Use of ground-dwelling arthropods as bioindicators of ecological condition in grassland and forest vegetation at eThekwini Municipality in KwaZulu-Natal

by

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Thesis submitted in fulfilment of the academic requirements for the degree of

Master of Science

in the Discipline of Ecological science,

School of Life Sciences

College of Agriculture, Engineering and Science

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Pietermaritzburg

South Africa

2018

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Preface

The work contained in this thesis was completed by the candidate in the School of Life Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Dr Zivanai Tsvuura and co-supervised by Dr Tarombera Mwabvu (University of Mpumalanga) and Dr Caswell Munyai (University of KwaZulu-Natal). The research was financially supported by the Durban Research Action Partnership (D'RAP) and the National Research Foundation (NRF). The contents of this work is my own and have not been submitted in any form to another university. Where use has been made of the work of others, it is acknowledged in the text. The thesis is formatted according to South African Journal of Botany.

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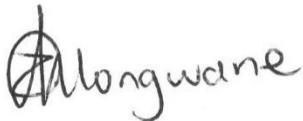
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Declaration 1: Plagiarism

I, Zabentungwa Thakasile Hlongwane, declare that:

      1. The research reported in this thesis, except where otherwise indicated or acknowledged, is my original research.

      2. This thesis has not been submitted in full or in part for any degree or examination to any other university.

      3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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      a) Their words have been re-written but the general information attributed to them has been referenced.

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Zabentungwa Thakasile Hlongwane

June 2018

Acknowledgements

I would like to dedicate this work to my late mother Tombi Irene Hadebe and my late grandmother Nomqhikizane Bhengu Hlongwane who never lived to witness this moment.

Abstract

Epigaeic arthropods are among the most diverse and abundant group of animals. They are important in the functioning of terrestrial ecosystems. Assemblages of arthropods may be affected by vegetation type, seasonality and disturbances such as alien plant invasion. The aim of this study was to develop a bioindicator tool for monitoring ecological conditions of the KwaZulu-Natal Sandstone Sourveld (KZNSS), which is one of the most threatened grasslands in KwaZulu-Natal. The objectives of this study were to 1) determine species abundance and species richness of ground-dwelling arthropods; 2) determine the effect of season on ground-dwelling arthropods; 3) determine functional diversity of ground-dwelling arthropods; and 4) determine if ground-dwelling arthropods distribution differs in three vegetation types in Tanglewood and Giba Gorge nature reserves in the KwaZulu-Natal Sandstone Sourveld. Ground-dwelling arthropods were sampled during the wet and dry seasons at two sites in each of the nature reserves. At each site, pitfall trap sampling was carried out in three vegetation types, namely intact grassland, riverine or scarp forest and a disturbed grassland vegetation. The disturbed grassland vegetation was an ecotone between grassland and forest dominated by alien invasive plants. Ants, beetles, spiders, terrestrial crustaceans, sand crickets, roaches, termites, millipedes, lacewigs, hemipterans and woodlice were the sampled taxa in both reserves.

A total of 6 150 specimens belonging to 60 morpho-species were sampled in Giba Gorge and Tanglewood Nature Reserve. Species abundance and richness varied among reserves as greater epigaeic arthropod abundance was observed in Tanglewood than in Giba Gorge Nature Reserve. However, Giba Gorge was the richer reserve than Tanglewood. Distribution of epigaeic arthropods varied among vegetation types, higher arthropod abundance was recorded in the forest than the disturbed and intact grassland. While higher species richness of epigaeic arthropods was recorded in an intact grassland. Ants were the most abundant and richest taxon at both sites and greater abundance of ants was recorded in the disturbed grassland which shows that ants are opportunistic organisms. Seasonality played an important role in epigaeic arthropod species abundance and richness. Higher abundance and richness was observed in the wet season. This shows that the wet season provides optimum food resources, temperature, soil moisture and diverse vegetation structure which is favourable to epigaeic arthropods.

Functional diversity varied across vegetation types. Forest supported a greater abundance of decomposers and predators while the disturbed grassland supported greater abundance of generalists and herbivores. This shows that functional guilds have different food resources and niche requirements and vegetation type plays an important role in functional diversity. Generalist arthropods were more abundant in the dry season unlike the predators, herbivores and decomposers which were more abundant in the wet season. Generalists have broad diets and are able to survive under unfavourable conditions.

A terrestrial crustacean, *Talitriator africana* occurred in all vegetation types but was more abundant in forest. An ant, *Pheidole* sp.02 (*megacephala* gp.) was the most widespread species. However, it was more abundant in disturbed grassland. These results suggest that *T. africana* and *Pheidole* sp.02 (*megacephala* gp.) could be useful potential indicators for monitoring ecological conditions in the KwaZulu-Natal Sandstone Sourveld.

Forests and grasslands should be conserved because they supported higher numbers of epigaeic arthropods and functional guilds. Arthropods play an important role in the functioning of terrestrial ecosystems. Disturbed grassland should be managed and restored back to a grassland because grasslands play an important role in the functioning of the ecosystem by providing direct and indirect ecosystem services

Chapter 1: Introduction and Literature Review

Introduction

A bioindicator is a species or a group of species that is used to assess the state of the environment and how the environmental conditions change over time (McGeoch, 1998; Hodkinson and Jackson, 2005). Changes in environmental conditions are often as a result of anthropogenic forces which include pollution, land use change, habitat transformation and introduction of alien invasive plants (McGeoch, 1998; Holt and Miller, 2011). They can also be as a result of natural forces which include climate change, drought and floods (McGeoch, 1998; Hodkinson and Jackson, 2005; Holt and Miller, 2011). Anthropogenic forces form the primary drive in the bioindicator research (Holt and Miller, 2011). Bioindicators play an important role in management and conservation of biodiversity in different ecosystems across the world (Pribadi et al., 2011).

Environmental changes as a result of anthropogenic activities have increased interest in the use of indicator species in environmental monitoring (Holt and Miller, 2011; Hodkison and Jackson, 2005). The use of invertebrate species as bioindicators in environmental monitoring started in the 1960s and has gained momentum since then (Holt and Miller, 2011). In addition, Hodkison and Jackson (2005) reported that the use of invertebrates as bioindicators of environmental change dates back to over 25 years ago. Ground-dwelling arthropods as bioindicators have been used successfully in conservation and management at least since the 1990s (Maelfait and Hendrickx, 1998; Hodkison and Jackson, 2005; Decaens et al., 2006). Ground-dwelling arthropods have been used as indicators of ecological conditions in soil conservation, water quality assessment, landscape management and pollution assessment (Hodkinson and Jackson, 2005; Decaens et al., 2006).

Lawes et al. (2005) reported that ground-dwelling arthropods are sensitive to environmental changes and often decline in abundance after environmental disturbance, this makes them ideal indicator species. Ground-dwelling arthropods that have been used as bioindicators of ecological conditions all over the world include ants, spiders, terrestrial crustacean,

earthworms, beetles, millipedes, termites and woodlice (McGeoch, 1998; Andersen et al. 2004; Lawes et al., 2005). In South Africa few studies have focused on the use of ground-dwelling arthropods as bioindicators of ecological conditions in terrestrial environments (Tshiguvho et al., 1999; McGeoch et al., 2002; Van Hamburg et al., 2004; Lawes et al., 2005). In addition, ground-dwelling arthropods have been used to monitor threatened ecosystems in South Africa.

Sandstone sourveld is a threatened ecosystem which is restricted to the interior of KwaZulu-Natal Province, South Africa. The vegetation consists of grassland but has scarp and riverine forest patches. Most of the habitat has been transformed by agriculture for sugarcane production and wood plantations. Sandstone sourveld is rich in flora and fauna, with a number of endemic species (Mucina and Rutherford, 2006). As a result of extensive human influences, grassland is one of the most threatened biome in the province and is classified as critically endangered by the South African National Biodiversity Institute and Ezemvelo KwaZulu-Natal Wildlife (Mucina and Rutherford, 2006). In addition, only a small portion (0.2%) of this grassland is conserved and protected, which negatively impacts ecosystem functioning (Mucina and Rutherford, 2006). As a result of the human-derived threats, studying processes occurring in this grassland type helps to understand dynamics and functions in order to influence conservation strategies that can help save species and habitats in the sandstone sourveld. In order to help inform management and conservation of the ecological condition of rangelands in the sandstone sourveld, bioindicators need to be identified in order to be used for monitoring. Human land use activities disrupt and change ecological environments in different ways (Andersen et al., 2002). As result, this has led to implementation of conservation and management practices in threatened environments.

Aim
The aim of this study was to develop a bioindicator tool for monitoring ecological conditions of the KwaZulu-Natal Sandstone Sourveld.

Objectives
1. To determine species abundance and species richness of ground-dwelling arthropods in Tanglewood and Giba Gorge Nature Reserves.

2. To determine the effect of season on ground-dwelling arthropods in the KwaZulu-Natal Sandstone Sourveld.
3. To determine if ground-dwelling arthropod assemblages differs in three vegetation types in the KwaZulu-Natal Sandstone Sourveld.
4. To determine functional diversity of ground-dwelling arthropods in Tanglewood and Giba Gorge Nature Reserves.

Literature Review

What are ground-dwelling arthropods?

Ground-dwelling arthropods are organisms that lack a backbone and are found in the soil, vegetation, logs and in sediments (De Lange, 1994). Decaens et al. (2006) reported that ground-dwelling arthropods are a diverse group of animals representing approximately 23 % of the known invertebrates species. Ground-dwelling arthropods play an important role in terrestrial ecosystems by providing ecosystem services such as pollination, litter decomposition and nutrient cycling (Seastedt and Crossley, 1984; Williams, 1993). Some arthropods are ecosystem engineers and play a major role in keeping the environment balanced (Longcore 1999; Williams, 1993; Longcore, 2003). In addition, ground dwelling arthropods are used in ecological restoration and conservation biology (Williams, 1993; Longcore, 2003).

Importance of ground-dwelling arthropods in grasslands

Grassland is one of the major biomes in the world with diverse vegetation systems (Egoh, et al., 2011; Boval and Dixon, 2012). In South Africa grassland is the second largest biome occupying approximately one third of the country land surface (SANBI, 2013). Ground-dwelling arthropods play a significant role in structuring grassland ecosystems (Barnett and Facey, 2016) through activities such as nutrient cycling, pollination, decomposition and pest control. Arthropod herbivores have the ability to change plant species richness by feeding on plant tissue and reducing competition between plant species (Olff and Ritchie, 1998; Barnett and Facey, 2016). Curry (1994) reported that ground-dwelling arthropods are responsible for maintaining soil fertility in grasslands by modifying soil properties and through decomposition of organic matter. This promotes vegetation growth (Curry, 1994; Barnett and Facey, 2016). Arthropod detritivores influence decomposition and mineralization processes through their

feeding and metabolic activities which directly affect vegetation (Curry, 1994). Arthropod predators such as spiders and ants have the ability to control population of other organisms through predation and competition processes (Willis and Landis, 2017) which keeps the ecosystem's food webs in a balanced state.

Ground-dwelling arthropods are important in grassland ecosystems particularly in organic matter processing, soil nutrients balancing, nutrient cycling and in ecosystem restoration (Snyder and Hendrix, 2008). In addition, they also play an important role as ecosystem engineers and consumers that have a major effect on plant and microbial diversity which indirectly influence grassland productivities (Willis and Landis, 2017). Hodkison and Jackson (2005) reported that macroinvertebrates are important in mineralisation of nutrients which help in vegetation growth. As such, ground-dwelling arthropods are used to examine changes in environmental conditions and help in providing early warning of environmental change which help in informing management and conservation strategies (Lawes et al., 2005; Cole et al., 2006).

Why are ground-dwelling arthropods used as bioindicators?

Ground-dwelling arthropods are an abundant group of animals (McGeoch, 1998; Hoffmann and Andersen, 2003; Andersen et al., 2004; Yekwayo, 2016) and their activities are important in ecosystem and environmental functioning (McGeoch, 1998; Hodkison and Jackson, 2005). In addition, the diverse assemblage of arthropods allows diverse functions in the ecosystem (McGeoch, 1998). Ground-dwelling arthropods are often used as bioindicators of ecological change because they are small in size which makes them more sensitive to changing environment (Paoletti, 1999; Andersen et al., 2002; Gerlach et al., 2013). In addition, arthropods have short life spans and high reproduction rate (Lawes et al., 2005). All these factors make ground-dwelling arthropods good indicators and acts as early warning or indicators of ecological and environmental change (Lawes et al., 2005; Jouquet et al., 2006). McGeoch (1998) reported that a good bioindicator species should be abundant, easy to identify, respond to environmental stresses, and its population should differ between the disturbed and undisturbed environments.

Response of ground-dwelling arthropods to anthropogenic activities

Clearing of natural habitats for different practices promotes environmental disturbance which is one the major threats to ground-dwelling arthropods species diversity (Nakamura et al., 2007). Response of ground-dwelling arthropods to environmental disturbances such as alien plant invasion and landuse changes may result in the geographic range shift in arthropod communities which has negative impact on the ecosystem (Samways et al., 1999; Mgobozi et al., 2008). Ants, beetles, spiders, termites, woodlice and millipedes respond differently to environmental disturbances (Hoffmann and Andersen, 2003; Lawes et al., 2005; Kotze and Lawes, 2008 Hadkinson and Jackson, 2005; Snyder and Hendrix, 2008). Their distribution, diversity and composition tend to decrease with increasing environmental stress, for example, the abundance and composition of dipteran larvae declines when the soil moisture decreases (Hoffmann and Andersen, 2003; Hodkinson and Jackson, 2005; Lawes et al., 2005; Snyder and Hendrix, 2008; Kotze and Lawes, 2008). However, ants can increase in abundance and composition following environmental disturbance (Berman et al., 2013).

Generally, ground-dwelling arthropods abundance decreases with increasing disturbance (Kotze and Lawes, 2008; Snyder and Hendrix, 2008). However, some pioneer species of ground dwelling arthropods tend to colonize disturbed habitats and their abundance and diversity increase over time (Snyder and Hendrix, 2008). De Lange (1994) reported that most ground dwelling-arthropods have poor dispersal abilities and they spend their whole lifecycle in one habitat which makes them more vulnerable to changing environment. Because of their poor dispersal abilities ants, terrestrial crustaceans and woodlice, depend largely on resources available in their macro-environments (Lawes et al. 2005; Kotze and Lawes, 2008; Yekwayo, 2016). In addition, this prevent ground-dwelling arthropods from escaping disturbances occurring in their habitats.

Habitat disturbance for different practices may promote the invasion of alien plants which remains one of the major issues in different ecosystems worldwide (Samways et al., 1996). Richardson and Van Wilgen (2004) reported that South Africa is among one of many countries largely affected by invasion of alien plants. Alien plants cause serious threats to biodiversity in South Africa (Samways et al., 1996; Mgobozi et al., 2008; Niba and Mafereka, 2015) in addition, alien plant invasion is the second major disturbance after land destruction in different

parts of the world. Alien plants are known for altering vegetation structure and outcompeting native species in the areas they invade (Mgobozi et al., 2008). This alters ecosystem functioning and result in the local extinction of native plant and animal species across the world (Samways et al., 1996; Mgobozi et al., 2008; Niba and Mafereka, 2015).

Alien plant invasion replace indigenous vegetation which in turn affects ground dwelling arthropods assemblages negatively (Samways et al., 1996). The impact of alien plant invasion on ground-dwelling arthropods varies with the intensity of invasion and the degree of change in the vegetation structure of indigenous plants (Mgobozi et al., 2008). Ground-dwelling arthropods assemblages decrease with increasing alien plant invasion intensity (Samways et al., 1996; McCabe and Gotelli, 2000; Mgobozi et al., 2008) if the level of invasion in minimal or intermediate some taxa of epigaeic macroinvertebrates become abundant and diverse (McCabe and Gotelli, 2000).

Factors affecting ground-dwelling arthropods abundance and diversity

The abundance, diversity and assemblage composition of ground-dwelling arthropods are affected by a number of factors such as vegetation type, vegetation structure, soil type, habitat condition, and different management practices (Kwok et al., 2011). Ground-dwelling arthropods are found primarily on the ground surface, soil and in vegetation (Snyder and Hendrix, 2008). Being in the soil makes ground-dwelling arthropods more prone to disturbances, such as, fire, ploughing, grazing, land pollution and clearing of the habitat (Curry, 2004; Kwok et al., 2011). Anthropogenic activities are a major threat to ground-dwelling arthropods diversity, abundance and composition because they largely damage soil structure and ecosystem which have a major influence on ground-dwelling arthropod diversity and abundance (Curry, 2004). Climate change is also a major threat to ground-dwelling arthropods diversity, abundance and composition (Curry, 2004; Kwok et al., 2011).

Soil properties and vegetation structure also affect ground-dwelling arthropods diversity, abundance and composition (Kotze and Lawes, 2008; Yekwayo et al., 2016). Soil and vegetation are directly affected by climate change which indirectly affect ground-dwelling arthropods diversity, abundance and composition (Curry, 1994; Curry, 2004). Increasing

temperatures above normal rate affect vegetation structure and different soil properties which impact negatively on ground dwelling arthropods community structure (Curry, 1994; Curry, 2004). In addition, as a result of these threats ground-dwelling arthropods could shift their distributional range to places with less environmental threats (Curry, 2004).

Factors affecting plant assemblages in grasslands

Vegetation is plays a fundamental role in ecosystem functioning (Egoh et al., 2011). Surrounding vegetation may influence ground-dwelling arthropods species diversity and abundance, therefore, it is important to study the factors affecting vegetation in grasslands (Yekwayo et al., 2016). Vegetation dynamics in grasslands is affected by a number of threats which include climate change and human induced activities (Pribadi et al., 2011). Disturbance as a result of human induced activities is one of the important components that lead to habitat destruction which is a major threat to ecosystem stability (Pribadi et al., 2011; Niba and Mofereka, 2015). Different forms of disturbance alter vegetation community structure by reducing vegetation cover, abundance and composition (Hobbs and Huenneke, 1992). In addition, disturbance does not only affect vegetation structure, diversity and composition, they also trigger invasion of alien plants (Richardson et al., 2007). Alien plants are the major threat to vegetation in different habitats as they compete with indigenous vegetation for resources such as water, sunlight and space (Niba and Mofereka, 2015). Invasive alien plants affect vegetation community dynamics and alter soil nutrient cycling, which also affects soil macroinvertebrates dynamics (Niba and Mofereka, 2015).

Climate, together with different environmental variables, also influences vegetation dynamics in different ecosystems. Climate and different environmental variables also play an important role in explaining different vegetation patterns across the world (He et al., 2007). Climatic variables include annual rainfall, soil properties and topography (He et al., 2007). In addition, these factors explain diversity and composition of vegetation in grasslands. Increase and decrease in seasonal temperature and annual precipitation indirectly affect soil properties which inversely affect vegetation structure and composition (He et al., 2007). Climate change could cause shift in vegetation structure which would affect ground dwelling arthropods diversity, abundance and composition.

