Use of Tenebrionid Beetles as Indicators of Habitat Quality

A research report submitted to the Faculty of Science, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science

Contents

List of Abbreviations

PRA	Participatory Rural Appraisal
DRFN	Desert Research Foundation of Namibia
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
IBI	Index of Biological Integrity
MAWRD	Ministry of Water and Rural Development
MET	Ministry of Environment and Tourism
Napcod	Namibia's Programme to Combat Desertification
TOEB	Tropenökologisches Begleitprogramm

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Declaration

I declare that this thesis is my own, unaided work. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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Shirley Hanrahan, Joh Henschel and Mary Seely deserve my most sincere thanks for their guidance, support and criticism throughout the project.

The study was mainly carried out at Olifantputs, and thanks are due to the farmers who offered us a camping site and did not grumble too much when we dug holes all over their grazing areas, accidentally left gates open, left strange markings on the trees…..

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Abstract

Tenebrionids are commonly found in arid and semi-arid regions, where they perform various functions. Being unable to fly, many have limited ranges, tending to remain in the same areas where the adults emerge. This study attempted to determine whether tenebrionid beetles have the potential to be used as indicators of quality of the habitat. It is thought that the physical environment affects populations of these organisms. The community compositions can therefore be related to such factors as the intensity of land use. Their response to land use pressure in terms of diversity and species compositions in areas experiencing different land use pressures was considered during this study. Size differences between beetles present at the different land use sites was also looked at. It was found that in general, the tenebrionid abundance and diversity appeared to be greater at the low land use intensity sites, Fewer dominant species were found to be present at the lower land use intensity sites. In general, the low land use sites appeared to offer more suitable habitats, beetles found there being larger than those found at the high land use intensity sites. A potential for the use of tenebrionid beetles as indicators of the habitat quality does exist, but longer term monitoring needs to be carried out in order to determine whether they are indeed responding to land use pressure.

Foreword

This project forms part of a larger study, which, bearing the needs of Napcod (Namibia's National Programme to Combat Desertification) in mind, is designed to find the most appropriate ways to assess the condition of western Namibian rangelands. Napcod is a collaboration between the Ministry of Agriculture, Water and Rural Development (MAWRD), the Ministry of Environment and Tourism (MET) and the Desert Research Foundation of Namibia (DRFN).

The biological integrity of the rangeland, a concept that incorporates properties of ecological function and biological diversity, was looked at. Within the larger study, information on land use patterns, history, tenure and common land management practices were also be considered. A set of biophysical indicators will be then be defined, combining a scientific approach as well as one aimed at local farming communities.

This study looked at the use of tenebrionid beetles as possible indicators of short-term changes in the condition of the rangeland.

The study was conducted under the auspices of the Desert Research Foundation (DRFN), a Namibian non-governmental organisation.

CHAPTER I

Introduction

Namibia, situated at the south-western edge of Africa, is the most arid country south of the Sahara. It experiences low rainfall, which declines from east to west, and is highly variable.
The unpredictable rainfall experienced means that a great variation exists in the plant productivity.
Water is the limiting resource, and its scarcity imposes many limitations on how the environment can be used (Jacobson et al., 1995).

1.1 Index of Biological Integrity (IBI)

Environmental and land use gradients, as well as changes in the environment, are often defined by vegetation parameters (e.g. Milchunas and Lauenroth 1993, Ward and Olsvig-Whittaker 1993, Nash and Whitford 1997). Other parameters, however, such as the processes mediated by soil biota, should also be considered. Soil biota are recognised as being important for the maintenance of soil characteristics, and soil fertility determines the primary and secondary productivity of the vegetation. Some organisms have more of an impact on the soil processes than others (Anderson 1994). The diversity and composition of the communities of organisms making use of the soil at various stages of their life cycles may undergo changes as a result of changes in land use regimes (Swift and Anderson 1993, Anderson 1994). It has been suggested that an Index of Biological Integrity (IBI), as developed for use in aquatic systems (Kerans and Karr, 1994; Angermeier and Karr, 1986; Angermeier and Schlosser, 1987; Fausch et al., 1990; Karr, 1991) be adapted to Namibian rangelands as part of Napcod's overall programme. The IBI uses an integrated approach to assess changes in habitat quality, considering the influences of ecological processes on changes in composition and structural biodiversity of organisms at multiple levels of organisation and at multiple spatial and temporal scales (Angermeier and Karr, 1994; Hughes et al., 1990; Karr, 1987). The IBI approach aims to provide tools that can be used in the maintenance and control of habitat condition. The biological integrity of a system can be assessed by means of indicators. The indicators are based on specific biological parameters, such as species richness, composition and abundance as well as the condition of the selected taxa. It is thought that these indices show different levels of ecosystem disturbance. The indicators should be sensitive to a number of different stresses. They should also be able to distinguish between human-induced disturbances and stresses occurring as a result of natural processes. Ideally, they should also be easy to measure (Angermeier and Karr, 1994; Noss, 1990; Hughes et al., 1990; Karr, 1987). In order to apply such an index, a good understanding of the ecosystem being studied is needed.

1.2 Land Use Strategies

While agriculture is one of the main economic activities, large areas of land are unsuitable for crop production or for farming with livestock. Namibian agriculture places a heavy emphasis on livestock production, but much of the land that has been zoned for agriculture is only suitable for nomadic forms of pastoralism, or for rotational grazing. The productivity of the agricultural systems varies greatly with the different management strategies in place and the constraints posed by environmental variability and resource availability.

During the colonial period, southern Africa was subject to the equilibrial paradigm of agricultural management and to a large extent, this view still persists today. In those systems that are in equilibrium, the amount of forage production that can be obtained from the land is totally dependent on the numbers of stock placed on that area of land (Behnke & Scoones, 1993; Ellis et al., 1993). It has now been realised that this model is not appropriate for the agriculture practised in many parts of southern Africa. The plant production in semi-arid and arid regions is now more commonly viewed as being mainly non-equilibrial, meaning that the numbers of livestock on the land is not necessarily related to the plant production of the area of land (Behnke & Scoones 1993, Ellis et al. 1993)

The land use strategies in effect today are largely the result of the social engineering policies of Namibia's colonial past, and the agricultural systems can broadly be divided into what is termed commercial and communal land.

Black Namibians were removed from the prime agricultural land, which was reserved for white farmers, and resettled in the more agriculturally marginalised land, which often had poorer soil and groundwater. This followed the recommendations set out in the Odendaal commission of 1963-64, which used racial classification as the basis on which to create separate "homelands", or communal areas. People confined to these communal areas were not able to survive and raise their livestock without resorting to the work offered on white owned commercial farms, where they were considered a cheap source of labour (Rhode, 1993).

Communal land is defined as an area in which all of the available natural resources are not private, but are owned by the state, in contrast to commercial land, which is privately owned. As such, the state land and boreholes sunk for the benefit of specific communities often become open access resources, for which nobody in the communities really feels responsible. The boreholes and pumps should be maintained by government agencies, but are often neglected and become run-down. Often, the traditional and state authorities are not able to control the livestock numbers in the areas used for grazing, or the access to the artificial water points. This tends to make the management of rangelands extremely difficult (Rhode, 1993). Within the communal areas, the main constraints to pastoral development are limited water and grazing resources, recurrent droughts, government neglect of the necessary infrastructure and an increase in population of both people and their livestock. Traditionally, Namibian people used to move livestock over long distances in order to find water and pasture, but this nomadic type of lifestyle began to disappear when the colonialists declared permanent homelands for the different ethnic groups. The environment should be managed as one that is in a state of disequilibrium, responding to environmental stresses in a flexible manner. The movement of livestock provides a way to circumvent the environmental stresses created by the largely uncontrollable swings in ecological productivity in such systems (Behnke & Scoones, 1993). The introduction of permanent settlements due to the Communal Land Areas Act interfered with the rotational grazing system that had previously been practised in these arid rangelands. In many areas, severe land degradation was the result. One of the main contributors to this land degradation was the fact that indigenous farmers were no longer able to manage their seasonal grazing areas effectively (Rhode, 1993).

At present there is much debate about whether the land management practised in communal rangelands are 'inappropriate' strategies. The orthodox, commercial farm management practices, have been, and often still are, based on the idea that conservative stocking rates should apply. These rates are compatible with ecosystems which are in equilibrium, and for which the carrying capacity can be calculated. This view has been challenged, (e.g. Behnke et al., 1993; Rhode 1993; Coppock, 1993). The arid and semi-arid environments respond to rainfall events episodically, resulting in the grazing systems in these areas not being in a state of equilibrium. The standard concepts of carrying capacity may therefore be more difficult to apply. In these regions, a number of different combinations of factors, aside from and including grazing pressure, are needed to cause changes within the system. If all of these factors are not known, then the effects of any particular stocking density will be unpredictable. As a result of the variations in these other factors, the effective management of arid rangelands cannot adhere to a single, conservative stocking rate which should apply in all cases (Behnke & Scoones, 1993)

The limiting environmental conditions in arid and semi-arid regions such as Namibia, have an effect not only on the quantity of the forage available to livestock, but on the quality as well. The quality of the forage in such areas is highly correlated with the availability of nutrients in the soil (Robertson 1998)

Highly intensive land use systems may have the effect of leading to excessive trampling, overgrazing, and eventually to range degradation.

The intensity of the use of the limited resources available in the communal areas of Namibia may be having an impact on the natural soil and vegetation systems in place. The ways in which land management systems in the communal areas interact with the productivity of the land as well as with land degradation needs to be investigated. Degradation is coupled with a change in soil characteristics, e.g. soil erosion and soil compaction. (Scoones, 1992; Behnke and Scoones, 1993; Steenekamp and Bosch, 1995). However, as a result of disturbances, whether natural or human-induced, the productivity and composition of the rangelands, even though less productive and diverse as a result of overuse, may become more resilient over the longer term (Walker et al., 1981, Scoones, 1992; Behnke and Scoones, 1993).

In order to determine the extent of land degradation, it is necessary to identify reliable/appropriate indicators of permanent environmental change. Potential biophysical indicators of range degradation have been proposed. These include changes in the fertility of the soil, vegetation production, and in the condition and productivity output of livestock (Behnke and Scoones, 1993, Bartels et al., 1993; Biot, 1993). In order for farmers to be able to make appropriate decisions relating to management of their rangelands, information about the condition of the land is necessary. Within the larger study, looking for appropriate measurements of rangeland condition, measures of biological integrity and various aspects of biodiversity, its functional properties and effects on the environment were used to assess the habitat. Local and indigenous practices were also considered, and a set of indicators was then derived after combining the different approaches.

1.3 Land use intensity indicators

Conventionally, vegetation indicators have been used to assess the condition of the rangeland and the extent of degradation. The use of these simplified models has, however, been questioned in a number of papers (e.g. Behnke and Scoones, 1993; Ellis et al., 1993; Coppock, 1993; Stafford-Smith and Pickup, 1993). In an arid region like Namibia, where rainfall is extremely erratic and variable (Dealie et al., 1993), vegetation composition is disturbed continuously. Vegetation growth is triggered by rainfall episodes. It is therefore very difficult to determine whether the condition of the rangelands is due to changes in vegetation composition resulting from temporary changes in rainfall patterns, or whether degradation is occurring as a result of human-induced disturbance, e.g. overstocking and overgrazing (Behnke & Scoones 1993, Mouton 1997). While vegetation may be going through a 'resting period', when no rain occurs, the underlying soils may still be intact, and invertebrate species may still be found within the system, albeit in reduced numbers.

The relatively small size of invertebrates, the fact that they are very sensitive to environmental variability and their diversity has led to them being considered as good indicators of the biodiversity and habitat condition of ecosystems (Weaver 1995, Pearson & Cassola 1992, Kremen et al. 1993, Kremen 1994)
No single species can, however, be used to indicate the condition of the broader habitat (Cairns 1986, Noss 1990). Natural systems are extremely complex and the possibility of one single species being used as an index of the way the entire community/ecosystem functions is remote. The presence or absence and species numbers and assemblages of groups of invertebrates have been used successfully as indicators of habitat conditions in a number of studies (e.g. Landres et al., 1988; Kremen, 1992; Kremen, 1994; Dufrène and Legendre, 1997; Majer and Beeston, 1996; Weaver, 1995). The use of invertebrate species assemblages typical for habitats could be useful in the determination of the impact of

different land management strategies (Dufrène and Legendre, 1997; Kremen, 1992; Majer and Beeston, 1996).

Namibia falls into Africa's Southwest Arid Zone, and as such is a centre of endemism for a wide range of organisms, and the degree of endemism in invertebrates in general and insects in particular is relatively high. Insects form the majority of species and biomass in Namibia, but less than a quarter of the insects have as yet been described. Although a lack of baseline data relating to the species richness of insects exists, preliminary analyses of endemism have been attempted, and show that great species richness exists within Namibian invertebrates (e.g. Koch 1960, Braine 1986). Of the approximately 100 000 known southern African species of insects, 35% are believed to occur within Namibia. Species richness and the degree of endemism vary between habitats, but western and central Namibia is considered the most significant area for insect endemism (Barnard et al. 1988). Insects, being smaller and fast breeding are generally more resilient to environmental changes than vertebrates, but they may be threatened by large-scale destruction of their habitats and land degradation (Barnard et al. 1998).

Termites are a well-studied group of invertebrates, and are known to actively contribute to various ecosystem processes (Zeidler 1999, Bond 1993, Jones 1994, Crawford & Seely 1994). Termites make up a major proportion of the soil macro fauna present in the more arid areas of Namibia. They possess many characteristics that could make them potential indicators of the general health of ecosystems, having a high taxonomic diversity and relatively sedentary habits. These organisms tend to remain in the same area for decades, once a colony has been established. The fact that individuals are present throughout the year and their obvious functional importance within ecological systems also play a role in the selection of these insects as possible indicator organisms. Within the larger study, previously mentioned in this chapter, which was aimed at elaborating parameters to be included in the index of biological integrity (IBI) as adapted for use in Namibian rangelands. Termites and tenebrionid beetles were considered separately, and their potential usefulness as indicators of the biological integrity of the system under investigation, along with soil and vegetation parameters, was investigated.

The fertility of the soil in any given area is also considered to be an important indicator of the condition of rangeland (Behnke et al. 1993), since soil condition is one of the most important factors contributing to the productivity of agricultural activities. Recent research efforts have been focused on the attempt to link forage production with the cycling of nutrients present in soil systems.

1.4 Tenebrionids as possible indicator organisms

The fact that biotic systems are very complex means that assessments of integrity should include a variety of different indicators. In the attempt to create an IBI applicable to Namibian rangelands, tenebrionid beetles have been proposed as possible indicators of relatively short-term changes in the condition of the land.

Adult tenebrionid beetles are large, apterous, detritivores and found mainly on the surface of the soil, a characteristic which makes them relatively easy to capture in pitfall traps (Ahearn 1971, Pietruszka 1980, Samways 1994, Seely et al. In prep.). The fact that they are unable to fly and therefore have a more limited range means that they may respond very rapidly to more localised stresses, either in terms of numbers of individuals or in species richness and diversity, which may provide a measure of the diversity of the beetles in the area. A high diversity of tenebrionid beetles is usually found in arid systems (Koch 1950, 1952, 1955,1962, Doyen & Tschinkel, 1974; Wharton and Seely, 1982; Pietruszka, 1980; Seely et al. In prep.), implying that they may possess good indicator properties. In the context of Napcod's objectives of community participation in projects, they may also prove to be good indicators, since they are generally highly visible and are relatively easy to identify. If the local communities can be trained to be able to identify the beetles having good indicator properties, they may then be able to make use of the resources available to them in a more sustainable manner. The amount of available resources and the stresses to which they are subjected (natural as well as human-induced) should, in theory, have an effect on the diversity of beetles. The highest diversity would occur in biomes providing the greatest varieties of suitable habitats (Holm, 1989; Marais and Irish, 1998), the suitable habitats possibly being the areas that are less degraded. This is suggested by studies showing that modification of the landscape as a result of land use pressures can have an immediate effect on the coleopteran species, such as tenebrionids, which have a limited range and a low mobility (Samways, 1994; Pearson and Cassola, 1992).

The ease and relatively low cost of pitfall trapping as a sampling procedure and the comparable nature of the data which will be obtained can make tenebrionid beetles a good choice of an indicator group for comparative studies between different sampling sites within the same type of ecosystem. The tenebrionid beetle distribution may give an idea of their reaction to disturbances. If adequate field observations are made, it is possible to make predictions about what might happen to the diversity and structure of the communities under different degrees of disturbance due to differing intensities of land use.

There are, however, some drawbacks to the use of tenebrionid beetles as possible indicators of habitat quality. Because of the large numbers of different beetle species present in arid and semi-arid areas, it is difficult to obtain information about the distribution and population parameters of a number of species. The functional properties of adult beetles, within ecological systems, has not yet been fully established, although many are known to be capable of recycling nutrients through the system. Many tenebrionid beetles, being detritivores and opportunistic omnivores many of which feed on seeds, are also thought to play a major role in the ecosystem processes in savanna ecosystems, although they are probably less important than birds and rodents. In general, adult beetles do not drive certain aspects of ecological systems, being more reactive, although beetle larvae, along with termites, are known to dominate the soil fauna in more arid environments (Barnard et al, 1998). An extensive data-base exists at Gobabeb, however, on the way tenebrionids in a hyper-arid and relatively pristine area relate to rainfall and other environmental factors (e.g. Koch 1950, 1952, 1955, 1962, Hamilton & Penrith 1977, Marcuzzi & Lafisca 1977, Wharton & Seely 1982, Wharton 1983, Louw 1986, Naidu & Hattingh 1988, Prinsloo, 1990, Hanrahan &Seely, 1990, Louw, 1990, Seely et al. In prep). It might therefore be possible to explain some of the population parameters observed in areas undergoing comparably intense land use strategies, and may provide a useful baseline for comparison.

It was proposed that, in areas experiencing less intense land use pressure, tenebrionid beetle larvae might have access to a larger amount of food, more protection from predators and a more favourable microclimate than they would have in an area experiencing greater land use pressure. The effect would be seen in the adult beetles found in less intensely used areas therefore being comparatively larger. The sizes of the adult beetles are dependent on the larval development, and size therefore provides an integrated measure of the soil conditions during the period of the larval development. Intensively used land may reduce the productivity and soil conditions may change, thereby affecting the beetle individuals and populations. The present study looked at the effects of land use intensity on the: (1). species richness, (2). aspects of diversity and (3). morphological features of tenebrionid beetles in western Namibian rangelands.

1.5 Preliminary Survey

1.5.1 Study Objective

To carry out a broad survey of the coleopteran diversity and abundance at five Napcod pilot sites of differing land use.

1.5.2 Hypothesis

Tenebrionid beetles differ in species richness and diversity on different farms experiencing different land use management strategies and having different rainfall and vegetation

1.6 Case Study

1.6.1 Study Objectives

(1) To carry out a more detailed survey of one farm and compare sites of high land use intensity and low land use intensity but similar topography.

(a) To record the tenebrionid beetle species present in the two sites

(b) To determine whether there is a difference between the species richness of tenebrionid beetles present in the 2 sites

(c) To determine whether the size of adult tenebrionid beetles differs at the two different sites

1.6.2 Hypotheses

(1) Tenebrionid species richness is greater in an area that is less intensely used than in an area that is more heavily used.

(2) Tenebrionid beetle assemblages at the two study areas on the same farm differ.

(3) Tenebrionid beetle species composition, at the high and low land use intensity sites, differs between seasons i.e. just after the rainy season and during the dry season

(4) The tenebrionid beetles present at a heavily used site are generally smaller than those at a less intensely used site.

CHAPTER 2

Initial Survey of Napcod Pilot Sites

2.1. Introduction

Namibia's Programme to Combat Desertification (Napcod) was established in parallel with Namibia signing the "International Convention to Combat Desertification." The programme addresses the political, socio-economic and biophysical issues that are related to the desertification process. One of Napcod's objectives was to establish interdisciplinary research programmes, linking research and training activities with capacity building of Namibians at various levels. The need to establish a reliable knowledge base relating to desertification in Namibia was addressed, because at present the condition of rangeland is based mainly on the perceptions of individual farm owners. These perceptions, on which land use planning is based, often do not take into account the natural ecological variation.

A broad survey was carried out at five farms that had been selected as Napcod sites, in the Kunene region of northwestern Namibia. The survey was undertaken in order to establish an inventory of beetles present at each site, and to determine whether these were affected by land use practices at the different farms. Beetles formed the main focus for this study, but within the larger study, aimed at determining an index of biological integrity, termites as well as vegetation and soil parameters were also considered. A site at which more in depth investigations were to be carried out was chosen on the basis of the results of both the beetle and termite abundance and diversity measures at the selected farms.

2.1.1 Pilot Sites

The survey to determine the tenebrionid species richness and diversity was undertaken at five different Napcod sites, the farms Grootberg, Olifantswater, Olifantputs, Waterval and De Riet (Fig. 1).
The farms at which the pilot study was carried out are all situated in the southern Kunene region of Namibia.
This study was undertaken in order to obtain some preliminary data, to facilitate the selection of a site at which further, more in depth studies would be carried out. All five farms are study sites that have been selected for pilot studies to be carried out by Napcod (Namibia's Programme to Combat Desertification). While each of the farms is situated on communal land, they all have a different land use history. Overall, the intensity of land use as well as the management strategies employed on the selected study sites is different, although the farms each have similar ecological backgrounds.

Land tenure map to be inserted !!

The study site at which longer term, more in-depth studies would be carried out was selected after the pilot study was carried out in March 1997, when the five sites selected by Napcod in the western Kunene region were surveyed.

The five surveyed sites included the farm Grootberg (S19°48' E14°22'), which was originally a governmental breeding station. The entire farm was handed over to the local community in 1992 and since that time it has been used only for selective grazing. The community is considering the formation of a conservancy and other community-based tourism activities, to enable them to benefit from the wildlife present in the area, one of the main possible attractions being elephants. The area consists mainly of acidic igneous and calcrete rocks, red arenosols and dark alluvial sands (von Harmse 1978), while the vegetation is dominated by open mopane bushland and wooded grasslands (Mouton et al. 1997, Zeidler 1999).

Olifantswater (S20°09' E14°54') has been a communal farm since 1898, and has never been fenced off for commercial farming purposes. Vegetation at this farm consists of *Commiphora* dominated bushland on very hilly terrain (Zeidler 1999). The main land use at this farm is small scale, subsistence crop farming and livestock husbandry.

Like Olifantswater, the farm Olifantputs (S20°15' E14°58') has been communal since the end of the last century. No physical farm boundaries are in place, due to the fact that fencing in communal areas is illegal.

Waterval (S20°20' E15°15') and De Riet (S20°28' E14°11') were both formerly commercial farms. They were incorporated into the communal areas after 1968, when the country was divided up into various ethnic homelands based on the recommendations set out in the Odendaal commission (Rhode 1993, DRFN, 1997, Robertson, in prep., Barnard et al. 1998). In contrast to the other farms, De Riet is not permanently occupied, and is used mainly by herders who have moved into the area looking for grazing for their livestock, as well elephants and other game. As a result of severe droughts during the late eighties and early nineties, farmers at De Riet lost significant numbers of livestock. After independence, most of the community members elected to leave the area. Since their departure, elephants and other game roam freely through de Riet. Herders have also moved into the area, and competition has often resulted between the herders and their cattle, and the local wildlife, for the use of the extremely limited resources.

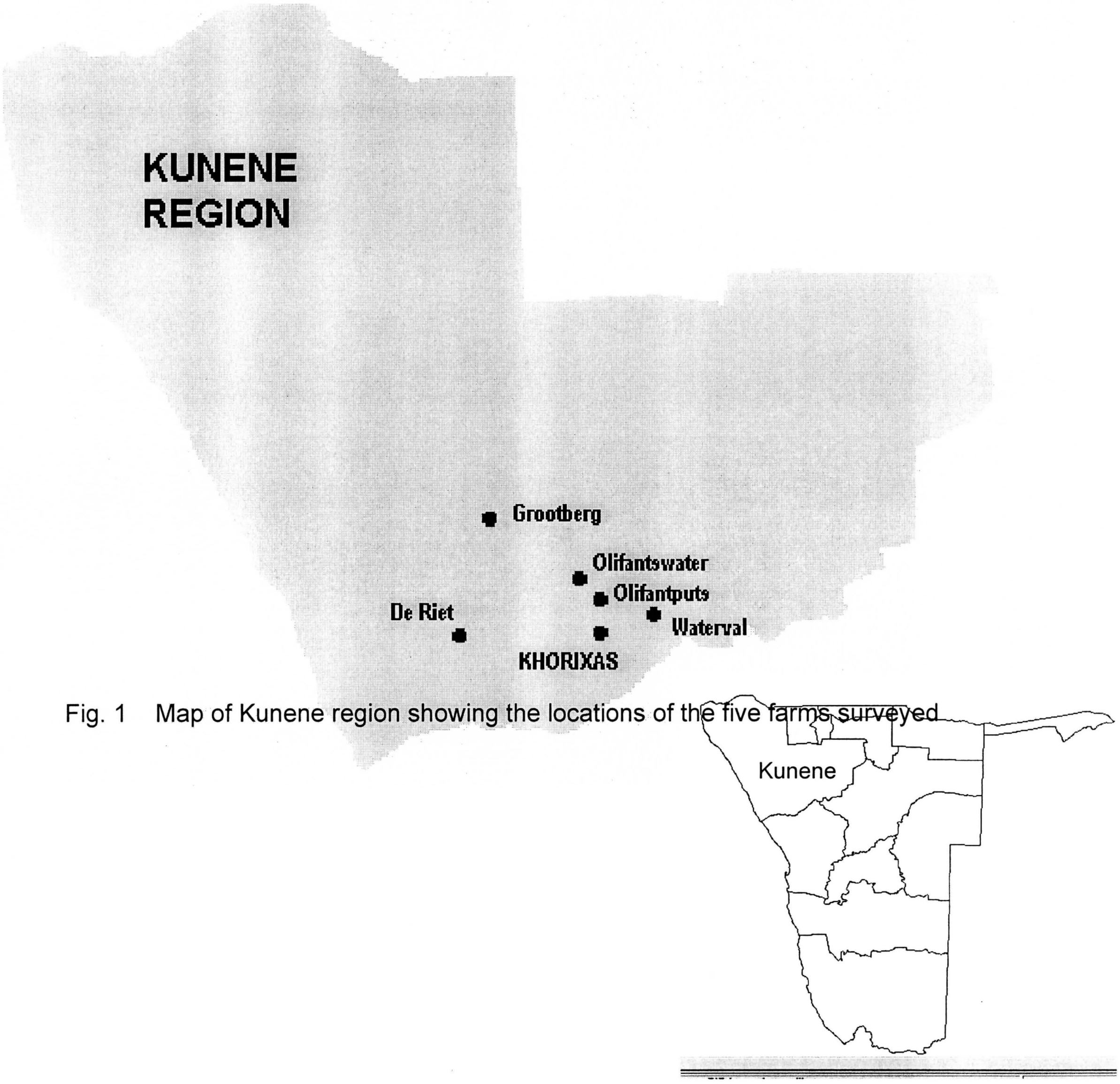


Fig. 1 Map of Kunene region showing the locations of the five farms surveyed

Fig.2 Map of Kunene region, showing the locations of the five farms surveyed and the main town of Khorixas. Insert shows the map of Namibia.

2.1.2 Climate

The Napcod pilot sites, at which the pilot study was undertaken, all lie within the summer rainfall zone. Rainfall is limited and variable. Thunderstorms, rarely exceeding one hour, are the usual form of precipitation, and hailstorms are not common occurrences. The rainfall (wet) season usually runs from November to April, with the effective rainfall occurring during February and March. Rainfall during the other months is generally negligible (Olszewski 1996). Drought is a fairly common occurrence in the area, and overstocking under these conditions can have detrimental effects on the condition of the habitat. Rainfall events trigger most biological and ecosystem processes occurring in arid environments, such as the area in which the study was carried out. The climatic conditions in the area are such that any agricultural practices other than with small stock are not generally suitable. Due to the patchiness in the spatial and temporal rainfall distribution, nomadism and migration allow for the resources to be optimally exploited and conserved. These management practices have been observed in areas close to the sites selected for this study (Bollig 1997, Sullivan 1998, Rhode 1994).

