ectoparasites. Ectoparasites from each host were preserved in 70% ethyl alcohol in a numbered vial for identification later, except for mites which were preserved in Oudeman's fluid (mixture of : 85 parts of 70% Alcohol, 5 parts of Glycerin and 5 parts of Glacial acetic acid). The Oudeman's fluid is recommended for fixing and preserving terrestrial mites (Wagstaffe & Fidler, 1955).

2.2.4 Processing of ectoparasites

2.2.4.1 Processing and identification of flea specimens

Flea specimens were processed in the Mammalogy laboratory of the State and National Museum of Namibia. Fleas were prepared using standard procedures and mounted onto glass slides as described below. From preservation of 70% alcohol, the fleas were kept in distilled water for one hour to rinse the alcohol off the specimens. The flea specimens were then transferred into 15% Potassium hydroxide (KOH) and left at room temperature for 6 days to dissolve and clear endodermal and mesodermal tissues, leaving only the exo-skeleton which is required for the identification of fleas. The KOH was rinsed off the fleas with distilled water for one hour and neutralized using 10% acetic acid for 30 minutes. Acetic acid was also rinsed off the fleas with distilled water for one hour. The specimens were dehydrated using different concentrations of alcohol: 70%, 80%, and 96% each for 30 minutes and absolute alcohol for an hour. Since the specimens were very dry after the dehydration process, they were softened using oil of cloves and later, mounted onto glass slides using the permanent specimen preservative Entellan (Mpofu 1999; Segerman 1995; Trpis 1994a, b). Canada Balsam was used when Entellan was not available. Canada Balsam and its diluting agent, xylene has been used as the standard mounting medium in many studies (Peterson, 1981; Kangombe, 2005). While xylene clears and hardens the tissue rapidly from absolute alcohol, it also helps in the consistency of Canada Balsam as the presence of water may cause loss of clearness and the medium takes a cloudy appearance (Peterson, 1981). The slides were then left to dry by air for 2 weeks making the specimens ready for identification.

Identification of the flea specimens was performed using the standard identification keys for flea species known to occur in the Southern African sub-region including Namibia. These identification keys were developed by Segerman (1995). The flea specimens were examined using a compound binocular microscope (Leitz) and the identified flea specimens were verified by a Mammalogy Curator at the National Museum of Namibia. The sex of each flea was determined using a compound binocular microscope by looking at the abdominal areas to check for the presence of processes of clasper in the males or spermatheca in the females (Segerman, 1995).

2.2.4.2 Processing and identification of tick specimens

The preserved specimens of ticks collected from the field were separately sent to a tick taxonomist in South Africa, Professor Ivan G Horak, Department of Veterinary Tropical Diseases, Faculty of Veterinary Science, University of Pretoria, Onderstepoort. (E-mail ivan.horak@up.ac.za. Tel: +27 (0)12 529 8371, Fax: +27 (0)12 529 8312).

2.2.4.3 Processing and identification of mite specimens

The preserved specimens of mites collected from the field were separately sent to a mite taxonomist in South Africa, Dr. Eddie Ueckermann, Plant Protection Research Institute, Private Bag X134, Queenswood, Pretoria, 0121 South Africa. E-mail UeckermannE@arc.agric.za. However, mites could not be identified before deadline.

2.2.5 Determination of small mammal species

2.2.5.1 Host species

The host species were identified using a standard identification key developed by Skinner and Smithers (1990). The identification key was developed for the identification of all terrestrial mammalian species known to occur in the Southern African sub-region.

2.2.5.2 Host sex

In order to determine the sex of hosts, the body of hosts were inspected for the presence of mammae, vagina and testis (Hoffmann, 1999; Eiseb 2002). Presence of testis signified a male whereas presence of mammae and vagina signified a female host. However, testis in males and mammae in females are not visible in juveniles. Thus, the distance between anus and the genitalia, which could be the penis or vagina, was measured. A larger distance of more than 2 cm between anus and genitalia indicated a male, whereas a shorter distance of less than 2 cm indicated a female (Hoffmann, 1999; Eiseb, 2002). Absence and presence of hair between the anus and genitalia was also used as a criterion to determine the sex of the host. Absence of hair signified a female while the presence of hair signified a male.

2.3 MANIPULATION AND ANALYSIS OF DATA

2.3.1 Intensity of infestation

Ectoparasite intensity is the number of ectoparasites per host (Schwan, 1986; Makundi & Kilonzo, 1994). Intensity of ectoparasite was calculated as the total number of individual ectoparasites collected divided by total number of host animals infested by ectoparasites. The median (the middle value of a ranked data set (Dytham, 1999)) intensity of infestation which normally used when data are not normally distributed could not be used in the present study because the calculated medians are zeros. Instead of medians, the actual calculated intensity of infestation of different ectoparasites was used based on studies done by Schwan (1986) and Makundi & Kilonzo (1994).

2.3.2 Prevalence of infestation

Prevalence of infestation is the percentage of host animals that are infested by ectoparasites. Prevalence was calculated as the total number of infested host animals divided by the total number of host animals that were examined multiplied by a hundred.

2.3.3 Species diversity

Species diversity of ectoparasites was calculated by means of a Shannon-Wiener's diversity index (H')

$$H' = -\Sigma p_i \ln p_i$$

where p_i is a proportion of individual species and ln is a natural logarithm. Shannon-Wiener's diversity index (H') is a measure of both the number of species and relative abundance of individuals of all species (Avenant, 2000).

In the present study, species diversity is presented as the actual calculated diversity (H'). The means were not used because data are not normally distributed. The medians were also not used because the calculated medians are zeros.

2.3.4 Data analysis

Two statistical software packages were used for the analysis of ectoparasite data. These are Statistical Package for the Social Sciences (SPSS) 11.5 for Windows and GenStat for Windows Discovery Edition 2, Fifth edition, Release 4.2. Days of trapping (16/month) were used as replicates while trapping months were used as factors. In case where comparison was between host sexes, sex difference was used as a factor. A Kolmorogov-Smirnov (K-S) test for was calculated using SPSS while a Kruskal-Wallis test and a Mann-Whitney U test were calculated using GenStat.

A Kolmorogov-Smirnov (K-S) test was used to determine whether different data were normally distributed. The data referred to herein is total number of individual fleas of different species, collected for 16 trapping session per month, species diversity of fleas per 16 trapping session per month and so on (depending on the question to be answered). A Kolmorogov-Smirnov test of normality indicated that the species diversity and abundance data of fleas (K-S=0.513, df=80, P=0.000

& K-S=0.399, *df*=80, *P*=0.000 respectively); ticks (K-S=0.532, *df*=80, *P*=0.000 & K-S=0.499, *df*=80, *P*=0.000 respectively) and abundance of mites (K-S=0.272, *df*=80, *P*=0.000) were not normally distributed (*P*<0.001). Mites and lice could not be identified.

Since the diversity and abundance data of fleas, ticks and mites were not normally distributed, Kruskal-Wallis test for mean ranks was used to determine whether the mean ranks of species diversity and abundance of fleas, ticks and mites differ between the 5 months. Kruskal-Wallis test is a nonparametric equivalent of the one-way analysis of variance and has a null hypothesis that all samples are taken from populations with the same median (Dytham, 1999).

A Mann-Whitney U test was also used to test whether there was a difference in prevalence and intensity of different ectoparasites between male and female hosts and between the months. This test, also widely known as the Wilcoxon-Mann-Whitney test and less widely as the Wilcoxon rank sum *W* test, is the nonparametric equivalent of the independent samples *t*-test which can only be used to test two groups (Dytham, 1999). However, unlike the *t*-test and one-way ANOVA it does not make assumptions about homogeneity of variances or normal distributions. It is a typical 'rank' test, meaning that the raw data is converted into ranks before the test is carried out. The advantage of this is that it is ideal for situations where the highest value went off the scale of if extreme values are making the *t*-test undesirable. The Mann-Whitney U test is slightly less powerful that a t-test or one-way ANOVA, but it is less likely to find a significant result when there is no real difference. However,

the lack of assumptions it makes about the distribution of the data makes it the preferred test in most cases (Dytham, 1999).

CHAPTER 3 RESULTS

3.1 Occurrence of small mammals and ectoparasites

A total of 179 hosts (146 individuals and 33 recaptures) were examined for the ectoparasites (Table 3.1) out of which 84 hosts were infested with different ectoparasites. A total of 12 different small mammal species representing 11 rodent species and 1 shrew species were caught and examined, of which 9 host species were infested with different ectoparasites while 3 host species were found with no ectoparasites at all. *Dendromus melanotis* dominated the catches with 25.1% followed by *Gerbillurus paeba* with 21.8%, whereas *Thallomys nigricauda* was the least caught host species with 0.01% (Figure 3.1(a), Table 3.1). Male hosts were trapped more freguently (57%) than the females (Table 3.2).

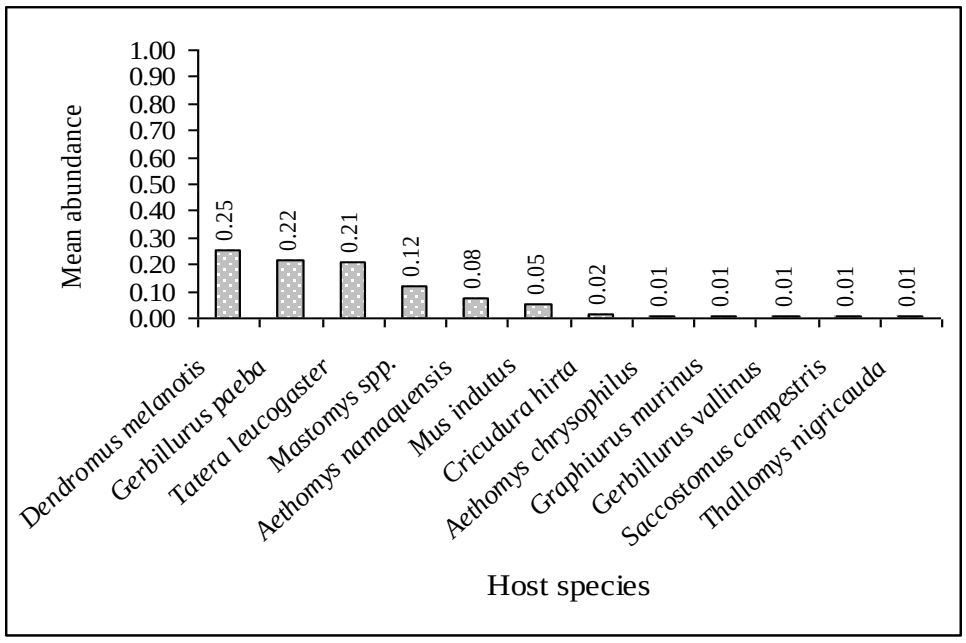

Figure 3.1(a) Mean abundance of small mammals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006).

Table 3.1 The number of host animal species examined for ectoparasites at Waterberg Plateau Park over a period of five months from December 2005 to June 2006 (except January and February 2006)

Host species		Number of small mammal of each species examined per month (Year: 2005-2006)					
Scientific names	Common names	Dec	Mar	Apr	May	Jun	Totals
Aethomys chrysophilus	Red veld rat	0	0	0	1	1	2
Aethomys namaquensis	Namaqua rock mouse	0	0	10	1	3	14
Crocidura hirta	Lesser red musk shrew	0	0	3	0	0	3
Dendromus melanotis	Grey-climbing mouse	3	0	2	6	34	45
Graphiurus murinus	Woodland dormouse	0	0	0	0	2	2
Gerbillurus paeba	Hairy-footed gerbil	10	6	6	4	13	39
Gerbillurus vallinus	Brush-tailed hairy footed gerbil	0	1	1	0	0	2
Mus indutus	Desert pygmy mouse	6	0	0	0	3	9
Mastomys spp.	Multimammate mouse	4	3	12	2	1	22
Saccostomus campestris	Pouched Mouse	0	0	1	0	1	2
Tatera leucogaster	Bushveld gerbil	10	7	4	8	9	38
Thallomys nigricauda	Black-tailed tree rat	0	0	0	0	1	1
Totals		33	17	39	22	68	179

The highest number of host animals 38% (*n*=68) were captured in June 2006 whereas the lowest number 9% (*n*=17) were captured in March 2006 (Table 3.1). *Dendromus melanotis* was the most abundant host species whereas *T. nigricauda* was the least caught and examined host.

Table 3.2 The number of male and female small mammal species captured and examined for ectoparasites at Waterberg Plateau Park from December 2005 to June 2006 (except January and February 2006).

Host species	Number of male (M) and female (F) small mammals examined (Year: 2005-2006)										Totals
	Dec		Mar		Apr		May		Jun		
	F	M	F	M	F	M	F	M	F	M	
Aethomys chrysophilus	0	0	0	0	0	0	0	1	0	1	2
Aethomys namaquensis	0	0	0	0	3	7	0	1	1	2	14
Crocidura hirta	0	0	0	0	2	1	0	0	0	0	3
Dendromus melanotis	3	0	0	0	2	0	1	5	7	27	45
Graphiurus murinus	0	0	0	0	0	0	0	0	1	1	2
Gerbillurus paeba	3	7	4	2	6	0	1	3	8	5	39
Gerbillurus vallinus	0	0	0	1	0	1	0	0	0	0	2
Mus indutus	2	4	0	0	0	0	0	0	1	2	9
Mastomys spp.	2	2	1	2	1	11	0	2	0	1	22
Saccostomus campestris	0	0	0	0	0	1	0	0	0	1	2
Tatera leucogaster	4	6	7	0	3	1	8	0	8	1	38
Thallomys nigricauda	0	0	0	0	0	0	0	0	0	1	1
Totals	14	19	12	5	17	22	10	12	26	42	179

Table 3.2 reveals that more male hosts 57% (*n*=100) were trapped and examined than females 43% (*n*=79).

3.2 Host species and flea species composition

From 84 infested hosts, 114 flea specimens belonging to 8 species of fleas were recovered. These flea species were collected from 29 host individuals belonging to 6 host species (Table 3.3 & 3.4). The 8 flea species were: *Listropsylla aricinae* DeMellion, 1949 (Hystrichpsyllidae: *Listropsylla*); *Listropsylla dorippae* Rothschild, 1904; *Xenopsylla cheopis* Rothschild, 1903 (Pulicidae: Xenopsyllinae); *Xenopsylla versuta* Jordan, 1925 *Xenopsylla nubica* Rothschild, 1903; *Xenopsylla philoxera* Hopkins, 1953; *Xenopsylla brasiliensis* Baker, 1904; *Pulex irritans* Linne, 1758 (Pulicidae: Pulex).

Xenopsylla philoxera was the most abundant species comprising 44% (*n*=50) of the 114 specimens recovered from all host species on all four study grids (Table 3.5). It was followed by *Xenopsylla nubica* 25.4% (*n*=29), *Xenopsylla cheopis* 13.1% (*n*=15), *Xenopsylla versuta* 10.5% (*n*=12), *Listropsylla aricinae* and *Listropsylla dorippae* 2.6% each (*n*=3), whereas *Xenopsylla brasiliensis* and *Pulex irritans* were the least abundant flea species comprising only 0.9% each (*n*=1). *Listropsylla aricinae, Xenopsylla brasiliensis* and *Pulex irritans* were each recovered from only on 1 host, *Aethomys namaquensis*, *Mastomys* sp. and *Tatera leucogaster*, respectively. Male fleas represented 55.3% (*n*=63), whereas females represented 44.7% (*n*=51) of the fleas that were collected.

Table 3.3 Total number of ectoparasites, total number of individual host animals and the host species infested by the different ectoparasite taxa recovered during the study period in December 2005, March, April, May and June 2006 at Waterberg Plateau Park.

	Ectoparasite taxa			
	Fleas	Ticks	Lice	Mites
Number of individual hosts infested	29	8	2	69
Number of ectoparasites	114	15	3	468
Host species infested	*Aethomys chrysophilus* *Aethomys namaquensis* *Gerbillurus paeba* *Mus indutus* *Mastomys* spp. *Tatera leucogaster*	*Aethomys chrysophilus* *Dendromus melanotis* *Gerbillurus paeba* *Mastomys* spp.	*Gerbillurus paeba* *Thallomys nigricauda*	*Aethomys chrysophilus* *Aethomys namaquensis* *Dendromus melanotis* *Gerbillurus paeba* *Mastomys* spp. *Saccostomus campestris* *Tatera leucogaster*

Table 3.3 indicates that *Gerbillurus paeba* was the only host species which was infested by all four ectoparasite taxa. More host individuals as well as host species were infested by mites. Mites were the most abundant ectoparasites recovered from hosts. Lice were recovered only from 2 host individuals that represented two separate species.

Table 3.4 Abundance of flea of different species recovered from 6 small mammal species captured at Waterberg Plateau Park over a period of five months from December 2005 to June 2006 except January & February 2006. (*n*=29). Included are total numbers of female and male fleas.