Conclusion

Use of ground-dwelling arthropods as bioindicators of ecological conditions has become popular all over the world (Hodkinson and Jackson, 2005). However, few studies have focused on the use of several soil macroinvertebrate groups as bioindicators, most studies focus on single taxon. This resulted in some taxa being understudied than other taxa. In South Africa few studies have focused on the use of soil macroinvertebrates as bioindicators of ecological conditions. More research is required mostly in endangered and threatened environments so that these habitats will be monitored and conserved for future generations.

References

Andersen, A. N., Fisher, A., Hoffmann, B. D., Read, J. L., Richards, R., 2004. Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. Austral Ecology 29, 87–92.

Andersen, A. N., Hoffmann, B. D., Müller, 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.

Berman, M., Andersen, A. N., Hély, C., Gaucherel, C., 2013. Overview of the distribution, habitat association and impact of exotic ants on native ant communities in New Caledonia. PLoS One 8, e67245

Barnett, K. L., Facey, S. L., 2016. Grasslands, invertebrates, and precipitation: a review of the effects of climate change. Frontiers in Plant Science 7, 1–7.

Boval, M., Dixon, R. M., 2012. The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. Animal 6, 748–762.

Cole, L., Bradford, M. A., Shaw, P. J., Bardgett, R. D., 2006. The abundance, richness and functional role of soil meso–and macrofauna in temperate grassland— a case study. Applied Soil Ecology 33, 186–198.

Curry, J.P., 1994. Grassland Invertebrates: Ecology, Influence on Soil Fertility and Effects on Plant Growth. Chapman and Hall, London.

Curry, J. P., 2004. Factors affecting the abundance of earthworms in soils. Earthworm Ecology, 91–113.

Decaens, T., Jimenez, J. J., Gioia, C., Measey, G. J., Lavelle, P., 2006. The values of soil animals for conservation biology. European Journal of Soil Biology 42, S23–S38.

De Lange, H. J., 1994. http://www.water.ncsu.edu/watershedss/info/macroinv.html. (Accessed 1 July 2016).

Egoh, B.N., Reyers, B., Rouget, M., Richardson, D.M., 2011. Identifying priority areas for ecosystem service management is South African grassland. Journal of Environmental Management 92, 1642–1650.

Gerlach, J., Samways, M., Pryke, J., 2013. Terrestrial invertebrates as bio–indicators: an overview of available taxonomic groups. Journal of Insect Conservation 17, 831–850.

He, M. Z., Zheng, J. G., Li, X. R., Qian, Y. L. 2007. Environmental factors affecting vegetation composition in the Alxa Plateau, China. Journal of Arid Environments 69, 473–489.

Hobbs, R. J., Huenneke, L. F., 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6, 324–337.

Hodkinson, I. D., Jackson, J. K., 2005. Terrestrial and aquatic invertebrates as bio–indicators for environmental monitoring, with particular reference to mountain ecosystems. Environmental Management 35, 649–666.

Hoffmann, B. D., Andersen, A. N., 2003. Responses of ants to disturbance in Australia, with particular reference to functional groups. Austral Ecology 28, 444–464.

Holt, E. A., Miller, S. W., 2011. Bioindicators: using organisms to measure environmental impacts. Nature Education Knowledge 3, 1–10.

Jouquet, P., Dauber, J., Lagerlöf, J., Lavelle, P., Lepage, M., 2006. Soil invertebrates as ecosystem engineers: intended and accidental effects on soil and feedback loops. Applied Soil Ecology 32, 153–164.

Kotze, D. J., Lawes, M. J., 2008. Environmental indicator potential of the dominant litter decomposer, *Talitriator africana* (Crustacea, Amphipoda) in Afrotemperate forests. Austral Ecology 33, 737–746.

Kwok, A. B.C., Eldridge, D.J., Oliver, I., 2011. Do landscape health indices reflect arthropod biodiversity status in the eucalypt woodlands of eastern Australia? Austral Ecology 36, 800–813.

Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., Mora, P., Rossi, J. P., 2006. Soil invertebrates and ecosystem services. European Journal of Soil Biology 42, S3–S15.

Lawes, M. J., Kotze, D. J., Bourquin, S. L., Morris, C., 2005. Epigaeic invertebrates as potential ecological indicators of Afromontane forest condition in South Africa1. Biotropica 37, 109–118.

Longcore, T. R., 1999. Terrestrial arthropods as indicators of restoration success in coastal sage scrub. Unpublished Doctoral dissertation. University of California, Los Angeles.

Longcore, T., 2003. Terrestrial arthropods as indicators of ecological restoration success in coastal sage scrub (California, USA). Restoration Ecology11, 397–409.

Maelfait, J. P., Hendrickx, F., 1998. Spiders as bio–indicators of anthropogenic stress in natural and semi–natural habitats in Flanders (Belgium): some recent developments. In: Selden, P.A., (ed.), Proceedings of the 17th European Colloquium of Arachnology, Edinburgh, pp. 293–300.

McCabe, D. J., Gotelli, N. J., 2000. Effects of disturbance frequency, intensity, and area on assemblages of stream macroinvertebrates. Oecologia 124, 270–279.

McGeoch, M. A., Van Rensburg, B. J., Botes, A., 2002. The verification and application of bioindicators: a case study of dung beetles in a savanna ecosystem. Journal of Applied Ecology 39, 661–672.

McGeoch, M., 1998. The selection, testing and application of terrestrial insects as bioindicators. Biological Reviews 73, 181–201.

Mgobozi, M. P., Somers, M. J., Dippenaar-Schoeman, A. S., 2008. Spider responses to alien plant invasion: the effect of short-and long-term *Chromolaena odorata* invasion and management. Journal of Applied Ecology 45, 1189–1197.

Nakamura, A., Catterall, C. P., House, A. P., Kitching, R. L., Burwell, C. J., 2007. The use of ants and other soil and litter arthropods as bio-indicators of the impacts of rainforest clearing and subsequent land use. Journal of Insect Conservation 11, 177-186.

Niba, A. S., Mafereka, P. S., 2015. Response of soil-surface dwelling invertebrates to alien invasive and indigenous plant cover in a sub-tropical Nature Reserve, Eastern Cape, South Africa. African Journal of Agricultural Research 10, 902–910.

Olff, H., Ritchie, M. E., 1998. Effects of herbivores on grassland plant diversity. Trends in Ecology and Evolution 13, 261–265.

Paoletti, M. G., 1999. The role of earthworms for assessment of sustainability and as bio–indicators. Agriculture, Ecosystems and Environment 74, 137–155.

Pribadi, T., Raffiudin, R., Harahap, I.S., 2011. Termites community as environmental bioindicators in highlands: a case study in eastern slopes of Mount Slamet, Central Java. Biodiversitas 12, 253–240.

Richardson, D. M., Van Wilgen, B. W., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? South African Journal of Science, 100, 45–52.

Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S. M., Stromberg, J.C., Kirkman, S.P., Hobbs, R.J., 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. Diversity and Distributions, 13, 126–139.

Samways, M. J., Caldwell, P. M., Osborn, R., 1996. Ground–living invertebrate assemblages in native, planted and invasive vegetation in South Africa. Agriculture, Ecosystems and Environment 59, 19–32.

SANBI., 2013. Grasslands Ecosystem Guidelines: Landscape Interpretation for Planners and managers. South African National Biodiversity Institute Grassland Programme, Pretoria.

Seastedt, T. R., Crossley Jr, D. A., 1984. The influence of arthropods on ecosystems. BioScience 34, 157–161.

Snyder, B. A., Hendrix, P. F., 2008. Current and potential roles of soil macroinvertebrates (earthworms, millipedes, and isopods) in ecological restoration. Restoration Ecology 16, 629–636.

Tshiguvho, T. E., Dean, W. R. J., Robertson, H. G., 1999. Conservation value of road verges in the semi-arid Karoo, South Africa: ants (Hymenoptera: Formicidae) as bio-indicators. Biodiversity and Conservation 8, 1683–1695.

Van Hamburg, H., Andersen, A. N., Meyer, W. J., Robertson, H. G., 2004. Ant community development on rehabilitated ash dams in the South African Highveld. Restoration Ecology 12, 552–558.

Williams, K. S., 1993. Use of terrestrial arthropods to evaluate restored riparian woodlands. Restoration Ecology 1, 107–116.

Wills, B. D., Landis, D. A. 2017. The role of ants in north temperate grasslands: a review. Oecologia, 1–16.

Yekwayo, I., 2016. Diversity value of Afromontane forest patches within KwaZulu-Natal timber production areas. Unpublished Doctoral dissertation. Stellenbosch University, Stellenbosch.

Yekwayo, I., Pryke, J. S., Roets, F., Samways, M. J., 2016. Surrounding vegetation matters for arthropods of small, natural patches of indigenous forest. Insect Conservation and Diversity 9, 224–235.

Chapter 2: Epigaeic ant diversity and distribution across the Sandstone Sourveld in KwaZulu-Natal

Abstract

Ants are among the most abundant group of soil macroinvertebrates and are important in the functioning of terrestrial ecosystems. They are sensitive to habitat change and may be affected by vegetation type, structure and disturbances, such as, alien plant invasion. The aim of this study was to determine diversity and abundance of ants in KwaZulu-Natal Sandstone Sourveld at Tanglewood and Giba Gorge Reserves, both in the eThekwini Municipality. Ground-dwelling ants were sampled at both sites in the wet and dry season between 2016 and 2017. At each site pitfall trap sampling was carried out in an intact grassland, riverine or scarp forest and a disturbed grassland vegetation type. Each vegetation type was replicated three times. Each consisted of ten pitfall traps. A total of 2 577 ground-dwelling ant specimens were collected 995 individuals at Giba Gorge, 1 582 individuals at Tanglewood. However, Giba Gorge was more speciose with 42 morpho-species compared to Tanglewood with 35 morpho-species. Ants were more abundant in the disturbed grassland vegetation than an intact grassland and the forest. Although *Pheidole* sp.02 (*megacephala* gp.) occurred across the vegetation types, it was more abundant in the disturbed grassland vegetation. These results suggest that *Pheidole* sp.02 (*megacephala* gp.) could be a useful potential indicator for monitoring ecological condition of the KwaZulu-Natal Sandstone Sourveld.

Introduction

Ants (Hymenoptera: Formicidae) are among the most dominant and diverse group of arthropods on earth (Wilkie et al., 2010; Del Toro et al., 2012; Guenard, 2013; Sonune and Chavan, 2016) and they are abundant in different terrestrial ecosystems. Ant diversity tends to peak in the tropical regions, and decreases with increasing latitude and altitude (Parr, 2005; Guenard 2013). Ants are the most influential and important organisms in different ecosystems (Bestelmeyer and Wiens, 1996; Del Toro et al., 2012; Guenard, 2013) their ecological role includes interactions with other organisms, such as, bacteria, fungi, plants, arthropods and vertebrates (Parr, 2005; Guenard, 2013). As a result, ants play an important role in the survival and control of a number of other species (Guenard 2013). In addition, ants play a notable role

at different trophic levels as decomposers, detritivores, herbivores, predators, and mutualists (Parr, 2005; Kotze and Lawes, 2008; de Castro Solar et al., 2016). As such, ants help in decomposition, nutrient cycling, pest control, seed dispersal, seed germination and pollination (Hoffman and Andersen, 2003; Parr, 2005; Sanders and Platner, 2007; Kotze and Lawes, 2008; de Castro Solar et al., 2016). In decomposition processes, ants break down leaf litter for onward processing by other organisms found in their environments (Lawes et al., 2005; Kotze and Lawes, 2008).

Ants are used as bioindicators of ecological change (Read and Andersen, 2000; Wang et al., 2000; Graham et al., 2004; Buczkowki and Richmond, 2012; Munyai and Foord, 2015b) because they are abundant, have a short lifespan, easy to sample and respond to changing environment at small scales. Ants also play an important role in the establishment of food chains and they are one of the well-studied group of social insects (Read and Andersen, 2000; Wang et al., 2000). In different terrestrial ecosystems ants have been used as bioindicators to assess restoration success after mining (Andersen, 1997; Hoffman, 2000), livestock grazing (Andersen et al., 2004; Nash et al. 2004), effect of disturbances in forests and grasslands (King et al., 1998; Hoffman and Andersen 2003; Andersen et al. 2004; Rosado et al. 2012; de Castro Solar et al., 2016) and the effect of different land uses (Bestelmeyer and Wiens, 1996; Gomez et al., 2003; Attwood et al., 2008; Lange et al., 2011; Yeo et al., 2011; Cuautle et al., 2016). In addition, ants are used to assess the functioning of soil in rural environments (De Bruyn, 1999), the effect of fire (Parr et al., 2004; Parr, 2005), logging practices (Andersen, 1997), alien plant invasion (Lenda et al., 2013) and pesticide use (Matlock and de la Cruz, 2003).

Ants are sensitive to ecological change, habitat disturbance affects ants enormously because they live and forage in the ground (Wang et al., 2000; Attwood et al., 2008; Schoeman and Foord, 2012). In addition, ant activities are influenced by vegetation structure, type, and complexity (Schoeman and Foord, 2012). Habitat disturbance may be associated with the removal of vegetation at ground level and alien plants invasion (Attwood et al., 2008, Mgobozi, 2010; Niba and Mafereka 2015), and this has serious implications on ant communities. Many ant species forage on leaf litter, seeds, fruits and other plant parts (Parr, 2005; Tantsi, 2012). The abundance and diversity of ants are positively correlated to vegetation diversity (Parr, 2005; Schoeman and Foord, 2012). The aim of this study was to determine ant diversity and

abundance in the Tanglewood and Giba Gorge nature reserves. We sought: 1) to determine species abundance, species composition and species richness in different vegetation types; 2) to investigate the effect of season on ant assemblages and 3) to compare species abundance, species composition and species richness among vegetation types.

Materials and Methods

Study sites

The study was conducted at two sites located in the KwaZulu-Natal Sandstone Sourveld in the eThekwini Municipality, KwaZulu-Natal Province, South Africa. Tanglewood Nature Reserve (29^0 62.574' S, 30^0 40.330' E) is a 70 ha privately-owned property located in the Pinetown area. Giba Gorge nature reserve (29^0 49.628' S, 30^0 46.916' E), which is managed by the eThekwini Municipality and the Hillcrest conservancy, covers 72 ha of predominantly grassland and a mixture of grassland with eucalypts. Besides intact grassland, the vegetation at the two sites also consists of riverine and scarp forests. Disturbed grassland is a mosaic of natural/secondary grasslands resulting from the previous conversion to eucalypt and pine plantations. The disturbance was as a result of the invasion of alien invasive plants. 60% of the area consisted patches of alien invasive plants, such as *Lantana camara, Eucalyptus grandis, Solanum mauritianum, Chromolaena odorata, Pinus elliotti, Acacia mearnisii, Tithonia diversifolia, Senna didymobotrya* and *Canna indica* both nature reserves.

The grassland is classified as KwaZulu-Natal Sandstone Sourveld (KZNSS), which is dominated by tall and short grasses, such as *Aristida junciformis*, *Diheteropogon amplectens, Digitaria eriantha* and *Monocymbium ceresiiforme.* KwaZulu-Natal Sandstone Sourveld experiences high rainfall in summer and dry conditions in winter, and most rainfall occurs between October and March with a mean annual rainfall of 700 to 1200 mm (Mucina and Rutherford, 2006). Midday temperature ranges from 16°C to 25°C in winter and 23°C to 33°C in summer (Mucina and Rutherford, 2006). The underlying geology is described as Ordovician Natal group sandstones and shallow nutrient-poor sandy soils (Mucina and Rutherford, 2006).
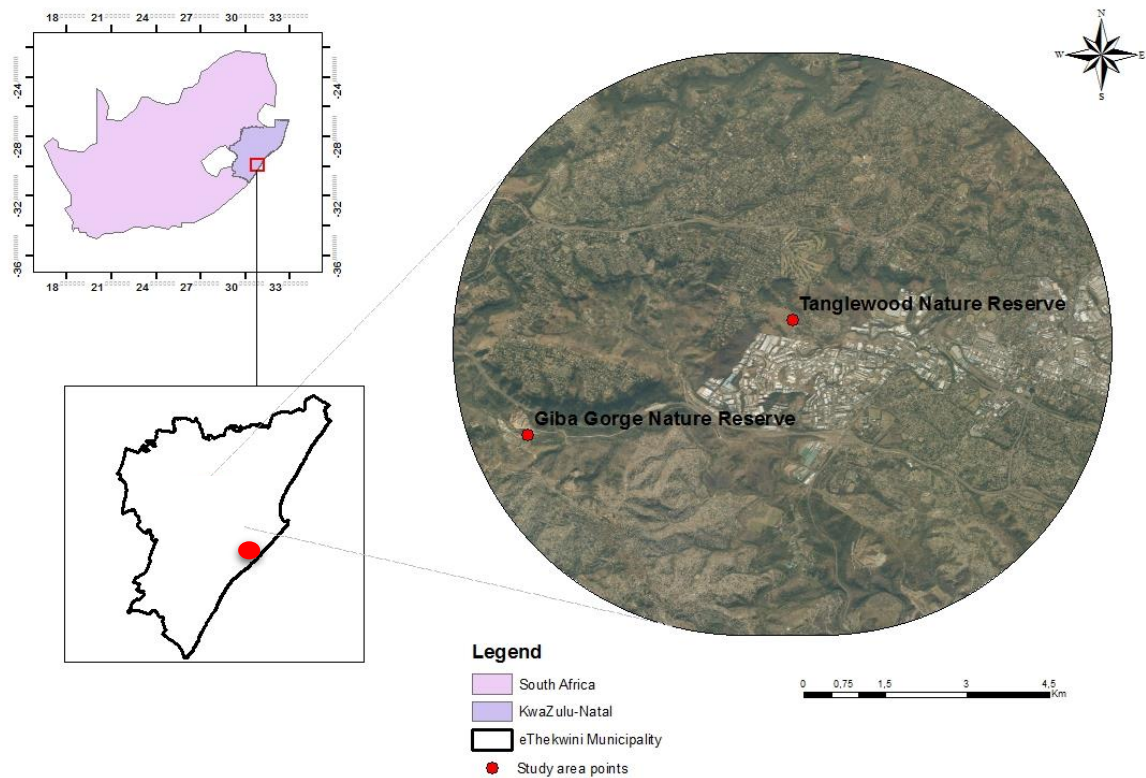
Fig. 2. 1. Map of the study area.

Ants Sampling

Ants were sampled using pitfall trapping, which is the most effective and widely used method for sampling ground-dwelling arthropods (Samways et al., 2010). Pitfall sampling collects a large number of specimens as compared to other methods used in collecting ground-dwelling arthropods (Gomez et al., 2003). Forest, intact grassland, and disturbed grassland vegetation types were identified at each site. Each vegetation type was replicated three times and each replicate had ten pitfall traps laid in a 2 × 5 grid with 10 m between adjacent pitfall traps as described by Munyai and Foord (2015a). Pitfall traps consisted of honey jars (64 mm diameter, 110 mm height, 500 ml volume) that were inserted each in a hole dug into the ground and the open end left flush with the soil surface. Jars were quarter-filled with 50 % propylene glycol solution for preserving collected specimens. Pitfall trap sampling was carried out in June and July 2016, which coincides with the dry season, and during the wet season in November and December 2016. Traps were removed after five days and taken to the laboratory where

ground-dwelling ants were sorted, identified and counted. Ants were identified to morpho-species or species level where possible, using identification keys and guides (Fisher and Bolton, 2016).