The farms Waterval, Grootberg, Olifantswater and Olifantputs all fall into the 179 to 587 mm per year rainfall range (average), although the total rainfall received in these areas in any normal year could actually be much higher or lower than the average. The normal rainfall received on these farms could therefore actually be anywhere between 52mm and 987mm of rain annually (Dealie et al 1993)
(Fig. 2). Long periods of drought, lasting for between five to eight years are common occurrences in the region (Olszewski 1996, Gewers 1936, Kamwi 1997). The mean evaporation rate is 3000 mm per year. This high rate of evaporation, which is approximately six times greater than the mean annual rainfall, means that any rainwater is lost from the system very quickly. Most of the rainfall is therefore unavailable on the soil surface (Jacobson et al. 1995, Simmonds & Forbes Irving 1995).

De Riet, the most arid of the sites investigated, being situated at the eastern edge of the Namib Desert receives less than 100 mm mean annual rainfall with a minimum as low as 17mm of rain per year. (Dealie et al. 1993).

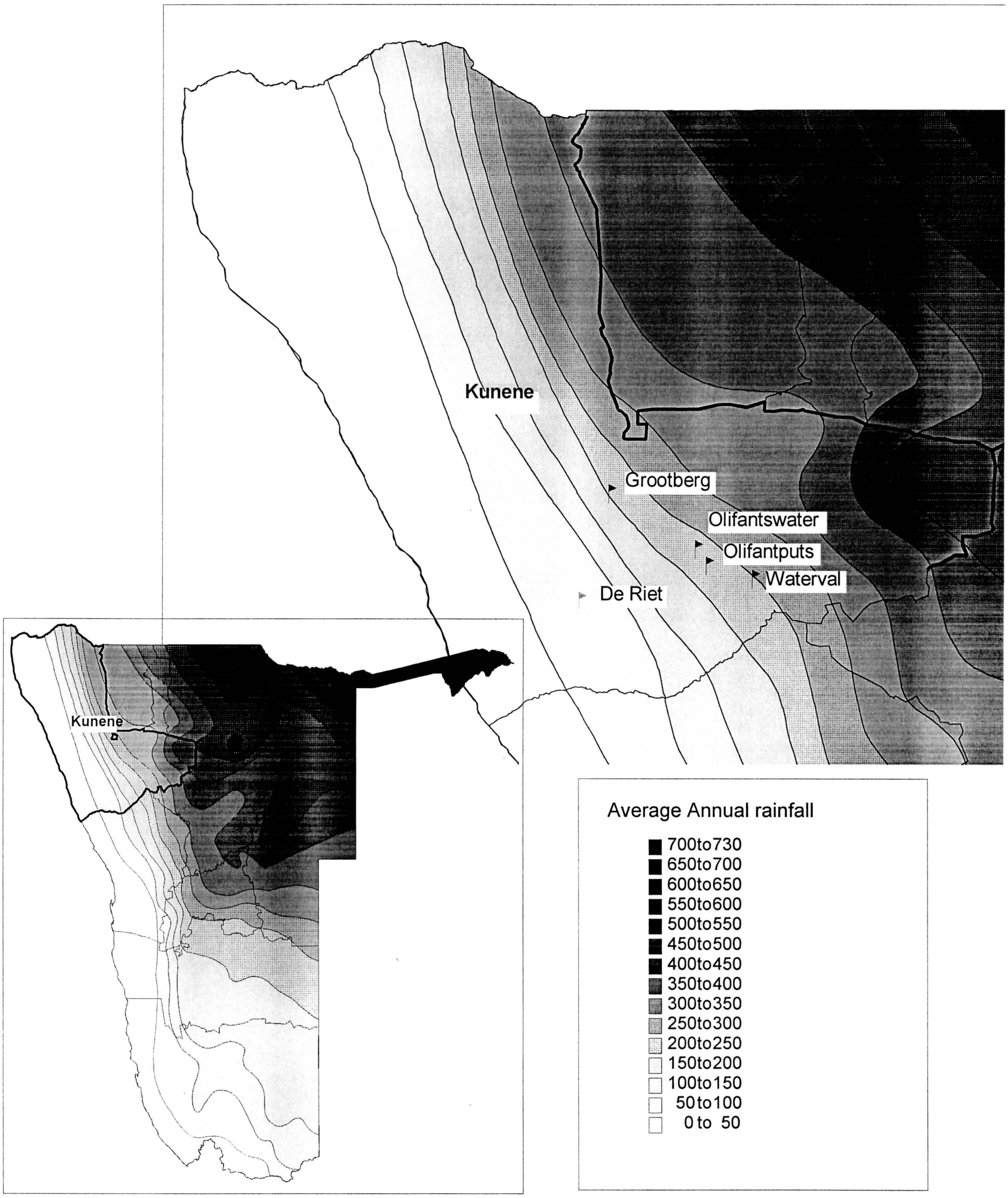


Fig. 3 Rainfall ranges in areas where the study was undertaken. Data supplied by the Biodiversity Task Force of Namibia

2.1.3 Vegetation and soils

Due to the low rainfall, a limited number of soil series are present in the area. The soils in the region vary with the aridity, which increases from east to west. Soils in the pilot study areas are highly calcareous and saline and their development is limited by the general barrenness of the area. The saline character of the soils in the region mean that the potential for agriculture is severely limited. In general, throughout the Kunene region, the soils are generally thin, and are poorly developed due to the arid climate and the relatively slow rate of weathering (Kamwi 1997, Simmonds and Forbes Irving 1995, Jacobson et al. 1995).

Vegetation in the southern Kunene region is determined mainly by rainfall regimes and the availability of moisture, which is often related to the topography and edaphic conditions (Loxton 1974). The study areas fall into the vegetation region described as mopane savanna by Giess (1971). The species composition of vegetation varies with rainfall across the region and tall *Colophospermum mopane* (Kirk ex Benth) and *Terminalia* woodlands are common in the eastern part of the Kunene region. Further west, the *Terminalia* species become more stunted shrublands, and to the extreme west of the region, ephemeral grasslands of *Stipagrostis* species are the norm.

A number of different types of acacias and *Commiphora* thorn shrubs are found in the region. *Colophospermum mopane* (Kirk ex Benth) occurs either in the form of a shrub, or as a tree, depending on the local conditions. It is of especial importance to local small-stock farmers, mainly because of its ability to produce green foliage, even when very little moisture is available. This characteristic makes the plant useful as a source of fodder during much of the dry season, when cut and fed to young goats and cattle. Various species of *Commiphora* are also of importance to local communal farmers, their seedpods serving as an alternative source of fodder (Rhode 1993, Craven & Marais 1992). The grasses that dominate the region are annual species such as *Stipagrostis* sp. and *Schmidtia* sp., but other less productive pioneer annual species are also prevalent in the dryer, western areas of the region (Müller 1985, Rhode 1993).

A medium to dense riparian woodland as well as grassland is found at De Riet. The most prevalent trees at this site are *Faidherbia albida* (Delile), *Acacia erioloba* (E. Meyer), *Colophospermum mopane* and *Salvadora persica* (L.). Endemic species of plants, suited to the arid conditions in this area, include species of *Euphorbia*, *Moringa* and *Acacia* (Jacobson et al. 1995). Waterval consists of open mixed bushland plains, with the most dominant trees being *C. mopane*, *Acacia reficiens* (Wawra) and *Catophractes alexandri* (D.Don). The farms Olifantswater, Olifantputs and Grootberg are similar in terms of their vegetation, all farms consisting of open bushland which is dominated by *C. mopane*, *Terminalia prunioides* (C.Lawson) and *Commiphora* spp. trees (Coates Palgrave 1983, Craven & Marais 1992, Müller 1985, Zeidler et al. 1998).

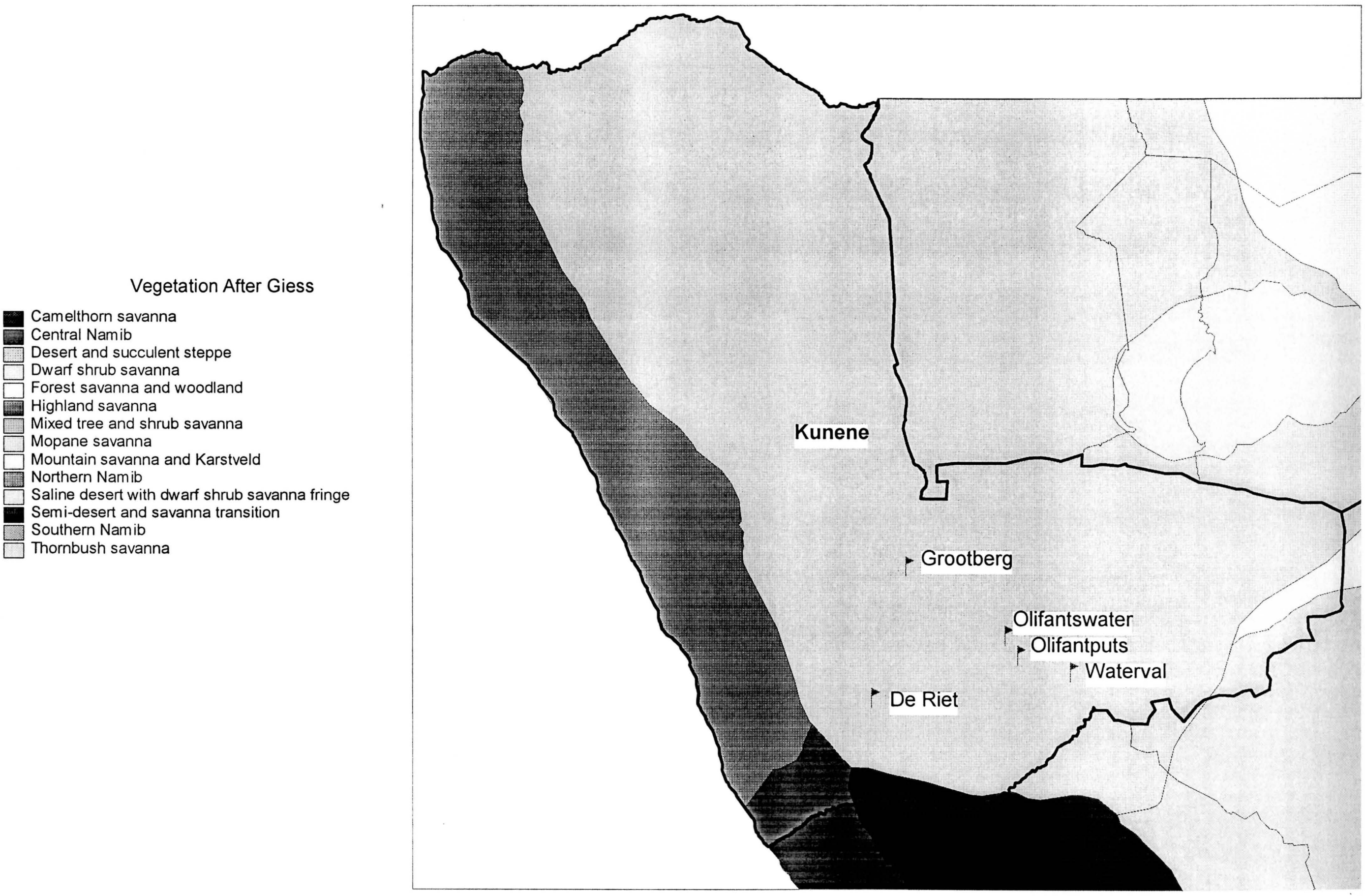


Fig. 4 Map showing vegetation types at the study sites. Data made available by the Biodiversity Task Force of Namibia

2.2 Sampling methods and experimental design

2.2.1 Study Period

The initial survey of the five Napcod pilot sites was conducted over a two-week period in March/April 1997, during the rainy season. Trapping was conducted over two days at each of the sites.

2.2.2 Beetle Trapping

The principal source of data gathering was by means of pitfall trapping, a technique that is extensively used in ecological studies, despite some drawbacks. Some beetle species tend to avoid the pitfall traps, and the possibility that some species are able to escape exists. Predators may also fall into the traps and eat some of the trapped beetles. In field experiments, pitfall traps are generally considered reliable, however, especially for the capturing of surface-active beetles (Dufrène and Legendre, 1997; Krasnov and Ayal, 1995; Palmer, 1994; Kromp, 1990).

During the initial two-week long survey, beetles were trapped along a land use intensity gradient at each selected site (Fig. 5). The gradient ran from the most intensely used areas around water points, and progressed towards less intensely used areas 5km away from the water points, where land use intensity was thought to be lower. Pitfall traps were buried in the ground, and levelled with the surface of the soil. On each farm, traps were placed in sets of three, each member of the set being placed within 5m of the others. Five sets of three traps were placed randomly in the vicinity of the water points and kraals, areas on the farms that were considered to be the most intensely used. Five more sets, containing three traps each, were placed along a land use gradient, moving away from the farms, towards relatively undisturbed areas. These five sets were placed at three intervals of 500m, and two intervals of 1km away from the farms. The traps were left in the ground for 48 hours at each site, and each trap was checked twice daily. No baits were placed in any of the traps. All beetles caught in the traps at this point in the study were removed from the system and later identified, tenebrionid beetles as well as any other coleopterans.

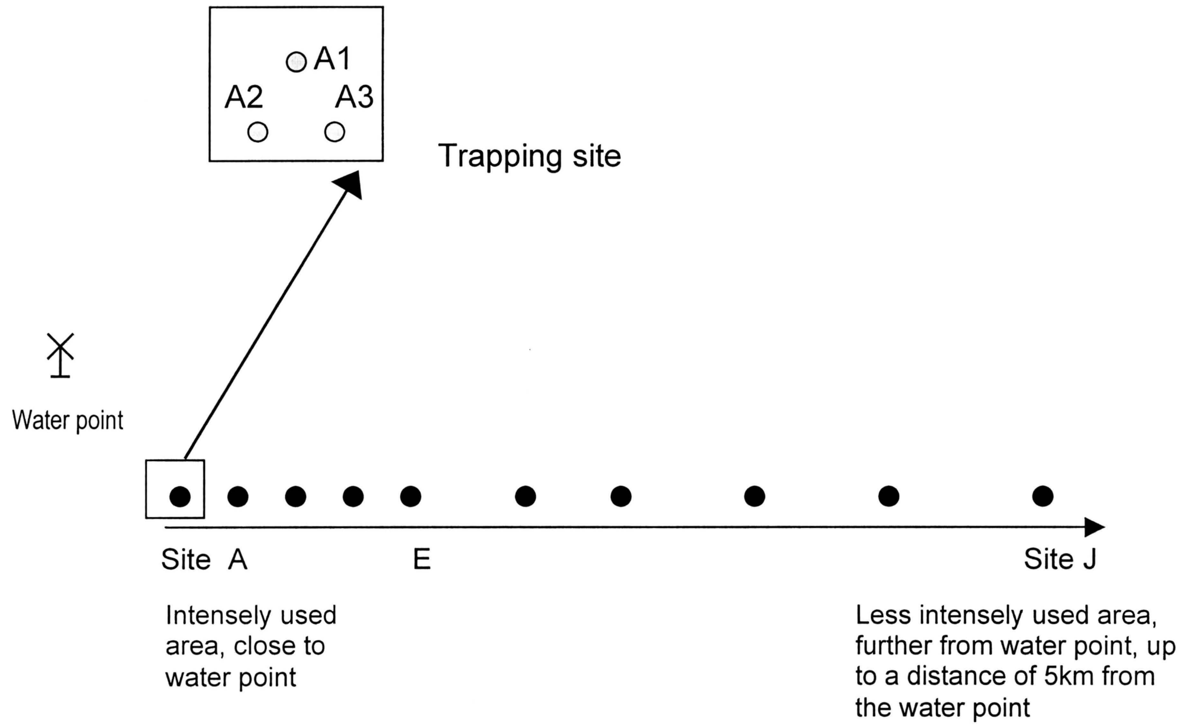


Figure 5.
Schematic diagram of experimental set-up applied to all farms surveyed during pilot study. Dots represent the ten sites along the land use gradient where beetles were trapped. The five sites close to the water point (sites A to E) were situated 500m apart, and the five sites further away from the water point, were each a distance of 1km apart

2.2.3 Analysis of species assemblages and diversity

The distribution of the data for the different sites was first tested, using frequency distribution plots (Magurran, 1988). Species inventory lists were then compiled.

Diversity indices measuring species richness, diversity, evenness and dominance were calculated, using methods described by Magurran (1988). The Shannon index was used to measure species richness and evenness. The Simpson index was used to calculate the dominance. Once these values had been obtained, comparisons could be made between the different sites as well as the different seasons (i.e. rainy season and dry season) Paired t-tests, ANOVA, cluster analysis Kruskall-Wallace and Mann-Whitney were used.

2.3 Pilot survey results

2.3.1 Species Assemblages

A total of 259 individual beetles, belonging to 60 species in 51 genera and 14 families were found during the survey (Table 1). The highest abundance was found on the farm Grootberg while the lowest was found at De Riet, where only nine different species of beetles were found, compared to the 29 species found at Olifantputs. Olifantputs was also the site that, while not having the greatest abundance of individual beetles, was, however the most species rich.

While Olifantswater, Waterval, Grootberg and De Riet showed results that were relatively similar, Olifantputs proved to be different from all of the other sites, in terms of species assemblage and composition, as well as in the abundance and diversity of species.

During the survey, the most common species found, over all sites were *Cryptochile consita* Haag,1872, *Physadesmia globosa* Haag-Rutenberg, 1875, *Zophosis boei*, Solier, 1834, *Mylabris* sp. and *Hybosorus* sp.

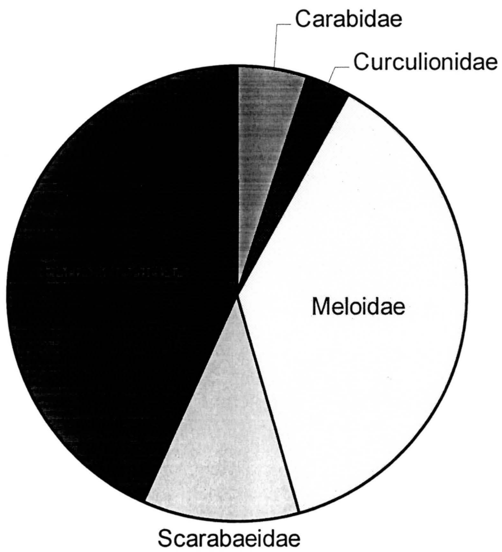
Beetles made up 91% of the total insect catch, tenebrionid beetles comprising 49%. There were, however, differences in tenebrionid beetle abundance within each of the different sites.

At each farm surveyed, there was a general trend of greater species richness as well as higher numbers of individual beetles at sites further away from water points. Smaller species of beetles were generally found closer to the water points, whereas relatively larger species were found further away (e.g. *C. consita, Psammodes* sp., *P. globosa*).

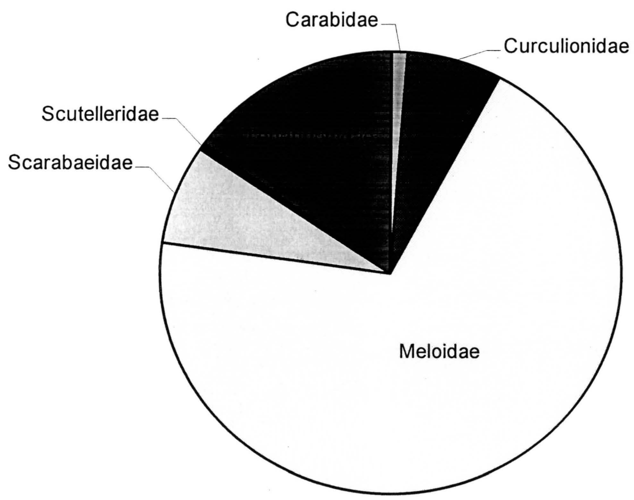
A significant difference was found between the tenebrionid abundance nearby and further away from water points ($p = 0.043$), and the general trend found was that the tenebrionids increased in abundance on moving further away from the water points.

The numbers of tenebrionid beetles found at each of the five study sites exceeded the other Coleopteran families in terms of the numbers of species as well as the numbers of individuals per species. Tenebrionids made up 26% of the overall catch at sites closer to the water points, and 78% of the total catch at sites further away from water points. The most dominant tenebrionid species found at all sites was *C. consita*.

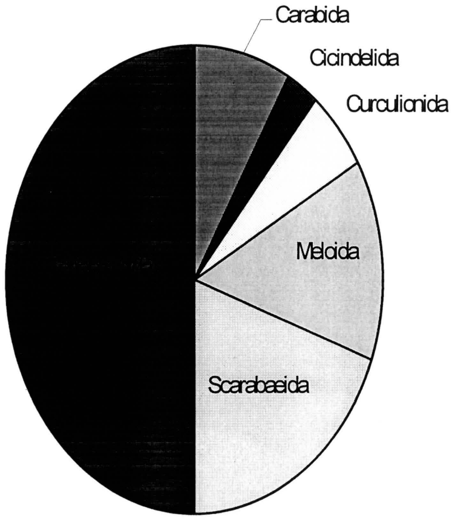
Within the other families of beetles recorded during the survey, a number of different species of Meloidae were most prevalent. These beetles were present at all of the selected study sites other than De Riet. The highest numbers of meloids were found at Grootberg and Waterval. Overall, Meloidae were much more abundant at sites closer to water points.



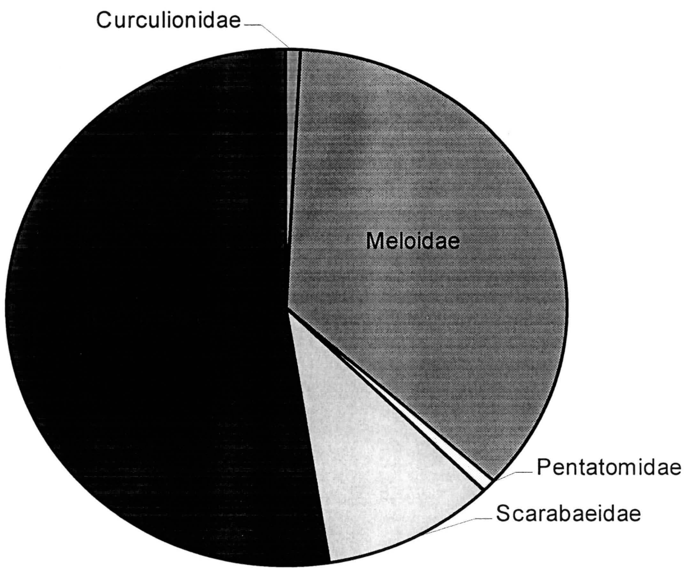
Olifantputs beetle assemblage



Waterval beetle assemblage



Olifantswater beetle assemblag



Grootberg beetle assemblage

Fig 6 (a – e) Beetle assemblages recorded at the five pilot sites during the preliminary study, March 1997

2.3.2 Species richness and diversity

Species richness and Shannon diversity indices were calculated according to the methods outlined in Magurran (1988) and compared over the five study sites (Table 2).

Table 1 Diversity indices and abundance of beetles recorded during the survey

	OP	OW	W	DR	G
α	20.07	10.68	13.75	6.316	12.68
H'	2.884	1.996	2.642	1.899	2.678
E	0.856	0.778	0.855	0.864	0.813
D	0.141	0.11	0.085	0.152	0.084
Species	29	13	22	9	27
N	65	26	55	20	93
% Beetles	83	92	73	95	82
%Tenebrionids	66	42	25	60	34

OP = Olifantputs, OW = Olifantswater, W = Waterval, DR = De Riet, G= Grootberg

The overall diversity indices measured were not very high, but of the farms surveyed, Olifantputs showed by far the greatest diversity (α = 20.07), with that of the other sites ranging between 10 and 14.

Waterval showed the next highest richness and diversity. The high abundance of Meloidae found at Grootberg was the main factor contributing to the high abundance of beetles present on this farm. A trend of decreasing species richness in relation to aridity appeared to exist in the areas considered during the survey, with the farm De Riet, displaying the lowest species richness. *P. globosa* was the dominant tenebrionid beetle present at this farm, making up 53% of all of the tenebrionids recorded, and 35% of the total beetle catch. In contrast, at

Olifantputs, *Cryptochile consita* was the most dominant tenebrionid beetle recorded. It made up 68% of the tenebrionid catch, but only 16% of the total beetle catch. A trend of decreasing species abundance was noticeable between the different farms investigated (Fig.8). Anova was used to compare the diversity and species richness at the different sites, and the sites were found to be significantly different in this regard ($p = 0.002$). Within each of the sites, beetles found closer to the water points were less abundant, and their species richness was lower than those found further away from the water points.

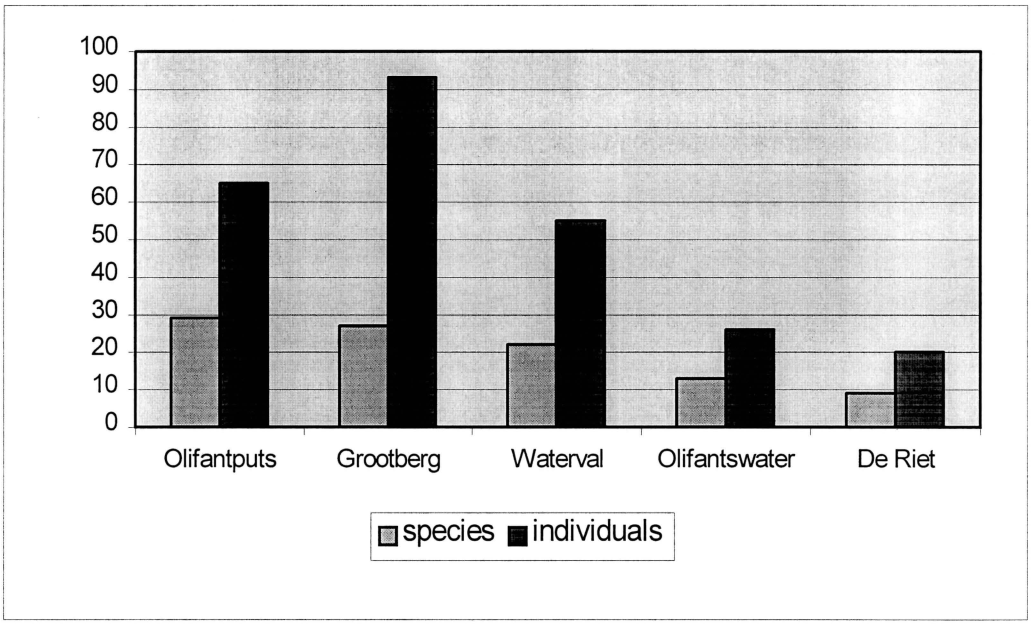


Fig. 7 Comparison between numbers of species and numbers of individual tenebrionid beetles present at the surveyed farms.

2.4 Discussion of preliminary results

2.4.1 Species richness, diversity and composition

The species richness and composition found at the selected study sites give an initial idea of the diversity of the area.

Tenebrionids were found to be more prevalent than any of the other families of beetles collected. This was true for all of the study sites.

Waterval and Grootberg have similar beetle species compositions, and the resources available to the beetles found at those sites may be similar. It is possible that the only certain species of beetles could be capable of surviving under the habitat conditions available on these farms. At both farms, at least four different species of Meloidae were found, and these were found exclusively at sites closer to the water points. The highest numbers of individuals of Meloidae were found on these farms. These beetles were found in close association with *Tribulus terrestris*, a plant that was relatively abundant at these two farms. *T. terrestris* is considered to be an indicator of degraded land, and is found mainly in the rural, semi-arid areas of southern Africa. It is dominant in areas used for cattle pasture, being found especially around boreholes. (Scott, 1990). The fact that large numbers of these organisms were found in the pit-traps is probably a result of the heavy rains experienced at the time of the survey. Many of the traps collected water, and the beetles were trapped in this way.

