

**ASSESSMENT OF EPIGEAL ARTHROPODS ALONG AN URBANIZATION
GRADIENT IN THE MUNICIPAL AREA OF POTCHEFSTROOM,
NORTH-WEST PROVINCE, SOUTH AFRICA.**

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Abstract

Human activities have dramatically altered the functioning of ecosystems through the ages. Urbanization illustrates the effect of anthropogenic activity by the transformation of natural areas to ecologically disturbed regions (development of towns, cities and settlements). The growing need for urban employment in South Africa has led to an increase in the number of informal settlements on the periphery of urban areas. These settlements result in fragmentation and sprawling of cities, which intensifies strain on the natural environment. Fragmentation in urban regions then leads to the formation of 'patches' of land which exhibit different disturbance levels and are generally typified as either urban, suburban or rural areas. These land use types may be ecologically studied along an urbanization gradient, with the intention of obtaining meaningful comparisons. An urbanization gradient contains an urban landscape which consists of a densely built and developed core surrounded by an area of decreasing development and increasing 'naturalness'. The use of urbanization gradients has been proven world-wide as a useful tool for the study of changes in ecological patterns and processes across landscapes. This approach has been used to examine many different impacts of urbanization, namely on invertebrate communities, bird community composition and plant community composition. Using biological indicators to determine the degree of anthropogenic impact on the environment has proven effective in past studies. These indicators can be used to monitor ecological change following habitat disturbance, identify changing trends over time, provide early warning systems of degradation and diagnose the cause of existing problems. Several authors have supported the use of arthropods as suitable indicators of disturbance. The aim of this study was to determine what impact disturbance, due to urbanization, may have had on the diversity and abundances of epigeal (surface roaming) arthropods (focussing on ants, beetles and spiders) following an urbanization gradient approach. In addition, plant and soil data were combined with the arthropod analysis for each site studied, in order to obtain a better picture of how arthropod community composition would change in relation to these factors. The ant group were the numerically dominant group of the arthropods studied, although the beetles did have the highest number of species captured. Spiders were caught in low abundances, but were also represented by a high number of species. Dramatic decreasing trends were observed with respect to the ant abundances and diversity from rural to the more urbanized sites. Quite the opposite, seemed to occur with the beetles and spiders, who were dominant in species and numbers in the urbanized areas. This trend may be explained on account of the occurrence of generalists and opportunistic beetle and spider species, which seem to thrive in these heterogenous urban habitats.

When considering environmental components, percentage bare-ground and sand concentration seemed to be the determining factors in the rural sites, around which the ant group aggregated. Sandy habitats with patches of bare-ground provide more favourable micro-habitats for the ant species to roam and scavenge in, and are advantageous for nest building. Clay concentration and abundance of fruit seemed to assist in providing favourable habitats for the opportunistic and generalist beetle species, in the urbanized areas. High clay concentrations in the urban areas provided ideal conditions for abundant organic covering which would favour saprophagous (feed on decaying organic matter) beetle species and support diverse prey for the predatory beetle and spider species to feed on. Abundance of fruit may have attracted numerous herbivorous beetles (frugivorous beetles). Urbanization seemed to have a more pronounced effect on ant diversity and abundances in comparison to the beetles and spiders, and therefore recommended for future utilization as a suitable “Bio-indicator” group for further local disturbance studies.

Keywords: epigeal arthropods, ants, beetles, spiders, urbanization gradient.

Uittreksel

Menslike aktiwiteite het die funksionering van ekosisteme deur die eeue verander. Verstedeliking illustreer die effek wat menslike aktiwiteite bydra tot die transformasie van natuurlike gebiede na ekologies versteurde gebiede (ontwikkeling van dorpe, stede en nedersettings). Die groeiende vraag na werk het daartoe gelei dat groot informele nedersettings op die rand van stede ontwikkel het in Suid-Afrika. Sulke nedersettings lei daartoe dat fragmentasie van die natuurlike omgewing plaasvind waardeur druk op die natuurlike omgewing geplaas word. Fragmentasie bring mee dat gebiede vorm met variërende vlakke van versteuring wat breedweg verdeel kan word in stedelike, sub-stedelike en landelike gebiede. Die verskillende gebiede kan ekologies bestudeer word teen 'n gradient ten einde betekenisvolle vergelykings te tref. Die gradiënt word beskryf as 'n hoogs ontwikkelde stedelike kerngebied wat geleidelik afneem in ontwikkelingstatus en toeneem in natuurlike omgewing. Verstedelikingsgradiënte is 'n goeie instrument in die studie van die veranderinge van ekologiese tendense en prosesse regoor landskappe. So 'n benadering word baie gebruik om die effek van verstedeliking op invertebraat-voël-plantgemeenskappe te illustreer. Biologiese indikatore word gebruik om die graad van menslike invloed op die omgewing te bepaal. Hierdie indikatore besit die vermoë om na habitatsversteuring ekologiese verandering te monitor, veranderende aspekte oor tyd te identifiseer, vroegtydige waarskuwing van degradasie te verleen en om bestaande probleme te diagnoseer. Hierdie aspekte ondersteun die gebruik van invertebrate as biologiese indikatore. Die doel met hierdie studie was om die impak van versteuring te bepaal wat as gevolg van verstedeliking bestaan en die effek daarvan op arthropood-bevolkings te bepaal teen 'n stad-na-landelike omgewings-gradiënt. Daar is slegs na arthropoda gekyk wat op die grondoppervlak beweeg soos miere, spinnekoppe en kewers. Plant-en gronddata word gekombineer met arthropood-analises vir elke studiegebied ten einde 'n beter beeld te verkry oor hoe die bevolkings van gebied tot gebied verskil. Mierbevolkings was die numeries dominante groep van die arthropood-bevolkingsamestelling, hoewel die kewers die hoogste spesiediversiteit gehad het. Spinnekoppe het 'n lae voorkoms vertoon, maar het ook 'n hoë spesiesamestelling gehad. Afnemende tendense is waargeneem in die mierbevolking van stedelike tot landelike gebiede. Die teenoorgestelde is waargeneem in kewerbevolkings asook by die spinnekoppe. Kewers en spinnekoppe was die dominante taksa in stedelike gebiede. Dit kan verduidelik word aan die hand van die voorkoms van opportunistiese spesies wat goed oorleef in heterogene verstedelike gebiede. Dit wil voorkom of persentasie oop grond en sandkonsentrasie bepalende faktore is vir hoë voorkoms van die miërgroep. Sanderige habitats en oop kolle verskaf miere meer ruimte en gunstige geleenthede om te soek na kos asook vir die bou van neste. Kleikonsentrasie en die beskikbaarheid van vrugte en sade bepaal die voorkoms van kewers en skep geskikte mikrohabitate in stedelike gebiede. Hoë kleikonsentrasie in stedelike gebiede bied ideale habitat vir 'n verskeidenheid van organiese bedekking, wat voedsel voorsien aan saprofiete wat op verrottende organiese produkte voed en dit verskaf prooi aan die

predatoriese kewerspesies en spinnekoppe. Voorkoms van vrugte lewer op sy beurt 'n verskeidenheid van herbivoriese (vrugtevreterende) kewers. Verstedeliking het 'n meer drastiese effek op mierdiversiteit en veelheid as op kewers en spinnekoppe. Verdere studie word voorgestel om die beskikbaarheid van geskikte bio-indikatore in versteurde gebiede na te vors.

Sleutelwoorde: Arthropoda (wat op die grondoppervlak beweeg), miere, kewers, spinnekoppe, verstedelikingsgradiënt.

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction: 1

1.1	Increasing urbanization.....	1
1.2	Importance of urban ecosystem studies globally and in South Africa.....	2
1.3	Importance of epigeal arthropod studies in an urban environment.....	3
1.4	Approaches in urban ecosystem studies.....	5
1.5	Study Objective.....	5
1.6	Hypothesis.....	6
1.7	Lay-out of Dissertation.....	6

Chapter 2 Materials and Methods 7

2.1:	Study Area.....	7
2.1.1:	Location.....	7
2.1.2:	History and Development of Potchefstroom.....	7
2.1.3:	Geology.....	7
2.1.4:	Topography.....	8
2.1.5:	Climate.....	8
2.1.6:	Vegetation.....	8
2.2:	Urbanization gradient approach and site characteristics.....	10
2.3:	Data Collected.....	15
2.3.1:	Arthropods.....	15
2.3.2:	Vegetation Survey.....	17
2.3.3:	Soil Survey.....	17
2.4:	Data analysis.....	18

Chapter 3	Results and Discussion	21
3.1	Description of sampled arthropods.....	21
3.2	Urbanization effect on epigeal arthropods.....	21
3.3	Seasonal effect on epigeal arthropods.....	42
3.4	Association between environmental factors and the epigeal arthropods.....	49
 Chapter 4	 Conclusions	 66
 References		 69

List of Tables

Table 2.1: Site characteristics for the different sampling localities of grasslands along an urbanization gradient in the Potchefstroom Municipal area.....	14
Table 2.2: Environmental variables used in the soil study of grasslands along an urbanization gradient in the Potchefstroom Municipal area.....	18
Table 3.1: List of arthropod morphospecies sampled from grasslands along an urbanization gradient in the Potchefstroom Municipal Area.....	20
Table 3.2: Ant Functional Groups (categorized according to the group's response to stress and disturbance; Andersen, 2000) found in grasslands along an urbanization gradient in the Potchefstroom Municipal Area	27
Table 3.3: Beetle families collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area and categorized according to their feeding habits.....	35
Table 3.4: Abbreviations used for epigeal arthropod morphospecies in ordination figures (used in Figures 3.5.2, 3.5.4 and 3.5.6).....	51
Table 3.5: Correlation coefficients for CCA Ordination Triplot in Figure 3.51.....	53
Table 3.6: Correlation coefficients for CCA Ordination Triplot in Figure 3.53.....	58
Table 3.7: Correlation coefficients for CCA Ordination Triplot in Figure 3.55.....	63

List of Figures

Figure 2.1: Biotopes of Potchefstroom. Colours represent biotopes (land use types) (Rost, 2002; Rothig, 2002).....	9
Figure 2.2: Examples of studied grasslands in the Potchefstroom Municipal area.....	9
Figure 2.3: VIS (Vegetation - Impervious surface - Soil) model of Ridd (1995) used to quantify the urbanization gradient in the study of epigeal arthropods in the grasslands of the Potchefstroom Municipal area.....	11
Figure 2.4: Surface classification of vegetation, impervious surfaces and soil according to ArcView for the Potchefstroom Municipal area.....	12
Figure 2.5: Map of Potchefstroom with sampling localities following a gradient indicated in the urban, suburban and rural areas.....	13
Figure 2.6: Trap layout per sampling locality following an urbanization gradient approach in the Potchefstroom Municipal area.....	15
Figure 3.1: Box and Whisker plot of the total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	21
Figure 3.2: Box and Whisker plot of the total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	22
Figure 3.3: Box and Whisker plot of the ant morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	22
Figure 3.4: Box and Whisker plot of the total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	23

Figure 3.5: Box and Whisker plot of the total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February	23
Figure 3.6: Box and Whisker plot of the of ant morphospecies richness (Margelef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	23
Figure 3.7: Box and Whisker plot of total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	24
Figure 3.8: Box and Whisker plot of the total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	24
Figure 3.9: Box and Whisker plot of the of ant morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	24
Figure 3.10: Generalised model of ant community organization, based on functional groups in relation to environmental stress and disturbance (Greenslade, 1978; Andersen, 1990, 1995).	26
Figure 3.11: Total number of functional group ant individuals (as classified in Table 3.3) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal Area for November 2002	29
Figure 3.12: Total number of functional group ant individuals (as classified in Table 3.3) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	29
Figure 3.13: Total number of functional group ant individuals (as classified in Table 3.3) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	30

Figure 3.14: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	30
Figure 3.15: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	31
Figure 3.16: Box and Whisker plot of beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	31
Figure 3.17: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	31
Figure 3.18: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	32
Figure 3.19: Box and Whisker plot of beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	32
Figure 3.20: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	33
Figure 3.21: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	33
Figure 3.22: Box and Whisker plot of beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	33

Figure 3.23: Total number of beetle individuals (categorized according to feeding habits, Table 3.3) collected in grasslands along the urbanization gradient in the Potchefstroom Municipal Area for November 2002.....	36
Figure 3.24: Total number of beetle individuals (as categorized according to feeding habits, Table 3.3) collected in grasslands along the urbanization gradient in the Potchefstroom Municipal Area for February 2003.....	37
Figure 3.25: Total number of beetle individuals (as categorized according to feeding habits, Table 3.4) collected in grasslands along the urbanization gradient in the Potchefstroom Municipal Area for July 2003.....	37
Figure 3.26: Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	38
Figure 3.27: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	38
Figure 3.28: Box and Whisker plot of spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	38
Figure 3.29: Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	39
Figure 3.30: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	39
Figure 3.31: Box and Whisker plot of spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	39

Figure 3.32: : Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.....	40
Figure 3.33: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	40
Figure 3.34: Box and Whisker plot of spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	40
Figure 3.35: Total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	42
Figure 3.36: Total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	42
Figure 3.37: Box and Whisker plot of the total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	43
Figure 3.38: Box and Whisker plot of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	43
Figure 3.39: Box and Whisker plot of ant morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003, July 2003.....	44
Figure 3.40: Total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003, July 2003	45

Figure 3.41: Total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	45
Figure 3.42: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	45
Figure 3.43: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	45
Figure 3.44: Box and Whisker plot of the beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003, July 2003	46
Figure 3.45: Total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	47
Figure 3.46: Total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	47
Figure 3.47: Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	48
Figure 3.48: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	48
Figure 3.49: Box and Whisker plot of spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003	48

Figure 3.50: PCA ordination biplot showing the relationship between environmental factors and the respective axes obtained from grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.....	49
Figure 3.51: CCA ordination triplot showing the relationship between epigeal arthropod groups, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	54
Figure 3.52: CCA ordination triplot showing the relationship between the epigeal arthropod morphospecies, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002	57
Figure 3.53: CCA ordination triplot showing the relationship between epigeal arthropod groups, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003	59
Figure 3.54: CCA ordination triplot showing the relationship between the epigeal arthropod morphospecies, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.....	61
Figure 3.55: CCA ordination triplot showing the relationship between epigeal arthropod groups, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003	64
Figure 3.56: CCA ordination triplot showing the relationship between epigeal arthropod morphospecies, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.....	65

1: Introduction

1.1 Increasing urbanization.

It is estimated that half of the world's human population reside in urban areas, with a predicted 66 % increase in urbanization over the next 25 years (McIntyre *et al.*, 2001). Although only covering less than 5% of the earth's surface, urban regions consume most of the energy available to the earth (Odum, 1997). The amount of energy consumed per unit area by these systems is at least one order of magnitude greater relative to other types of ecosystems (McIntyre *et al.*, 2001), and this impact on the environment is regarded as an 'ecological footprint'. An 'ecological footprint' may impact surrounding biota by changing their diversity due to habitat fragmentation, invasion of exotic species, land-usage change and the eventual alteration of global biogeochemical cycles.

Urbanization is characterized by an increase in the diversity of human habitation, together with extensive modification of the landscape, creating a system that doesn't take the depletion of natural resources into consideration (McDonnell & Pickett, 1990). Urban ecosystems are dramatic manifestations of man's impact on the environment, consisting of a wide array of heterogeneous materials with diverse properties and complex interactions (Ridd, 1995). The urbanization process is regarded by McDonnell & Pickett (1990) as an unplanned experiment, driven by political, economic and cultural decisions, leading to massive conversions of natural environments to highly disturbed man made regions. Urbanization may also be described as the process of converting rural landscape into city or town landscapes (McDonnell *et al.*, 1997; Anthrop, 2000). Alarukka *et al.* (2002) characterized cities and towns as urban areas, exhibiting the following features: a) high human population densities; b) highly developed areas with business, industrial and residential components; c) degradation, alteration, modification and fragmentation of natural habitats (due to anthropogenic disturbances); d) warmer temperatures (2-3°C) than in the surrounding suburban and rural areas (urban heat island effect); e) higher numbers of exotic, invasive, accidental and generalist floral and faunal species. According to Botkin & Beveridge (1997) urban dwellers in a city are exposed to higher concentrations of pollutants (toxic chemicals, airborne particles, noise, etc.) than their rural neighbours. As economic development increases, more people leave the rural areas for the city. In order to help people live in better environments in an increasingly urbanized world, more attention should be focused on the impact of urban areas on natural ecosystems.

A city changes the landscape and therefore the relationship between biological and physical aspects of the environment (Botkin & Beveridge, 1997). The conversion of natural landscapes to modified urban landscapes throughout the world is expected to continue with many of these urbanized regions becoming even more modified (Alig & Healy, 1987; Richards, 1990; Douglas, 1994). This large-scale modification of the

environment due to high human density in urban areas is collectively categorized as urban land use (Godron & Forman, 1983; Roodman, 1996). Rural environments, at the other end of the land-use spectrum, are sparsely populated with humans and consequently exhibit less built-on land and lower concentrations of used energy, materials, water and waste products (Godron & Forman, 1983).

1.2 Importance of urban ecosystem studies globally and in South Africa.

A great need for more comprehensive studies on ecological impacts of urbanization exists (Brown & Roughgarden, 1989; Rogers, 1994; Penner, 1994). Ecologists have historically been reluctant to study urban ecological systems because they were perceived as 'unnatural' and containing many research problems (Cairns, 1987; Ludwig, 1989; McDonnell & Pickett, 1990; Botkin, 1990). Unfortunately, this occurred during a period when managers, scientists, legislators and the general public already critically needed ecological information concerning urban areas (McDonnell *et al.*, 1997).

The growing need for urban employment in South Africa has led to an unprecedented increase in the number of squatters and informal settlements on the periphery of urban areas. These informal settlements together with sub-urbanization, have resulted in fragmentation and sprawling of cities, thereby intensifying strain on the natural environment. Fragmentation in urban regions has led to the formation of 'patches' of land, exhibiting different disturbance levels and generally classified as either urban, suburban or rural areas. These land-use types may be ecologically compared and studied along a gradient, with the intention of obtaining meaningful comparisons. Niemelä *et al.* (2000) defined such a gradient as an urban landscape consisting of a densely built and developed core surrounded by an area of decreasing development and increasing 'naturalness'.

A disturbance gradient from urban through suburban to rural environments is an effective tool for studying the effects of urbanization on ecological systems as proven in previous studies (McDonnell & Pickett, 1990; McDonnell *et al.*, 1997; Niemelä *et al.*, 2000; Hahs & McDonnell, 2006). Examples of these gradient studies in urban areas include the study of arthropod (McIntyre *et al.*, 2001; Niemelä *et al.*, 2002; Vepsäläinen & Wuorenrinne, 1978, Chudzicka & Skibinska, 1998; Miyashita *et al.*, 1998; Blair, 1999 and Gibbs & Stanton, 2001), bird (Blair, 1996; Millsap & Bear, 2000 and Mortberg, 2001), plant (Tonteri & Haila, 1990; Guntenspergen & Levenson, 1997; McDonnell *et al.*, 1997; Kostel-Hughes *et al.*, 1998) and reptile communities (Germaine & Wakeling, 2001); forest ecosystems (McDonnell & Pickett, 1997), leaf litter decomposition and nutrient cycling (Pouyat *et al.*, 1997; Carreiro *et al.*, 1999; Pavao-Zuckerman & Coleman, 2005), pollution (Callender & Rice, 2000; Lovett *et al.*, 2000; Gingrich & Diamond, 2001), water quality (Wear *et al.*, 1998) and the structure of landscape elements (Medley *et al.*, 1995; Luck & Wu, 2002; Zhang *et al.*, 2004). Many of these studies, showed varying species responses to the effects of the urbanization at

community levels (McDonnell & Pickett, 1990; Niemelä, 1999). Some species showed favourable responses to urbanization, thriving in urban environments, while others avoided cities (Alaruikka *et al.*, 2002). Modified habitats almost always create new havens for exotic and generalist species, while native and specialist species may react negatively and disappear altogether from these areas (Eversham *et al.*, 1996; Chudzicka & Skibinska, 1998).

The use of gradient analysis techniques provides a context to integrate humans as critical components affecting ecosystems, as well as addressing both ecological questions and practical environmental problems facing urban areas (McDonnell *et al.*, 1993). Quantification of changes in ecosystem structure and function in relationship to urbanization levels (gradient paradigm) could provide a better understanding of urban impacts on ecosystems, assisting scientists in developing new research questions and management strategies (McDonnell *et al.*, 1997). The characterization of urbanization gradients seems a difficult task with regard to South African cities, as zonation of local cities differs from international ones (European cities with older, more established developmental patterns). Urban-rural gradients do however seem similar globally, with only a difference in the type of ecosystem involved. World-wide gradient studies involving anthropogenic induced landscape changes could be compared, with the intention of identifying generalities in community structures. An international database, of such a nature, already exists, namely, GLOBENET, which started in 1998 at the Helsinki University, Finland (Niemelä *et al.*, 2000). Ecological data gathered from gradient studies using carabid beetles can be accessed, and global recurring patterns identified (Niemelä *et al.*, 2000). The knowledge obtained through this database could ensure international collaboration among researchers and managers with the objective of decreasing adverse effects of anthropogenic impacts and the implementation of essential conservation policies.

1.3 Importance of epigeal arthropod studies in an urban environment.

Human disturbance, although seen as ecologically hazardous, can create new favourable conditions for species (Davis, 1978), as in the case of insects, which may be species rich in some urban environments (Lehvävirta *et al.*, 2006). These urban environments or green areas (gardens and parks) are highly fragmented, leading to 'isolation and edge effects' which could affect insect populations (Murcia, 1995; Risser, 1995) and cause changes in species composition of specific taxa, such as carabid beetles (Halme & Niemelä, 1993; Thacker, 1996; Magura *et al.*, 2001 and Koivula *et al.*, 2002). Carabids have often been studied and proposed to be used as indicators of the biotic effects of urbanization (Niemelä *et al.*, 2002 and Rainio & Niemelä, 2003). However, studies have shown that even though differences in carabid assemblages were found along different levels of disturbance in urban forests, carabids may not be the best indicators of urban stress as previously anticipated. This observation could be attributed to urban environments not being suitable for specialist species (Lehvävirta *et al.*, 2006). The specialist species are usually the first to suffer

from human disturbance, fragmentation and habitat isolation (Koivula *et al.*, 2002; Kotze & O'Hara, 2003 and Rainio & Niemelä, 2003).

In addition to fragmentation and habitat isolation, intensive recreational use leading to 'human trampling' are also characteristic of urban green spaces (Lehvävirta *et al.*, 2006). Recent urban woodland studies show that the effects of human trampling include aspects such as paths, reduced groundcover and eroded areas (Rudnický & McDonnell, 1989; Liddle, 1997; Lehvävirta, 1999; Florgard, 2000; Grandchamp *et al.*, 2000; Lehvävirta & Rita, 2002; Malmivaara *et al.*, 2002). Trampling alters rates of litter decomposition and soil nitrogen mineralization (Pouyat *et al.*, 1997), affecting a whole ecosystem. Insect fauna compositions may change as a result of trampling; as in a South African game park study, where large mammals were the most important factor influencing epigeal arthropod assemblages (Rivers-Moore & Samways, 1996); and in another survey where the number of invertebrates in grassland litter declined with increased human trampling (Duffey, 1975). Although ecological effects of trampling are assumed significant in urban green areas, little is known about the impacts on taxonomic groups other than plants. Lehvävirta *et al.* (2006) encouraged further studies on different insect groups pertaining to the effects of trampling.

Epigeal insect fauna are described as potential indicator taxa of environmental changes (Gandhi *et al.*, 2001; Rainio & Niemelä, 2003) and have shown to respond significantly to habitat edges and patch size differences (Didham *et al.*, 1998; Magura *et al.*, 2001). McIntyre *et al.* (2001) further supported the use of epigeal arthropods in urban studies, for the following reasons: (1) the variety of roles played by this group in ecosystem functioning, including nutrient cycling, food web dynamics and pollination, (2) large sample sizes which can be obtained from this group due to their high abundance, (3) arthropods have short generation periods causing them to respond quickly to the environmental impact, and (4) the importance of conserving this group due to their rapid decline in abundance and diversity as a result of change in their habitat. These animals are also said to be well suited as biological indicators of human disturbance due to the specialized niches they occupy and the sensitivity of such micro-habitats to environmental change. However, little is known on how exactly arthropods respond to anthropogenic impacts, encouraging further studies and to better understand how their diversity is affected by urbanization (McIntyre *et al.*, 2000). Once this understanding is acquired, a framework for sustainable management of disturbed habitats can be developed (Grandchamp *et al.*, 2000). It seems possible to evaluate anthropogenic impacts on the environment following a disturbance gradient with data obtained from studies involving 'biological indicators' (Andersen, 1997a). Trends that change over time could be monitored, providing an early warning system to degradation and diagnosis of the cause of existing problems (Cairns, 1995).

1.4 Approaches in urban ecosystem studies

Urban ecological studies have received more attention in recent years due to the exponential increase in urban development. Knowledge on how these ecosystems function is urgently needed. Long Term Ecological Research (LTER) Programmes have been developed in the USA, integrating social and ecological approaches with the intention to develop a better understanding of anthropogenic impacts on natural ecosystems. This research could then raise understanding concerning urban ecology by developing realistic models for 'unnatural systems' and eventually providing solutions to environmental problems. The basic framework of the programme considers the inclusion of man's interactions at different levels in a spatial context and not over time (McDonnell *et al.*, 1997). The measure of urbanization in space is therefore the distance from the urban core to the more 'natural' rural regions (McDonnell *et al.*, 1997). A local survey was started in 2002 for the city of Potchefstroom with similar aims to that of the LTER Programme of the USA. This assessment took a multidisciplinary approach, analyzing different biota such as plants, birds and arthropod communities along an urbanization gradient (Cilliers *et al.*, 2004). The ecological data acquired from such studies may be useful in planning future urban developments for Potchefstroom and minimizing future environmental impacts.

According to Lehvävirta *et al.* (2006) the small number of ecological studies completed in urban environments must lead to more intensive efforts to (1) develop an appropriate theoretical framework for urban ecology (Niemelä, 2000), (2) evaluate the impact of humans in highly altered urban environments, and (3) to study more than one taxonomic group in order to determine the indicator properties of different taxa (Rainio & Niemelä, 2003).

1.5 Study Objective

The main objective of this study was to determine the epigeal arthropod species diversity collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area. It was also determined whether environmental aspects such as seasonal influence, soil (physical and chemical) characteristics and the vegetation of the area could be associated with and have an effect on this arthropod group's diversity. Further, an assessment was made of which group of biota, namely ants, beetles and spiders would be the most effective indicators of habitat disturbance following an urbanization gradient in local conditions.

1.6 Hypothesis

Human disturbance resulting from urbanization will have an impact on the composition and diversity of the arthropod communities, on account of the specialized niches that these animals occupy as well as their sensitivity to environmental change.

1.7 Lay-out of dissertation

- **Introduction:** Literature overview of why the study is necessary. This chapter includes the study objective and hypothesis.
- **Materials & Methods:** Provides a description of the area studied, approaches followed in the collection of the arthropod specimens and procedures used for data accumulation, analysis and interpretation.
- **Results & Discussion:** Provides a description of the arthropod morphospecies that were collected and a discussion on the effect of the urbanization gradient, seasonal influence and environmental factors on the diversity of this group and whether associations between these different components do occur.
- **Conclusions:** Explains whether the study objective and hypothesis were reached and provides recommendations for future studies of a similar nature.
- **References**

2: Materials and Methods

2.1 Study Area

2.1.1 Location

This study was conducted in the municipal area of Potchefstroom (situated between 27°00' and 27°07'E longitude, 26°40' and 26°44'S latitude at an altitude of 1350m) in the North-West Province, South Africa, for the period November 2002 to July 2003.

2.1.2 History and Development of Potchefstroom:

Potchefstroom, regarded as the first settlement north of the Vaal River, was founded in 1838 by Andries Hendrik Potgieter on the banks of the Mooi River. This river has received consistent attention over the years and is considered as an important green belt area today (Bawcombe & Kuijers, 1988). Potchefstroom has been an important centre since its inception. Initially considered as a religious, governmental centre and military base, it later developed into a flourishing educational; sports-recreation centre and industrial region (Bawcombe & Kuijers, 1988). With a population of +/- 400 000, this area is made up of Potchefstroom City (formerly White area), Ikageng (previously a Black residential area established in 1954), a number of informal black settlements, Promosa (formerly a Coloured area established in 1959) and Mohadin (previously an Indian area established in 1971) (Prinsloo, 1988).

2.1.3 Geology:

The rock types in the Potchefstroom are classified into three groups, namely the Wolkberg, Chuniespoort and Pretoria Groups (SACS, 1980). The dominant rock type found in the area is from the Pretoria Group of the Transvaal Sequence. This Group is mainly made up of quartzite, shale and prominent volcanic elements in the Hekpoort Andesite Formation, as well as diabase sills that intrude into the Strubenkop shale (Nel *et al.*, 1939; SACS, 1980).

2.1.4 Topography:

The Potchefstroom area forms part of the Central Interior Plain with the landscape varying from flat to undulating plains (Kruger, 1983). The undulating plains and ridges are only observable in the natural regions of the city because urbanization had reshaped the original landscape in the urban areas. Craul (1985) described such modification of topography as ‘man-made’ land.

2.1.5 Climate:

South Africa is divided into 15 climatic zones with Potchefstroom situated in the Highveld area (Weather Bureau, 1988). This area has a precarious, warm, temperate to semi-dry climate in a summer rainfall region. Climatic contrasts between summer and winter are normal with extreme conditions like drought, flooding, hail, frost and rare snow occurring (Weather Bureau, 1988). The mean annual rainfall in this region is 610 mm.