Statistical analysis

Analysis of Similarity (ANOSIM) and Similarity Percentage (Simper) with 9999 permutations in PAST3 was used to determine if there were any significant similarities in species composition of ants among the vegetation type (Hammer et al., 2001). The differences or similarities between ant species composition across different vegetation types were analysed using Non-Metric Multidimensional Scaling (nMDS) in PAST3 with data ordered by replicates. Species accumulation curves were used to determine whether adequate sampling of ants between different vegetation types had been done (Hammer et al. 2001).

The species accumulation curves were produced in EstimateS 9.1.0 with samples randomized 100 times for all vegetation types separately as well as for all vegetation types combined in each site. Six non-parametric estimators were used to provide the best overall ground-dwelling ant species estimates for the vegetation types. The Abundance-based Coverage Estimator (ACE) and an Incident-based Coverage Estimator (ICE) are the most robust and accurate estimators of species richness (Colwell, 2013) while Chao2, Jacknife, Michaelis-Menten richness estimator (MM) and Bootstrap richness estimator provide the least biased estimates should insufficient sampling be encountered (Magoba, 2010; Colwell 2013; Yekwayo et al., 2016).

To determine whether there were differences in species abundance and richness across vegetation type at each site, a Generalised Linear Model with Poisson distribution and log link function was used (Quinn and Keough, 2002; Sokal and Rohlf, 2012). To determine the effect of season on ant abundance at the two sites, Generalised Linear Model with poison distribution and log link function was used. Generalised linear models were run using SPSS version 23 (IBM SPSSS, 2015). All analyses used a significance level of 0.05.

Results

In total, 2 577 ant specimens were collected from the two sites during the wet and dry seasons, representing 55 morpho-species in 22 genera and five subfamilies (Appendix 2.1).

Myrmicinae (27 morpho-species, 85 % of the total abundance and seven genera) was the most abundant and diverse subfamily, followed by Ponerinae (13 morpho-species, 8 % of the total abundance and eight genera). Dolichoderinae was the least abundant and least species-rich subfamily (two morpho-species, 0.0015 % of the total abundance and only one genus) and the Dorylinae had two morpho-species and two genera that made up 0.0027% of the total abundance. With 1 351 specimens and 27 morpho-species from three sub-families, the disturbed grassland vegetation had more specimens followed by an intact grassland with 800 specimens and 40 morpho-species. *Pheidole* sp.02 (*megacephala* gp), *Myrmicaria* sp.01 and *Lepisiota* sp.01 (*capensis* gp) occurred across all vegetation types in the study area (Appendix 2.1).

In Tanglewood Reserve, the highest species abundance and species richness were recorded in the disturbed grassland vegetation type while at Giba Gorge Reserve, it was in an intact grassland. The forest had the least number of ants in both reserves (Figs. 2.2. and 2.3). The wet season had higher species richness and abundance than the dry (Figs. 2.4 and 2.5). The observed accumulation curves were slow to reach an asymptote in both reserves, indicating that more samples or sampling effort are required to get a representative sample of ant species found in Tanglewood and Giba Gorge Reserves (Figs. 2.6a. and 2.6b.). The percentages of completeness for ant species in each vegetation type per site ranged from 60 % to 90 % of the potential species richness (Table 2.1).

The Non-Metric Multidimensional Scaling plot showed similarities in species composition of ants among disturbed grassland, forest and grassland vegetation types (Fig. 2.7). Natural grassland and a disturbed grassland had similar species composition than the forest.

The Similarity Percentage indicated that an intact grassland and disturbed grassland had similar species composition. The overall percentage of similarity was higher when the disturbed grassland and a grassland were compared in Tanglewood and Giba Gorge Nature Reserves (Table 2.2).

Greater abundance of ants was recorded in the disturbed grassland than in the forest and intact grassland in Tanglewood (X^2 = 6.969; df = 2; p< 0.05). However, there were no significant differences in ant abundance across vegetation types in Giba Gorge (X^2 = 1.919; df = 2; p> 0.05). Intact grassland was the richest vegetation type than the forest and a disturbed

grassland in Giba Gorge (X^2 = 10.242; df = 2; p< 0.05). There were no significant differences in ant richness across vegetation types in Tanglewood (X^2 = 1.029; df = 2; p> 0.05). The wet season samples had greater abundance of ants than the dry season in Tanglewood (X^2 = 4.606; df = 1; p< 0.05) however, there was no significant different between the wet and dry seasons in Giba Gorge (X^2 = 1.692; df = 1; p> 0.05). Wet season was the richer season than the dry season in Giba Gorge (X^2 = 6.086; df = 1; p< 0.05). However, there was no significant difference in species richness of ants between dry and the wet season in Tanglewood (X^2 = 6.086; df = 1; p< 0.05). ANOSIM showed significant differences in ant community among vegetation types at Giba Gorge (p <0.01; R = 0.69) and Tanglewood (p = 0.011; R = 0.47).

Table 2. 1. Percentage completeness of ground-dwelling ant assemblages derived from six richness estimators (ACE mean, ICE mean, Jack2, Chao 2, MM Mean and Bootstrap) available in EstimateS 9.1.0 package (Colwell, 2013) across three vegetation types in Tanglewood and Giba Gorge Reserves

	Minimum	Maximum
Tanglewood		
Disturbed grassland	76.2	94.8
Forest	60.9	85.2
Intact grassland	62.9	85.1
Giba Gorge		
Disturbed grassland	67.4	86.2
Forest	60.5	83.2
Intact grassland	70.3	89.5
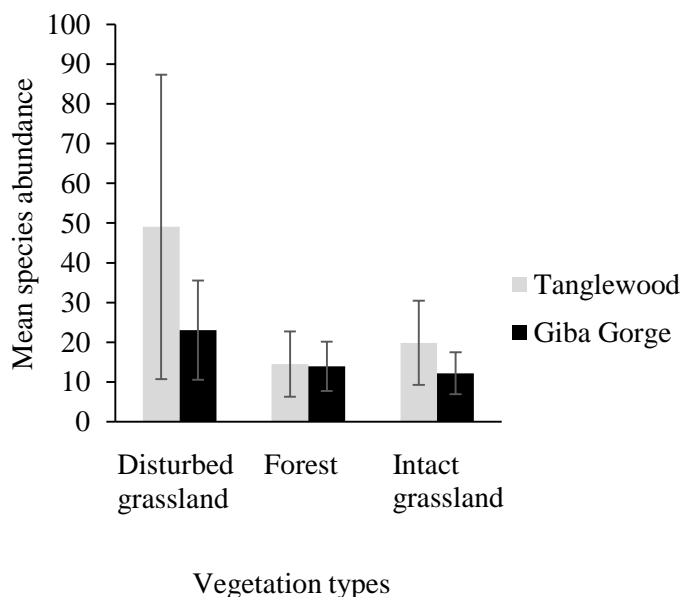
Fig. 2. 2. Mean (±SE) species abundance of epigaeic ants sampled at different vegetation types in Tanglewood and Giba Gorge Reserves.
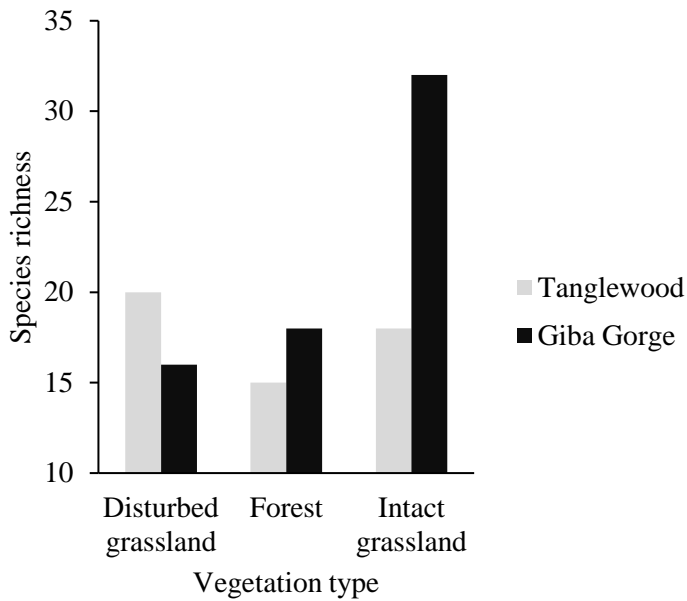
Fig. 2. 3. Species richness of epigaeic ants sampled at different vegetation types in Tanglewood and Giba Gorge Reserves.
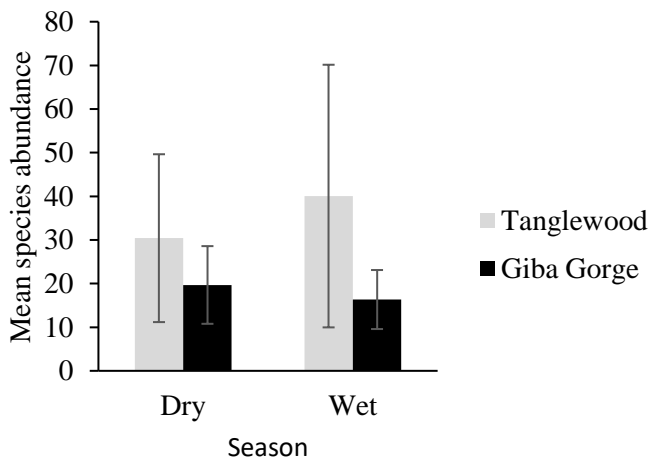
Fig. 2. 4. Mean (±SE) species abundance of epigaeic ants sampled in wet and dry season at Tanglewood and Giba Gorge Nature Reserves.
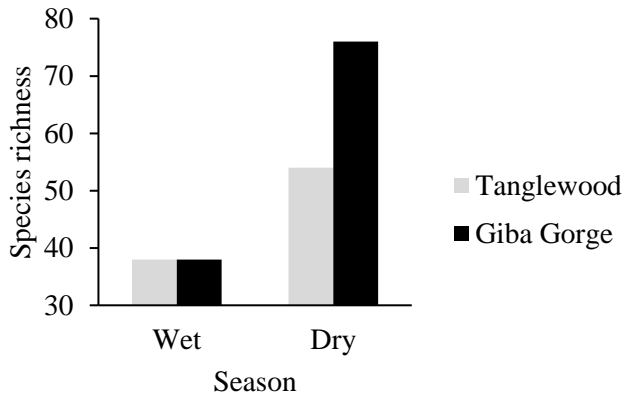
Fig. 2. 5. Species richness of epigaeic ants sampled in wet and dry season at Tanglewood and Giba Gorge Nature Reserves.
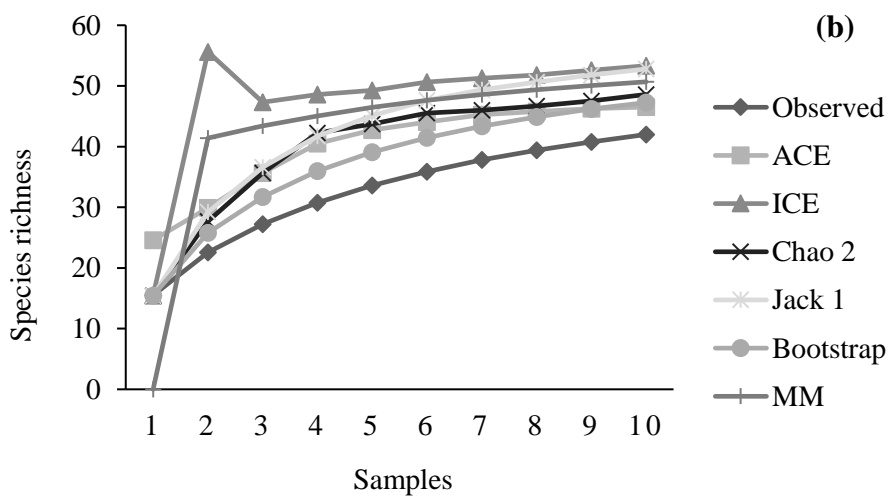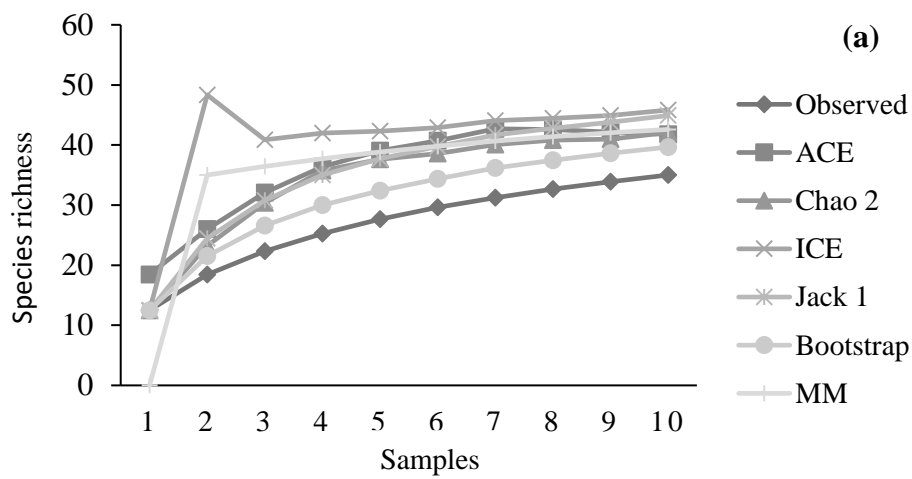
Fig. 2. 6. Estimated species accumulation curves in three vegetation types at (a) Tanglewood Reserve (b) Giba Gorge Reserve.
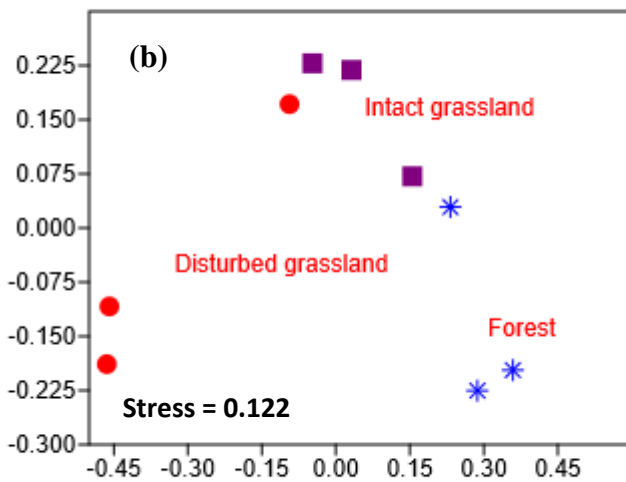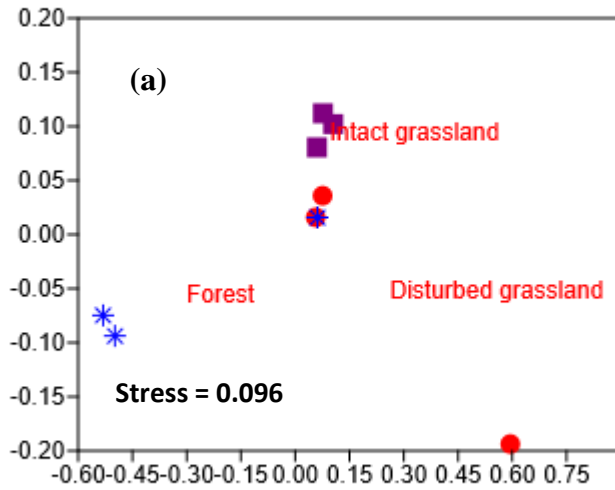
Fig. 2. 7. Non-metric Multidimensional Scaling (nMDS) of epigaeic ant assemblages in three vegetation types in (a) Tanglewood and (b) Giba Gorge Reserves. Circles represent disturbed grassland, stars represent forest and squares represent intact grassland.

Table 2. 2. Overall similarity of epigaeic ant species composition sampled in the forest, disturbed and intact vegetation type

Vegetation type comparison	Overall percentage similarity
Tanglewood	
Disturbed grassland vs Forest	31.8
Disturbed grassland vs Intact grassland	48.1
Intact grassland vs Forest	30.8
Giba Gorge	
Disturbed grassland vs Forest	19.1
Disturbed grassland vs Intact grassland	38.3
Intact grassland vs Forest	31.8

Discussion

Ant abundance differed among vegetation types, season and sites. The abundance of ants also differed among different subfamilies and genera. Subfamily Myrmicinae was the most abundant and species-rich subfamily followed by Ponerinae and Formicinae. Myrmicinae comprises generalist species and occurs abundantly in almost all the major habitats types across all geographic regions (Sonune and Chavan, 2016; Ant Web, 2017). This conforms to findings from other studies (e.g. Rosado et al., 2012; Costa-Milanez, 2014; Munyai and Foord, 2015b). *Pheidole, Myrmicaria* and *Tetramorium* were the most abundant genera across disturbed grassland, forest, and an intact grassland vegetation types in Tanglewood and Giba Gorge Reserves. These ant genera are abundant and speciose in several ecosystems because they are pioneer species and have great ability to adapt and to diversify in different ecological niches (Achury et al., 2011; Rosado et al., 2012; Costa-Milanez et al., 2014).

The abundance of ants in Tanglewood and Giba Gorge Reserves can be explained using the intermediate disturbance hypothesis which states that species diversity and abundance tend to be greater under moderate levels of disturbance (Bongers et al., 2009). Disturbance creates macro-environments with suitable resources and habitat conditions which allow for some species to persist and dominate (McCabe and Gotelli, 2000; Bongers et al., 2009). Berman et

al. (2013) found that exotic ants were more abundant in disturbed habitats than undisturbed habitats. Disturbed grassland vegetation in Tanglewood and Giba Gorge Reserves consisted of patches of alien invasive plants. Alien invasive plants are responsible for modifying habits, food resources, and biotic interaction and they provide optimum and suitable resources to ground-dwelling arthropods (Niba and Mafereka, 2015, Niba and Yekwayo, 2016). The impact of alien plants on insect assemblages is not always negative because alien plants may provide nesting and foraging sites (Harris et al., 2004). Alien plants may have more resources for insects than indigenous vegetation (Harris et al., 2004). However, some alien plants may have a detrimental effect on abundance of ground-dwelling arthropod assemblages (Samways and Moore, 1991; Samways et al., 1996). The effect of alien plants on ground-dwelling arthropods also depends on the intensity of the invasion (Samways et al., 1996; Niba and Mafereka, 2015). Minimal or moderate invasion intensity by alien plants has lower or no impact on the abundance of ground-dwelling arthropods (Niba and Mafereka, 2015).