The four species of *Zophosis* recorded at Waterval and Grootberg also have the ability to move very quickly over long distances, into habitats that may be more suitable for their survival, i.e. those habitats where resources may be less limited. Although many species of *Zophosis* generally show a greater level of tolerance to high soil surface temperatures than many other tenebrionid beetle species (Wharton & Seely 1982, Seely et al. *In prep.*), all the *Zophosis* beetles recorded during the survey at all sites were found at sites far away from water points. The exception to this was the farm De Riet, where, surprisingly, no species of *Zophosis* were recorded at all.

The lowest diversity index was calculated for De Riet, and this is possibly attributable to the fact that this particular farm falls into the lower extreme of the Namibian rainfall range gradient. The area is much more arid than any of the other study sites, which all fall into the 179 to 587mm rainfall range (Fig.2). On the other hand, the diversity of tenebrionid beetles occurring in the Namib desert is exceptionally high, with more than two hundred species being found in this foggy desert (Koch 1962, Wharton & Seely 1982, Seely et al. *In prep.*). De Riet is situated on the eastern edge of this desert, where the average rainfall is less than 28mm per year. In this area, many tenebrionid beetles have become adapted to making use of fog water, and this is considered to be one of the reasons for their high diversity. Looked at in this context, the low diversity of tenebrionid beetles is surprising. A possible reason for the result could be that the farm is located in an area to which people had been forced to move and attempt to farm. In arid areas, while the number of endemic species is generally found to be high, the overall species richness and diversity tends to be lower (Barnard et al., 1998; Simmons et al., 1998). The dominance, calculated according to the Simpson index, was, however, highest at this site. This could mean that the habitat has possibly become unsuitable for a number of tenebrionid species in favour of more arid-adapted species. De Riet was the one site that had not experienced any rain at the time of the study, and this could have affected the beetle diversity. Many species adapted to arid environments tend to either show an extremely rapid response or alternatively an extremely slow response to rainfall events, and the study period may have occurred at a time of "no longer" as well as "not yet". If rainfall had been better at the time the study was undertaken, beetles might have been more diverse. The low numbers of species and high dominance on this farm may therefore reflect the state of the environment.

A very high diversity of beetles generally occurs in areas where food resources show strong fluctuations (Seely et al. *In prep.*). As the timing of the survey coincided with a period of heavy rainfall in the area after a period of drought, these fluctuations could have been more pronounced than usual at the time of the study, possibly leading to a higher diversity. Some species may, however, respond more gradually to changes in the condition of the habitat, and their numbers may increase more slowly, over a longer period of time. These species may therefore not have been present in the adult form at the time of the study.

2.4.2 Beetle distribution ranges and assemblages

Very few inventories exist which relate to the patterns of species assemblages and distribution of many of these organisms in Namibia in general (Marais & Irish *unpublished*) and in the area surveyed in particular. Of the tenebrionid beetles found, *Cryptochile consita* was the most prevalent. The emergence of adult beetles of this species is triggered by rainfall, and once they emerge, they are active for most of the year (Penrith & Endrödy-Younga 1994). Their range of distribution includes areas that are extremely arid, being widespread in the western parts of southern Africa, and they are therefore capable of surviving for several seasons without the emergence of adult forms (Endrödy-Younga 1989, Penrith & Endrödy-Younga 1994). When sufficient rainfall does, however, occur, they respond almost immediately (Penrith & Endrödy-Younga, 1994). This may account for their high abundance at the time of the survey.

A high diversity of species is also usually found in areas where high rates of endemism are found (Huston, 1994). All of the sites investigated are situated in a region considered to be a hotspot of species endemism in Namibia (Simmons et al., 1998; Barnard et al. 1998). While most of the species found during this survey are not endemic to Namibia, rather to the western southern African region (Koch 1962, Schulze 1962,1978, Louw 1979, Penrith 1979, 1986, Endrödy-Younga 1989, Penrith & Endrödy-Younga 1994), it should be mentioned that the survey was undertaken over a very short period of time, and at a relatively small number of sites.

More in depth studies, and lengthier periods of monitoring, which would include actively searching for beetles not likely to fall into traps as well as data gathered from pit-trapping would yield a greater number of endemic species.

Land use pressure

In the Namib Desert, long-term studies have shown that the community composition of these beetles differs considerably in relation to the amount of food available, the vegetation cover, the amount of water available, the soil type and hardness as well as variations in the climate (Seely et al. *In prep*). Land that is heavily grazed and trampled by livestock has reduced vegetation cover and formed harder, more compact soil conditions, and these factors may have an adverse effect on the populations of some beetle species in the areas. A large amount of data has been collected on the population dynamics of tenebrionid beetles in the Namib Desert, and their reactions to various environmental parameters has been well documented. The sites at which beetles were collected for this survey are all situated in a region adjacent to the Namib Desert. Information gathered about beetles in the hyper-arid Namib, which falls within the protected areas network (Simmons et al., 1998) is not confounded by factors relating to land use pressures. This may later be extrapolated to answer questions relating to land use in areas situated just outside of the Namib. The ranges of some beetles found in the Namib also extend slightly eastwards so potential for comparison between the reactions of the same species of beetles found under differing environmental and land use pressures exists. These may be having an appreciable effect on the population dynamics, diversity and species assemblages of beetles at the different sites. At all of the sites, evidence of a large amount of trampling by livestock was visible, more so nearer to the water points than further away. The soil at these sites was extremely compact, and many bare patches and walking trails were apparent. Most of the tenebrionid species found during the survey are dependent on sheltered microhabitats, (Koch 1962, 1963, Schulze 1963, Penrith 1978, Louw 1979, Penrith & Endrödy-Younga 1994) and the large number of bare patches created by the trampling of livestock may have had the effect of decreasing populations of some species near the water points. This may account for the higher abundance and higher species diversity of these beetles at sites further from the water points and homesteads. Human-induced disturbance may be having an appreciable effect on the population dynamics, diversity and population dynamics of beetles at the different sites. On the other hand, an increase of dung near water points may provide more food to some species, which would explain a change in the assemblage.

At all of the sites surveyed, *C. consita* were found in much greater abundance at sites relatively far away from water. These beetles are usually associated with areas where sufficient shelter is available, as they are relatively slow moving (Endrödy-Younga 1989, Penrith & Endrödy-Younga 1994). They are, in general, adapted to conditions that are less extreme in terms of aridity, temperature and substrate. This characteristic may have contributed to their low abundance at areas closer to the water points, where vegetation cover has been reduced, and the many bare patches allow the soil to heat up considerably during the day. Nevertheless, the presence of these beetles at all sites may mean that they are able to adapt to changes brought about in their habitat due to the influence of people and livestock more successfully than other species of tenebrionids. The fact that most individuals were present at the sites situated further from water points suggests that they may be affected by land use practices. The habitats closer to the homesteads are possibly less suitable for their survival than those further away. *C. consita* is known to show strong associations with particular types of substrates (Penrith & Endrödy-Younga 1994), and modification of the environment by the trampling of large numbers of livestock is likely to be having an effect on their patterns of dispersal. Other species of beetles that occur in the area but were absent at the time the survey was undertaken, might respond more gradually to the changes in the habitat resulting from rainfall events.

As at all of the study sites, those beetles caught at the sites further from water were mainly larger species of beetles, which have relatively long legs (pers. obs.), notably *Psammodes* sp. These beetles were also mainly present at the sites where land use intensity was lower. These beetles tend to prefer relatively sheltered environments, and generally avoid long periods of activity in open areas, where vegetation cover is minimal. They also seem to prefer relatively sandy areas, which are not too difficult to dig into. This preference suggests a possible reason for their being found further away from sources of water.

The five farms considered showed a great variation in the diversity and abundance of beetles present. These differences may be a result of the differences in the land use histories and patterns of land use and management practised. Small species of arthropods have been shown to respond significantly to small-scale changes in grassland structure, and the local impacts imposed by grazing intensity (Dennis et al. 1998). The habitat parameters, such as the soil, vegetation and water resources available to the beetles further away from the areas immediately surrounding the water points and kraals may also be more suitable for the survival of beetles.

Whether the beetles are responding to ecological factors, or whether they are reacting to modification of their habitat because of human impact has yet to be established. The most prevalent beetle at this farm was *Physadesmia globosa*. This beetle was only recorded at De Riet. As in the cases with the other more dominant beetles found at the different sites, more individuals were found further away from the sources of water. This diurnal species is known to prefer sandy, litter-strewn and otherwise well-shaded areas that are generally subjected to less extreme microhabitat conditions, and it is capable of moving rapidly over open areas (Marcuzzi & Lafisca 1977, Ward 1996, Fergusen 1989, Cloudsely-Thompson 1990) It's range of distribution includes the Namib and the pro-Namib, and it is well adapted to arid conditions, which possibly explains why it was only recorded at the farm De Riet, which is situated on the eastern edge of the Namib.

Based on the results of the survey, Olifantputs was selected as a site where longer-term, more detailed ecological data would be gathered. In order for people to manage the land in a sustainable manner, knowledge about the species present in the area, their assemblages, patterns of distribution and abundance and changes in any of these characteristics as a result of human or natural disturbances needs to be available. This survey provided some information about what species are present in the communal areas. Tenebrionid beetles appeared to be a good candidate for use as an indicator group, being more diverse and abundant than any of the other species of beetles found during the survey. They also conform to most of the criteria necessary for a good indicator group, as outlined in Halfter, 1998 and Kremen, 1992.

CHAPTER 3

Initial Survey at selected study site: Olifantputs

3.1 Introduction

The communal farm Olifantputs was selected as the primary study site, based on the results of the study conducted in March 1997. Results of that study, conducted at five different Napcod sites (Chapter 2), showed that a greater diversity of tenebrionid beetles was present at this farm, than at any of the other farms surveyed. (Fig.8 – map of boundaries etc. of Olifantputs).

3.2 Preliminary indicators of habitat condition

At Olifantputs, the potential of termites, soil and vegetation parameters, as well as tenebrionid beetles, as indicators of the condition of the habitat, were tested. This preliminary study gave a first approximation of which parameters could be considered useful indicators of the condition of the habitat at the selected sites, each experiencing a different level of grazing pressure.

Termite diversity and dominance were not different at the high and low land use intensity sites, although they were the most abundant soil organisms found. Vegetation measures were similar at the two land use intensity sites, although woody biomass was slightly higher at the site experiencing lower land use pressure. When all vegetation parameters were summed up, however, it appeared that a higher availability of resources existed at the lower land use intensity site. Soil fertility factors emerged as a major contender for use in determining the condition of the habitat, soil carbon being identified as one of the most important factors in discriminating between the range condition at the two selected study sites (Zeidler 1999).

The vegetation and soil parameters, as well as the measures of termite diversity supplied the necessary background information relating to the prevailing conditions at Olifantputs at the time of the study.

The present study focused on the potential indicator properties of tenebrionid beetles, but the other factors mentioned were looked at within the larger indicator project, and all were combined so as to obtain a better description of the area in which the work was carried out.

Map of farm etc.

Fig 8. Map of boundaries of the communal farm, Olifantputs

It is estimated that Olifantputs covers approximately 5000 hectares. Farming with cattle, donkeys and goats is the main land use practised at this farm, and in terms of the climatic variability in the area, agriculture is not a viable option. A case study was carried out at Olifantputs, which has been under communal land management since 1898. All stock are kept in relatively high numbers, and, according to the data collected by the Ministry of Water and Rural Development, between 1990 and 1998, farmers at this farm overstocked continuously. During 1998, the total number of cattle kept on the farm was 457, while goats numbered 1046. The stocking rate recommended for this farm by MAWRD is 167 livestock units per hectare, rather than the 457 recorded during 1998 (Zeidler 1999).

3.3 Methods

During October 1997, a month was spent in the field, looking at the tenebrionid beetle abundance and diversity at two different sites located on the communal farm of Olifantputs. One site was situated in an area of the farm experiencing intense land use pressure, relatively close to the farmsteads, kraals and water point, and the other in a less heavily used part of the farm. The plots at each of the land use intensity sites were similar in terms of the soil and vegetation parameters.

At one site within both the high and low land use intensity site, an area measuring half a hectare was mapped out. Five sets of pit traps, each consisting of a subset of three traps, were placed within each half-hectare. The traps were set in sets of three at each of the five sites, with a minimum of 5m between the traps within each of the sets. Four of the sets containing three traps, were placed 50m apart, and one subset was placed in the centre of the resulting square, at an angle of 45 to each of the other four sets of traps (Fig.). Stones, sand and a small amount of litter, of available, were placed inside the traps, to afford those insects caught with a measure of protection against predators, both within and outside of, the traps. Traps that were removed or damaged in some way, were removed and replaced. In contrast to the study carried out during March 1997, only tenebrionid beetles were considered during this study, as these were found to be the most species rich and diverse of the beetles trapped during the initial survey previously carried out (Chapter 2). Trap dimensions were the same as those mentioned in the previous chapter. All tenebrionids trapped in this way were removed from the system and later identified. Beetles were placed into vials containing a solution of 70% ethanol and preserved for later measurement. The project reference collection, started during March 1997, was supplemented. Beetles other than tenebrionids, as well as any other organisms found in the traps, such as lizards or scorpions, were released immediately when the traps were emptied.

The length and width of the beetles trapped was recorded, and compared between the two land use intensity sites. The abdomen width and total body length of each of the individual tenebrionids collected at each site was measured, using Vernier callipers, and recorded. Body lengths were measured in the midline from the tip of the head to the tip of the abdomen. Width was measured at the point where the abdomen was at its widest.

As in the previous, pilot survey, beetles were identified, where possible, to species level with the help of the reference collection started earlier, Judith Diaz, the technician and the curator of the insect collection of the National Museum in Windhoek, Eugene Marais.

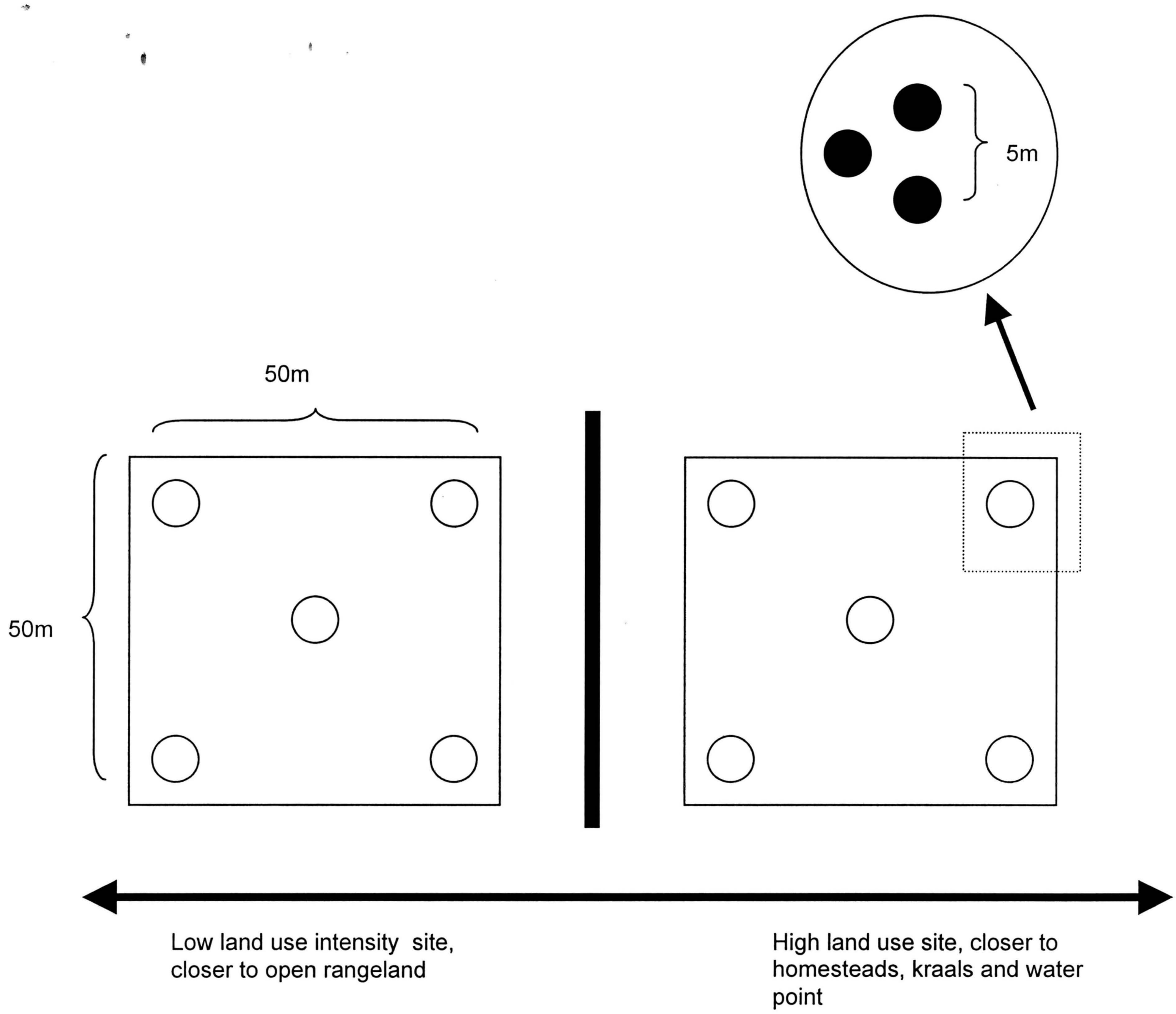


Fig 9. Generalised sketch of layout of plots at high and low land use intensity sites. Open circles denote sites containing subsets of three pit traps each. Filled circles show the positioning of the three traps placed at each sites within the half-hectare plot. The same design was applied at both the high and the low land use intensity sites.

3.4 Results and Discussion – Olifantputs 1997

3.4.1 Species assemblages and composition

During the October 1997 trapping session, 135 individual beetles of eight different species were found. All recorded individuals were caught in pit-traps. Of the beetles caught, most individuals were found at the high intensity site, where 74 beetles, making up 55% of the total catch were recorded, while 45% were recorded at the low land use intensity site. The most dominant beetle found during this period was *Zophosis* sp., which made up 69% of the total beetle catch in the pit traps. This beetle was followed in dominance by *Stenocara aenescens*, which comprised 8% of the total catch.

Fig 10. Total numbers of individual tenebrionid beetles caught in pit-traps during October 1997 sampling period

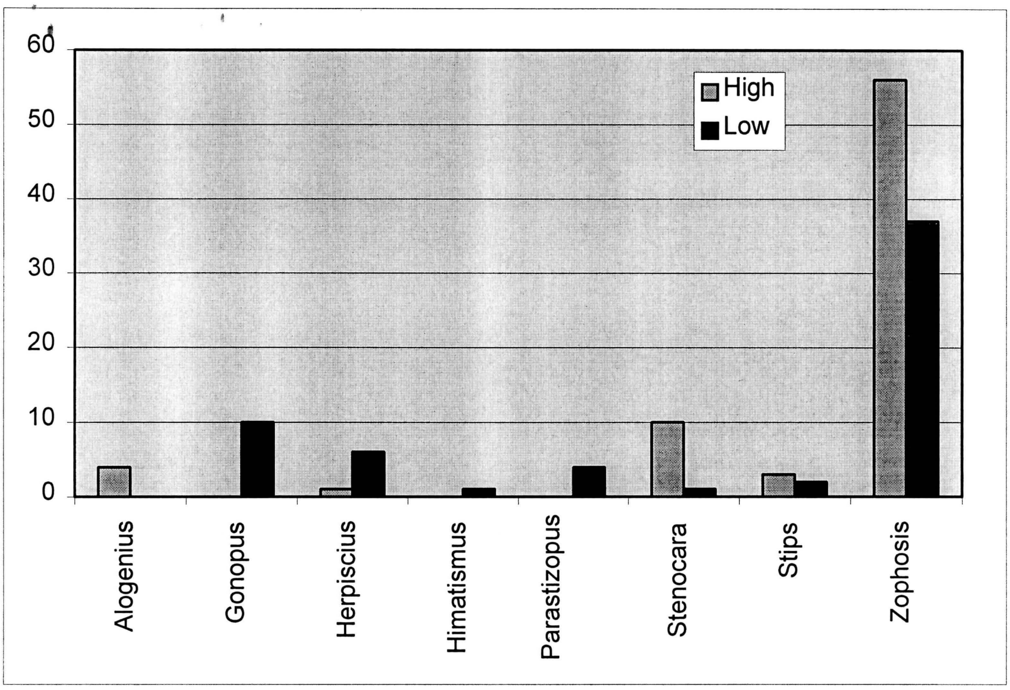


Fig 11. Numbers of individual tenebrionid beetles caught in pit traps at high and low land use intensity sites during October 1997

The high and low land use intensity sites sampled during October 1997 were compared using a Kruskall-Wallace paired rank test, because only one set of results was available from each land use intensity site for this sampling period, and no significant difference was found between the beetle assemblages at the two sites during this sampling period (p = 0.314).

Table 2 Presence of beetles at all separate high and low land use intensity areas during October 1997 sampling session.

	Oct-97	
	H	L
Alogenius sp.	+	
Gonopus tibialis		+
Herpiscius sp.	+	+
Himatismus sp.		+
Parastizopus sp.		+
Stenocara aenescens	+	+
Stips dohrni	+	+
Trachynotidus sp.		+
Zophosis sp.	+	+

Five of the eight tenebrionid beetles recorded during October 1997 were present only at either the high or the low land use intensity sites, and four, *Zophosis* sp. Herpiscius sp., *Stips dohrni* and Stenocara *aenescens*, were present at both land use intensity sites. Of the beetles present at both land use intensity sites, only *Herpiscius* was found in greater abundance at the low land use intensity site. A greater number of individuals present at the high land use intensity site was recorded for all the other tenebrionid beetles present.

The total number of individual beetles recorded (abundance) was relatively low during this study. This may be attributable to the fact that the study was carried out towards the end of the dry season, and no rain had been recorded in the area for at least six months prior to the period during which the beetles were trapped. Most of the beetles were recorded at the high land use intensity site, but their numbers were only marginally higher than those at the low land use site (55% at high vs. 45% at low).

Gonopus tibialis was found only at the low land use intensity site, and only one Herpiscius specimen was recorded at the high land use intensity site. These beetles are known to prefer habitats where soil is soft enough for them to burrow into. They are nocturnal, and tend to dig themselves into burrows, where they hide, during the day time (Wharton & Seely 1981, Schultze 197.., Endrody-Younga 19..). The fact that both these beetles were found only at the high land use intensity site may also be related to the fact that they have been seen to share considerable niche overlap, often sharing the same burrows during the day time (Rasa19..).

3.4.2 Tenebrionid diversity measures

Diversity indices were calculated for the different sites, and the results are shown in table 6.

Table 3 Diversity Indices calculated for the beetle assemblages at the high and low land use intensity sites during the successive sampling periods

	October 1997	
	H	L
H'	0.83	1.25
E	0.52	0.64
α	1.20	2.05
D	0.59	0.39
S	5	8

Diversity measures calculated for tenebrionid beetles during October 1997 were generally low. The diversity at the separate land use intensity sites during the different sampling sessions appeared to follow a trend of higher species diversity at the low land use sites than at the high intensity sites.

The evenness (Shannon E) showed a similar trend as that of the species diversity.

The dominance (Simpson, D) calculated during October 1997 was greater at the high land use intensity sites than at the low land use intensity sites. Zophosis was the most dominant, overall, being both the most numerous overall, as well as the most prevalent at the high land use intensity site. It was followed in abundance and dominance by Stenocara aenescens. Both beetles have relatively long legs, and are very fast moving. The fact that they were most prevalent in the high land use intensity areas could be a result of them being able to exploit a resource that the other beetles recorded, all of which are more slow moving, may not be able to. They may have the advantage of being better able to make use of the patches of shelter in between the larger, open areas, where the vegetation has been trampled by livestock.

The October sampling session was undertaken during the dry season, when environmental stress was more pronounced, especially since no rain occurred during the six months prior to the sampling period. It was therefore expected that diversity recorded during October would be slightly lower than at other times of the year. During the dry season, the large herds of livestock and the associated trampling may have had a detrimental effect on the already limited vegetation availability. More litter was available at the low land use sites than at the high land use sites as well, and the grass to bare ground ratio at the high intensity site was found to be 1:3. The tree canopy cover was also higher at the low intensity land use sites (Zeidler 1998).

3.4.3 Tenebrionid size

Overall, there was no difference between the lengths of the beetles at the different sites (p = 0.117). Beetles that had been found in numbers sufficient for statistical analysis, i.e. n > 6, were compared. Of the eight different types of beetles recorded during October 1997, only *Zophosis* sp. was found in sufficiently high numbers at both land use intensity sites to enable comparison, (low land use intensity sites, n=37; high land use intensity sites, n=56).

Table 4. Length and shape differences between the comparable beetles at the high and low land use intensity sites

Beetle	**Length**		**Length/width**	
	H	**L**	**H**	**L**
October 1997				
Zophosis	0.94±1.069	0.799±0.229	1.72±0.169	1.91±0.503
	(p = 0.038)		(p = 0.007)	

The table shows mean and standard deviations calculated for the beetles at the different land use intensity sites

The beetles at the two sites differed in length (p = 0.038). Beetles at the low land use intensity sites were generally longer than those at the high sites, most individuals being between 0.6 and 0.7cm long. At the high land use intensity sites, most beetles measured less than 0.6cm in length. The beetles found at the low land use intensity sites showed a wider range of length to width ratios than those at the high intensity sites, ranging between 1.8 and 2 at the low sites, and not more than 1.7 at the high land use intensity sites. The beetles at the high land use intensity sites showed a tendency of being narrower than those at the low land use intensity sites.

Beetles present at the high land use intensity site were narrower than those found at the low land use intensity site. This could be related to the resources available, both to the adults and to the larvae. The sizes of adult beetles can be directly related to the resources available to the larvae. The preliminary, background study, determined that below ground biomass was greater at the low land use intensity site (Zeidler 1999). This might have explained the size differences in the adult beetles at the high and low land use intensity sites, as more food was probably available to the larvae, which live and feed underground. The study also found that the vegetative resource availability was higher at the low land use intensity site.

At this stage of the study it was not entirely possible to determine whether the differences in community assemblages and diversity of beetles was attributable to the effects of land management, or merely differences in environmental parameters at the selected sites, and the associated adaptations of the beetles exploiting these environmental conditions. A longer term, more in-depth study, with a broadened sampling protocol was therefore considered necessary.

CHAPTER 4

Olifantputs Case Study : March and October 1998

4.1 Introduction

During March and October 1998, a greater number of sites within the selected high and low land use intensity areas at the communal farm Olifantputs were sampled, to gain a better idea of the potential of tenebrinids as indicators of the condition of the habitat on this particular farm. The sampling protocol was also expanded to include other methods of determining what beetles were present in the area, in order to supplement the data collected from traps. Napcod has formed an interactive relationship with the local community at this farm, and is making use of the tools of participatory rural appraisal (PRA) to obtain information on socio-economic issues as well as land use history, current practices and land tenure. Some of this information was incorporated into the present study.

While beetles formed the main focus of this study, within the larger project, information relating to vegetation, soil and its associated parameters, ie total soil carbon, light fraction, total soil nitrogen and phosphorous, as well as termite species richness, community composition and relative abundance were also collected. For the purposes of this study, these parameters provided a rich source of background data, on which results of the beetle study could be overlaid. Comparisons were then possible, and an impression of the biological integrity of the ecological system in place at Olifantputs, and also where and how tenebrionid beetles fit into the concept of biological integrity could be established.

4.2 Methods

4.2.1 Sampling Period

Two trapping sessions, each one-month long, were carried out at Olifantputs, one during the rainy season (March/April 1998) and the other during the dry season (October 1998). Comparative data are available from the pilot studies carried out during March/April 1997 and from a further month long field session carried out during October 1997, so effectively, data over two rainfall seasons were obtained.

