Ant diversity and composition in a reforested landscape of Buffelsdraai Landfill Conservancy, KwaZulu-Natal

by

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Submitted in fulfilment of the academic requirements of

Master of Science

In Entomology

School of Life Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

South Africa

20 March 2019

PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Biology, School of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by National Research Foundation (NRF).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Dr TC Munyai

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Signed: Prof S.H. Foord

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DECLARATION 1: PLAGIARISM

I, Sbongiseni Xolo, declare that:

(i) the research reported in this thesis, except where otherwise indicated or acknowledged, is my original work;

(ii) this thesis has not been submitted in full or in part for any degree or examination to any other university;

(iii) this thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

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

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this thesis is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

S. Xolo

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Signed: Sbongiseni Xolo

Date: 20 March 2019

DECLARATION 2: CONFERENCE PROCEEDINGS AND DISCLAIMER

Please note that chapter two and three of this thesis were written as stand-alone data chapters and therefore some repetition was unavoidable.

The conferences at which this work has been presented at are shown below.

1. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. The 4th National Conference on Global Change 2018, Polokwane, Limpopo, 3-6 December 2018. Oral Presentation: Presented by TC Munyai.
2. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. D'RAP Annual Research Symposium 2018, Durban, Paradise Valley Nature Reserve, 03 December 2018. Oral Presentation: Presented by S Xolo.
3. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. BIMF – FBIP Student forum 2018, PE, Cape Resort, 13-16 August 2018. Oral Presentation: Presented by S Xolo.
4. Xolo S, Foord S.H., Slotow R. & Munyai T.C. Checklist of epigaeic ants in Buffesldraai Landfill Conservancy, South Africa. CAES Postgraduate Research Day, Pietermaritzburg, University of KwaZulu-Natal PMB Campus, 22 May 2018. Poster Presentation: Presented by S Xolo.
5. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. D'RAP Annual Research Symposium 2017, Durban, Paradise, 01 December 2017. Oral Presentation: Presented by TC Munyai.
6. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. Symposium of Conservation Practice 2017, Fern Hill Conference Centre, 6-10 November 2017. Oral Presentation: Presented by S Xolo.
7. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. CAES Postgraduate Research Day, Durban, University of KwaZulu-Natal Westville Campus, 26 October 2017. Poster Presentation: Presented by S Xolo.
8. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. BIMF – FBIP Student forum 2017, Durban, Salt Rock Hotel, 14-17 August 2017. Oral Presentation: Presented by S Xolo.
9. Xolo S., Foord S.H., Slotow R. & Munyai T.C. Ant diversity and composition in reforested landscape of Buffelsdraai landfill, KwaZulu-Natal. Combined Congress of the entomological and Zoological Societies of Southern Africa, CSIR International Convention Centre, Pretoria, 03 – 07 July 2017. Poster Presentation: Presented by S Xolo.

ABSTRACT

Restoration of degraded and reclaimed landscapes provide a useful framework to evaluate the recovery of biodiversity loss. A reforestation project was initiated in 2008 by eThekwini Municipality in Buffelsdraai Landfill Conservancy, aiming to offset carbon emissions over a 20-year period and increase climate change adaptation through biodiversity and ecosystem services restoration. The project offered an opportunity to evaluate to what extent reforestation for carbon sequestration can have co-benefits for biodiversity. The current study monitors the recovery of habitat restoration practices (planting of indigenous forest trees) in Buffelsdraai Landfill Conservancy, eThekwini Municipality, KwaZulu-Natal Province, in South Africa. The main aim of the study was to evaluate how biodiversity recovers following forest restoration. The study used ants (Formicidae: Hymenoptera) as a model organism as they comprise a significant component of invertebrate diversity and a keystone taxon in the terrestrial ecosystems. The study objectives were to provide ant checklist in a reforested landscape and to describe ant diversity patterns along a gradient of restoration and to identify the environmental variables which drive the diversity patterns along a reforestation gradient. Using a standardized pitfall survey, ants were sampled across eight sites, each replicated four times, which included sugarcane (unrestored), grassland and scarp forest (natural reference sites), short-term (0-2 year), medium-term (3-5 years) and long-term (6-8 years) restored sites. Ant sampling was conducted in April-May 2017 (early dry season) and December 2017 (wet season). Environmental (habitat structure) and soil surveys were conducted at each plot. A total of 27 439 ant specimens comprising of 96 species in 31 genera, and six subfamilies were collected. Sample coverage estimator was larger than 0.97, indicating that inventory completion approximated most of the ant assemblages found in the study area. Myrmicinae, Ponerinae and Formicinae were the most abundant and species-rich subfamilies, with *Tetramorium*, *Pheidole* and *Monomorium* as the most species-rich genera. The most numerically dominant species were *Pheidole megacephala* species group and *Anoplolepis custodiens*. Ant species richness and activities were significantly highest in the restored and grassland sites and low in forest site, and lowest in unrestored sugarcane. Species richness responded with a hump-shaped response as patterns of species richness significantly decreased with increasing bare-ground cover. High species diversity and composition was associated with open habitats with grass layer. Forest had the most distinct assemblages. Leaf litter, vegetation structure, canopy cover and bare-ground cover, were the four predictor variables which had major influences on ant assemblage structure. Four forest indicator taxa were identified (*Pheidole* UKZN_11 (*megacephala* gp.),