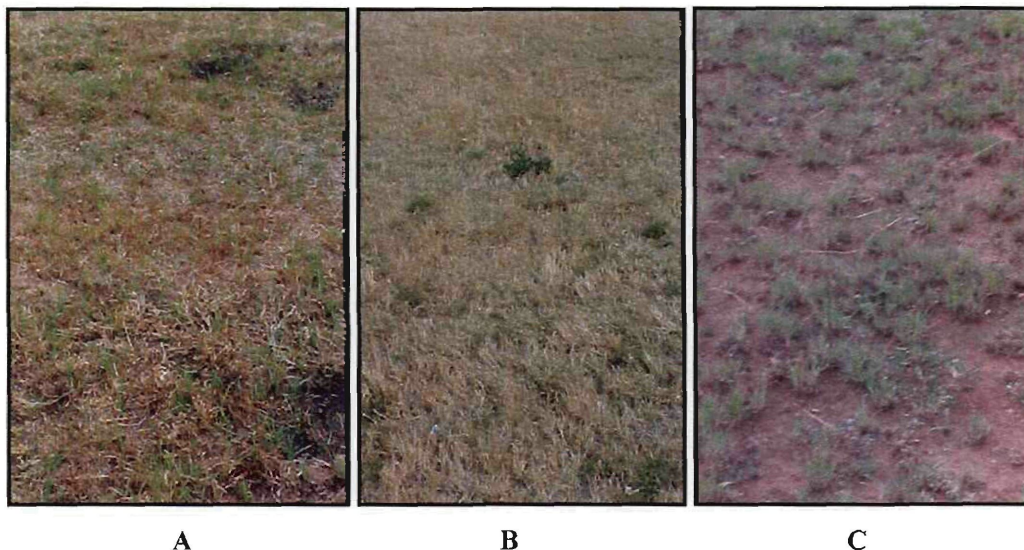
2.1.6 Vegetation:

Potchefstroom is located in the Dry Sandy Highveld Grassland of the Grassland Biome (Rutherford & Westfall, 1994 and Bredenkamp & Van Rooyen, 1996). Grasslands in general have a poor conservation status, with only small concentrations of natural vegetation still remaining, often as a result of overgrazing (Bredenkamp & Van Rooyen, 1996). The Grassland Biome is considered to have an extremely high biodiversity. In an attempt to map the Vegetation of South Africa (VEGMAP), three vegetation types can be recognized in the Potchefstroom Municipal Area, namely the Carletonville Dolomite Grassland, Rand Highveld Grassland and Andesite Mountain Bushveld (Mucina & Rutherford, 2006). Recently, the importance of urban vegetation studies has been realised and this has lead to the development of a comprehensive research programme on urban open spaces in cities in the North West Province of South Africa (Cilliers, 1998). Different land use types (urban, suburban, rural) were selected for this project according to a classification system called “biotope mapping” (Cilliers *et al.*, 2004). Different biotopes (e.g. managed green spaces, natural and semi-natural areas, industrial areas etc.) have already been identified for Potchefstroom (Rost, 2002; Röthig, 2002) (Figure 2.1).



Major Biotopes	Colour
Central City (commercial / residential)	Pink
CBD	Red
Managed green spaces	Light green
Natural and semi-natural areas	Dark green
Industrial areas	Brown
Surface Water (rivers, dam)	Blue

Figure 2.1: Biotopes of Potchefstroom. Colours represent different biotopes (land use types) (Rost, 2002; Röthig, 2002).



A

B

C

Figure 2.2: Examples of studied grasslands in the Potchefstroom Municipal area:

A - Urban Site (February 2003)

B - Suburban Site (February 2003)

C - Rural Site (February 2003)

2.2 Urbanization gradient approach and site characteristics:

An urbanization gradient approach was used in this study. According to McDonnell & Pickett (1990), the gradient paradigm can be summarized as the view that environmental variation is ordered in space, and that spatial environmental patterns govern the corresponding structure and function of ecological systems, be they populations, communities or ecosystems. The urban-rural gradient approach can therefore be used to investigate how urbanization is changing the ecological patterns and processes across the landscape. According to Hahs & McDonnell (2006), urbanization created complex non-linear gradients, and therefore transects being put out along the urbanization gradient would not necessarily give an accurate representation of gradients in the urban landscape, because transects are highly dependent upon their placements. Hahs & McDonnell (2006) suggested that multi-dimensional non-linear methods should be used to ensure a more accurate representation of gradients in urban areas. They further proposed that the urban-rural gradient needed to be quantified for the purpose of comparing different ecological studies. According to them there are several different measures of urbanization which include the use of three main variable groups, namely demographic variables (e.g. density of people, density of dwellings, number of people per unit urban land-cover), physical variables (e.g. road density, fraction of impervious surface, distance to Central Business District) and landscape metrics (e.g. mean patch size, dominant land-cover, number of patches). Hahs & McDonnell (2006) objectively selected a subset of measures to represent urbanization from a larger group of commonly used measures, but mentioned that the applicability of those measures need to be tested for other landscapes. Due to time constraints and unavailability of some of the measures, Hahs & McDonnell's approach was not tested in this study. Physical measures were used to quantify the urbanization gradient, in the form of the Vegetation - Impervious surface - Soil (V-I-S) model of Ridd (1995). According to Ridd (1995), the combination of impervious surface material, green vegetation and exposed soil are the most fundamental components of the urban ecosystem, in terms of contrast to the surrounding environment as well as contrast within the city. For this method of quantification, remote sensing is used to classify different study sites into urban or rural areas. Remote sensing divides the Earth's surface into remote sensing lineage pixels. By classifying the image pixels into vegetation, impervious surface or soil, the degree of urbanness can be determined.

In the V-I-S model (Ridd, 1995) (Figure 2.3) the Soil –Vegetation ($S - V$) axis represents land that is not yet urbanized, or urban land undergoing change. There is little or no impervious surfaces in non-urban or pre-urban environments. The Vegetation –Impervious ($V - I$) axis represents a typical residential sequence. The traditional commercial and industrial areas lie on the Impervious-Soil ($I - S$) axis.

For this study 12 sampling sites of grasslands were selected covering all four wind directions from the city centre (Figure 2.4). Sites were subjectively selected based on soil and vegetation type (clayey grasslands) to

ensure that those sites are comparable. Aerial photographs were then used to determine the degree of urbanness of each study site (Phinn *et al.*, 2002). An area of 0.5 km x 0.5 km around each study site was used to determine the urbanness (Figure 2.3). Using the aerial photograph of Potchefstroom and ArcView, each 0.5km x 0.5km square was divided into vegetation, impervious surfaces and soil. The specific surfaces used in ArcView to classify vegetation, impervious surfaces and soil are in Figure 2.4.

According to the percentage impervious surface and vegetation cover it was easy to distinguish between the rural and urban study sites (Figure 2.4) There was however, a gradual transition from the urban to the suburban study sites with respect to percentage impervious surface and vegetation cover. The rural study sites were those with a vegetation cover of 96-100 % and a impervious surface cover of 0-2 %, the suburban study sites were represented by a vegetation cover of 47-52 % and a impervious surface of 46-49%, the urban study sites were represented by sites with a vegetation cover of 5-36 % and an impervious cover of 61-95 % (Table 2.1).

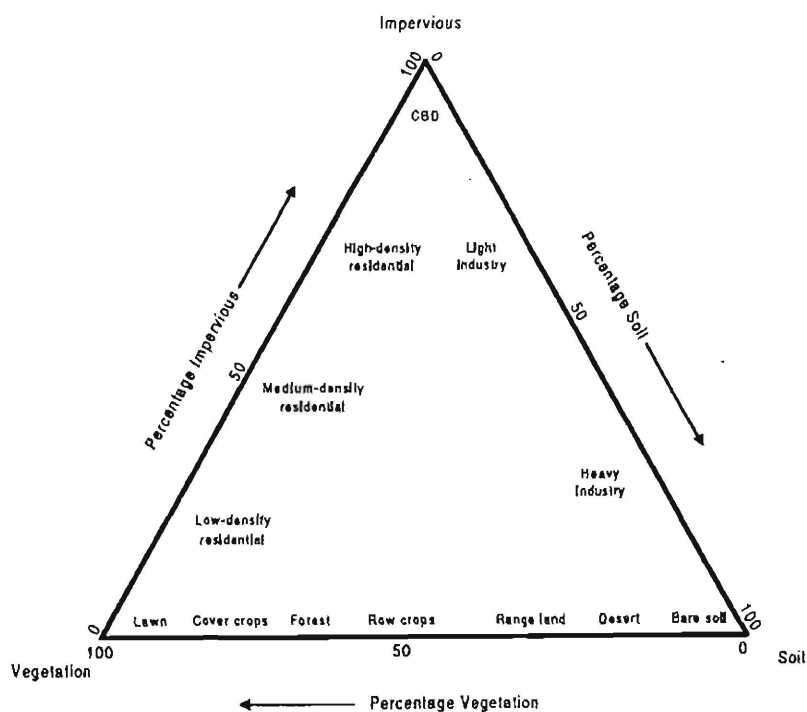


Figure 2.3: VIS (Vegetation - Impervious surface - Soil) model of Ridd (1995) used to quantify the urbanization gradient in the study of epigeal arthropods in the grasslands of the Potchefstroom Municipal Area.

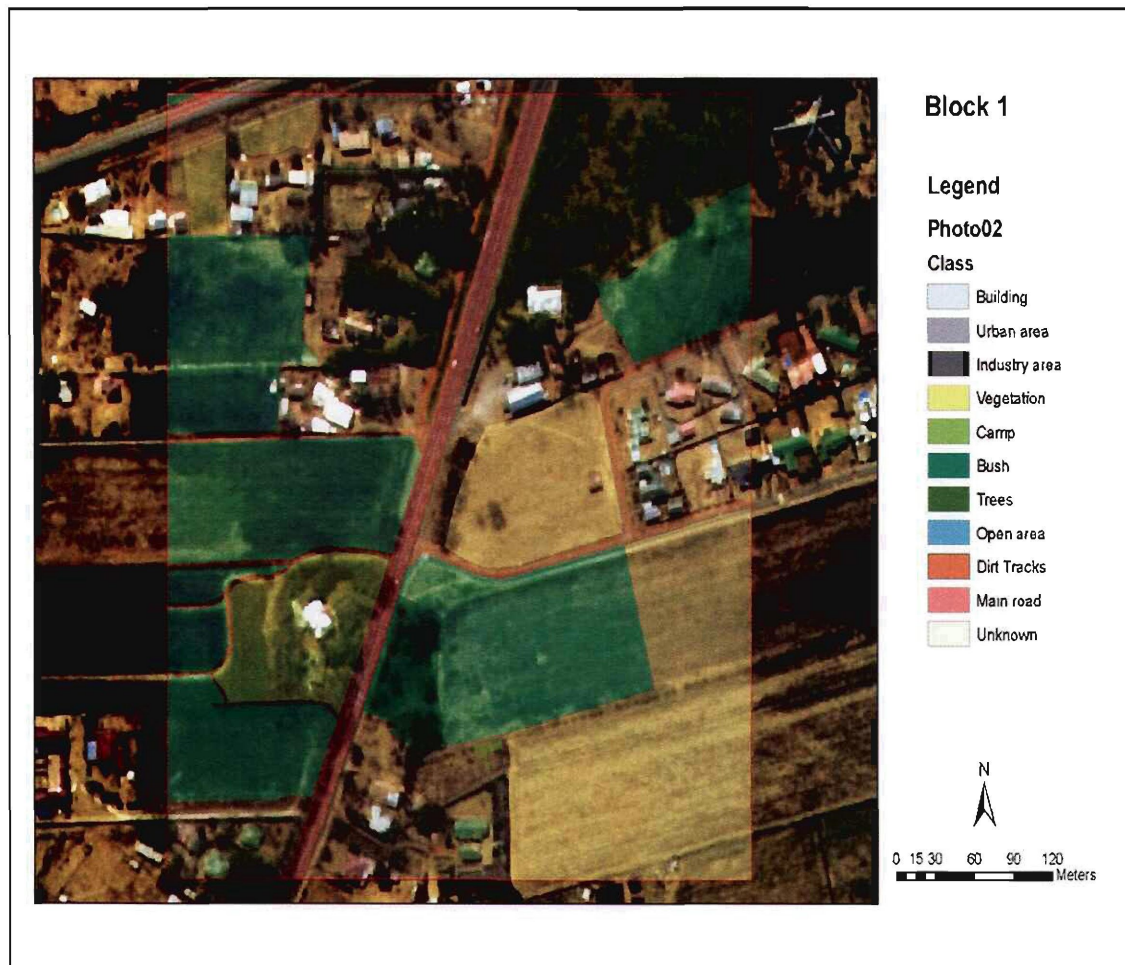


Figure 2.4: Surface classification of vegetation, impervious surfaces and soil according to ArcView for the Potchefstroom Municipal area.

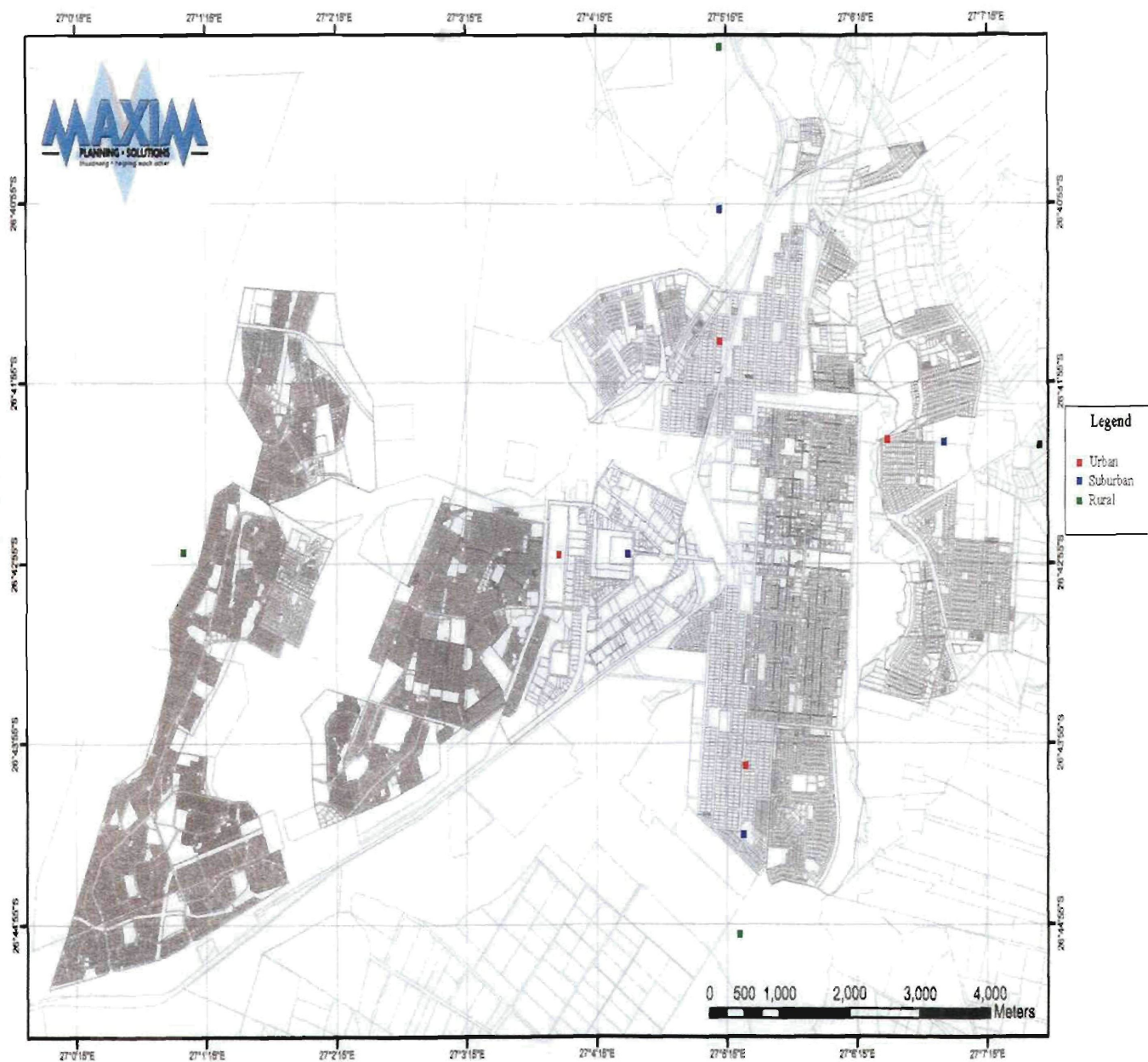


Figure 2.5: Map of Potchefstroom with sampling localities following a gradient indicated in the urban, suburban and rural areas.

Table 2.1: Site characteristics for the different sampling localities of grasslands along an urbanization gradient in the Potchefstroom Municipal area.

Sampling localities	Symbols	Co-ordinates	%Vegetation	%Impervious Surface	% Soil
Northern Urban	UN	26 41.682 S 27 05.639 E	36	61	3
Eastern Urban	UE	26 42.040 S 27 05.713 E	33	65	2
Western Urban	UW	26 42.751 S 27 03.843 E	32	67	1
Southern Urban	US	26 43.735 S 27 05.784 E	5	95	0
Northern Suburban	SN	26 40.843 S 27 06.242 E	50	49	1
Eastern Suburban	SE	26 42.052 S 27 06.156 E	52	46	2
Western Suburban	SW	26 42.839 S 27 04.170 E	48	48	4
Southern Suburban	SS	26 44.589 S 27 05.558 E	47	48	5
Northern Rural	RN	26 35.290 S 27 07.081 E	96	2	2
Eastern Rural	RE	26 39.929 S 27 11.347 E	100	0	0
Western Rural	RW	26 41.611 S 27 01.049 E	100	0	0
Southern Rural	RS	26 46.396 S 27 06.05 E	100	0	0

Sampling Period:

Sampling or collection of arthropod, vegetation and soil data occurred during November 2002, February 2003 and July 2003 (representatives of summer and winter months).

Sampling Locality Lay-out:

For each sampling locality, 3 transects were layed out approximately 50 meters apart in accordance to Alarukka *et al.* (2002). Within each transect, 3 traps were placed out 4 meters apart. In highly urbanized regions, 4 traps per transect were provided with consideration to 'human tampering'.

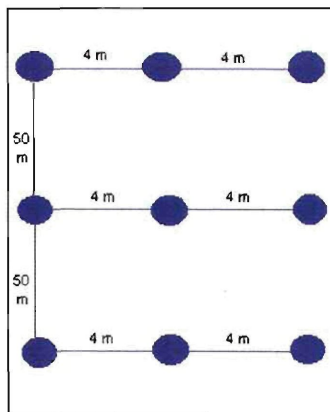


Figure 2.6: Trap layout per sampling locality following an urbanization gradient approach in the Potchefstroom Municipal area.

2.3. Data Collection

2.3.1. Arthropods

2.3.1.1 Pitfall Trapping:

The advantages of pitfall trapping are that traps are simple and effective to use, require little field work, sample continuously throughout day and night and don't require field identification. The disadvantages are that catches vary with habitat structure on the ground and with the locomotory behaviour of species (Andersen, 1997b). Pitfall trapping has been successfully used as a sampling technique in previous disturbance studies (Greenslade, 1973; Majer, 1978; Andersen, 1991).

Two methods of collecting soil arthropods are discussed by Andre *et al.* (2002) namely:

- (1) The direct method: Where animals are physically separated from the soil by an apparatus.
- (2) Indirect method: Depends on the movement of the organisms towards the trapping device.

For this study the indirect method of 'pitfall trapping' was utilised. This technique involved the following:

- A soil auger was used to bore holes into the soil of the sampling area.
- 250ml plastic bottles with screw top lids removed, were then positioned into holes flush with the ground surface (same technique used in the studies of Andersen, 1997b; Grandchamp *et al.*, 2000; Alaruikka *et al.*, 2002).
- A 40% ethanol solution (used as a trapping, killing and preserving liquid for the fauna) was added until each container was half full (same procedure followed in the study of Lehvävirta *et al.*, 2006).
- Fine soil was then re-introduced around the rim of each bottle with the use of a spade in order to create a natural 'roaming' environment for the soil fauna.
- Sampling period from activation of traps to collection was 48 hours (similar to procedure followed in the study of Andersen, 1997b).
- On collection, individual containers were removed, filled to the top with 70% ethanol and labelled (similar to the procedure followed in the study of Lehvävirta *et al.*, 2006). The information on each label consisted of a location code and the date of collection. Each container was then sealed tightly for further preservation and transported to the laboratory.
- When opened at the laboratory, the contents of each sample bottle were carefully decanted into Petri-dishes. Sorting and examination through material proceeded by using a Zeiss Stemi DV4 Zoom stereo-microscope.
- Arthropod morphospecies numbers from all sample containers were recorded on data sheets.
- Specimens from the selected groups (namely ants, beetles and spiders) were sent to the Department of Agriculture's National Insect and Arachnological collections in Pretoria, South Africa for further examination. Identifications where possible were made to either family, sub-family, genus and species level. The specimens that could not be identified by the Specialists to species level were categorized into morphospecies.
- Data was entered into a spread sheet (as seen in Appendix A, B and C) and analysed using Primer and Statistica 7 software packages.
- Species abundance's and diversity were compared along the urbanization gradient and for the respective seasons using Kruskal-Wallis ANOVAs (in accordance to Grandchamp *et al.*, 2000; Alaruikka *et al.*, 2002).

It was necessary to practise trial runs before the real sampling took place in order to refine techniques, manage time efficiently and deal with unforeseen circumstances.

2.3.2: Vegetation Survey

The following vegetation characteristics were recorded for each sampling locality:

- Percentage vegetation cover.
- Percentage bare ground.
- Percentage organic matter.
- Percentage rockiness.
- Average forb height.
- Average grass height.
- Percentage indigenous plant species.
- Percentage species in bloom
- Percentage species with fruit.

2.3.3: Soil Survey

Both physical and chemical analysis of soil were incorporated in this study. Compound soil samples of approximately 500g were taken at a depth of 300mm. A soil analysis method described by Van Rensburg *et al.* (1998) was utilised and the following environmental variables (Table 2.2) emphasized.

Table 2.2: Environmental variables used in the soil study of grasslands along an urbanization gradient in the Potchefstroom Municipal area

Environmental variables:	Types:
Exchangeable ions	Ca, Mg, K, Na, CEC, Base Saturation
Nutrient status	Ca, Mg, K, Na, P, pH (KCl)
Heavy metals	Pb, Cr, Cd, As, Se, B, Mn, Cu, Zn
Particle size distribution	> 2mm, Sand, Silt, Clay
1:2 Extract	Total N percentage, Walkley-Black analysis

2.4: Data analysis

To test the statistical significance of any changes in abundance, species richness or community structure of the three epigeal arthropod groups studied, two methods were applied. First, analysis of variance (Kruskal-Wallis ANOVA) in accordance to Grandchamp *et al.* (2000) and Alarukka *et al.* (2002) was utilised to assess changes in the arthropod abundances and diversity (Margalef indices used). Secondly, multivariate analysis incorporating the arthropod, vegetation and soil data were analysed with CANOCO (Canonical Correspondence Analysis programme) using several ordination techniques (Ter Braak, 1992). Ordination is the arrangement of the arthropod, vegetation and soil data in relation to each other in terms of their similarity of species composition and their associated environmental controls (Kent & Coker, 2000), and may therefore be used in gradient analysis. Ordination techniques used, included Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA). PCA's are widely used to synthesize environmental data and is according to Kent & Coker (2000) one of the best methods of analysis in this regard. In PCA's, two variables are compared or ordinated together (Bi-plots), where as in CCA'S, three variables are ordinated for comparison (Tri-plot). According to Ter Braak & Verdonschot (1995) a CCA ordination triplot diagram can consist of points representing Species and Sampling sites and arrows for quantitative Environmental variables. Each Species point in the diagram is positioned to represent the average of the Sampling site points in which it occurs. The quantitative value for each environmental variable is represented by individual arrows. The length of each arrow indicates the correlation of the variables with the ordination axes. Four possible alternatives exist explaining the type of abundances that can occur in a CCA diagram, namely,

- **Centroid principle:** States that species are at the centre of their niche habitat and therefore sampling sites that contain a particular species are scattered around that point. This means that sampling sites close to the species point tend to have a higher abundance of that species than sites further away from that species point.
- **Distance rule:** The abundance of a species is greatest when the sampling site point coincides with the species point and decreases in all directions from the site point.
- **Biplot rule:** States that an arrow representing a environmental variable, points in the direction of maximum change for the associated variable and that the arrow length is proportional to this

maximum rate of change. Variables with short arrows don't vary much across the diagram. In a perpendicular direction the variable does not change in value. The origin (0,0) indicates the mean of the variable when considering the ranking the projected points. For environmental variables the origin also indicates a zero correlation.

- **Sign of the correlation coefficients:** represents an alternative qualitative rule of interpretation between variables. The importance of defined gradients can be interpreted by the magnitude of the eigenvalue (an eigenvalue > 0.3 indicates a strong gradient).

The CANOCO-programme allows quick determinations of how community composition varies with the environment using correlation co-efficients to analyse the data (Ter Braak & Smilauer, 1998). Abbott *et al.* (2003) used a similar statistical approach in their study of the impacts of logging and burning on arthropod diversity and abundances in a forest in Western Australia.

Table 3.1: List of arthropod morphospecies sampled from grasslands along an urbanization gradient in the Potchefstroom Municipal Area

Acari:		Coleoptera:		Collembola:	
	Mesostigmata (diverse)		Staphylinidae sp.1		Poduroidae (diverse)
	Metastigmata (diverse)		Staphylinidae sp.2		Entomobryidae (diverse)
	Prostigmata (diverse)		<i>Anthicus</i> sp.1 (Anthicidae)		Sminthuridae (diverse)
			<i>Anthicus</i> sp.2 (Anthicidae)		
Araneae:			<i>Formicomus</i> sp.1 (Anthicidae)	Hymenoptera (Formicidae):	
	Salticidae sp.1		<i>Heterodera</i> sp.1 (Chrysomelidae)		<i>Anoplolepis custodiens</i>
	Salticidae sp.2		Chrysomelidae sp.1		<i>Anoplolepis</i> sp.2
	Salticidae sp.3		Chrysomelidae sp.2		<i>Camponotus</i> sp.1
	Lycosidae sp.1		<i>Baris</i> sp.1 (Curculionidae)		<i>Pheidole</i> sp.1
	Gnaphosidae sp.1		<i>Gronops</i> sp.1 (Curculionidae)		<i>Monomorium fastidium</i>
	Gnaphosidae sp.2		<i>Protostrophus</i> sp.1 (Curculionidae)		<i>Monomorium</i> sp.2
	Philodromidae sp.1		Curculionidae sp.1		<i>Monomorium</i> sp.3
	<i>Osteanus melanopygius</i> (Linyphiidae)		<i>Heteronychus arator</i> (Scarabaeidae)		<i>Tetramorium</i> sp.1
	<i>Palfuria</i> sp.1 (Zodariidae)		<i>Onthophagus</i> sp.1 (Scarabaeidae)		<i>Lepisiota</i> sp.1
	<i>Apochinomma</i> sp.1 (Corinnidae)		Scarabaeidae sp.1		<i>Lepisiota</i> sp.2
	Araneae unidentified sp.1		<i>Saprinus</i> sp.1 (Histeridae)		<i>Meranoplus</i> sp.1
	Araneae unidentified sp.2		Histeridae sp.1		Formicidae unidentified sp.1
	Araneae unidentified sp.3		<i>Brachinus</i> sp.1 (Carabidae)		
	Araneae juvenile sp.1		Carabidae sp.1		
			Carabidae sp.2		
			Dermestidae sp.1		
			<i>Gonocephalum</i> sp.1 (Tenebrionidae)		
			Cucujoidae sp.1		
			Aphodidae sp.1		
			Coleoptera sp.1		
			Coleoptera unidentified sp.1		

3: Results and Discussion

3.1 Description of sampled arthropods:

The sampled arthropods were sorted and grouped into morphospecies which formed part and represented large groups such as ants; beetles; spiders; wasps and flies, springtails; mites; grasshoppers and crickets and termites. From these morphospecies, a selection of surface roaming (epigeal) arthropods, namely; ants (Hymenoptera: Formicidae); beetles (Coleoptera) and spiders (Araneae) were used for the urbanization, seasonal and environmental analysis (collected morphospecies listed in Table 3.1). A total of 3452 individuals, represented by 12 morphospecies were collected for the ants; 417 individuals represented by 26 morphospecies for the beetles; and 135 individuals represented by 14 morphospecies collected for the spiders.

3.2 Urbanization effect on epigeal arthropods

3.2.1 Ants:

In the November analysis (Figures 3.1 - 3.3) no statistical significant differences occurred between ant abundances, morphospecies diversity and the different land use types. A defined trend was however observable where large species abundances and diversity occurred in the less disturbed, natural rural areas and further decreased, the more urbanized the sites became.