Flea species	Host species						Sex of fleas		**Total**
	Aethomys chrysophilus (*n*=1)	*Aethomys namaquensis* (*n*=4)	*Gerbillurus paeba* (*n*=4)	*Mus indutus* (*n*=1)	*Mastomys* spp. (*n*=6)	*Tatera leucogaster* (*n*=13)	Male	Female	
Listropsylla aricinae	3	0	0	0	0	0	0	3	**3**
Listropsylla dorippae	1	1	0	0	1	0	2	1	**3**
Pulex Irritans	0	0	0	0	0	1	1	0	**1**
Xenopsylla brasiliensis	0	0	0	0	1	0	1	0	**1**
Xenopsylla cheopis	5	2	2	0	5	1	0	15	**15**
Xenopsylla nubica	0	0	2	0	1	26	29	0	**29**
Xenopsylla philoxera	0	0	0	1	8	41	22	28	**50**
Xenopsylla versuta	5	1	0	0	5	1	8	4	**12**
Total	**14**	**4**	**4**	**1**	**21**	**70**	**63**	**51**	114

Table 3.4 demonstrates that the flea *X. nubica*, *X. philoxera* and *L. dorippae* were each recovered from 3 different host species and they were recorded in highest numbers of 29 and 50 respectively (excluding *L. dorippae* with a recorded number of only 3 specimens). However, *X. cheopis* and *X. versuta* were both recovered from 4 different host species, whereas, *L. aricinae*, *X. brasiliensis* and *P. irritans* were each recovered from only one host species and were recorded in lowest numbers of 3, 1 and 1 respectively. The abundance of different species of fleas per trapping session in each month is represented in Table 3.5.

Table 3.5 Abundance of different species of fleas recovered from small mammals during the study at Waterberg Plateau Park from December 2005 to June 2006 excluding January & February 2006. (*n*=114).

	Number of individual flea species (Year: 2005-2006)					
Flea species	Dec	Mar	Apr	May	Jun	Total
Listropsylla aricinae	0	0	0	3	0	3
Listropsylla dorippae	0	0	2	1	0	3
Pulex irritans	1	0	0	0	0	1
Xenopsylla brasiliensis	0	0	1	0	0	1
Xenopsylla cheopis	6	0	4	5	0	15
Xenopsylla nubica	27	0	2	0	0	29
Xenopsylla philoxera	43	1	1	2	3	50
Xenopsylla versuta	1	0	6	5	0	12
Total	78	1	16	16	3	**114**

X. philoxera was the only flea species collected during each month of the study period. It was the most abundant flea species in December comprising 55% of the total flea specimens (*n*=78) collected. This was followed by *X. nubica* 35% and *X. cheopis* 8% and the least *P. irritans* and *X. versuta* both comprising 1%. During March and June the

only *X. philoxera* was recovered (Table 3.5). The mean abundance of different species of fleas collected during the study period is presented on Figure 3.1(b). Flea species *Xenopsylla philoxera* was the most abundant, while *Pulex irritans* and *Xenopsylla brasiliensis* were the least abundant flea species collected during the study.

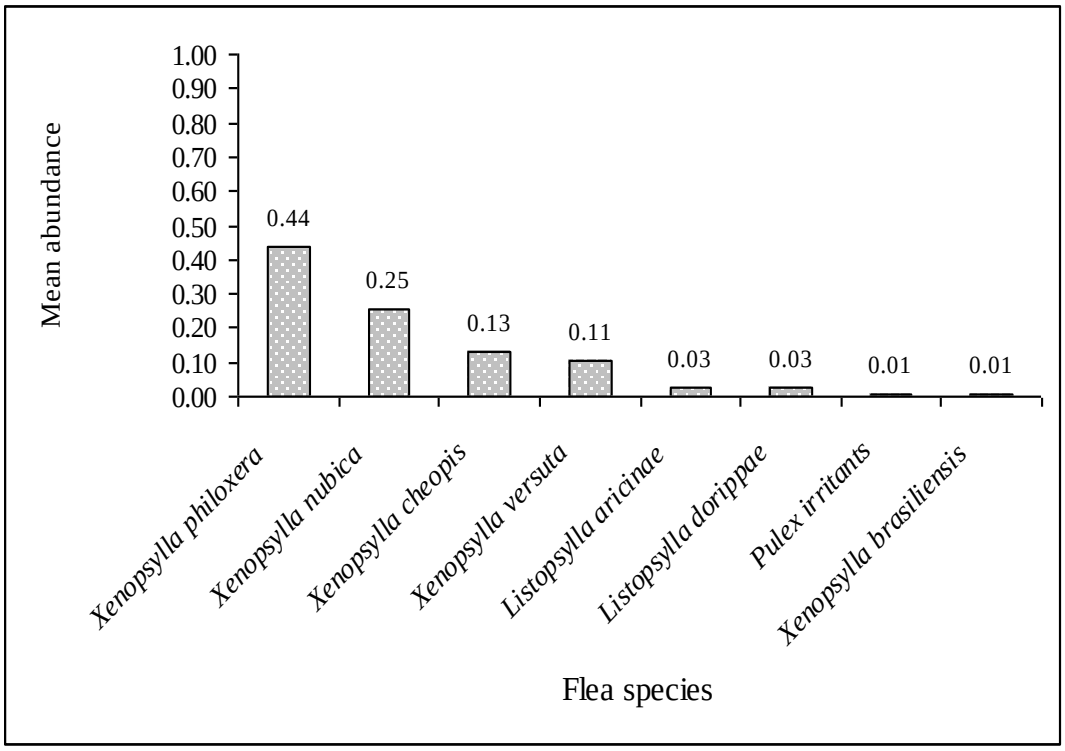

Figure 3.1(b) Mean abundance of fleas collected from small mammals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006).

3.3 Prevalence of fleas

As mentioned in section 2.3.2, Prevalence of infestation is the percentage of host animals that are infested by ectoparasites. Prevalence of fleas was calculated as the total

number of animals infested with fleas divided by the total number of host animals that were examined times hundred. Figure 3.1(c) demonstrates that the prevalence of fleas was highest in December and least in June. Kruskal-Wallis test revealed that there was a significant difference (H=5.58, *df*=4, *P*<0.001) in the prevalence of fleas amongst the 5 months. Mann-Whitney U test revealed the significant difference in prevalence of fleas during December and March (U=80.0, *P*=0.008), December and June (U=80.0, *P*=0.008) and during March and June (U=128.0, *P*<0.001).

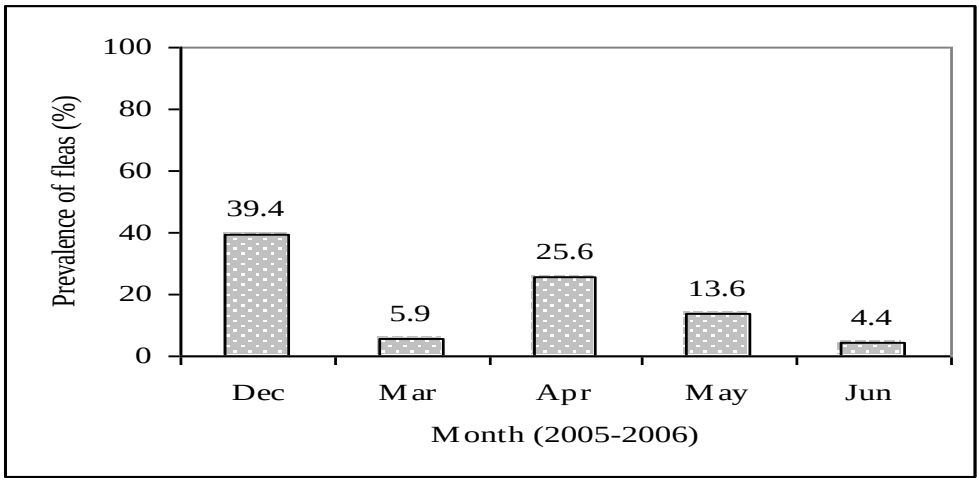

Figure 3.1(c) Prevalence (percentage infestation) of fleas irrespective of species of fleas and infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006).

Table 3.6 Prevalence of fleas on different species of host captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006). Sample size of hosts (number of small mammal) examined during the period of the study are presented in Appendix 8.

	Prevalence of fleas (%) (Year: 2005-2006)				
Host animal species	Dec	Mar	Apr	May	Jun
Aethomys chrysophilus	0	0	0	**100**	0
Aethomys namaquensis	0	0	**30.0**	0	**33.3**
Gerbillurus paeba	**30.0**	0	**16.7**	0	0
Mus indutus	**16.7**	0	0	0	0
Mastomys spp.	**75.0**	0	**33.3**	0	0
Tatera leucogaster	**60.0**	**14.3**	**50.0**	**25.0**	**22.2**

Fleas were most prevalent on hosts in December and April (Table 3.6). *Tatera leucogaster* was infested with fleas in all the months. *Aethomys chrysophilus*, *A. namaquensis* and *M. indutus* were least infested with fleas. The following 6 host species were not infested by fleas: *C. hirta, D. melanotis, G. murinus, G. vallinus, S. campestris and T. nigricauda.* Kruskal-Wallis test revealed that there was a significant difference (H=4.10, *df*=4, *P*=0.034) in the prevalence of fleas on different species of host amongst the 5 months. Mann-Whitney U test indicated the significant difference (*U*=1.0, *P*=0.016) in prevalence of fleas between *T. leucogaster* and *M. indutus* (Table 3.6).

Prevalence of fleas on female and male hosts is presented in Figure 3.2. Mann-Whitney U test indicated that there was no difference (*U*=8.0, *P*=0.347) in prevalence of fleas between female and male hosts. Figure 3.2 illustrates that prevalence of fleas was lowest in March for both male and female host, whereas the highest prevalence was recorded in December and May for males and females respectively.

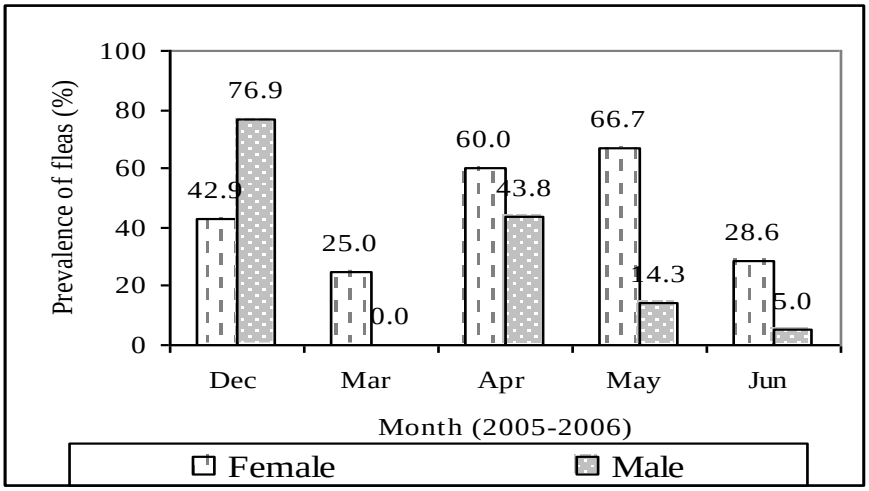

Figure 3.2 Overall prevalence of fleas with respect to sex of infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 except January & February 2006. Sample sizes for female (F) and male (M) small mammal hosts in different months were as follows: December F=14, M=19; March F=12, M=5; April F=17, M=22; May F=10, M=12; June F=26, M=42.

The relative frequency of fleas per host is presented on a frequency distribution figure in Appendix 11. A figure in Appendix 11 reveals that 83.8 % of small mammals examined were not infested by fleas whereas 8.9 % were infested by only one individual flea.

3.4 Intensity of infestation of fleas (total flea index)

As defined in section 2.3.1 of this paper, medians could not be used as it gives zeros. The intensity of infestation is the number of ectoparasites per host. *Tatera leucogaster*, *Mastomys* spp and *G. paeba* were selected for determination of monthly intensity of infestation of fleas on small mammals because they were captured in all months during the study period. *Aethomys chrysophilus, A. namaquensis* and *M. indutus* were excluded

as their sample sizes per month were small and in some months some host species were not caught as revealed in Table 3.1 & 3.6.

The intensity of infestation of fleas for *T. leucogaster*, *Mastomys* spp and *Gerbillurus paeba* are represented in Table 3.7.

Table 3.7 The intensity of infestation of fleas (number of fleas per infested host) on three selected infested host species captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 except January & February 2006.

	Intensity of fleas on selected host species (Year: 2005-2006)				
Host species	Dec	Mar	Apr	May	Jun
Tatera leucogaster	**10**	**1**	**1**	**1**	**2**
Mastomys spp.	**4**	**0**	**2**	**0**	**0**
Gerbillurus paeba	**1**	**0**	**1**	**0**	**0**

The intensity of infestation of fleas on selected host species ranged from 1 to 10 fleas per individual host. A Kruskal-Wallis test revealed that there was no significant difference in the monthly intensity of fleas for all host species: *T. leucogaster* (H=2.130, *df*=4, *P*=0.237); *Mastomys* spp. (H=2.308, *df*=4, *P*=0.145) and *G. paeba* (H=1.259, *df*=4, *P*=0.065). Mann Whitney U test revealed that there was no significant difference (*U*=11.0, *P*=0.754) in the intensity of infestation of fleas between female and male hosts.

Figure 3.3 reveals that, the intensity of infestation of fleas was lowest in March for both female and male hosts. However, the highest intensity of fleas was recorded in December for females and in May for male hosts.

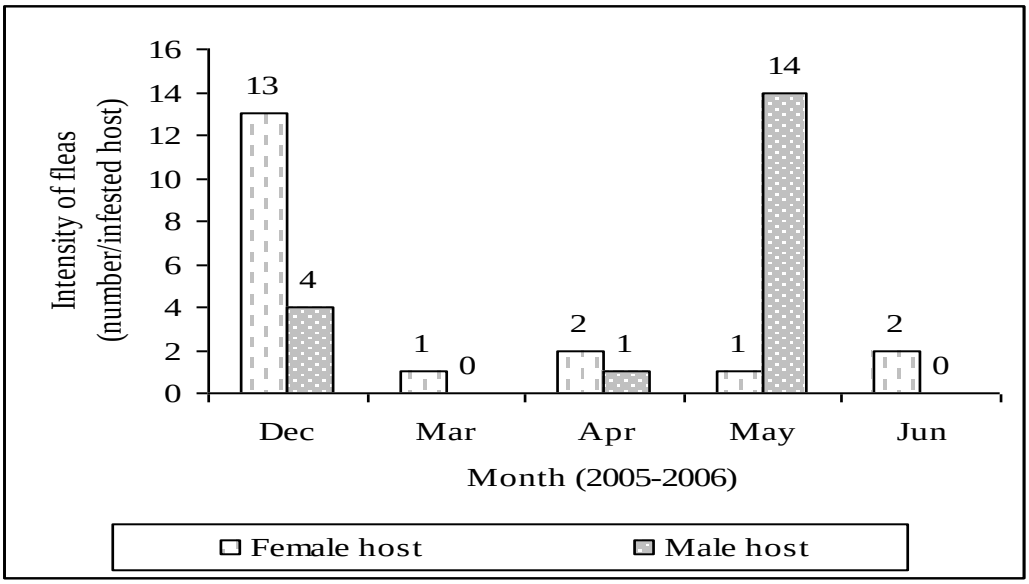

Figure 3.3 Intensity of infestation of fleas (number of fleas per infested host) with respect to sex of all infested hosts captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 excluding January & February 2006. Sample sizes for female (F) and male (M) small mammal hosts in different months were as follows: December F=14, M=19; March F=12, M=5; April F=17, M=22; May F=10, M=12; June F=26, M=42.

3.5 Species diversity of fleas

Species diversity (Shannon-Wiener's Index) of fleas on different small mammal captured in different months illustrated in Figure 3.4 (a) and Figure 3.4 (b) ranged from 0 to 1.68 and 0 to 1.30 respectively. A Kruskal-Wallis test revealed that there was a significant difference in species diversity of fleas amongst the 5 months on different host species ($H=4.65$, $df=4$, $P<0.01$). Species diversity was highest in December and least in March and June. Mann-Whitney U test indicated that there was a significant difference in species diversity of different species of hosts between December and March ($U=85.0$,

P=0.004) and between December and June (*U*=85.0, *P*=0.004). Figure 3.4 (b) reveals that species diversity of fleas was highest on *Mastomys* spp. during April and lowest during March and June for all host species infested. Generally, fleas were more diverse in April and less diverse in March and June 2006.