4.2.2 Pit trapping

For the longer-term study, carried out at Olifantputs, pitfall traps were placed in the study area in order to determine the species richness of tenebrionid beetles in heavily grazed areas and in areas that have been less intensely used. These sites were selected after consultation with the local communal farmers. Trapping was done according to methods described in Southwood (1978), and Uys and Urban (1996), and those methods which have been extensively used in the Namib and elsewhere (Pietruszka, 1980; Wharton and Seely, 1982; Prinsloo, 1990; Griffin, 1990; Seely et al. In prep., Dufrène and Legendre, 1997; Krasnov et al. 1996; Faragalla and Adam, 1985; Pearson and Cassola, 1991; Krasnov and Ayal, 1995; Ayal and Merkl, 1994)

The same method of trapping beetles as had been used during the October 1997 sampling period was applied during March and October 1998. In contrast to the one plot in which beetles were trapped during October 1997, three replicate sites were sampled for tenebrionid beetles in this manner in the heavily used area and three in the less intensely used area selected, making up 45 pit traps for each land use strategy, with a total of 90 traps in all.

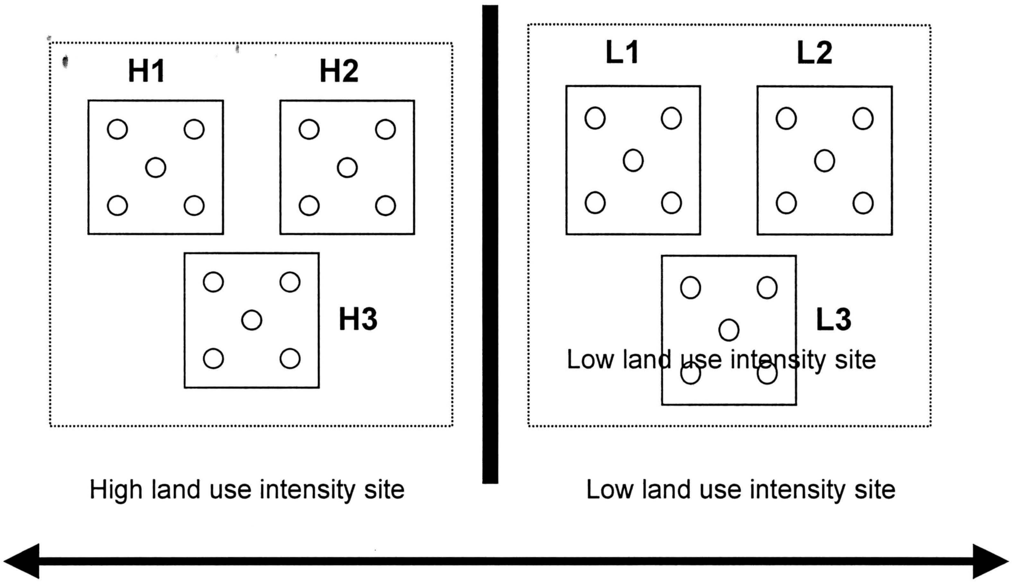


Fig 12. Generalised sketch of trapping sites within each of the land use intensity areas where beetles were sampled

The sets of traps were emptied daily for seven consecutive days during each sampling session. Stones, sand and a small amount of leaf litter, if available, were placed inside the traps, to afford those insects caught a measure of protection against predators.

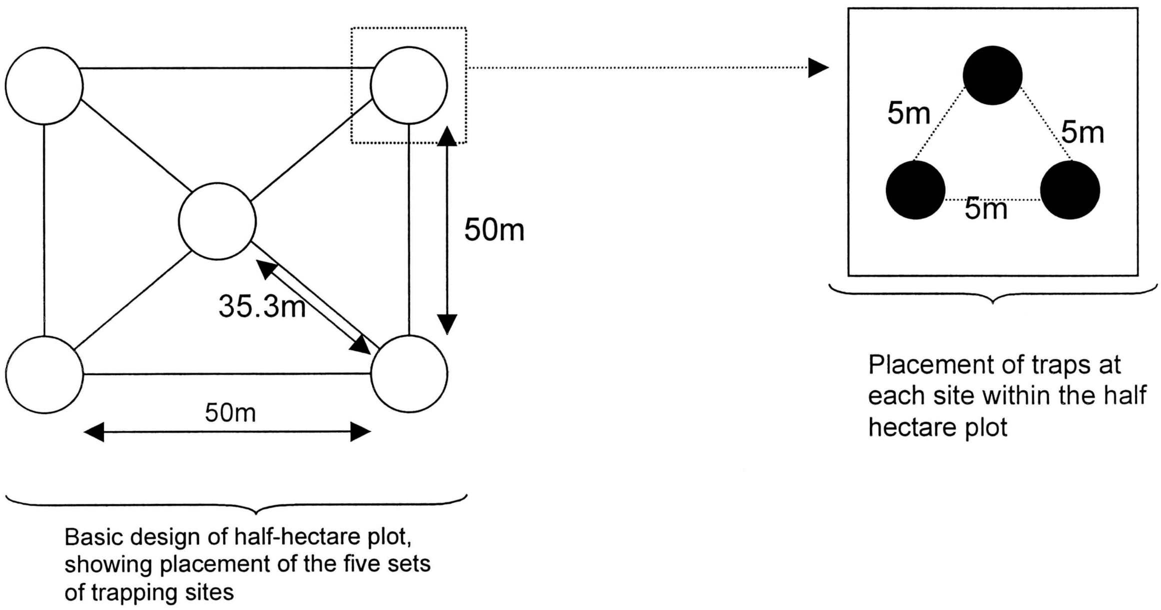


Fig. 13. Sketch of the basic experimental design. Open circles denote sites containing subsets of three pit traps each. Filled circles show the positioning of the three traps placed at each site within the half-hectare plot. The same design was applied to all plots at both sampling sites.

As has been described earlier (Chapter 3), the abdomen width and total body length of each of the individual tenebrionid beetles collected at each site was measured.

The project reference collection was updated after each trapping session. On completion of the project, the collection was deposited at the Gobabeb Training and Research Centre, in the Namib Desert, and a duplicate set has been placed at the National Museum in Windhoek.

4.2.3 Transect Walk

In addition to the pitfall trapping, a walk, based on the line transect method for the estimation of population densities as described in Southwood (1978) was undertaken within three different, randomly selected sites within both the high and the low land use intensity study areas at Olifantputs.

The walks were undertaken in order to augment the pitfall trapping, to record beetle species that were present in the area but are not caught in the traps. Predators caught in the traps, e.g. lizards, spiders and scorpions, may have eaten some of the beetles in the traps thus removing a potential record. The walk also provided an indication of activity patterns of certain species of tenebrionid beetles.

Two 50m line transects, each 30m apart, were laid out (Fig.7). The number and species of any tenebrionid beetles seen within a distance of 2.5m of the transect line while walking at a constant speed, along the transect, were recorded.

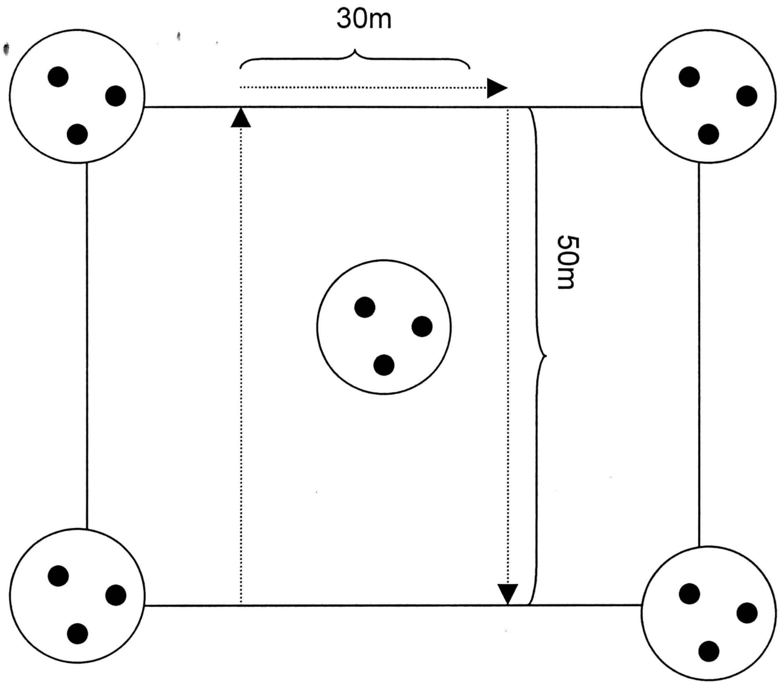


Fig 14. Design of transect walk. The same procedure was followed at all sites. Open circles represent the trapping sites within the half-hectare plot.

Each complete transect walk lasted approximately one hour.

The numbers and species of tenebrionid beetles seen during the walks were recorded, and only voucher specimens were captured. In addition to these voucher specimen, exuvia encountered while searching the area for beetles were also collected, in order to gain a better idea of the beetles normally present at the study sites, even if live specimens were not actually seen while conducting the transect walks.

4.3 Olifantputs as a case study: Results and Discussion

4.3.1 Environmental conditions

While the amount of rainfall varied greatly over the study period, the average temperature conditions appeared to remain relatively constant. During 1998, the annual rainfall recorded in the area totalled almost 200mm less than that of the previous year. Maximum temperatures in the area showed very little variation over the ten years before the study as well (Fig. 10). While a clear seasonal rainfall trend exists, 1998 was a particularly bad year, with almost no rainfall occurring during and immediately before both sampling periods. This contrasts greatly with 1997, when 161 mm of rain was recorded during March compared to 0 mm of rain recorded during October.

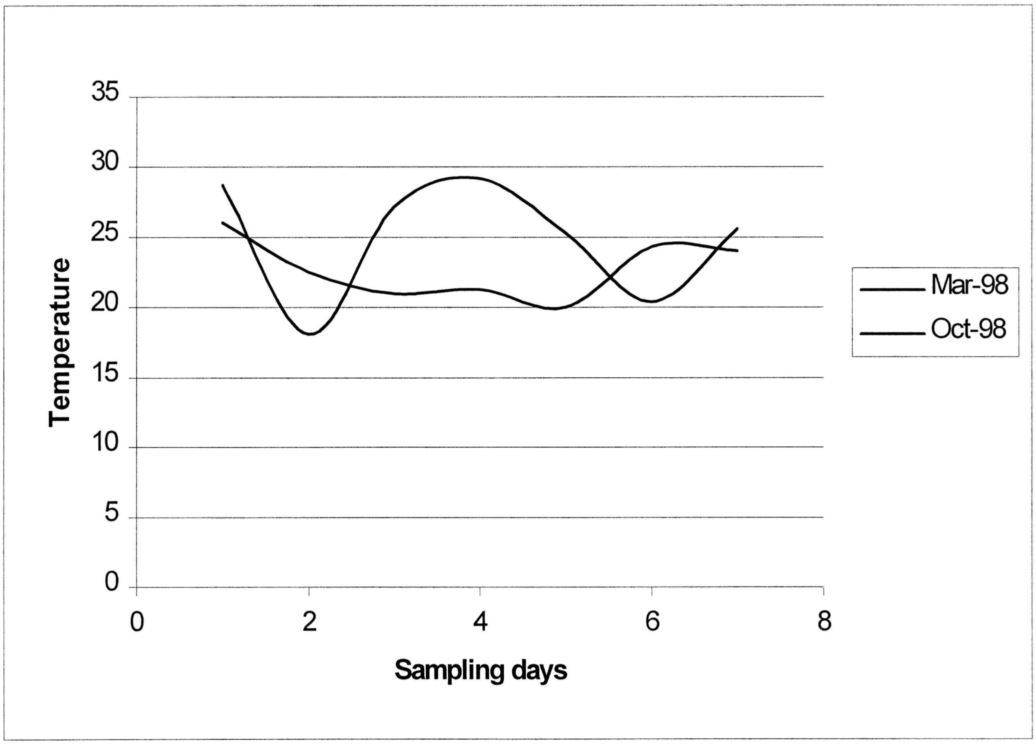


Fig. 15 Average daily temperatures recorded during each period of study.

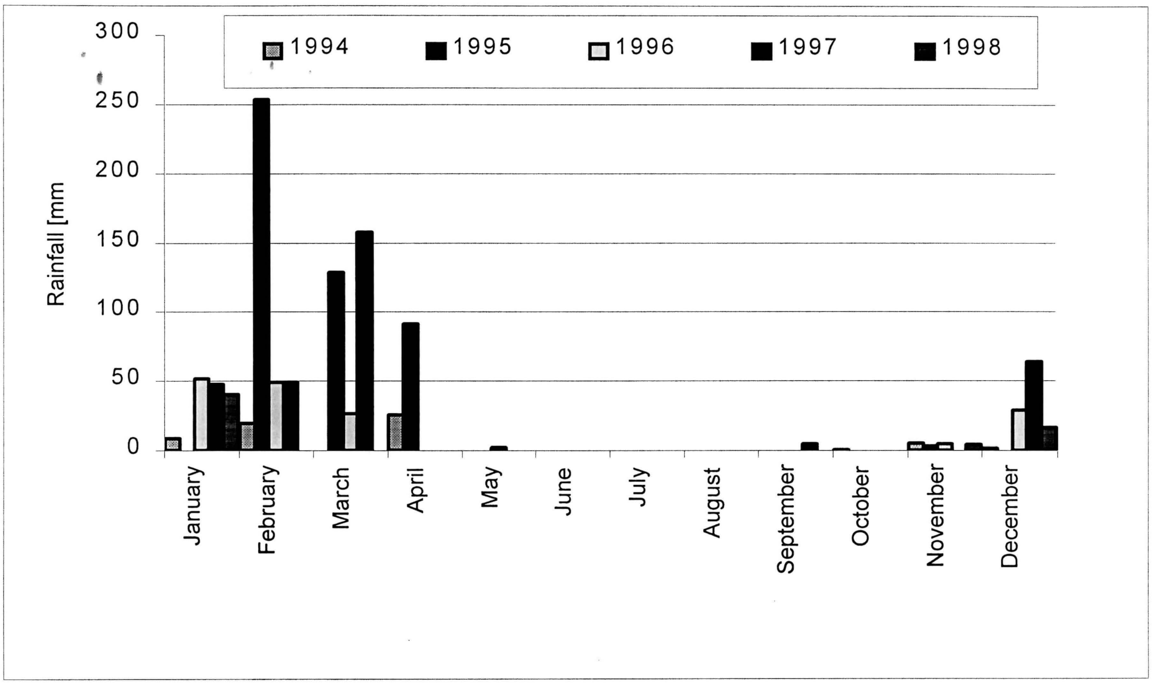


Fig. 16 Rainfall recorded at Khorixas, where the weather station closest to Olifantputs for the two seasons over which the study was carried out, and for three years before the start of the study. Data supplied by the Namibian Meteorological Service.

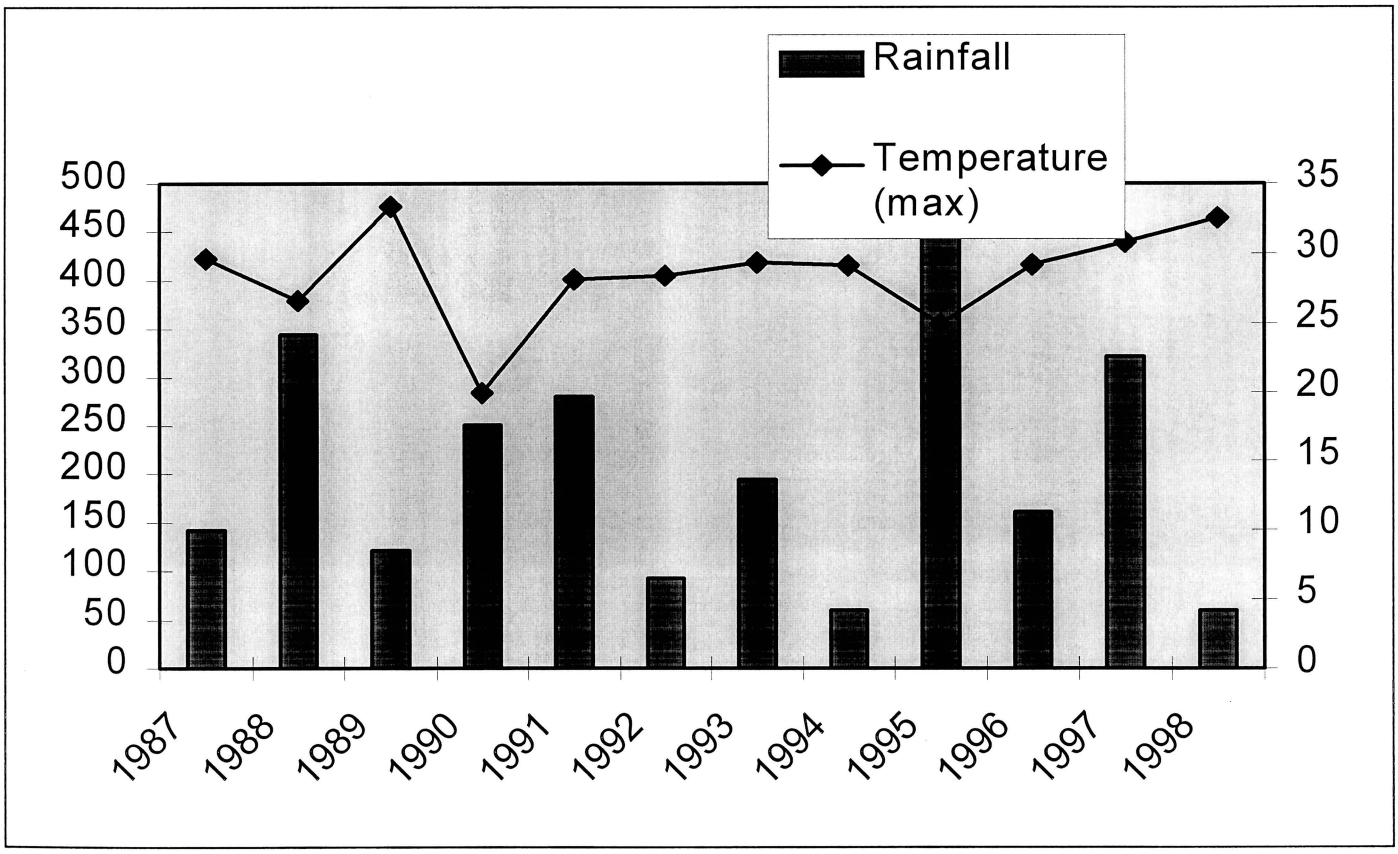


Fig.17 Annual rainfall averages and maximum temperatures recorded at Khorixas weather station during the study period and ten years before the study period. Data supplied by the Namibian Meteorological Service

Vegetation cover at Olifantputs was found by Zeidler (1999) to be more diverse and plentiful during the March sampling period than October. Evidence of heavy grazing was present in October 1998. Forage quantity and quality were severely constrained at the higher land use intensity sites at Olifantputs throughout this period of the study. Tree density was also found to be higher at the low land use intensity sites than at the low land use sites. Litter inputs were also observed to be greater at the low land use sites than at the high land use sites. Dung inputs were, however, greater at the high land use intensity sites during October than in March. Soil parameters differed seasonally as well as between the different study sites, although the variation between the seasons was greater than between the differing land use intensity sites.

4.3.2 Tenebrionid assemblage and composition

Beetle abundance differed between the different sampling periods. March yielded the greatest abundance of individual beetles (Table 3).

Table 3. Total numbers of individual beetles caught in pit-traps and on standardised walks

Beetle	March 1998	October 1998
Alogenius sp.	-	-
Asphaltesthes costatus	1	29
Asphaltesthes sp.	-	6
Asphaltesthes afrogermanicus	-	4
Brinckia debilis	-	18
Cryptochile consita	6	4
Decoriplus hieroglyphicus	5	-
Gonopus sp.	33	3
Herpiscius sp.	11	1
Himatismus sp.	1	-
Horatoma sp.	-	1

Pachynotelus	43	-
Parastizopus sp.	5	2
Platyphanus similis	-	5
Psammodes sp.	64	22
Psammodes vialis	3	7
Renatiella scrobipennis	61	8
Stenocara aenescens	173	8
Stenocara gracilipes	-	1
Stips dohrni	24	4
Trachynotidus sp.	-	1
Zophosis sp.	362	75
TOTALS	**792**	**199**

During March 1998, 239 beetles of 11 species were recorded in the pit traps. Of these beetles, *Zophosis* was again the most dominant species found in the traps, making up 36% of the total beetle catch. During this trapping period *Zophosis* was followed in richness by *Gonopus* sp., which made up 13% of the total catch in the traps.

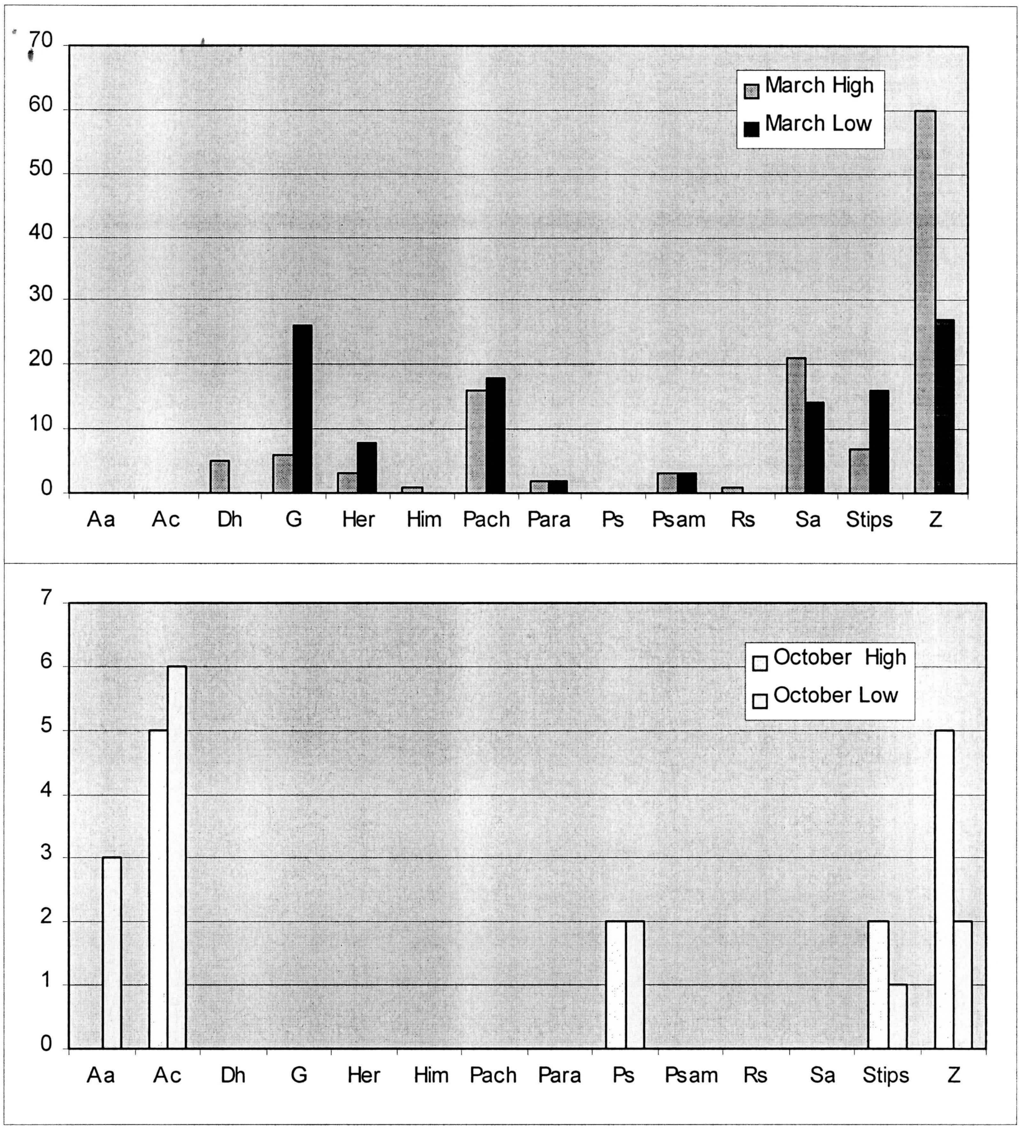
A greater number of beetles were found on the transect walks than in the pitfall traps. The total number of individuals flushed out found during the walks was approximately double the number of beetles caught in the traps. In total, 554 beetles of 12 different species were found on the walks. The most dominant beetle found using this method was *Zophosis*, which made up 49% of the beetles recorded. Three of the species found on the walks, *Asphaltesthes costatus*, *Cryptochile consita* and *Psammodes vialis* were not present at all in the pitfall traps, while *Decoriplus hieroglyphicus* was found in the traps but not on the walks. Seven species of beetle, which had not been present during the previous sampling period, were found during March 1998, and *Alogenius* sp. was found only during October 1997, and not in any of the subsequent sampling periods.

More individual beetles were recorded, both on the walks and in the traps, at the high land use intensity site than at the low land use intensity site. 53% of the beetles caught in traps and 71% of those recorded on the walks were found at the high land use intensity site.

During the October 1998 sampling session, 28 beetles were found in the traps, and 192 beetles were recorded during the walks. Of these, the traps at the high and low land use intensity sites each comprised 50% of the beetle catch, while 60% of the beetles recorded on the walks were found at the low land use intensity site. As in the previous sampling sessions, *Zophosis* was the most dominant species found, this time making up 25% of the total catch in the pitfall traps and 40% of the beetles recorded on the walks. Six species that had not been present during the previous two sampling periods, either in the pit traps or on the walks, were found during October 1998, *Asphaltesthes afrogermanicus, Brinckia debilis, Horatoma* sp.*, Platyphanus similis, Stenocara gracilipes* and *Trachynotidus* sp.

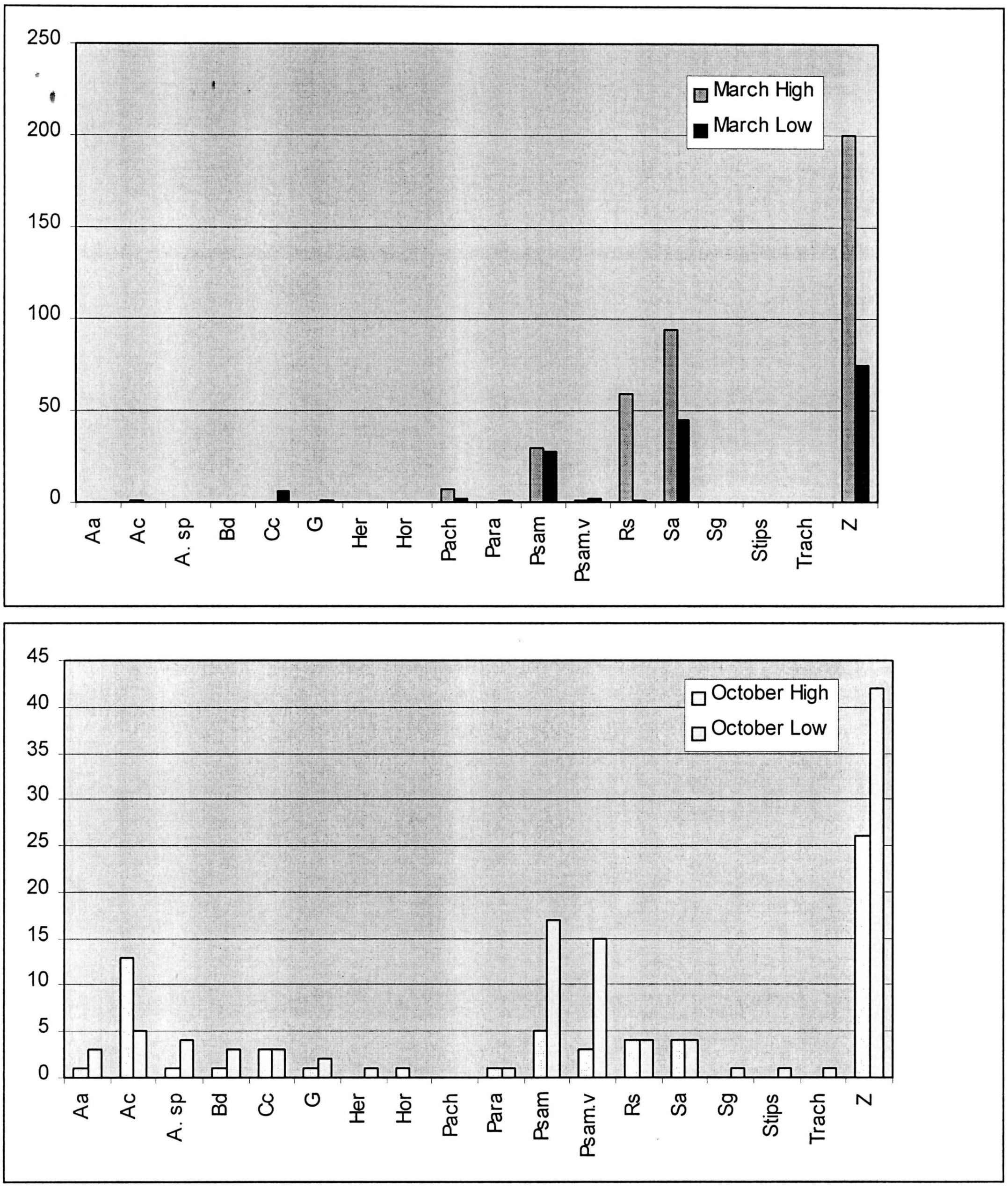
Overall, more beetles were recorded during active searches than were caught in pitfall traps, and the lowest number of individual beetles were trapped during October 1998. During March 1998, the greatest number of different species as well as of individual beetles was recorded. Differences between the beetle abundance during the different sampling sessions, ie the seasonal difference, were tested for, using the Mann-Whitney U test. The abundance of beetles was found to be significantly different during each sampling session ($p = 0.018$).