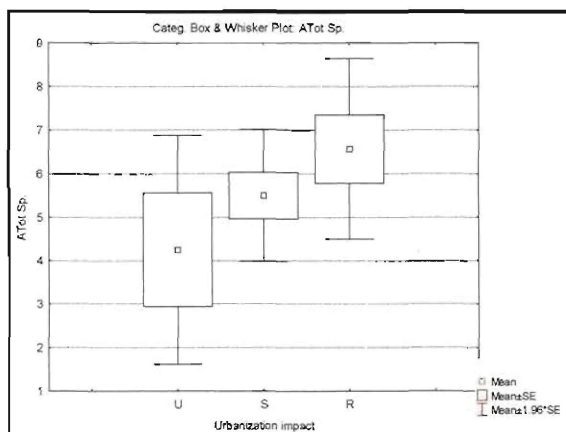


Figure 3.1: Box and Whisker plot of the total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

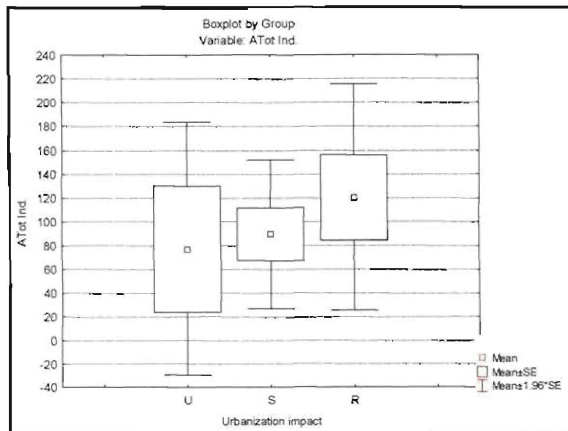


Figure 3.2: Box and Whisker plot of the total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

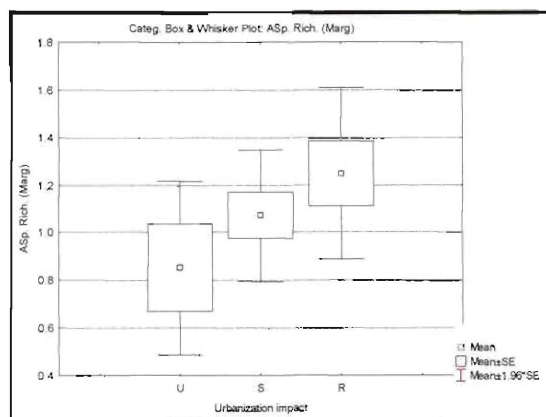


Figure 3.3: Box and Whisker plot of the ant morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

For the February analysis, again a trend was observable where ant abundances and diversity were high in the rural areas and lower in the more urbanized areas. Total number of ant morphospecies (Figure 3.4) in the rural sites differed statistically significant from those in the urban ($p= 0.000865$) and suburban sites ($p= 0.001554$). Total number of ant individuals (Figure 3.5) in the rural sites showed statistically significant differences from the urban ($p= 0.048595$) and suburban sites ($p= 0.005459$). Ant morphospecies richness (Figure 3.6) in the rural sites differed statistically significant from the urban ($p= 0.014500$) and suburban sites ($p= 0.045609$).

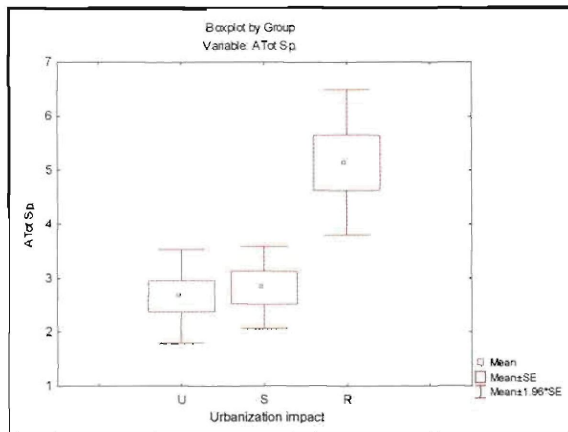


Figure 3.4: Box and Whisker plot of the total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

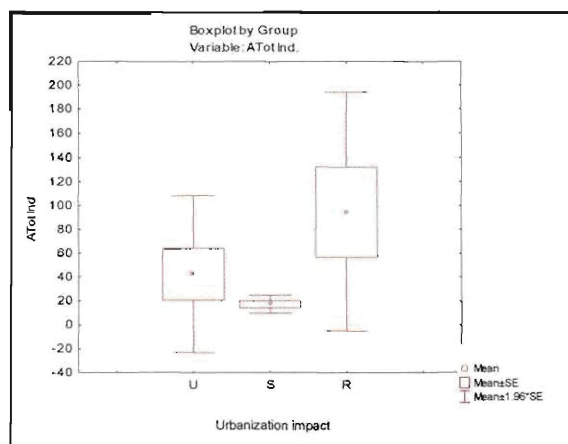


Figure 3.5: Box and Whisker plot of the total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

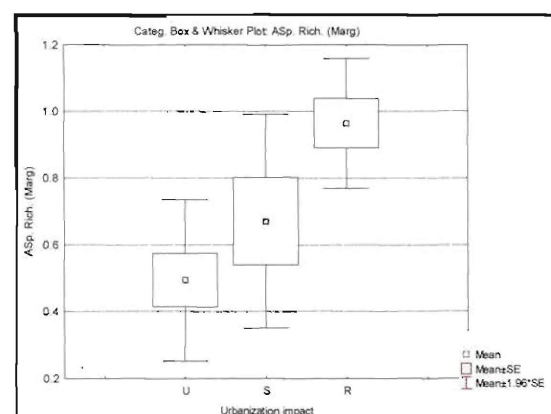


Figure 3.6: Box and Whisker plot of the of ant morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

July analysis, showed a opposite trend in comparison to the sampling months of November and February with respect to the total number of ant species, individuals and species richness (Figures 3.7, 3.8 and 3.9). The largest ant diversity and abundance's were found in the urbanized sites (especially suburban areas) in comparison to the more undisturbed rural sites.

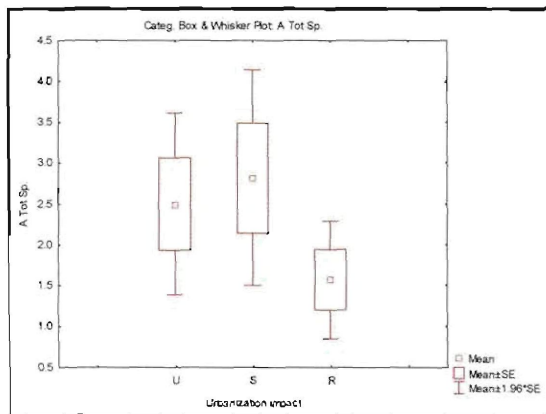


Figure 3.7: Box and Whisker plot of total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

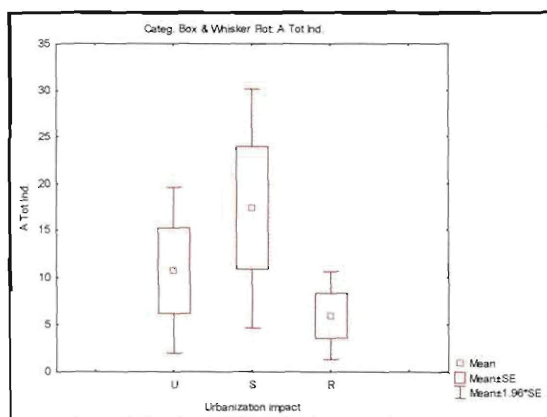


Figure 3.8: Box and Whisker plot of the total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

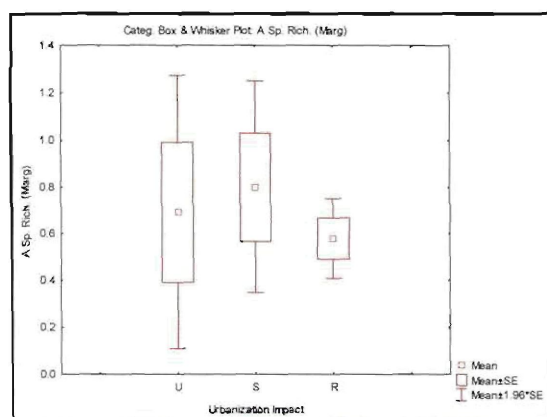


Figure 3.9: Box and Whisker plot of the of ant morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

An explanation for the trends observed in the respective sampling months of the current study may be answered by reference to studies of a similar nature. Some surveys show ant species richness responding inconsistently (Landsberg *et al.*, 1997), in some cases increasing (Greenslade & Mott, 1979; Majer & Beeston, 1996) and in others decreasing (Anthony *et al.*, 1991) in response to disturbance. Woinarski *et al.* (2002) studied the variation in ant species richness between different land-use types, and recorded 43 ant species at the disturbed (grazed) sites, compared with 64 species found in the undisturbed areas. The differences recorded between ant assemblages in the disturbed and undisturbed sites in Woinarski *et al.* (2002) study were statistically significant.

Bestelmeyer & Wiens (1996) found that altered vegetation, as a result of anthropogenic disturbance, can lead to the decrease of ant species richness, due to the reduction of available niches. Andersen (1997a) mentioned that ant species composition is highly correlated with plant species composition, and will therefore be altered with changing plant diversity. In a New South Wales study (Australia), the ant community composition varied systematically with vegetation structure and land condition (Andersen *et al.*, 2003). Habitat disturbance, and the reduction of vegetation structure, can have a negative influence on specialised and dominant ant groups, due to changes in micro-climate and food supplies (Andersen, 1995; Read & Andersen, 2000). On the other hand, opportunistic (sometimes exotic) and generalist species may flourish and be more abundant in highly stressed environments as a result of a decline in competitive pressure (Andersen, 1997a; Wilson & Taylor, 1967; Williams & Gaston, 1994). Some of these opportunistic species, namely *Tetramorium* spp. and generalists, namely *Pheidole* sp. and *Monomorium* sp. were captured in the current study, and found to be abundant in the disturbed urbanized areas. Andersen (1997a) further stated the reason for the low ant diversity in highly stressed or disturbed environments, is due to this reduction in competitive pressure. Other surveys firmly support that ant species composition can be altered by changes in vegetation (plant richness and organic cover) due to disturbance (Majer, 1983; Majer & Flugge, 1984; Andersen, 1997a).

Another explanation for the large ant diversity and abundances found in the rural sites, may be due to an increased percentage in bare ground and open habitats present in these more natural areas. Andersen *et al.* (2002) surveyed ant assemblages sampled from different land use types, and found that the sites with more open habitats (higher percentage bare ground) supported more a diverse ant fauna. Some ant species typically increase in abundance when disturbance opens up closed habitats (Andersen, 1995). Cattle and sheep grazing can contribute to higher percentages of open habitats and bare-ground in rural areas. According to Greenslade & Mott (1979); Hutchinson & King (1980); Whitford *et al.* (1999) and Read & Andersen (2000) sites studied that were subjected to grazing showed an increase in ant abundances.

According to Andersen (1997c), a bio-indicator group is most effective when supported by a predictive understanding of how the group's community is organized. This provides a powerful means of distinguishing the impact of anthropogenic disturbance from inherent site variability, and allows a "bio-indicative signal" to be correctly interpreted (Wright, 1995; Reynoldson *et al.*, 1995). This is especially true in the context of limited replication that is typical of impact studies, where fewer control sites may be insufficient to indicate the extent of natural variation (MacNally, 1996).

Ant monitoring programmes, already developed, are supported by an understanding of community dynamics, to an extent not matched by any other terrestrial group (Andersen, 1997a). Andersen (1997c) mentioned that the key to predictive understanding of ant community organization lies in the recognition of functional groups (Figure 3.10), and how these groups respond to environmental stress and disturbance (anthropogenic). Some of the ant species captured in the current study are representatives of these functional groups, and are listed in Table 3.2.

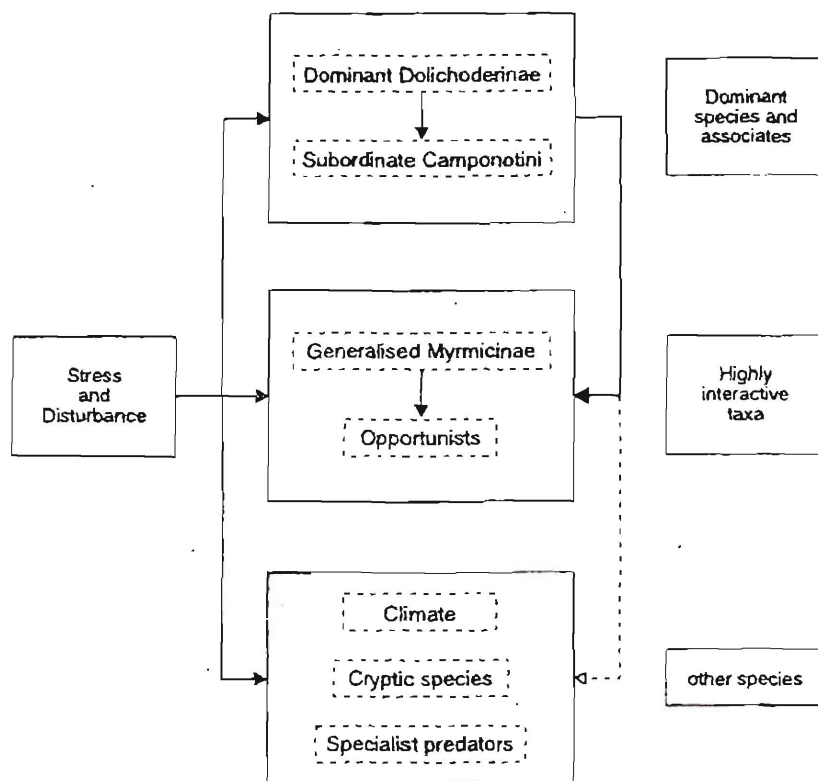


Figure 3.10: Generalised model of ant community organization, based on functional groups in relation to environmental stress and disturbance (Greenslade, 1978; Andersen, 1990, 1995)

According to Andersen (1990) and Bestelmeyer & Wiens (1996), functional group composition is said to respond predictably to habitat disturbance in temperate and semiarid regions (characteristic of South African conditions). This group's composition also varies systematically with vegetation type, as subjected by environmental stress (Andersen, 1995, 1997a). Habitat disturbance can have a negative influence on specialised ants, primarily through changes in vegetation structure, micro-climate and food supplies (Andersen, 1995). Andersen (1988, 1990) and Andersen & McKaige (1987) studies in temperate South Eastern Australia, revealed that disturbance typically resulted in the proliferation of Opportunistic species. At highly stressed or disturbed sites, ant diversity (and therefore competitive pressure) is low and the most abundant species that flourish are usually opportunists (*Tetramorium* and *Lepisiota* species) and generalists (Generalised Myrmicinae: *Monomorium* and *Pheidole* species).

Table 3.2: Ant Functional Groups (categorized according to the group's response to stress and disturbance: Andersen, 2000) found in grasslands along an urbanization gradient in the Potchefstroom Municipal area.

Functional groups	Species
<u>Opportunists:</u> Are unspecialised, poorly competitive ruderal species (Grime, 1979), who's distributions appear to be strongly influenced by competition from other ants. They often have wide habitat distributions, but predominate only at sites where stress or disturbance severely limit ant productivity and diversity, and therefore where behavioural dominance is low (Andersen, 1997a)	<i>Tetramorium</i> sp.1 <i>Lepisiota</i> sp.1 <i>Lepisiota</i> sp.2
<u>Generalized Myrmicinae:</u> Are ubiquitous members of ants communities throughout the warmer regions of the world, and often among the most abundant ants (unspecialized ants with wide habitat and climatic tolerances, Andersen, 1997a) There is often competitive tension between them and the dominant Dolichoderines (will be discussed later).	<i>Monomorium fastidium</i> <i>Monomorium</i> sp.2 <i>Monomorium</i> sp.3 <i>Pheidole</i> sp.1
<u>Subordinate Camponotini:</u> Are very often diverse and abundant in rich ant communities. Most are behaviorally submissive to the dominant Dolichoderines (will be discussed later), and many are ecologically segregated from them owing to their large body size and often nocturnal foraging.	<i>Camponotus</i> sp.1 <i>Camponotus</i> sp.2

<u>Climate specialists:</u>	
Cold climate specialists: These taxa have distributions centered on cool temperate regions	<i>Anoplolepis custodiens</i> <i>Anoplolepis</i> sp.2
Tropical climate specialists: These taxa have distributions centered on the humid tropics.	<i>Meranoplus</i> sp.1
Both cold and tropical climate specialists are characteristic of habitats where the abundance of dominant Dolichoderines are low, and aside from their habitat tolerances, they are often unspecialized ants.	

According to Andersen (2000) the dominant Dolichoderinae (mentioned in Table 3.2), are competitively dominant taxa which by definition are those species that predominate in environments experiencing low levels of stress and disturbance. Dolichoderines are often absent entirely from even moderately stressful habitats, which is the case in the current survey.

The ant morphospecies which represented functional groups in the current study, abundance's were calculated and compared across the urbanization gradient for the respective sampling seasons. In November (Figure 3.11) it was clear that in the rural sites the Climate Specialists (*Anoplolepis custodiens*, *Anoplolepis* sp.2, *Meranoplus* sp.1) were abundant and dominant, although the Generalized Myrmicinae (*Monomorium fastidium*, *Monomorium* sp.2, *Monomorium* sp.3, *Pheidole* sp.1) were also numerous in these areas. When examining the urbanized sites (urban and suburban) it appeared as though the Climate Specialists were almost absent in comparison to the largely abundant Generalized Myrmicinae and Opportunists (*Tetramorium* sp. 1, *Lepisiota* sp.1 and *Lepisiota* sp.2). The proliferation of Opportunists and Generalized Myrmicinae in the urbanized sites (highly stressed or disturbed sites), is similar to the trend discovered in Australian studies (Andersen & McKaige, 1987 and Andersen 1988, 1990). February's analysis (Figure 3.12), showed a similar trend to November, although there appeared to be larger variation in numbers between the different functional groups across the urbanization gradient. The July (winter) analysis (Figure 3.13) showed a total absence of Climate Specialists, even in the rural sites. The Generalized Myrmicinae and Opportunists,

however persisted in all three land use types (rural, suburban and urban, Figure 3.13) This study showed that the Generalized Myrmicinae and Opportunistic species persisted, were adaptable and abundant even when subjected to the pressure of dry seasonal conditions (winter) and habitat disturbance (urbanization).

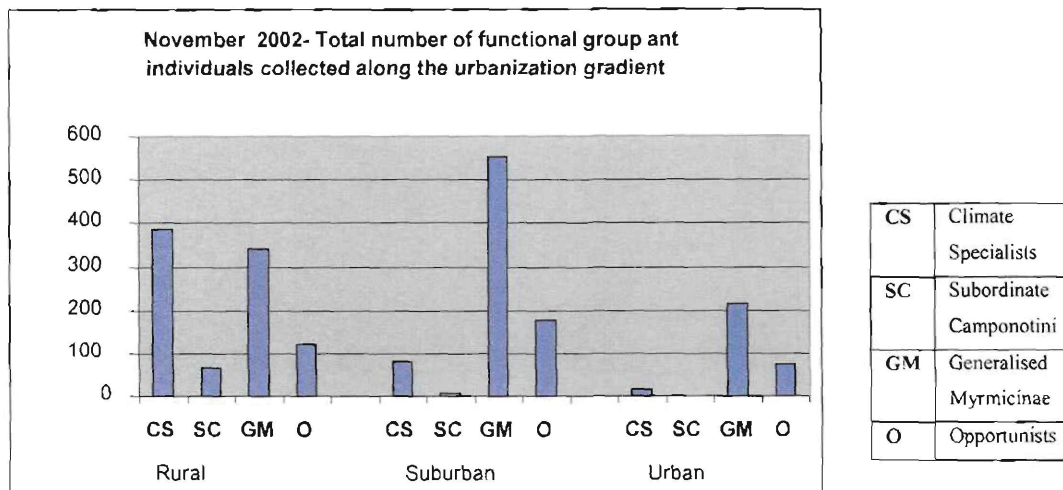


Figure 3.11: Total number of functional group ant individuals (as classified in Table 3.3) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal Area for November 2002.

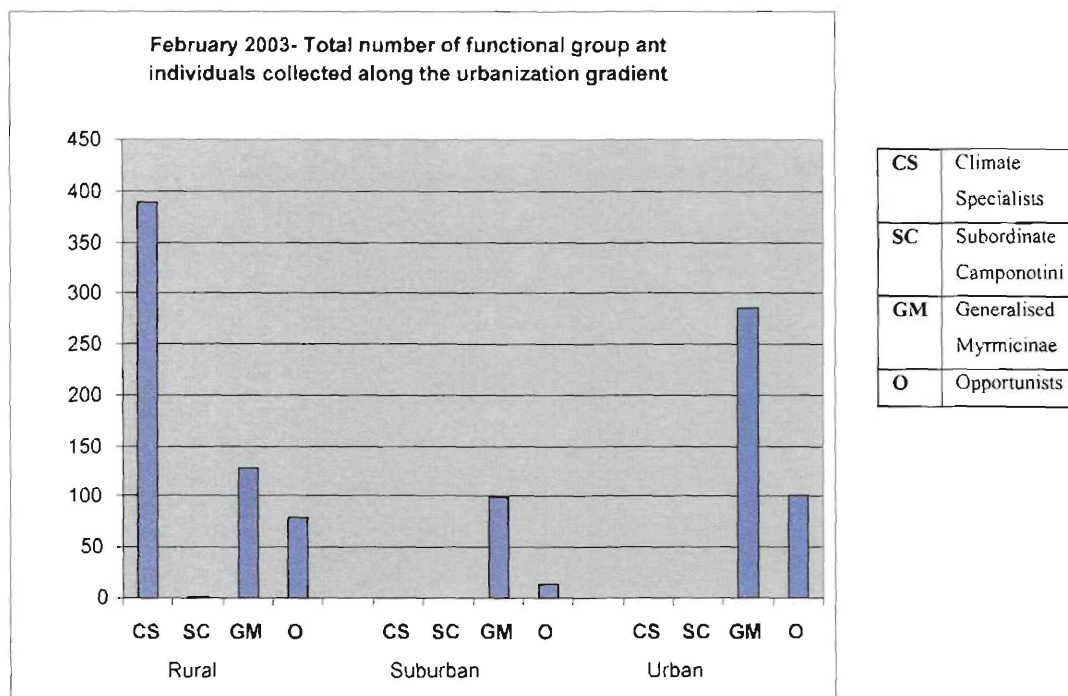


Figure 3.12: Total number of functional group ant individuals (as classified in Table 3.3) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

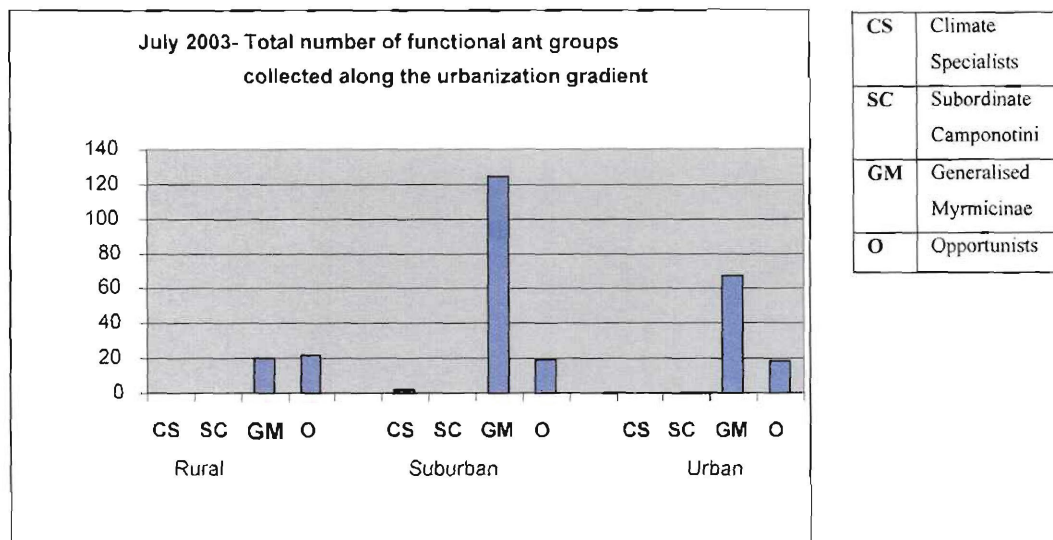


Figure 3.13: Total number of functional group ant individuals (as classified in Table 3.3) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

3.2.2. Beetles:

In the November and February analysis (Figures 3.14, 3.15, 3.16, 3.17, 3.18 and 3.19) no statistical significant differences with regard to the total number of beetle species were observable, although a general trend did occur, where beetle abundances and diversity were high in the urbanized areas (urban and suburban sites) and low in the ‘less disturbed’ rural areas.

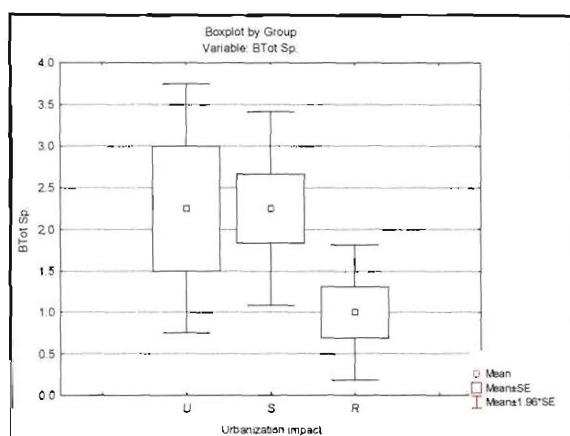


Figure 3.14: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

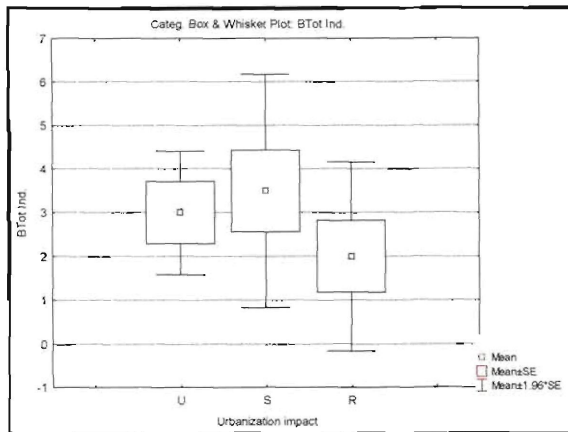


Figure 3.15: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

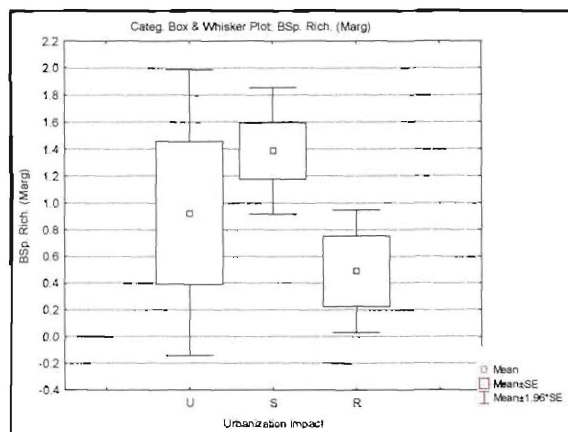


Figure 3.16: Box and Whisker plot of the beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

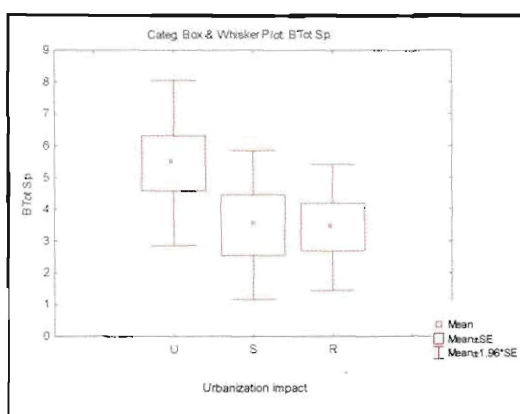


Figure 3.17: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

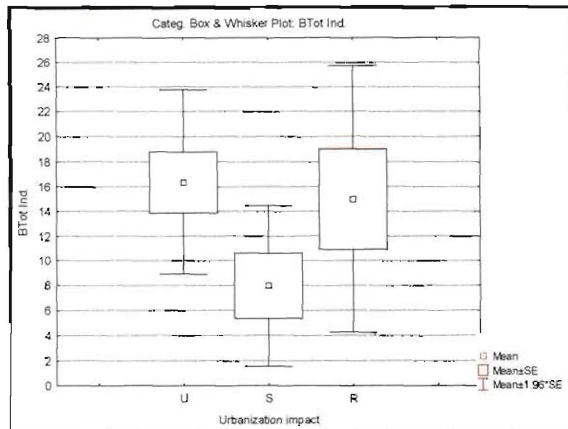


Figure 3.18: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

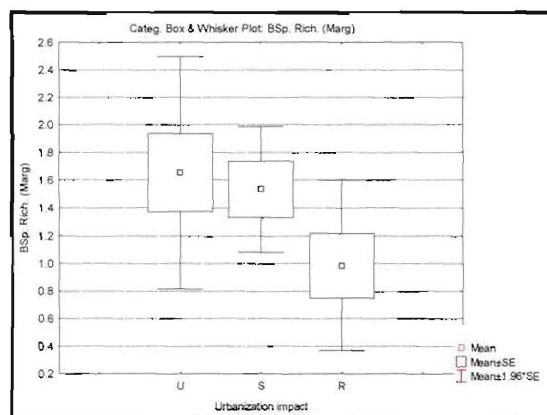


Figure 3.19: Box and Whisker plot of the beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

When considering the sampling month of July, the total number of beetle morphospecies (figure 3.20), total number of beetle individuals (figure 3.21) and beetle morphospecies richness (figure 3.22) showed statistical significant differences between the urban and rural sites ($p < 0.05$) for all three determinations.