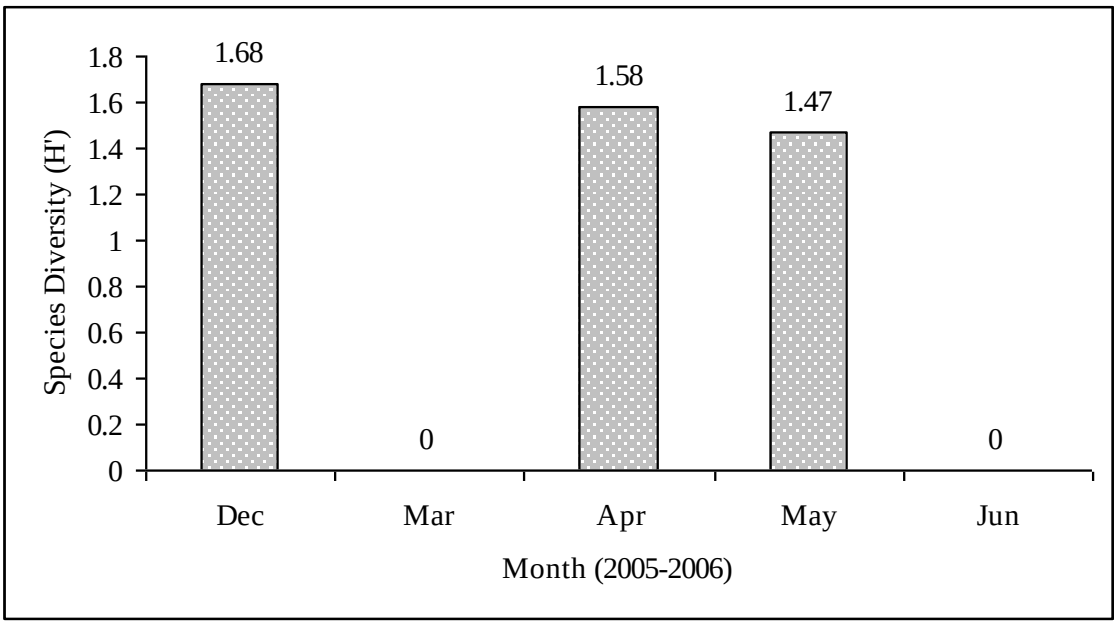

Figure 3.4 (a) Species diversity (Shannon-Wiener's Index) of fleas on small mammals encountered at Waterberg Plateau Park during the study period from December 2005, March, April, May and June 2006. Note: The species diversity presented in a graph is the actual calculated Shannon-Wiener's diversity index. Not the mean or median diversity. On the figure, 0 means that fleas collected belong to a single species.

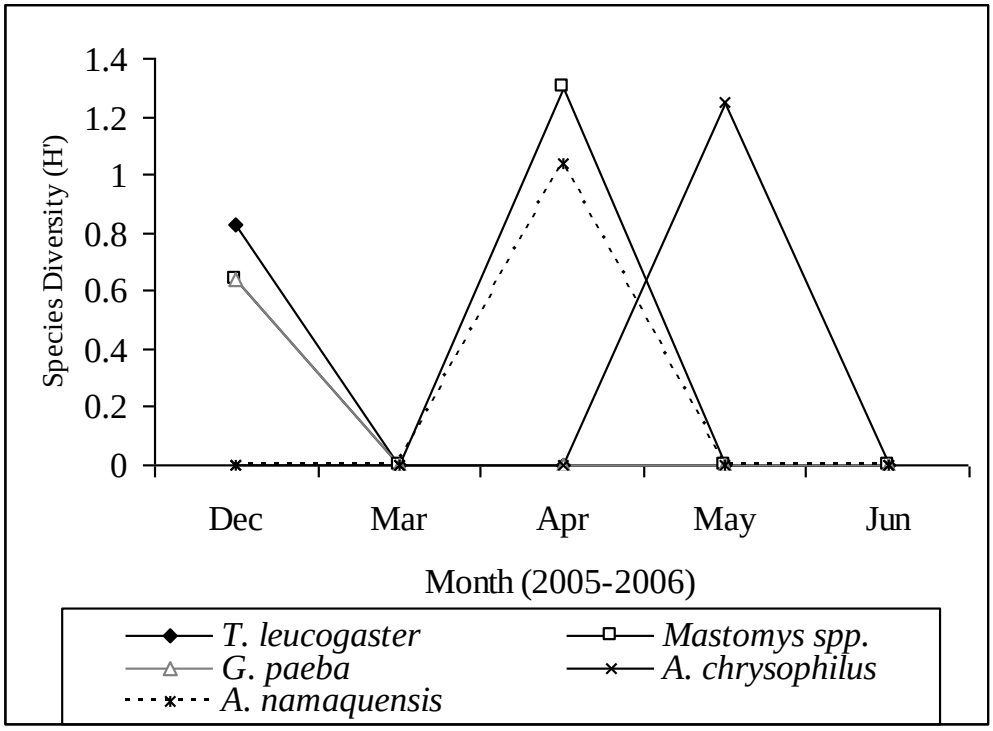

Figure 3.4 (b) Species diversity (Shannon-Wiener's Index) of fleas on different species of small mammals encountered at Waterberg Plateau Park during the study period from December 2005, March, April, May and June 2006.

Table 3.8 Species diversity (Shannon-Wiener's Index) of fleas recovered from female and male hosts encountered at Waterberg Plateau Park during the study period in December 2005, March, April, May and June 2006.

	Species diversity of fleas with respect to sex of host animals	
	Female	Male
Month (2005-2006)	Species diversity (H')	Species diversity (H')
December	0.6739	1.1860
March	0	-
April	0.7963	1.6770
May	0	1.2540
June	0	-

Note: (0) means only one species of flea recovered; (-) means no any flea recovered

Mann-Whitney U test (U=7.0, P=0.251) showed that there was no significant difference in species diversity between female and male hosts

3.6 Host species and tick species composition

Fifteen (15) ixodid tick specimens belonging to 3 species of ticks were recovered from 8 individuals of hosts belonging to 4 species of small mammals (Table 3.9). The 3 species of ticks were *Haemaphysalis elliptica* Audouin, 1826, *Hyalomma truncatum* Koch, 1844 and *Rhipicephalus neumanni* Walker, 1990. Figure 3.4(c) shows that *Hyalomma truncatum* was the most abundant species (80%) of all tick specimens collected whereas *Haemaphysalis elliptica* was the least (7%). *Gerbirullus paeba* had the highest infestation of ticks. All tick species collected were immature. Six individual ticks were in a larva stage, whereas 9 were in a nymph stage (Table 3.9). *Haemaphysalis elliptica* was only recorded on *G. paeba*.

Table 3.9 Tick species and their abundance on different host species captured at Waterberg Plateau Park from December 2005, March, April, May and June 2006. *n* represents the sample size of the host.

	Host species				
Tick species	*Aethomys chrysophilus* (*n*=1)	*Dendromus melanotis* (*n*=1)	*Gerbillurus paeba* (*n*=5)	*Mastomys* spp. (*n*=1)	Total
Haemaphysalis elliptica	0	0	1	0	**1**
Hyalomma truncatum	0	1	11	0	**12**
Rhipicephalus neumanni	1	0	0	1	**2**
Total	**1**	**1**	**12**	**1**	**15**

Hyalomma truncatum and *Rhipicephalus neumanni* were both recorded on 2 different host species with *H. truncatum* recorded in a highest number of 12 specimens. *Haemaphysalis elliptica* was only recorded on *G. paeba* (Table 3.9)

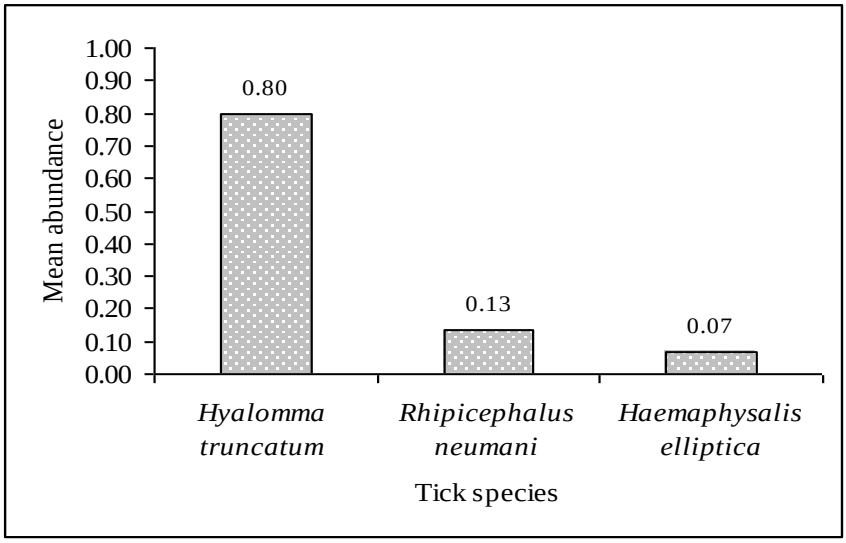

Figure 3.4(c) Mean abundance of ticks collected from small mammals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006).

Table 3.10 Number of immature stages of Ixodid tick species collected from 8 individual infested hosts encountered at Waterberg Plateau Park during December 2005, March, April, May and June 2006.

	Number of ticks collected		
Tick species	Larva	Nymphs	Total
Haemaphysalis elliptica	0	1	1
Hyalomma truncatum	5	7	12
Rhipicephalus neumanni	1	1	2
Total	6	9	15

Nymphs were more recovered than larvae. Most of the nymphs belonged to *H. truncatum*. Individual number of ticks recovered during 16 trapping sessions in each month is presented in Table 3.11.

Table 3.11 Seasonal abundance for the tick species collected during the study at Waterberg Plateau Park from December 2005, March, April, May and June 2006.

	Number of individual ticks (2005-2006)					Total
Tick species	Dec	Mar	Apr	May	Jun	
Haemaphysalis elliptica	1	0	0	0	0	1
Hyalomma truncatum	8	0	0	1	3	12
Rhipicephalus neumanni	0	0	1	1	0	2
Total	9	0	1	2	3	15

More individual ticks were collected in December than in other months. No ticks were collected during March as revealed in Table 3.11.

3.7 Prevalence of ticks

Prevalence is the percentage of host animals captured that are infested by ectoparasites (section 2.3.2). The prevalence of ticks during the trapping session of each month are presented in Figure 3.5, whereas prevalence of ticks on different species of hosts per trapping session of each month are presented in Figure 3.6. Kruskal-Wallis test revealed that there was no significant difference (H=1.799, *df*=4, *P*=0.156) in the prevalence of ticks amongst the in 5 months.

The prevalence of ticks was highest in December 2005 and least in March 2006 (no hosts were infested by ticks) as revealed in Figure 3.5.

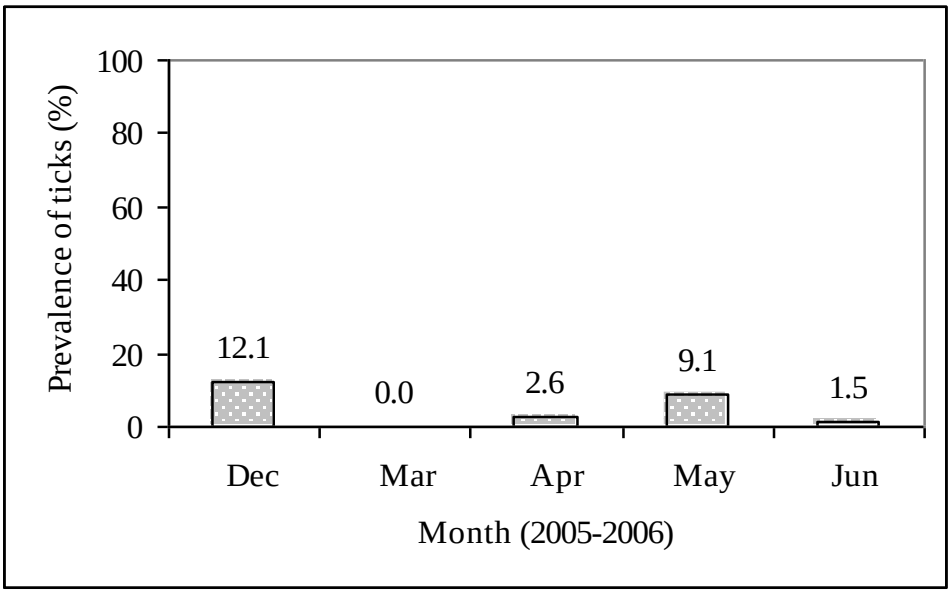

Figure 3.5 Prevalence (percentage infestation) of ticks irrespective of species of infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006).

Figure 3.6 indicates that the highest prevalence of ticks was in December and only *G. paeba* which was infested. In March, there were no hosts that were infested with ticks. In April and June, *Mastomys* spp. and *G. paeba* were the only host species infested with ticks respectively, whereas in May two host species: *A. chrysophilus* and *D. melanotis* were recorded infested by ticks by the same percentage. Kruskal-Wallis test revealed that there was no significant difference (H=2.128, *df*=4, *P*=0.276) in the prevalence of ticks on different species of host amongst the in 5 months.

The following 8 host species were not infested by ticks: *A. namaquensis, C. hirta, G. murinus, G. vallinus, Mus indutus, S. campestris, T. leucogaster* and *T. nigricauda.*

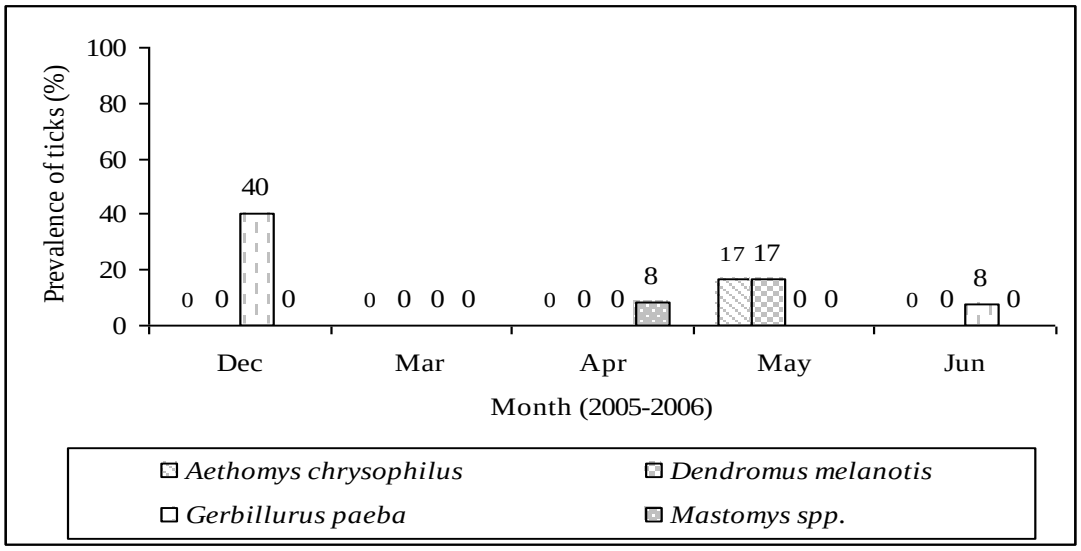

Figure 3.6 Prevalence (percentage infestation) of ticks in relation to the species of infested host animal species captured at Waterberg Plateau Park over a period of five months from December 2005 to June 2006 (excluding January & February 2006). Sample size of hosts (number of small mammal) examined during the period of the study are presented in Appendix 9.

Mann-Whitney U test revealed that there was no difference (U=9.0, P=0.465) in prevalence of ticks between male & female hosts. Figure 3.7 shows that no female and male hosts infested by tick were recorded in March, April & May and in March & June respectively. The prevalence of ticks on male small mammal hosts was highest in May 2006. Sample sizes of female and male hosts examined per trapping session of each month are presented in Table 3.2.

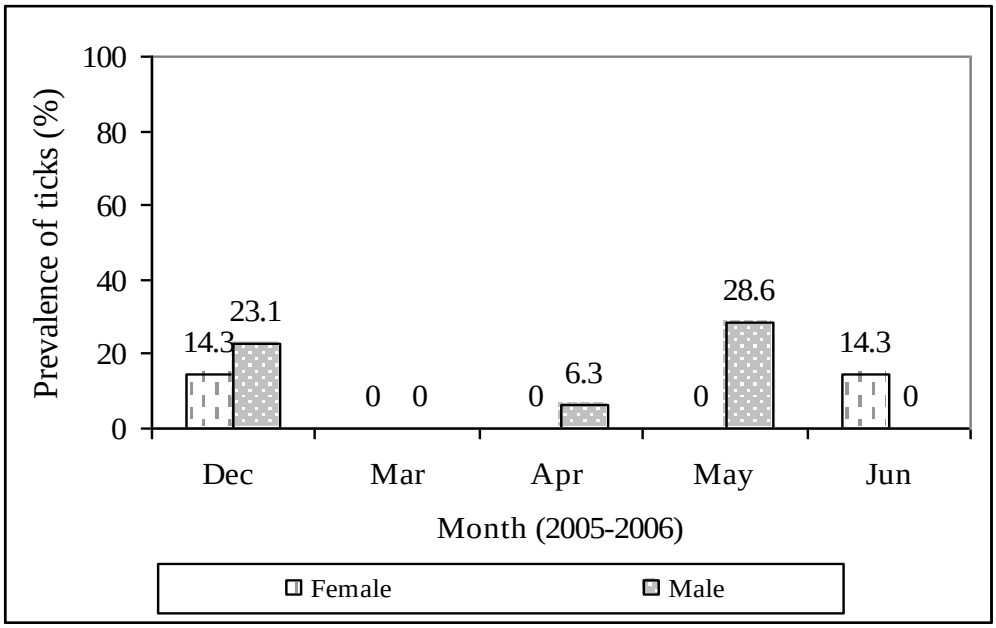

Figure 3.7 Prevalence (percentage infestation) of ticks with respect to sex of infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 except January & February 2006. Sample sizes for female (F) and male (M) small mammal hosts in different months were as follows: December F=14, M=19; March F=12, M=5; April F=17, M=22; May F=10, M=12; June F=26, M=42.