Intact grassland and disturbed grassland vegetation had greater ant species richness than the forest in both Tanglewood and Giba Gorge Reserves. Forests are characterised by high leaf litter deposition in the ground, which influences resource availability, macroclimatic conditions and available nesting sites for ants (Silva et al., 2011). These forest conditions may have a negative effect on ant species richness. Yekwayo (2016) found that grasslands supported higher arthropod abundance and richness compared to forests, particularly ant species, which made up 61 % of the sampled individuals in forest and grassland habitats. Ant diversity and richness decline sharply in forest habitats because ants do not do well in shaded environments (Bestelmeyer and Wiens, 1996). Ants body temperature decrease with the decreasing air temperature, this reduces ants foraging activities, which explains the decline in ant diversity and richness in shaded environments (Porter and Tschinkel, 1987). Furthermore, ants prefer warm climatic conditions and forage in sites with low vegetation which probably explains the high species richness in an intact grassland and disturbed grassland vegetation type (Kyerematen et al., 2014). Species accumulation curves did not reach an asymptote for either sites, which suggests that we have not collected all species present in the sites. However, species richness per vegetation type did reach an asymptote and species inventory completeness were above 60 %, both of which suggests that observed samples were an adequate representative of the species in each vegetation type.

There was considerable overlap of ant species across the forest, intact grassland and disturbed grassland vegetation types. All vegetation types had fewer unique species, most species were common across disturbed grassland, forest and an intact grassland. The level of similarity between the sites was very high. *Pheidole* sp.02 (*megacephala* gp), which are associated with warm tropical and subtropical environments, was common and abundant in disturbed grassland sites. This is consistent with Hoffman et al. (1999) and Vanderwoude et al. (2000) who reported that *P. megacephala* is generally found in disturbed environments, such as, agricultural land and urban areas. In addition, the species altitudinal range is wide as it occurs abundantly in lowlands and also occurs at high elevation sites of ca. 2000 m (Hoffman et al., 1999). *Leptogenys schwabi*, a member of the Ponerinae, only occurred in the forest and disturbed grassland vegetation type but was more abundant in the forest at both sites. *Leptogenys schwabi* is associated with riverine and eastern coastal belt forest of South Africa, which may explain its abundance in the forest vegetation type (Ant Web, 2017).

Seasons influence the composition of ground-dwelling ant assemblages (Keroumi et al., 2012). The wet season was associated with high abundance and greater species richness of ants than the dry season in both sites. These results are in agreement with the findings of Keroumi et al., (2012), who reported greater abundance and species richness of ants in the wet compared to dry season in an Argan forest of Morocco, which is dominated by endemic Argan trees (*Argania spinosa*). Munyai and Foord (2015b) reported that ground-dwelling ants are intolerant to cold conditions and they are active and abundant in the wet compared to dry season. Activities of ground-dwelling ants are affected by food resource availability, temperature, moisture and solar radiation, the influence of these factors declines in the dry season and increase in the wet season (Abhinandini and Venkatesha, 2013). In the wet season, the greater availability of food resources may reduce interspecific competition resulting in increases in abundance (Keroumi et al., 2012). In addition, foraging activities of ground-dwelling ants are greater in the wet than dry season because the dry season in the tropics and subtropics is associated with cooler climatic conditions which forces many invertebrates to hibernate thus reducing their abundance (Keroumi et al., 2012).

Species abundance and richness of ants in KwaZulu-Natal Sandstone Sourveld are influenced by vegetation type. The disturbed grassland vegetation supported more ants than an intact grassland and forest vegetation types. The results support the intermediate hypothesis which state that diversity and abundance peaks at the intermediate levels of disturbances (Bongers et al., 2009). Disturbed grassland vegetation type was dominated by alien plants, which may provide adequate resources, which may explain the great number of ants in the disturbed vegetation. Ants play an important role in the functioning of the ecosystem and they provide a number of ecosystem services. Ecosystem services provided by ants are affected by anthropogenic activities and disturbances. It is important to monitor and manage our natural forest and grasslands to prevent habitat loss and infestation of alien plants which have major implications on biodiversity and ecosystem functioning. Although *Pheidole* sp.02 (*megacephala* gp) was the most widespread and abundant ant species in all the vegetation types. However, *Pheidole* sp.02 (*megacephala* gp.) was more abundant in the disturbed grassland vegetation type, which suggests that *Pheidole* sp.02 (*megacephala* gp.) may be an indicator for disturbed vegetation.

References

Abhinandini, D. I., Venkatesha, M. G., 2013. Seasonal abundance and activity pattern of commonly occurring household ant species (Hymenoptera: Formicidae). Zoology and Ecology 23, 217–223.

Achury, R., Chacón de Ulloa, P., Arcila, Á., 2011. Effects of the heterogeneity of the landscape and the abundance of *Wasmannia auropunctata* on ground ant assemblages in a Colombian tropical dry forest. Psyche: A Journal of Entomology 2012, 1–12.

Andersen, A.N., Fisher, A., Hoffmann, B.D., Read, J.L., Richards, R., 2004. Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. Austral Ecology 29, 87–92.

Andersen, A., 1997. Using ants as bioindicators: multiscale issues in ant community ecology. Conservation Ecology 1, 1–8.

Ant Web., 2017. http://www.antweb.org (Accessed on 15 September 2017)

Attwood, S. J., Maron, M., House, A. P. N., Zammit, C., 2008. Do arthropod assemblages display globally consistent responses to intensified agricultural land use and management? Global Ecology and Biogeography 17, 585–599.

Berman, M., Andersen, A. N., Hély, C., Gaucherel, C., 2013. Overview of the distribution, habitat association and impact of exotic ants on native ant communities in New Caledonia. PLoS One 8, e67245.

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.

Bongers, F., Poorter, L., Hawthorne, W. D., Sheil, D., 2009. The intermediate disturbance hypothesis applies to tropical forests, but disturbance contributes little to tree diversity. Ecology Letters 12, 798–805.

Buczkowski, G., Richmond, D. S., 2012. The effect of urbanization on ant abundance and diversity: a temporal examination of factors affecting biodiversity. PLoS One 7, e41729.

Colwell, R.K., 2013. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. http//www.purl.ocls.org/estimates. (Accessed on 10 September 2017)

Costa-Milanez, C. B., Lourenco-Silva, G., Castro, P.T.A., Majer, J.D., Ribeiro, S.P., 2014. Are ant assemblages of Brazilian veredas characterised by location or habitat type? Brazilian Journal of Biology 74, 89–99.

Cuautle, M., Vergara, C. H., Badano, E. I., 2016. Comparison of ant community diversity and functional group composition associated to land use change in a seasonally dry oak forest. Neotropical Entomology 45, 170–179.

De Bruyn, L. L., 1999. Ants as bioindicators of soil function in rural environments. Agriculture, Ecosystems and Environment 74, 425–441.

de Castro Solar, R. R., Barlow, J., Andersen, A. N., Schoereder, J. H., Berenguer, E., Ferreira, J. N., Gardner, T. A., 2016. Biodiversity consequences of land-use change and forest disturbance in the Amazon: a multi-scale assessment using ant communities. Biological Conservation 197, 98–107.

Del Toro, I., Ribbons, R. R., Pelini, S. L., 2012. The little things that run the world revisited: a review of ant-mediated ecosystem services and disservices (Hymenoptera: Formicidae). Myrmecological News 17, 133–146.

Fisher, B. L., Bolton, B., 2016. Ants of Africa and Madagascar - A Guide to the Genera. University of California Press, California. United States.

Gómez, C., Casellas, D., Oliveras, J., Bas, J. M., 2003. Structure of ground-foraging ant assemblages in relation to land-use change in the northwestern Mediterranean region. Biodiversity and Conservation 12, 2135–2146.

Graham, J. H., Hughie, H. H., Jones, S., Wrinn, K., Krzysik, A. J., Duda, J. J., Chamberlin-Graham, C., 2004. Habitat disturbance and the diversity and abundance of ants (Formicidae) in the Southeastern Fall-Line Sandhills. Journal of Insect Science 4, 1–15.

Guenard, B., 2013. An overview of the species and ecological diversity of ants. htpp://www.els.net(doi:10.1002/9780470015902.a0023598). (Accessed on 3 November 2017).

Hammer, O., Harper, D. A. T., Ryan, P. D., 2001. Paleontological statistics software: package for education and data analysis. Palaeontologia Electronica 4, 1–9.

Harris, R. J., Toft, R. J., Dugdale, J. S., Williams, P. A., Rees, J. S., 2004. Insect assemblages in a native (kanuka – *Kunzea ericoides*) and an invasive (gorse – *Ulex europaeus*) shrub land. New Zealand Journal of Ecology 28, 35–47.

Hoffmann, B. D., Andersen, A. N., 2003. Responses of ants to disturbance in Australia, with particular reference to functional groups. Austral Ecology 28, 444–464.

Hoffmann, B., 2000. Changes in ant species composition and community organisation along grazing gradients in semi-arid rangelands of the Northern Territory. Rangeland Journal 22, 171–189.

Hoffmann, B.D., Andersen, A.N., Hill. G.J., 1999. Impact of an introduced ant on native rain forest invertebrates: *Pheidole megacephala* in monsoonal Australia. Oecologia 120, 595–604.

Keroumi, A. E., Naamani, K., Soummane, H., Dahbi, A., 2012. Seasonal dynamics of ant community structure in the Moroccan Argan Forest. Journal of Insect Science 12, 1–19.

King, J. R., Andersen, A. N., Cutter, A. D., 1998. Ants as bioindicators of habitat disturbance: validation of the functional group model for Australia's humid tropics. Biodiversity and Conservation 7, 1627–1638.

Kotze, D., Lawes, J. L., 2008. Environmental indicator potential of the domestic litter decomposer, *Talitriator africana* (Crustacea, Amphipoda) in Afrotemperate forests. Austral Ecology 33, 737–746.

Kyerematen, R., Owusu, E. H., Acquah-Lamptey, D., Anderson, R. S., Ntiamoa-Baidu, Y. 2014. Species composition and diversity of insects of the Kogyae Strict Nature Reserve in Ghana. Open Journal of Ecology 4, 1061–1079.

Lange, M., Weisser, W. W., Gossner, M. M., Kowalski, E., Turke, M., Joner, F., Fonseca, C. R., 2011. The impact of forest management on litter-dwelling invertebrates: a subtropical–temperate contrast. Biodiversity and Conservation 20, 2133–2147.

Lawes, M. J., Kotze, D. J., Bourquin, S. L., Morris, C., 2005. Epigaeic invertebrates as potential ecological indicators of Afromontane forest condition in South Africa. Biotropica 37, 109–118.

Lenda, M., Witek, M., Skórka, P., Moroń, D., Woyciechowski, M., 2013. Invasive alien plants affect grassland ant communities, colony size and foraging behaviour. Biological Invasions 15, 2403–2414.

Magoba, R. N. N., 2010. Comparative impact of invasive alien trees and vineyards on arthropod diversity in the Cape Floristic Region, Western Cape. (Doctoral dissertation) Stellenbosch University, Cape Town.

Matlock Jr, R. B., de la Cruz, R., 2003. Ants as indicators of pesticide impacts in banana. Environmental Entomology 32, 816–829.

McCabe, D. J., Gotelli, N. J., 2000. Effects of disturbance frequency, intensity, and area on assemblages of stream macroinvertebrates. Oecologia 124, 270–279.

Mucina, L., Rutherford, M. C., 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Munyai, T. C., Foord, S. H. 2015a. Temporal patterns of ant diversity across a mountain with climatically contrasting aspects in the tropics of Africa. PLoS One 10, e0122035.

Munyai, T. C., Foord, S. H., 2015b. An inventory of epigeal ants of the western Soutpansberg Mountain Range, South Africa. Koedoe 57, 1–12.

Niba, A. S., Mafereka, P. S., 2015. Response of soil-surface dwelling invertebrates to alien invasive and indigenous plant cover in a sub-tropical nature reserve, Eastern Cape, South Africa. African Journal of Agricultural Research 10, 902–910.

Niba, A. S., Yekwayo, I., 2016. Epigaeic invertebrate community structure in two subtropical nature reserves, Eastern Cape, South Africa: Implications for conservation management. Arachnology Letters 52, 7–15.

Parr, C. L., 2005. Ant assemblages in a Southern African Savanna: Local processes and conservation implications. Unpublished Doctoral Dissertation. University of Pretoria, Pretoria.

Parr, C. L., Robertson, H. G., Biggs, H. C., Chown, S. L., 2004. Response of African savanna ants to long-term fire regimes. Journal of Applied Ecology 41, 630–642.

Porter, S. D., Tschinkel, W. R., 1987. Foraging in *Solenopsis invicta* (Hymenoptera: Formicidae): effects of weather and season. Environmental Entomology 16, 802–808.

Quinn, G. P., Keough, M. J., 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge, United Kingdom.

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.

Rosado, J. L., De Gonçalves, M. G., Dröse, W., Eduardo, J. E., Krüger, R. F., Feitosa, R. M., Loeck, A. E., 2012. Epigeic ants (Hymenoptera: Formicidae) in vineyards and grassland areas in the Campanha region, state of Rio Grande do Sul, Brazil. Check List 8, 1184–1189.

Samways, M. J., Caldwell, P. M., Osborn, R., 1996. Ground-living invertebrate assemblages in native planted and invasive vegetation in South Africa. Agriculture, Ecosystems and Environment 59, 19–32.

Samways, M. J., McGeoch, M. A., New, T. R., 2010. Insect Conservation: A Handbook of Approaches and Methods. Oxford University Press, Oxford, United Kingdom.

Samways, M. J., Moore, S. D., 1991. Influence of exotic conifer patches on grasshopper (Orthoptera) assemblages in a grassland matrix at a recreational resort, Natal, South Africa. Biological Conservation 57, 117–137.

Sanders, D., Platner, C., 2007. Intraguild interactions between spiders and ants and top-down control in a grassland food web. Oecologia 150, 611–624.

Schoeman, C. S., Foord, S. H., 2012. A checklist of epigaeic ants (Hymenoptera: Formicidae) from the Marakele National Park, Limpopo, South Africa. Koedoe 54, 1–7.

Silva, P. S. D., Bieber, A. G. D., Corrêa, M. M., Leal, I. R., 2011. Do leaf-litter attributes affect the richness of leaf-litter ants? Neotropical Entomology 40, 542–547.

Sokal, R.R., Rohlf, F. J., 2012. Biometry: The Principles and Practice of Statistics in Biological Research, fourth ed. W.H. Freeman and Company, New York.

Sonune, B. V., Chavan, R. J., 2016. Distribution and diversity of ants (Hymenoptera: Formicidae) around Gautala Autramghat Sanctuary Aurangabad Maharashtra, India. Journal of Entomology and Zoological Studies 4, 361–364.

Tantsi, N., 2013. Long-term impacts of *Chromolaena odorata* (L.) invasion and ungulate grazing on ant body size and communities in Hluhluwe-iMfolozi Park. Unpublished Masters Thesis. University of Pretoria, Pretoria.

Vanderwoude, C., Lobry de Bruyn, L. A., House, A. P. N., 2000. Response of an open forest ant community to invasion by the introduced ant, *Pheidole megacephala*. Austral Ecology 25, 253–259.

Wang, C., Strazanac, J., Butler, L., 2000. Abundance, diversity, and activity of ants (Hymenoptera: Formicidae) in oak-dominated mixed Appalachian forests treated with microbial pesticides. Environmental Entomology 29, 579–586.

Wilkie, K. T. R., Mertl, A. L., Traniello, J. F. 2010. Species diversity and distribution patterns of the ants of Amazonian Ecuador. PLoS One 5, e13146.

Yekwayo, I., 2016. Diversity value of Afromontane forest patches within KwaZulu-Natal timber production areas. Unpublished Doctoral Dissertation. Stellenbosch University, Cape Town.

Yekwayo, I., Pryke, J. S., Roets, F., Samways, M. J., 2016. Surrounding vegetation matters for arthropods of small, natural patches of indigenous forest. Insect Conservation and Diversity 9, 224–235.

Yeo, K., Konate, S., Tiho, S., Camara, S. K., 2011. Impacts of land use types on ant communities in a tropical forest margin (Oum Cote d'Ivoire). African Journal of Agricultural Research 6, 260–274.

Chapter 3: Epigaeic arthropod assemblages in different vegetation types in KwaZulu-Natal Sandstone Sourveld

Abstract

Epigaeic arthropods are among the most diverse group of animals on Earth. They are abundant in different terrestrial ecosystems and they play an important role in the functioning of the ecosystems. Arthropods are sensitive to environmental changes and their assemblages may be affected by habitat type, vegetation structure and disturbances, such as, alien plant invasion. The study asked the following questions: 1) How do epigaeic arthropods abundance, richness and distribution vary with vegetation type and season? 2) How do epigaeic arthropods functional guilds vary with vegetation type and season at Tanglewood and Giba Gorge Nature Reserves, in eThekwini Municipality? Epigaeic arthropods were sampled in the wet and dry season in 2016. At each site, pitfall trap sampling was carried out in an intact grassland, riverine or scarp forest and in a disturbed grassland habitat. Each habitat was replicated three times, and each replicate had ten pitfall traps. Tanglewood had greater number of epigaeic arthropod individuals (3429 individuals) than Giba Gorge (2721 individuals). However, Giba Gorge was more speciose with 133 morpho-species than Tanglewood with 115 morpho-species. Epigaeic arthropods were more abundant in the forests than in intact and disturbed grassland vegetation. *Pheidole* sp.02 (*megacephala* gp*)* and *Talitriator africana* occurred across all vegetation types. However, *Pheidole* sp.02 (*megacephala* gp*)* was more abundant in the disturbed grassland vegetation with 13% of the total abundance unlike *Talitriator africana* which was more abundant in the forest with 28% of the total abundance. These results suggest that *Pheidole* sp.02 (*megacephala* gp*)* and *Talitriator africana* could be useful potential indicators for monitoring ecological conditions of the KwaZulu-Natal Sandstone Sourveld because their assemblage was largely affected by vegetation type.

Introduction

Epigaeic arthropods are invertebrates that live and forage on the soil surface (De Lange, 1994; Gaigher, 2008), and are the most abundant and diverse group of invertebrates that represents a notable portion of the biodiversity in different ecosystems (Basset et al., 2007). Epigaeic arthropods are found in the soil, vegetation, tree logs and sediments in terrestrial ecosystems (Gaigher, 2008). These arthropods are regarded as ecosystem engineers and umbrella species (McGeoch, 1998; Basset et al., 2007; Cole et al., 2006; Viana Junior et al., 2014) because they can modify the habitat. The activities of terrestrial arthropods help in facilitating decomposition of organic matter and nutrient cycling and increase soil porosity, which in turn increases water infiltration (Cole et al., 2006; Viana Junior et al., 2014). Invertebrates, particularly most flightless epigaeic arthropods including some spiders, have poor dispersal abilities (Uys et al., 2009), which restricts them to specific microhabitats which in turn makes them vulnerable to changing environments. As such, epigaeic arthropod assemblages respond to changing environmental conditions very quickly. McCabe and Gotelli (2000), Hoffmann and Andersen (2003) and Basset et al. (2007), reported that epigaeic arthropod species composition, abundance and richness may increase or decrease due to habitat disturbance. However, increase or decrease in epigaeic arthropod composition, abundance and richness depends largely on the intensity and frequency of disturbance or environmental stress, which is why most arthropods are used as bioindicators in different habitats (Maelfait and Hendrickx, 1998; Anderson et al., 2002; Hodkinson and Jackson, 2005; Kotze and Lawes, 2008).