During March 1998, more beetles were found during the walks and in the pitfall traps at the high land use intensity sites, but during October 1998 a similar number of individual beetles were found in the traps, while a greater number of individual beetles were recorded at the low intensity site during the walks (Table 4).



Aa = *Asphaltesthes afrogermanicus* ; Ac = *Asphaltesthes costatus*; Dh = *Decoriplus hieroglyphicus*; G = *Gonopus tibialis*; Her = *Herpiscius* sp.; Him = *Himatismus* sp.; *Pachynotelus damarinus*; Para = *Parastizopus* sp.; Ps = *Platyphanus similis*; Psam = *Psammodes* sp.; Rs = *Renatiella scrobopennis*; Sa = *Stenocara aenescens*; Stips = *Stips dohrni*; Z = *Zophosis* sp.

Fig.18 Tenebrionid abundance recorded in pit traps at high and low land use intensity sites during March and October 1998.



Aa = *Asphaltesthes afrogermanicus*; Ac = *Asphaltesthes costatus*; A. sp = *Asphaltesthes* sp.; Bd = *Brinckia debilis*; Cc = *Cryptochile consita*; G = *Gonopus tibialis*; Her = *Herpiscius* sp; Hor = *Horatoma* sp.; Pach = *Pachynotelus* sp.; Para = *Parastizopus* sp.; Psam = *Psammodes* sp.; Psam.v = *Psammodes vialis*; Rs = *Renatiella scrobipennis*; Sa = *Stenocara aenescens*; Sg = *Stenocara gracilipes*; Stips = *Stips dohrni*; Trach = *Trachynotidus* sp.; Z = *Zophosis* sp.

Fig 18(b) Beetle abundance recorded during active searches at high and low land use intensity sites during March and October 1998.

A Kruskal-Wallis, non-parametric test was performed on results obtained during October 1997, March 1998 and October 1998. Beetle assemblages found during October 1997 and October 1998 were significantly different from those found during March 1998 ($p = 0.02$ and $p = 0.042$ respectively) and assemblages found during October 1997 were found not to be significantly different from those found during October 1998 ($p = 0.094$). A cluster analysis was performed with the results obtained during the different sampling periods. This indicated that the assemblages found during October 1997 and October 1998 were more similar to each other than to the assemblages found during March 1998 (Fig. 19).

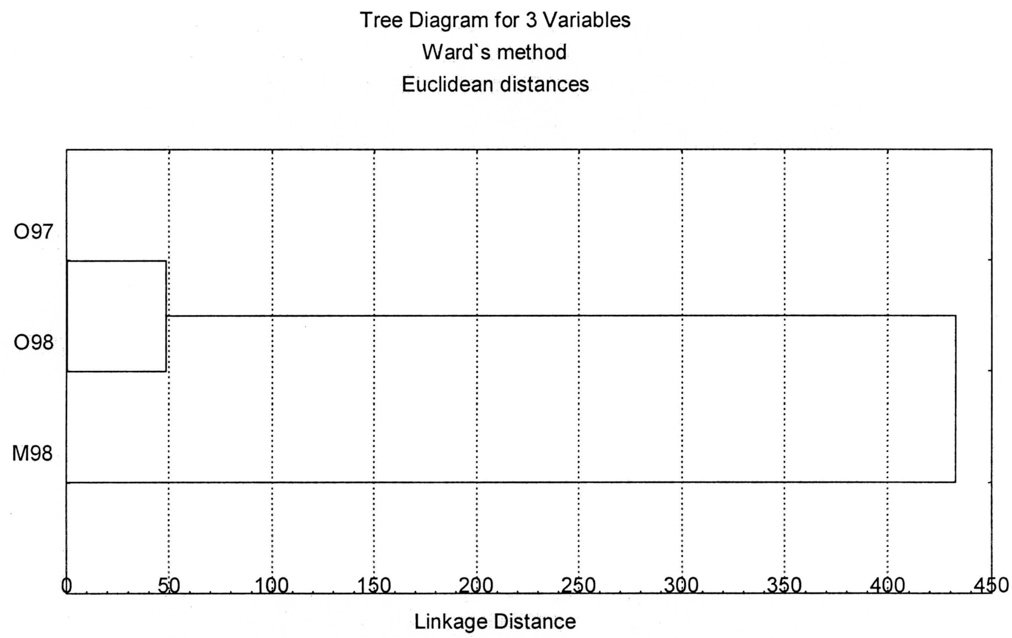


Fig. 19 Cluster analysis performed on beetle assemblages during the separate sampling sessions. O97 = October 1997, O98 = October 1998, M98= March 1998

The beetle assemblages at the separate sites within the high and low land use intensity areas were also considered. The three sites within the high land use intensity area (H1, H2, H3) and the low land use intensity area (L1, L2, L3) sampled during March 1998 and October 1998 were compared, using Anova. The high and low land use intensity sites sampled during October 1997 were compared using a Kruskal-Wallis paired rank test, because only one set of results was available from each land use intensity site for this sampling period, and no significant difference was found between the beetle assemblages at the two sites during this sampling period ($p = 0.314$).

Assemblages at the three separate sites within the high land use intensity sites were not significantly different ($p = 0.501$), similarly at the low land use intensity sites ($p = 0.449$). When the results from the three sites within each land use area were pooled, however, and the assemblages found at the high intensity site compared with those at the low site, the beetle assemblages at the high intensity site were found to be significantly different from those at the low intensity site ($p = 0.044$).

Assemblages of beetles caught in the traps during March 1998 were found not to be different at the high and low land use intensity sites ($p = 0.075$, $F = 2.090$), in contrast to those recorded during the walks ($p = 0.001$, $F= 4.382$). Cluster analyses were then performed on the data obtained from the traps and the walks within the different sites at the high and low land use intensity areas (Figs. 20 & 21). Results from the walks showed that, in general, assemblages at the individual high intensity sites were more similar to each other than they were to the individual low intensity sites. Exceptions were the sites H1 and L1, which were dissimilar to all other sites. Assemblages at the high and low land use intensity sites found by pit trapping also showed a general similarity between individual sites within the high and low land use sites, with the exception being the site L2, which was more similar to the site H1.

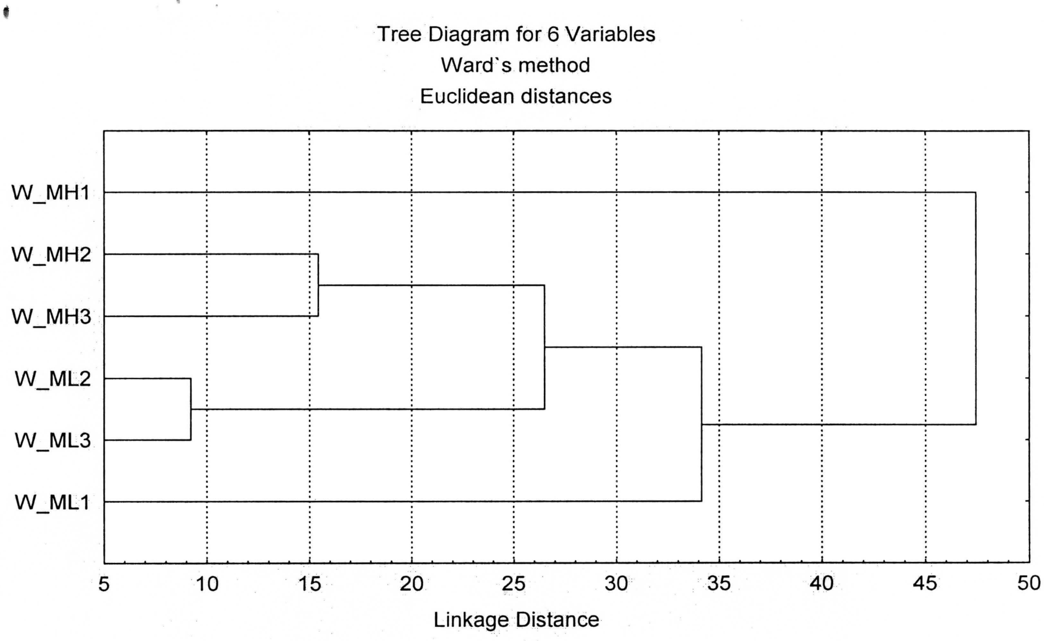


Fig. 20 Cluster analysis performed on beetle assemblages recorded during March 1998. Data from walks only.
WMH1, WMH2, WMH3 = High land use intensity sites 1,2 and 3
WML1, WML2, WML3 = Low land use intensity sites 1,2, and 3

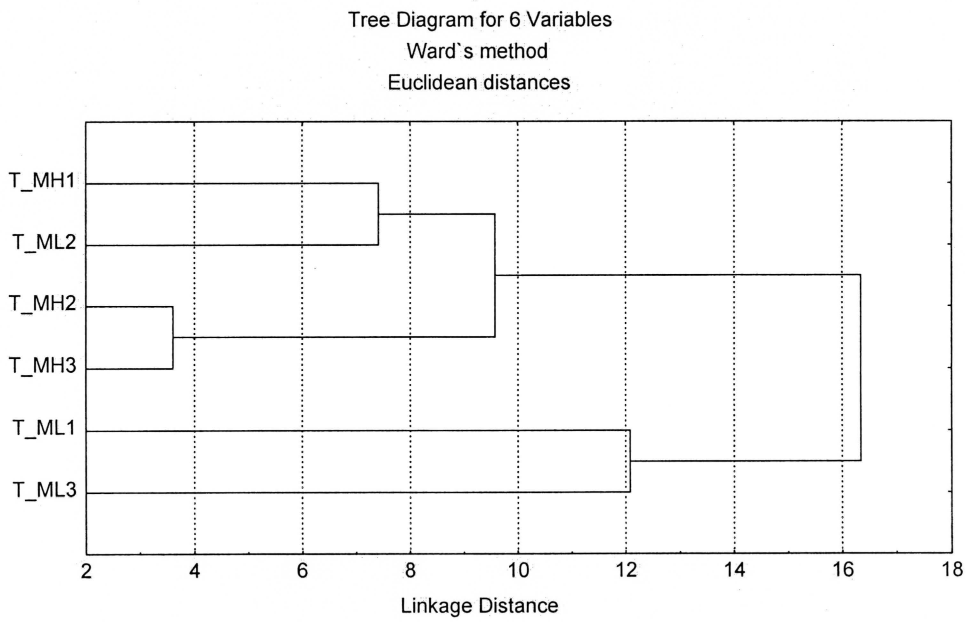


Fig. 21. Cluster analysis performed on beetle assemblages recorded from traps during March 1998
TMH1, TMH2, TMH3 = High land use intensity sites 1,2, and 3,
TML1, TML2, TML3 = Low land use intensity sites 1,2, and 3,

When the assemblages at the high and low land use intensity sites sampled during October 1998 were considered in the same way as that described for March 1998, it was found that no difference existed between the assemblages at the high and low land use sites (p = 0.132)

When the data from the traps and walks at the three separate sites in the high and low land use areas were subjected to separate cluster analyses (Figs. 21 & 22), both the traps and walks showed similar results. Assemblages at the high and low land use intensity areas were clumped together, with the exception of the site H2, which in both cases was clustered with the assemblages at the low intensity sites.

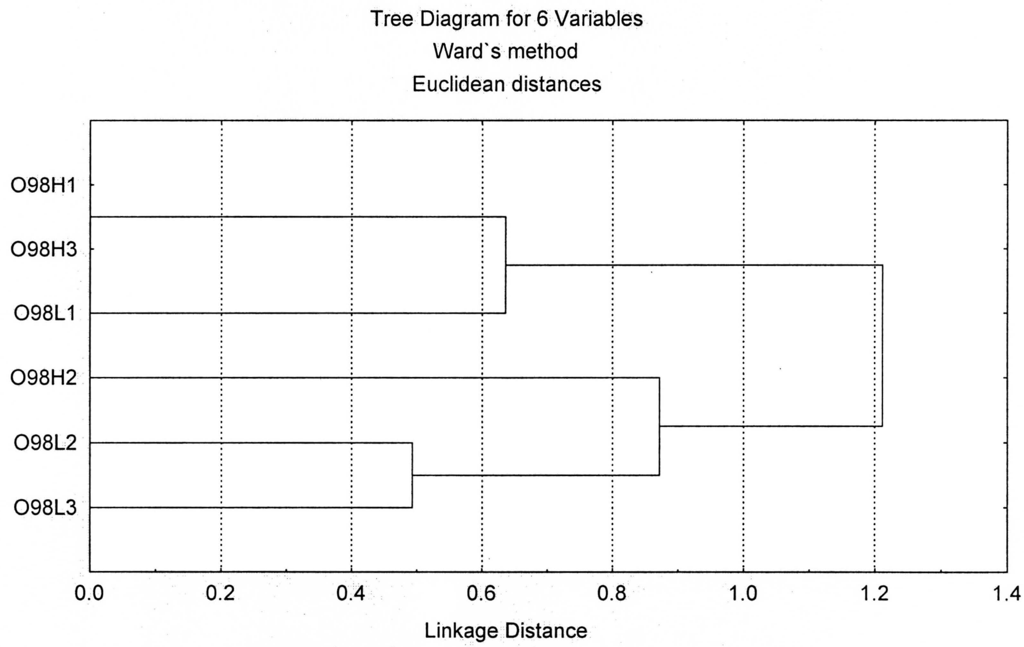


Fig. 22 Cluster analysis performed on assemblages at all high and low land use intensity areas sampled during October 1998. Data from traps only.
O98H1, 2, 3 = High land use intensity areas
O98L1, 2, 3 = Low land use intensity areas

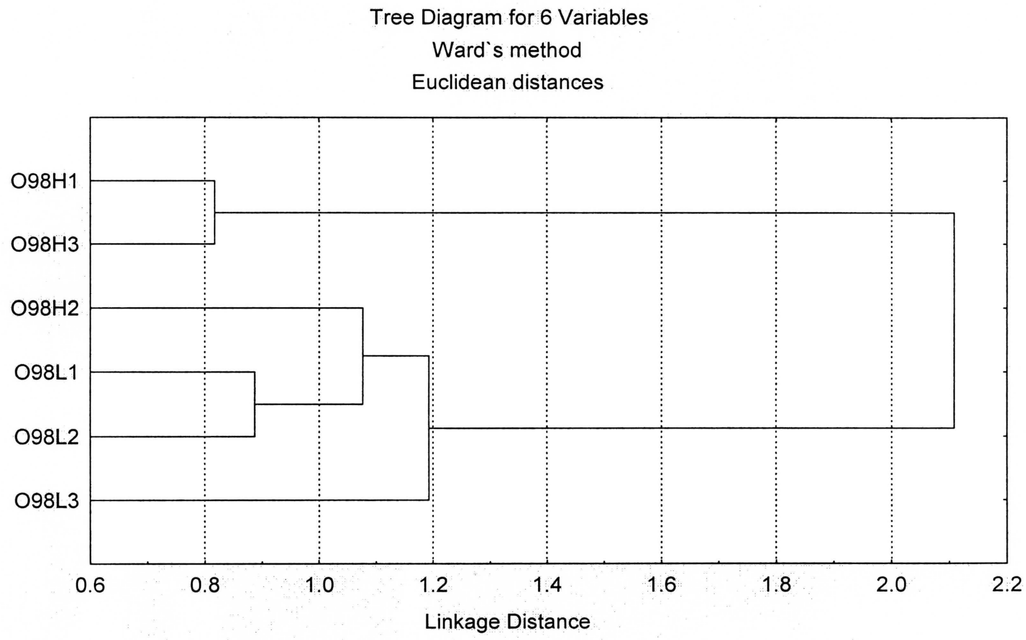


Fig.22 Cluster analysis performed on assemblages recorded during walks at all high and low land use intensity areas during October 1998.
O98H1, 2, 3 = High land use intensity areas
O98L1, 2, 3 = Low land use intensity areas

Each beetle species found was also considered separately, for each of the six sampling sites within the high and low land use intensity areas (see also Appendix). The assemblages found by pit trapping during all of the sampling sessions were then considered separately, with all data from the separate high and low land use intensity sites being pooled, since there was found to be no significant difference between the individual sites at the high and low land use intensity areas. A cluster analysis was then performed, and generally showed similarities between the high and low intensity land use sites during the same sampling periods (Fig.22).

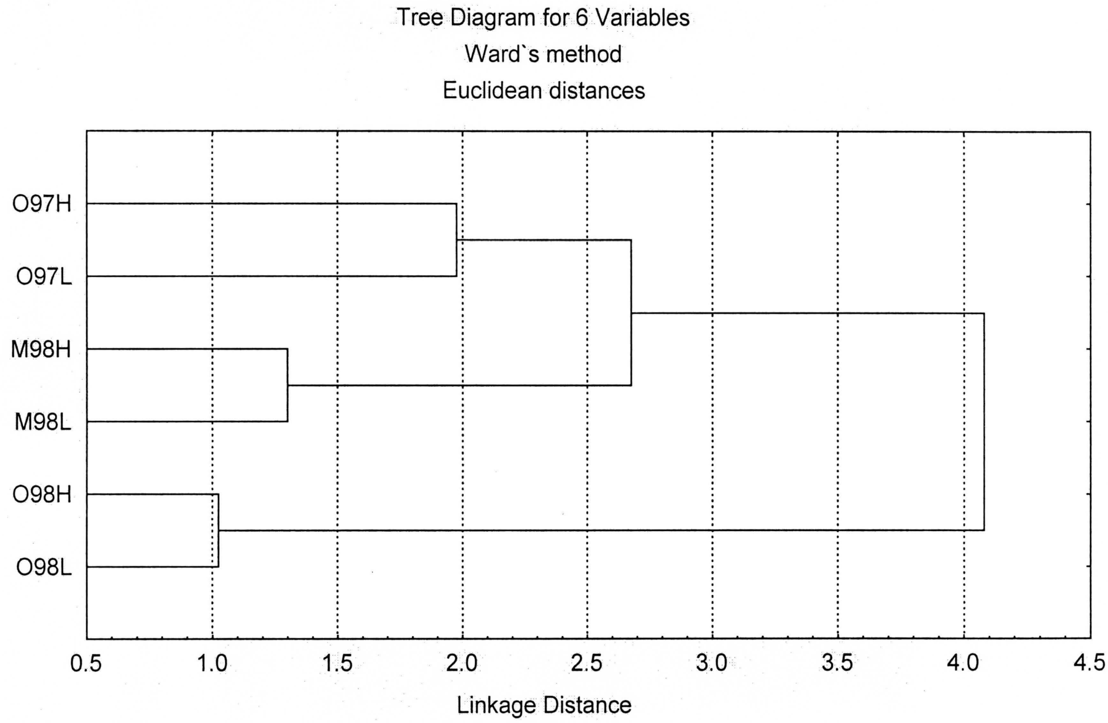


Fig.23 Cluster analysis performed on assemblages during all study periods, with data from all high and low land use intensity areas pooled and log- transformed.
O97H, O97L = High and low land use intensity sites, October 1997
M98H, M98L = High and low land use intensity sites, March 1998
O98H, O98L = High and low land use intensity sites, October 1998

When all of the high and low land use intensity areas that had been sampled during all of the trapping periods were considered by means of clustering, no real trends were apparent. The same data was then log-transformed, and the cluster run again. All cases from October 1998 were clustered together, and the March 1998 and October 1997 assemblages were similarly clustered together (Fig.23).

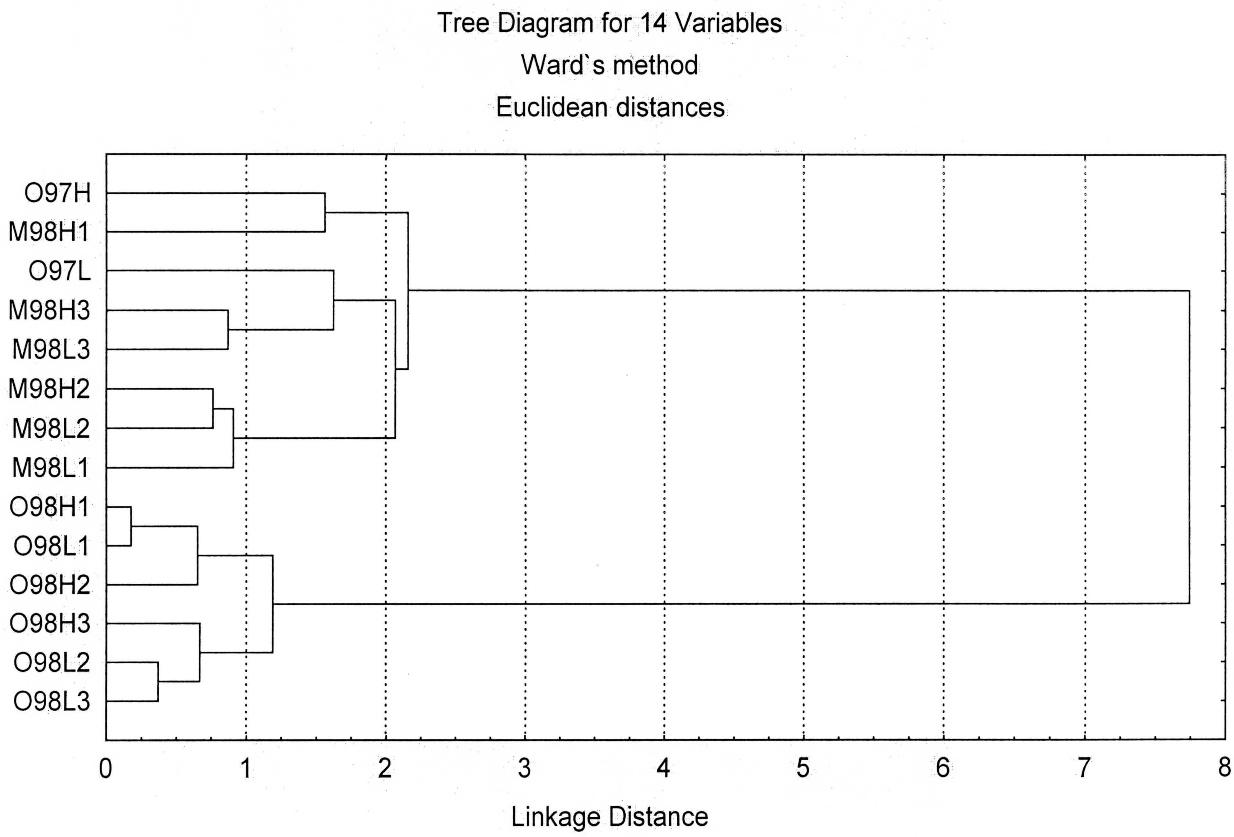


Fig. 24 Cluster analysis performed on assemblages at all sites in high and low land use intensity areas, data logged.
O97H, O97L = High and low land use intensity sites, October 1997
M98H1, M98H2, M98H3 = High land use intensity sites 1,2, and 3, March 1998
M98L1, M98L2, M98L3 = Low land use intensity sites 1,2, and 3, March 1998
O98H1, O98H2, O98H3 = High land use intensity sites 1,2 and 3, October 1998
O98L1, O98L2, O98L3 = Low land use intensity sites 1,2 and 3, October 1998

Over all of the trapping periods, few beetle species were found only at the high or low land use intensity sites. *Alogenius* sp., *Decoriplus hieroglyphicus* and *Horatoma* sp. were only found in the high land use intensity areas, while *Trachynotidus* sp. was only present in the low land use intensity areas. Most of the other beetles recorded during the study were present at both land use intensity sites (Table 5). 41% of all of the beetles recorded were present only during October 1998, while the beetles *Zophosis* sp., *Stips dohrni, Stenocara aenescens, Parastizopus* sp., *Herpiscius* sp. and *Gonopus tibialis*, together making up 27% of the total beetle catch during all sampling periods, were present throughout the period of the study.

Table 5 Presence of beetles at all separate high and low land use intensity areas during all sampling sessions.

	Mar-98						Oct-98					
	H1	H2	H3	L1	L2	L3	H1	H2	H3	L1	L2	L3
Asphaltesthes afrogermanicus							+			+	+	+
Asphaltesthes costatus							+	+	+	+	+	+
Asphaltesthes sp.							+			+	+	+
Brinckia debilis							+			+	+	
Cryptochile consita				+	+	+	+	+			+	+
Decoriplus hieroglyphicus	+	+										
Gonopus tibialis		+	+	+	+	+	+			+		+
Herpiscius sp.			+	+	+							
Himatismus sp.		+										
Horatoma sp.							+					
Platyphanus similis							+	+		+		+
Psammodes vialis							+			+	+	+
Pachynotelus sp.	+	+	+	+	+	+						
Parastizopus sp.		+	+			+			+		+	
Psammodes sp.	+	+	+	+	+		+	+		+	+	+
Renatiella scrobipennis	+	+	+				+	+		+		+
Stenocara aenescens	+	+	+	+	+	+	+	+		+	+	
Stenocara gracilipes											+	+
Stips dohrni	+	+	+	+	+	+		+	+		+	
Trachynotidus sp.											+	
Zophosis sp.	+	+	+	+	+	+	+	+	+	+	+	

The highest beetle abundance overall was recorded during the March 1998 sampling period. The difference between beetle abundance during the March 1998 and October 1998 trapping periods may be the result of seasonal changes in the numbers of individual beetles present in the area.

Zophosis was present in comparatively high numbers throughout the study and was followed in abundance by *Stenocara aenescens* and *Gonopus tibialis*. While *Zophosis* was almost always the most prevalent of all beetles found, the percentage of the total catch that this beetle made up decreased over the period of the study. A greater number of different species of beetles was found with each successive sampling period, and this accounts for the decrease in the percentage of the total catch made up by *Zophosis*. The gap between the number of *Zophosis* sp. individuals recorded, and the next most prevalent beetle decreased with each successive sampling period as well. Seely et al. (In prep.) observed a decline in overall *Zophosis* abundance, after an initial population increase, in successive years after heavy rains.

Beetles not recorded during October 1997 were recorded during the subsequent sampling periods, and of these, some were found either exclusively in the traps or on the walks. During all periods when active searches were undertaken, a greater number of individual beetles were recorded during the searches than were found in the pit traps. Some beetles, which were never recorded in the traps, were seen very often, and in relatively large numbers during the walks.