The relative frequency of ticks per host is presented on a frequency distribution figure in Appendix 12. A figure in Appendix 12 reveals that 95.5 % of small mammals examined were not infested by ticks whereas 2.8 % were infested by only one individual tick.

3. 8 Intensity of infestation of ticks (total tick index)

The intensity of infestation is the number of ectoparasites per infested host. As defined in section 2.3.1 of this paper, medians could not be used as it gives zeros which are meaningless; instead the actual calculated intensity of infestation of ticks was used. The

intensity of ticks of different species of hosts per trapping session of each month is presented in Table 3.12.

Table 3.12 The intensity of infestation of ticks (number of ticks per infested host) on infested host species captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006). *n* represents the sample size of the host.

	Intensity of ticks on infested host species (Year: 2005-2006)				
Host species	Dec	Mar	Apr	May	Jun
Aethomys chrysophilus (*n*=1)	0	0	0	**1**	0
Dendromus melanotis (*n*=1)	0	0	0	**1**	0
Gerbillurus paeba (*n*=5)	**2**	0	0	0	**3**
Mastomys spp. (*n*=1)	0	0	**1**	0	0

The intensity of infestation of ticks on infested host species ranged from 0 to 3 ticks on individual host (Table 3.12). Intensity of infestation of ticks was highest on *G. paeba* than on other infested hosts (Table 3.12).

The intensity of infestation of ticks on infested hosts ranged from 0 to 3 ticks per host (Figure 3.8). A Kruskall-wallis test revealed that there was no significant difference in the mean ranks of the monthly intensity of ticks between the host species ($H=1.734$, $df=4$, $P=0.171$).

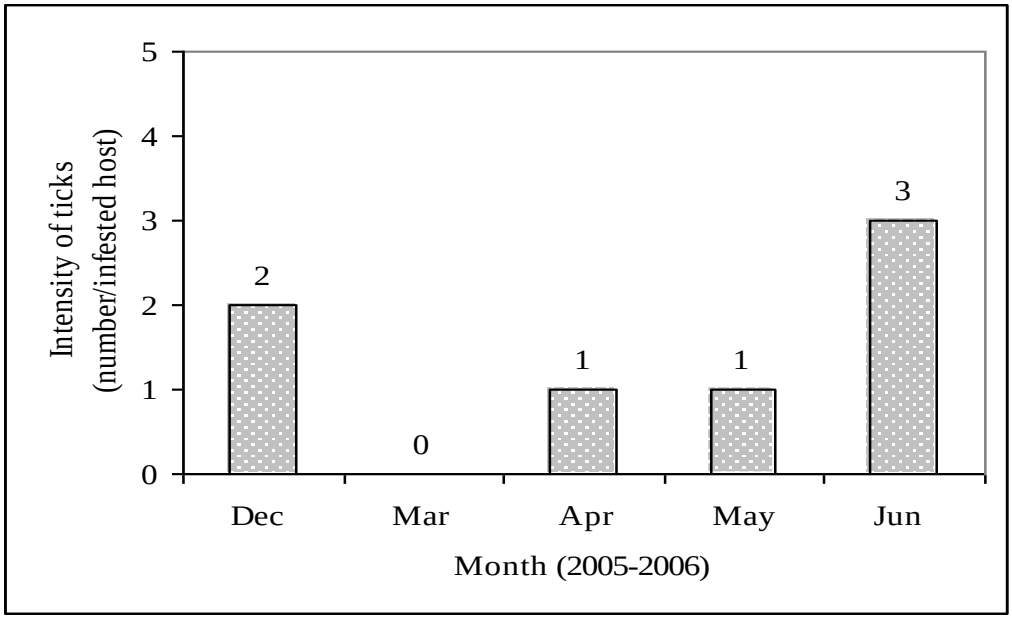

Figure 3.8 The intensity of ticks (number of ticks per infested host) on small mammals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 excluding January & February 2006. The sample sizes of hosts in each month are as follow: Dec=33, Mar=17, Apr=39, May=22, Jun=68.

Mann-Whitney U test (U=11.0, P=0.735) showed that there was no significant difference in the intensity of ticks between female and male hosts. Figure 3.9 illustrates that no ticks were recovered from male and female hosts in March 2006. Therefore intensity of ticks was lowest in March for both female and male hosts. However, the highest intensity of ticks was recorded in December for males and in June for females.

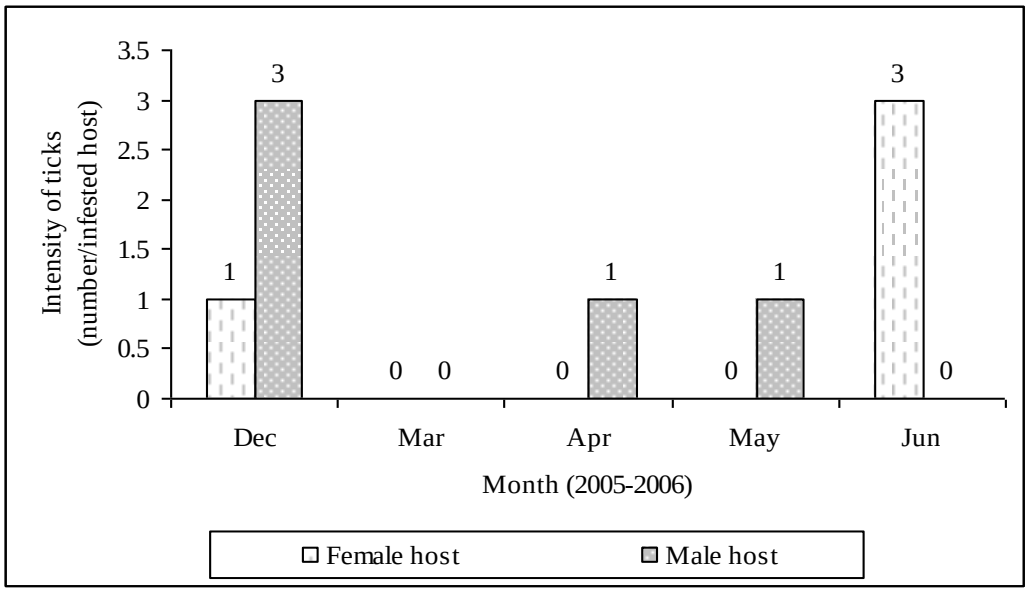

Figure 3.9 Intensity of ticks (number of ticks per infested host) with respect to sex of infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 excluding January & February 2006. Sample sizes for female (F) and male (M) small mammal hosts in different months were as follows: December F=14, M=19; March F=12, M=5; April F=17, M=22; May F=10, M=12; June F=26, M=42.

3.9 Species diversity of ticks

Species diversity (Shannon-Wiener's Index) of ticks on small mammals captured illustrated in Figure 3.10 ranged from 0 to 0.35. Kruskal-Wallis test revealed that there was no significant difference in species diversity of ticks between the 5 months (H=0.1481, *df*=4, *P*=0.406). Species diversity of ticks was highest in December and zero in all the other 4 months of the study period. No ticks were recovered during March. Only one tick was recovered from small mammal hosts in April. The three individual ticks recovered in June belonged to the same species.

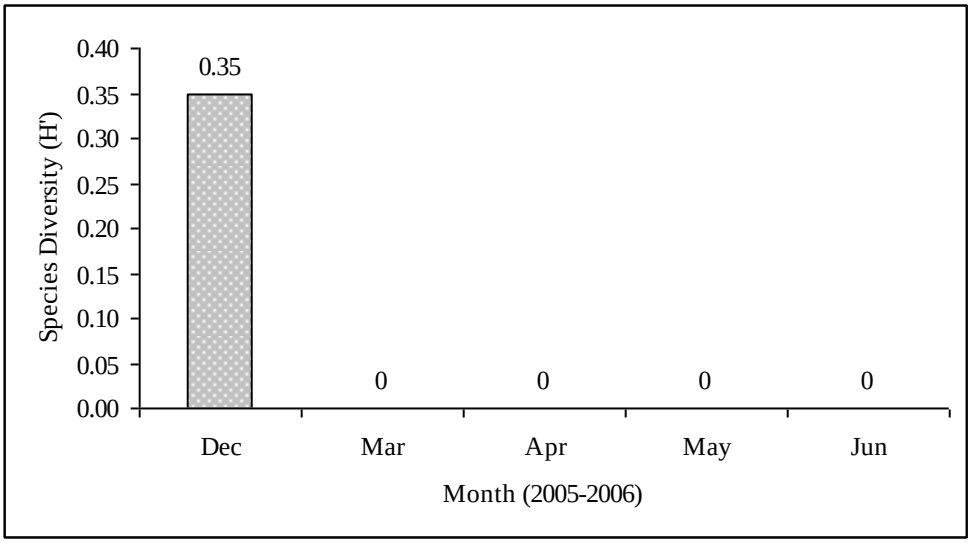

Figure 3.10 Species diversity (Shannon-Wiener's Index) of ticks recovered from small mammals encountered at Waterberg Plateau Park during the study period from December 2005, March, April, May and June 2006. Note: The species diversity presented in a graph is the actual calculated Shannon-Wiener's diversity index. Not the mean or median diversity. 0 means, only a single species of ticks recovered in April, May and June; in March no ticks were recovered. The sample sizes of hosts in each month are as follow: Dec=33, Mar=17, Apr=39, May=22, Jun=68.

There were no ticks recovered from female and male hosts in March, April, May and June respectively. However, ticks recovered from female hosts during December and June and from male hosts during April belonged to only one species. Only male hosts harboured a diverse community of ticks in December (H'=0.3488) & May (H'=0.6931). Mann-Whitney U test revealed that there was no significant difference (U=7.5, P=0.296) in the species diversity of ticks between the female and male hosts amongst 5 months.

3.10 Prevalence of mites

Prevalence of mites is the percentage of host animals that are infested by ectoparasites (section 2.3.2). Prevalence was calculated as the total number of infested host animals divided by the total number of host animals that were examined times hundred. The prevalence of mites did not vary much in different months (Figure 3.11). Prevalence was highest in May (45.5%) and lowest in March (35.3%). Kruskal-Wallis test revealed that there was no significant difference (H=6.775, *df*=4, *P*=0.098) in the prevalence of mites amongst the 5 months. Prevalence of mites on different species of hosts is presented in Table 3.13.

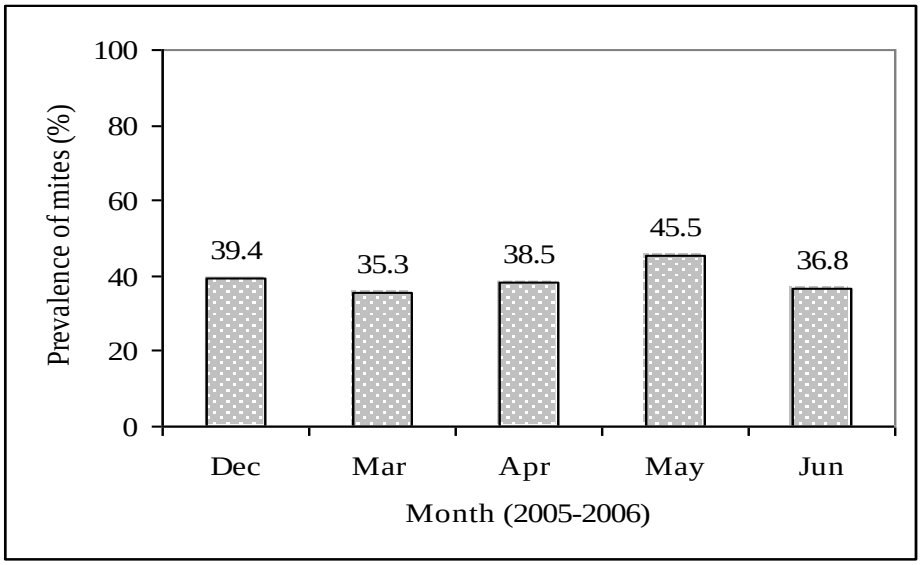

Figure 3.11 Prevalence (percentage infestation) of mites irrespective of species of infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 (excluding January & February 2006). The sample sizes of hosts in each month are as follow: Dec=33, Mar=17, Apr=39, May=22, Jun=68.

Table 3.13 Prevalence (Percentage infestation) of mites in relation to the species of infested host animal species captured at Waterberg Plateau Park over a period of five months from December 2005 to June 2006 (excluding January & February 2006). Sample size of hosts (number of small mammal) examined during the period of the study are presented in a table Appendix 10.

	Prevalence of mites (%) per month (Year: 2005-2006) with respect to host animal species				
Host animal species	Dec	Mar	Apr	May	Jun
Aethomys chrysophilus	0	0	0	**100**	0
Aethomys namaquensis	0	0	0	0	**33.3**
Dendromus melanotis	0	0	0	**50.0**	**58.8**
Gerbillurus paeba	**40.0**	**50**	0	**25.0**	**7.7**
Mastomys spp.	**50.0**	**33.3**	**91.7**	**100**	**100**
Saccostomus campestris	0	0	**100**	0	0
Tatera leucogaster	**70.0**	**28.6**	**75.0**	**37.5**	**22.2**

Mites were most prevalent on hosts in May and June (Table 3.13). *Mastomys* spp. and *T. leucogaster* were infested with mites in all the months. Mites were only present on *A. chrysophilus, A. namaquensis* and *S. campestris* during 1 of the 5 months. Kruskal-Wallis test revealed that there was no significant difference (H=5.789, *df*=4, *P*=0.510) in the prevalence of mites on different species of hosts amongst the 5 months.

The following 5 host species were not infested by mites: *C. hirta, G. murinus, M. indutus, G. vallinus and T. nigricauda.*

Mann-Whitney U test (*U*=2.0, *P*=0.028) revealed that there was a significant difference in prevalence of mites between female and male hosts. Figure 3.12 shows that prevalence of mites was lowest in April and December for female and male hosts

respectively, whereas the highest prevalence was recorded in December and May for females and males respectively.

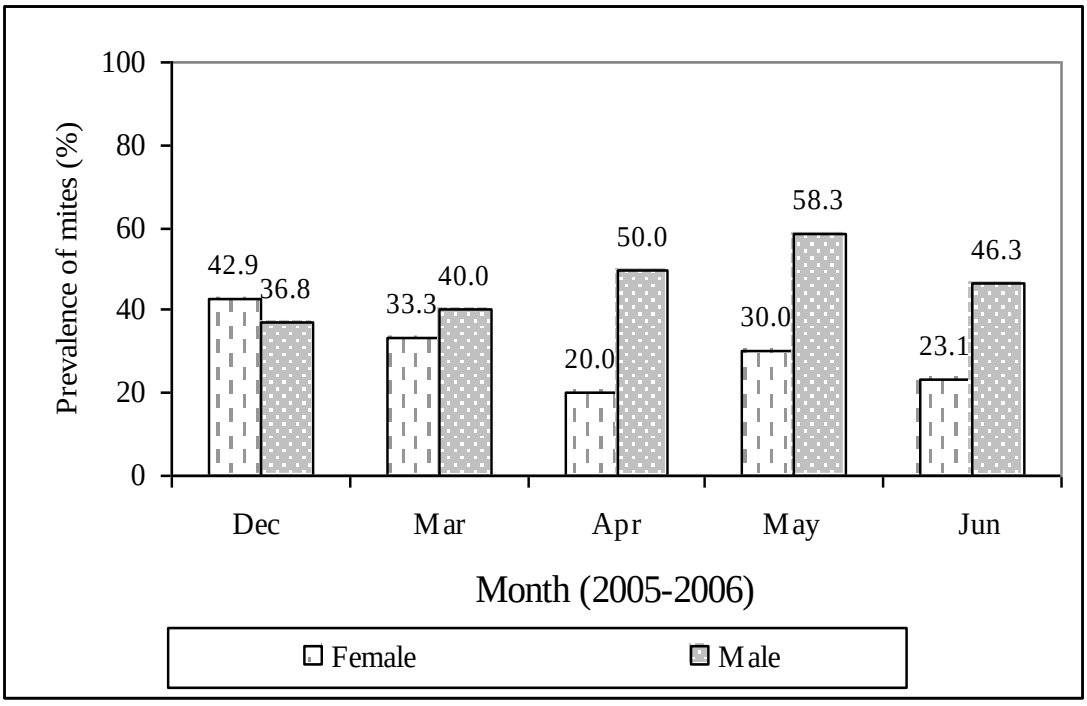

Figure 3.12 Prevalence (percentage infestation) of mites with respect to sex of infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 excluding January & February 2006. The sample sizes of female and male hosts examined during the study is presented in Table 3.2.