Epigaeic arthropods are found in many terrestrial ecosystems including grassland, savanna, forest, fynbos, Nama Karoo, Succulent Karoo, Desert and thicket (Samways et al., 1996; Lawes et al., 2005; Uys et al., 2009; Botha et al., 2015). Although epigaeic arthropods are diverse, abundant and found in most habitats, their dominance and abundance vary amongst forest, grassland and disturbed habitats. Species like *Talitriator africana*, *Leptogenys cf schwabi* and *Tetramorium avium* are more dominant in forests than grasslands and disturbed habitats in Australia and South Africa. (Hoffmann and Andersen, 2003; Lawes et al., 2005; Basset et al., 2008). Moreover, type and condition of habitat influence epigaeic arthropod assemblages in ecosystems (Saint-Germain et al., 2007).

Epigaeic arthropods consist of various functional guilds, and as a result, their response to habitat types and conditions vary even between congeneric species (Saint-Germain et al., 2007; Basset et al., 2008). Arthropod functional guild activities shape the ecosystem. For example, predators control prey populations and may stabilise food webs (Joseph et al., 2017). Decomposers breakdown leaf litter material which contribute to organic matter formation especially in forest habitat (Lawes et al., 2005). Herbivores utilize nectar and pollen and contribute to pollination of a number of flowering plants (Sinu and Sharma, 2013). Habitat type remains an important factor because functional guilds depend on food resources found in the organic leaf litter layer in the forest (Lawes et al., 2005). In addition, some arthropods depend on resources found on the grass layer in the grassland habitat (Wiezik and Suitok, 2011).

Seasonality is an important factor that governs functional diversity of arthropods (Basset et al. 2008). Wet season tends to be more favourable to the functional diversity of arthropods because the wet season is characterised by optimum temperature, soil moisture and radiation which promotes favourable conditions for herbivores, decomposers, predators and generalists and give rise to abundant food resources (Lassau et al., 2005; Vilisics et al., 2012; Liu et al., 2013; Gonzalez-Reyes et al., 2017). Dry season negatively affect functional diversity as limited food resources are available and the dry season is characterised by unfavourable climatic conditions which largely affects vegetation and availability of resources (Basset et al., 2008; Liu et al. 2013; Gonzalez-Reyes et al., 2017).

Environmental disturbance strongly affects functioning of many terrestrial ecosystems (Lassau et al., 2005; Basset et al., 2008; Hoffman and Andersen, 2003; Kwon et al., 2013). Variations in environmental disturbance regimes reduce functional diversity of many arthropod groups (Hoffman and Andersen, 2003; Lassau et al., 2005; Kwon et al., 2013). Disturbed environments are characterised by invasion of alien plants, reduced vegetation cover and large patches of bare soil (Hoffman and Andersen, 2003; Graham et al., 2004) which has a detrimental effect on various functional groups of arthropods. Environmental disturbance has a detrimental effect on decomposers, herbivores, predators as less resources are available, and the competition becomes high (Graham et al., 2004). Herbivores such as pollinators, nectar feeders and frugivorous insects are attracted to alien plants and forage on their fruits, flowers

and leaves (Imura, 2003; Proches et al., 2008). As a result, herbivores might thrive in the environment with alien plants (Proches et al., 2008).

Environmental disturbance affects epigaeic arthropods species composition, abundance and richness (Hoffmann and Andersen et al., 2003). McCabe and Gotelli (2000) reported that an increase intensity and frequency of disturbance may results in the removal of key resources required by arthropods for survival and recolonization. Reduction in key resources might result in the decrease in numbers of some functional groups of epigaeic arthropods. In addition, mortality of soil arthropods under high disturbance intensity depends on environmental heterogeneity (Gongalsky et al., 2012). Lawes et al (2005) reported that some epigaeic taxa cannot avoid the impact of local disturbances which eliminates more groups of arthropods. In order to determine the impact of habitat type (disturbed, forest and grassland) we asked;

1. How do epigaeic arthropods abundance, richness and distribution vary with vegetation type and season?
2. How do epigaeic arthropods functional guilds vary with vegetation type and season?

Materials and Methods

Study sites

The study was conducted at two sites in the KwaZulu-Natal Sandstone Sourveld in the eThekwini Municipality, KwaZulu-Natal Province, South Africa. Tanglewood Farm Private Nature Reserve (29^0 62.574' S, 30^0 40.330' E) and Giba Gorge Nature Reserve (29^0 49.628' S, 30^0 46.916' E). The two sites consist of three vegetation types; namely a riverine or scarp forests, intact grassland and a disturbed grassland.

The grassland is classified as KwaZulu-Natal Sandstone Sourveld (KZNSS), which is dominated by tall and short grasses, such as *Aristida junciformis*, *Diheteropogon amplectens, Digitaria eriantha* and *Monocymbium ceresiiforme.* Patches of alien invasive plants, such as *Lantana camara, Eucalyptus grandis, Solanum mauritianum, Chromolaena odorata, Pinus elliotti, Acacia mearnisii, Tithonia diversifolia, Senna didymobotrya* and *Canna indica* are dominant in the disturbed grassland. The two sites experience high rainfall in summer and dry

conditions in winter. Most rainfall occur between October and March with mean annual rainfall between 700 and 1200 mm (Mucina and Rutherford 2006). Midday temperature ranges from 16 ^{0}C to 25 ^{0}C in winter and 23 ^{0}C to 33 ^{0}C in summer (Mucina and Rutherford 2006). The underlying geology is described as Ordovician Natal group sandstones and shallow nutrient-poor sandy soils (Mucina and Rutherford 2006).

Sampling for epigaeic arthropods

Epigaeic arthropods were sampled in 2016 during the wet and the dry season using pitfall trapping method in forest, intact grassland and disturbed grassland at Tanglewood and Giba Gorge Reserves. Each vegetation type was replicated three times. Replicates were separated by at least 300 m apart to avoid pseudo replication. In each replicate, 10 pitfall traps were positioned in a 2 × 5 sampling grid with 10 m spacing between pitfall traps as described by Munyai and Foord (2015). Pitfall traps were made out of honey jars (64 mm diameter, 110 mm height, 500 ml volume) were inserted in a hole dug into the ground and left flush with the soil surface. Jars were quarter-filled with 50 % propylene glycol solution for preserving collected specimens. Sampling took place in June and July 2016, which coincides with the dry season, and during the wet season in November and December 2016. Traps were removed after 5 days and taken to the laboratory where epigaeic arthropods were sorted, identified and counted. Epigaeic arthropods were identified to morpho-species or species level (where possible) using identification keys and guides. Fisher and Bolton (2016) was used to identify the ant species collected to genus level. Dippenaar-Schoeman (2014) was used to identify the spider species collected to family or genus level. Braack (2000), Weaving (2000), Picker et al. (2002), and Smith (2008) were used to identify beetle, termite, sand cricket, lace wig and cockroach to family level. Unidentified species were sorted to morpho-species level for all collected taxa.

Functional groups

Epigaeic arthropods were grouped into four functional groups e.g. generalist, decomposers, herbivores and predators, following work done by King et al. (1998), Kotze and Lawes (2008), Vilisics et al. (2012), Kwon et al. (2013), and Sinu and Sharma (2013). Species that feed on nectar, plant tissue, fruits and pollen were classified as herbivores (Howe and Jander, 2008; Ali and Agrawal, 2012). Species that feed on decaying or dead plant and animal material were classified as decomposers (Kotze and Lawes, 2008; Vilisics et al., 2012). Species with broad diet and forage on a variety of food resources were classified as generalists (Vander-Zanden,

2010; Li et al. 2014). Species that hunts and feed on other organisms were classified as predators (Hurd and Eisenberg, 1990).

Statistical analysis

A non-metric multidimensional scaling (nMDS) based on Bray-Curtis similarity was used to determine whether there were differences in ground-dwelling arthropod assemblages between habitats (Hammer et al., 2001). In addition, Analysis of Similarity (ANOSIM) with 9999 permutations in PAST3 was used to determine if there were any significant similarities in species composition of ground-dwelling arthropods among habitats (Hammer et al., 2001). The test statistic R demonstrates the degree of similarity or difference between habitats, where the R values close to 1 indicates high separation between habitats and values close to 0 indicates less separation between habitats (Quinn and Keough, 2002).

Generalized linear model with poison distribution and loglink function was used to determine the effect of vegetation type on abundance and species richness of epigaeic arthropods in Tanglewood and Giba Gorge Reserves. In order to determine the effect of seasonality on epigaeic arthropods abundance and species richness generalized linear model with poison distribution and loglink function was used. The effect of vegetation type on epigaeic arthropod functional guilds abundance and richness was determined using generalised linear model with poison distribution and loglinear function. The effect of seasonality on epigaeic arthropod functional guilds abundance and richness was also determined using generalised linear model with poison distribution and loglink function.

To predict asymptotic species richness of the overall data in each site, the non-parametric species estimators (ACE, ICE, Chao2, Jacknife2, MM and Bootstrap) were calculated in EstimateS 9.1.0 with samples randomized 1000 times for all vegetation types separately, as well as all vegetation types combined for each site.

Results

A total of 6 150 individuals representing 162 morpho-species of ants, spiders, beetles, terrestrial crustaceans, sand crickets, cockroaches, lace wigs, millipedes and termites were collected (Appendix 3.1). The order Hymenoptera was the most abundant and species rich (41% of the total abundance; 55 morpho-species) followed by Coleoptera (7% of the total

abundance, 35 morpho-species) and Araneae (4% of the total abundance; 32 morpho-species). The Amphipoda was the least species rich order but second most abundant (Appendix 3.2). While, the Dermaptera, Hemiptera and also millipedes were the least abundant and least species rich taxa in both sites (Appendix 3.2). The forest habitat had highest abundance but with the least number of species (43% of the total abundance; 87 morpho-species) than the disturbed (35% of the total abundance, 92 morpho-species) and the grassland (21% of the total abundance; 116 morpho-species) (Appendix 3.1).

None of the observed accumulation curves reached an asymptote in both sites. However, species richness increased with number of samples, which suggested that more sampling effort was required to get representatives of all the epigaeic arthropods in Tanglewood and Giba Gorge (Fig. 3.5a and 3.5b).

The percentage of completeness ranged from 60 % to 80 % of the potential species richness within the three vegetation types. Percentage of completeness greater than 60% indicate adequate representation of species found in an area (Table 3.1).

The Non-Metric Multidimensional Scaling ordination showed less separation in epigaeic arthropods species composition between grassland, forest and a disturbed grassland in Tanglewood (Stress = 0.04; Fig 3.6a) and in Giba Gorge (Stress= 0.019; Fig 3.6b).

Abundance of epigaeic arthropods was greater in the forest than an intact grassland and disturbed grassland in Tanglewood (X^2 = 21.555; df = 2; p< 0.05) and in Giba Gorge (X^2 = 11.421; df = 2; p< 0.05). There was no significant difference in epigaeic arthropods species richness across vegetation types in Tanglewood (X^2 = 1.577; df = 2; p> 0.05). However, there was a significant difference in species richness of epigaeic arthropods across vegetation types in Giba Gorge (X^2 = 6.794; df = 2; p< 0.05). High abundance of epigaeic arthropods was observed in Tanglewood (X^2 = 4.803; df = 1; p< 0.05) and in Giba Gorge (X^2 = 18.964; df = 1; p< 0.01) during the wet season compared to the dry season. Similarly, species richness was greater in the wet season than the dry season in Tanglewood (X^2 = 9.229; df = 1; p< 0.01) and in Giba Gorge (X^2 = 10.624; df = 2; p< 0.01).

A total of 6 150 collected individuals representing 162 morpho-species of epigaeic arthropods were grouped into four broad functional guilds (generalist, predators, decomposers

and herbivores) (Appendix 3.1). Generalists were the most abundant functional guild representing (35% of the total abundance) followed by decomposers representing (24% of the total abundance) and predators representing (16% of the total abundance) (Appendix 3.1). Predators were the most species rich functional guild (102 morpho-species) followed by herbivores (33 morpho-species) and decomposers (33 morpho-species) (Appendix 3.1). Generalists were the most abundant functional guild in the disturbed grassland in both sites while decomposers were the most abundant functional guild in the forest (Table 3.3). Across all habitats, predators were the most species-rich functional guild in both sites (Table 3.4).

Decomposers were the most abundant functional group in the wet season, followed by generalists and the predators (Table 3.5). While generalists were the most abundant functional guild in the dry season followed by predators and decomposers (Table 3.5). Predators were the most speciose functional guild in both seasons (Table 3.6). Decomposers and predators were more abundant in the forest than in intact and disturbed grassland, while generalist and herbivores were more abundant in the disturbed grassland than the forest and grassland in Tanglewood ($X^2 = 273.0$; df = 11; p< 0.01) and in Giba Gorge ($X^2 = 155.168$; df = 11; p< 0.01). Functional guild species richness differed significantly across vegetation types in Tanglewood ($X^2 = 112.786$; df = 11; p< 0.01) and in Giba Gorge ($X^2 = 132.540$; df = 11; p< 0.01). Decomposers, herbivores, predators were more abundant in the wet season than the dry season however, generalists were more abundant in the dry season than the wet season in Tanglewood ($X^2 = 85.256$; df = 8; p< 0.01) and in Giba Gorge ($X^2 = 91.154$; df = 8; p< 0.01). Species richness of arthropods functional guilds was greater in the wet season than the dry season in Tanglewood ($X^2 = 144.132$; df = 8; p< 0.01) and in Giba Gorge ($X^2 = 155.409$; df = 8; p< 0.01). ANOSIM showed significant differences in epigaeic arthropods species composition among vegetation types in Tanglewood (Global R = 0.769; p < 0.005) and in Giba Gorge Reserves (Global R = 0.514; p < 0.005).
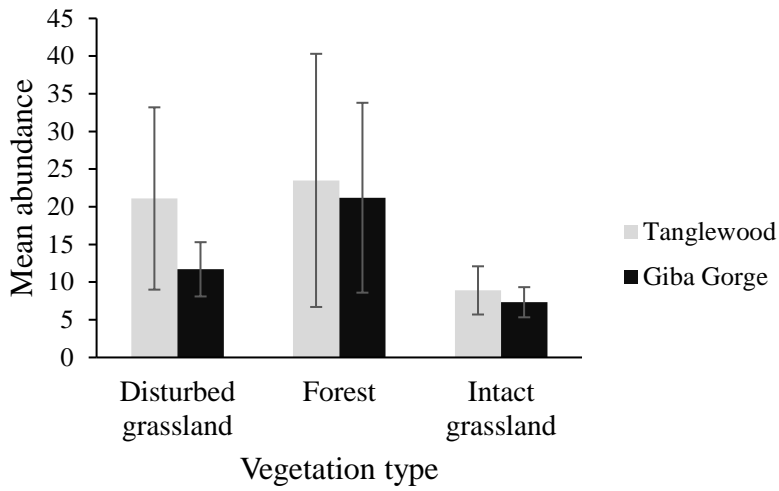
Fig. 3. 1. Mean (±SE) species abundance of epigaeic arthropods sampled at different vegetation types in Tanglewood and Giba Gorge Reserves.
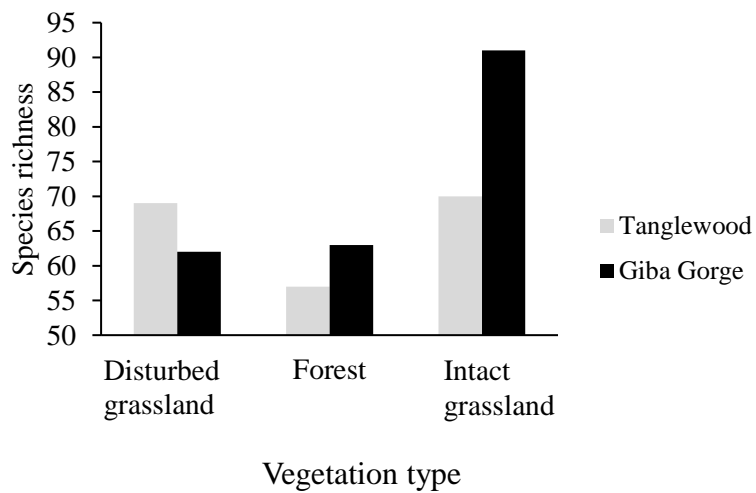
Fig. 3. 2. Total species richness of epigaeic arthropods sampled at different vegetation types in Tanglewood and Giba Gorge Nature Reserves.
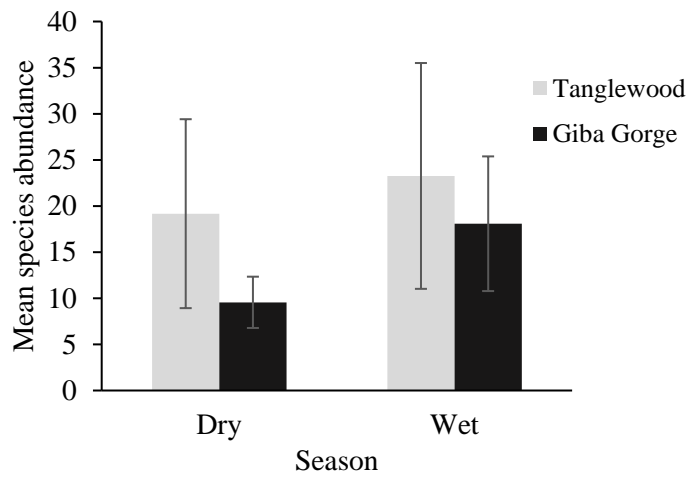
Fig. 3. 3. Mean (±SE) species abundance of epigaeic arthropods sampled in dry and wet season at Tanglewood and Giba Gorge Reserves.
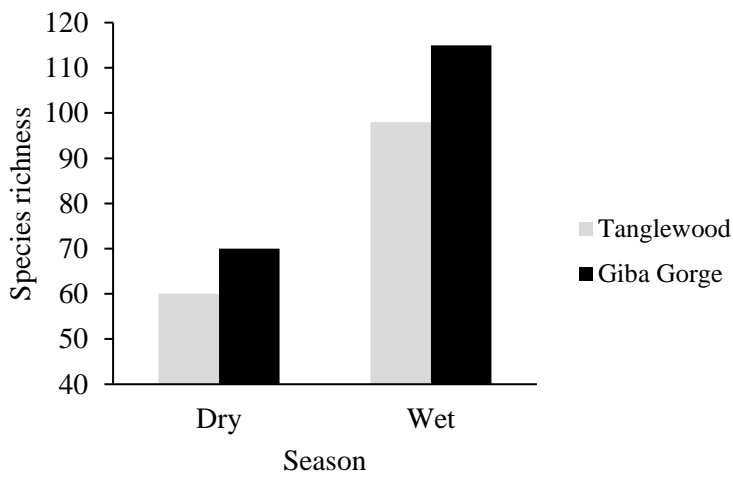
Fig. 3. 4. Total species richness of epigaeic arthropods sampled in wet and dry season at Tanglewood and Giba Gorge Reserves.