Some of the species recorded may have a seasonal pattern of occurrence, accounting for their presence or absence during some sampling periods. The abundance of *Gonopus tibialis, Herpiscius* sp., *Stenocara aenescens* and *Zophosis* sp. was comparatively low during both the October 1997 and October 1998 sampling periods and peaked during March 1998. This may be due to seasonal variations in the activity of these beetles, or to the fact that the March sampling period fell within the rainy season, when more resources would have been available. An increase in resource availability may also have the effect of triggering the emergence of some species from pupae into adult forms, accounting for the higher abundance recorded during the wet season.

Gonopus and *Herpiscius* were found to be most abundant at the low land use intensity sites, and this may be because these beetles prefer habitats that are more sheltered, or where the soil is stable (Wharton & Seely 1981). They are nocturnal, and need habitats that contain more areas where they are able to hide away during the day, and where the soil is soft enough to burrow into. They also tend to prefer more moist soils, which may explain their higher abundance during March 1998, when more than 100mm of rainfall was recorded. *Gonopus* and *Herpiscius* are known to show considerable niche overlap, often sharing the same burrows during the daytime (Rasa 1994).

While *Zophosis* and *Stenocara* also seemed to show seasonal variation in their abundance, these particular beetles were more prevalent at the high land use sites throughout the study. During March 1998, in both the traps and on the walks the number of individuals found at the high land use intensity sites was almost double that found at the low land use intensity sites. During October 1998, their abundance at the two sites was much more similar. The availability of suitable habitats may be an explanation for this pattern. A higher amount of grass was available at the low land use intensity sites, possibly leading to the greater number of different species and individuals being present at this site. Species with greater vagility and tolerance to higher temperatures or other environmental extremes may move further away, in this case to the better resource patches at the low land use intensity area. It is possible that with vegetation being more limited in the intensely grazed areas, they may have been exploiting the greater dung inputs in this area resulting from the higher livestock numbers. *Stenocara* sp. was sometimes observed, during the transect walks, or just moving to and from study sites, after sampling, to be feeding on dung. The availability of dung may not fluctuate much across seasons, but may remain moist for longer and be more palatable in the wet season.

In contrast, the beetles *Decoriplus hieroglyphicus* and *Pachynotelus damarinus* were only found during March, and were not present during either of the October sampling periods. These beetles were also found only on the walks, and were not caught in the pit traps. Both species need habitats with enough cover, in the form of stones under which they hide or bushes and trees (Louw 1979, Penrith 1979, Penrith & Endrödy-Younga 1994). *Decoriplus* is nocturnal, but has been seen to be active during the day in areas containing dense foliage. Both of these beetles were slightly more abundant at the low land use intensity sites than at the high land use site, and the more sheltered habitats occurring at this site may have contributed to this. Being generally small and slow moving (Louw 1979), it is not totally surprising that they were seen only on the walks. These beetles also have characteristically cryptic markings, making them easier to miss while performing active searches. This could have been a factor contributing to the lower abundance recorded. Some species of *Decoriplus* are known to be active during autumn and winter, and *Pachynotelus* has a seasonal activity pattern (Louw, 1979), being most active between January and June (Penrith & Endrödy-Younga 1994, Louw 1977, Holm 1970, Koch 1952, 1958). This could account for the fact that these beetles were found only during the March sampling period. Adult *Pachynotelus* beetles tend to become active for short periods after rain only, which could also explain their presence during March 1998 rather than any of the October sampling periods (Penrith & Endrödy-Younga 1994, Louw 1977, Holm 1970, Koch 1952, 1958).

The fact that the beetle abundance was so much greater during March 1998 than either of the October sampling periods could also have been due to the fact that some beetles have extremely long larval stages. Some species need a certain threshold amount of moisture, in the form of rainfall before the adult forms emerge, others respond opportunistically (Wharton & Seely 1981, Seely et al. In prep.). Even if good rains occur, such as those experienced during the 1996 rainy season, the beetles may only respond gradually, some emerging up to a year or 18 months after the rainfall periods (eg. *Pachynotelus* sp., *Cryptochile* sp.). Beetles that are dependent on rainfall and the associated increase in vegetation would therefore be expected to be less abundant during October as well as during years of low rainfall.

Overall, the assemblages found at the high land use intensity sites were different from those found at the low land use intensity sites during March 1998. . The fact that these beetles tend to hide under rocks or logs rather than dig burrows for themselves (Penrith 1977, Wharton & Seely

1981,Wharton, 1983 Scholtz & Holm 1989), and their preference for harder substrates, could be a limiting factor of their abundance at the higher impact sites. A similar trend was found when the October 1997 and October 1998 assemblages were considered. Most beetles other than *Zophosis* sp., *Stenocara aenescens* and *Stips dohrni*, that were present at both the high and the low land use sites, were recorded either in equal or in higher numbers at the low land use intensity sites than at the high land use intensity sites.

Clustering of data from the walks carried out during March 1998 generally grouped beetle assemblages at the high land use intensity sites together and those at the low land use together. The exceptions were the sites H1 and L1. At both of these sites, *Psammodes* sp., *Stenocara aenescens* and *Zophosis* were found in much greater abundance than the other species recorded. Of all three plots considered in the high land use areas, the numbers of individuals of these beetles was highest at H1. The same case was observed at L1. Beetle distribution is often patchy, and their abundance is generally higher in specific sites within an area where conditions are most suitable. Species tend to display aggregated distributions among groups of sampling sites (Gaston et al. 1998, Dennis et al. 1998). This pattern of distribution may be the reason why these sites were grouped together. Clustering of data from the traps showed L2 and H1 to be similar to each other. During the October 1998 sampling *Platyphanus similis* was found only in the traps. Of the other beetles recorded at this time, the majority of species were recorded during the walks (71%). Of these, *Herpiscius* sp., *Stenocara gracilipes* and *Trachynotidus* sp. were found only at the low land use intensity site. The occurrence of *Herpiscius*, *Trachynotidus* and *Stenocara gracilipes* at the low land use intensity site may reflect their habitat preferences. These beetles are all relatively long legged, have good vision and are capable of great speed. They are well adapted to extremes in environmental conditions and areas offering very little in the way of shelter. They could therefore have been reacting to the intensity of land use, as they appeared to prefer the habitat offered by the low land use intensity site. The conditions at the high land use intensity may have been unfavourable even for these arid adapted beetles. More individuals were recorded during the walks at the low land use intensity sites and this could be related to the fact that more hiding places may have been available at these sites. Those at the high land use sites may have been more widely dispersed due to the many open patches created by the trampling of large herds of livestock.

Overall, very few tenebrionid beetle species were restricted to a specific land use intensity site. Examination of the soil and vegetation parameters at the high and low land use intensity sites on the farm Olifantputs showed a rather marginal difference between the two sites in this regard. By October, very little standing vegetation was available at either site. Litter was slightly more plentiful at t the lower land use intensity site, which could account for the slightly higher beetle abundance at this site. Grazing pressure, and the associated effects of trampling, was thought to be relatively similar at both land use intensity sites. The reason for this is that livestock were allowed to range all over the farm, in search of suitable grazing areas (Zeidler 1999). Throughout the study, *Alogenius* and *Horatoma* were only recorded at the high land use sites, and *Trachynotidus* was found present only at the low sites. While most beetles were present under both land use intensity regimes, their general abundance was greater at the low intensity sites. This could be an indication that although they could generally survive under both land use regimes, their populations fared better in areas which were slightly less disturbed.

The community composition of termites at the high and low land use intensity sites on the same farm also appeared to be responding to factors other than merely the environmental variability. The communities of these soil organisms was found by Zeidler (1999) to be strongly related to the grazing activity, with a lower abundance being found at the sites where grazing pressure was much more intense. On the whole, grass feeding termites were dominant at both the high and the low land use intensity study sites.

Fig.25. High land use intensity site, Olifantputs, March 1998

Fig. 26 Low land use intensity site, Olifantputs, March 1998

4.3.3 Tenebrionid Diversity

Diversity indices were calculated for the different sites, and the results are shown in table 6.

Table 6 Diversity Indices calculated for the beetle assemblages at the high and low land use intensity sites during the successive sampling periods

	March 1998		October 1998	
	H	L	H	L
H'	1.67	1.9	1.29	1.44
E	0.69	0.91	0.49	0.90
α	2.94	0.81	0.24	0.22
D	0.28	0.17	1.91	2.79
S	11	10	15	17

The greatest diversity of beetles (Shannon H') was found during March 1998, The diversity at the separate land use intensity sites during the different sampling sessions appeared to follow a trend of higher species diversity at the low land use sites than at the high intensity sites. The species overall diversity, was, however, relatively low throughout all of the sampling periods. The evenness (Shannon E) showed a similar trend as that of the species diversity.

The dominance (Simpson, D) was found to be greatest during the October 1998 sampling period. During March 1998, dominance was greater at the high land use intensity sites, but this pattern was reversed during October 1998, when a greater dominance was seen at the low land use intensity sites. The lowest overall dominance value obtained during the study was for the low land use intensity sites during March 1998. The alpha diversity index was found to be at its greatest at the high land use intensity sites, also during March 1998. The opposite situation occurred at the sites sampled during October 1998. During this period, the low land use intensity sites returned the highest dominance values and at the same time, the alpha diversity was lowest.

The overall beetle diversity was highest during March 1998. This was true at both the high and low intensity sites. This may be due to seasonal variation, as the highest rainfall recorded during the period of the study was during March. In contrast, the diversity during the two October sampling periods was relatively low. During both of these periods, no rainfall was recorded at the study sites. These fluctuations in rainfall events may have an effect on the diversity of the beetles present. Beetles adapted to arid environments tend to respond rapidly to rainfall events (Penrith & Endrödy-Younga 1994, Seely et al. In prep). Species diversity has been found to reach a peak when the disturbance intensity or frequency is at an intermediate level (Didham et al. 1998). The March 1998 sampling period was towards the end of the main rainy season of the year, and vegetation had begun to respond to the available moisture at that time. This response was likely to have affected the diversity of the beetles. The physical stress to which beetles at both high and low land use intensity sites were exposed would therefore have been reduced. The two October sampling sessions, in contrast, were carried out during the dry season, when environmental stress was more pronounced, especially since no rain occurred during the six months prior to either of the October sampling periods. It was therefore expected that diversity recorded during October would be slightly lower. During the dry season, the stress due to the environmental parameters would have been amplified by the large herds of livestock and the associated trampling and reduction of the already limited vegetation availability. More litter was available at the low land use sites than at the high land use sites as well, and the grass to bare ground ratio at the high intensity site was found to be 1:3. The tree canopy cover was also higher at the low intensity land use sites (Zeidler

1998). When all high and low land use intensity sites, over the different sampling periods were considered, a trend of greater diversity of beetle species at the low land use sites as compared to the high sites was apparent. Previous studies have shown that most species are adversely affected by physical stress related to land use pressure and habitat fragmentation, resulting in lower densities and diversities in areas that are disturbed (Dennis et al. 1998, Didham et al. 1998). Positive interactions between various species present in the low land use intensity areas could also have contributed to the greater diversity of beetles at these sites. It has been found that species in harsh environments that interact positively have a great influence on the diversity in these areas. One species often facilitates the improvement of conditions, either directly or indirectly, to the benefit of the survival of other rather less tolerant species (Didham et al. 1998). Of the species recorded during the study, it is known that *Gonopus* and *Herpiscius* species often interact in this way, sometimes sharing the same burrows, food and defence mechanisms (Rasa 1994). While not many studies have been carried out on the biology of some of the species recorded, it is possible that similar trends may exist between many of the other groups of species recorded during the study.

The dominance was lowest during March 1998, the same period when the diversity was calculated to be highest. This result is not surprising, because dominance is known to be inversely related to diversity (Magurran 1988, Zar 1984, Huston 1994, Green 1979). During the next sampling period, October 1998, the highest dominance overall was recorded. Conditions at the sites during this period were the worst experienced over the entire study, and both sites appeared to be equally lacking in standing vegetation and litter. From casual observations at both the high and low land use intensity sites, it appeared that almost no standing vegetation was present, and large areas where no litter could be seen at all, were present at both sampling sites. At this time, the beetles *Asphaltesthes costatus* and *Zophosis* were the most prevalent beetles at both the high and low land use intensity sites, both on the walks and in the traps. Both beetles are well adapted to arid conditions, and tend to be opportunistic feeders. This may have the effect of almost eliminating other species that are more restricted in terms of their habitat, food and activity preferences, accounting for the lower diversity and higher dominance at the high intensity land use sites.

Zophosis sp., *Stenocara aenescens* and *Psammodes* sp. were the dominant species during each sampling period. All three have generally long legs and tend to shelter opportunistically when they find burrows of other animals, patches of litter or under logs or stones. They may also have greater levels of physical tolerances than the beetles found to be more rare over the study period. All are known to be able to survive in extremely arid environments (Wharton & Seely 1981, Penrith 1977, 1979). These beetles were consistently found in higher abundance and greater dominance at the high land use intensity sites. They beetles also fall into the category of decomposers (Marais & Irish, unpublished), and as such are able to take advantage of the increase in resource availability, provided by the dung inputs of the large herds of livestock at the high land use intensity sites. This behaviour was actually observed a number of times while undertaking transect walks, or just generally moving around the area.

Overall, at all sites and during all study periods, the diversity appeared to be greater in the areas where the impact of land use was lower. Dominance was, as expected, greater where diversity was lowest, and was also higher where land use intensity was greatest. Evenness of beetle distribution was also greatest at the sites of highest diversity.

As in the case of the beetles, termite diversity and activity showed a strong seasonal variation. Termite diversity and activity was higher in March than in October. Nutrient availability in the soil also fluctuated with the seasons, rather than between the sites, as did vegetation (Zeidler 1999). These factors would have had an effect on the diversity of organisms such as beetles, that make use of the substrate, and whose larvae live within the soil, playing a role in the mediation of some soil processes. A lower nutrient availability in the soil could mean a decrease in the diversity of adult beetles, due to a reduction in resources for the soil dwelling larvae. It could, alternatively, affect not only the diversity of the adult tenebrionids, but also their size. If larval abundance remains the same, but the amount of available resources decreases, then larvae would probably develop into smaller adult beetles than they would have if more food had been available to them during their growing phase.

4.3.4 Tenebrionid size measures

Table 6. Length and shape differences between the comparable beetles at the high and low land use intensity sites

Beetle	With		Length		**Length/width**	
	H	**L**	**H**	**L**	**H**	**L**
March 1998						
Gonopus	*1.146±0.108*	*1.155±0.090*	0.46±0.186	1.85±0.269	1.66±0.082)	1.53±0.317
	(p=0.923)		(p = 0.001)		(p = 0.208)	
Pachynotelus	*0.406±0.051*	*0.344±0.041*	0.67±0.092	0.59±0.067	1.66±0.113	1.73±0.103
	(p=0.0001)		(p = 0.011)		(p = 0.027)	
Stenocara aenescens	0.594±0.085	0.577±0.089	1.13±0.119	1.14±0.168	1.92±0.236	2.00±0.287
	(p=0.789)		(p = 0.892)		(p = 0.363)	
Stips dohrni	0.771±0.084	0.758±0.088	1.05±0.117	1.05±0.121	1.39±0.085	1.36±0.058
	(p=0.789		(p = 0.867)		(p = 0.385)	
Zophosis	*0.531±0.132*	*0.458±0.0121*	0.92±0.208	0.77±0.189	1.74±0.138	1.69±0.147
	(p=0.003)		(p = 0.0003)		(p = 0.955)	
October 1998						
Asphaltesthes costatus	0.260±0.024	0.267±0.020	0.69±0.055	0.69±0.031	2.67±0.317	2.60±0.170
	(p=0.715)		(p = 0.584)		(p = 0.783)	

The table shows mean and standard deviations calculated for the beetles at the different land use intensity sites (see also Appendix 1) H=High land use intensity site, L=low land use intensity site

Overall, there was no difference between the lengths of the beetles at the different sites ($p = 0.117$). Beetles that had been found in numbers sufficient for statistical analysis, i.e. $n > 6$, were compared.
Lengths of beetles at the high and low land use intensity sites sampled during March 1998 were not significantly different ($p = 0.636$).
Of the eight beetle species recorded at both the high and low land use intensity sites, only four were found in sufficient numbers to enable statistical comparison. Of these four, *Gonopus tibialis*, *Pachynotelus* sp. and *Zophosis* sp. were of differing lengths at the two sites (Table 6). Lengths of *Gonopus tibialis* beetles at the high and low land use sites were different ($p = 0.001$). Beetles at the low land use intensity sites were generally longer than those at the high intensity sites, with individuals at the low sites ranging in length between 1.6 and 2.2cm, while those caught in the high land use intensity areas ranged between 0.8 and 1.4cm. Most *Pachynotelus* individuals recorded at the low land use intensity sites measured between 0.6 and 1.2 cm in length, and none were found to be longer than 1.4cm at the high intensity sites. Beetles at the high land use sites were found to be wider than those at the low land use sites ($p = 0.027$). *Zophosis* sp. individuals differed in length at the two sites ($p = 0.0003$) as well.
Most individuals measured at the low land use intensity site were less than 0.7cm in length, and greater than 0.7cm at the high land use intensity sites.

Beetle sizes at the high and low land use intensity sites sampled during October 1998 were not significantly different ($p = 0.846$). Of the beetles found during the October 1998 sampling period, five different species of beetles were found at both the high and the low land use intensity sites. Of these, only one was found in high enough numbers at both sites to allow comparison, *Asphaltesthes costatus*. Individuals were, however, not significantly different in size at either of the sites.

Again, during March 1998, only a few species were comparable. Of these, *Gonopus* and *Pachynotelus* individuals were longer at the low land use intensity sites. Adults are known to display a wide variety of sizes and shapes, depending on the conditions available to the larvae (Schultze 1978). Size of adult beetles would therefore be directly attributable to the amount of resources available to the larvae. *Zophosis* beetles were longer at the low land use intensity site. In contrast, beetles measured during October 1998 were all of similar size at both the high and low land use intensity sites.

CHAPTER 5

5.1 Tenebrionids and the Index of Biological Integrity

The index of biological integrity (IBI), is a tool, which can be used in an attempt to assess the condition of rangeland and habitat. Areas that are degraded can be identified, if threshold values for this index have been determined. The IBI can therefore be of use when trying to differentiate between human-induced land degradation and natural changes in the overall condition of the environment.

The availability an quality of fodder, soil fertility and the biodiversity and function of soil biota, viz. termites and tenebrionid beetles, and how these relate to land use management strategies, were all parameters that were suggested as important measures of biological integrity in north western Namibian rangelands.

The scoring system, on which the developed index is based, was derived from data collected at study sites in the communal and commercial farming areas in northwestern Namibia. Data collected on the current vegetation, soil, termite and beetle condition at the study sites was used to develop a scoring system, which, taking all the measured parameters into consideration, would allow comparisons between the different sites. According to Barbour et al (1995), parameters relating to community and taxonomic structure, individual condition, as well as biological processes, should all be taken into consideration when assessing biological condition, as they are thought to provide a good reflection of the ecological systems.

For the purposes of this study, which concentrated on the condition of tenebrionid beetles on one specific communal farm, in terms of community assemblage, taxonomic composition as well as individual, specific condition, sites experiencing high and low land use pressure were compared. Community structure included species richness, diversity and dominance measures. Taxonomic composition included specific identity, rare and extremely common key taxa. Individual condition included size differences between beetles of the same species, at the different land use intensity sites within the same farm. Different scores were assigned, according to the condition of the beetles in terms of the parameters already mentioned. A score of 1 denoted a poor condition of the rangeland, and a score of 3, a condition that could be classified as being better.

Only a few species of beetles were found in sufficient numbers for comparison between the high and low land use intensity sites during the study. Of these, a few species were significantly different in their sizes (length, width and length/width ratio) at the separate land use intensity sites. These were therefore the only beetles that could reasonably be used in the elaboration of a preliminary biological index, and give some idea of the potential indicator properties of tenebrionid beetles within the overall index developed for the sites during this study.

Table 7. Specific attributes and diversity measures derived for use in habitat assessment at the two land use intensity sites

Beetle	**High land use intensity site**			**Low land use intensity site**		
Mean ± SD	**L**	**W**	**L/W**	**L**	**W**	**L/W**
Gonopus	0.46	1.15	1.66	1.85	1.16	1.53
Pachynotelus	0.67	0.41	1.66	0.59	0.34	1.73
Zophosis	0.93	0.52	1.73	0.79	0.45	1.8
Diversity Measures	**High land use intensity site**			**Low land use intensity site**		
H'	1.48			1.67		
E	0.59			0.91		
α	1.59			0.51		
D	1.10			1.48		
S	13			13.5		

L= Length of beetles, W = beetle width, L/W= length:width ratio

A score for each site was determined after calculation of the diversity measures and size attributes of the selected beetles, i.e. those present in sufficient numbers at each study to allow for comparison, and that showed significant size differences between the two land use intensity sites.

Table 8. Habitat assessment scores derived and applied to high and low land use intensity sites at Olifantputs

		High	Low
Pachynotelus	Length	3	1
	Width	3	1
	L/W	1	3
Gonopus	Length	1	3
	Width	1	3
	L/W	3	1
Zophosis	Length	3	1
	Width	3	1
	L/W	1	3
H'		1	3
E		1	3
S		1	3
α		3	1
D		1	3
Total Score		**26**	**30**

5.2 Final Conclusions and Recommendations

Scores calculated showed that the sites were marginally different, although these scores were relatively close to those calculated for soil and vegetation parameters at Olifantputs by Zeidler (1999). Habitat at the high land use intensity site was found to be in an extremely poor condition (Zeidler 1999).

In general, some beetles appeared to be restricted to, and also in a "better" condition at the lower land use intensity site . This was particularly true of Gonopus, and this result could probably be related to the known preference of these beetles for areas with a softer substrate. The low land use intensity site at Olifantputs was found to be providing a greater amount of resources, especially in the form of litter, and this increased resource availability could have influenced the higher scores calculated for be presence of Gonopus at this site.

In contrast, the other two beetles found in sufficient numbers to allow for inclusion in the calculation of scores, Zophosis and Pachynotelus, appeared to be in a better condition at the higher land use intensity sites.

Pachynotelus beetles are strongly dependent on rainfall. Larvae remain in the soil, and adults emerge only when enough rainfall has been received to allow an increase in the vegetation in a specific area. This genus is widely distributed over southern Africa, appears to be sporadically active, especially after rain (Holm 1970, Penrith & Endrody-Younga 1994). The emergence of the adults, however, does not occur immediately after the rainfall event, but rather, is timed so as to co-incide with the most suitable stage of growth of the plants on which they feed . This would therefore imply that these beetles would show strong seasonal variation, and this was indeed the case.

Zophosis was present in comparatively high numbers throughout the study and was followed in abundance by *Stenocara aenescens* and *Gonopus tibialis*

When all high and low land use intensity sites, over the different sampling periods were considered, a trend of greater diversity of beetle species at the low land use sites as compared to the high sites was apparent. This may indicate that the beetles were responding to the land use pressure, by increasing in diversity in the areas experiencing less pressure. Previous studies have shown that most species are adversely affected by physical stress related to land use pressure and habitat fragmentation, resulting in lower densities and diversities in areas that are disturbed (Dennis et al. 1998, Didham et al. 1998). Positive interactions between various species present in the low land use intensity areas could also have contributed to the greater diversity of beetles at these sites. It has been found that species in harsh environments that interact positively have a great influence on the diversity in these areas. One species often facilitates the improvement of conditions, either directly or indirectly, to the benefit of the survival of other rather less tolerant species (Didham et al. 1998). Of the species recorded during this study, it is known that *Gonopus* and *Herpiscius* species often interact in this way. These beetles often share the same burrows, food and defence mechanisms (Rasa 1994). While not many studies have been carried out on the biology and distribution of some of the species recorded, it is possible that similar trends may exist between many of the other groups of species recorded during the study.

Overall, a greater seasonal variation was found than differences in beetle diversity measures within the high and low land use intensity sites at Olifantputs. This was also found for the vegetation and soil parameters measured, as well as for the termites and beetles. Future studies would need to look at a greater number of sites, on farms of differing land use management systems, but with a similar ecological background, although this study does provide a baseline from which to start.

Grazing pressure at both the high and low land use intensity sites considered, was extremely high, and whether these areas have already been irreparably damaged, and how the state of the vegetation and soil affects the beetle presence and condition still needs to be investigated.

While the biological integrity of the area was not fully established during this study, it can be used as a foundation on which the full establishment of biological indicators can be developed. The selected sites appeared to be marginal in terms of all of the parameters measured (Zeidler 1999). These measures include termites and tenebrionid beetles. Some beetles were significantly different in their sizes, diversity and abundance at the high and low land use intensity sites, and future studies could start by looking at these specific beetles in more detail, on a larger scale, using the information gathered during the in-depth study at Olifantputs as a base from which to work.. The parameters measured for the beetles, and the criteria, as related to the IBI, should be refined, and adapted to other habitats, though. Tenebrionid beetles are relatively easy to catch and identify. A reference collection has already been started and updated during the course of this study. Further monitoring of beetle diversity measures in the area could therefore be facilitated, and those species not recorded during this study would only need to be added to the existing collection.