The relative frequency of mites per host is presented on a frequency distribution figure in Appendix 13. A figure in Appendix 13 reveals that 61.5 % of small mammals examined were not infested by mites whereas 7.8 % were infested by only one individual mite.

3.11 Intensity of infestation of mites (total mite index)

The intensity of infestation was calculated as the total number of mites recovered per monthly trapping session per host infested by mites. *T. leucogaster*, *Mastomys* spp. and *G. paeba* were selected for analysis of mean intensity of infestation of mites on small mammals because they were captured in all months and their sample sizes were large. The mean was used instead of medians because medians were found to be zeros (refer to section 3.4 & 3.8). *A. chrysophilus*, *A. namaquensis*, *D. melanotis* and *S. campestris* were excluded because of small sample sizes as revealed in Table 3.1. The mean intensity of infestation of mites for *T. leucogaster*, *Mastomys* spp and *Gerbillurus paeba* are represented in Table 3.14

Table 3.14 Intensity of infestation of mites (number of mites per infested host) on three selected infested host species captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 except January & February 2006.

	Intensity of infestation of mites (Year: 2005-2006)				
Host species	Dec	Mar	Apr	May	Jun
Tatera leucogaster	**6**	**8**	**8**	**9**	**10**
Mastomys spp.	**3**	**8**	**9**	**12**	**4**
Gerbillurus paeba	**2**	**4**	0	**2**	**1**

The intensity of infestation of mites on selected host species ranged from 0 to 12 mites per individual host. Kruskall-wallis test revealed that there was no significant difference in the mean ranks of intensity of infestation of mites in different monthly trapping sessions for host species; *T. leucogaster* (H=1.187, *df*=4, *P*=0.608) and *G. paeba* (H=0.9763, *df*=4, *P*=0.397). However, a significant difference was detected on

Mastomys spp. (H=7.266, *df*=4, *P* <0.01). Mann-Whitney U test revealed significant differences in intensity of infestation of mites of *Mastomys* spp. between December & April (*U*=68.0, *P*=0.004), March & April (*U*=73.0, *P*=0.009), April & May (*U*=78.0, *P*=0.022) and between April & June (*U*=71.0, *P*=0.007)

Mann-Whitney U test revealed that there was no significant difference (*U*=9.0, *P*=0.465) in the intensity of infestation of mites between females and male hosts. Figure 3.13 reveals that, the intensity of infestation of mites on both female and male hosts increased from December to April and start decreasing as from May. The lowest intensity of mites on both female and male hosts was recorded in December whereas the highest intensity of mites was recorded in April for male hosts and in May for female hosts.

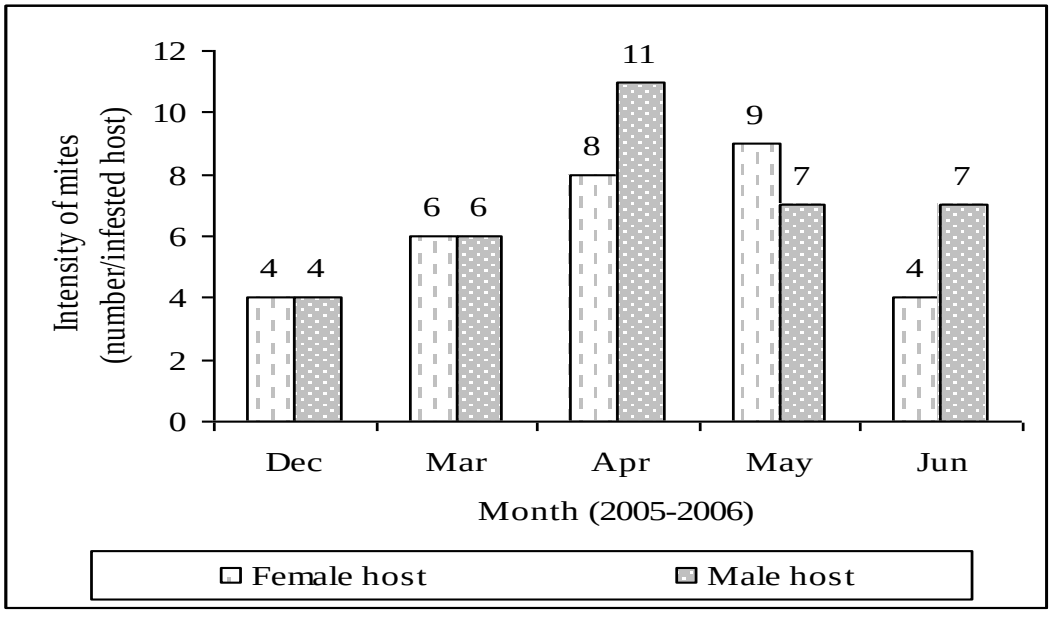

Figure 3.13 Intensity of mites (number of mites per infested host) with respect to sex of infested host animals captured at Waterberg Plateau Park during the study period from December 2005 to June 2006 excluding January & February 2006. Error bars can not be presented due to reasons stated in section 3.4 above figure 3.3.

3.12 Species diversity of mites

Mites could not be identified. However, the mite specimens were sent to South Africa for identification.

3.13 Lice

Lice could not be identified and only 3 individual specimens were collected. The lice specimens were not sent anywhere because lice taxonomist can not be found so far.

CHAPTER 4 DISCUSSION

Small mammals at Waterberg Plateau Park were not found to be unique as anticipated. All small mammal species captured have been recorded in most areas of Namibia. However, *D. melanotis* was not recorded before in the area of Waterberg. The ectoparasite taxa recorded in the present study comprise fleas, lice, mites and ticks. The flea species were not unique at this area. However, the present study recorded a larva belonging to a tick species *Rhipicephalus neumanni* for the very first time from small mammals that occur naturally in the field (Horak pers. comm. 2006). The nymph of *R. neumanni* was also recorded only for a second time in the wild. Walker *et. al.,* (2003) indicate that sheep are the preferred host and to lesser extent goats. Lice and mites could not be identified and therefore, species of these ectoparasites are not discussed in this study.

4.1 Fleas

In the present study, the flea species *Listropsylla aricinae, Pulex irritans* and *Xenopsylla brasiliensis* exclusively infested rodents *Aethomys chrysophilus, Tatera leucogaster and Mastomys* spp. respectively (Table 3.4). This pattern may suggest that these flea species are either host specific or perhaps they prefer these hosts. According to Rosenweig (1996), host specificity is ecologically important because fleas have evolved mechanisms to escape or reduce biotic pressures such as competition. It might also be possible that some fleas were not collected from the specific hosts because the hosts

were only brushed on their posterior part of their body. Density dependant optimal foraging theory predicts that individuals of competing species should restrict themselves to their special habitats, only when they and their competitors of other species are similarly common (Rosenweig, 1996). When species restrict themselves to their special habitats, they compete minimally and this gives them the best chance to survive and co-exist.

In contrast, Kangombe (2005) found *X. brasiliensis* as a host generalist or broad niche species after this particular species was recorded on three different host species: *T. leucogaster, G. paeba* and *T. nigricauda* during her study. Braak *et al.* (1996) also reported that the principal hosts for flea species *X. brasiliensis* include *Aethomys, Mastomys, Rattus* and *Thallomys.*

However, the flea species *Xenopsylla cheopis* and *Xenopsylla versuta* were recorded on five and four different host species respectively (Table 3.4). This suggests that these flea species are not host specific and they lack host preference. Many fleas utilize an intermediate strategy between total specificity and generalization and several studies describe different host species being shared by a particular flea species (Bittencourt, 2003). Trips (1994) reported that lack of host specificity may increase the potential for acquisition and interspecific transmission of pathogens among wild animals. It may also be disadvantageous for any ectoparasite to be host specific because if the specific host is not available, it will suffer and it may as well die. The flea species *X. cheopis* is believed

to be one of the most efficient and the principal vector of bubonic plague from rodents to man in the epidemiological history of plague in Southern Africa (Scientific and Industrial Research Organization: Division Entomology, 1979; Segreman, 1995) as well as in Namibia (Shangula, 1998). *X. cheopis* success as a principal vector of bubonic plague is probably based on the fact that it shows no host preference or host specificity pattern.

This study has shown the significant seasonal variation in the occurrence of fleas at Waterberg Plateau Park. The Prevalence was higher (39.4%) during summer (December 2005), the time when it was very hot and dry, than during autumn (March 2006, warm & wet) and winter (June 2006, cold & dry) as revealed in Figure 3.1 and Table 3.6.

Unlike lice, which are little affected by climate, Twigg, (1978) reported that fleas often undergo seasonal cycles where adult fleas become most abundant during summer season. This is because part of the life cycle of fleas (eggs) is spent on the host where the eggs are deposited in the host fur and carried into the burrows and hatched successfully due to stable climate in burrows but since egg can fall off from the host while foraging they can be exposed to harsh climatic conditions and may not survive. The larvae and eggs of fleas develop only within fairly narrow temperature and humidity ranges: *Xenopsylla cheopis* -13^{o}C to 34+^{o}C; *Pulex irritans* -8^{o}C to 34^{o}C; *Nosopsyllus fasciatus* - 5^{o}C to 29^{o}C (Twigg, 1978). The larvae show similar but narrower ranges of tolerance (Twigg, 1978).

This study found a weak negative correlation between number of fleas per 16 trapping session of each month & the monthly mean rainfall (r=-0.4407) however, there was a strong positive correlation between number of fleas and the mean temperature (r=+0.8878). The biological reason for high abundance and prevalence of fleas when temperature is higher is not known as the author did not come across such information. But, it is assumed that high number of fleas and higher prevalence during summer was most probably due to fleas reproduction activities as fleas mate and eggs are laid on the host before winter in order for the lifecycle to be completed and not necessarily because of the number of hosts as there was a very weak negative correlation between number of fleas recovered (r=-0.1226), prevalence (r=-0.1575) and the total number of hosts examined. Therefore, climate especially temperature and humidity is important in the maintenance of flea populations on mammals and within their burrows (Twigg, 1978).

Marshall (1981) and Makundi & Kilonzo (2004) reported that the apparent changes in flea population according to season and climate could easily be caused by fluctuations in the number of hosts or changes in their activities. When hosts are fewer especially during winter, ectoparasites to be found might be fewer because there will be inadequate niche for the ectoparasites to live and survive, the cold condition may also not be favourable for the ectoparasites as it does to the host. They further reported that seasonal changes in the prevalence of fleas are generally common especially in areas with pronounced seasonality in temperature and rainfall. In a study in the Lake Nakuru National Park in Kenya, Schwan (1986) was able to demonstrate seasonal variations in

the prevalence and abundance of fleas infesting rodents. Similar observations have been made in Vietnam (Olson, 1969), (java (Hirst, 1927); (the United States of America (Layne, 1963; Smith, 1955; Eskey and Haas, 1940); (Hawaii (Kartman *et al*., 1955) all In: Makundi and Kilonzo (1994)).

The host species *Aethomys chrysophilus*, *Aethomy namaquensis*, *Gerbirullus paeba*, *Mus indutus*, *Mastomys* spp and *Tatera leucogaster* were infested by fleas whereas, *Crocidura hirta*, *Dendromus melanotis*, *Graphirulus murinus*, *Gerbirullus vallinus Saccostomus campestris* and *Thallomys nigricauda* did not habour any flea (Table 3.4 & 3.7). This suggests that the host species may influence the prevalence of fleas. This was supported by Price (1977); Kuris *et al.* (1980); Kennedy (1990) who reported that habitat (host) selection of a particular parasite is related to a host because parasites needs a host which provides it with a place to live, forage, mate and lay their eggs. Ectoparasites are generally subjected to both on-host conditions (e.g. body temperature) and external environment of the host and therefore, the structure of parasite communities and diversity are more determined by this complex host-habitat-parasite relationships (Karsnov *et al*., 1998; Bell & Burt, 1991; Buchman, 1991; Guegan *et al*., 1992). Different species of host which harbor fleas fill different niches and hence offer different types of conditions for flea to perform their life activities.

A higher prevalence of fleas was observed in *T. leucogaster* which was also infested throughout the study period whereas *Mastomys* spp. and *G. paeba* were only infested

during December 2005 and not during March and June 2006 (Table 3.7). This pattern suggests that temperature and rainfall seem to influence the prevalence of fleas on host species. The relevance of climatic conditions in the incidence of plague in India was investigated and their findings made it clear that epidemics only occurred at certain times of the year in certain parts of India. There was a periodicity in the number of cases at any place and it was also found that there were certain optimum conditions for fleas: For example a relative humidity of 0.70 and a temperature of between 18.3^{o}C and 29.4^{o}C were the favourable conditions for the hatching of flea larvae. On the other hand, very high temperature of over 29.4^{o}C and dry air would reduce the period of infectivity, the length of the flea's life and also the larval production of the flea (Twigg, 1978).

The seasonal prevalence of plague at that time in India illustrated that broadly, a rise in temperature to a daily average of 28^{o}C combined with a drop in the relative humidity have caused a fall in the number of cases. In Bombay the heaviest epidemic was in the early part of the year whereas in May to July, when the daily average temperature was 35^{o}C, there were only sporadic cases. At Poona, 80 miles away but at 2,000 feet, epidemic occurred in the last part of the year, the off season being March to May when the weather was dry.

In places such as Java with a more uniform climate there are small fluctuations in epidemics. The periodicity in this climate runs parallel with variations in the flea index. In India too, although early studies have indicated that temperature and saturation

deficiency of the air bore a critical relation to epidemics of plague, where climatic conditions were at all times suitable to the onset and spread of plague, the disease could occur throughout the year (Brooks, 1917: In Twigg, 1978).

A higher prevalence observed in *T. leucogaster* (Table 3.5 & 3.7) could be attributed to the fact that the physical contact of this particular species may be necessary during communication for precise species recognition (Mills & Hes, 1997). This habit provides an opportunity for transfer of fleas from one host to another. This can also be explained by behavioral differences of flea species, and a general health of the hosts. The host species *C. hirta* for example which did not harbor any flea was observed to be in generally good health condition with high fat content (observed when tattooing) as compared to the rest of the host species captured. Animals which are in good health are unlikely to be infested.

Mann-Whitney U-test revealed that there was no significant difference in the percentage infestation (U=8.0, P=0.347), intensity of infestation (U=11.0, P=0.754) and species diversity (U=7.0, P=0.251) of fleas between female and male hosts during this study. This was in contrast with many studies which have reported sexual differences in the prevalence of fleas such as a study by Prez-orella & Schulte-Hostedde (2005) and Kangombe (2005) which reported higher prevalence in males than in females. This was the case perhaps because males are more active foragers and eat larger quantity of food than females making males to have a greater chance of acquiring infective larvae and/or

the other hosts that are infested. Male hosts are also known to be more infested by variety of ectoparasites as most of ectoparasites are known to favor the host den (Holland, 1949). In fact, the only time that some species of ectoparasites leave the nest is when they are on the animal when the animal is outside during the mating season. Because male hosts appear to relocate to different nests and move greater distances than females (Wells-Gosling and Heaney, 1984), it is possible that natural selection has favoured some ectoparasite species in which males maximize dispersal distances and minimize inbreeding (Walter & Proctor, 1999). However, a case at WPP was different in that there were no significant difference in intensity of infestation between females and male hosts, suggesting that sex of the host is not a factor to the intensity of fleas. This is most probably because both female and male hosts share the same burrows. In support of this study, Kangombe (2005) reported a non-significant difference in intensity of infestation and species diversity of fleas between female and male hosts.

The non significant difference (Table 3.7) observed in the intensity of infestation of fleas among *T. leucogaster, Mastomys spp.* and *G. paeba* during the period of the study may be influenced by the method used to brush off the fleas. The animals were brushed alive. Due to handling, not all parts of the animal could be brushed especiallt the head part. However, flea intensity is known to be inversely proportional to rainfall (Olson, 1969) and plague epidemics are of greater duration and intensity in dry months or years. (Hirst, 1927 In: Twigg, 1978) showed the predilection of *X. cheopis* for warm and dry conditions, flea count being temporarily lowered on rain days which was also the case

during this study. In contrast, Cole (1945) indicated that the intensity of infestation of *X. cheopis* was correlated with the temperature but not with rainfall, relative humidity or saturation deficit.

It was found that temperature had a differential effect upon the sexes of *Xenopsylla*. On days when the mean temperature was high (21^{o}C-24^{o}C), males outnumbered females on rats, but on colder days the reverse was found. In order to survive, both sexes must feed more frequently at higher temperatures, but the effect was reported to be greater on the males (Cole, 1945), most probably because males require feeding before the epithelial plug is unblocked in the testes (Akin, 1984 In: Rust & Dryden, 1997) in order to perform their reproduction activities.