Table 3. 1. Percentage completeness of epigaeic arthropod assemblages derived from six richness estimators (ACE mean, ICE mean, Jack2, Chao 2, MM Mean and Bootstrap) available in EstimateS 9.1.0 package (Colwell, 2013) across three vegetation types in Tanglewood and Giba Gorge Reserves

Vegetation type	Minimum	Maximum
Tanglewood		
Disturbed	67.5	81.0
Forest	60.0	84.7
Intact grassland	60.0	84.4
Giba Gorge		
Disturbed	67.3	86.0
Forest	60.1	84.3
Intact grassland	68.3	86.2

Table 3. 2. Overall similarity of epigaeic arthropods composition sampled in the forest, disturbed and intact grassland vegetation types

Habitat comparison	Overall similarity between habitat types (%)
Tanglewood	
Disturbed grassland vs Forest	38.3
Disturbed grassland vs Intact grassland	40.1
Intact grassland vs Forest	21.2
Giba Gorge	
Disturbed grassland vs Forest	16
Disturbed vs Intact grassland	50.4
Intact grassland vs Forest	33.4
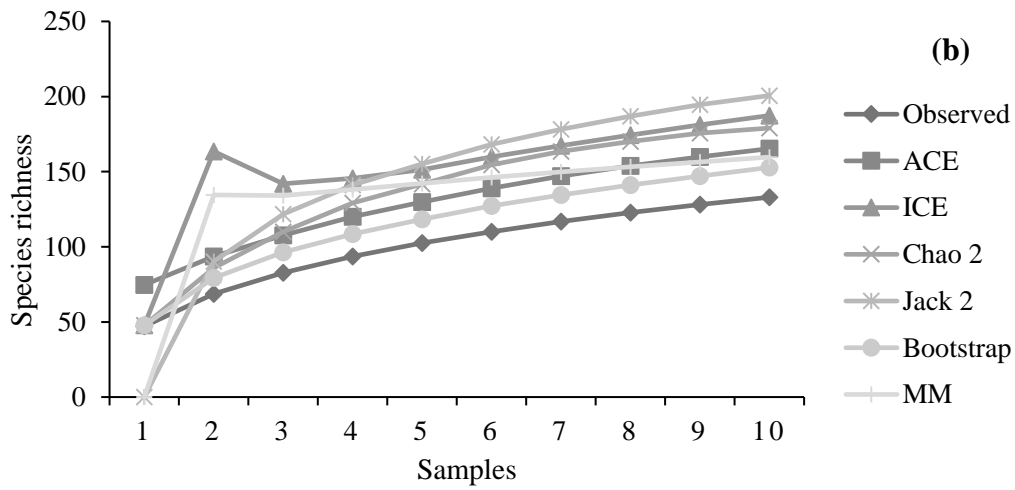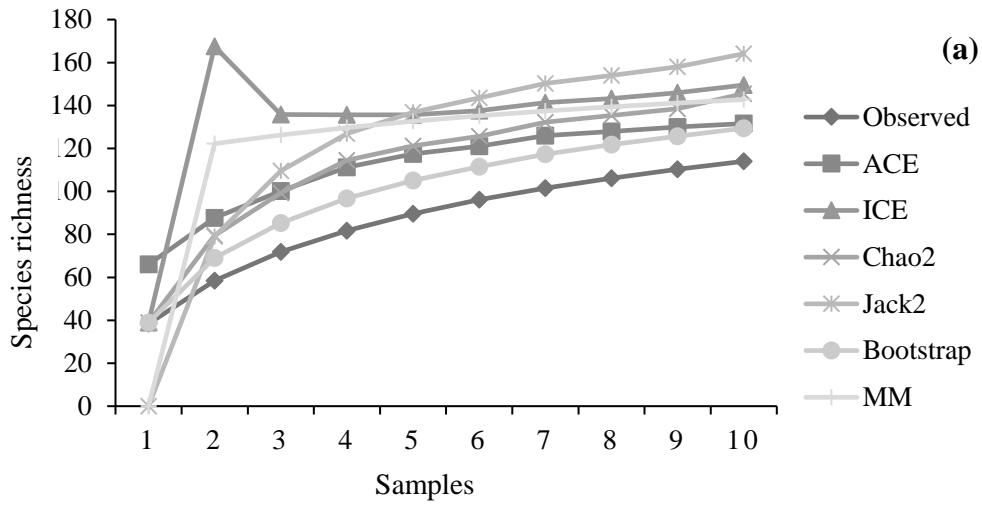
Fig. 3. 5. Species accumulation curves estimated with a confidence interval of 95 % in three habitat types in (a) Tanglewood and (b) Giba Gorge Nature Reserves
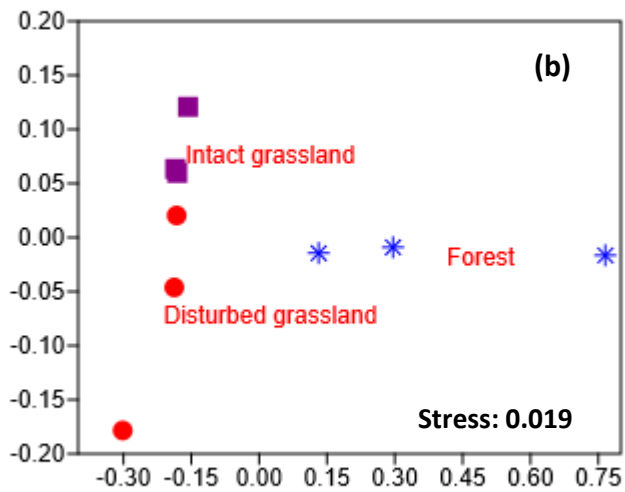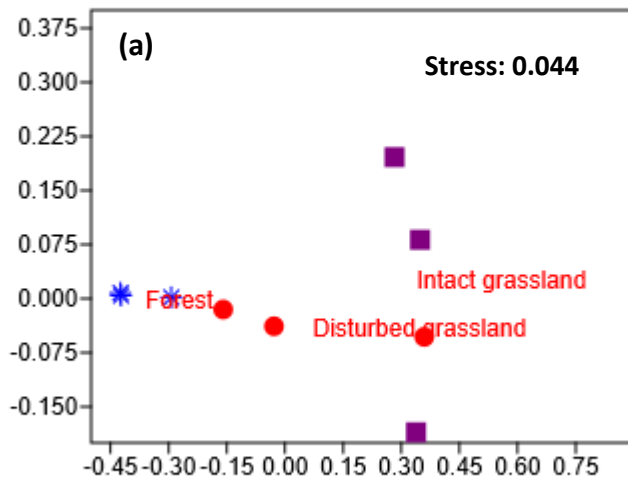
Fig.3. 6. Non-metric Multidimensional Scaling (nMDS) of epigaeic arthropods assemblages in three vegetation types in (a) Tanglewood and (b) Giba Gorge Reserves. Circles represent disturbed grassland, stars represent forest and squares represent an intact grassland

Table 3. 3. Mean (±SE) species abundance of functional guild sampled across three vegetation type in Tanglewood and Giba Gorge Nature Reserves

Study site and Vegetation type	Functional guild	Mean Abundance	Std. Error
Tanglewood Reserve			
Disturbed grassland	Decomposers	36.4	31.1
	Generalists	112.5	91.2
	Herbivores	5.9	1.4
	Predators	3.7	0.6
Forest	Decomposers	1122	100.3
	Generalists	24.8	21.1
	Herbivores	4.8	1.2
	Predators	4.1	1.3
Intact grassland	Decomposers	9.2	6.2
	Generalists	43.6	24
	Herbivores	5.2	1.5
	Predators	3.4	0.5
Giba Gorge Reserve			
Disturbed grassland	Decomposers	2.4	6.3
	Generalists	64.8	32.8
	Herbivores	10.6	4.6
	Predators	4.2	0.9
Forest	Decomposers	95.1	81.8
	Generalists	28	16.6
	Herbivores	6.6	2.9
	Predators	6.8	3
Intact grassland	Decomposers	4.2	2.1
	Generalists	32.2	17.4
	Herbivores	4.4	0.9
	Predators	4.4	0.6

Table 3. 4. Total species richness of arthropod functional guilds sampled across three vegetation types in Tanglewood and Giba Gorge Reserves

Study site	Functional guild	Disturbed grassland	Forest	Intact grassland
Tanglewood	Decomposers	9	9	6
	Generalists	8	5	8
	Herbivores	15	16	17
	Predators	37	31	42
Giba Gorge	Decomposers	8	9	13
	Generalists	5	5	10
	Herbivores	14	18	19
	Predators	36	32	52

Table 3. 5. Mean (±SE) species abundance of functional guild sampled in the wet and dry season in Tanglewood and Giba Gorge Nature Reserves

Season	Functional guild	Mean	Std. Error
Tanglewood Reserve			
Dry	Decomposers	34.1	25.9
	Generalists	97.7	76.9
	Herbivores	5.9	1.7
	Predators	4.5	0.8
Wet	Decomposers	96.1	87.9
	Generalists	76.6	54.3
	Herbivores	8	1.6
	Predators	4.3	0.8
Giba Gorge Reserve			
Dry	Decomposers	16.4	7.89
	Generalists	53.5	22.7
	Herbivores	3.7	0.69
	Predators	3.6	0.4
Wet	Decomposers	43.9	38.9
	Generalists	43.4	19.2
	Herbivores	13.1	3.9
	Predators	7.6	1.9

Table 3.6. Total species richness of arthropod functional guilds sampled in the wet and dry season in Tanglewood and Giba Gorge Reserves

Study site	Functional guild	Dry	Wet
Tanglewood	Decomposers	7	12
	Generalists	7	9
	Herbivores	12	23
	Predators	5	58
Giba Gorge	Decomposers	8	20
	Generalists	6	10
	Herbivores	18	22
	Predators	39	65

Discussion

Species accumulation curves of the observed species did not reach an asymptote at either sites, which suggests that sampling should be increased in order to get representative samples of all epigaeic arthropods in Tanglewood and Giba Gorge Reserves. Other sampling techniques which target ground-dwelling arthropods e.g. leaf litter sampling, active searching and sieving should have been employed to increase sampling effort. However, species richness per habitat did reach an asymptote and species inventory completeness were between 60 % and 86 %, both of which suggests that observed samples were representative of the species in each habitat

Vegetation type influences epigaeic arthropods species abundance (Lassau and Hochuli, 2004). In the present study, abundance differed among vegetation type, epigaeic arthropods taxa, seasons and sites. Ants were the most abundant group followed by terrestrial crustaceans and beetles. Millipedes, lace wigs and hemipterans were the least abundant taxa. Ants are some the most abundant group of animals on earth and thrive in warm temperate regions (Del Toro et al., 2012; Kyerematen et al., 2014). These results, conforms to findings from other studies (e.g. Kotze and Samways, 2001; Kyerematen et al., 2014; Yekwayo et al., 2016) where they found ants to be the most abundant taxa than the other groups of arthropods sampled in the forest and the grassland. Ant genus *Pheidole* and terrestrial crustacean genus *Talitriator* were the most abundant across the study area. *Pheidole* is the most abundant, dominant, widespread and hyper diverse genus across many terrestrial environments in the world (Fisher et al. 2012). *Talitriator* consists of decomposer species that are abundant in forests of South Africa (Kotze and Lawes, 2007). Previous studies (e.g. Lawes et al., 2005; Kotze and Lawes, 2007, 2008)

found *Talitriator africana* to be the most abundant decomposer in Afrotemperate forest in KwaZulu-Natal.

Epigaeic arthropods were more abundant in the forest than in a natural grassland in both Tanglewood and Giba Gorge Reserves. Natural forests are characterised by high quality habitat, with a vast number of resources including fallen fruits, seeds, wood, leaf litter (Silva et al., 2011; Yekwayo et al., 2016). In addition, natural forests are characterised by high vegetation diversity and complex vegetation structure which provides suitable habitat for ground-dwelling arthropods (Yekwayo et al., 2016). These factors have a positive influence on ground-dwelling arthropod abundance (Yekwayo et al., 2016). Cole et al. (2016) and Yekwayo et al. (2016) found greater abundance of ground-dwelling arthropods in native forest than in grassland and pine blocks. A number of studies focusing on single taxon, such as ants (Sonune and Chavan, 2016), terrestrial crustaceans (Lawes et al., 2005; Kotze and Lawes, 2007; Kotze and Lawes, 2008), beetles (Gardner-Gee et al., 2015), spiders (Pettersson 1996; Kwon et al., 2014) and termites (Vasconcellos, 2010) have shown that diversity and abundance are greater in forest habitat than surrounding habitats.

Vegetation and habitat complexity influence epigaeic arthropods species richness (Wiezik and Suitok, 2011). Intact grassland habitat had a greater species richness than the forest and disturbed habitat across the study area. Grasslands are comprised of complex vegetation made up of short or tall grasses, forbs and few trees (Drury et al., 2015; Boon et al., 2016), which increases the availability of micro-habitats, food, shelter, nesting and foraging sites for epigaeic arthropods. Consistent with this, Yekwayo et al. (2016) reported that grasslands supported higher arthropod abundance and species richness compared to forests and surrounding habitats in the study conducted at Goodhope and Maybole timber plantation estates in the midlands of KwaZulu-Natal. The study area comprised of natural forest patches, grassland and pine blocks plantations. The forest and the disturbed habitat were characterised by dense tall vegetation which forms shade and cool microclimate which might have a detrimental effect on epigaeic arthropod species richness (Silva et al., 2011; Wiezik and Suitok, 2011). Open habitats like grassland receive direct sunlight and are warmer than habitats protected by tree canopy cover, as a result, grassland host high diversity of arthropods (Wiezik and Suitok, 2011).

Non-metric Multidimensional Scaling (nMDS) showed less separation in of the community composition of epigaeic arthropods among the three habitats in both sites. The disturbed grassland and a grassland community composition were remarkably similar on both sites. The disturbed grassland is a transformed intact grassland with similar vegetation to the grassland this might explain the similarity in community composition and similar groupings in the ordination plot.

Pheidole sp.02 (*megacephala* gp.) and *Talitriator africana* were the most abundant species. *Pheidole* sp.02 (*megacephala* gp.) occurred across habitats but was more abundant in the disturbed habitat. *Pheidole* (*megacephala* gp.) comprised of generalist species and is widespread in most geographic regions across the world (Fischer et al., 2012). In addition, *Pheidole* sp.02 (*megacephala* gp.) is a generalist species and is able to recolonise and dominate in various habitats and may be found abundantly in disturbed habitats (King et al., 1998). These results are consistent with Hoffman et al. (1999) and Vanderwoude et al. (2000), who reported that *P. megacephala* is found in disturbed environments, such as agricultural land and urban areas. In the present study, *Talitriator africana* was found across habitats but was more abundant in the forest. *Talitriator africana* is a decomposer and is associated with breaking down leaf litter material and it is found abundantly in forests.

The wet season was associated with high species abundance and richness of epigaeic arthropods in both reserves. This is consistent with the findings of Yi and Moldente (2005), Coelho and Ribeiro (2006), Keroumi et al. (2012) and Liu et al. (2013), who observed a greater species abundance and richness of epigaeic arthropods in the wet season than the dry season. The wet season is associated with favourable microclimatic conditions which promotes complex vegetation structure and diversity (Yi and Moldente, 2005; Liu et al., 2013), thus, resulting in high availability of resources, which then promotes high degree of activities of epigaeic arthropods. In addition, an increase in temperature and rainfall in the wet season increases soil moisture and vegetation structure (Yi and Moldente, 2005; Liu et al. 2013; Abhinandini and Venkatesha, 2013). These abiotic factors have a positive influence on foraging and nesting activities, which promotes epigaeic arthropods abundance and richness (Coelho and Ribeiro, 2006; Liu et al., 2013). Templer et al. (2012) and Abhinandini and Venkatesha (2013) reported that soil temperature and moisture decline in the dry season and cause temporal changes in the surface activity of ground-dwelling arthropods. In addition, epigaeic arthropods expand their ranges and increase their rate of reproduction in warmer

climatic conditions explains further the greater species abundance and richness during the wet season (Templer et al., 2012).

The wet season harboured more individuals and most functional guilds were abundant and speciose in the wet season than the dry season. The wet season is characterised by great availability of good quality food resources, temperature, soil moisture and radiation that are favourable to epigaeic arthropods (Yi and Moldente, 2005; Liu et al., 2013). Decomposers were most abundant in the wet season where they break down leaf litter (Gessner et al., 2010; Kwon et al., 2013). Leaf litter and woody debris are more abundant in forest during the wet season, this which is why decomposers were abundant in the wet season (Vilisics et al., 2012).

Herbivores and predators had more species in the wet season than the dry season. In the present study herbivores were associated more with the disturbed grassland vegetation type, which was dominated by patches of flowering alien plants. Herbivores utilize vegetation material, nectar, pollen and seeds (Proches et al., 2008). The disturbed grassland vegetation type had mixed vegetation varying from flowering alien plants, grasses, and trees. The complexity in this habitat type favoured the abundance of herbivores during the wet season because diversity and complexity of vegetation peaks in the wet season (Proches et al., 2008). However, generalists were more abundant in the dry season probably because they are able to utilize a variety of food resources and environments (Li et al., 2014).

Generalist arthropods were the most abundant functional guild followed by decomposers and predators. Generalist species have broad ecological requirements and can survive under disturbed and undisturbed habitat types and under wet and dry climatic conditions (Li et al., 2014; Yekwayo et al., 2016). In the present study, dominant generalist species comprised of genera, such as, *Pheidole*, *Myrmicaria* and *Crematogaster*. The dominance of these genera is consistent with other studies, which demonstrated that *Pheidole*, *Myrmicaria*, *Monomorium* and *Crematogaster* are abundant in many terrestrial ecosystems (Achury et al. 2011; Rosado et al. 2012; Costa-Milanez et al., 2014).

Detritivores were more abundant in the forest than in an intact grassland and the disturbed grassland habitat. Forest are characterised by high leaf litter deposition (Silva et al., 2011; Kwon et al., 2013). Detritivores are known for breaking down leaf material in the forest and

this service is important because it provides the forest soils with nutrients for plant growth (Gessner et al., 2010; Kwon et al., 2013). The greater availability of food may explain the greater abundance of detritivores in the forest than in an intact grassland and the disturbed habitat. The present findings are supported by previous studies (e.g. Lawes et al., 2005; Kotze and Lawes, 2007, 2008).