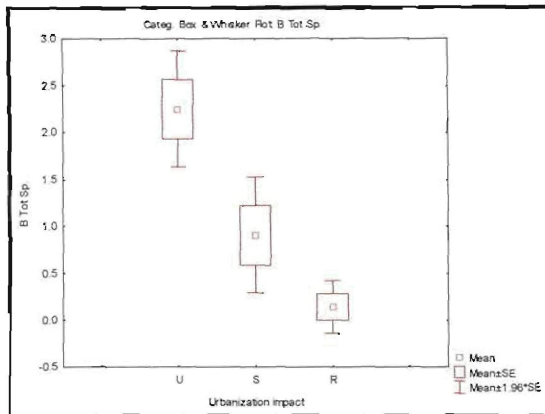


Figure 3.20: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

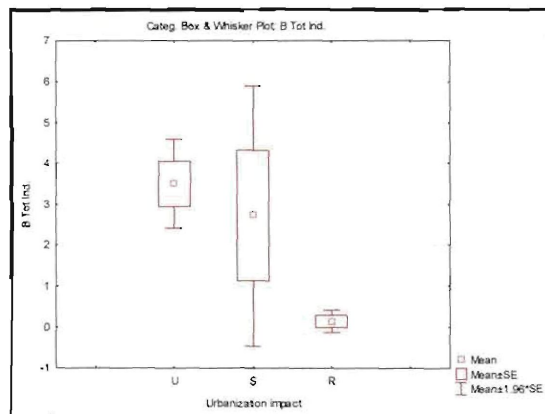


Figure 3.21: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

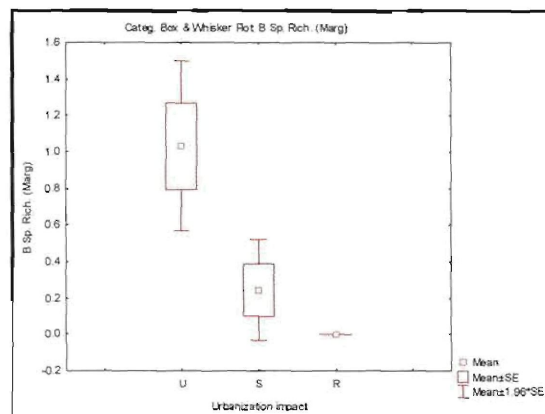


Figure 3.22: Box and Whisker plot of beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

A possible explanation for this general trend of higher beetle abundance and diversity in the urban sites compared to the rural sites for all three of the sampling months may be answered by reference to similar studies performed. Lehvavirta *et al.* (2006) tested whether fragmentation or trampling (as a result of urbanization) had any effect on beetle assemblages (namely Carabids) in urban woodland forests in Finland. Carabid beetles are often useful in disturbance studies as they react predictably to environmental changes (Lovei & Sunderland, 1996; Niemelä *et al.*, 2000), are easy to catch and identify and their ecology is well known enough to enable *a priori* predictions about their responses to anthropogenic effects such as fragmentation (Kotze & Samways, 1999, 2001; Heliola *et al.*, 2001). Lehvavirta *et al.* (2006) mentioned that the 'more natural' forest species (similar to the rural species collected in the current study in terms of occupying undisturbed habitats) should decrease in number with increased woodland fragmentation due to habitat changes (same effect caused by urbanization), microclimate changes and the invasion of open habitat species. Halme & Niemelä (1993) and Koivula *et al.* (2002) hypothesized that open habitat and generalist species would benefit from fragmentation of habitats because of the creation of an 'edge habitat' suitable for them. Lehvavirta *et al.* (2006) found that the abundance of the beetle group (carabids) decreased with increasing distance from the edge towards the less disturbed forest interior. Lehvavirta *et al.* (2006) also revealed that the open habitat species group were found to be less vulnerable and more tolerant to trampling than the natural forest species. Lehvavirta *et al.* (2006) results showed a surprisingly high beetle species richness (37 species) found in the fragmented and trampled urban woodlands. A comparative study (Halme & Niemelä, 1993) in Southern Finland recorded only 25 species in a less anthropogenically disturbed rural woodland. A similar trend found in the current study, of higher beetle abundances and diversity in more open and trampled urbanized areas, could be due to the presence and invasion of a large number of open habitat and generalist beetle species, which are more tolerant to habitat disturbance (trampling and fragmentation), and the absence of more sensitive, specialist rural species. According to Niemelä (1999 b), the reason for the greater beetle diversity may be that urban habitats offer more heterogeneous environments in terms of habitat types, patch configuration, size and isolation, and nutrient enrichment, than rural environments do.

The percentage ground cover and organic matter present in the plots where sampling took place may also be an important contributing factor influencing beetle abundances and diversity in the current study. Typically higher percentages of bare ground were encountered in the rural sites, where as, high organic covering (leaf litter, weed cover, crop residues, etc) prevailed in the more urbanized areas. Krooss & Schaefer (1998) performed a study on the effects of ploughing (which alters ground cover) on beetle (Staphylinidae) species richness. Beetle species richness was higher (65 Staphylinid species) in unploughed plots compared to ploughed plots (54 Staphylinid species). Ploughing reduces organic covering and opens up more bare soil, resulting in a drier microclimate on the soil surface (favourable only for thermophilic species). Krooss & Schaefer (1998) also mentioned that the unploughed covered plots sustained more abundant potential prey for the feeding beetles (organic matter supports higher abundance of prey). The amount of organic covering

present, determines the abundance of saprophytic and detritus feeding species upon which many macro-arthropod groups (such as beetles) feed. Spermatophagous beetles, such as the *Amara* species from the family. Carabidae also benefit from organic covering, as they feed on seeds from weeds retained on the soil surface (Andersen, 1999). Organic matter (in the form of dense weeds and undersown grass) also provides cover, which is favourable for a range of epigeal arthropods, including beetles (Vickerman, 1976; Speight & Lawton, 1976; Powell *et al.*, 1985a; Clark *et al.*, 1993). Ferguson & McPherson (1985) found that organic matter at the soil surface increased the niche availability, to which the high number of carabid beetles caught in their study, was attributed to. Abundance of organic matter in an area surveyed may be regarded as a factor controlling the biodiversity of soil fauna occurring there.

In the study of Becker (1975), the beetle family classification system compiled by Clark (1895); Mank (1923); Voris (1934); Balduf (1935); Clausen (1940) and Borror & DeLong (1971) was used to group together and differentiate beetle specimens collected according to their feeding habits. The beetle families collected in the current study were categorized accordingly (Table 3.3):

Table 3.3 Beetle families collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area and categorized according to their feeding habits

Terrestrial predators (carnivores)	Carabidae Staphylinidae Cucujoidae
Possible terrestrial predators (few records)	Histeridae
Saprophagous (feed on decaying organic matter or fungus)	Scarabaeidae Dermestidae Tenebrionidae
Herbivorous (feed on living, vascular plant material)	Chrysomelidae Curculionidae

Becker (1975) supports the hypothesis that the specialized feeding requirements (trophic specialization) of herbivorous insects makes it more difficult for these fauna to establish and maintain populations in altered

and disturbed environments (due to urbanization) in comparison to carnivorous insects with polyphagous habits. Predatory beetles are trophic generalists (opportunists) and find it easier to establish and persist in disturbed habitats and may also have greater physiological resilience to withstand unfavourable conditions.

The collected beetle families (categorized according to feeding habits, Table 3.3) abundance's were compared across the urbanization gradient for the respective months. The November analysis (Figure 3.23) showed that the terrestrial predators were abundant across all three land use types (rural, suburban and urban). A high fluctuation of herbivorous species occurred in the suburban sites, which could be attributed to the higher plant diversity and abundance of fruit present in these sites in comparison to the rural areas (the suburban sites sampled can be regarded as ecotones with a generally higher diversity). Much of the same tendencies as seen in November also occurred in the February analysis (Figure 3.24). July however showed a total absence of the specific feeding groups (terrestrial predators, saprophagous and herbivorous species) in the rural sites. When examining the urbanized sites, these feeding groups were present, with high fluctuations of saprophagous feeders in the suburban areas (Figure 3.25) The suburban sites had high organic cover relative to the other land-use types and could therefore supply favourable conditions for the saprophagous species.

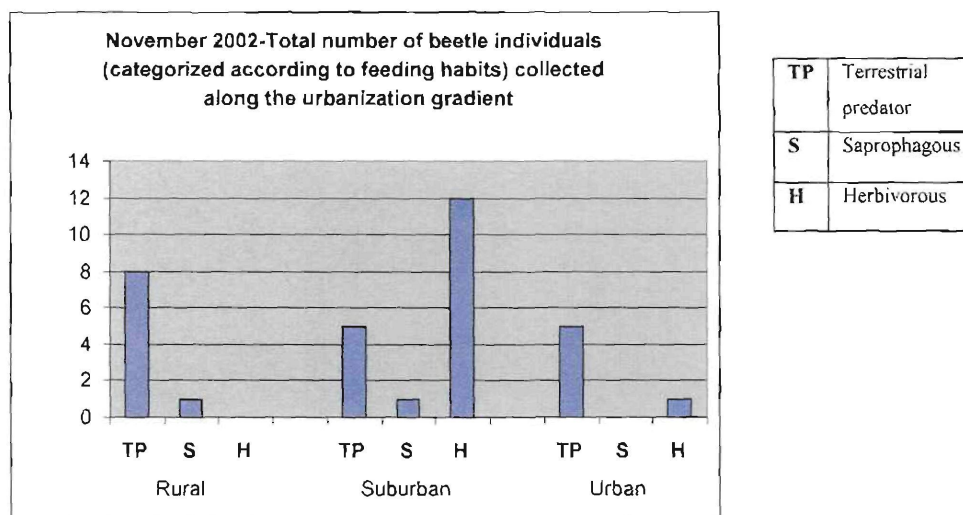


Figure 3.23: Total number of beetle individuals (categorized according to family feeding habits, Table 3.3) collected in grasslands along the urbanization gradient in the Potchefstroom Municipal Area for November 2002.

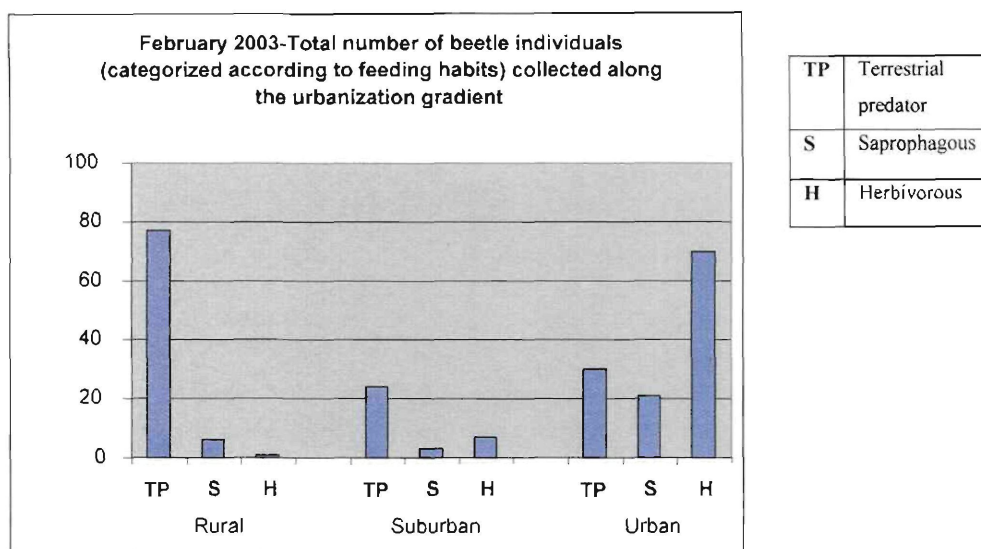


Figure 3.24: Total number of beetle individuals (categorized according to family feeding habits, Table 3.3) collected in grasslands along the urbanization gradient in the Potchefstroom Municipal Area for February 2003.

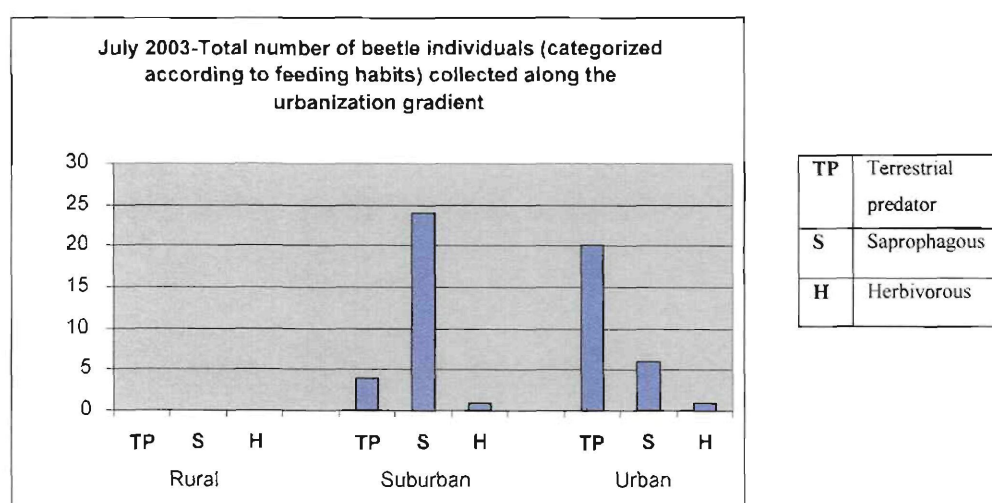


Figure 3.25: Total number of beetle individuals (categorized according to family feeding habits, Table 3.3) collected in grasslands along the urbanization gradient in the Potchefstroom Municipal Area for July 2003.

3.2.3 Spiders

The November, February and July determinations (figures 3.26, 3.27, 3.28, 3.29, 3.30, 3.31, 3.32, 3.33, 3.34) showed no statistical significant differences between urban, suburban or rural sites. When comparing the sampling months, it seemed that in November and July, urbanization had the greatest impact on the spider's abundances and diversity with larger variation in abundances and diversity observable between the suburban sites and the other two land use types, relative to what was found in February.

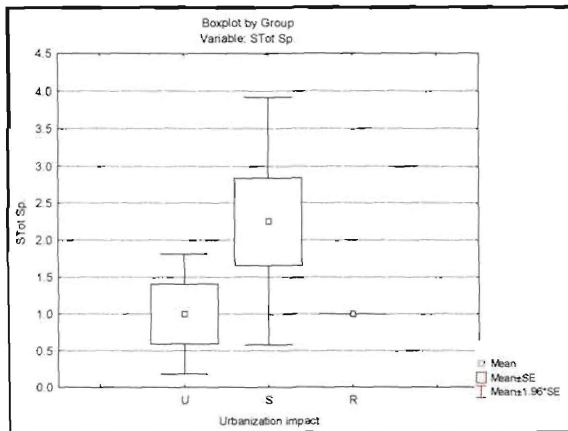


Figure 3.26: Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

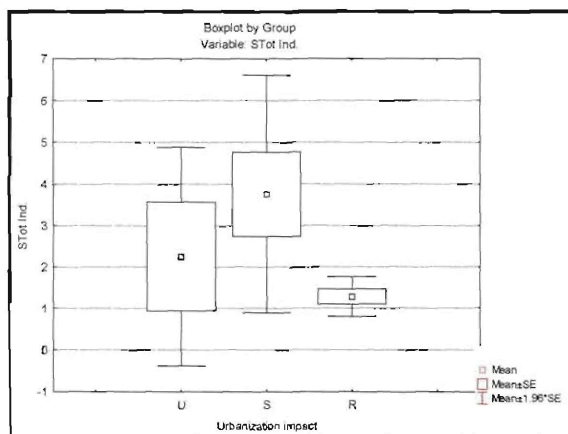


Figure 3.27: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

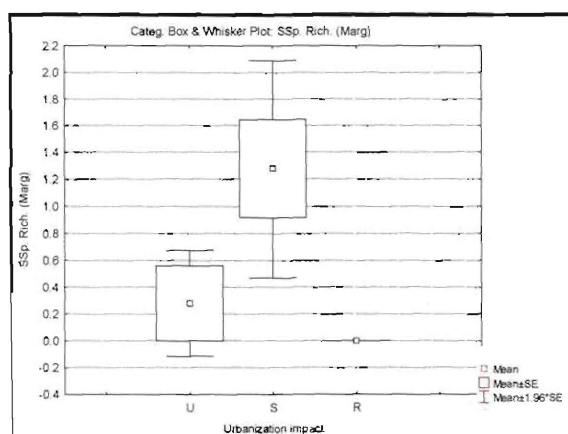


Figure 3.28: Box and Whisker plot of spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

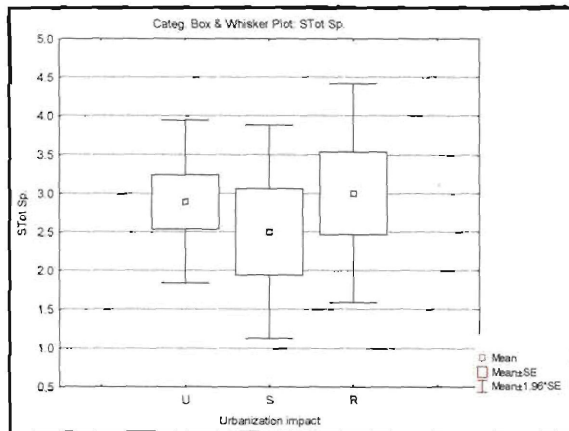


Figure 3.29: Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

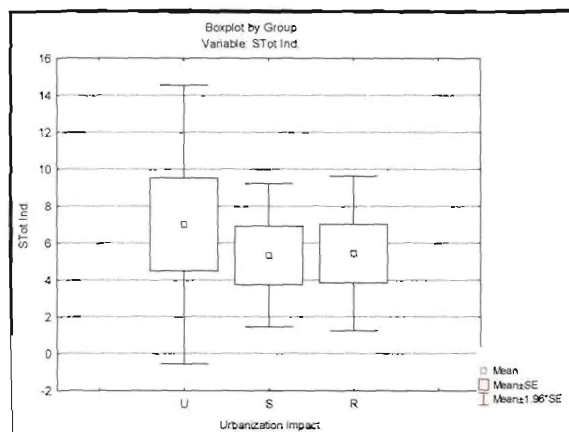


Figure 3.30: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

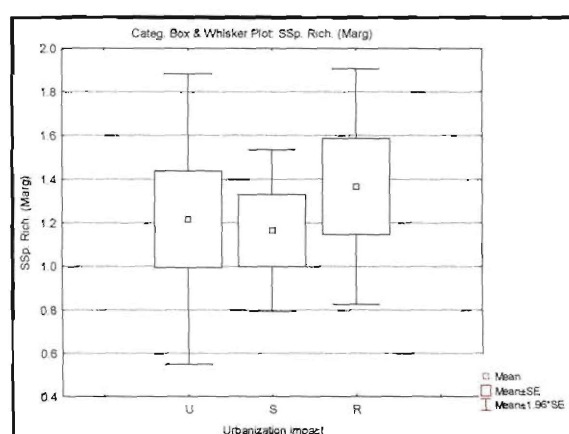


Figure 3.31: Box and Whisker plot of spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

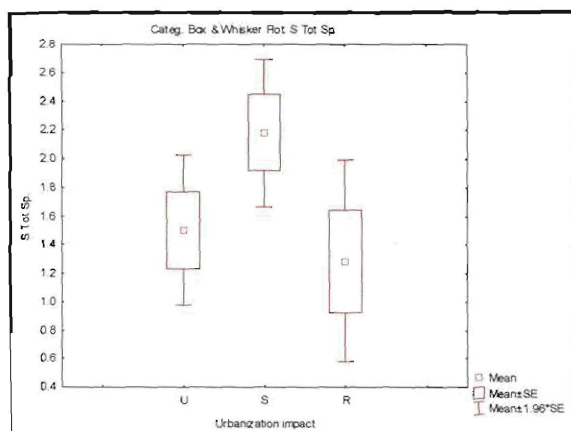


Figure 3.32: Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

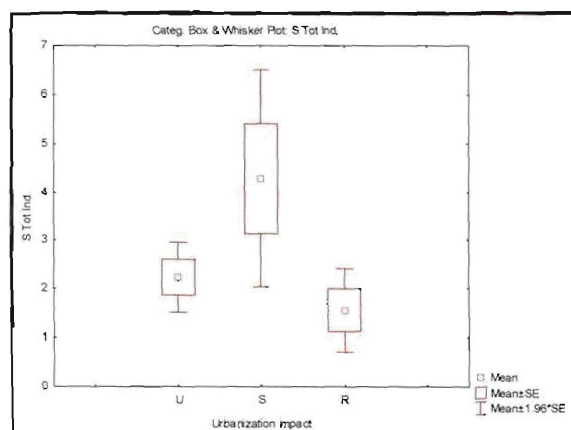


Figure 3.33: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

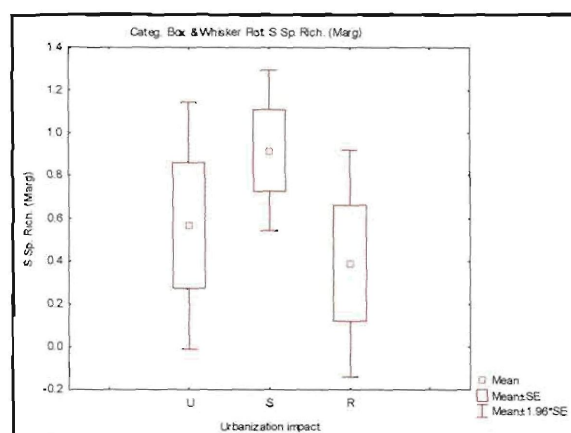


Figure 3.34: Box and Whisker plot of spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

The findings in November and July (figures 3.26, 3.27, 3.28, 3.32, 3.33, 3.34), concurs with Alaruikka *et al.* (2002) who investigated the effects of urbanization on abundances and diversity of ground dwelling spiders along an urban-rural forest gradient in Southern Finland. Alaruikka *et al.* (2002) results showed spider species richness to be very similar across the urban-rural gradient (59 species in urban, 55 species in suburban and 56 in rural sites), but when examining spider individuals, higher numbers were found in the suburban sites (997 individuals) than urban sites (907 individuals) and rural sites (859 individuals). Alaruikka *et al.* (2002) found that the differences in overall spider abundances collected from the different land use sites along a gradient (urban, suburban and rural) were not statistically different. This may be explained on account that the spiders collected in this study were not strictly specialized in their habitats and therefore more adaptable to land use change (similar findings supported by the studies of Huhta, 1965; Palmgren, 1972; Palmgren & Bistrom, 1979; Vaisanen & Bistrom, 1990). This arthropod group may also be more resilient to anthropogenic impact in comparison to the other groups discussed (namely ants and beetles). The study performed by Strehlow (1993) in Western Australia found that spiders rapidly recolonized an area following an autumn fire, with species richness returning to pre-fire levels after 2 years. A higher percentage of organic matter (cover) in the suburban sites sampled may also be a contributing factor to the large spider diversity and abundances in these areas. A survey performed in a deciduous forest in Delaware, USA displayed a higher diversity of spiders with increased leaf litter depth (Utez, 1975).

A relationship with respect to the impact of urbanization, seems to exist between the beetles and spiders, which were both abundant in the urbanized sites and low in the less disturbed rural habitats. According to Ekschmitt *et al.* (1997) soil surface-dwelling ground beetles and wolf spiders (Lycosidae) are common and abundant predators in agroecosystems. It is possible in the current study, that the same situation existed with respect to the occurrence of opportunistic, generalist predator beetles and spiders in the urban habitats, which offer heterogeneous environments for these two groups. Urban habitats support diverse prey, and these predatory beetles and spiders could be considered as true generalists, feeding on many different kinds of insect taxa (Sunderland, 1975; Hengeveld, 1980; Nyffeler *et al.*, 1994) and consuming considerable amounts of prey organisms (Sopp & Wratten, 1986; Mansour & Heimbach, 1993). Alaruikka *et al.* (2002) hypothesized that there is a larger likelihood of collecting specialist beetle and spider species in rural environments than urban environments, therefore further supporting the theory of generalist species dominating urban habitats. Some literature has even shown that ground beetles and (wolf) spiders were studied simultaneously, because they represent one functional unit, namely a trophic guild (Lang *et al.*, 1999).

3.3 Seasonal effect on epigeal arthropods:

3.3.1 Ants:

The total number of ant individuals caught for November 2002, February 2003 and July 2003 were 2036, 1096 and 320 individuals respectively (Figure 3.35).

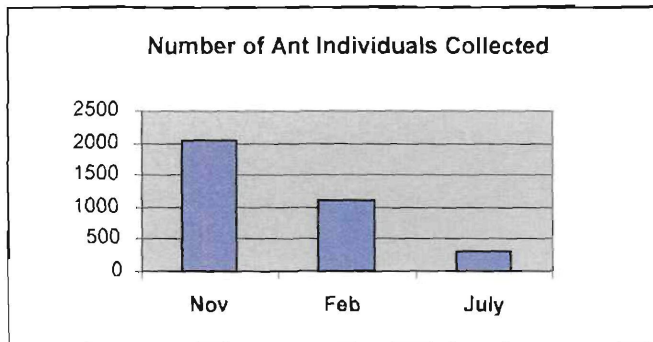


Figure 3.35: Total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003

The total number of ant morphospecies collected for November 2002, February 2003 and July 2003 were 11, 10 and 9 species, respectively (Figure 3.36).

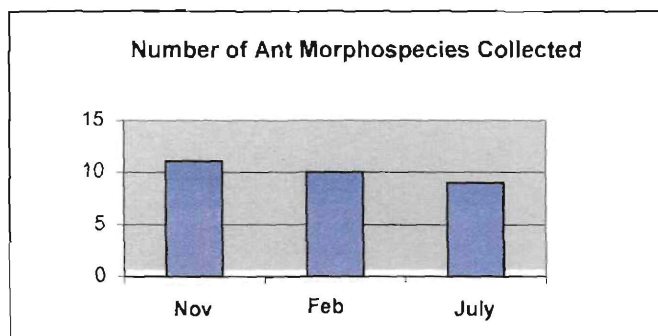


Figure 3.36: Total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003

ANOVA analysis was also utilized to determine if statistical significance occurred between ant abundances, diversity and the respective season. Read & Andersen (2000) used ANOVA analysis in their ant studies, to determine the effect of grazing on ant species abundances. Figures 3.37 and 3.38 represent the total number of morphospecies and total number of individuals of the ant group respectively. The total number of ant morphospecies collected in November (Figure 3.37) differed statistically significantly from February ($p=0.005549$) and July ($p=0.000007$). Total number of ant individuals in July (Figure 3.38) differed statistically

significantly from November ($p= 0.000001$) and February ($p= 0.004839$). Ant species richness (Figure 3.39) in November differed statistically significantly from February ($p=0.0028684$) and July ($p= 0.0070256$).

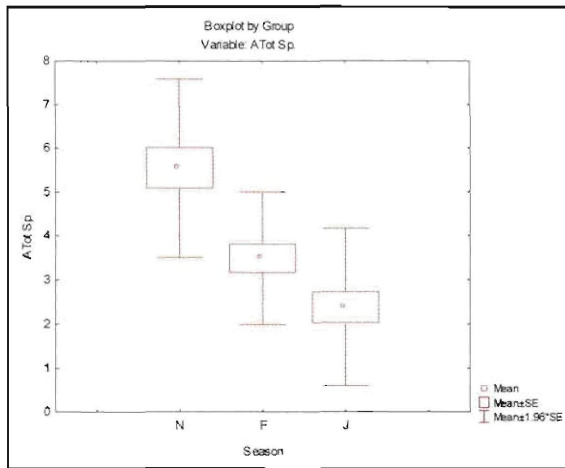


Figure 3.37: Box and Whisker plot of the total number of ant morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003, July 2003.

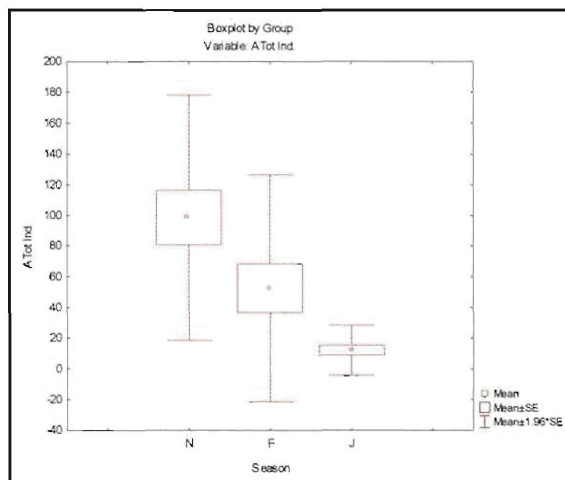


Figure 3.38: Box and Whisker plot of the total number of ant individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003, July 2003.

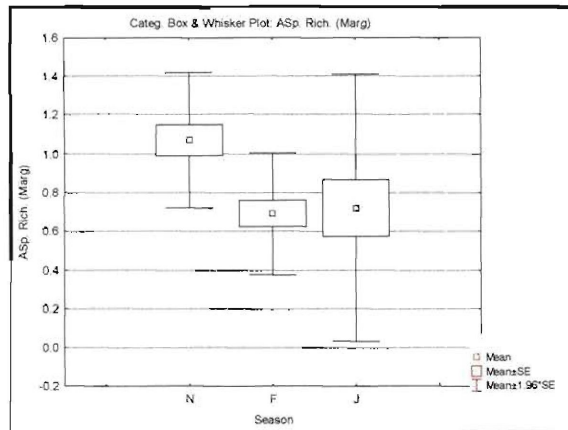


Figure 3.39: Box and Whisker plot of ant morphospecies richness collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area (Margalef index) for November 2002, February 2003, July 2003.

Statistical significant differences occurred for these determinations and a general trend was observable, where the greatest ant diversity and abundances occurred during the wet summer months (November) and lower values during the drier winter months (July). These findings are supported by Bestelmeyer & Wiens (2003), who's study revealed large ant abundances during high temperatures and wet conditions (summer months). They further explained that ants (and other small arthropods) are sensitive to variation in temperature and humidity (microclimatic conditions) and display maximum levels of activity during wet, summer seasons. Ants have differential tolerances to microclimatic conditions, and variation of these microclimates in time can affect species activity patterns (Cerdeira *et al.*, 1997; Bestelmeyer, 2000a; Bestelmeyer & Wiens, 2003). Clear differences among ant species and the environmental conditions in which they roam / scavenge exist (according to Bestelmeyer & Wiens, 2003).

3.3.2 Beetles

The total number of beetle individuals (Figure 3.40) collected in November 2002, February 2003 and July 2003 were 61, 297 and 59 individuals respectively, and the total number of beetle morphospecies (Figure 3.41) collected for the respective months were 14, 23 and 12 morphospecies.