As stated at the beginning of the discussion, the monthly comparison will mostly be done between December, March and June. The observed higher species diversity of fleas in December than in March and June is still not clear. However fleas seem to be more active when it is dry and hot rather than when it is raining or when it is cold. This was supported by a Kruskal-Wallis test ($H=4.65$, $df=4$; $P<0.01$) and a Mann-Whitney U test which detected a significant difference in species diversity of fleas between December & March ($U=80.0$, $P=0.008$) and between December & June ($U=80.0$, $P=0.008$). Species diversity in March and June could not be calculated as the individual fleas recovered during these months belonged to a single species (*X. philoxera*) as revealed in Figure 3.4. This suggests that the activity of most species of fleas is influenced by changes in

temperature and rainfall (humidity). The mean temperature and rainfall during the study months in December 2005, March and April 2006 were recorded as: 36^{o}C & 2 mm, 23^{o}C & 130 mm and 14^{o}C & 1 mm respectively (Appendix 1). This study has revealed that fleas are probably more active when it is dry and hot rather than when dry and cold or when it is wet and warm probably because during rain fleas and their eggs may be susceptible to drowning and during winter they can die of the cold.

4.2 Ticks

The tick species *Haemaphysalis elliptica* exclusively infested the rodent *Gerbirullus paeba* (Table 3.10). This pattern suggests that this tick species either prefers that host or it is host specific. In contrast, domestic dogs and wild carnivores, such as the larger cats, foxes, jackals and wild dogs, are reported to be the main hosts of adult *H. elliptica* (Walker *et al*., 2003). The immature stages of this particular tick species prefer murid rodents, but may occur on the same hosts as the adults. The literature contains many references to *H. elliptica* feeding on cattle and other livestock, but this species is primarily specialized to feed on carnivores and the records from livestock may result from the close association between domestic dogs and livestock (Walker *et al*., 2003). Adult stages of *H. elliptica* attach on the head, neck and shoulders of the host, suggesting that this tick species is a site specific, but in severe infestation Walker *et al*. (2003) reported that they attach all over the body.

In the present study, ticks did not show a significant difference in their abundance, intensity or species diversity among the 5 months.

Unlike fleas which move around in the host fur, ticks are known to be stationary on their host, site specific and remain attached tightly on the host body. Since the head and neck of the hosts were not searched for ticks due to handling of the hosts, more *H. elliptica* could have been collected if the animals were killed and a full examination on all parts of the body was done. This in a way reduced the number of ticks collected. Therefore it should be considered that the changes in the abundance, prevalence, intensity and diversity of ticks indicated as seasonal may have been influenced by other factors such as temperature and humidity and the method used for tick collection during the study. During the present study, it was observed that ticks were present on host when it was cold or warm and dry, however ticks were not recovered when it was warm and very wet, implying that they do not like rain probably because they can drown. This study found that there was a negative correlation between the number of ticks and rainfall (r=-0.5963), however there was a strong positive correlation between number of ticks and the temperature (r=+0.7474).

The tick species *Hyalomma truncatum* and *Rhipicephalus neumanni* were both recorded on two different host species *Dendromus melanotis* & *Gerbirullus paeba* and *Aethomys chrysophilus & Mastomys* spp. respectively (Table 3.9). This suggests that these tick species are not host specific and they may lack host preference. However, Walker *et al*.

(2003) reported that the preferred hosts of adult *H. truncatum* are large domestic herbivores (cattle, sheep, goats, camels and horses) and wild herbivores. Giraffes and domestic dogs can be particularly heavily infested. Adult ticks attach to herbivores in the tail switch, around the anus, on the lower perineum, and on the legs, including around the feet. The immature stage feed on hares and on rodents, particularly gerbils and can also attach to humans.

By far the commonest recorded hosts of *R. neumanni* adults are sheep. They have also been found on both Karakul and Boer goats, and once on a horse. *R. neumanni* usually attach on the feet between claws and they have been known to affect up to 300 sheep at a time and the host of immature stages in the field are not known (Walker, 1990). In this study, the immature stages (1 nymph & 1 larva) were collected from the rodents (*A. chrysophilus* (nymph) & *Mastomys* spp. (larva)). According to Horak (pers. comm., 2006), it is the very first time that a larva of this particular tick species was recorded from natural occurring rodent species, whereas, it is only a second time the nymph of *R. neumanni* was recorded from rodents in the Southern Africa region.

Haemaphysalis elliptica is a three-host tick (Walker *et al*., 2003). The female feeds for 1 to 2 weeks, engorging slowly initially but rapidly on the last day before detachment. She lays approximately 5000 eggs within 7 to 28 days of detaching from host animal. The eggs hatch within 2 to 26 weeks and the nymph within 2 to 7 weeks. Adults are present throughout the year with peak numbers either from winter to early summer or from

spring to early summer or from spring to late summer (Walker *et al*., 2003). *H. truncatum* undergoes two-host life cycle, which normally takes a year to complete. Adults are present in the largest numbers in the late wet summer months and the immature stages in the dry autumn to spring months. The life cycle of *R. neumanni* is not yet well known, however in the laboratory condition, this particular tick behaves as a three-host species (Walker, 1990). The larvae and nymphae were fed on rabbits and the adults on sheep. One female laid a total of 3 420 eggs. When kept in incubator unfed larvae survived for ±150days, unfed nymphae for ±180, and adult for over 150 days. Seasonal occurrence of *R. neumanni* is not yet well known (Walker, 1990).

The host species *Aethomys chrysophilus*, *Dendromus melanotis, Gerbirullus paeba*, and *Mastomys* spp were infested by ticks whereas, *Aethomys namaquensis, Crocidura hirta*, *Graphirulus murinus*, *Gerbirullus vallinus, Mus indutus*, *Saccostomus campestris, Tatera leucogaster* and *Thallomys nigricauda* did not harbor any ticks (Table 3.4 & 3.13). This suggests that the host species may influence the prevalence of ticks. Ticks attach to different host species because they provide specific niches for ticks to perform their life activities. Generally, the greater the habitat (i.e host) variety, the greater the species diversity, which contribute to the amount of niches available within that particular habitat (Rosenzweig, 1996).

A higher prevalence of ticks was observed in *G. paeba* which was the only host species infested during December whereas *A. chrysophilus, D. melanotis* and *Mastomys* spp.

were infested only during April and May 2006 (Figure 3.6). The characteristic combination of temperature and rainfall and in an area was reported to have a very strong influence on the ability of species of ticks to survive in those areas (Walker *et al*., 2003). The general prevalence of ectoparasites has been reported to be higher on male hosts than on females (Prez-orella & Schulte-Hostedde, 2005: Walter & Proctor, 1999). However, in the present study no significant difference in the prevalence (U=9.0, P=0.465), intensity of infestation (U=11.0, P=0.735) and species diversity (U=10.0, P=0.317) of ticks between females and male hosts were recorded (Figure 3.7 & 3.9; page 68). This is perhaps due to a shorter period of this study or the way the ticks were recovered from the hosts due to handling as they had to be removed while the animals were alive. Due to the very small sample size of ticks and their hosts, the intensity of ticks within the host species across months could not be tested statistically. The intensity of infestation of adult ticks on dogs and wild carnivores of Transvaal, South Africa was reported by Horak *et al*. (1987) that the higher intensities were generally present from June to January and lower during March. The reason for this pattern is not known. However, lower intensities of ticks during March reported by Horak *et al*. (1987), has supported the findings of the present study in which ticks were not recovered during March 2006. There was also a weak positive correlation (r=+0.2264) between number of hosts examined and number of ticks recovered.

Species diversity of ticks was only recorded in December while the rest of the study month species diversity of ticks could not be calculated because either no tick was

recovered during that particular month or if ticks were collected, they belonged to a single species (Figure 3.10). Low diversity of ticks may be influenced by the size of the tick sample which may be influenced by the method used for tick specimens' collection as stated earlier above this section 4.2.

4.3 Mites

The host species *Aethomys chrysophilus, Aethomy namaquensis, Dendromus melanotis Gerbirullus paeba, Mastomys* spp, *Saccostomus campestris* and *Tatera leucogaster* were infested by mites whereas, *Crocidura hirta, Graphirulus murinus, Gerbirullus vallinus Mus indutus*, and *Thallomys nigricauda* did not harbor any mite, most probably because they are not preferred hosts for mites (Table 3.13).

A higher prevalence of mites was observed in *T. leucogaster* and *G. paeba.* These two host species were infested by mites throughout 5 months of the study period than other hosts. The lowest overall mite prevalence was recorded in March 2006 (35.3%), this might be influenced by the lower number of hosts (Table 3.1 & Figure 3.13) which were captured during this month and due to perhaps higher rainfall which was recorded during this month (Appendix 1).

In the present study, there was no significant difference in the number of mites amongst the 5 months. However, more mites (n=468) were collected throughout the study than

fleas (*n*=114), ticks (*n*=15), and lice (*n*=3). The possible reason can be thet the brush technique favours the collection of mites. Thus, the pattern that was found with regard to the abundances for the different taxa may be influenced by the method, especially given that the abundance for fleas (also easily removed by brushing) was also high, but ticks and lice were in low abundance (not that easily removed). The possible reason can be that the brush technique favours the collection of mites. Thus the pattern that was found with regard to the abundances for the different taxa may be influenced by the method, especially given that the abundance for fleas (also easily removed by brushing) was also high, but ticks and lice were in low abundance (no that easily removed).

Comparatively, very little is known regarding mites in Namibia as well as in South Africa (Braak *et al.*, 1996). Limited information is available on the life cycle of the relevant species in Southern Africa however, it can be suggested that reproduction of ectoparasites in general occurs at the same time with the reproduction of their host. Reproduction of *Mastomys* spp. was reported to be seasonal, starting after the rain and extending well into the dry season. Reproduction of *Mastomys* spp. was also reported to be strongly related to rainfall pattern (Baker, 1938 In: Leirs *et al*, 1994). Christian (1979) In: Perrin & Boyer (2000) reported the reproduction of *G. paeba* to be extremely seasonal and limited by the occurrence of rain.

Generally an individual will maximize its reproductive success by breeding at such a time that young will grow up in the most favorable conditions (Baker, 1938 In: Leirs *et*

al., 1994). This would seem to be the same in ectoparasites. Bronner *et al*. (1988) suggested that, in South Africa, *Mastomys natalensis* is an opportunistic breeder, reproducing continuously unless limited by low temperatures in the dry winter. This may suggest that temperature have an effect in the reproduction and of host and may be the same for ectoparasites.

Kruskal-Wallis test for mean ranks revealed that there was no difference in the intensity of infestation of mites among *T. leucogaster* (H=1.187, *df*=4, *P*=0.608) and *G. paeba* (H=0.9763, *df*=4, *P*=0.397). However, a significant difference was detected on *Mastomys* spp. (H=7.266, *df*=4, *P*<0.01) as the mite intensity among *Mastomys* spp. was relatively low in December and June most probably due to lower rainfall during this two months as well as change in temperature. Although some taxonomic studies have been done on mites associated with southern African rodents (Zumpt, 1961 In: Horak *et al*., 1987), Braack *et al*. (1996) reported that very little appears to have been published on the prevalence rates, infestation intensities, interaction and effects of mites on these hosts. The role of rodent-associated mites in the epidemiology of large mammal diseases appear to be minimal, but some laelapine and other mites have been linked with a variety of viral, bacterial and protozoan pathogens of humans and domestic animals (Domrow, 1987). The intensity of infestation did not vary significantly (Figure 3.13) between male and female hosts during the months of the study (Mann-Whitney U test: (*U*=5.00, *P*=0.151)).

A non-invasive method which was used to collect ectoparasites from the hosts during the present study could influence the prevalence, intensity of infestation of ectoparasites of small mammals in such a way that it was only possible to brush the posterior half part of the host body while the anterior half part of the host was inside the Perspex tube that it was not accessable for brushing. It might be because of this method that very few lice and ticks were collected because some ectoparasites, lice in particular are known to prefer specific sites on their host's body, especially parts of the host's head (Borror *et. al*., 1989) which could not be accessed. Ticks also remain attached to the skin of their host's body, which makes it difficult to removethem by the brushing method. The number of mites and fleas collected could also be higher, however these ectoparasites especially fleas can jump and move faster at the anterior part or out of the host's body while in the process of ectoparasites collection.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

Fleas

There was a significant difference in the prevalence of fleas between December and March and between December and June. Lower prevalence of fleas during March and June was most probably associated with heavy precipitation during March and lower temperature during June respectively. The difference on the prevalence of fleas on different species of host was not significant. However, the significant difference in prevalence of fleas was detected between *T. leucogaster* and *M. indutus* most probably because of very small sample size of *M. indutus*. There was no difference (U=8.0, P=0.347) in prevalence of fleas between female and male hosts.

Intensity of infestation of fleas did not differ significantly amongst *T. leucogaster*, *Mastomys* spp. and *G. paeba.* Intensity of infestation of fleas did not also differ significantly between *T. leucogaster* & *Mastomys* spp and between *Mastomys* spp. and *G. paeba.* However, there was a significant difference in the intensity of infestation of fleas between *T. leucogaster* and *G. paeba* (U=3.0; P=0.032). The difference in intensity of infestation of fleas between female and male hosts did not differ significantly (U=11.0; P=0.754) during the study period.

There was a significant difference in species diversity of fleas amongst the months. Specie diversity was found to be higher during summer (December) and lower during

autmn (March) and winter (June) most probably because of the pronounced seasonality in terms of temperature and precipitation. During December species diversity was higher on *T. leucogaster* than on *Mastomys* spp and *G. paeba* and lower during March and June. However, there was no significant difference (U=7.0; P=0.251) in species diversity between females and male hosts during the period of the study.

Ticks

There was no significant difference in species diversity, intensity of infestation and in prevalence of ticks amongst the 5 months; amongst different species of hosts and between female and male hosts. The present study recorded a larva belonging to a tick species *Rhipicephalus neumanni* for the very first time from the wild (Horak pers. comm. 2006). The nymph of *R. neumanni* was also recorded only for a second time in the wild. Meaning the larva *R. neumanni* has been known to infest only domestic animals but the present study have shown that the larvae and nymphs of *R. neumanni* do also infest wild animals especially rodents.

Mites

Mites could not be identified. Therefore calculation of species diversity of mites was not possible. The difference in prevalence of mites amongst 5 months and different species of host was not significant. Prevalence of mites was higher on male host than on females. It is possible that natural selection has favoured some mite species in which males maximize dispersal distances and minimize inbreeding (Walter & Proctor, 1999).

Lice

Only three individual ticks were recovered during the study. These lice could not be identified. Therefore, results of lice could not be presented and possible conclusions could not be drawn regarding lice ectoparasites.

In general, it would seem logical to finally conclude that there is a correlation between the number of ectoparastes infesting the small mammals and the season, but further detailed study would be required in order to substantiate this theory.

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APPENDICES

APPENDIX 1: Mean monthly temperature (°C) and rainfall (mm) with their Standard Error of means (SEM) at Waterberg Plateau Park during the study period.

Months	Mean Rainfall (mm) & SEM	Mean Temperature (°C) & SEM
December 2005	**2 ± 0.17**	**36 ± 0.35**
March 2006	**130 ± 0.91**	**23 ± 0.20**
April 2006	38 ± 1.83	20 ± 0.66
May 2006	18 ± 1.29	17 ± 0.46
June 2006	**1 ± 0.04**	**14 ± 0.32**

APPENDIX 2: Data sheet for the number of all ectoparasites collected during the study.