Predators were the most speciose functional guild across habitat types at both sites. Predators control population and richness of other invertebrates which excludes some invertebrates in the ecosystem (Kwon et al., 2013; Yekwayo 2016; Joseph et al., 2017). Spiders were the dominant predators in both sites. This is consistent with Yekwayo (2016), who found that spiders contributed more than 50 % of the sampled predators in natural forest, pine blocks and a grassland. Spiders are generalist predators that are able to survive under various environmental conditions (Yekwayo et al., 2016; Joseph et al., 2017), which makes them the most speciose functional guild.

Vegetation type and seasonality and are important factors that influences the distribution, abundance and species richness of ground-dwelling arthropods in Tanglewood and Giba Gorge Nature Reserves. The results suggest that managed KwaZulu-Natal Sandstone Sourveld habitats supported more epigaeic arthropods species abundance and richness than the disturbed habitat, which is found outside the nature reserves and not managed. As such, habitat disturbance has a detrimental effect on epigaeic arthropods species richness and abundance. Therefore, grassland and forest habitats need to be managed to prevent disturbances in order to prevent the loss of biodiversity. The dominance of *Pheidole* sp.02 (*megacephala* gp.) in disturbed grassland habitat suggest that this species is an indicator of disturbed grassland and the dominance of *Talitriator africana* in forest habitat suggest that this species is an indicator of forest habitat.

References

Abhinandini, D. I., Venkatesha, M. G., 2013. Seasonal abundance and activity pattern of commonly occurring household ant species (Hymenoptera: Formicidae). Zoology and Ecology 23, 217–223.

Achury, R., Chacón de Ulloa, P., Arcila, Á., 2012. Effects of the heterogeneity of the landscape and the abundance of *Wasmannia auropunctata* on ground ant assemblages in a Colombian tropical dry forest. Psyche: A Journal of Entomology 2012, 1–12.

Ali, J. G., Agrawal, A. A., 2012. Specialist versus generalist insect herbivores and plant defence. Trends in Plant Science 17, 293–302.

Andersen, A. N., Hoffmann, B. D., Müller, 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.

Basset, Y., Missa, O., Alonso, A., Miller, S. E., Curletti, G., De Meyer, M., Eardley, C., Lewis, O.T., Mansell, M.W., Novotny, V., Wagner, T., 2007. Changes in Arthropod assemblages along a wide gradient of disturbance in Gabon. Conservation Biology 22, 1552–1563.

Basset, Y., Missa, O., Alonso, A., Miller, S. E., Curletti, G., Meyer, M. D., Wagner, T., 2008. Choice of metrics for studying arthropod responses to habitat disturbance: one example from Gabon. Insect Conservation and Diversity 1, 55–66.

Boon, R., Cockburn, J., Douwes, E., Govender, N., Ground, L., Mclean, C., Slotow, R., 2016. Managing a threatened savanna ecosystem (KwaZulu-Natal Sandstone Sourveld) in an urban biodiversity hotspot: Durban, South Africa. Bothalia-African Biodiversity and Conservation 46, 1-12.

Botha, M., Siebert, S. J., Van den Berg, J., Maliba, B. G., Ellis, S. M. 2015. Plant and arthropod diversity patterns of maize agro-ecosystems in two grassy biomes of South Africa. Biodiversity and Conservation 24, 1797–1824.

Braack, L., 2000. Field Guide to Inserts of the Kruger National Park. Struik Publishers, Cape Town.

Coelho, I. R., Ribeiro, S. P., 2006. Environment heterogeneity and seasonal effects in ground-dwelling ant (Hymenoptera: Formicidae) assemblages in the Parque Estadual do Rio Doce, MG, Brazil. Neotropical Entomology 35, 19–29.

Cole, L., Bradford, M. A., Shaw, P. J., Bardgett, R. D., 2006. The abundance, richness and functional role of soil meso-and macrofauna in temperate grassland— a case study. Applied Soil Ecology 33, 186–198.

Cole, R. J., Holl, K. D., Zahawi, R. A., Wickey, P., Townsend, A. R., 2016. Leaf litter arthropod responses to tropical forest restoration. Ecology and Evolution 6, 5158–5168.

Costa-Milanez, C. B., Lourenco-Silva, G., Castro, P.T.A., Majer, J.D., Ribeiro, S.P., 2014. Are ant assemblages of Brazilian veredas characterised by location or habitat type? Brazilian Journal of Biology 74, 89–99.

De Lange, H. J., 1994. http://www.water.ncsu.edu/watershedss/info/macroinv.html. (Accessed 1 July 2016).

Del Toro, I., Ribbons, R. R., Pelini, S. L., 2012. The little things that run the world revisited: a review of ant-mediated ecosystem services and disservices (Hymenoptera: Formicidae). Myrmecological News 17, 133–146.

Dippenaar-Schoeman, A. S., 2014. Field Guide to the Spiders of South Africa. Lapa Publishers, Cape Town.

Drury, C. C., Ramdhani, S., Naidoo, S., Carbutt, C., Boodhraj, R., Mbatha, P., 2016. A lot gone but still hanging on: Floristics of remnant patches of endangered KwaZulu-Natal Sandstone Sourveld. Bothalia-African Biodiversity and Conservation 46, 1-13.

Fischer, G., Garcia, F. H., Peters, M. K., 2012. Taxonomy of the ant genus *Pheidole* Westwood (Hymenoptera: Formicidae) in the Afrotropical zoogeographic region: definition of species groups and systematic revision of the *Pheidole pulchella* group. Zootaxa 3232, 1–43.

Fisher, B.L., Bolton, B., 2016. Ants of Africa and Madagascar - A Guide to the Genera. University of California Press, California.

Gaigher, R. 2008. The effect of different vineyard management systems on the epigaeic arthropod assemblages in the Cape Floristic Region, South Africa. Unpublished Doctoral Dissertation, Stellenbosch University, Stellenbosch.

Gardner-Gee, R., Stanley, M. C. Beggs, J. R., 2015. Re-forestation restores native dominance in an island beetle fauna. Restoration Ecology 23, 268–276.

Gessner, M. O., Swan, C. M., Dang, C. K., McKie, B. G., Bardgett, R. D., Wall, D. H., Hättenschwiler, S., 2010. Diversity meets decomposition. Trends in Ecology and Evolution 25, 372–380.

Gongalsky, K. B., Malmström, A., Zaitsev, A. S., Shakhab, S. V., Bengtsson, J. B., Persson, T., 2012. Do burned areas recover from inside? An experiment with soil fauna in a heterogeneous landscape. Applied Soil Ecology 59, 73– 86.

González-Reyes, A. X., Corronca, J. A., Rodriguez-Artigas, S. M., 2017. Changes of arthropod diversity across an altitudinal ecoregional zonation in northwestern Argentina. PeerJ 5, e4117.

Graham, J.H., Hughie, H.H., Jones, S., Wrinn, K., Krzysik, A.J., Duda, J.J., Freeman, D.C., Emlen, J.M., Zak, J.C., Kovacic, D.A. and Chamberlin-Graham, C., 2004. Habitat disturbance and the diversity and abundance of ants (Formicidae) in the Southeastern Fall-Line Sandhills. Journal of Insect Science 4, 1–15

Hammer, O., Harper, D. A. T., Ryan, P. D., 2001. Paleontological statistics software: package for education and data analysis. Palaeontologia Electronica 4, 1–9.

Hodkinson, I. D., Jackson, J. K. 2005. Terrestrial and aquatic invertebrates as bio-indicators for environmental monitoring, with particular reference to mountain ecosystems. Environmental Management 35, 649–666.

Hoffmann, B. D., Andersen, A. N., 2003. Response of ants to disturbance in Australia, with particular reference to functional groups. Austral Ecology 28, 444–464.

Hoffmann, B.D., Andersen, A.N., Hill. G.J., 1999. Impact of an introduced ant on native rain forest invertebrates: *Pheidole megacephala* in monsoonal Australia. Oecologia 120, 595–604.

Howe, G. A., Jander, G., 2008. Plant immunity to insect herbivores. Annual Reviews of Plant Biology 59, 41– 66.

Hurd, L. E., Eisenberg, R. M., 1990. Arthropod community responses to manipulation of a bitrophic predator guild. Ecology 71, 2107–2114.

Imura, O., 2003. Herbivorous arthropod community of an alien weed *Solanum carolinense* L. Applied Entomology and Zoology 38, 293–300.

Joseph, G. S., Mauda, E. V., Seymour, C. L., Munyai, T. C., Dippenaar-Schoeman, A., Foord, S.H., 2017. Landuse change in savannas disproportionately reduces functional diversity of invertebrates predators at the highest trophic levels: Spiders as an example. Ecosystems, 1–13.

Keroumi, A. E., Naamani, K., Soummane, H., Dahbi, A., 2012. Seasonal dynamics of ant community structure in the Moroccan Argan Forest. Journal of Insect Science 12, 1–19.

King, J. R., Andersen, A. N., Cutter, A. D., 1998. Ants as bioindicators of habitat disturbance: validation of the functional group model for Australia's humid tropics. Biodiversity and Conservation 7, 1627–1638.

Kotze, D. J., Lawes, M. J., 2007. Viability of ecological processes in small Afromontane forest patches in South Africa. Austral Ecology 32, 294–304.

Kotze, D. J., Samways, M. J., 2001. No general edge effects for invertebrates at Afromontane forest/grassland ecotones. Biodiversity and Conservation 10, 443–466.

Kotze, D., Lawes, J. L., 2008. Environmental indicator potential of the domestic litter decomposer, *Talitriator africana* (Crustacea, Amphipoda) in Afrotemperate forests. Austral Ecology 33, 737–746.

Kwon, T. S., Lee, C. M., Kim, T. W., Kim, S. S., Sung, J. H., 2014. Prediction of abundance of forest spiders according to climate warming in South Korea. Journal of Asia-Pacific Biodiversity 7, e133-e155.

Kwon, T. S., Park, Y. K., Lim, J. H., Ryou, S. H., Lee, C. M., 2013. Change of arthropod abundance in burned forests: different patterns according to functional guilds. Journal of Asia-Pacific Entomology 16, 321–328.

Kyerematen, R., Owusu, E. H., Acquah-Lamptey, D., Anderson, R. S., Ntiamoa-Baidu, Y. 2014. Species composition and diversity of insects of the Kogyae Strict Nature Reserve in Ghana. Open Journal of Ecology 4, 1061–1079.

Lassau, S. A., Hochuli, D. F., 2004. Effects of habitat complexity on ant assemblages. Ecography 27, 157–164.

Lassau, S. A., Hochuli, D. F., Cassis, G., Reid, C. A., 2005. Effects of habitat complexity on forest beetle diversity: do functional groups respond consistently? Diversity and Distributions 11, 73–82.

Lawes, M. J., Kotze, D. J., Bourquin, S. L., Morris, C., 2005. Epigaeic Invertebrates as Potential Ecological Indicators of Afromontane Forest Condition in South Africa1. Biotropica 37, 109–118.

Li, S., Jovelin, R., Yoshiga, T., Tanaka, R., Cutter, A. D., 2014. Specialist versus generalist life histories and nucleotide diversity in Caenorhabditis nematodes. Proceedings of the Royal Society of London B: Biological Sciences 281, 1–10.

Liu, R., Zhu, F., Song, N., Yang, X., Chai, Y., 2013. Seasonal distribution and diversity of ground arthropods in microhabitats following a shrub plantation age sequence in desertified steppe. PloS One, 8, e77962.

Maelfait, J. P., Hendrickx, F., 1998. Spiders as bio-indicators of anthropogenic stress in natural and semi-natural habitats in Flanders (Belgium): some recent developments. In: Selden, P.A., (ed.), Proceedings of the 17th European Colloquium of Arachnology, Edinburgh, 293–300.

McCabe, D. J. and Gotelli, N. J., 2000. Effect of disturbance frequency, intensity, and area on assemblages of stream macroinvertebrates. Oecologia 124, 270–279.

McGeoch, M., 1998. The selection, testing and application of terrestrial insects as bioindicators. Biological Reviews 73, 181–201.

Mucina, L., Rutherford, M. C., 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Munyai, T. C., Foord, S.H., 2015. An inventory of epigeal ants of the western Soutpansberg Mountain Range, South Africa. Koedoe 57, 1–12.

Pettersson, R. B., 1996. Effect of forestry on the abundance and diversity of arboreal spiders in the boreal spruce forest. Ecography 19, 221-228.

Picker, M., Griffiths, C., Weaving, A., 2002. Field Guide to Insects of South Africa. Struik Nature Publishers, Cape Town.

Proches, S., Wilson, J. R., Richardson, D. M., Chown, S. L., 2008. Herbivores, but not other insects, are scarce on alien plants. Austral Ecology 33, 691–700.

Quinn, G. P., Keough, M. J., 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge, United Kingdom.

Rosado, J. L., De Gonçalves, M. G., Dröse, W., Eduardo, J. E., Krüger, R. F., Feitosa, R. M., Loeck, A. E., 2012. Epigeic ants (Hymenoptera: Formicidae) in vineyards and grassland areas in the Campanha region, state of Rio Grande do Sul, Brazil. Check List 8, 1184–1189.

Saint-Germain, M., Buddle, C.M., Larrivee, M., Mercado, A., Motchula, T., Reichert, E., Sackett, T.E., Sylvain, Z. and Webb, A., 2007. Should biomass be considered more frequently as a currency in terrestrial arthropod community analyses? Journal of Applied Ecology 44, 330–339.

Samways, M. J., Caldwell, P. M., Osborn, R., 1996. Ground-living invertebrate assemblages in native, planted and invasive vegetation in South Africa. Agriculture, Ecosystems and Environment 59, 19–32.

Silva, P. S. D., Bieber, A. G. D., Corrêa, M. M., Leal, I. R., 2011. Do leaf-litter attributes affect the richness of leaf-litter ants? Neotropical Entomology 40, 542–547.

Sinu, P. A., M. V. Sharma., 2013. Insect functional guilds in the flowering canopy of *Myristica Fatua* in a lowland swamp, Central Western Ghats, India. Tropical Conservation Science 6, 653–662.

Smith, L., 2008. Remarkable Insects of South Africa. Briza Publishers, Pretoria. South Africa.

Sokal, R.R., Rohlf, F. J., 2012. Biometry: The Principles and Practice of Statistics in Biological Research, fourth ed. W.H. Freeman and Company, New York.

Sonune, B. V., Chavan, R. J., 2016. Distribution and diversity of ants (Hymenoptera: Formicidae) around Gautala Autramghat Sanctuary Aurangabad Maharashtra, India. Journal of Entomology and Zoological Studies 4, 361–364.

Tantsi, N., 2013. Long-term impacts of *Chromolaena odorata* (L.) invasion and ungulate grazing on ant body size and communities in Hluhluwe-iMfolozi Park, South Africa. Unpublished Master's Thesis, University of Pretoria, Pretoria.

Templer, P. H., Schiller, A. F., Fuller, N. W., Socci, A. M., Campbell, J. L., Drake, J. E., Kunz, T. H. 2012. Impact of a reduced winter snowpack on litter arthropod abundance and diversity in a northern hardwood forest ecosystem. Biology and Fertility of Soils 48, 413–424.

Uys, C., Hamer, M., Slotow, R., 2009. Turnover in flightless invertebrate species composition over different spatial scales in Afrotemperate forest in the Drakensberg, South Africa. African Journal of Ecology 47, 341–351.

Vander Zanden, H. B., Bjorndal, K. A., Reich, K. J., Bolten, A. B., 2010. Individual specialists in a generalist population: results from a long-term stable isotope series. Biology Letters 6, 711–714.

Vanderwoude, C., Lobry de Bruyn, L. A., House, A. P. N., 2000. Response of an open forest ant community to invasion by the introduced ant, *Pheidole megacephala*. Austral Ecology 25, 253–259.

Vasconcellos, A., 2010. Biomass and abundance of termites in three remnant areas of Atlantic Forest in northeastern Brazil. Revista Brasileira de Entomologia 54, 455-461.

Vasconcelos, H. L., 1999. Effects of forest disturbance on the structure of ground-foraging ant communities in central Amazonia. Biodiversity and Conservation 8, 407–418.

Viana-Junior, A. B., Reis, Y. T., Costa, A. P. M., Souza, V. B., 2014. Termite assemblages in dry tropical forests of Northeastern Brazil: Are termites bioindicators of environmental disturbances? Sociobiolog*y* 61, 324–331.

Vilisics, F., Bogyó, D., Sattler, T., Moretti, M., 2012. Occurrence and assemblage composition of millipedes (Myriapoda, Diplopoda) and terrestrial isopods (Crustacea, Isopoda, Oniscidea) in urban areas of Switzerland. ZooKeys 176, 199–124.

Weaving, A., 2000. South African Insects and their World. Struik Publishers, Cape Town.

Wiezik, M., Wieziková, A., Svitok, M., 2011. Vegetation structure, ecological stability, and low-disturbance regime of abandoned dry grasslands support specific ant assemblages in Central Slovakia. Tuexenia 31, 301–315.

Yekwayo, I., 2016. Diversity value of Afromontane forest patches within KwaZulu-Natal timber production areas. Unpublished Doctoral Dissertation, Stellenbosch University, Stellenbosch.

Yekwayo, I., Pryke, J. S., Roets, F., Samways, M. J., 2016. Surrounding vegetation matters for arthropods of small, natural patches of indigenous forest. Insect Conservation and Diversity 9, 224–235.

Yi, H., Moldenke, A., 2005. Response of ground-dwelling arthropods to different thinning intensities in young Douglas fir forests of western Oregon. Environmental Entomology 34, 1071–1080

Chapter 4: General Summary and Recommendations

Summary of findings

Epigaeic arthropods are known to respond to changes and modifications in their ecosystems by showing variations in species diversity and distribution (Ponge, 2013). Species diversity and distribution are influenced largely by the surrounding vegetation and season (Yi and Moldente, 2005; Wiezik and Suitok, 2011; Yekwayo et al., 2016). In the present study, ground-dwelling arthropods were used as bioindicators of ecological conditions in the KwaZulu-Natal Sandstone Sourveld.

Firstly, the study investigated species diversity and distribution and examined the effect of seasonality on epigaeic ant species diversity across vegetation types. In Chapter 2, seasonality was shown to have variable influence on epigaeic ant diversity and distribution. Epigaeic ant diversity was higher in the wet season than the dry season. It is known that the wet season is characterised by optimum climatic conditions and greater resource availability that are favourable to ant communities (Yi and Moldente, 2005; Liu et al., 2013). Vegetation type also played a major role in epigaeic ants communities, ants were more abundant in the disturbed grassland than the forest and the intact grassland. Disturbed grassland was a native grassland previously, which was transformed to pine and eucalyptus plantation. The lack of management of these plantations resulted in grass growing back and increased invasion by alien plants. The reduced complexity of vegetation in the disturbed grassland may explain the higher diversity of ants in this vegetation type than in the forest and in an intact grassland.