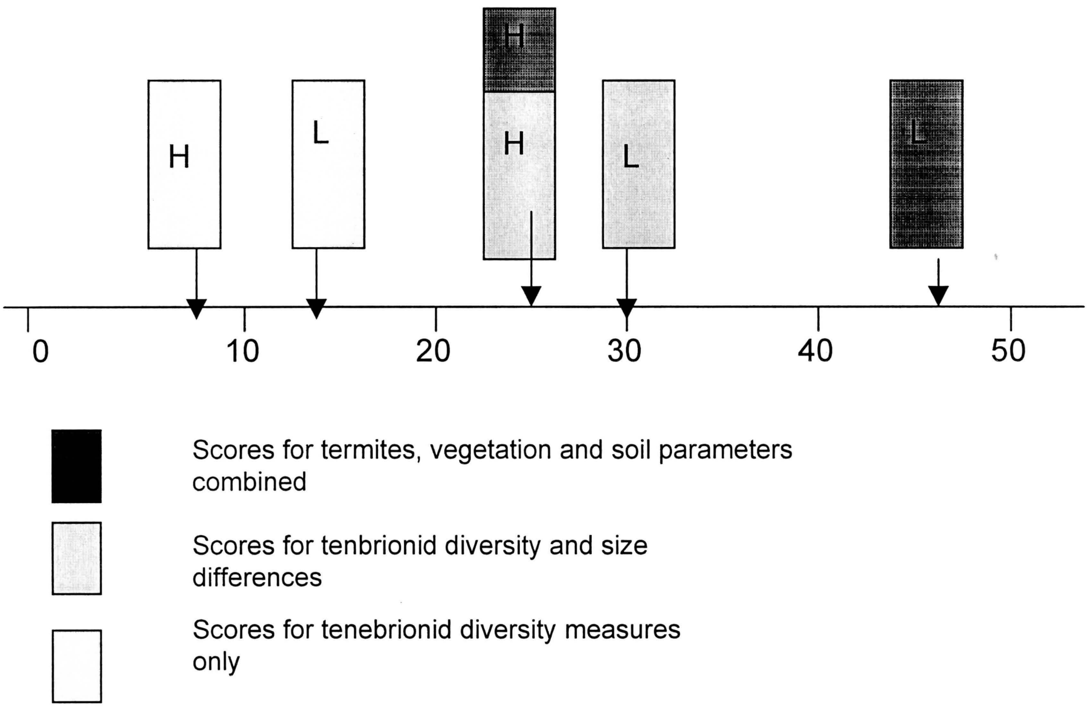


Fig.27 Rating of scores derived for sites at high and low land use intensity areas

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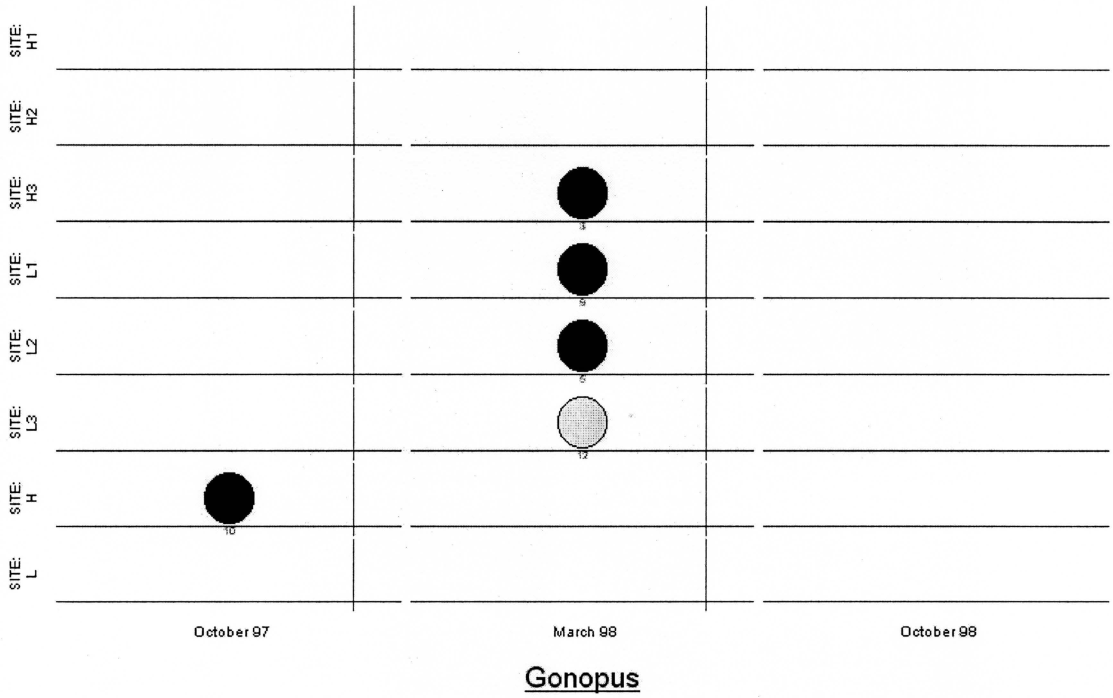
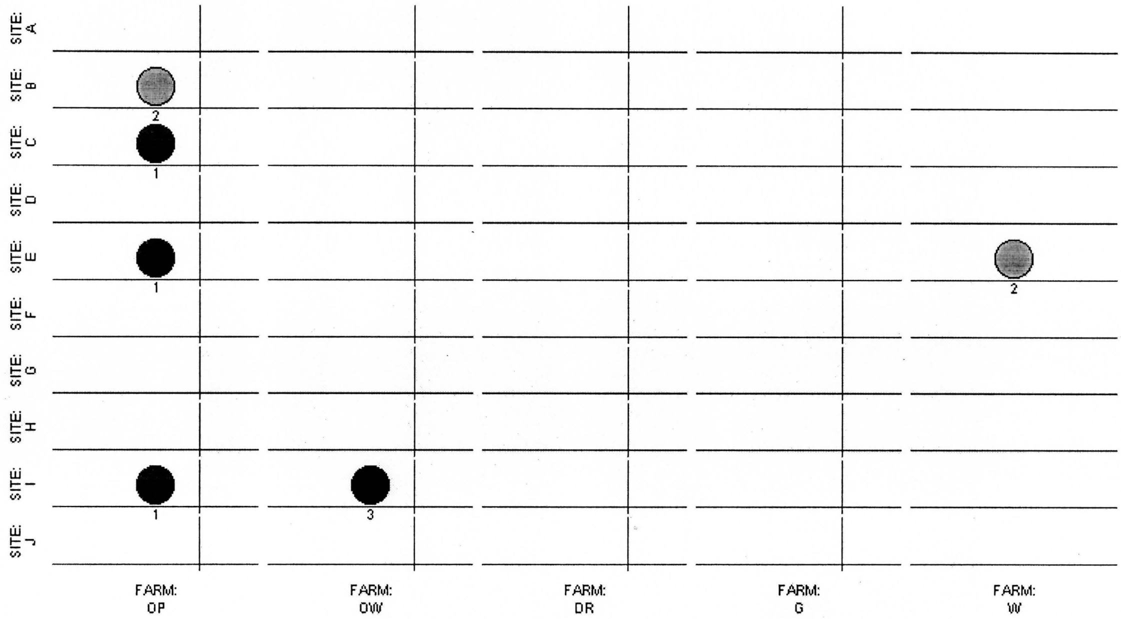
List of all insects recorded at the five farms during the survey carried out at five Napcod pilot sites during March 1997

	Olifantputs	Olifantswater	Grootberg	De Riet	Waterval
CARABIDAE					
Anthia circumscripta	2				
Chlaerius perspicillatus Boheman	1				1
Graphipterus bilineatus Boheman	2	1			
Graphipterus sp.1	1				
Graphipterus sp.2	1				
Passalidius fortipes Burchell	1				
Lebiinae sp.1		1			
CICENDELIDAE					
Manticora damarensis Pèringuey 1892					1
CURCULIONIDAE					
Brachycerus sp. 1	2				
Brachycerus sp. 2	1				
Episus sp.		1			
Siderodactylus sp.		1	1		
Spartacerus mendax	4				
HYBOSORIDAE					
Hybosorus sp.	1	5	7	4	1
MELOIDAE					
Cylindrithorax thoracica			2		
Ceroctis phalerata Erichson	1		1		1
Ceroctis sp.			13		11
Mylabris hybrida		3	16	11	10
Mylabris occulata			1		
Mylabris sp.1			1		1
Mylabris sp.2			2		2
Mylabris sp.3					3
SCARABAEIDAE					
Aphodiinae sp.1			1		
Aphodiinae sp.2					1
Catharsius sp.				1	
Gymnopleurus humanus			2		
Peritrichia bella					2
Scarabaeus sp.				2	5
Schizonycha sp.	2				1
TENEBRIONDAE					
Brinckia debilis Pèringuey 1899	1				2
Cryptochile consita Haag 1872	11		16		5
Drosochrini sp.	1		1		

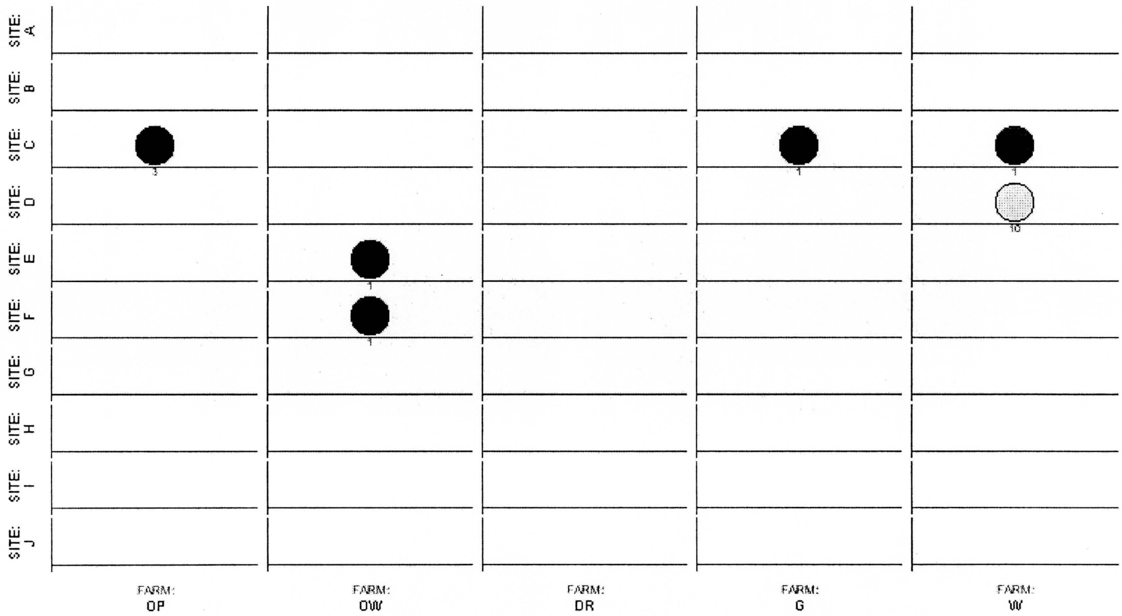
Eurychora sp.			2	1	
Gonopus tibialis Fabricius	4		1		
Herpiscius sp.	1	1			
Himatismus sp.	1		1	1	1
Horatoma praetoriusi Koch 1852			1		
Oxurina sp.				2	
Pachynotelus damarinus Penrith & Endrödy-Younga, 1994	1	3			
Parastizopus sp.	1		1		
Phanerotomea sp.	1			1	
Physadesmia globosa Haag-Rutenberg 1875				7	
Psammodes fartus Pèringuey					1
Psammodes sp.	7				1
Psammodes vialis Burchell	5		5		2
Renatiella scrobipennis Haag-Rutenberg 1875		4			
Stenocara aenescens Haag-Rutenberg 1875		1	4		
Stenocara gracilipes Solier 1834	1	1	1		
Stips dohmi Haag	3		3		
Trachynotidus damarinus Pèringuey 1904					1
Triaenogenius sp.	1				
Zophosis boei Solier 1834	2	6	2		
Zophosis sp. 1				5	1
Zophosis sp.2	1	1	1		
Zophosis sp.3					1
FORFICULIDAE					
Sp.1		1			
SCUTELLERIDAE					
Bagrada hilaris			1		
Sp.1		1			
PENTATOMINAE					
Sp.1		1			
TETTIGONIDAE					
Acanthoplus discoidalis Walker	1		1		
TOTAL	**65**	**26**	**93**	**20**	**55**

Distribution of *Gonopus tibialis* across sites and sampling period

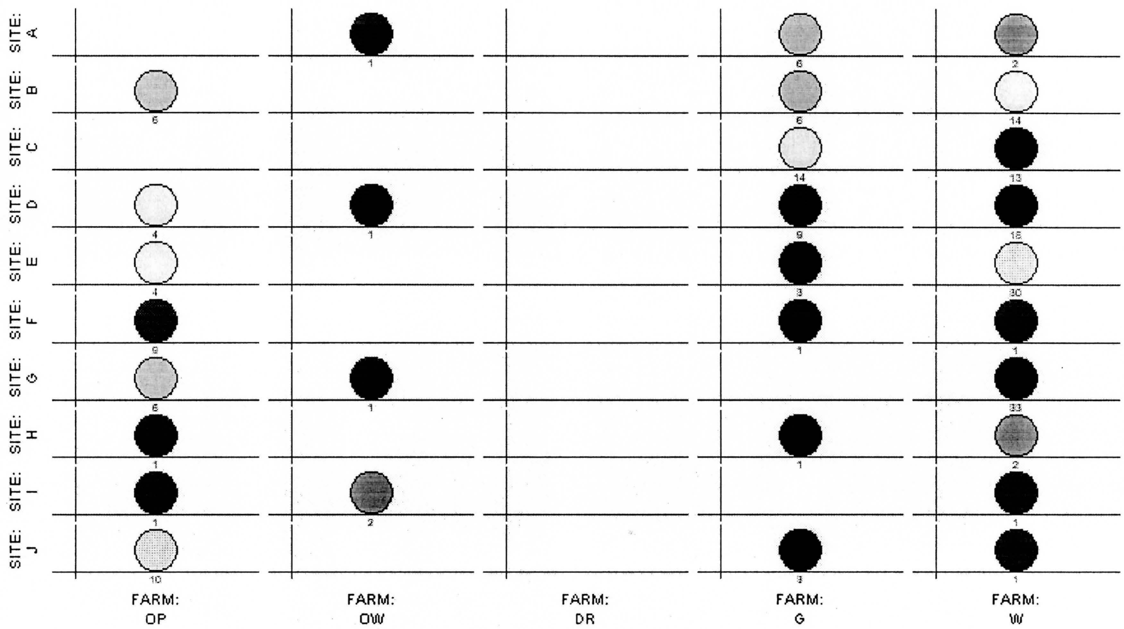




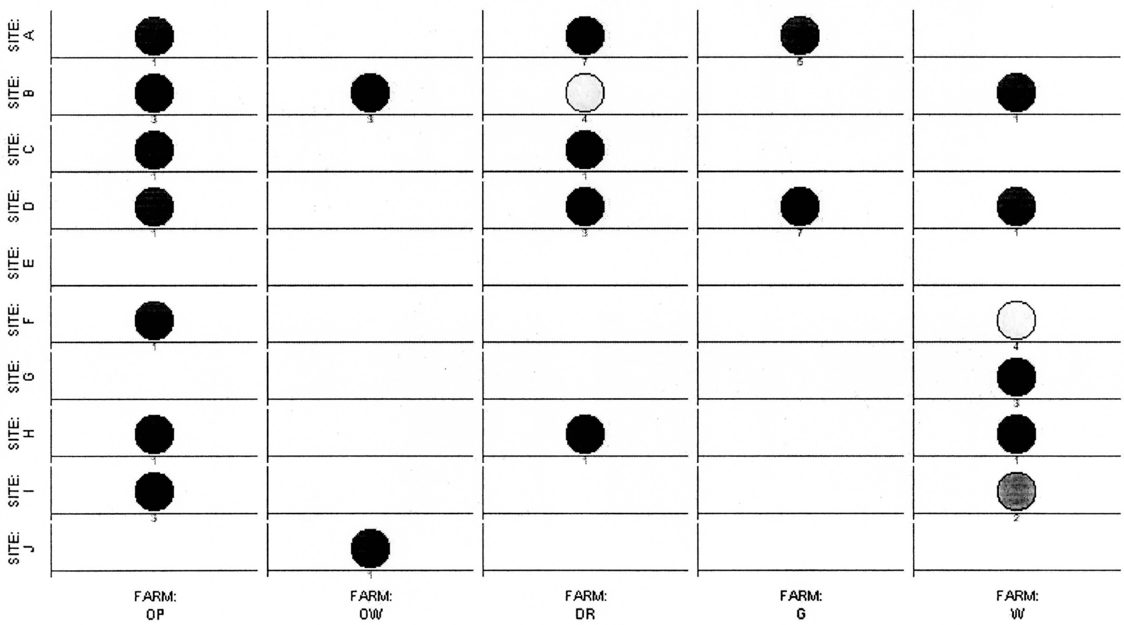
Carabidae



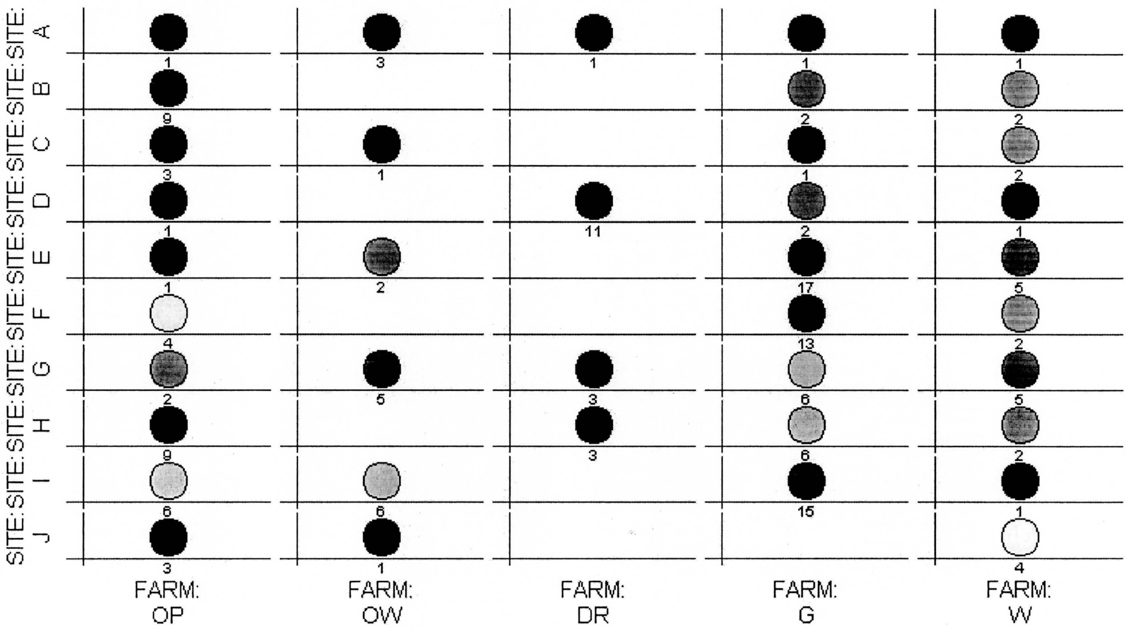
Curculionidae



Meloidae

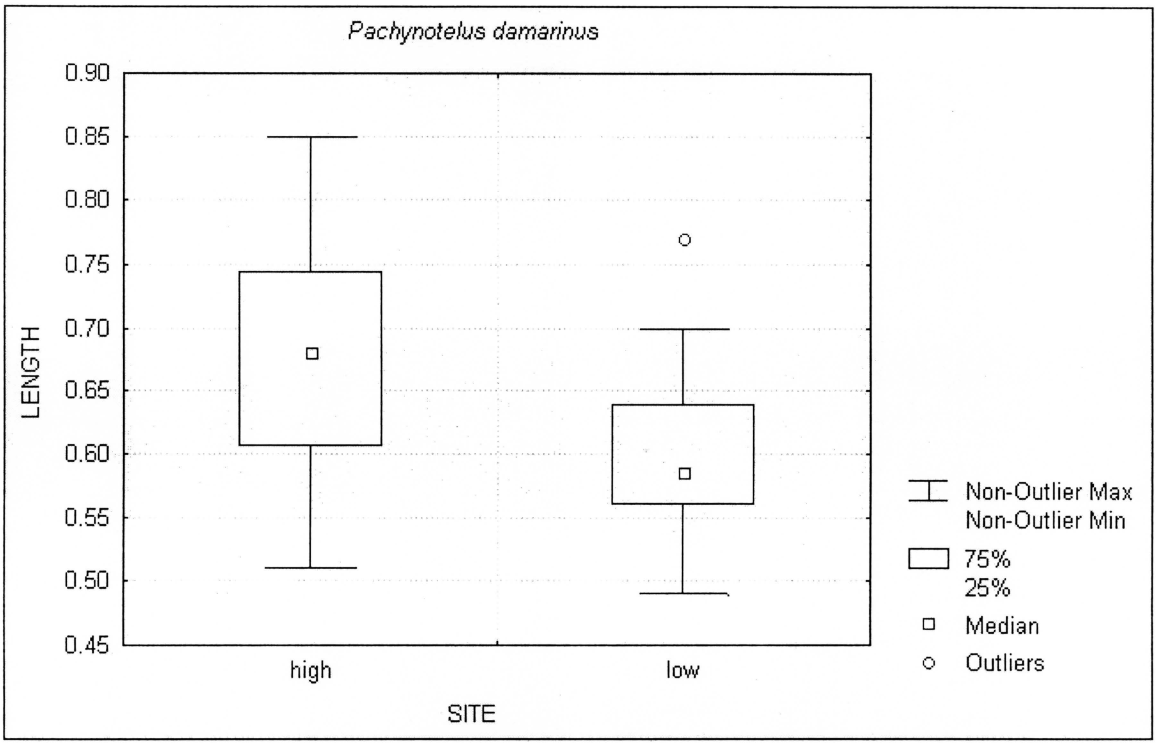


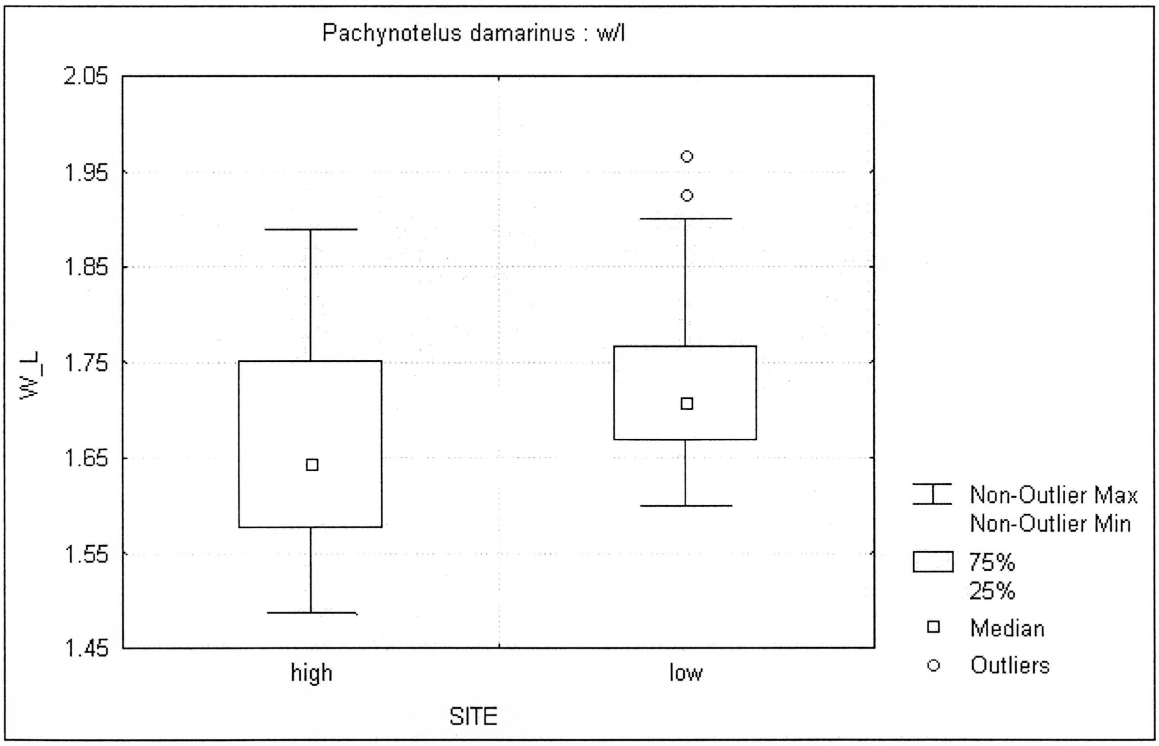
Scarabaeidae

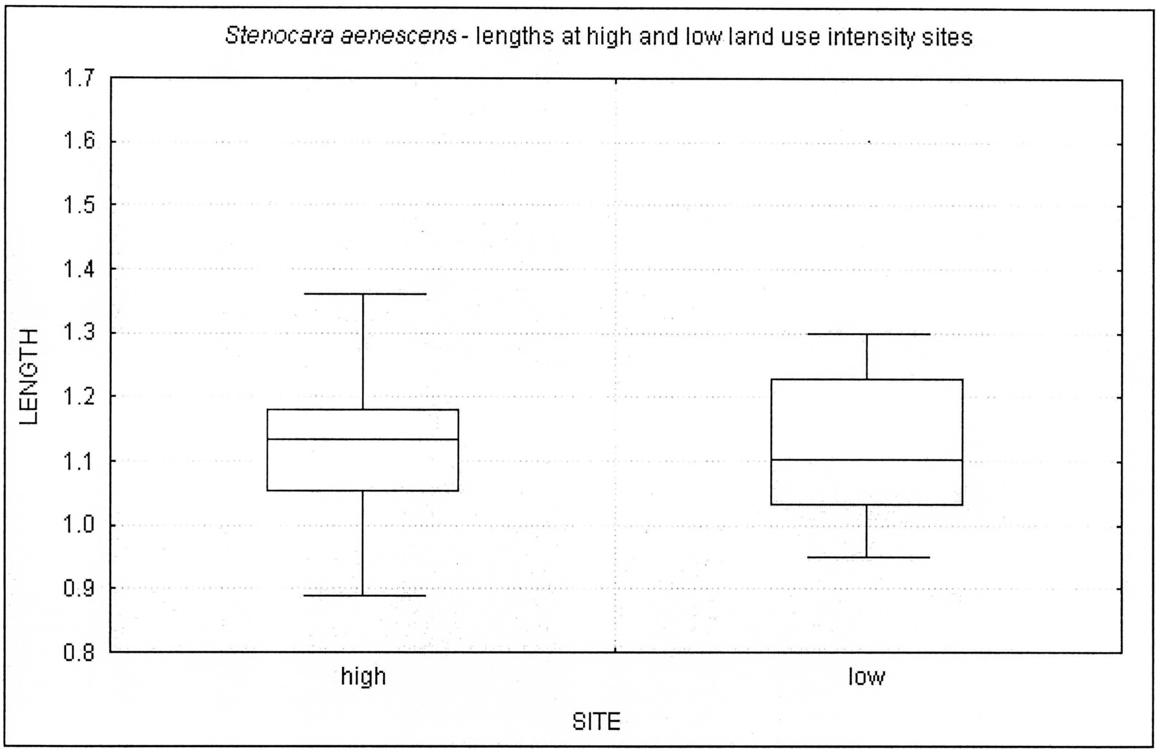


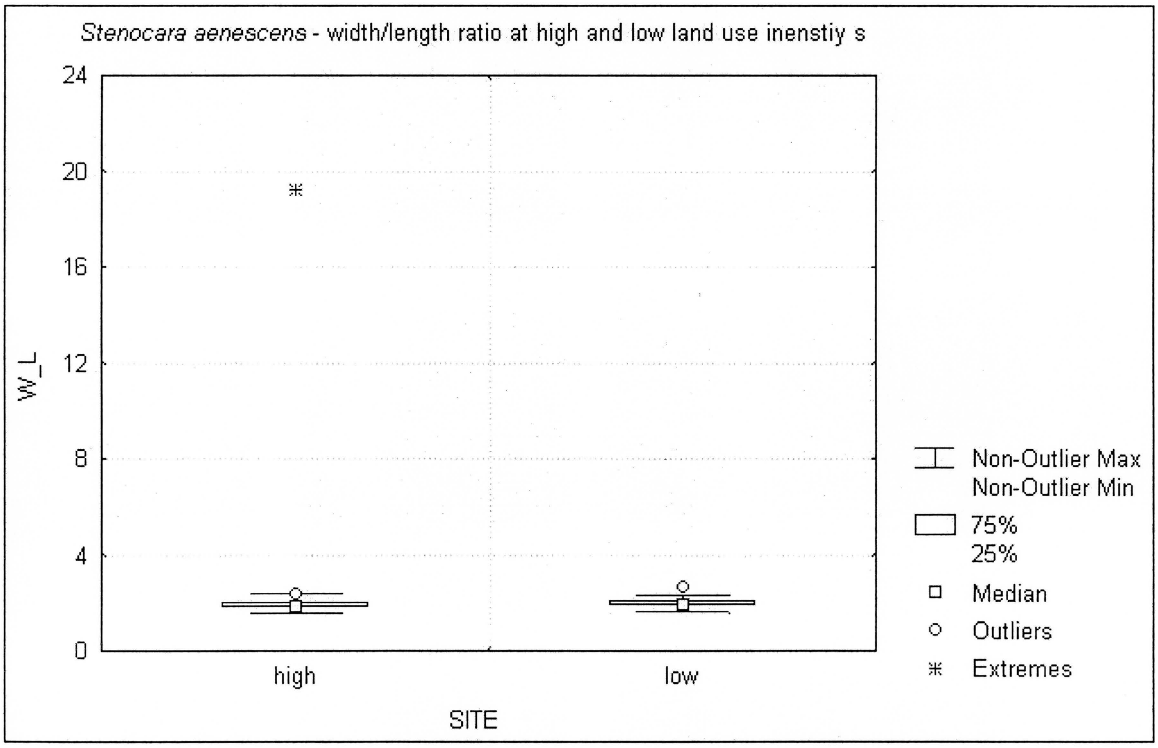
Tenebrionidae

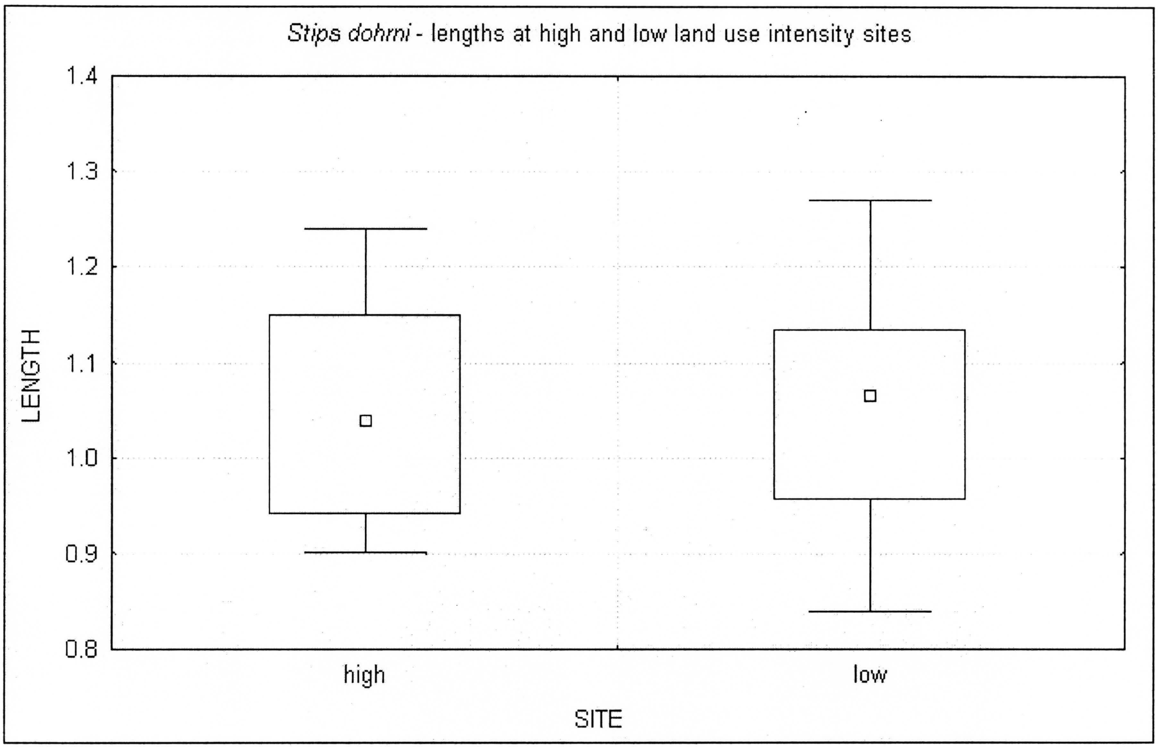
Size differences at high and low land use intensity sites observed during March 1998