Field no.	Plot #	Month & Year	Date	Host sp.	Host sex	Host age	Fleas	Ticks	Lice	Mites
SB001	A1	Dec-05	7	*T. leucogaster*	f	adult	0	0	0	1
SB003	A1	Dec-05	7	*M. indutus*	m	adult	1	0	0	0
SB004	A1	Dec-05	7	*G. paeba*	m	juvenile	0	0	0	2
SB005	A1	Dec-05	7	*T. leucogaster*	m	adult	1	0	0	0
SB007	A1	Dec-05	7	*Mastomys sp.*	m	adult	5	0	0	0
SB008	A1	Dec-05	7	*G. paeba*	f	adult	0	1	0	0
SB016	A1	Dec-05	8	*T. leucogaster*	m	adult	0	0	0	1
SB017	A1	Dec-05	8	*G. paeba*	m	adult	1	3	0	0
SB021	A1	Dec-05	8	*T. leucogaster*	m	adult	3	0	0	0
SB029	A1	Dec-05	9	*Mastomys sp.*	m	adult	3	0	0	1
SB031	A1	Dec-05	9	*G. paeba*	m	adult	1	4	0	3
SB032	A1	Dec-05	9	*Mastomys sp.*	f	adult	4	0	0	4
SB044	A1	Dec-05	10	*G. paeba*	m	juvenile	0	1	0	1
SB047	A2	Dec-05	11	*T. leucogaster*	f	adult	31	0	0	11
SB048	A2	Dec-05	11	*T. leucogaster*	f	adult	0	0	0	1
SB049	A2	Dec-05	12	*T. leucogaster*	m	adult	5	0	0	3
SB052	A2	Dec-05	13	*T. leucogaster*	m	adult	17	0	0	20
SB053	A2	Dec-05	13	*T. leucogaster*	f	adult	5	0	0	3
SB054	A2	Dec-05	13	*G. paeba*	m	adult	1	0	0	0
SB059	B2	Dec-05	20	*G. paeba*	f	adult	0	0	0	1

SB066	A1	Mar-06	12	*G. paeba*	f	adult	0	0	0	3
SB067	A1	Mar-06	12	*G. paeba*	m	juvenile	0	0	1	4
SB083	A2	Mar-06	16	*G. paeba*	f	adult	0	0	0	4
SB092	B2	Mar-06	26	*T. leucogaster*	f	adult	0	0	0	3
SB093	B2	Mar-06	26	*Mastomys sp.*	m	adult	0	0	0	8
SB094	B2	Mar-06	27	*T. leucogaster*	f	adult	1	0	0	12
SB108	A1	Apr-06	14	*Mastomys sp.*	m	adult	0	0	0	3
SB113	A2	Apr-06	16	*T. leucogaster*	f	adult	1	0	0	12
SB117	A2	Apr-06	19	*S. campestris*	m	adult	0	0	0	31
SB118	A2	Apr-06	19	*Mastomys sp.*	m	adult	0	0	0	7
SB119	A2	Apr-06	19	*A. namaquensis*	m	adult	1	0	0	0
SB122	B1	Apr-06	20	*Mastomys sp.*	m	adult	0	0	0	25
SB124	B1	Apr-06	21	*A. namaquensis*	m	adult	1	0	0	0
SB125	B1	Apr-06	21	*Mastomys sp.*	m	adult	2	0	0	4
SB127	B1	Apr-06	22	*A. namaquensis*	m	adult	2	0	0	0
SB128	B1	Apr-06	22	*Mastomys sp.*	m	adult	1	0	0	23
SB129	B1	Apr-06	22	*Mastomys sp.*	f	adult	0	0	0	11
SB130	B1	Apr-06	23	*G. paeba*	f	adult	1	0	0	0
SB131	B1	Apr-06	23	*Mastomys sp.*	m	adult	0	0	0	4
SB133	B1	Apr-06	23	*Mastomys sp.*	m	adult	0	0	0	3
SB136	B2	Apr-06	24	*Mastomys sp.*	m	adult	1	0	0	7
SB138	B2	Apr-06	24	*Mastomys sp.*	m	adult	0	0	0	1
SB139	B2	Apr-06	25	*Mastomys sp.*	f	adult	5	0	0	0
SB140	B2	Apr-	25	*T. leucogaster*	f	adult	0	0	0	2

		06								
SB143	B2	Apr-06	25	*Mastomys sp.*	m	adult	0	1	0	0
SB153	B2	Apr-06	27	*Mastomys sp.*	m	adult	0	0	0	13
SB154	B2	Apr-06	27	*T. leucogaster*	m	adult	1	0	0	11
SB157	A1	May-06	12	*T. leucogaster*	f	adult	1	0	0	1
SB161	A1	May-06	12	*G. paeba*	m	juvenile	0	0	0	2
SB164	A1	May-06	14	*T. leucogaster*	f	adult	1	0	0	5
SB175	A2	May-06	19	*Mastomys sp.*	m	adult	0	0	0	2
SB177	B1	May-06	20	*Mastomys sp.*	m	adult	0	0	0	21
SB178	B1	May-06	20	*A. chrysophilus*	m	adult	14	1	0	5
SB183	B2	May-06	24	*T. leucogaster*	f	adult	0	0	0	20
SB185	B2	May-06	25	*D. melanotis*	m	adult	0	1	0	2
SB189	B2	May-06	27	*D. melanotis*	m	adult	0	0	0	1
SB191	B2	May-06	27	*D. melanotis*	m	adult	0	0	0	14
SB192	A1	Jun-06	12	*D. melanotis*	f	adult	0	0	0	3
SB194	A1	Jun-06	12	*D. melanotis*	m	adult	0	0	0	1
SB195	A1	Jun-06	12	*D. melanotis*	m	adult	0	0	0	4
SB198	A1	Jun-06	13	*T. leucogaster*	f	adult	1	0	0	11
SB199	A1	Jun-06	13	*D. melanotis*	m	adult	0	0	0	2
SB202	A1	Jun-06	13	*D. melanotis*	m	adult	0	0	0	9
SB208	A1	Jun-06	14	*D. melanotis*	m	adult	0	0	0	9
SB215	A1	Jun-06	15	*G. paeba*	f	juvenile	0	3	0	1
SB225	A2	Jun-06	17	*Mastomys sp.*	m	adult	0	0	0	4
SB233	A2	Jun-06	18	*T. leucogaster*	f	adult	2	0	0	0

SB234	A2	Jun-06	18	*T. leucogaster*	f	adult	0	0	0	8
SB238	A2	Jun-06	18	*A. namaquensis*	m	adult	0	0	0	1
SB281	B2	Jun-06	24	*D. melanotis*	m	adult	0	0	0	20
SB282	B2	Jun-06	24	*D. melanotis*	m	adult	0	0	0	8
SB283	B2	Jun-06	24	*D. melanotis*	m	adult	0	0	0	6
SB286	B2	Jun-06	25	*D. melanotis*	m	adult	0	0	0	6
SB287	B2	Jun-06	25	*D. melanotis*	f	adult	0	0	0	2
SB289	B2	Jun-06	25	*D. melanotis*	m	adult	0	0	0	2
SB290	B2	Jun-06	25	*D. melanotis*	m	adult	0	0	0	5
SB300	B2	Jun-06	26	*D. melanotis*	f	adult	0	0	0	1
SB302	B2	Jun-06	26	*D. melanotis*	m	adult	0	0	0	1
SB304	B2	Jun-06	26	*D. melanotis*	m	adult	0	0	0	8
SB307	B2	Jun-06	26	*D. melanotis*	m	adult	0	0	0	5
SB311	B2	Jun-06	27	*D. melanotis*	m	adult	0	0	0	2
SB312	B2	Jun-06	27	*D. melanotis*	m	adult	0	0	0	15
SB320	B2	Jun-06	27	*D. melanotis*	m	adult	0	0	0	18
SB325	B2	Jun-06	27	*T. nigricauda*	m	adult	0	0	2	0
							114	15	3	468

APPENDIX 3: Data sheet for all flea species recovered from small mammals during the study.

Field number	Plot#	Month	Date	Host sp.	Host sex	mass (g)	Host age	# of fleas	Family	Subfamily	Genus	Species	Flea sex
SB003	A1	Dec	7	*M. indutus*	m	4	adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	f
SB005	A1	Dec	7	*T. leucogaster*	m	33	adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	m
SB007 A	A1	Dec	7	*Mastomys sp.*	m	33	adult	5	Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	f
SB007 B	A1	Dec	7	*Mastomys sp.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	m
SB007 C	A1	Dec	7	*Mastomys sp.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	m
SB007 D	A1	Dec	7	*Mastomys sp.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	f
SB007 E	A1	Dec	7	*Mastomys sp.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	f
SB017	A1	Dec	8	*G. paeba*	m	28	adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	f
SB021 A	A1	Dec	8	*T. leucogaster*	m	16	adult	3	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	m
SB021 B	A1	Dec	8	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	m
SB021 C	A1	Dec	8	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	m
SB029 A	A1	Dec	9	*Mastomys sp.*	m	33	adult	3	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	m
SB029 B	A1	Dec	9	*Mastomys sp.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	f
SB029 C	A1	Dec	9	*Mastomys sp.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	f
SB031	A1	Dec	9	*G. paeba*	m	29	adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	m
SB032 A	A1	Dec	9	*Mastomys sp.*	f	24	adult	4	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	f
SB032 B	A1	Dec	9	*Mastomys sp.*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	f
SB032 C	A1	Dec	9	*Mastomys sp.*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	f
SB032 D	A1	Dec	9	*Mastomys sp.*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	f
SB047 A	A2	Dec	11	*T. leucogaster*	f	82	adult	31	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	m
SB047 B	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	m
SB047 C	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	m

SB047 D	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	f
SB047 E	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 F	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 G	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 H	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB047 I	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 J	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB047 K	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB047 L	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 M	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 N	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB047 O	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 P	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB047 Q	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB047 R	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 S	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB047 T	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 U	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M

SB047 V	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 W	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 X	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 Y	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB047 Z	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 AA	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 BB	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB047 CC	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB047 DD	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB047 EE	A2	Dec	11	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB049 A	A2	Dec	12	*T. leucogaster*	m	>100	adult	5	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB049 B	A2	Dec	12	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB049 C	A2	Dec	12	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB049 D	A2	Dec	12	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB049 E	A2	Dec	12	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Pulex*	*irritans*	M
SB052 A	A2	Dec	13	*T. leucogaster*	m	104	adult	17	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB052 B	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB052 C	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M

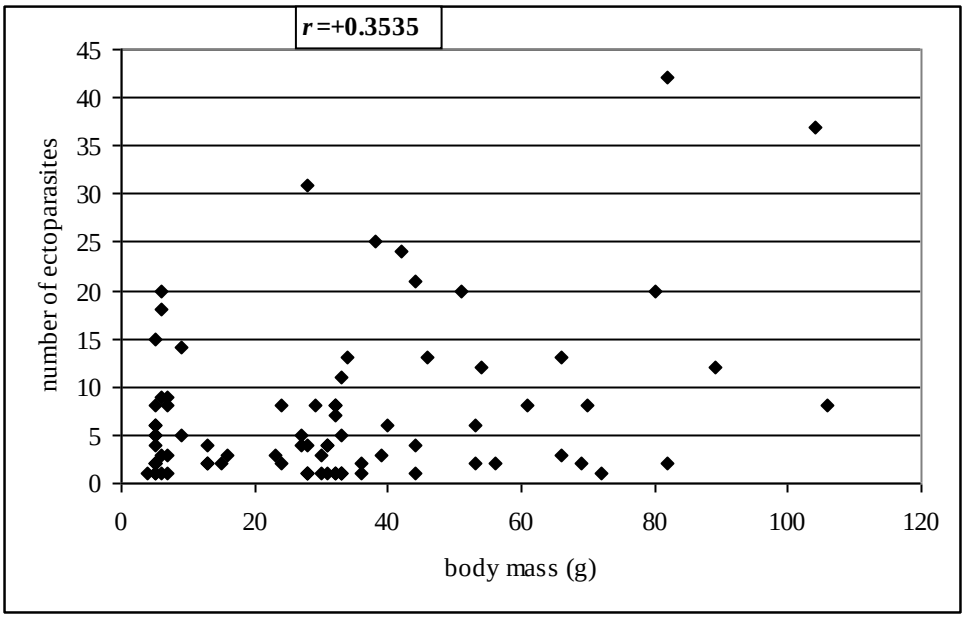
SB052 D	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB052 E	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB052 F	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB052 G	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB052 H	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB052 I	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB052 J	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	F
SB052 K	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB052 L	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB052 M	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB052 N	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB052 O	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB052 P	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB052 Q	A2	Dec	13	*T. leucogaster*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB053 A	A2	Dec	13	*T. leucogaster*	f	70	adult	5	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB053 B	A2	Dec	13	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB053 C	A2	Dec	13	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB053 D	A2	Dec	13	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M

SB053 E	A2	Dec	13	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB054	A2	Dec	13	*G. paeba*	m	32	adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB094	B2	Mar	27	*T. leucogaster*	f	66	adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB113	A2	Apr	16	*T. leucogaster*	f		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB119	A2	Apr	19	*A. namaquensis*	m		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB124	B1	Apr	21	*A. namaquensis*	m		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	M
SB125 A	B1	Apr	21	*Mastomys sp.*	m		adult	2	Pulicidae	Xenopsyllinae	*Xenopsylla*	*nubica*	M
SB125 B	B1	Apr	21	*Mastomys sp.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*dorippae*	F
SB127 A	B1	Apr	22	*A. namaquensis*	m		adult	2	Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB127 B	B1	Apr	22	*A. namaquensis*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*dorippae*	M
SB128	B1	Apr	22	*Mastomys sp.*	m		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB130	B1	Apr	23	*G. paeba*	f		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB136	B2	Apr	25	*Mastomys sp.*	m		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*brasiliensis*	M
SB139 A	B2	Apr	27	*Mastomys sp.*	f		adult	5	Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	F
SB139 B	B2	Apr	27	*Mastomys sp.*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	M
SB139 C	B2	Apr	27	*Mastomys sp.*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	M
SB139 D	B2	Apr	27	*Mastomys sp.*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	M
SB139 E	B2	Apr	27	*Mastomys sp.*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	M
SB154	B2	Apr	27	*T. leucogaster*	m		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB157	A1	May	12	*T. leucogaster*	f		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB164	A1	May	14	*T. leucogaster*	f		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB178 A	B1	May	20	*A. chrysophilus*	m		adult	14	Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB178 B	B1	May	20	*A.*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	m

				chrysophilus									
SB178 C	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	M
SB178 D	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB178 E	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB178 F	B1	May	20	*A. chrysophilus*	m		adult		Hystrichpsyllidae	Listropsyllinae	*Listropsylla*	*aricinae*	F
SB178 G	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	F
SB178 H	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	F
SB178 I	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*versuta*	M
SB178 J	B1	May	20	*A. chrysophilus*	m		adult		Hystrichpsyllidae	Listropsyllinae	*Listropsylla*	*aricinae*	F
SB178 K	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB178 L	B1	May	20	*A. chrysophilus*	m		adult		Hystrichpsyllidae	Listropsyllinae	*Listropsylla*	*aricinae*	F
SB178 M	B1	May	20	*A. chrysophilus*	m		adult		Hystrichpsyllidae	Listropsyllinae	*Listropsylla*	*dorippae*	M
SB178 N	B1	May	20	*A. chrysophilus*	m		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*cheopis*	F
SB198	A1	Jun	13	*T. leucogaster*	f		adult	1	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	F
SB233 A	A2	Jun	18	*T. leucogaster*	f		adult	2	Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
SB233 B	A2	Jun	18	*T. leucogaster*	f		adult		Pulicidae	Xenopsyllinae	*Xenopsylla*	*philoxera*	M
Total								**114**					

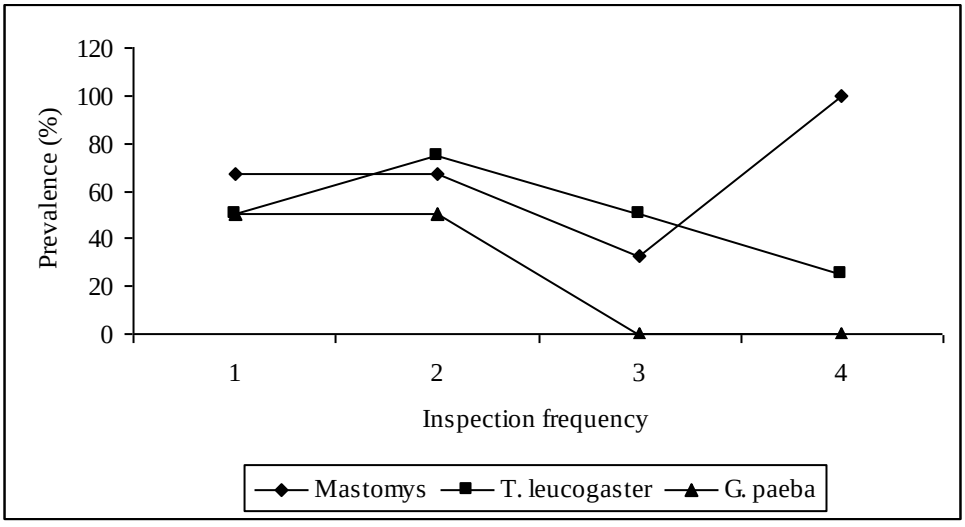
APPENDIX 4: Data sheet for all tick species recovered from small mammals during the study

Field number	Plot number	Month	Host species	Host sex	Host age	Genus	Species	Age	Number of ticks
SB008	A1	Dec	*G. paeba*	F	adult	*Hyalomma*	*truncatum*	larva	1
SB017 A	A1	Dec	*G. paeba*	M	adult	*Haemaphysalis*	*elliptica*	nymph	3
SB017 B	A1	Dec	*G. paeba*	M	adult	*Hyalomma*	*truncatum*	larva	
SB017 C	A1	Dec	*G. paeba*	M	adult	*Hyalomma*	*truncatum*	nymph	
SB031 A	A1	Dec	*G. paeba*	M	adult	*Hyalomma*	*truncatum*	nymph	4
SB031 B	A1	Dec	*G. paeba*	m	adult	*Hyalomma*	*truncatum*	nymph	
SB031 C	A1	Dec	*G. paeba*	m	adult	*Hyalomma*	*truncatum*	nymph	
SB031 D	A1	Dec	*G. paeba*	m	adult	*Hyalomma*	*truncatum*	nymph	
SB044	A1	Dec	*G. paeba*	m	juvenile	*Hyalomma*	*truncatum*	larva	1
SB143	B2	Apr	*Mastomys sp.*	m	adult	*Rhipicephalus*	*neumanni*	nymph	1
SB178	B1	May	*A. chrysophilus*	m	adult	*Rhipicephalus*	*neumanni*	larva	1
SB185	B2	May	*D. melanotis*	m	adult	*Hyalomma*	*truncatum*	larva	1
SB215 A	A1	Jun	*G. paeba*	f	juvenile	*Hyalomma*	*truncatum*	larva	3
SB215 B	A1	Jun	*G. paeba*	f	juvenile	*Hyalomma*	*truncatum*	nymph	
SB215 C	A1	Jun	*G. paeba*	f	juvenile	*Hyalomma*	*truncatum*	nymph	
Total									15