Chapter 3 focused on understanding variation of epigaeic arthropod species abundance and richness across vegetation types and season. Seasonality had a similar influence on epigaeic arthropods communities as found for ants in Chapter 2. When more taxa were investigated the response to diverse vegetation types was different. Epigaeic arthropods had greater abundance in the forest than in an intact grassland and disturbed grassland. In addition, epigaeic arthropods were more speciose in an intact grassland than the forest and the disturbed grassland. The high abundance and greater species richness of epigaeic arthropods in the forest and in an intact grassland suggest that disturbance have a negative influence on epigaeic arthropods. These

results suggest that it may be better to focus on many taxa than on one taxon because the response of a taxon may not be representative of all the taxa. Based on the findings when more taxa are investigated, I suggest that different sampling techniques that target all epigaeic arthropod taxa should be employed to get representatives of the species.

In the second part of chapter 3, I examined whether functional guild of epigaeic arthropods varied with season and vegetation types. The effect of seasonality varied among functional guilds with generalist arthropods being more abundant in the dry season unlike the predators, herbivores and decomposers which were more abundant in the wet season. These results demonstrated that generalists are able to survive and thrive under unfavourable conditions. On the other hand, the abundance of herbivores and decomposers in the wet season suggest that these functional guilds depend on high resource availability and specific resources which might not be abundant in the dry season. Hence, the abundance of herbivores may decline in the dry season.

Functional diversity varied across vegetation types. Decomposers and predators had greater abundance in the forest unlike the generalists and herbivores which were more abundant in disturbed grassland. The forest provides suitable and abundant resources for decomposers and it is not surprising that decomposers were abundant in the forest (Kotze and Lawes 2008). Decomposers are associated with the leaf litter layer in the forest (Kotze and Lawes 2008; Vilisics et al., 2012). These results demonstrate that resources in the habitat have an influence on the abundance of functional guilds. In addition, functional guilds have different resource and habitat preferences (Mitchell and Litt, 2016). Ali and Agrawal (2012) reported that herbivorous arthropods feed on plant parts, such as, pollen, nectar and leaves. Vegetation complexity in the disturbed grassland may have provided optimal conditions that supported greater abundance of herbivores in the disturbed grassland (Hertzog et al., 2016).

Pheidole sp.02 (*megacephala* gp.) and *Talitriator africana* were the most widespread and abundant species in all vegetation type. However, *Pheidole* sp.02 (*megacephala* gp.) was more abundant in the disturbed grassland and *Talitriator africana* was more abundant in the forest.

Pheidole sp.02 (*megacephala* gp.) may be an indicator for disturbed grassland and *Talitriator africana* may be an indicator for undisturbed forest.

Recommendations

- Forest and intact grassland should be conserved because they supported higher numbers of epigaeic arthropods and functional guilds (Chapter 3). Management of grasslands and forests should seek to prevent or limit invasion by alien plants because invasive alien plants have detrimental effects on biodiversity and reduce ecosystem stability (Richardson and van Wilgen, 2004; Mgobozi et al., 2008). Invasive alien plants are responsible for the decline in plant and animal species diversity and abundance in terrestrial ecosystems (Clusella-Trullas and Garcia, 2017; Chapter 3). Alien invasive plants are known for changing vegetation structure, which reduces indigenous plant species richness and plant productivity (Richardson and van Wilgen, 2004; Mgobozi et al., 2008)

- Disturbed grassland should be managed in a manner that eliminates alien invasive plants and it should be restored to an undisturbed grassland because, grasslands provide direct and indirect ecosystem services, regulate climate through carbon sequestration support a number of plant and animal species (Egoh et al., 2011).

- Future studies should include the effect of environmental variables, such as soil type, soil depth, vegetation diversity and composition on epigaeic arthropod communities. Such studies will improve understanding of ecosystem dynamics rather than only influences on epigaeic arthropod communities.

- Species accumulation curves did not reach asymptote therefore, number of replicates per vegetation type should be increased to increase sampling effort and to get adequate representation of all epigaeic arthropods found in Tanglewood and Giba Gorge Nature Reserves.

References

Clusella-Trullas, S., Garcia, R. A., 2017. Impacts of invasive plants on animal diversity in South Africa: A synthesis. Bothalia-African Biodiversity and Conservation 47, 1–12.

Egoh, B.N., Reyers, B., Rouget, M., Richardson, D.M., 2011. Identifying priority areas for ecosystem service management is South African grassland. Journal of Environmental Management 92, 1642–1650.

Hertzog, L. R., Meyer, S. T., Weisser, W. W., Ebeling, A., 2016. Experimental manipulation of grassland plant diversity induces complex shifts in aboveground arthropod diversity. PloS One, 11, e0148768.

Kotze, D., Lawes, J. L., 2008. Environmental indicator potential of the domestic litter decomposer, *Talitriator africana* (Crustacea, Amphipoda) in Afrotemperate forests. Austral Ecology 33, 737–746.

Liu, R., Zhu, F., Song, N., Yang, X., Chai, Y., 2013. Seasonal distribution and diversity of ground arthropods in microhabitats following a shrub plantation age sequence in desertified steppe. PloS One, 8, e77962.

Mgobozi, M. P., Somers, M. J., Dippenaar-Schoeman, A. S., 2008. Spider responses to alien plant invasion: the effect of short-and long-term *Chromolaena odorata* invasion and management. Journal of Applied Ecology 45, 1189–1197.

Mitchell, A. B., Litt, A. R., 2016. Non-native plant shifts functional groups of arthropods following drought. Biological invasions 18, 1351-1361.

Ponge, J. F., 2013. Disturbances, organisms and ecosystems: a global change perspective. Ecology and Evolution 3, 1113–1124.

Richardson, D.M., Van Wilgen, B.W., 2004. Invasive alien plants in South Africa: How well do we understand the ecological impacts? South African Journal of Science 100, 45–52.

Vilisics, F., Bogyó, D., Sattler, T., Moretti, M., 2012. Occurrence and assemblage composition of millipedes (Myriapoda, Diplopoda) and terrestrial isopods (Crustacea, Isopoda, Oniscidea) in urban areas of Switzerland. ZooKeys 176, 199–124.

Wiezik, M., Wieziková, A., Svitok, M., 2011. Vegetation structure, ecological stability, and low-disturbance regime of abandoned dry grasslands support specific ant assemblages in Central Slovakia. Tuexenia 31, 301–315.

Yekwayo, I., Pryke, J. S., Roets, F., Samways, M. J., 2016. Surrounding vegetation matters for arthropods of small, natural patches of indigenous forest. Insect Conservation and Diversity 9, 224–235.

Yi, H., Moldenke, A., 2005. Response of ground-dwelling arthropods to different thinning intensities in young Douglas fir forests of western Oregon. Environmental Entomology 34, 1071–1080

Appendices

Appendix 2. 1. Number of ground-dwelling ants sampled across different vegetation types (disturbed grassland, forest and grassland) in Tanglewood and Giba Gorge Reserves during the dry and wet season.

Sub-family	Genus	Disturbed grassland	Forest	Intact Grassland
Dolichoderinae	*Tetramorium*	30	47	35
Doryline	*Aenictus*	0	0	2
Doryline	*Parasycia*	0	0	5
Formicinae	*Camponotus*	19	3	21
Formicinae	*Lepisiota*	14	22	7
Formicinae	*Nylanderia*	16	0	32
Formicinae	*Polyrhachis*	0	0	3
Myrmicinae	*Crematogaster*	4	3	30
Myrmicinae	*Monomorium*	1	1	2
Myrmicinae	*Myrmicaria*	85	36	74
Myrmicinae	*Pheidole*	1118	222	498
Myrmicinae	*Solenopsis*	10	1	6
Myrmicinae	*Strumigenys*	0	0	1
Myrmicinae	*Technomyrmex*	0	0	4
Ponerinae	*Anochectus*	2	0	0
Ponerinae	*Bothroponera*	17	0	18
Ponerinae	*Hypoponera*	0	1	0
Ponerinae	*Leptogenys*	16	79	20
Ponerinae	*Mesoponera*	16	9	28
Ponerinae	*Ophthalmopone*	2	0	0
Ponerinae	*Plectroctena*	1	2	11
Ponerinae	*Pseudoponera*	0	0	3
Total	**22**	**1351**	**426**	**800**

Appendix 3. 1. Epigaeic arthropods sampled across different habitat types (disturbed, forest and grassland) in Tanglewood and Giba Gorge Nature Reserves during the dry and wet season.

Morpho-species	Functional guild	Disturbed grassland	Forest	Intact Grassland
Ampipoda: Talitridae				
Talitriator africana	Decomposer	350	1752	73
Araneae				
Clubionidae				
Clubiona africana	Predator	0	0	6
Clubiona belvis	Predator	1	0	0
Clubiona sp.01	Predator	6	4	5
Corinnidae				
Afroceto martini	Predator	17	3	8
Afroceto sp.01	Predator	23	1	15
Araneae sp.02	Predator	0	0	2
Cambalinda sp.01	Predator	2	0	2
Cambalinda sp.02	Predator	0	1	0
Copa flavoplumosa	Predator	7	0	4
Copa sp.01	Predator	4	0	10
*Copa sp.*02	Predator	4	1	4
*Copa sp.*03	Predator	0	2	1
*Copa sp.*04	Predator	2	2	12
*Copa sp.*05	Predator	2	0	0
*Copa sp.*06	Predator	1	0	3
Pronophaea natalica	Predator	10	2	10
Pronophaea sp.01	Predator	1	3	3
Zoropsidae sp.01	Predator	0	0	1
Dysderidae				
Dysdera crocata	Predator	0	0	1
Gnapphosidae		0	0	0
Xerophaeus patrici	Predator	0	1	0
Nemesiidae				
Hermacha bicolor	Predator	6	3	14
Nemesiidae sp.01	Predator	0	1	5
Pholcidae				
Leptopholcus sp.01	Predator	1	4	11
Leptopholcus sp.02	Predator	0	2	1
Leptopholcus sp.03	Predator	3	1	6
Leptopholcus sp.04	Predator	0	0	7
Phyxelididae				
Themacrys sp.01	Predator	0	1	1
Solpugidae	Predator			
Solpuga sp.01	Predator	0	0	1
Solpuga sp.02	Predator	0	0	2
Sparassidae				
Sparassidae sp.01	Predator	2	1	0

Zodariidae				
Psammorygma sp.01	Predator	1	0	1
Themacrys sp.01	Predator	0	0	2
Zodariidae sp.01	Predator	1	0	0
Zoropsidae				
Zoropsidae sp.01	Predator	0	0	6
Araneae sp.01	Predator	3	2	5
	Predator			
Blattodea				
Blaberidae				
Bantua sp.01	Predator	29	8	11
Bantua sp.02	Predator	11	5	8
Derocalymma sp.01	Predator	0	1	3
Temnopteryx sp.01	Predator			1
Blattidae				
Deropeltis erythrocephala	Predator	3	0	1
Polyphagidae				
Hostilia sp.01	Predator	0	2	0
Coleoptera		2	7	0
Bostrichidae sp1	Predator			
Carabidae				
Carabidae sp.01	Predator	5	95	26
Carabidae sp.02	Predator	4	3	1
Carabidae sp.03	Predator	0	4	0
Carabidae sp.04	Predator	1	2	0
Carabidae sp.05	Predator	1	0	0
Carabidae sp.06	Predator	0	0	1
Carabidae sp.07	Predator	2	0	0
Carabidae sp.08	Predator	2	3	0
Cerapterus sp.01	Predator	0	0	1
Coleoptera sp.01	Predator	0	1	0
Thermophilum homoplatum	Predator	3	1	1
Cicindelinae (carabidae)	Predator			
Cicindelinae sp.01	Predator	0	0	2
Curculionidae				
Curculionidae sp.01	Herbivore	0	12	25
Curculionidae sp.02	Herbivore	4	6	7
Scarabaeidae				
Scarabaeidae sp.01	Herbivore	8	17	12
Scarabaeidae sp.02	Herbivore	3	12	0
Scarabaeidae sp.03	Herbivore	2	6	4
Scarabaeidae sp.04	Herbivore	18	0	7
Scarabaeidae sp.05	Herbivore	0	0	1
Scarabaeidae sp.06	Herbivore	0	77	5
Scarabaeidae sp.07	Herbivore	0	1	1
Scarabaeidae sp.08	Herbivore	0	9	3

Scarabaeidae sp.09	Herbivore	2	1	5
Scarabaeidae sp10	Herbivore	1	0	1
Scarabaeidae sp11	Herbivore	0	0	1
Tenebrionidae	Herbivore			
Tenebrionidae sp.01	Herbivore	0	14	2
Tenebrionidae sp.02	Herbivore	0	1	2
Tenebrionidae sp.03	Herbivore	0	3	2
Tenebrionidae sp.04	Herbivore	0	0	1
Tenebrionidae sp.05	Herbivore	0	0	2
Tenebrionidae sp.06	Herbivore	0	0	1
Tenebrionidae sp.07	Herbivore	1	1	0
Tenebrionidae sp.08	Herbivore	0	0	2
Trogidae				
Trogidae sp.01	Herbivore	1	0	0
Coleoptera sp.01	Herbivore	2	6	5
Dermaptera				
Labiduridae				
Euborellia annulipes	Decomposer	6	10	2
Diplopoda				
Odontopygidae				
Odontopygidae sp.01	Decomposer	0	15	0
Odontopygidae sp.02	Decomposer	7	6	0
Odontopygidae sp.03	Decomposer	0	2	0
Odontopygidae sp.04	Decomposer	2	0	0
Sphaerotheriidae				
Sphaerotherium sp.01	Decomposer	0	2	0
Spirosteptidae				
Spirosteptidae sp.01	Decomposer	2	1	0
Diplopoda sp.01	Decomposer	1	0	0
Hemiptera				
Coreidae				
Petascelis sp.01	Predator	2	4	0
Ochteridae				
Octhteridae sp1	Predator	5	0	0
Pyrrhocoridae				
Pyrrhocoridae sp.01	Predator	6	3	0
Reduviidae				
Reduviidae sp.01	Predator	1	0	0
Scutelleridae				
Scutelleridae sp.01	Predator	1	0	0
Tessaratomidae				
Encosternum delegorguei	Predator	2	1	2
Hemiptera				
Hemiptera sp.01	Predator	5	3	3
Hymenoptera				
Dolichoderinae				

Species	Guild			
Technomyrmex sp.01	Predator	0	0	1
Technomyrmex sp.02	Predator	0	0	3
Dorylinae				
Aenictus sp.01	Predator	0	0	2
Parasycia sp.02	Generalist	0	0	2
Parasyscia sp.01	Generalist	0	0	3
Formicinae				
Camponotus sp.01 (*cintellus* gp.)	Herbivore	2	2	5
Camponotus sp.02 (*maculatus* gp.)	Herbivore	17	1	1
Camponotus sp.04	Herbivore	0	0	14
Camponotus sp.05	Herbivore	0	0	1
Lepisiota sp.01 (*capensis* gp.)	Predator	12	20	7
Lepisiota sp.03 (*capensis* gp.)	Predator	2	0	0
Lepisiota sp.04 (*capensis* gp.)	Predator	0	2	0
Nylanderia sp.01	Generalist	11	0	32
Nylanderia sp.02	Generalist	5	0	0
Polyrhachis sp.01	Generalist	0	0	2
Myrmicinae				
Crematogaster sp.01	Generalist	0	0	27
Crematogaster sp.02	Generalist	0	3	3
Crematogaster sp.03 (*rufigina* gp.)	Generalist	4	0	0
Monomorium sp.01 (*monomorium* gp.)	Generalist	1	1	2
Myrmicaria sp.01	Generalist	85	36	74
Pheidole sp.01 (*megacephala* gp.)	Generalist	68	5	75
*Pheidole sp.*02 (*megacephala* gp.)	Generalist	845	222	383
*Pheidole sp.*03	Generalist	205	0	4
Pheidole sp.03 (*megacephala* gp.)	Generalist	0	0	36
Solenopsis sp.01	Predator	0	0	1
Solenopsis sp.02	Predator	5	0	4
Solenopsis sp.03	Predator	5	1	1
Strumigenys sp.01	Predator	0	0	1
Tetramorium ?notiale	Predator	2	0	0
Tetramorium cf. setigerum	Predator	9	2	5
Tetramorium notiale	Predator	4	0	0
Tetramorium sp.01 (*squaminode* gp)	Predator	11	27	4
Tetramorium sp10 (*similimum* gp.)	Predator	3	2	0
Tetramorium sp11	Predator	0	0	2
Tetramorium sp12	Predator	0	0	2
Tetramorium sp13	Predator	0	4	0
Tetramorium sp.02	Predator	0	0	2
Tetramorium sp.03 (*simillimum* gp.)	Predator	1	7	3
Tetramorium sp.04 (*sericeiventre* gp.)	Predator	0	0	11
Tetramorium sp.05	Predator	0	0	5

Tetramorium sp06	Predator	0	0	1
Tetramorium sp.08 (squminode gp.)	Predator	0	5	0
Ponerinae				
Anochectus sp.02	Predator	2	0	0
Bothroponera sp.01	Predator	0	0	3
Bothroponera sp.02	Predator	17	0	15
Hypoponera sp.01	Predator	0	1	0
Leptogenys schwabi	Predator	16	78	0
Leptogenys cf *intermedia*	Predator	0	1	20
Mesopnera sp.01	Predator	10	8	28
Mesoponera sp.03	Predator	0	1	0
Mesoponera sp.04	Predator	6	0	0
Ophthalmopone sp.01	Predator	2	0	0
Plectroctena sp.01	Predator	1	2	10
Plectroctena sp.02	Predator	0	0	1
Pseudoponera sp.01		0	0	4
Isopoda				
Oniscidae				
Oniscidae sp.01	Decomposer	51	41	10
Oniscidae sp.02	Decomposer	3	2	2
Oniscidae sp.03	Decomposer	0	11	3
Isoptera				
Hodotermitidae				
Hodotermes massambicus	Herbivore	0	0	2
Termitidae				
Macrotermes natalensis	Herbivore	2	0	0
*Microcerotermes sp.*01	Herbivore	0	6	0
Odontototermes badius	Herbivore	17	18	34
Trinervitermes sp.01	Herbivore	0	0	5
Orthoptera				
Anostostomatidae				
Onosandrus sp.01	Herbivore	23	5	11
Onosandrus sp.02	Herbivore	0	2	
Orthoptera				
Gryllidae				
Gryllidae sp.01	Herbivore	81	7	24
Gryllidae sp.02	Herbivore	13	3	8
Gryllidae sp.03	Herbivore	9	11	4
Gryllidae sp.04	Herbivore	18	5	9
Gryllidae sp.05	Herbivore	2	0	1
Orthoptera sp.01	Herbivore	1	0	1
Overall Total		**2180**	**2675**	**1295**

Appendix 3. 2. Epigaeic arthropods orders sampled across different habitat types (disturbed grassland, forest and grassland) in Tanglewood and Giba Gorge Nature Reserves during the wet and dry season.

Orders	Disturbed grassland	Forest	Intact Grassland
Amphipoda	350	1754	73
Araneae	97	35	147
Blattodea	43	16	24
Coleoptera	62	282	122
Dermaptera	6	10	2
Diplopoda	12	25	1
Hemiptera	22	11	6
Hymenoptera	1351	426	800
Isopoda	54	54	15
Isoptera	19	24	41
Orthoptera	164	38	64