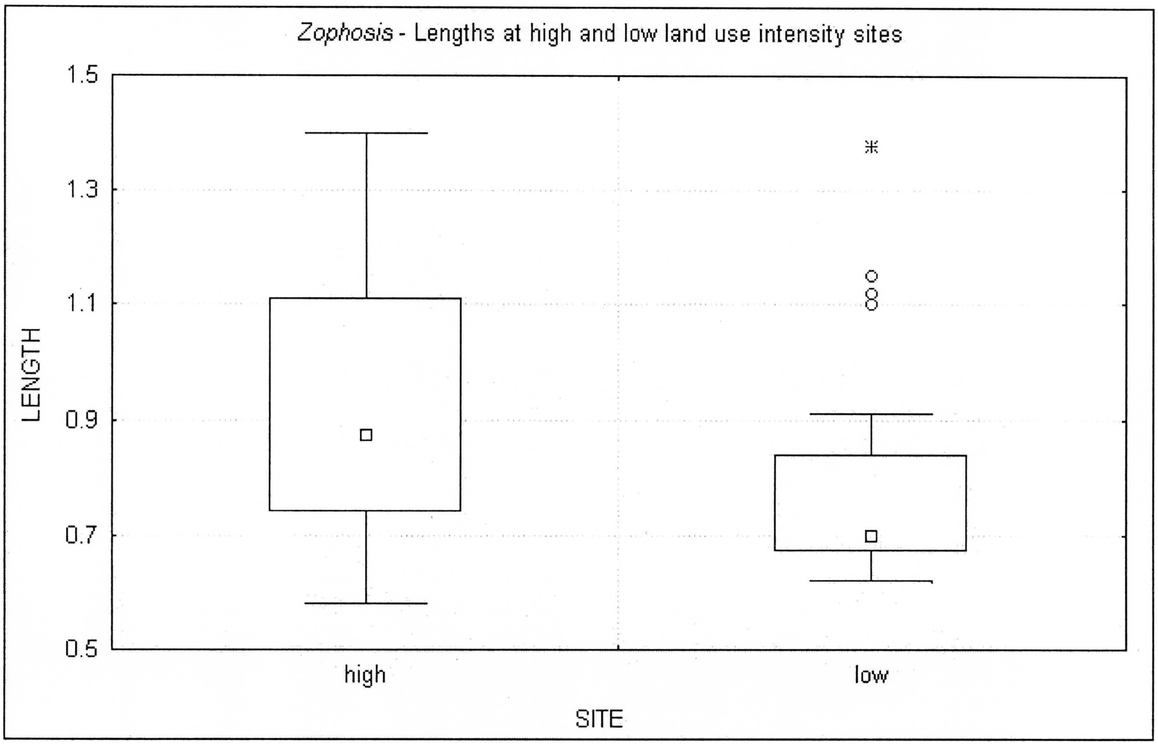



Stenocara aenescens - lengths at high and low land use intensity sites
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
LENGTH
high
low
SITE

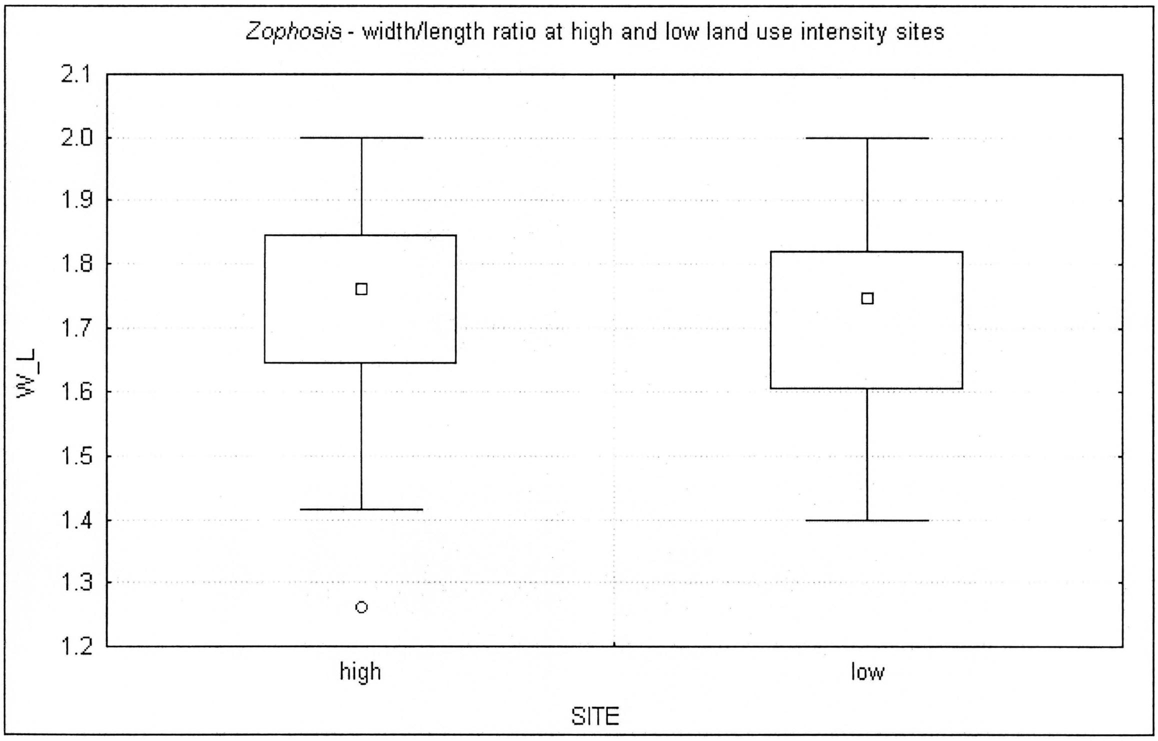

Stenocara aenescens - width/length ratio at high and low land use inenstiy s
24
20
16
12
8
4
0
W_L
high
low
SITE
Non-Outlier Max
Non-Outlier Min
75%
25%
Median
Outliers
Extremes


Stips dohrni - lengths at high and low land use intensity sites
1.4
1.3
1.2
1.1
1.0
0.9
0.8
LENGTH
high
low
SITE


Stips dohrni - width/length ratio at high and low land use intensity sites
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
W_L
high
low
SITE

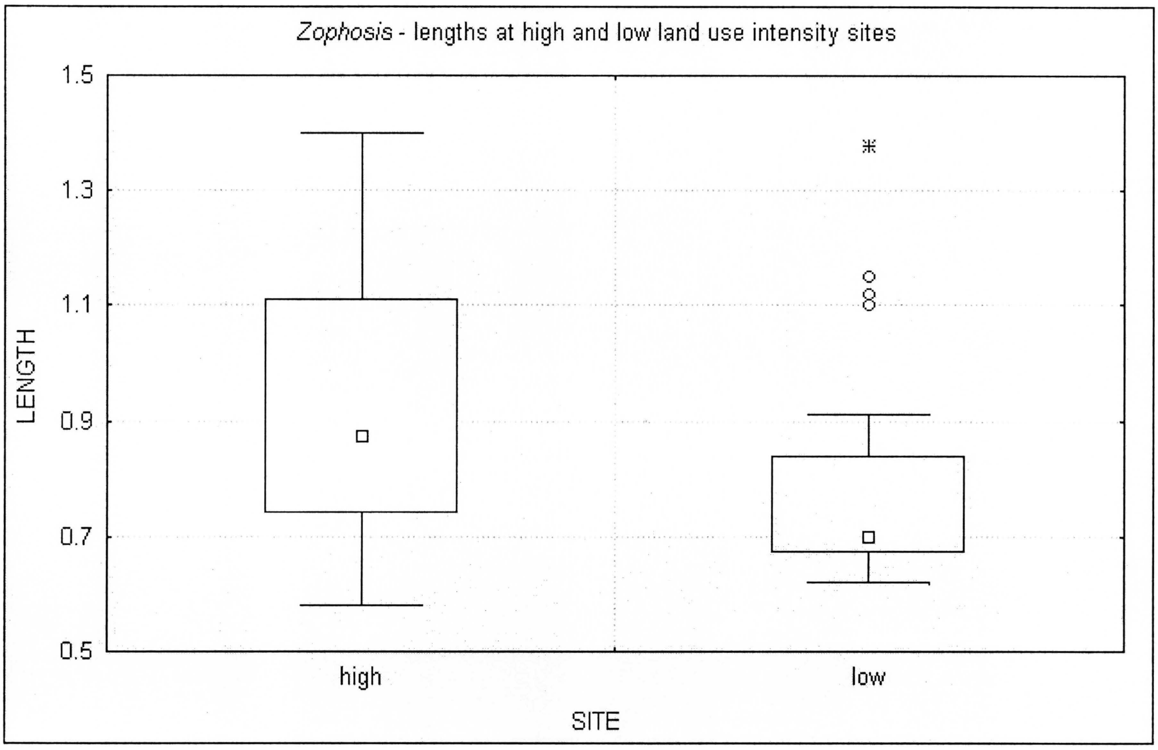


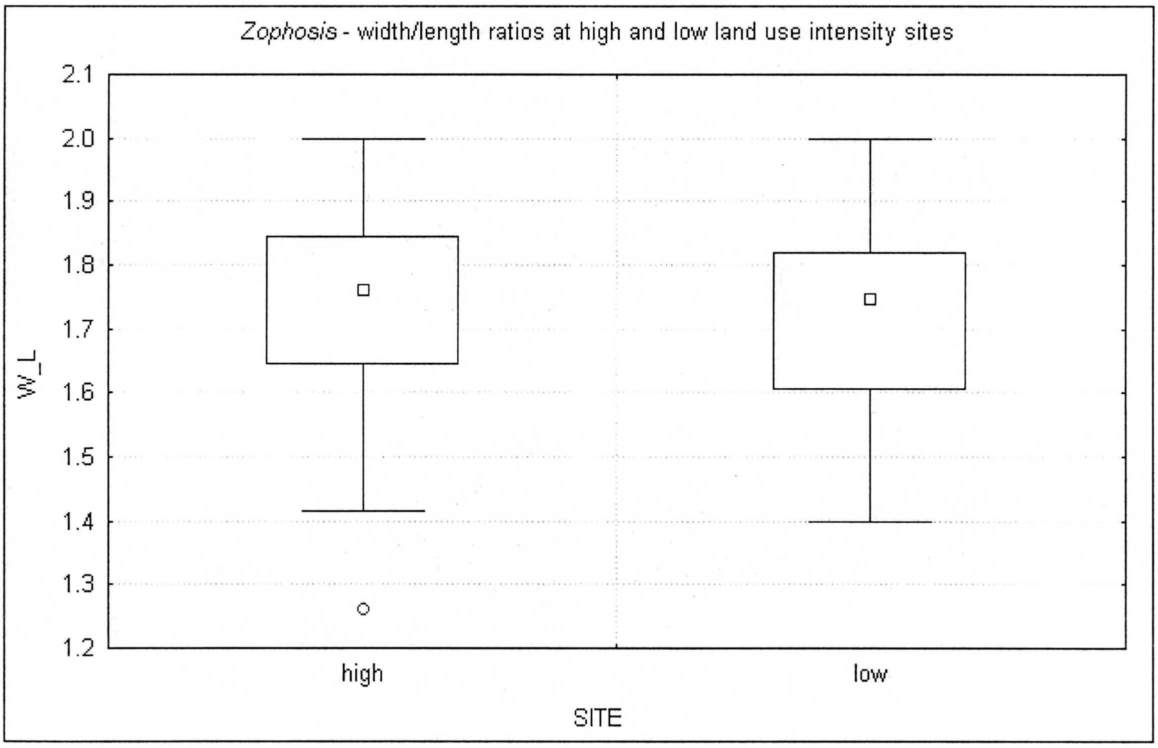
Zophosis - Lengths at high and low land use intensity sites
1.5
1.3
1.1
0.9
0.7
0.5
LENGTH
high
low
SITE



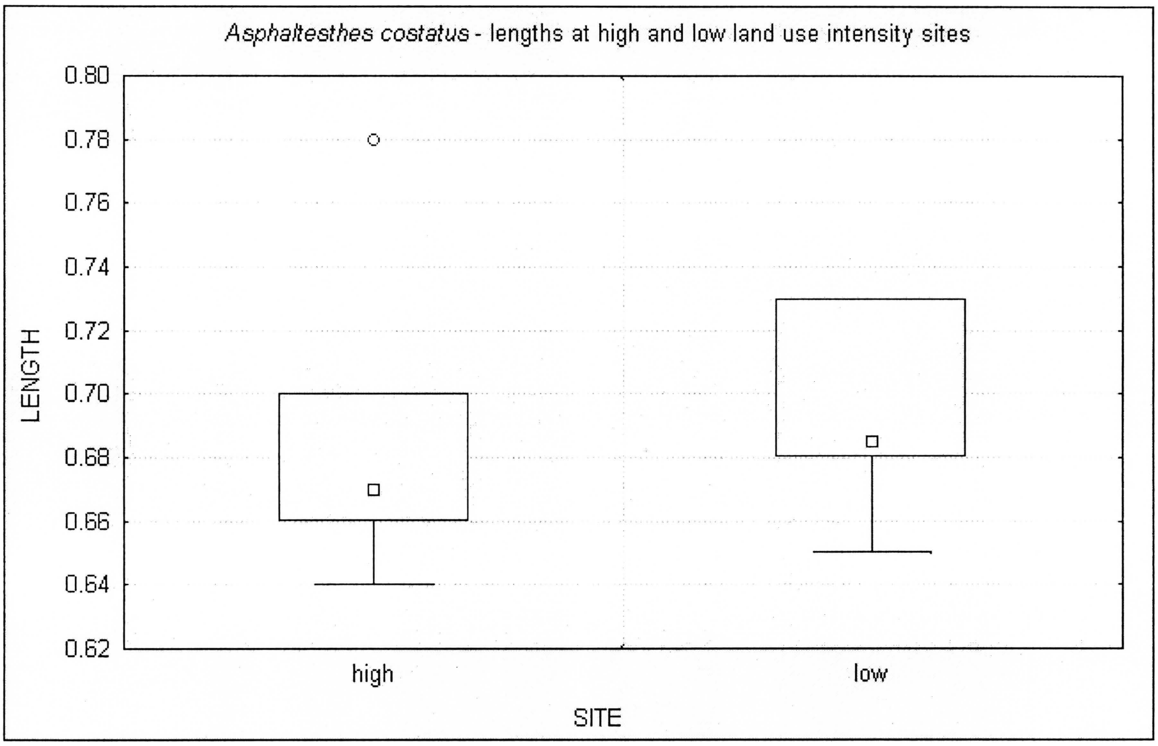
Zophosis - width/length ratio at high and low land use intensity sites
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
W_L
high
low
SITE

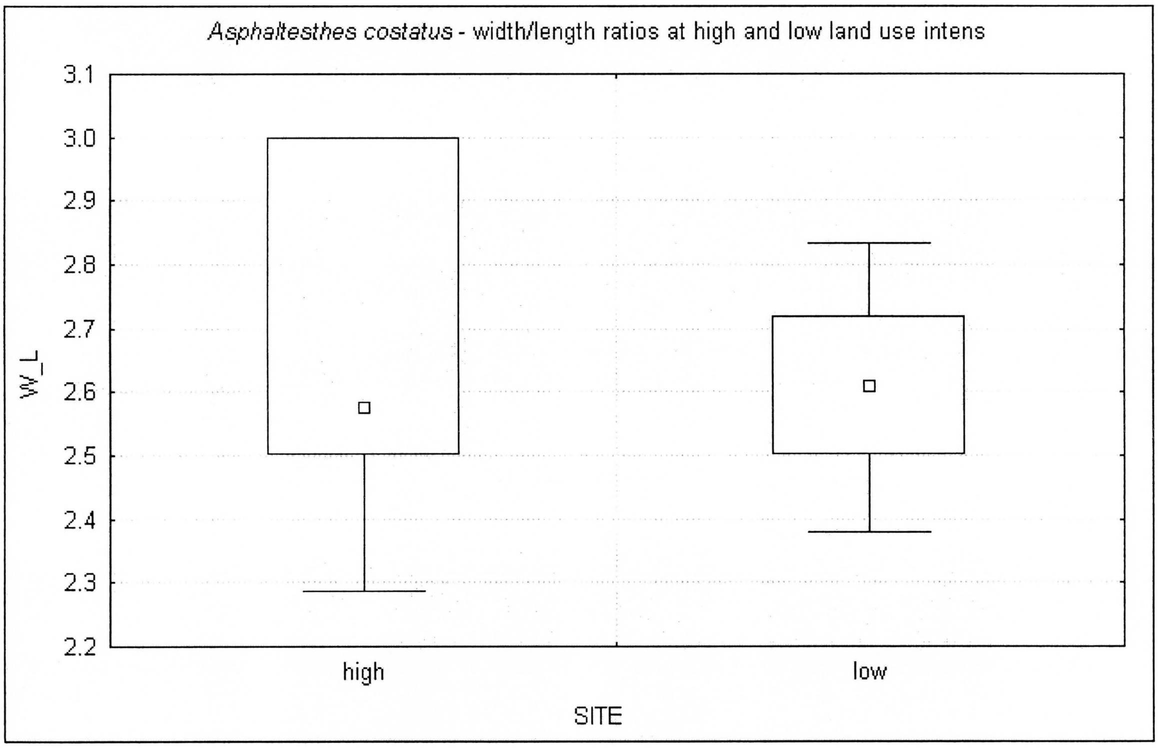
Size differences at high and low land use intensity sites observed during October1997





Size differences at high and low land use intensity sites observed during October1998





Traps – O97,M98,O98

NONPAR STATS Depend.: GON	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 5.122388 p =.0772		
	Code	Valid N	Sum of Ranks
oct 97	100	2	18.00000
march 98	101	6	57.00000
oct 98	102	6	30.00000

NONPAR STATS Dependent: GON	Independent (grouping) variable: SAMPLE Chi-Square = 6.014815, df = 2, p = .0494			
	oct 97	march 98	oct 98	Total
<= Median: observed	1.000000	2.00000	6.00000	9.00000
expected	1.285714	3.85714	3.85714	
obs.-exp.	-.285714	-1.85714	2.14286	
> Median: observed	1.000000	4.00000	0.00000	5.00000
expected	.714286	2.14286	2.14286	
obs.-exp.	.285714	1.85714	-2.14286	
Total: observed	2.000000	6.00000	6.00000	14.00000

NONPAR STATS Depend.: AC	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 11.93443 p =.0026		
	Code	Valid N	Sum of Ranks
oct 97	100	2	9.00000
march 98	101	6	27.00000
oct 98	102	6	69.00000

NONPAR STATS Dependent: AC	Independent (grouping) variable: SAMPLE Chi-Square = 14.00000, df = 2, p = .0009			
	oct 97	march 98	oct 98	Total
<= Median: observed	2.000000	6.00000	0.00000	8.00000
expected	1.142857	3.42857	3.42857	
obs.-exp.	.857143	2.57143	-3.42857	
> Median: observed	0.000000	0.00000	6.00000	6.00000
expected	.857143	2.57143	2.57143	
obs.-exp.	-.857143	-2.57143	3.42857	
Total: observed	2.000000	6.00000	6.00000	14.00000

NONPAR STATS Depend.: ALOG	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 6.000000 p =.0498		
	Code	Valid N	Sum of Ranks
oct 97	100	2	21.00000
march 98	101	6	42.00000
oct 98	102	6	42.00000

NONPAR STATS	Independent (grouping) variable: SAMPLE Chi-Square = 6.461538, df = 2, p = .0395			
Dependent: ALOG	oct 97	march 98	oct 98	Total
<= Median: observed	1.000000	6.000000	6.000000	13.00000
expected	1.857143	5.571429	5.571429	
obs.-exp.	-.857143	.428571	.428571	
> Median: observed	1.000000	0.000000	0.000000	1.00000
expected	.142857	.428571	.428571	
obs.-exp.	.857143	-.428571	-.428571	
Total: observed	2.000000	6.000000	6.000000	14.00000

NONPAR STATS	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 6.312574 p =.0426		
Depend.: HER	Code	Valid N	Sum of Ranks
oct 97	100	2	24.50000
march 98	101	6	47.50000
oct 98	102	6	33.00000

NONPAR STATS	Independent (grouping) variable: SAMPLE Chi-Square = 7.466666, df = 2, p = .0239			
Dependent: HER	oct 97	march 98	oct 98	Total
<= Median: observed	0.00000	4.000000	6.00000	10.00000
expected	1.42857	4.285714	4.28571	
obs.-exp.	-1.42857	-.285714	1.71429	
> Median: observed	2.00000	2.000000	0.00000	4.00000
expected	.57143	1.714286	1.71429	
obs.-exp.	1.42857	.285714	-1.71429	
Total: observed	2.00000	6.000000	6.00000	14.00000

NONPAR STATS	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 6.000000 p =.0498		
Depend.: HIM	Code	Valid N	Sum of Ranks
oct 97	100	2	21.00000
march 98	101	6	42.00000
oct 98	102	6	42.00000

NONPAR STATS	Independent (grouping) variable: SAMPLE Chi-Square = 6.461538, df = 2, p = .0395			
Dependent: HIM	oct 97	march 98	oct 98	Total
<= Median: observed	1.000000	6.000000	6.000000	13.00000
expected	1.857143	5.571429	5.571429	
obs.-exp.	-.857143	.428571	.428571	
> Median: observed	1.000000	0.000000	0.000000	1.00000
expected	.142857	.428571	.428571	
obs.-exp.	.857143	-.428571	-.428571	
Total: observed	2.000000	6.000000	6.000000	14.00000

NONPAR STATS Depend.: P_SIM	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 6.933335 p =.0312		
	Code	Valid N	Sum of Ranks
oct 97	100	2	11.00000
march 98	101	6	33.00000
oct 98	102	6	61.00000

NONPAR STATS Dependent: P_SIM	Independent (grouping) variable: SAMPLE Chi-Square = 7.466667, df = 2, p = .0239			
	oct 97	march 98	oct 98	Total
<= Median: observed	2.000000	6.00000	2.00000	10.00000
expected	1.428571	4.28571	4.28571	
obs.-exp.	.571429	1.71429	-2.28571	
> Median: observed	0.000000	0.00000	4.00000	4.00000
expected	.571429	1.71429	1.71429	
obs.-exp.	-.571429	-1.71429	2.28571	
Total: observed	2.000000	6.00000	6.00000	14.00000

NONPAR STATS Depend.: PACH	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 11.83740 p =.0027		
	Code	Valid N	Sum of Ranks
oct 97	100	2	9.00000
march 98	101	6	69.00000
oct 98	102	6	27.00000

NONPAR STATS Dependent: PACH	Independent (grouping) variable: SAMPLE Chi-Square = 14.00000, df = 2, p = .0009			
	oct 97	march 98	oct 98	Total
<= Median: observed	2.000000	0.00000	6.00000	8.00000
expected	1.142857	3.42857	3.42857	
obs.-exp.	.857143	-3.42857	2.57143	
> Median: observed	0.000000	6.00000	0.00000	6.00000
expected	.857143	2.57143	2.57143	
obs.-exp.	-.857143	3.42857	-2.57143	
Total: observed	2.000000	6.00000	6.00000	14.00000

NONPAR STATS Depend.: PARA	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 6.787881 p =.0336		
	Code	Valid N	Sum of Ranks
oct 97	100	2	11.00000
march 98	101	6	61.00000
oct 98	102	6	33.00000

NONPAR STATS Dependent: PARA	Independent (grouping) variable: SAMPLE Chi-Square = 7.466667, df = 2, p = .0239			
	oct 97	march 98	oct 98	Total
<= Median: observed	2.000000	2.00000	6.00000	10.00000
expected	1.428571	4.28571	4.28571	
obs.-exp.	.571429	-2.28571	1.71429	
> Median: observed	0.000000	4.00000	0.00000	4.00000
expected	.571429	1.71429	1.71429	
obs.-exp.	-.571429	2.28571	-1.71429	
Total: observed	2.000000	6.00000	6.00000	14.00000

NONPAR STATS Depend.: PSAM	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 6.787881 p =.0336		
	Code	Valid N	Sum of Ranks
oct 97	100	2	11.00000
march 98	101	6	61.00000
oct 98	102	6	33.00000

NONPAR STATS Dependent: PSAM	Independent (grouping) variable: SAMPLE Chi-Square = 7.466667, df = 2, p = .0239			
	oct 97	march 98	oct 98	Total
<= Median: observed	2.000000	2.00000	6.00000	10.00000
expected	1.428571	4.28571	4.28571	
obs.-exp.	.571429	-2.28571	1.71429	
> Median: observed	0.000000	4.00000	0.00000	4.00000
expected	.571429	1.71429	1.71429	
obs.-exp.	-.571429	2.28571	-1.71429	
Total: observed	2.000000	6.00000	6.00000	14.00000

NONPAR STATS Depend.: STEN_A	Independent (grouping) variable: SAMPLE Kruskal-Wallis test: H (2, N= 14) = 10.50000 p =.0053		
	Code	Valid N	Sum of Ranks
oct 97	100	2	21.00000
march 98	101	6	63.00000
oct 98	102	6	21.00000

NONPAR STATS Dependent: STEN_A	Independent (grouping) variable: SAMPLE Chi-Square = 8.555555, df = 2, p = .0139			
	oct 97	march 98	oct 98	Total
<= Median: observed	1.000000	1.00000	6.00000	8.00000
expected	1.142857	3.42857	3.42857	
obs.-exp.	-.142857	-2.42857	2.57143	
> Median: observed	1.000000	5.00000	0.00000	6.00000
expected	.857143	2.57143	2.57143	
obs.-exp.	.142857	2.42857	-2.57143	
Total: observed	2.000000	6.00000	6.00000	14.00000