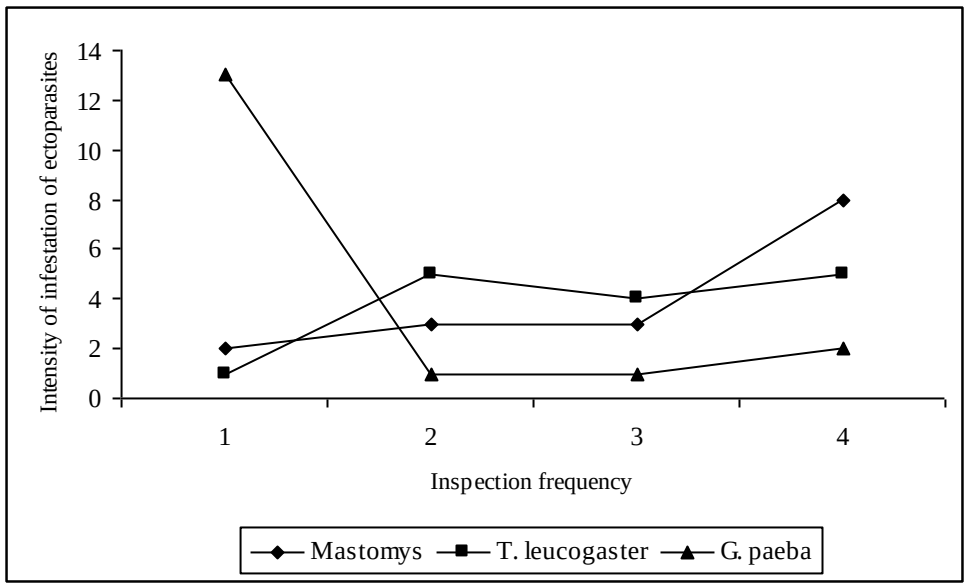
APPENDIX 5: Host body mass and ectoparasite load

Removal of ectoparasites from the hosts once per month seemed to have no effect on the prevalence of ectoparasite on *Mastomys* spp. However, a negative effect was observed on *T. leucogaster* and *G. paeba* as there was a decrease in the prevalence when the inspection frequency increases (Appendix 6)



APPENDIX 6: The Prevalence (%) of all ectoparasites (fleas, ticks, lice, mites) per examination session for the selected 3 different host species.

Removal of ectoparasites from the hosts once per month seemed to have no effect in the intensity of infestation of ectoparasites *Mastomys* spp. However, a negative effect was observed on *G. paeba* as there was a decrease in the intensity of infestation of ectoparasites when the inspection frequency increases (Appendix 7).



APPENDIX 7: The intensity of infestation of all ectoparasites (fleas, ticks, lice, mites) per examination session for the selected 3 different host species.

APPENDIX 8: Prevalence of fleas in different species of hosts. In each case, *n* represents the sample size of hosts (number of small mammal) examined during the period of the study.

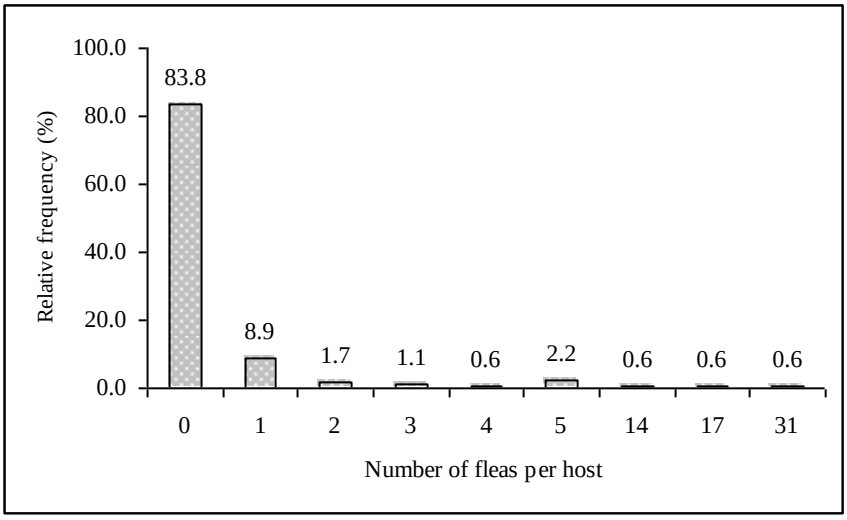
	Prevalence of fleas (%) (Year: 2005-2006)				
Host animal species	Dec	Mar	Apr	May	Jun
Aethomys chrysophilus	0 (*n*=0)	0 (*n*=0)	0 (*n*=0)	**100** (*n*=1)	0 (*n*=1)
Aethomys namaquensis	0 (*n*=0)	0 (*n*=0)	**30.0** (*n*=10)	0 (*n*=1)	**33.3** (*n*=3)
Gerbillurus paeba	**30.0** (*n*=10)	0 (*n*=6)	**16.7** (*n*=6)	0 (*n*=4)	0 (*n*=13)
Mus indutus	**16.7** (*n*=6)	0 (*n*=0)	0 (*n*=0)	0 (*n*=0)	0 (*n*=3)
Mastomys spp.	**75.0** (*n*=4)	0 (*n*=3)	**33.3** (*n*=12)	0 (*n*=2)	0 (*n*=1)
Tatera leucogaster	**60.0** (*n*=10)	**14.3** (*n*=7)	**50.0** (*n*=4)	**25.0** (*n*=8)	**22.2** (*n*=9)

APPENDIX 9: Prevalence of mites in different species of hosts. In each case, n represents the sample size of hosts (number of small mammal) examined during the period of the study.

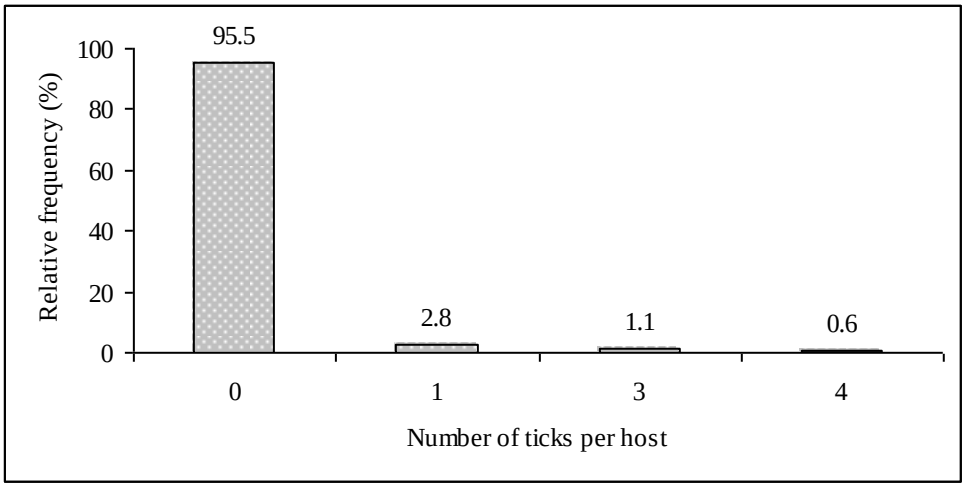
	Prevalence of mites (%) per month (Year: 2005-2006) with respect to host animal species				
Host animal species	Dec	Mar	Apr	May	Jun
Aethomys chrysophilus	0 (*n*=0)	0 (*n*=0)	0 (*n*=0)	**100** (*n*=1)	0 (*n*=1)
Aethomys namaquensis	0 (*n*=0)	0 (*n*=0)	0 (*n*=10)	0 (*n*=1)	**33.3** (*n*=3)
Dendromus melanotis	0 (*n*=3)	0 (*n*=0)	0 (*n*=2)	**50.0** (*n*=6)	**58.8** (*n*=34)
Gerbillurus paeba	**40.0** (*n*=10)	**50** (*n*=6)	0 (*n*=6)	**25.0** (*n*=4)	**7.7** (*n*=13)
Mastomys spp.	**50.0** (*n*=4)	**33.3** (*n*=3)	**91.7** (*n*=12)	**100** (*n*=2)	**100** (*n*=1)
Saccostomus campestris	0 (*n*=0)	0 (*n*=0)	**100** (*n*=1)	0 (*n*=0)	0 (*n*=1)

APPENDIX 10: Prevalence of ticks in different species of hosts. In each case, *n* represents the sample size of hosts (number of small mammal) examined during the period of the study.

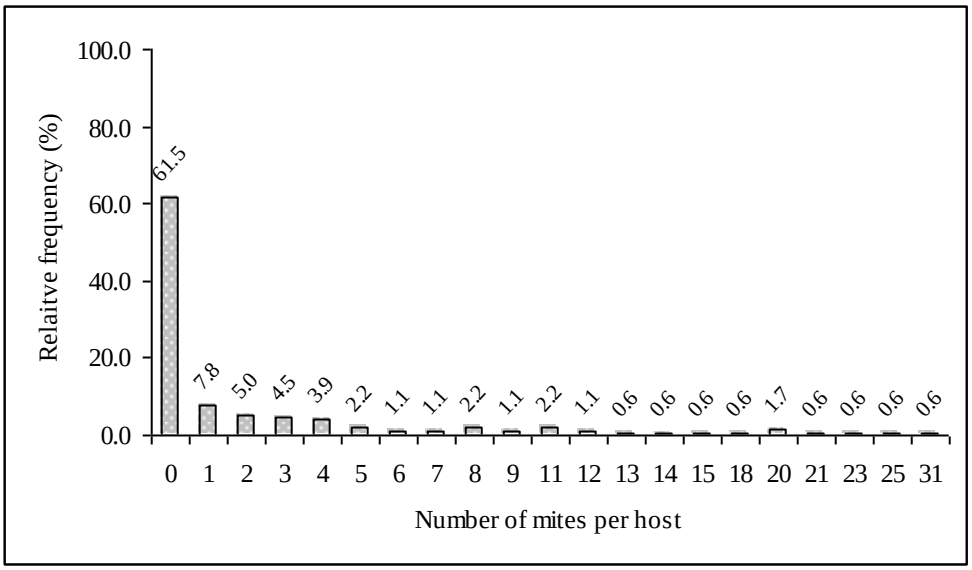
	Prevalence of ticks (%) with respect to host animal species (Year: 2005-2006)				
Host species	Dec	Mar	Apr	May	Jun
Aethomys chrysophilus	0 (*n*=0)	0 (*n*=0)	0 (*n*=0)	**16.7** (*n*=1)	0 (*n*=1)
Dendromus melanotis	0 (*n*=3)	0 (*n*=0)	0 (*n*=2)	**16.7** (*n*=6)	0 (*n*=34)
Gerbillurus paeba	**40** (*n*=10)	0 (*n*=6)	0 (*n*=6)	0 (*n*=4)	**7.7** (*n*=13)
Mastomys spp.	0 (*n*=4)	0 (*n*=3)	**8.3** (*n*=12)	0 (*n*=2)	0 (*n*=1)



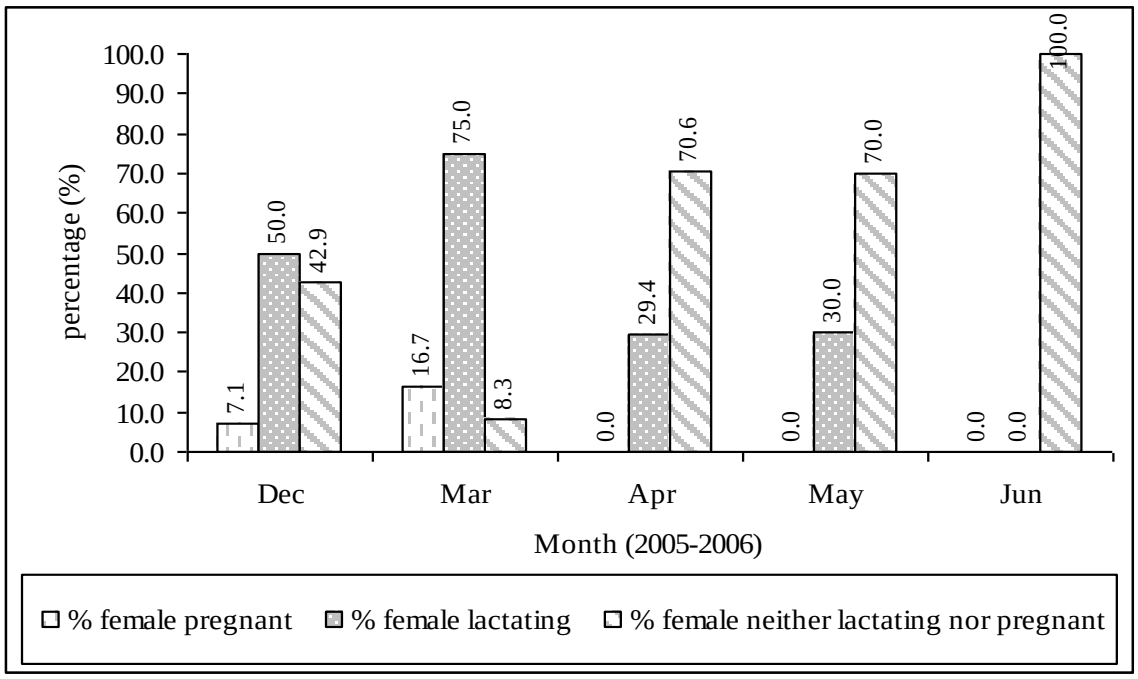
APPENDIX 11: Frequency distribution of fleas on small mammals examined during the period of the study.



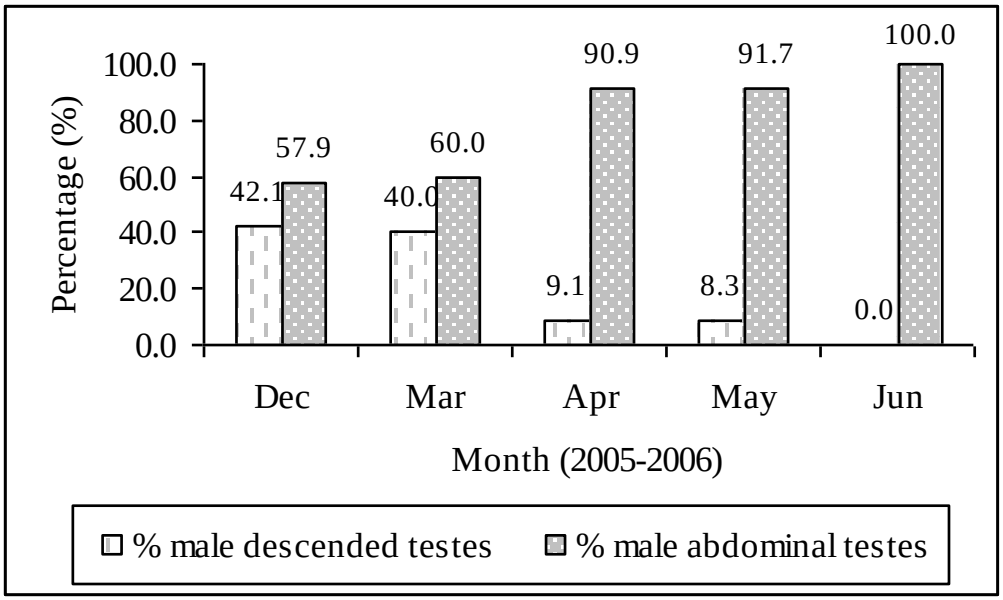
APPENDIX 12: Frequency distribution of ticks on small mammals examined during the period of the study.



APPENDIX 13: Frequency distribution of mites on small mammals examined during the period of the study.



APPENDIX 14: Reproductive status of the female small mammals captured at Waterberg Plateau Park during the study. Sample sizes (*n*) of female hosts in each month are as follow: Dec (*n*=14); Mar (*n*=12); Apr (*n*=17); May (*n*=10), Jun (*n*=26).



APPENDIX 15: Reproductive status of the male small mammals captured at Waterberg Plateau Park during the study. Sample sizes (*n*) of male hosts in each month are as follow: Dec (*n*=19); Mar (*n*=5); Apr (*n*=22); May (*n*=12), Jun (*n*=42).