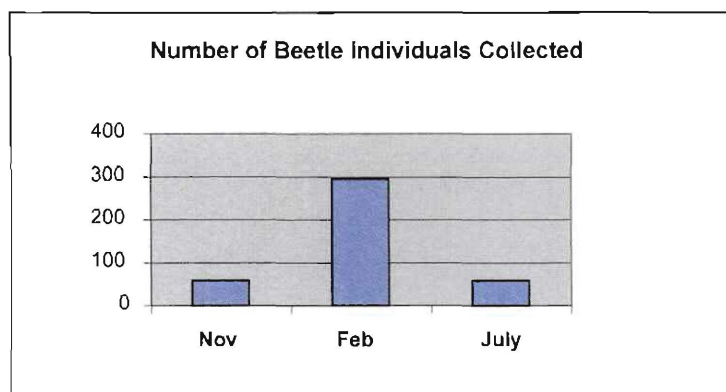


Figure 3.40: Total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003.

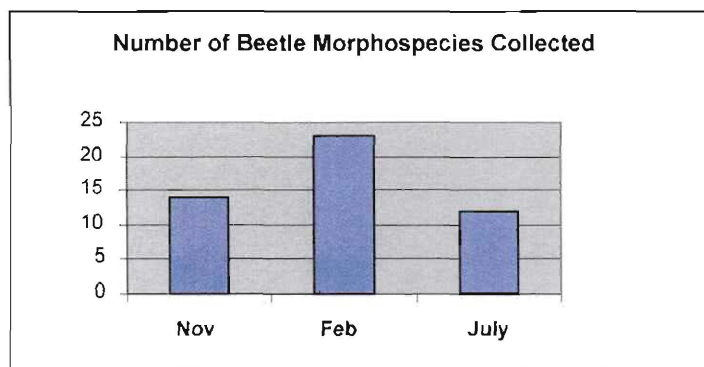


Figure 3.41: Total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003.

The ANOVA determinations for the effect of seasonal difference on beetle diversity, revealed some statistical significant differences. The total number of beetle morphospecies (Figure 3.42) in July differed statistically significantly from those in November ($p= 0.017$) and February ($p= 0.000015$). Also, the total number of beetle individuals (Figure 3.43) in July differed statistically significantly from those in November ($p= 0.0044$) and February ($p= 0.000005$). No statistical significant difference with respect to beetle species richness and sampling months (Figure 3.44) were observable. From these determinations, a clear trend was observed, where large beetle abundances and diversity occurred in February. Arthropod summer populations increase slowly during the first few months of summer (November) then tend to peak in population growth later in the season (February).

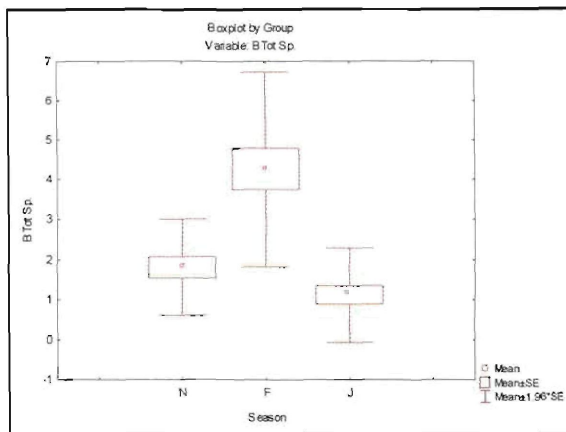


Figure 3.42: Box and Whisker plot of the total number of beetle morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area. for November 2002, February 2003 and July 2003.

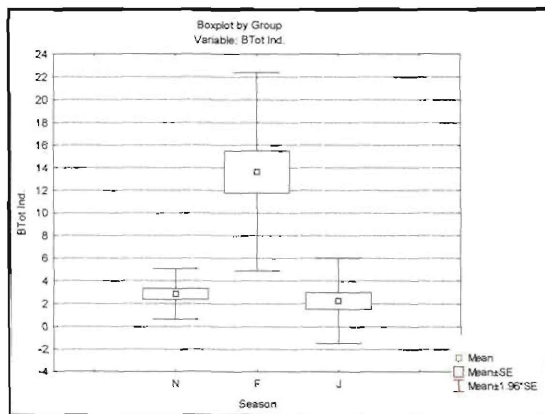


Figure 3.43: Box and Whisker plot of the total number of beetle individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area. for November 2002, February 2003 and July 2003.

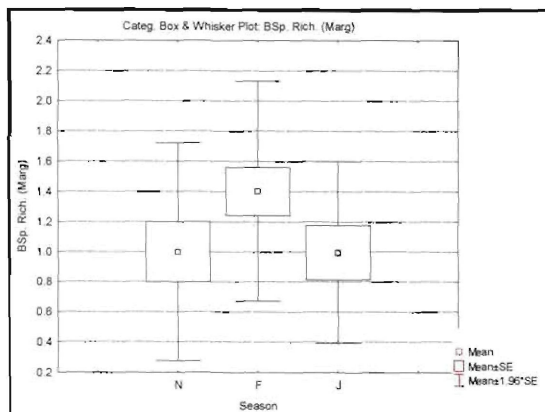


Figure 3.44: Box and Whisker plot of the beetle morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area. for November 2002, February 2003 and July 2003.

3.3.3 Spiders

The total number of spider individuals (Figure 3.45) collected for November 2002, February 2003 and July 2003, were 54, 63 and 18 individuals respectively.

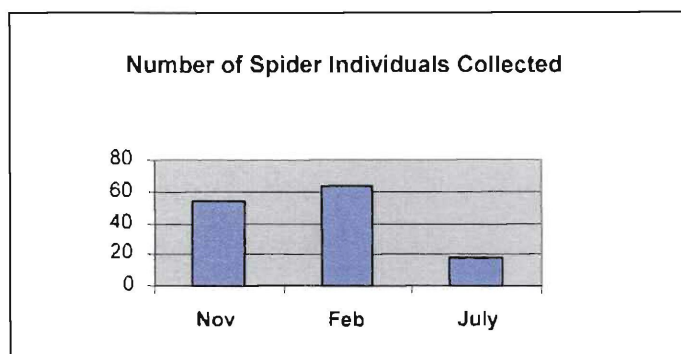


Figure 3.45: Total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003.

The total number of spider morphospecies (Figure 3.46) collected for November 2002, February 2003 and July 2003, were 6, 12 and 9 species respectively.

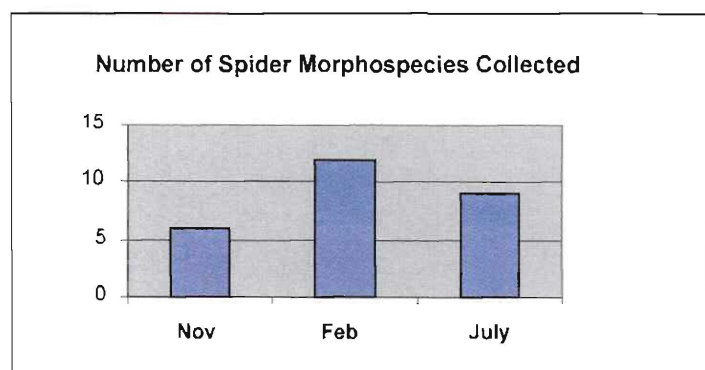


Figure 3.46: Total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003.

ANOVA analysis showed that the total number of spider morphospecies (Figure 3.47) in the month of November differed statistically significantly from those in February ($p=0.012$). Also, the total number of spider individuals (Figure 3.48) in November differed statistically significantly from those in February ($p=0.018$). No statistically significant differences occurred between the spider morphospecies richness (Margalef index) for the respective sampling months (Figure 3.49). Higher spider diversity and abundances were sampled in February, relative to the other sampling months. The large abundance of spiders collected in

February could be due to the completion of this group's breeding season (arthropod populations peak during late summer months) and higher abundance of prey available.

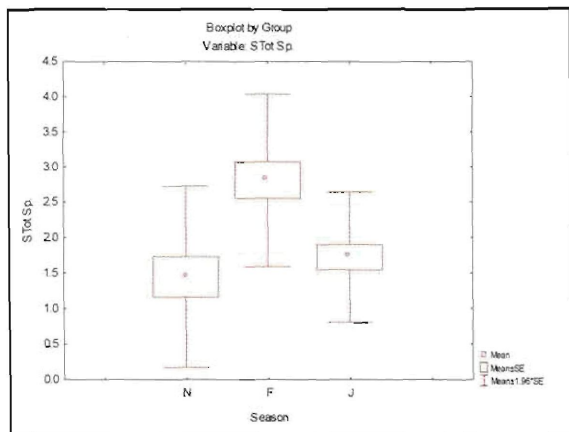


Figure 3.47: Box and Whisker plot of the total number of spider morphospecies collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003.

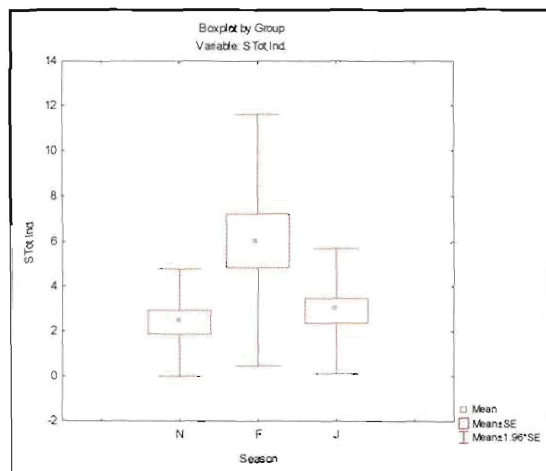


Figure 3.48: Box and Whisker plot of the total number of spider individuals collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003.

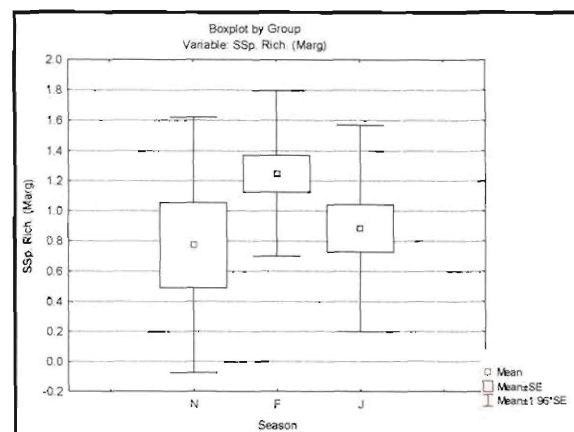


Figure 3.49: Box and Whisker plot of the spider morphospecies richness (Margalef index) collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002, February 2003 and July 2003.

3.4 Association between Environmental factors and Epigeal arthropods (Multi -Variate Analysis of Arthropod, Soil and Vegetation data)

To better explain the results and trends of the epigeal arthropod analysis, it was necessary to consider the influence environmental factors may have on the fauna's distribution. According to Juen & Traugott (2004) environmental constraints can affect single species of the arthropod groups studied, and therefore such a mutli-variate analysis is important in order to better explain trends. The environmental factors included soil (physical and chemical) and vegetation characteristics recorded for each sampling site (urban, suburban and rural) (Figure 3.50).

1.0

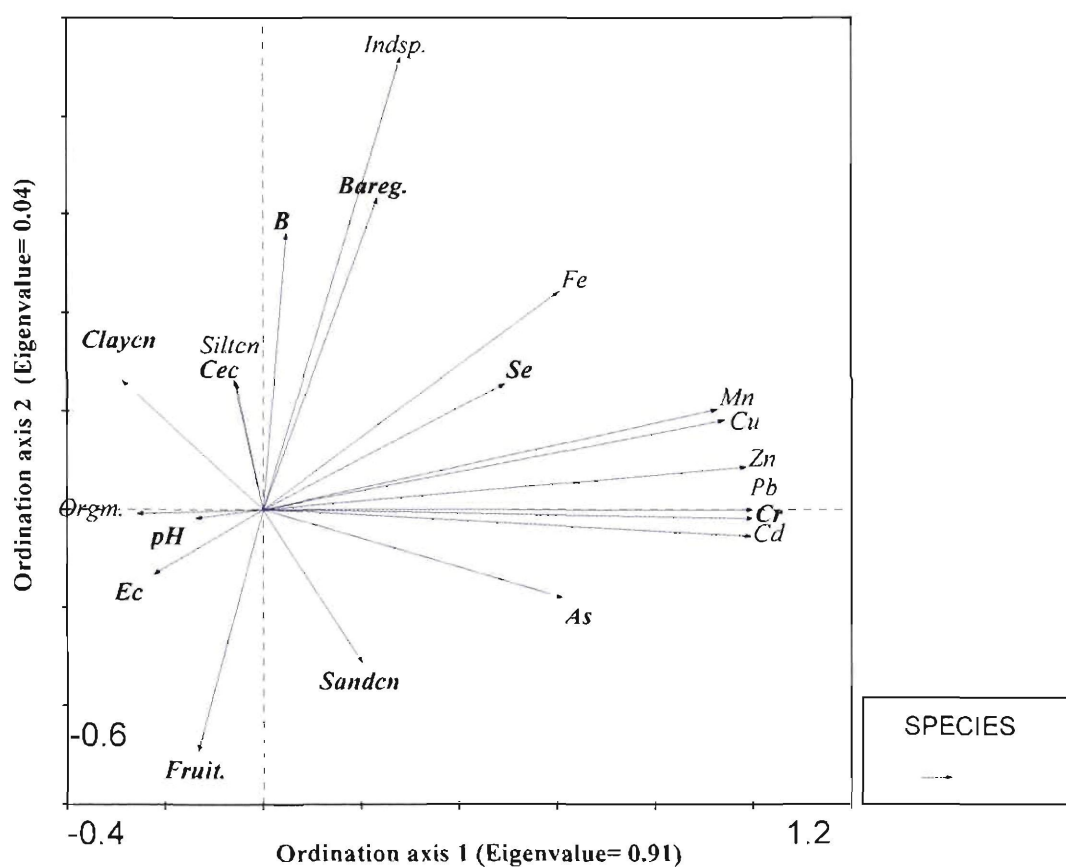


Figure 3.50: PCA ordination biplot showing the relationship between environmental factors and the respective axes obtained from grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

Certain environmental factors such as manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), chromium (Cr) and cadmium (Cd) are closely associated with each other and therefore necessary to include only one of these variables in the multi-variate analysis. The following environmental factors listed below (and highlighted in bold in Figure 3.50) were utilized for analysis for the respective sampling months:

November 2002: Sand concentration (Sandcn), Clay concentration (Claycn), pH, Electric conductivity (Ec), Boron (B), Arsenic (As), Selenium (Se), Cation Exchange (Cec), Bareground (Bareg), Fruit.

February 2003: Sand concentration (Sandcn), Clay concentration (Claycn), pH, Electric conductivity (Ec), Boron (B), Chromium (Cr), Arsenic (As), Selenium (Se), Cation Exchange (Cec), Bareground (Bareg), Fruit.

July 2003: Sand concentration (Sandcn), Clay concentration (Claycn), pH, Electric conductivity (Ec), Chromium (Cr), Arsenic (As), Selenium (Se), Cation Exchange (Cec), Bareground (Bareg), Fruit.

The epigeal fauna (abbreviations used for different morphospecies are indicated in Table 3.4), classified into ant, beetle and spider groups, were ordinated together with the sites in which they were sampled (urban, suburban or rural) and the site's corresponding environmental data by performing Canonical Correspondence Analysis (CCA) for the respective months (November 2002, February 2003 and July 2003). The environmental factors are all quantitative characters and are represented as vectors in the CCA-ordinations of the epigeal arthropod groups and their sampling sites (ie, UN=Urban North, RS =Rural South SW =Suburban West) for November 2002, February and July 2003, and are presented in Figures 3.51, 3.52, 3.53, 3.54, 3.55 and 3.56.

Table 3.4: Abbreviations used for epigeal arthropod morphospecies in ordination figures (used in Figures 3.5.2, 3.5.4 and 3.5.6)

Abbreviation	Species	Abbreviation	Species	Abbreviation	Species
Ants		Beetles		Spiders	
AAnoc	<i>Anoplolepis custodiens</i>	BSta1	Staphylinidae sp.1	SSal1	Salticidae sp.1
AAno2	<i>Anoplolepis</i> sp.2	BSta2	Staphylinidae sp.2	SSal2	Salticidae sp.2
ACam	<i>Camponotus</i> sp.1	BAph	Aphodidae sp.1	SSal3	Salticidae sp.3
APhe	<i>Pheidole</i> sp.1	BHet	<i>Heteroderus</i> sp.1	SLyc	Lycosidae sp.1
AMonf	<i>Monomorium fastidium</i>	BGon	<i>Gonocephalum</i> sp.1	SGna1	Gnaphosidae sp.1
AMon2	<i>Monomorium</i> sp.2	BFor	<i>Formicomus</i> sp.1	SGna2	Gnaphosidae sp.2
AMon3	<i>Monomorium</i> sp.3	BCuc	Cucujoidae sp.1	SPhi	Philodromidae sp.1
ATet	<i>Tetramorium</i> sp.1	BAnt1	<i>Anthicus</i> sp.1	SOstm	<i>Osteanus melanopygius</i>
ALep1	<i>Lepisiota</i> sp.1	BAnt2	<i>Anthicus</i> sp.2	SPal	<i>Palfuria</i> sp.1
ALep2	<i>Lepisiota</i> sp.2	BHis	Histeridae sp.1	SApo	<i>Apochinomma</i> sp.1
AMer1	<i>Meranoplus</i> sp.1	BSap	<i>Saprinus</i> sp.1	SArau1	Araneae unidentified sp.1
AForu	Formicidae unidentified sp.1	BCur	Curculionidae sp.1	SArau2	Araneae unidentified sp.2
		BSca	Scarabaeidae sp.1	SArau3	Araneae unidentified sp.3
		BOnt	<i>Onthophagus</i> sp.1	SAraj	Araneae juvenile sp.1
		BChr1	Chrysomelidae sp.1		
		BChr2	Chrysomelidae sp.2		
		BBra	<i>Brachinus</i> sp.1		
		BBar	<i>Baris</i> sp.1		
		BDer	Dermistidae sp.1		
		BCar1	Carabidae sp.1		
		BCar2	Carabidae sp.2		
		BCol1	Coleoptera sp.1		
		BColu	Coleoptera unidentified sp.1		
		BGro	<i>Gronops</i> sp.1		
		BHeta	<i>Heteronychus arator</i>		
		BPro	<i>Protostrophus</i> sp.1		

November 2002 analysis

From Figure 3.51 and Table 3.5 it is clear that bare ground (Bareg.) is most highly correlated with ordination axis 1 with a correlation coefficient of 0.83 (Table 3.5). Other environmental factors which are associated to ordination axis 1 are electrical conductivity (Ec), cation exchange capacity (CEC), sand concentration (Sandcn) and pH with correlation coefficients of -0.69, -0.57, 0.49 and - 0.48 respectively. The percentage of plants which are in fruit is most highly correlated with ordination axis 2 with a correlation coefficient of 0.43 (Table 3.5). The eigenvalue for the first ordination axis of the triplot is 0.48 and the second 0.25, representing 21.8 % and 34.3 % of the total variance respectively. The gradient along the second ordination axes is not a strong one ($t < 0.3$)

The epigeal arthropod group most closely associated with the occurrence of high percentage bare ground (Bareg.) and sand concentration (Sandcn) were the ants. It was also evident that most of the rural sites were aggregated closer to bareground. This confirms the assumption made in the ANOVA ant analysis for November, that the reason for the high ant abundance and diversity in the rural areas was due to the high percentage bare ground and sand concentration occurring in these sites (supported by studies of Andersen *et al.*, 2002), providing more favorable microhabitats for the ants to roam in and suitable nest building conditions.

The epigeal arthropod group associated with decreasing bare ground and an increase in clay concentration and fruit, were the beetles. Most of the suburban and some of the urban sites were associated with high clay concentration (Claycn.) and abundant fruit (Fruit.) (Figure 3.51). This supports the findings in the ANOVA beetle analysis for November, of high beetle abundance and diversity occurring in the more urbanized sites, which according to Figure 3.51, is due to the beetle group's affinity to sites with high Clay Concentration and percentage fruit.

The spiders were clustered near the suburban sites (Figure 3.51), supporting the results found in the ANOVA spider analysis for November of high spider diversity and abundances in the suburban areas.

Table 3.5: Correlation coefficients for CCA Ordination Triplot in Figure 3.51

	Ordination axes 1	Ordination axes 2
Sanden	0.49	-0.09
Claycn	-0.35	0.02
pH	-0.48	0.14
Ec	-0.69	-0.11
B	0.01	0.19
As	0.18	0.26
Se	0.38	0.23
Cec	-0.57	0.17
Bareg.	0.83	0.18
Fruit.	-0.13	0.43

November

1.0

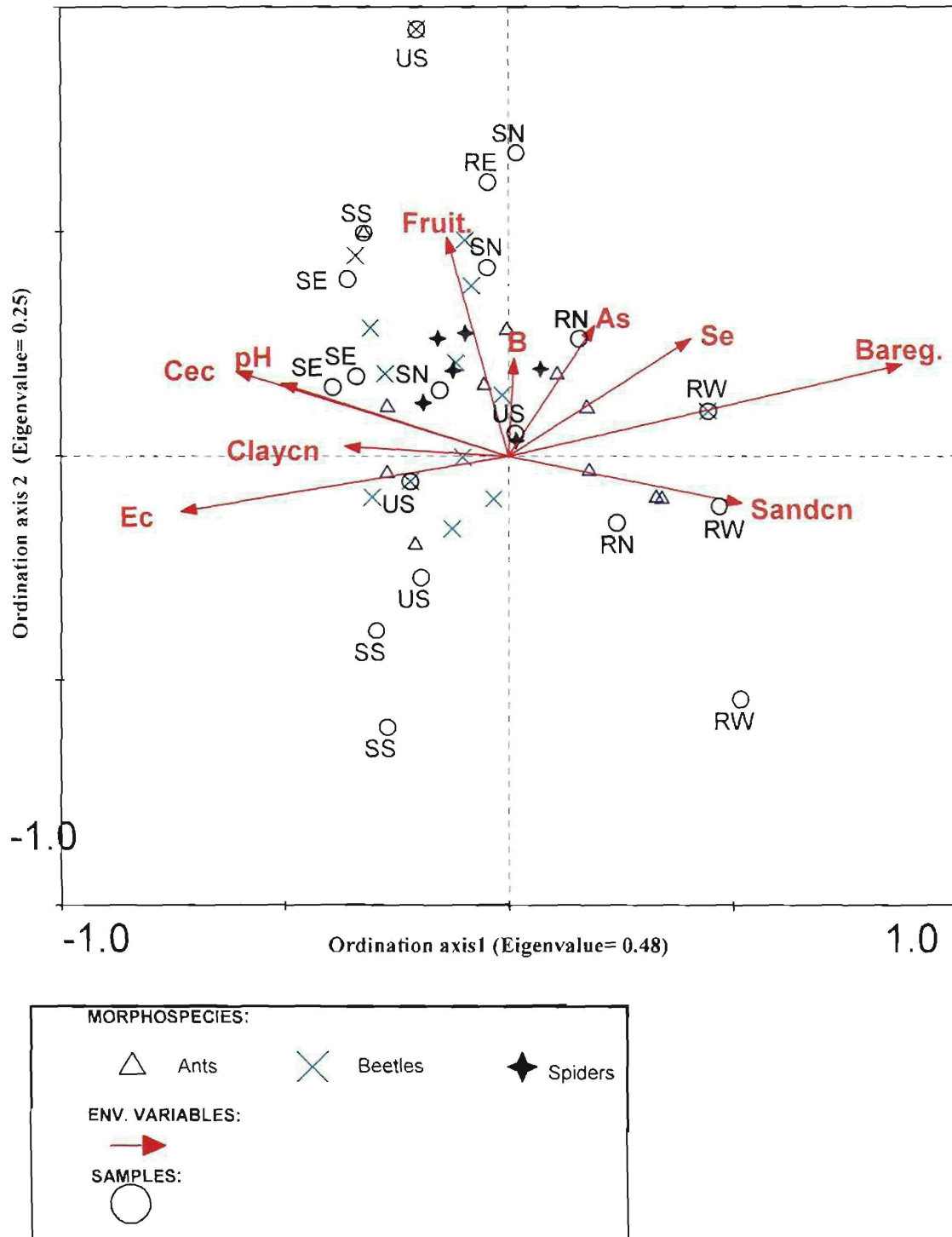


Figure 3.51: CCA ordination triplot showing the relationship between epigeal arthropod groups, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002.

In Figure 3.52, the morphospecies for the respective epigeal groups (ants, beetles and spiders) were included in the ordination. With regard to ants, the species found in the rural sites where high percentage bare-ground, sand concentration and selenium occurred, were *Tetramorium* sp.1 (ATet), *Monomorium* sp.2 (AMon2), *Camponotus* sp.1 (ACam) and *Anoplolepis custodiens* (AAnoc). Species associated with the more urbanized sites (suburban and urban) where high pH and clay concentration (Claycn.) occurred, were *Pheidole* sp.1 (APhe), *Lepisiota* sp.1 (ALep1) and sp.2 (ALep2) and *Monomorium fastidium* (AMonf). According to Andersen's classification of ant functional groups (Table 3.2), *Monomorium fastidium*, *Pheidole* and *Lepisiota* species, represent the Generalized Myrmicinae and Opportunistic functional group species. These species typically flourish in disturbed environments (Andersen, 1997c). *Camponotus* sp.1 and *Anoplolepis custodiens* belong to the Subordinate Camponotini and Cold climate specialists, respectively (Table 3.2).

The following beetle species found; Staphylinidae sp.1 (BSta1) and 2 (BSta2), *Baris* sp.1 (BBar), Scarabaeidae sp.1 (BSca), Curculionidae sp.1 (BCur), *Protothrophus* sp.1 (BPro), *Anthicus* sp.1 (BAnt), *Formicomus* sp.1 (BFor), Histeridae sp.1 (BHis), Chrysomelidae sp.1 (BChr1) and *Heteroderus* sp.1 (BHet); were associated with the urbanized sites, where a high percentage clay content and abundance of fruit existed. According to the classification of beetle families following feeding habits (Table 3.3), Staphylinidae are categorized as terrestrial predators and Histeridae as potential terrestrial predators. These carnivorous predators may be considered as adaptable to altered or disturbed habitats (as a result of urbanization) due to their polyphagous feeding habits. The family Scarabaeidae are categorized as saprophagous feeders (feed on organic matter) and would thrive especially in the urbanized sites, where organic cover is more abundant. The presence of herbivorous species (which feed on living plant material) represented by the families Curculionidae and Chrysomelidae could be attributed to the abundance of fruit in the urbanized areas. Beetle species, with the exception of Carabidae sp.2, were entirely absent from the less disturbed rural areas. The Carabidae family are categorized as terrestrial predators.

Previous disturbance studies involving beetles (Halme & Niemela, 1993; Koivula *et al.*, 2002; Lehvävirta *et al.*, 2006), found that generalist species are abundant and thrive in open habitat urbanized areas, especially where fragmentation and trampling have occurred. These urban habitats are usually more heterogeneous environments in terms of habitat type, patch configuration, size and isolation, and nutrient enrichment when compared to more natural rural environments (Niemelä, 1999a), and therefore favourable for these open habitat and generalist species. Disturbed habitats also create unfavourable conditions for specialized rural species, meaning less competitive pressure for the generalists.

The higher percentage organic covering in the urban areas, compared to rural regions, may be another determining factor for the large species richness present. Krooss & Schaefer (1998) study on Staphylinid

beetles, showed a higher species richness in unploughed plots (with more organic covering) than ploughed plots (with a higher bare-ground percentage).

The spiders collected were clustered near the suburban sites, and represented by the following species; Araneae sp.1 (SArau1), Araneae unidentified sp.1 (SArau3), Gnaphosidae sp.1 (SGnal) and Lycosidae sp.1 (SLyc). Similar to the beetles, the spiders were almost absent from the rural areas, which may possibly indicate the presence of opportunistic generalist predator spider species.

1.0

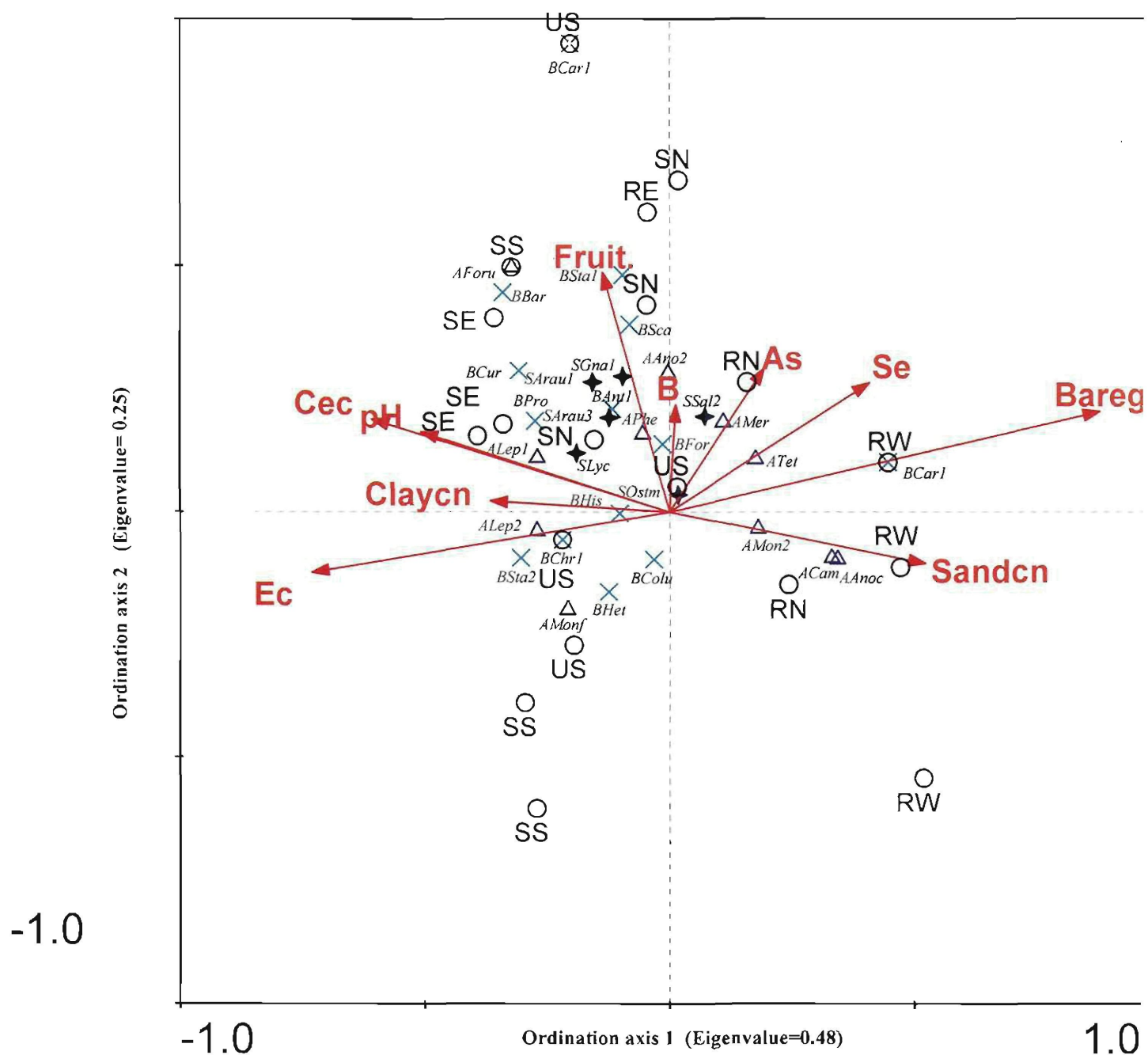


Figure 3.52: CCA ordination triplot showing the relationship between the epigeal arthropod morphospecies, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for November 2002 (abbreviations used for morphospecies are provided in Table 3.4 and for sites in Table 2.1)

February 2003 Analysis

From Figure 3.53 and Table 3.6 it is clear that bare ground (Bareg.) is also highly correlated with ordination axis 1 with a correlation coefficient 0.87 in the February 2003 analysis (Table 3.8). Other environmental factors which are somewhat correlated to ordination axis 1 are boron (B) and chromium (Cr) with correlation coefficients of -0.26 and 0.41 respectively. The percentage plants which were in fruit (Fruit) are most highly correlated with ordination axis 2 with a correlation coefficient of 0.75 (Table 3.6). The eigenvalue for the first ordination axis of the triplot is 0.73 and the second 0.45, representing 22.8 % and 38.3 % of the total variance respectively.

Similar trends seen in November's ordination, also occurred in February's determination. The ants were again aggregated close to the rural sites, where a high percentage of bare-ground existed and high values of Chromium and Sand concentration occurred. This supports the findings of high ant species richness and abundance present in the rural areas, completed in the ANOVA ant analysis for February.

The beetles were widely distributed between the urban and suburban sites, where fruit (Fruit.) was abundant and high values of electric conductivity (Ec), Cation-Exchange (CEC) and Boron (B) occurred. This supports findings from the ANOVA beetle analysis for February, of high beetle species richness and abundance found in the urbanized areas.

The majority of spiders were dispersed in close proximity to the suburban sites, although some rural species did occur. This supports findings from the ANOVA spider analysis for February, of higher spider abundances in the urbanized sites.

Table 3.6: Correlation coefficients for CCA Ordination Triplot in Figure 3.53

	Ordination axis 1	Ordination axis 2
Sandcn	0.076	-0.29
Claycn	0.072	0.27
pH	0.082	0.68
Ec	-0.38	0.54
B	-0.26	-0.19
Cr	0.41	-0.16
As	0.29	0.26
Sc	0.14	-0.67
Cec	-0.27	0.41
Bareg.	0.87	-0.16
Fruit.	-0.23	0.75

February

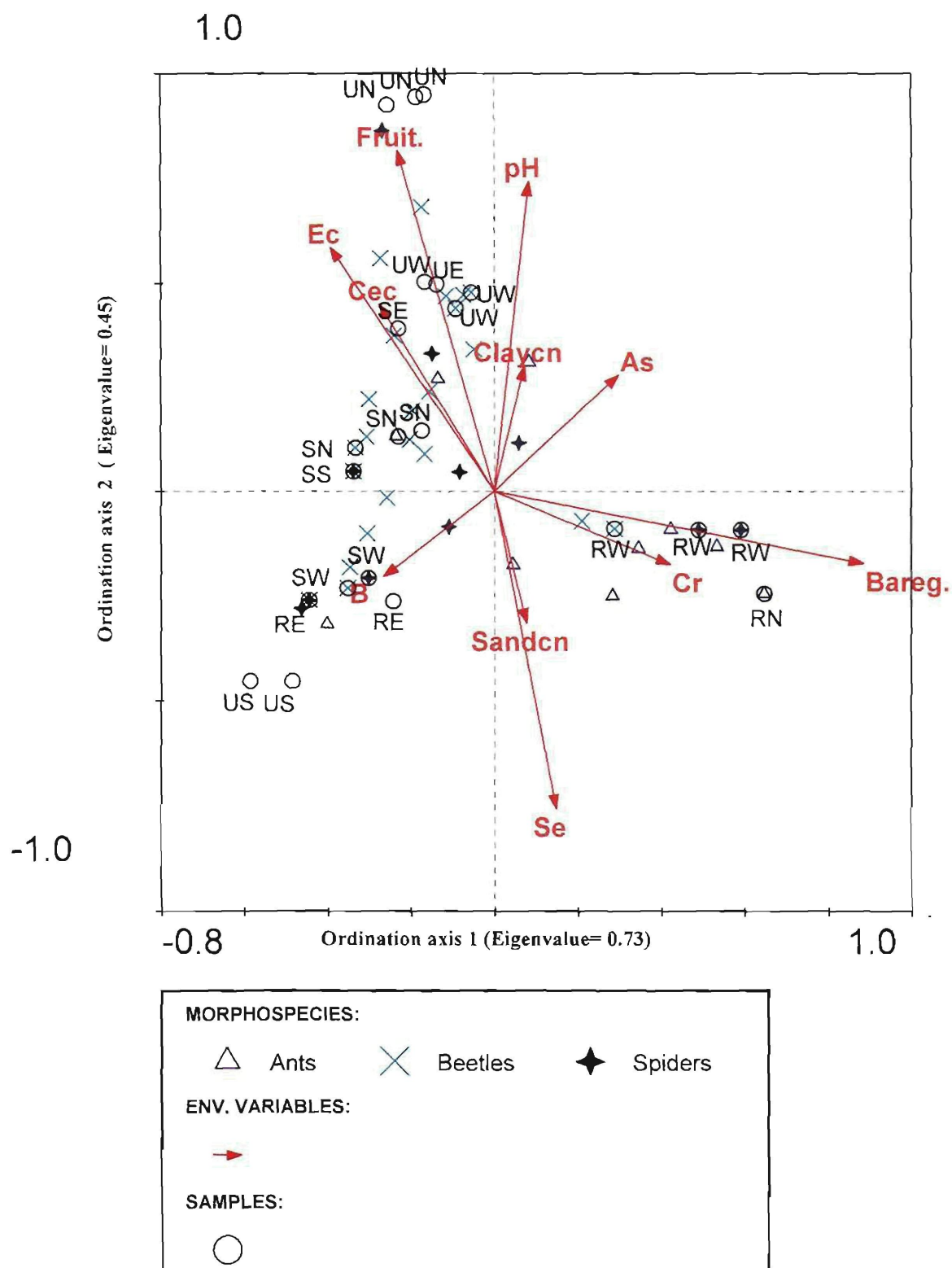


Figure 3.53: CCA ordination triplot showing the relationship between the epigeal arthropod groups, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003.

The morphospecies identified for each epigeal group in the previous ordination (Figure 3.53) are included in Figure 3.54. The ant morphospecies found predominantly at the rural sites were *Anoplolepis custodiens* (Anoc) and *Anoplolepis* sp.2 (Ano2) (highly correlated with the percentage bare-ground vector), *Camponotus* sp.1 (ACam), *Monomorium* sp.2 (AMon2) (correlated with the Chromium vector), *Meranoplus* sp.1 (AMer1) and *Lepisiota* sp.2 (ALep2) (correlated with the Sand concentration vector). The ant species found predominantly at the urban sites were *Lepisiota* sp.1 (ALep1) and *Monomorium fastidium* (AMonf). According to Andersen's functional group classification (Table 3.2), *Lepisiota* is an opportunistic species, which predominates at sites where stress or disturbance severely limits ant productivity and diversity, and where behavioural dominance is low and therefore reduced competition exists. *Monomorium fastidium* forms part of the Generalized Myrmicinae, which are unspecialized ants with wide habitat tolerances and abundant in habitats where dominant specialized ant groups are absent.

Beetle morphospecies that were predominant in the urban regions were Curculionidae sp.1 (BCur), Chrysomelidae sp.1 (BChr1), *Gonocephalum* sp.1 (BGon) (Tenebrionidae), *Brachinus* sp.1 (BBra) (Carabidae), Coleoptera sp.1 (BColl) and *Heteronychus arator* (BHet) (Scarabaeidae). The morphospecies associated with the suburban areas were Chrysomelidae sp.2 (BChr2), *Anthicus* sp.1 (BAnt1) and sp.2 (BAnt2), *Formicomus* sp.1 (BFor), Scarabaeidae sp.1 (BSca), Dermistidae sp.1 (BDer), *Protostrophus* sp.1 (BPro), *Heteroderus* sp.1 (BHet), *Gronops* sp.1 (BGro), Histeridae sp.1 (BHis), Staphylinidae sp.1 (BSta1), Carabidae sp.1 (BCar1) and *Saprinus* sp.1 (BSap). The families Chrysomelidae, Curculionidae are categorized as herbivorous species (according to Table 3.3) and were aggregated near to high abundance of fruit (Figure 3.54). Saprophagous morphospecies found were represented by the families, Tenebrionidae, Scarabaeidae and Dermistidae and were predominant in urbanized sites with high organic cover (matter). Terrestrial predators and possible predators (Table 3.3) collected were represented by Carabidae, Histeridae and Staphylinidae. As discussed earlier, these carnivorous predators have polyphagous (versatile feeders) habits and can therefore adapt and be abundant in urbanized areas. Rural species captured were *Onthophagus* sp.1 (BOnt) (Scarabaeidae) and Staphylinidae sp.2 (BSta2). Scarabaeidae and Staphylinidae also represent saprophagous and carnivorous species respectively.

The spider morphospecies widely distributed over the urban and suburban sites, were Araneae juvenile sp.1 (SAraj), Lycosidae sp.1 (SLyc), *Osteanus melanopygius* (SOstm) (Linyphiidae), Salticidae sp.1 (SSal1) and sp.2 (SSal2), *Apochinomma* sp.1 (SApo) (Corinnidae), Gnaphosidae sp.1 (SGnal) and Araneae unidentified sp.1 (SArau1). Two morphospecies collected at the rural sites were *Palfuria* sp.1 (SPal) (Zodariidae) and Araneae unidentified sp.2 (SArau2).

February

1.0

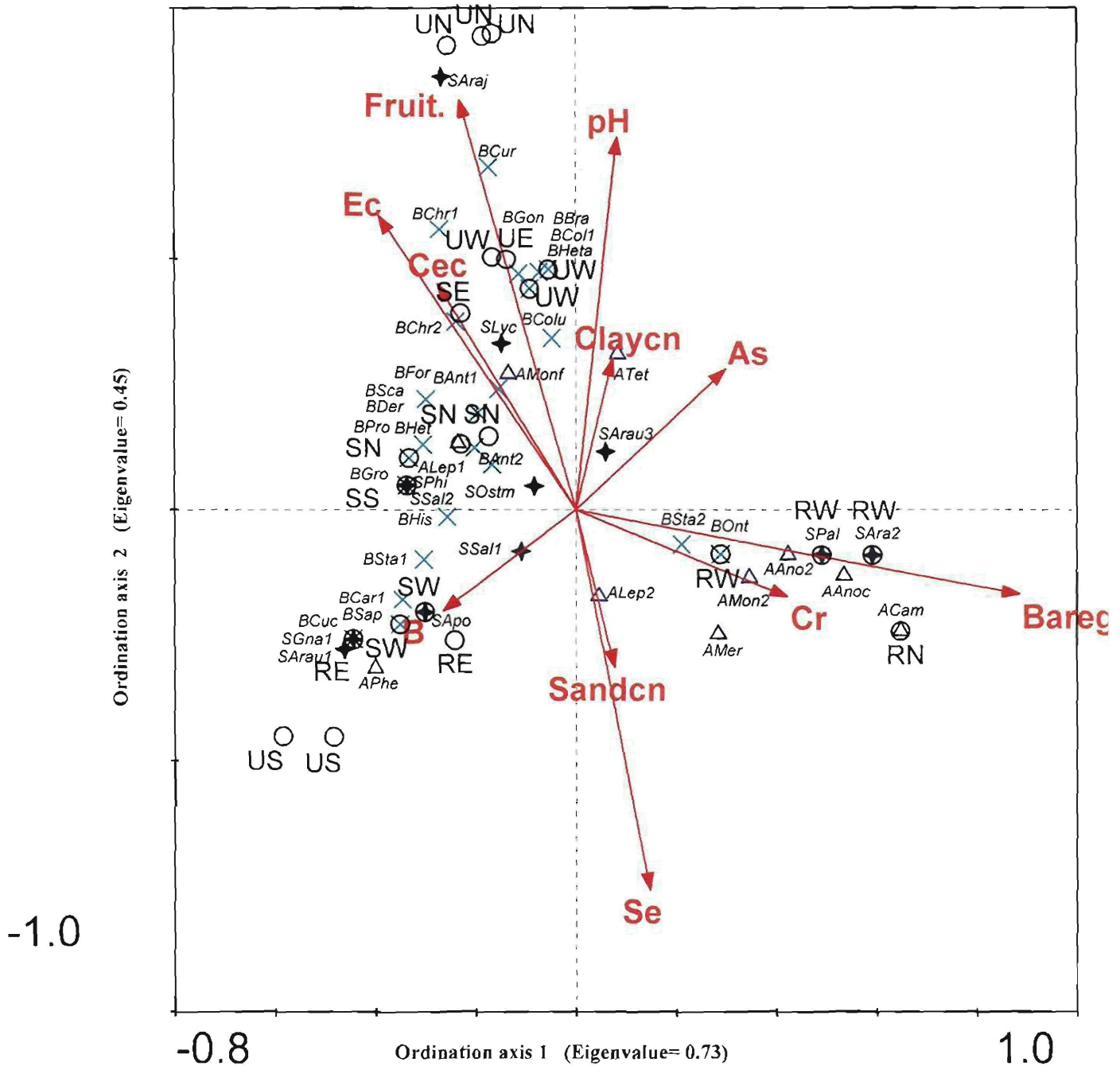


Figure 3.54: CCA ordination triplot showing the relationship between the epigeal arthropod morphospecies, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for February 2003 (abbreviations used for morphospecies are provided in Table 3.4 and for sites in Table 2.1).

July 2003 Analysis

From Figure 3.55 and Table 3.7 it is clear that bare ground (Bareg.) and fruit (Fruit) is most highly correlated with ordination axis 1 with a correlation coefficients of -0.55 and 0.80 respectively (Table 3.7). Other environmental factors which are closely correlated to ordination axis 1 are clay concentration (Claycn), sand concentration (Sandcn.), cation exchange (Cec) with correlation coefficients of 0.54, -0.14 and 0.20 respectively. Selenium (Se) and pH are most highly correlated with ordination axis 2 with correlation coefficients of 0.43 and -0.33, respectively (Table 3.7). The eigenvalue for the first ordination axis of the triplot is 0.59 and the second 0.48, representing 15.3 % and 28.7 % of the total variance respectively.

This ordination (Figure 3.55) is very congested compared to November and February's determinations, meaning that species, environmental components and sampling sites aren't as well distributed and distinguishable. Certain trends are however recognizable such as ants that were aggregated close to high percentage bare-ground, and beetles that were once again distributed around abundant fruit and high clay concentration.

In Figure 3.56, the ant morphospecies more closely associated with high percentage bare-ground (Bareg) and sand concentration (Sandcn) were *Anoplolepis* sp.2 (AAno2), *Monomorium fastidium* (AMonf), *Monomorium* sp.2 (AMon2) and *Monomorium* sp.3 (AMon3), *Lepisiota* sp.1 (ALep1) and *Lepisiota* sp.2 (ALep2). *Anoplolepis* species are expected to have a preference for patches of bare-ground and sandy habitats, as this environment is beneficial for nest building.

The beetle morphospecies associated with abundant fruit and high clay concentration were Cucujoidae sp.1(BCuc), *Gonocephalum* sp.1 (BGon) (Tenebrionidae), Chrysomelidae sp.1 (BChr1), Aphodidae sp.1 (BAph), Staphylinidae sp.1 (BSta1), Staphylinidae sp. 2 (BSta2) and Carabidae sp.2 (BCar2) (Figure 3.47). The Chrysomelidae family are categorized as herbivorous species (Table 3.3) and therefore found at sites where an abundance of fruit occurred.

Table 3.7: Correlation coefficients for CCA Ordination Triplot in Figure 3.55

	Ordination axis 1	Ordination axis 2
Sandcn	-0.14	0.01
Claycn	0.54	-0.09
pH	-0.07	-0.33
Ec	-0.11	0.04
Cr	-0.05	0.01
As	0.12	-0.03
Se	-0.25	0.43
Cec	0.20	0.01
Bareg.	-0.55	-0.07
Fruit.	0.80	-0.06

July

1.0

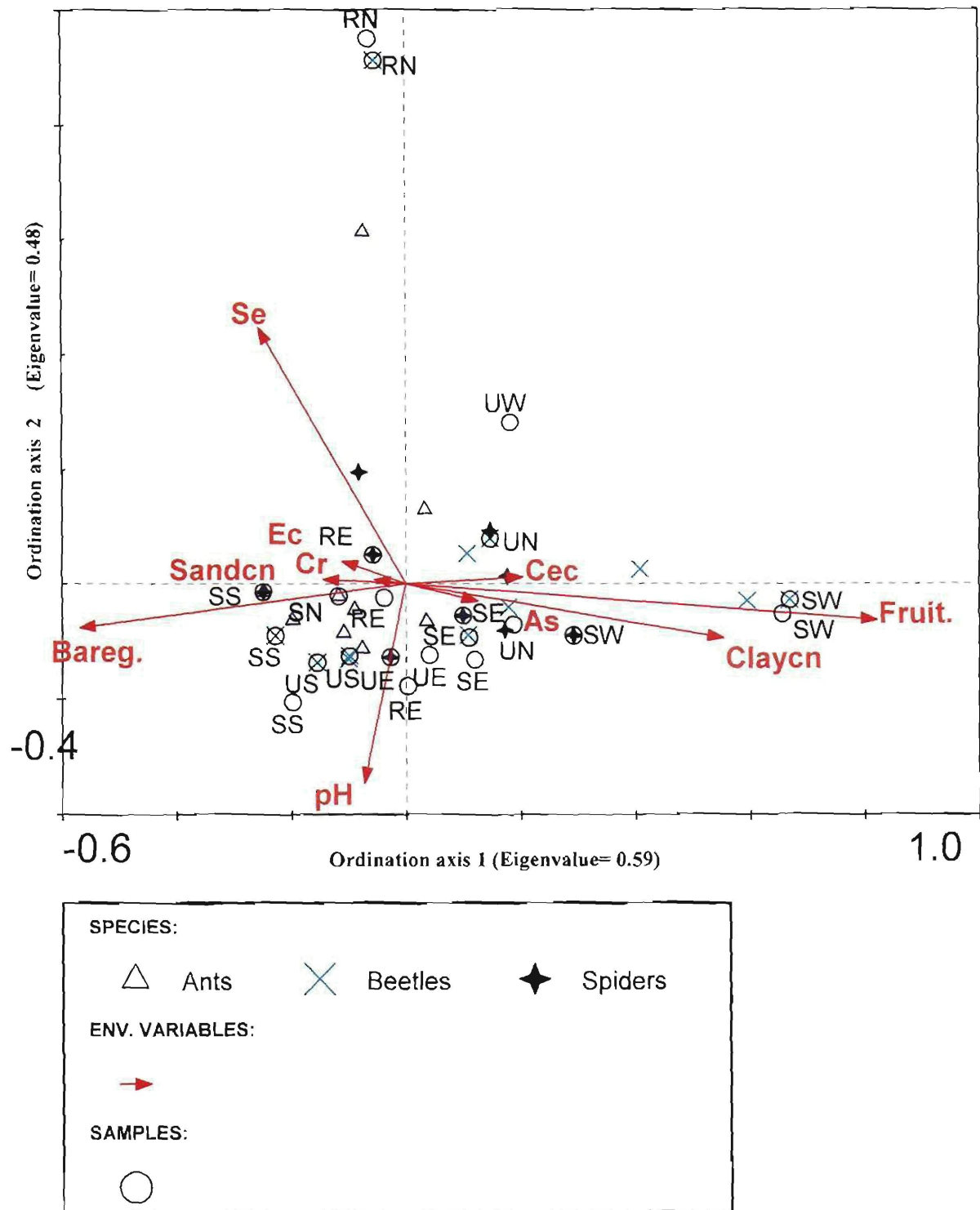


Figure 3.55: CCA ordination triplot showing the relationship between the epigeal arthropod groups, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003.

July

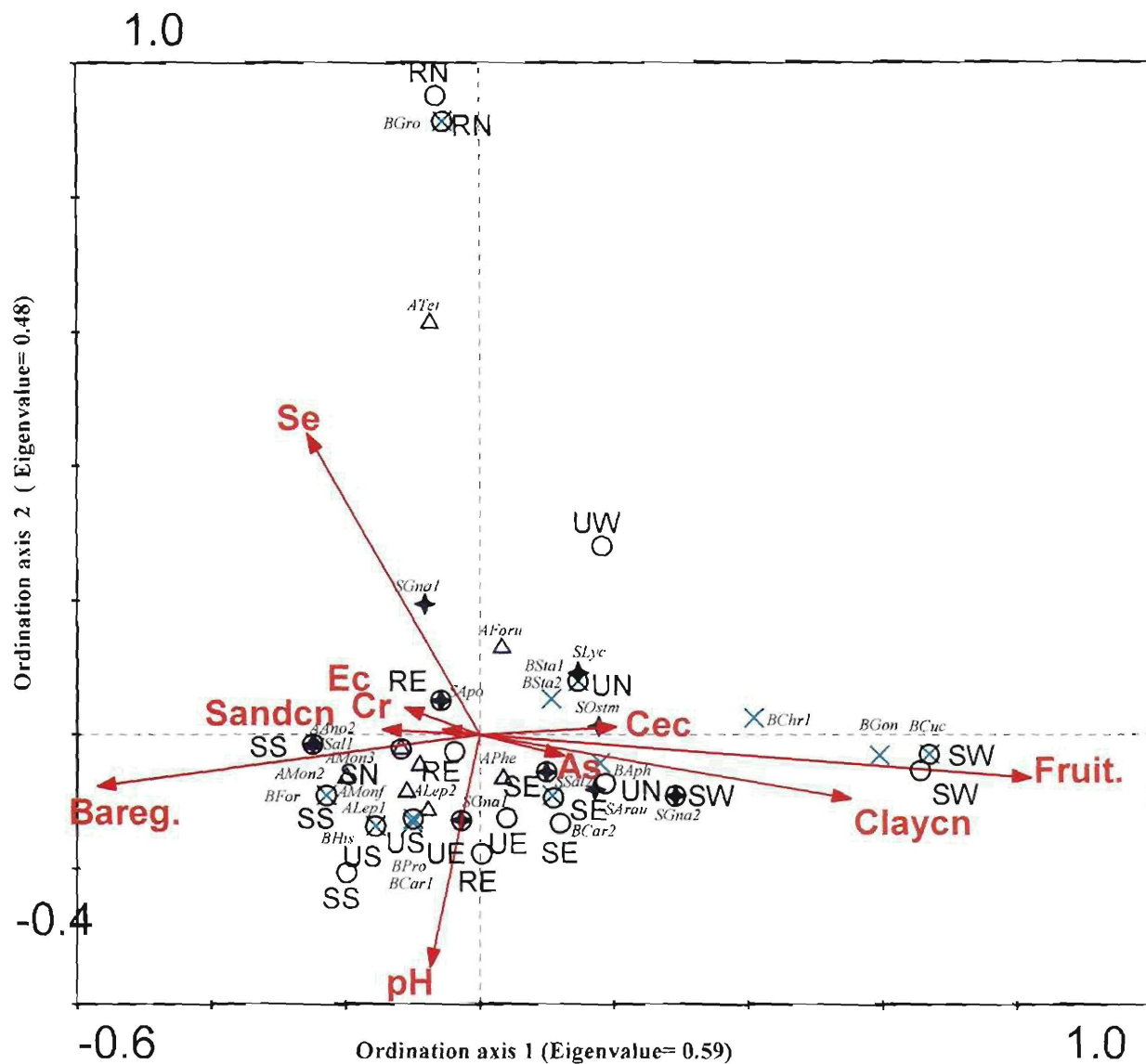


Figure 3.56: CCA ordination triplot showing the relationship between epigeal arthropod morphospecies, sampling sites and related soil and vegetation factors collected in grasslands along an urbanization gradient in the Potchefstroom Municipal area for July 2003 (abbreviations used for morphospecies are provided in Table 3.4 and for sites in Table 2.1).

4: Conclusions

To understand the importance of the current study, one needs to keep in mind that it is part of a larger project which aims to produce a system of bio-indication for environmental conditions along an urbanization gradient. This is a new field of research in South Africa, meaning an establishment of baseline data as well as identification of possible epigeal arthropod parameters in the assessment of possible future ecological studies.

As expected, seasonal changes had a large impact on the abundance and morphospecies numbers of the epigeal arthropods collected. The largest number of morphospecies and individuals captured for the individual groups (ants, beetles and spiders) were for the sampling months of November 2002 and February 2003. The occurrence of high arthropod activity and large population numbers during the summer months may be attributed to the fluctuation of population numbers after breeding and an increase in available prey (similar findings seen in the study of Bestelmeyer & Wiens, 2003).

Urbanization seemed to have a defined impact on the epigeal arthropod diversity along the urban to rural gradient that was studied. Of the groups, ants (Formicidae) constituted by far the largest part of the arthropods collected (3452 ant individuals collected compared to 417 beetle individuals and 135 spider individuals) and thereby the most vulnerable group on which anthropogenic disturbance (urbanization) could have an effect. A similar trend occurred in arthropod studies performed in Australia (Andersen 1995, 1997 a, 1997b, 1997c; Read & Andersen 2000; Andersen *et al.*, 2002 and Andersen *et al.*, 2003), where ants were found to be the dominant group collected in conditions comparable to South Africa (namely semi- arid savannah). Decreasing trends were observed with respect to the total number of ant morphospecies and total number of individuals collected from the rural sites in comparison to the more urban sites (along the urbanization gradient) (ANOVA ant analysis for February 2003 showed statistical significant differences ($p < 0.05$) between the rural, suburban and urban sites from which the ants were collected). Consideration was also made to the influence environmental factors may have had on the distribution of the ant group. Bareground and sand concentration played a major role with respect to the distribution of the morphospecies found at the rural sites. The ant morphospecies collected at the rural sites were clearly associated with these two environmental factors (CCA ordinations for November 2003 and February 2004). This is supported by literature which mentions that sandy habitats with patches of bare-ground provide more favourable micro-habitats for ant species to roam and scavenged in and are advantageous for nest building (Andersen *et al.*, 2002) The ant morphospecies collected at the urban sites were clearly generalists and opportunistic species

(belonging to the Opportunistic and Generalized Myrmicinae functional groups) that thrived in altered or disturbed habitats (namely urbanized sites) where competitive pressure from the more behaviourally dominant specialized ant species (Subordinate Camponotini, Climate specialists and Dolichoderinae) were absent.

The beetle group, although not as abundant as the ants, had the highest total number of morphospecies (26) in comparison to the other two epigeal groups (spiders-14 morphospecies and ants-12 morphospecies) and therefore the greatest morphospecies diversity collected in the current study. When examining the impact, urbanization may have had on the beetle diversity and abundances, a clear trend was observed, where the total number of beetle morphospecies and individuals were greater in the urbanized sites than the rural sites (seen in ANOVA beetle analysis). This trend may be due to the abundance of opportunistic predatory beetle species in these urbanized sites, which are considered to be trophic generalists and so find it easier to establish themselves as a group and persist in altered or disturbed habitats (than do the herbivorous species) and perhaps have greater physiological resilience to withstand unfavourable conditions (Becker, 1975) Also, the occurrence of the Saprophagous (feed on decaying organic matter) beetle morphospecies in the urban habitats could have accounted for the greater beetle diversity and abundance found there. With consideration to the environmental effect, clay concentration and abundance of fruit (which appeared to be higher in the urban areas) seemed to be the two determining factors around which the majority of beetle morphospecies associated with (frugivorous beetles) (clearly seen in the CCA ordinations for November 2002 and February 2003).

The spider group, although the least abundant in comparison to the ant and beetle groups, did have the second largest number of morphospecies collected (14-morphospecies). When examining the effect of urbanization, this group seemed to be the least effected by the disturbance factor with respect to differences in morphospecies numbers and individuals. The spider group displayed similar trends with respect to the beetle group where the total number of spider morphospecies and individuals remained high in the urban areas (ANOVA spider analysis). The majority of the spider and beetle morphospecies collected at the urban sites appeared to be opportunistic generalist predator species who thrive in heterogeneous environments which offer diverse prey, providing the opportunity to feed on a variation of insect prey (these beetle and spider groups may be considered as true generalists) (Ekschmitt *et al.*, 1997; Sunderland, 1975; Hengeveld, 1980 and Nyffeler *et al.*, 1994). In other ecological surveys, spiders (e.g. wolf spiders) have been studied simultaneously with ground beetles because they represent a functional unit, namely a trophic guild (Lang *et al.*, 1999).

From the results of the analysis presented in this study, it is clear that urbanization had the most pronounced effect on ant diversity and abundances in comparison to the other two epigeal groups (beetles and spiders)

discussed. The ant group may therefore be best suited as a biological indicator in future disturbance studies performed under local South African conditions. This recommendation contrasts the European belief, where “biological indicative” groups such as beetles (e.g. carabids) have been used successfully for many years in disturbance gradient studies. As previously mentioned an international database (GLOBENET) exists (started in 1998 at the University of Helsinki, Finland) where ecological data from carabid beetle gradient studies may be accessed and global patterns identified (Niemelä *et al.*, 2000). When considering the type of environment, European conditions are dissimilar to South Africa and therefore may be more reasonable to compare ecological arthropod studies performed in similar conditions as in the case of Australian studies (Australia and South Africa have relatively similar climate and habitat types in comparison to Europe). Ants have been successfully used as bio-indicators in the Australian environment (used in Australian mining industry) for more than 20 years, because of this group’s practicality and reliable record of use (Andersen, 1997a). It is mentioned that ants are ideal candidates to use as bio-indicators in the Australian environment for the following reasons (Majer, 1983; Greenslade, 1984; Andersen, 1990):

- This group’s exceptional high abundance and diversity.
- Their ecological importance at all trophic levels.
- Relative ease of sampling and sorting of this group (species may be classified into functional groups, Andersen, 1995).
- Their sensitivity to ecological change.

Ants have also been used in a Biodiversity Integrity Index, as a framework for the estimation of biodiversity changes at regional scales (Majer & Beeston, 1996). This process involves the identification of major regional land uses, and the impacts of each land use on ant biodiversity (similar to the current study where the diversity of arthropods collected from different land use types, namely urban, suburban and rural, were compared). Ants play an important role in the environment. They act as key ecosystem engineers (Woinarski *et al.*, 2002), have major effects on soil structure and function (de Bruyn & Conacher, 1990), energy flow (Matthews & Kitching, 1984) and seed dynamics (Andersen & Morrison, 1998; Andersen *et al.*, 2000). Ants are considered as the most dominant terrestrial invertebrate group in Australian studies (Andersen, 2003) and should therefore be utilized in future local ecological disturbance studies.

REFERENCES:

- ABBOTT, I., BURBIDGE, T., STREHLOW, K., MELLICAN, A. & WILLS, A. 2003. Logging and burning impacts on cockroaches, crickets, grasshoppers and spiders in Jarrah forest, Western Australia. *Forest Ecology and Management* **174**: 383-399.
- ALARUIKKA, D., KOTZE, D.J., MATVEINEN, K. & NIEMELÄ, J. 2002. Carabid beetle and spider assemblages along a forested urban-rural gradient in southern Finland. *Journal of Insect Conservation* **6**: 195-206.
- ALIG, G.I. & HEALY, R.G. 1987. Urban and built-up land area changes in the United States: an empirical investigation of determinants. *Land Economy* **63**: 215-226.
- ANDERSEN, A.N. 1988. Immediate and longer-term effects of fire on seed predation by ants in sclerophyllous vegetation in south-eastern Australia. *Australian Journal of Ecology* **13**: 285-293.
- ANDERSEN, A.N. 1990. The use of ant communities to evaluate change in Australian terrestrial ecosystems: a review and a recipe. *Proceedings of the Ecological Society of Australia* **16**: 347-357.
- ANDERSEN, A.N. 1991. Sampling communities of ground-foraging ants: pitfall catches compared with quadrat counts in an Australian tropical savanna. *Australian Journal of Ecology* **16**: 273-279.
- ANDERSEN, A.N. 1995. A classification of Australian ant communities, based on functional groups which parallel plant life-forms in relation to stress and disturbance. *Journal of Biogeography* **22**: 15-29.
- ANDERSEN, A.N. 1997a Ants as indicators of ecosystem restoration following mining: a functional group approach. (In Hale, P. & Lamb, D., ed. *Conservation outside nature reserves*. University of Queensland Press, Queensland. p.132-137).
- ANDERSEN, A.N. 1997b Using ants as bioindicators: multi-scale issues in ant community ecology. *Conservation Ecology* **1**:1-9.

- ANDERSEN, A.N. 1997c. Functional groups and patterns of organization in North American ant communities: a comparison with Australia. *Journal of Biogeography* **24**: 433-460.
- ANDERSEN, A.N. 1999. My bioindicator or yours? Making the selection. *Journal of Insect Conservation* **3**: 61-64.
- ANDERSEN, A.N. 2000. The Ants of Northern Australia: A guide to the Monsoonal Fauna. CSIRO Publications, Melbourne.
- ANDERSEN, A.N. & MCKAIGE, M.E. 1987. Ant communities at Rotamah island, Victoria, with particular reference to the disturbance of *Rhytidoponera tasimaniensis*. *Proceedings of the Royal Society of Victoria* **99**: 141-146.
- ANDERSEN, A.N. & MORRISON, S. 1998. Myrmecochory in Australia's seasonal tropics: Effects of disturbance on distance dispersal. *Australian Journal of Ecology* **23**: 483-491.
- ANDERSEN, A.N., HOFFMAN, B.D., MULLER, W.J. & GRIFFITHS, A.D. 2002. Using ants as bioindicators in land management: simplifying assessment of ant community responses. *Journal of Applied Ecology* **39**: 8-17.
- ANDERSEN, A.N., FISHER, A., HOFFMAN, B.D., READ, J.L., & RICHARDS, R. 2003. The use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. CSIRO Sustainable Ecosystems and Tropical Savannas CRC, Tropical Ecosystems Research Centre, PMB 44 Winnellie, NT 0822, Australia.
- ANDRE, H.M., DUCARME, X. & LEBRUN, PH. 2002. Soil Biodiversity: myth, reality or conning? *Oikos* **96**: 3 – 24.
- ANTHONY, C.D., FORMANOWICZ, D.R. & BRODIE, E.D. 1991. Effect of mine reclamation on ant community structure in eastern Texas. *Texas Journal of Science* **43**: 261-272.
- ANTHROP, M. 2000. Changing patterns in the urbanized countryside of Western Europe. *Landscape Ecology* **15**: 257-270.
- BALDUF, W.V. 1935. The Bionomics of Entomophagous Coleoptera. John S. Swift, St. Louis.

- BAWCOMBE, P. & KUIJERS, A. 1988. Potchefstroom 1838-1988. Potchefstroom: Departement Openbare Betrekkinge, Potchefstroomse Universiteit vir Christelike Hoër Onderwys. 78pp.
- BECKER, P. 1975. Island colonization by carnivorous and herbivorous Coleoptera. Department of Zoology, University of Michigan, Ann Arbor, Michigan, U.S.A.
- BESTELMEYER, B.T. & WIENS, J.A. 1996. The effects of land use on the structure of ground-foraging ant communities in the Argentine Chaco. *Ecological Applications* **6**: 1225-1240.
- BESTELMEYER, B.T. 2000a. The trade-off between thermal tolerance and behavioural dominance in a subtropical South American ant community. *Journal of Animal Ecology* **69**: 998-1009.
- BESTELMEYER, B.T. 2000b. A multiscale perspective on ant diversity in semiarid landscapes. Dissertation. Colorado State University, Fort Collins, CO, U.S.A.
- BESTELMEYER, B.T. & WIENS, J.A. 2003. Scavenging ant foraging behavior and variation in the scale of nutrient redistribution among semi-arid grasslands. *Journal of Arid Environments* **53**: 373-386.
- BLAIR, R.B., 1996. Land use and avian species diversity along an urban gradient. *Ecology Applied* **6**: 506-519.
- BLAIR, R.B., 1999. Birds and butterflies along an urban gradient: Surrogate taxa for assessing biodiversity? *Ecology Applied* **9**: 164-170.
- BORROR, D.J. & DELONG, D.M. 1971. An introduction to the study of insects, 3rd ed. Holt, Rinehart & Winston, New York.
- BOTKIN, D. 1990. Discordant Harmonies. Oxford University Press, New York.
- BOTKIN, D.B. & BEVERIDGE, C.E. 1997. Cities as environments. *Urban Ecosystems* **1**: 3-19.
- BREDENKAMP, G.J. & VAN ROOYEN, N. 1996. Dry Sandy Highveld Grassland. (In Low, A.B. & Rebelo, A.G., ed. Vegetation of South Africa, Lesotho and Swaziland. Pretoria: Dept of Environmental Affairs & Tourism. p.41-42).

- BROWN, J. & ROUGHGARDEN, J. 1989. US ecologists address global change. *Trends in Ecological Evolution* **4**: 255-256.
- CAIRNS, J. 1987. Disturbed ecosystems as opportunities for research in restoration ecology (*In Restoration ecology: a synthetic approach to ecological research*. Cambridge University Press, Cambridge, England. p. 307-320).
- CAIRNS, J. 1995. Protecting our national and global life support systems. (*In Rehabilitating damaged ecosystems*. (2nd ed.). CRC Press. p 142-147).
- CALLENDER, E. & RICE, K.C., 2000. The urban environmental gradient: Anthropogenic influences on the spatial and temporal distributions of lead and zinc in sediments. *Environmental Science and Technology* **34**: 232-238.
- CARREIRO, M.M., HOWE, K., PARKHURST, D.F. & POUYAT, R.V., 1999. Variation in quality and decomposability of red oak leaf litter along an urban-rural gradient. *Biology of Fertile Soils* **30**: 258-268.
- CERDA, X., RETANA, J. & CROS, S. 1997. Thermal disruption of transitive hierarchies in Mediterranean ant communities. *Journal of Animal Ecology* **66**: 363-374.
- CHUDZICKA, E. & SKIBINSKA, E. 1998. Diversity of reactions of insect communities as a response to anthropogenic pressure. *Memorabilia Zoology* **51**: 13-30.
- CILLIERS, S.S. 1998. Phytosociological studies of urban open spaces in Potchefstroom, North West Province, South Africa. Unpublished. P.hD. thesis. Potchefstroom University for Christian Higher Education, Potchefstroom.
- CILLIERS, S.S., MULLER, N. & DREWES, E. 2004. Overview on urban nature conservation: situation in the western-grassland biome of South Africa. *Urban Forestry & Urban Greening* **3**: 49-62.
- CLARK, C.U. 1995. On the food habits of certain dung and carrion beetles. *Journal of the New York Entomological Society* **3**: 61-67
- CLAUSEN, C.P. 1940. Entomophagous Insects. McGraw-Hill, New York.

- CRAUL, P.J. 1985. A description of urban soils and their desired characteristics. *Journal of Arboriculture* **11**: 330-339.
- DAVIS, B.N.K. 1978. Urbanization and the diversity of insects (*In Diversity of Insect Faunas*. Symposium of the Royal Entomological Society of London. 9. Blackwell. Oxford. p.126-138).
- DE BRUYN L.A.L. & CONACHER A.J. 1990. The role of termites and ants in soil modification: A review *Australian Journal of Soil Research* **28**: 55-93.
- DIDHAM, R.K., HAMMOND, P.M., LAWTON, J.H., EGGLETON, P. & STORK, N.E. 1998. Beetle species responses to tropical forest fragmentation. *Ecological Monographs* **68**: 295-323.
- DOUGLAS, I. 1994. Human settlements (*In Changes in land use and land cover: a global perspective*. Cambridge University Press. Cambridge. p. 149-169).
- DUFFEY, E. 1975. The effects of human trampling on the fauna of grassland litter. *Biological Conservation* **7**: 255-274.
- EKSCHMITT, K., WEBER, M. & WOLTERS, V., 1997. Spiders, Carabids and Staphylinids: The ecological potential of predatory macro-arthropods. *Fauna in Soil Ecosystems* 307-362.
- EVERSHAM, B.C., ROY, D.B. & TELFER, M.G. 1996. Urban, industrial and other manmade sites as analogues of natural habitats for Carabidae. *Annales Zoologici Fennica* **33**: 149-156.
- FLORGARD, C. 2000. Long-term changes in indigenous vegetation preserved in urban areas. *Landscape and Urban Planning* **52**: 101-116.
- GANDHI, K.J.K., SPENCE, J.R., LANGOR, D.W. & MORGANTINI, L.E. 2001. Fire residuals as habitat reserves for epigaeic beetles (Coleoptera: Carabidae and Staphylinidae). *Biological Conservation* **102**: 131-141.
- GERMAINE, S.S. & WAKELING, B.F. 2001. Lizard species distributions and habitat occupation along an urban gradient in Tucson, Arizona, USA. *Biological Conservation* **97**: 229-237.
- GIBBS, J.P. & STANTON, E.J. 2001. Habitat fragmentation and arthropod community change: Carrion beetles, phoretic mites and flies. *Ecology Applied* **11**: 79-85.

- GINGRICH, S.E. & DIAMOND, M.L. 2001. Atmospherically derived organic surface films along an urban-rural gradient. *Environmental Science and Technology* **35**: 4031-4037.
- GODRON, M. & FORMAN, R.T.T. 1983. Landscape modification and changing ecological characteristics. (*In* Disturbance and ecosystems, components and response. Springer-Verlag. New York. pp.12-28).
- GRANDCHAMP, A.C., NIEMELÄ, J. & KOTZE, J. 2000. The effects of trampling on assemblages of ground beetles (Coleoptera, Carabidae) in urban forests in Helsinki, Finland. *Urban Ecosystems* **4**: 321-332.
- GREENSLADE, P.J.M. 1973. Sampling ants with pitfall traps: digging-in effects. *Insect Society* **20**: 343-353.
- GREENSLADE, P.J.M. 1978. Ants. The physical and biological features of Kunoth paddock in central Australia. CSIRO Division of Land resources technical paper No.4. Canberra. Australia.
- GREENSLADE, P.J.M. & MOTT, J.J. 1979. Ants of sown pastures in the Katherine area, Northern Territory, Australia (Hymenoptera: Formicidae) (*In* Proceedings of the second Australian conference on grassland invertebrate ecology. Government Printer. Wellington. pp.42-49).
- GREENSLADE, P.J.M. & GREENSLADE, P. 1984. Invertebrates and environmental assessment. *Environment and Planning* **3**: 13-15.
- GRIME, J.P. 1979. Plant Strategies and Vegetation Processes. John Wiley, Chichester.
- GUNTENSPERGEN, G.R. & LEVENSON, J.B. 1997. Understorey plant species composition in remnant stands along an urban-to-rural land-use gradient. *Urban Ecosystems* **1**: 155-169.
- HAHS, A.K. & MCDONNELL, M.J. 2006. Selecting independent measures to quantify Melbourne's urban-rural gradient. *Landscape and Urban Planning* **78**: 435-448.
- HALME, E. & NIEMELÄ, J. 1993. Carabid beetles in fragments of coniferous forests. *Annales Zoologici Fennici* **30**: 17-30.
- HELIOLA, J., KOIVULA, M. & NIEMELÄ, J. 2001. Distribution of carabid beetles (Coleoptera, Carabidae) across a boreal forest-clearcut ecotone. *Conservation Biology* **15**: 370-377.

- HENGVELD, R. 1980. Qualitative and quantitative aspects of the food of ground beetles (Coleoptera, Carabidae): A review. *Netherlands Journal of Zoology* **30**: 555-563.
- HUHTA, V. 1965. Ecology of spiders in the soil and litter of Finnish forests. *Annales Zoologici Fennica* **2**: 260-308.
- HUTCHINSON, K.J. & KING, K.L. 1980. The effects of sheep stocking level on invertebrate abundance, biomass and energy utilization in a temperate, sown grassland. *Journal of Applied Ecology* **17**: 369-387.
- JUEN, A. & TRAUGOTT, M. 2004. Spatial distribution of epigaeic predators in a small field in relation to season and surrounding crops. *Agriculture, Ecosystems and Environment* **103**: 613-620.
- KENT, M. & COKER, P. 2000. Vegetation Description and Analysis. John Wiley & Sons. Great Britain.
- KOIVULA, M. 2002a. Alternative harvesting methods and boreal carabid beetles (Coleoptera, Carabidae). *Forest Ecology and Management* **167**: 103-121.
- KOIVULA, M. 2002b. Boreal carabid beetles (Coleoptera, Carabidae) assemblages in thinned uneven-aged and clear-cut spruce stands. *Annales Zoologici Fennica* **39**: 131-149.
- KOSTEL-HUGHES, F., YOUNG, T.P. & MCDONNELL, M.J. 1998. The soil seed bank and its relationship to the above ground vegetation in deciduous forests in New York City. *Urban Ecosystems* **2**: 43-61.
- KOTZE, D.J. & SAMWAYS, M.J. 1999. Support for the multi-taxa approach to biodiversity assessment, as shown by epigaeic invertebrates in an afro-montane forest. *Journal of Insect Conservation* **3**: 125-143.
- KOTZE, D.J. & O'HARA, R.B. 2003. Species decline-but why? Explanations of carabid beetle (Coleoptera, Carabidae) declines in Europe. *Oecologia* **135**: 138-148.
- KROOSS, S., & SCHAEFER, M. 1998. The effect of different farming systems on epigeic arthropods: a five-year study on the rove beetle fauna (Coleoptera: Staphylinidae) of winter wheat. *Agriculture, Ecosystems and Environment* **69**: 121-133.
- KRUGER, G.P. 1983. Terrain morphological map of Southern Africa. Soil and Irrigation Research Institute, Department of Agriculture. Pretoria. Government Printer.

- LANDSBERG, J., JAMES, C.D., MORTON, S.R., HOBBS, T., STOL, J., DREW, A. & TONGWAY, H. 1997. The effects of artificial sources of water on rangeland biodiversity. Environment Australia and CSIRO, Lyneham ACT.
- LANG, A., FILSER, J. & HENSCH, J.R. 1999. Predation by ground beetles and wolf spiders on herbivorous insects in a maize crop. *Agriculture, Ecosystems and Environment* **72**: 189-199.
- LEHVÄVIRTA, S. 1999. Trampling and urban forest structure. *Urban Ecosystems* **3**: 45-56.
- LEHVÄVIRTA, S., KOTZE, D.J., NIEMELA, J., MANTYSAARI, M. & O'HARA, B. 2006. Effects of fragmentation and trampling on carabid beetle assemblages in urban woodlands in Helsinki, Finland. *Urban Ecosystems* **9**: 13-26.
- LEHVÄVIRTA, S. & RITA, H. 2002. Natural regeneration of trees in urban woodlands. *Journal of Vegetation Science* **13**: 57-66.
- LIDDLE, M.J. 1997. Recreation ecology: the ecological impact of outdoor recreation and ecotourism. Chapman and Hall. London.
- LOVEI, G.L., & SUNDERLAND, K.D. 1996. Ecology and behaviour of ground beetles (Coleoptera: Carabidae). *Annual Review of Entomology* **41**: 231-256.
- LOVETT, G.M., TRAYNOR, M.M., POUYAT, R.V., CARREIRO, M.M., ZHU, W.X. & BAXTER, J.W., 2000. Atmospheric deposition to oak forests along an urban-rural gradient. *Environmental Science and Technology* **34**: 4294-4300.
- LUDWIG, D.F. 1989. Anthropic ecosystems. *Bulletin of the Ecological Society of America* **70**: 12-14.
- LUCK, M. & WU, J. 2002. A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecology* **17**: 327-339.
- MACNALLY, R. 1996. A winter's tale: Among-year variation in bird community structure in a south-eastern Australian forest. *Australian Journal of Ecology* **21**: 280-291.
- MAGURA, T., TOTHMERESZ, B. & MOLNAR, T. 2001. Forest edge and diversity: carabids along forest-grassland transects. *Biodiversity and Conservation* **10**: 287-300.

- MALMIVAARA, M., LOFSTROM, I. & VANHA-MAJAMAA, I. 2002. Anthropogenic effects on understorey vegetation in *Myrtillus* type urban forests in Southern Finland. *Silva Fennica* **36**: 367-381.
- MAJER, J.D. 1978. An improved pitfall trap for sampling ants and other epigaeic invertebrates. *Journal of the Australian Entomological Society* **17**: 261-262.
- MAJER, J.D. 1983. Ants: bio-indicators of mine site rehabilitation, land-use and land conservation. *Environmental Management* **7**: 375-383.
- MAJER, J.D. & FLUGGE, R. 1984. The influence of spraying on Argentine and native ants. Western Australian Institute of Technology and School of Biology.
- MAJER, J.D. & BEESTON, G. 1996. The biodiversity integrity index: An illustration using ants in Western Australia. *Conservation Biology* **10**: 65-73.
- MANK, H.G. 1923. The biology of Staphylinidae. *Annals of the Entomological Society of America* **16**: 220-237.
- MANSOUR, F. & HEIMBACH, U. 1993. Evaluation of lycosid, micryphantid and linyphiid spiders as predators of *Rhopalosiphum padi* (Hom: Aphididae) and their functional response to prey density- laboratory experiments. *Entomophaga* **38**: 79-87.
- MATTHEWS E. G. & KITCHING R.L. 1984. Insect Ecology. University of Queensland Press. Brisbane.
- MCDONNELL M. & PICKETT, S.T.A. 1990. Ecosystem structure and functions along urban-rural gradients: An unexploited opportunity in Ecology. *Ecology* **71**: 1232-1237.
- MCDONNELL M., PICKETT, S.T.A. & POUYAT, R.V. 1993. The application of the ecological gradient paradigm to study urban effects (*In* Humans as components of ecosystems: subtle human effects and the ecology of populated areas. Springer-Verlag. New York. p. 175-189).
- MCDONNELL, M.J., PICKETT, S.T.A., GROFFMAN, P., BOHLEN, P., POUYAT, R.V., ZIPPERER, W.C., PARMELEE, R.W., CARREIRO, M.M. & MEDLEY, K. 1997. Ecosystem processes along an urban-to-rural gradient. *Urban Ecosystems* **1**: 21-36.

- MCINTYRE, N.E., KNOWLES-YANEZ, K. & HOPE, D. 2000. Urban ecology as an interdisciplinary field: differences in the use of "urban" between the social and natural sciences. *Urban Ecosystems* **4**: 5-24.
- MCINTYRE, N.E., RANGO, J., FAGAN, W.F. & FAETH, S.H. 2001. Ground arthropod community structure in a heterogenous urban environment. *Landscape and Urban Planning* **52**: 257-274.
- MEDLEY, K.E., MCDONELL, M.J. & PICKETT, S.T.A. 1995. Forest-landscape structure along an urban-to-rural gradient. *Professional Geography* **47**: 159-168.
- MILLSAP, B.A. & BEAR, C., 2000. Density and reproduction of burrowing owls along an urban development gradient. *Wildlife Management* **64**: 33-41.
- MIYASHITA, T., SHINKAI, A. & CHIDA, T. 1998. The effects of forest fragmentation on web spider communities in urban areas. *Biological Conservation* **86**: 357-364.
- MORRIS, C. 1992. Academic Press Dictionary of Science and Technology. Academic Press. Inc. San Diego. CA. USA.
- MORTBERG, U.M. 2001. Resident bird species in urban forest remnants: Landscape and habitat perspectives. *Landscape Ecology* **16**: 193-203.
- MUCINA, L. & RUTHERFORD, M.C. 2006. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.
- MUELLER-DOMBOIS, D. & ELLENBERG, H. 1974. Aims and methods of vegetation ecology. New York: Wiley.
- MURCIA, C. 1995. Edge effects in fragmented forests: Implications for conservation. *Trends in Ecology and Evolution* **10**: 58-62.
- NEL, L.T., TRUTER, F.C. & WILLEMSE, J. 1939. The geology of the country around Potchefstroom and Klerksdorp. An explanation of sheet 61. Geology Survey. Union of South Africa. Dept. of Mines.
- NEL, W. 1991. The management and maintenance of natural areas in the city environment. *Environmental Planning and Management* **3**: 55-63.

- NIEMELÄ, J. 1999a. Is there a need for a theory of urban ecology? *Urban Ecosystems* **3**: 57-65.
- NIEMELÄ, J. 1999b. Ecology and urban planning. *Biodiversity Conservation* **8**: 119-131.
- NIEMELÄ, J., KOTZE, J., ASHWORTH, A., BRANDMAYR, P., DESENDER, K., NEW, T., PENEV, L., SAMWAYS, M. & SPENCE, J. 2000. The search for common anthropogenic impacts on biodiversity: a global network. *Journal of Insect Conservation* **4**: 3-9.
- NIEMELÄ, J., KOTZE, D.J., VENN, S., PENEV, L., STOYANOV, I., SPENCE, J., HARTLEY, D. & DE OCA, M. 2002. Carabid beetle assemblages (Coleoptera, Carabidae) across urban-rural gradients: An international comparison. *Landscape Ecology* **17**: 387-401.
- NYFFELER, M., STERLING, W.L. & DEAN, D.A. 1994. Insectivorous activities of spiders in United States field crops. *Journal of Applied Entomology* **118**: 113-128.
- ODUM, E.P. 1997. Ecology: A Bridge between Science and Society. Sinauer. Sunderland. MA.
- PALMGREN, P. 1972 Studies on spider populations of the surroundings of the Tvarminne Zoological Station, Finland. *Comments from Biology* **52**: 1-133.
- PALMGREN, P. & BISTROM, O. 1979. Populations of Araneae (Arachnoidea) and Staphylinidae (Coleoptera) on the floor of a primeval forest in Mantyharju, Southern Finland. *Annales Zoologici Fennici* **16**: 177-182.
- PAVAO-ZUCKERMAN, M.A. & COLEMAN, D.C. 2005. Decomposition of chestnut oak (*Quercus prinus*) leaves and nitrogen mineralization in an urban environment. *Biology of Fertile Soils* **41**: 343-348.
- PENNER, J.E. 1994. Atmospheric chemistry and air quality (*In Changes in land use and land cover, a global perspective*. Cambridge University Press. Cambridge. p. 175-209).
- PHINN, S., STANFORD, M. & SCARTH, P. 2002. Monitoring the composition of urban environments based on the vegetation – impervious surface – soil (VIS) model by subpixel analysis techniques. *International Journal of Remote Sensing* **23**: 4131-4153.
- POWELL, W., DEAN, J.A., & DEWAR, A. 1985. The influence of weeds on polyphagous arthropod predators in winter wheat. *Crop Protection* **4**: 298-312.

POUYAT, R.V., MCDONNELL, M.J. & PICKETT, S.T.A., 1997. Litter decomposition and nitrogen mineralization in oak stands along an urban-rural land-use gradient. *Urban Ecosystems* **1**: 117-131.

PRINSLOO, W.J. deV. 1988. Potchefstroom 150. Potchefstroom: Potchefstroom Stadsraad.

RAINIO, J. & NIEMELÄ, J. 2003. Ground beetles (Coleoptera: Carabidae) as bioindicators. *Biodiversity and Conservation* **12**: 487-506.

READ, J.L. & ANDERSEN, A.N. 2000. The value of ants as early warning bioindicators: responses to pulsed cattle grazing at an Australian arid zone locality. *Journal of Arid Environments* **45**: 231-251.

REYNOLDSON, T.B., BAILEY, R.C., DAY, K.E. & NORRIS, R.H. 1995. Biological guidelines for freshwater sediment based on benthic assessment sediment using a multivariate approach for predicting biological state. *Australian Journal of Ecology* **20**: 198-219.

RIDD, M.K. 1995. Exploring a V-I-S (vegetation-impervious surface-soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities. *International Journal of Remote Sensing* **16**: 2165-2185.

RICHARDS, J.F. 1990 Land transformation (*In* The earth as transformed by human action. Cambridge University Press with Clark University. Cambridge. p. 163-178).

RISSER, P.G. 1995. The status of the science examining ecotones. *BioScience* **45**: 318-325.

RIVERS-MOORE, N.A. & SAMWAYS, M.J. 1996. Game and cattle trampling, and the impacts of human dwellings on arthropods at a game park boundary. *Biodiversity and Conservation* **5**: 1545-1556.

ROGERS, P. 1994. Hydrology and water quality (*In* Changes in land use and land cover: a global perspective. Cambridge University Press. Cambridge. p. 231-257).

ROODMAN, D.M. 1996. Rapid urbanization continues (*In* Vital signs. W.W. Norton and Company. Inc. New York. p. 94-95).

ROST, V. 2002. Urban biotope mapping in Potchefstroom-south, South Africa. Unpublished report for Diplom-Ingenieur. Dept. Landscape Architecture. University of Applied Sciences. Erfurt. Germany.

- RÖTHIG, M. 2002. Urban biotope mapping in Potchefstroom-north, South Africa. Unpublished report for Diplom-Ingenieur. Dept. Landscape Architecture. University of Applied Sciences. Erfurt. Germany.
- RUDNICKY, J.L. & MCDONNELL, M.J. 1989. Forty-eight years of canopy change in a hardwood-hemlock forest in New York City (USA). *Bulletin of the Torrey Botanical Club* **116**: 52-64.
- RUTHERFORD, M.C. & WESTFALL, R.H. 1994. Biomes of Southern Africa: An objective categorization. *Memoirs of the Botanical Survey of South Africa* **63**: 1-94.
- SACS. 1980. Stratigraphy of South Africa. Part 1 (comp. L.E. Kent). Lithostratigraphy of the Republic of South Africa, Namibia and the Republic of Botswana, Transkei and Venda. Pretoria: Dept. Mineral and Energy Affairs.
- SOPP, P. & WRATTEN, S.D. 1986. Rates of consumption of cereal aphids by some polyphagous predators in the laboratory. *Entomologia Experimentalis et Applicata* **41**: 69-73.
- SPEIGHT, M.R. & LAWTON, J.H. 1976. The influence of weed cover on the mortality imposed on artificial prey by predatory ground beetles in cereal fields. *Oecologia* **23**: 211-223.
- STREHLOW, K. 1993. Impact of fires on spider communities inhabiting semi-arid shrublands in Western Australia's wheatbelt. B.Sc. Honours Thesis. Murdoch University.
- SUNDERLAND, K.D. 1975. The diet of some predatory arthropods in cereal crops. *Journal of Applied Ecology* **12**: 507-515.
- TER BRAAK, C.J.F. 1992. Canonical community ordination -1: basic theory and linear methods. *Ecoscience* **1**: 127-140.
- TER BRAAK, C.J.F. & SMILAUER, P. 1998. Canoco Release 4. Reference manual and user's guide to Canoco for Windows: Software for Canonical Community Ordination. Microcomputer Power. Ithaca. NY.
- TER BRAAK, C.J.F. & VERDONSCHOT, P.F.M. 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57**: 153-298.

- THACKER, J.R.M. 1996. Carabidologists and fragmented habitats. *Trends in Ecology and Evolution* **11**: 103-104.
- THIELE, H. 1977. Carabid beetles in their environments. Springer-Verlag, Berlin Heidelberg, New York.
- TONTERI, T. & HAILA, Y. 1990. Plants in a boreal city: Ecological characteristics of vegetation in Helsinki and its surroundings, southern Finland. *Annales Botanici Fennica* **27**: 337-352.
- UTEZ, G.W. 1975. Temporal and spatial variation in species diversity of wandering spiders (Araneae) in deciduous forest litter. *Environmental Entomology* **4**: 719-724.
- VAISANEN, R. & BISTROM, O. 1990. Boreal forest spiders and the preservation of biotic diversity: Results from the Finnish primeval forests. *Acta Zoologica Fennica* **190**: 373-378.
- VAN HAMBURG, H., BRONNER, G.N., MORGENTHAL, T., VERMAAK, A., DE LE REY, A., MEYER, W.J., VAN HEERDEN, D. & KOTZE, J. 2003. The succession and diversity of biological assemblages on rehabilitated ash disposal sites associated with power stations in South Africa: working towards a dynamic model. *Ecosystems and Sustainable Development* **2**: 991-1004.
- VAN RENSBURG, L., DE SOUSA CORREIA, R.I., BOOYSEN, J. & GINSTER, M. 1998. Revegetation on a Coal Fine Ash Disposal Site in South Africa. *Journal of Environmental Quality* **27**: 1479-1486.
- VEPSALAINEN, K. & WUORENRINNE, H. 1978. Ecological effects of urbanization on the mound building *Formica* L. species. *Memorabilia Zoology* **29**: 191-202.
- VICKERMAN, G.P. 1976. The arthropod fauna of undersown grass and cereal fields. *Scientific Proceedings of the Royal Dublin Society* **6**: 273-283.
- VORIS, R. 1934. Biological investigations on the Staphylinidae (Coleoptera). *Transactions of the Academic Society of St Louis*. **28**: 231-261.
- WEATHER BUREAU. 1988. Climate of South Africa. Report no. 40. Pretoria: Government Printer.
- WEAR, D.N., TURNER, M.G. & NAIMAN, R.J. 1998. Land cover along an urban-rural gradient: Implications for water quality. *Ecology Applied* **8**: 619-630.

- WILLIAMS, P.H. & GASTON, K.J. 1994. Measuring more of biodiversity: can higher taxon richness predict wholesale species richness. *Biological Conservation* **67**: 211-217.
- WILSON, E.O. & TAYLOR, R.W. 1967. The ants of Polynesia (Hymenoptera: Formicidae) *Pacific Institute of Monographs* **14**: 1-109.
- WHITFORD, W.G., VAN ZEE, J., NASH, M.H., SMITH, W.E. & HERRICK, T.E. 1999. Ants as indicators of exposure to environmental stressors in North American desert grasslands. *Environmental Monitoring and Assessment* **54**: 143-171.
- WOINARSKI, J.C.Z., ANDERSEN, A.N., CHURCILL, T.B. & ASH, A.J. 2002. Response of ant and terrestrial spider assemblages to pastoral and military land use, and to landscape position in a tropical savanna woodland in northern Australia. *Australian Ecology* **27**: 42-53.
- WRIGHT, J.F. 1995. Development and use of a system for predicting the macro-invertebrate fauna in flowing waters. *Australian Journal of Ecology* **20**: 181-197.
- ZHANG, L., WU, J., ZHEN, Y. & JOING, S. 2004. A GIS-based gradient analysis of urban landscape pattern of Shanghai metropolitan area, China. *Landscape Urban Planning* **69**: 1-16.

Appendix A1: Epigeal Arthropod Data

Nov 2002 (Ants)

	Anoc-CS	Camp-SC	Phe-GM	Monf-GM	Tet-O	Mon2-GM	Lep1-O	Lep2-O	Ano2-CS	Mon3-GM	Mer-CS	Foru	Tot
RN	7	6	21	23	23	0	10	0	1	15	2	0	108
RN	0	6	22	2	3	0	0	0	2	1	5	0	41
RN	99	7	46	13	5	0	1	0	0	2	10	0	183
RE	0	0	11	2	0	0	0	0	0	5	0	0	18
SS	0	0	17	5	0	0	9	7	45	0	0	1	84
SS	0	0	5	93	1	0	0	2	0	0	0	0	101
SS	11	6	6	152	8	0	4	15	0	12	0	0	214
SN	0	0	0	5	1	0	0	0	1	0	4	0	11
SN	0	0	25	15	16	0	0	2	6	0	8	0	72
SN	0	0	37	17	13	0	1	1	3	0	2	0	74
RW	0	3	6	0	3	0	0	0	4	14	0	0	30
RW	50	6	42	0	29	0	0	1	30	60	2	0	220
RW	162	36	1	6	18	0	0	0	0	21	0	0	244
SE	0	0	5	25	1	0	18	8	0	0	0	0	57
SE	0	0	33	11	0	0	11	4	0	0	0	0	59
SE	0	0	57	33	0	0	41	15	0	0	0	0	146
US	14	0	52	59	1	0	25	29	3	50	0	0	233
US	0	0	4	0	2	0	2	0	0	0	0	0	8
US	0	0	4	35	0	0	11	6	0	0	0	0	56
US	0	0	10	1	0	0	0	0	0	0	0	0	11
RN	1	0	11	14	28	0	0	0	0	3	9	0	66

Feb 2003 (Ants)

	Anoc-CS	Camp-SC	Phe-GM	Monf-GM	Tet-O	Mon2-GM	Lep1-O	Lep2-O	Ano2-CS	Mon3-GM	Mer-CS	Foru	Tot
RN	100	1	1	4	0	0	0	0	0	3	2	0	111
UN	0	0	2	15	9	0	0	0	0	0	0	0	26
UN	0	0	2	7	24	0	0	0	0	0	0	0	33
UN	0	0	1	15	6	0	0	0	0	0	0	0	22
SW	0	0	30	0	0	0	1	0	0	0	0	0	31
SW	0	0	11	1	0	0	0	0	0	0	0	0	12
RE	0	0	39	11	0	0	0	0	0	3	1	0	54
RE	2	0	20	0	1	0	0	0	0	0	0	0	23
UW	0	0	0	0	30	0	2	0	0	0	0	0	32
UW	0	0	1	0	17	0	0	0	0	0	0	0	18
UW	0	0	0	0	2	0	0	0	0	0	0	0	2
SS	0	0	10	1	5	0	0	0	0	0	0	0	16
SN	0	0	0	5	0	0	0	0	0	0	0	0	5
SN	0	0	9	2	3	0	0	0	0	0	0	0	14
SN	0	0	6	3	2	0	0	1	0	0	0	0	12
RW	0	0	1	9	30	0	0	0	2	7	0	0	49
RW	24	0	8	4	5	0	0	0	0	7	0	0	48
RW	254	0	2	8	40	0	0	3	4	1	0	0	312
SE	0	0	3	18	0	0	1	0	0	0	0	0	22
US	0	0	208	5	0	0	1	2	0	0	0	0	216
US	0	0	0	0	0	0	0	0	0	0	0	0	0
US	0	0	16	9	1	0	0	0	0	0	0	0	26
UE	0	0	2	3	7	0	0	0	0	0	0	0	12

Appendix A2: Epigeal Arthropod Data

July 2003 (Ants)

	Anoc-CS	Camp-SC	Phe-GM	Monf-GM	Tet-O	Mon2-GM	Lep1-O	Lep2-O	Ano2-CS	Mon3-GM	Mer-CS	Foru	Tot
RN	0	0	0	0	1	0	0	0	0	0	0	0	1
RN	0	0	0	0	4	0	0	0	0	1	0	0	5
RN	0	0	1	0	15	0	0	0	0	0	0	0	16
UN	0	0	2	0	2	0	0	0	0	0	0	0	4
UN	0	0	3	0	0	0	0	0	0	0	0	0	3
SW	0	0	5	0	0	0	0	0	0	0	0	0	5
SW	0	0	0	0	0	0	0	0	0	0	0	0	0
SW	0	0	4	0	0	0	0	0	0	0	0	0	4
RE	0	0	0	0	0	0	0	0	0	1	0	0	1
RE	0	0	2	0	0	0	0	0	0	4	0	0	6
RE	0	0	6	5	2	0	0	0	0	0	0	0	13
UW	0	0	1	0	1	0	1	0	0	1	0	1	5
UW	0	0	2	0	0	0	0	0	0	0	0	0	2
SS	0	0	10	3	2	0	2	1	2	32	0	0	52
SS	0	0	3	1	0	0	0	1	0	1	0	0	6
SS	0	0	1	2	4	0	8	1	0	50	0	0	66
SN	0	0	0	1	0	1	0	0	0	0	0	1	3
SN	0	0	3	0	0	0	0	0	0	8	0	0	11
RW	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	0	0	14	2	0	0	2	2	0	0	0	0	20
SE	0	0	9	0	0	0	0	0	0	0	0	0	9
SE	0	0	15	1	0	0	0	0	0	0	0	0	16
US	0	0	4	0	0	0	0	0	0	0	0	0	4
US	0	0	11	0	0	0	3	1	0	25	0	0	40
UE	0	0	13	0	0	0	1	0	0	0	0	0	14
UE	0	0	3	2	0	0	6	3	0	0	0	0	14

Appendix A3: Epigeal Arthropod Data

Nov 2002 (Beetles)

	Sta1	Sta2	Het	Gon	Form	Cuc	Ant1	Ant2	His	Ont	Car1	Chr1	Chr2	Bra	Der	Car2	Gro	Col	Heta	Coleu	Pro	Aph	Tot
RN	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	109
RN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42
RN	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	186
RE	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
SS	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88
SS	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104
SS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	215
SN	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
SN	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73
SN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
RW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
RW	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	223
RW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	244
SE	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62
SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	64
SE	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	154
US	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	236
US	0	0	1	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	13
US	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58
US	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	13
RN	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	70

Feb 2003 (Beetles)

	Sta1	Sta2	Het	Gon	Form	Cuc	Ant1	Ant2	His	Ont	Car1	Chr1	Chr2	Bra	Der	Car2	Gro	Col	Heta	Coleu	Pro	Aph	Tot
RN	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	114
UN	1	0	0	0	2	0	0	0	0	0	0	18	1	0	2	0	0	0	0	1	0	0	51
UN	2	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	58
UN	0	0	0	0	3	0	0	0	0	0	0	6	2	0	0	0	0	0	0	0	0	0	36
SW	0	4	1	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	41
SW	0	5	0	0	0	0	0	0	1	0	0	2	0	0	0	6	0	0	0	1	0	0	28
RE	15	3	0	0	9	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	87
RE	15	0	0	0	1	0	1	1	2	0	0	0	1	0	1	0	0	0	0	0	0	0	45
UW	1	4	1	7	0	0	1	0	3	0	0	3	1	1	0	3	0	0	0	0	0	0	58
UW	0	0	0	2	4	0	0	1	0	0	0	0	0	0	1	0	0	1	1	2	0	0	31
UW	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	8
SS	3	0	0	0	8	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	30
SN	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6
SN	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	16
SN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
RW	0	18	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	69
RW	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58
RW	1	11	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	325
SE	2	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28
US	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	8	0	0	0	0	0	0	231
US	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	1	0	0	0	0	0	0	0	0	0	0	12	0	0	0	1	0	0	0	0	0	0	41
UE	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	20

Appendix A4: Epigeal Arthropod Data

July 2003 (Beetles)

	Sta1	Sta2	Het	Gon	Form	Cuc	Ant1	Ant2	His	Ont	Car1	Chr1	Chr2	Bra	Der	Car2	Gro	Col	Heta	Coleu	Pro	Aph	Tot
RN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
RN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6
RN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
UN	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	8
UN	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	8
SW	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
SW	0	0	0	16	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	18
SW	0	0	0	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	10
RE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
RE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
RE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
UW	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
UW	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
SS	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	53
SS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
SS	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67
SN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
SN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
RW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
SE	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	18
US	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	9
US	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4	0	0	0	0	0	0	45
UE	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	16
UE	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	0	18

Appendix A5: Epigeal Arthropod Data

Nov 2002 (Spiders)

	Sal1	Sal2	Sal3	Lyc	Gna1	Gna2	Phi	Ostm	Pal	Apo	Gna3	Ara1	Ara2	Araj	Tot
RN	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
RN	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
RN	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
RE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
SS	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
SS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SS	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
SN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SN	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4
SN	0	2	0	0	0	0	0	0	0	0	2	0	2	0	6
RW	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
RW	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
RW	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
SE	0	0	0	2	1	0	0	1	0	0	4	0	0	0	8
SE	0	0	0	1	1	0	0	0	0	0	1	0	1	0	4
SE	0	1	0	1	0	0	0	0	0	0	1	0	3	0	6
US	0	0	0	5	0	0	0	0	0	0	0	0	1	0	6
US	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
US	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
RN	0	0	0	2	2	0	0	1	0	0	2	0	0	0	7

Feb 2003 (Spiders)

	Sal1	Sal2	Sal3	Lyc	Gna1	Gna2	Phi	Ostm	Pal	Apo	Gna3	Ara1	Ara2	Araj	Tot
RN	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
UN	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
UN	0	0	0	4	0	0	0	1	0	0	0	0	1	1	7
UN	0	0	0	5	0	0	0	0	0	0	0	0	1	20	26
SW	1	0	0	2	0	0	0	5	0	0	0	0	0	0	8
SW	0	0	0	0	0	0	0	9	0	1	0	0	1	0	11
RE	0	0	0	1	1	0	0	0	0	0	1	0	1	0	4
RE	0	0	0	2	0	0	0	0	0	0	0	0	1	0	3
UW	0	0	0	4	0	0	0	4	0	0	0	0	1	0	9
UW	1	0	0	2	0	0	0	3	0	0	0	0	1	0	7
UW	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2
SS	0	1	0	3	0	0	1	0	0	0	1	0	0	0	6
SN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SN	0	0	0	2	0	0	0	1	0	0	0	0	1	0	4
SN	0	0	0	1	0	0	0	2	0	0	0	0	0	0	3
RW	0	0	0	0	0	0	0	4	0	0	0	0	1	0	5
RW	0	0	0	2	0	0	0	1	0	0	0	1	0	0	4
RW	1	0	0	1	0	0	0	4	3	0	0	0	5	0	14
SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	1	0	0	1	0	0	0	1	0	0	1	0	0	0	4
US	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
US	0	0	0	1	0	0	0	0	0	0	1	0	0	1	3
UE	0	0	0	1	0	0	0	2	0	0	0	0	0	0	3

Appendix A6: Epigeal Arthropod Data

July 2003 (Spiders)

	Sal1	Sal2	Sal3	Lyc	Gna1	Gna2	Phi	Ostm	Pal	Apo	Gna3	Ara1	Ara2	Araj	Tot
RN	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
RN	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
RN	0	0	0	2	0	0	0	0	0	0	1	0	0	0	3
UN	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
UN	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
SW	0	0	0	0	0	1	0	3	0	0	0	0	1	0	5
SW	0	0	0	3	0	0	0	7	0	0	0	0	2	0	12
SW	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
RE	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
RE	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
RE	0	0	0	1	0	0	0	1	0	1	0	0	0	0	3
UW	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
UW	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
SS	0	0	1	0	0	0	0	1	0	0	0	0	0	0	2
SS	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
SS	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2
SN	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
SN	0	0	0	1	0	0	0	1	0	0	2	0	0	0	4
RW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2
SE	0	1	0	0	0	0	0	2	0	0	0	0	1	0	4
SE	0	0	0	1	0	0	0	8	0	0	0	0	2	0	11
US	0	0	0	1	0	0	0	0	0	0	0	0	1	0	2
US	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
UE	0	0	0	1	0	0	0	3	0	0	0	0	0	0	4

Appendix B1: Vegetation Data

Nov 2002

	Veg%	Bareg%	Orgm%	Rock%	Forbh	Grassh	Indsp%	Bloom%	Fruit%
RN	60	35	2	10	8	25	80	20	0
RN	60	35	2	1	8	20	88	25	0
RN	70	25	2	1	8	20	86	7	7
RE	90	10	10	0	4	25	94	13	19
SS	40	30	20	0	8	4	13	50	13
SS	30	10	60	0	4	4	75	0	0
SS	70	5	50	0	4	4	44	0	0
SN	70	15	50	0	12	8	67	8	50
SN	80	5	60	0	0	0	58	8	8
SN	70	10	40	0	0	0	55	11	33
RW	70	30	5	0	25	22	96	17	0
RW	60	45	2	0	25	22	100	19	0
RW	60	40	5	1	5	22	100	26	0
SE	90	5	25	1	6	6	50	10	10
SE	80	10	15	3	6	6	56	11	11
SE	80	5	20	5	6	8	56	11	0
US	90	5	20	0	8	8	25	13	0
US	85	5	5	0	6	7	18	0	45
US	0	0	0	0	0	0	0	0	0
US	80	5	50	0	8	6	27	9	9
RN	60	35	2	1	8	20	88	25	0

Feb 2003

	Veg%	Bareg%	Orgm%	Rock%	Forbh	Grassh	Indsp%	Bloom%	Fruit%
RN	70	25	2	1	8	20	86	7	7
UN	95	5	10	0	4	4	45	73	27
UN	95	5	20	0	4	4	40	70	30
UN	95	5	10	0	4	4	40	80	40
SW	95	2	5	0	15	6	27	33	13
SW	100	0	5	0	10	10	33	22	0
RE	70	15	15	0	2	20	83	0	0
RE	68	25	10	0	2	25	89	0	0
UW	80	15	25	0	6	8	25	50	13
UW	70	20	30	0	6	6	0	33	33
UW	90	5	40	0	6	6	50	0	0
SS	75	10	30	0	4	6	56	67	33
SN	75	10	40	0	10	40	47	40	7
SN	75	10	40	0	10	40	60	40	30
SN	70	10	40	0	10	40	46	54	15
RW	70	30	5	0	25	22	96	17	0
RW	60	45	2	0	25	22	100	19	0
RW	60	40	5	1	5	12	100	26	0
SE	85	5	40	1	6	10	83	33	8
US	90	5	20	0	8	8	25	13	0
US	85	5	5	0	6	7	18	0	45
US	0	0	0	0	0	0	0	0	0
UE	85	10	20	2	4	4	47	47	27

Appendix B2: Vegetation Data

July 2003

	Veg%	Bareg%	Orgm%	Rock%	Forbh	Grassh	Indsp%	Bloom%	Fruit%
RN	60	10	70	2	5	25	100	0	0
RN	70	5	80	3	5	25	100	0	0
RN	60	10	80	0	5	30	100	0	0
UN	70	30	0	0	2	2	50	10	0
UN	80	10	5	0	2	2	50	10	0
SW	0	0	0	0	0	0	0	0	0
SW	50	5	40	0	8	6	40	0	40
SW	60	2	40	0	6	7	38	0	38
RE	0	0	0	0	0	0	0	0	0
RE	50	20	20	0	1	15	100	0	0
RE	48	30	15	0	1	15	100	0	0
UW	50	10	40	0	0	4	0	10	0
UW	50	10	60	0	0	4	0	0	0
SS	40	60	10	2	4	4	0	0	0
SS	50	35	25	5	4	10	0	0	0
SS	40	50	10	5	4	5	0	0	0
SN	50	10	50	0	5	8	54	0	0
SN	60	10	40	0	5	8	56	0	0
RW	50	40	20	0	5	10	100	9	0
SE	65	10	50	1	3	5	78	0	0
SE	60	15	60	3	3	5	60	0	0
SE	70	5	25	5	3	5	90	10	0
US	80	1	10	0	6	7	19	0	6
US	0	0	0	0	0	0	0	0	0
UE	40	5	53	0	2	2	21	14	7
UE	50	5	45	0	4	4	58	8	0

Appendix C1: Soil Data

Nov 2002

	Sandcn	Siltcn	Claycn	pH	Ec	Cu	Fe	Mn	Zn	B	Pb	Cr	Cd	As	Se	Cec
RN	72.8	14	13.2	6.1	0.1	1.57	77.91	4.23	2.32	0.5	8.8	740	0.08	5.5	7.4	13.5
RN	72.8	14	13.2	6.1	0.1	1.57	77.91	4.23	2.32	0.5	8.8	740	0.08	5.5	7.4	13.5
RN	72.8	14	13.2	6.1	0.1	1.57	77.91	4.23	2.32	0.5	8.8	740	0.08	5.5	7.4	13.5
RE	47.8	25.7	26.6	5.6	0.1	0.51	79.85	1.52	0.41	10.3	0.61	34	0.01	0.01	5.9	26.25
SS	37.65	27.8	34.6	6.9	0.3	0.085	5.995	0.105	0.18	0.12	0.045	0.34	0.01	0.01	1.77	20.845
SS	37.65	27.8	34.6	6.9	0.3	0.085	5.995	0.105	0.18	0.12	0.045	0.34	0.01	0.01	1.77	20.845
SS	37.65	27.8	34.6	6.9	0.3	0.085	5.995	0.105	0.18	0.12	0.045	0.34	0.01	0.01	1.77	20.845
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
RW	67	6.5	26.6	6	0.1	0.01	5.43	0.08	0.03	0.01	0.01	0.07	0.01	0.09	3.97	6.6
RW	67	6.5	26.6	6	0.1	0.01	5.43	0.08	0.03	0.01	0.01	0.07	0.01	0.09	3.97	6.6
RW	67	6.5	26.6	6	0.1	0.01	5.43	0.08	0.03	0.01	0.01	0.07	0.01	0.09	3.97	6.6
SE	33.8	24.15	42.05	7.3	0.2	0.025	5.985	0.015	0.01	0.07	0.01	0.05	0.01	1.235	3.26	26.215
SE	33.8	24.15	42.05	7.3	0.2	0.025	5.985	0.015	0.01	0.07	0.01	0.05	0.01	1.235	3.26	26.215
SE	33.8	24.15	42.05	7.3	0.2	0.025	5.985	0.015	0.01	0.07	0.01	0.05	0.01	1.235	3.26	26.215
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
US	21.45	34.95	39.05	6.9	0.2	0.03	5.31	0.015	0.015	0.07	0.01	0.02	0.01	0.01	2.61	22.415
RN	72.8	14	13.2	6.1	0.1	1.57	77.91	4.23	2.32	0.5	8.8	740	0.08	5.5	7.4	13.5

Feb 2003

	Sandcn	Siltcn	Claycn	pH	Ec	Cu	Fe	Mn	Zn	B	Pb	Cr	Cd	As	Se	Cec
RN	72.8	14	13.2	6.1	0.1	1.57	77.91	4.23	2.32	0.5	8.8	740	0.08	5.5	7.4	13.5
UN	66.45	9.8	23.8	6.7	0.2	0.025	3.735	0.075	0.015	0.01	0.01	0.07	0.01	1.905	1.195	17.185
UN	66.45	9.8	23.8	6.7	0.2	0.025	3.735	0.075	0.015	0.01	0.01	0.07	0.01	1.905	1.195	17.185
UN	66.45	9.8	23.8	6.7	0.2	0.025	3.735	0.075	0.015	0.01	0.01	0.07	0.01	1.905	1.195	17.185
SW	38.1	12	49.9	6.3	0.2	0.02	2.54	0.1	0.03	0.18	0.01	0.01	0.01	0.01	1.37	20.34
SW	38.1	12	49.9	6.3	0.2	0.02	2.54	0.1	0.03	0.18	0.01	0.01	0.01	0.01	1.37	20.34
RE	47.8	25.7	26.6	5.6	0.1	0.51	79.85	1.52	0.41	10.3	0.61	34	0.01	0.01	5.9	26.25
RE	47.8	25.7	26.6	5.6	0.1	0.51	79.85	1.52	0.41	10.3	0.61	34	0.01	0.01	5.9	26.25
UW	53.7	17.9	28.4	6.6	0.2	0.02	6.82	0.05	0.01	0.01	0.01	0.09	0.01	1.66	2.02	21.09
UW	53.7	17.9	28.4	6.6	0.2	0.02	6.82	0.05	0.01	0.01	0.01	0.09	0.01	1.66	2.02	21.09
UW	53.7	17.9	28.4	6.6	0.2	0.02	6.82	0.05	0.01	0.01	0.01	0.09	0.01	1.66	2.02	21.09
SS	37.65	27.8	34.6	6.9	0.3	0.085	5.995	0.105	0.18	0.12	0.045	0.34	0.01	0.01	1.77	20.845
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
RW	67	6.5	26.6	6	0.1	0.01	5.43	0.08	0.03	0.01	0.01	0.07	0.01	0.09	3.97	6.6
RW	67	6.5	26.6	6	0.1	0.01	5.43	0.08	0.03	0.01	0.01	0.07	0.01	0.09	3.97	6.6
RW	67	6.5	26.6	6	0.1	0.01	5.43	0.08	0.03	0.01	0.01	0.07	0.01	0.09	3.97	6.6
SE	33.8	24.15	42.05	7.3	0.2	0.025	5.985	0.015	0.01	0.07	0.01	0.05	0.01	1.235	3.26	26.215
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
UE	21.45	34.95	39.05	6.9	0.2	0.03	5.31	0.015	0.015	0.07	0.01	0.02	0.01	0.01	2.61	22.415

Appendix C2: Soil Data

July 2003

	Sandcn	Siltcn	Claycn	pH	Ec	Cu	Fe	Mn	Zn	B	Pb	Cr	Cd	As	Se	Cec
RN	45.8	26.25	27.95	5.6	0.2	0.01	3.32	0.14	0.02	0.05	0.01	0.01	0.01	0.01	6.655	17.525
RN	45.8	26.25	27.95	5.6	0.2	0.01	3.32	0.14	0.02	0.05	0.01	0.01	0.01	0.01	6.655	17.525
RN	45.8	26.25	27.95	5.6	0.2	0.01	3.32	0.14	0.02	0.05	0.01	0.01	0.01	0.01	6.655	17.525
UN	66.45	9.8	23.8	6.7	0.2	0.025	3.735	0.075	0.015	0.01	0.01	0.07	0.01	1.905	1.195	17.185
UN	66.45	9.8	23.8	6.7	0.2	0.025	3.735	0.075	0.015	0.01	0.01	0.07	0.01	1.905	1.195	17.185
SW	38.1	12	49.9	6.3	0.2	0.02	2.54	0.1	0.03	0.18	0.01	0.01	0.01	0.01	1.37	20.34
SW	38.1	12	49.9	6.3	0.2	0.02	2.54	0.1	0.03	0.18	0.01	0.01	0.01	0.01	1.37	20.34
SW	38.1	12	49.9	6.3	0.2	0.02	2.54	0.1	0.03	0.18	0.01	0.01	0.01	0.01	1.37	20.34
RE	47.8	25.7	26.6	5.6	0.1	0.51	79.85	1.52	0.41	10.3	0.61	34	0.01	0.01	5.9	26.25
RE	47.8	25.7	26.6	5.6	0.1	0.51	79.85	1.52	0.41	10.3	0.61	34	0.01	0.01	5.9	26.25
RE	47.8	25.7	26.6	5.6	0.1	0.51	79.85	1.52	0.41	10.3	0.61	34	0.01	0.01	5.9	26.25
UW	53.7	17.9	28.4	6.6	0.2	0.02	6.82	0.05	0.01	0.01	0.01	0.09	0.01	1.66	2.02	21.09
UW	53.7	17.9	28.4	6.6	0.2	0.02	6.82	0.05	0.01	0.01	0.01	0.09	0.01	1.66	2.02	21.09
SS	37.65	27.8	34.6	6.9	0.3	0.085	5.995	0.105	0.18	0.12	0.045	0.34	0.01	0.01	1.77	20.845
SS	37.65	27.8	34.6	6.9	0.3	0.085	5.995	0.105	0.18	0.12	0.045	0.34	0.01	0.01	1.77	20.845
SS	37.65	27.8	34.6	6.9	0.3	0.085	5.995	0.105	0.18	0.12	0.045	0.34	0.01	0.01	1.77	20.845
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
SN	34.6	39.4	26	7.6	0.2	0.01	0.55	0.01	0.01	0.01	0.01	0.04	0.01	3.14	4.35	20.45
RW	67	6.5	26.6	6	0.1	0.01	5.43	0.08	0.03	0.01	0.01	0.07	0.01	0.09	3.97	6.6
SE	33.8	24.15	42.05	7.3	0.2	0.025	5.985	0.015	0.01	0.07	0.01	0.05	0.01	1.235	3.26	26.215
SE	33.8	24.15	42.05	7.3	0.2	0.025	5.985	0.015	0.01	0.07	0.01	0.05	0.01	1.235	3.26	26.215
SE	33.8	24.15	42.05	7.3	0.2	0.025	5.985	0.015	0.01	0.07	0.01	0.05	0.01	1.235	3.26	26.215
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
US	86.2	3.6	10.2	5.5	0.1	0.01	5.22	0.05	0.01	0.01	0.01	0.01	0.01	0.01	5.44	3.06
UE	21.45	34.95	39.05	6.9	0.2	0.03	5.31	0.015	0.015	0.07	0.01	0.02	0.01	0.01	2.61	22.415
UE	21.45	34.95	39.05	6.9	0.2	0.03	5.31	0.015	0.015	0.07	0.01	0.02	0.01	0.01	2.61	22.415