Tetramorium UKZN_04 (*squaminode* gp.); *Tetramorium* UKZN_28 (*setigerum* gp.) and *Leptogenys attenuate*), and one indicator for grassland (*Lepisiota capensis*). No indicators were found for sugarcane sites. *Solenopsis* UKZN_01 and *Pheidole* UKZN_09 were potential indicator for restored sites. The restoration sites were transitioning from sugarcane plantation, and were drawing most of their colonisation from grasslands at this stage. This study shows that open woodlands are ideal habitats for maximising species diversity, as they provide a complex habitat for many species, and the availability of local natural grassland as a source of invertebrates assists restoring functioning, even if we expect the community to transition to forest species as regrowth progresses.

ACKNOWLEDGMENTS

I would like to thank God for all the good times and good days of my life. Amen.
I would also like to share my special acknowledgments to the following people and parties for their kind contribution and hard work towards the success of this project:

First and foremost, I would like to acknowledge my supervisors all three of them for their time invested in this project:
Dr Thinandavha C Munyai, my supervisor, you have been there man, from day one and throughout. If I were to outline all your inputs, this acknowledgement section would be for you alone. You brought light on my darkest end and you never lost your temper. Thank you, man, for being the engine that kept me going till this far. I know you have a lot that you wish to achieve, I wish you all the best, do not let that fire die down. Tshipiriti!!!

Prof Rob Slotow, my co-supervisor, you brought thoughtful inputs that guided this project in a right direction, you made things happen and I have to mention this, your hands were never too tight to get us (Dr Munyai ant lab) everywhere we needed to go. Your great ideas, time and dedication was valuable to me and I am sincerely grateful for that. You the man!!!

Prof Stefan H Foord, my co-supervisor, me and Nomah were stuck, we didn’t have a clue where to start analysing our data. Thank you so much for teaching us new techniques and statistics of this project. We would like to send our apologies for ruining your trip to Durban with your family but if it wasn’t for you, our project would have not made this far. Ndolivhuwa!!!

All my supervisor’s comments, edits and recommendations were never too harsh to discourage me. Each and every one of you played a significant role that made this project a success. NGIYABONGA!!!

Special thanks to Fatima Alli, Richard Winn and Errol Douwes, for hospitality and access to Buffelsdraai Landfill and Durban Research Action Partnership and eThekwini Municipality. Special thanks to Mbali Mbonambi for encouragement and support. Special thanks to various field and laboratory assistants: Nokubonga Thabethe, Nomathamsanqa Mkhize, Carol Kunene, Busi Ndaba, Thandeka Mahlobo, Samke Colvel, and Mthobisi Hadebe.

I would like to acknowledge the Durban Research Action Partnership, with funding from eThekwini Municipality, as well as National Research Foundation (NRF) for funding this project. Special thanks to NRF Land Use Chair: Prof O Mutanga and Ms Precious Nciliba. Special thanks to the College of Agriculture, Engineering and Sciences for funding one local conference. I would like to acknowledge the Gay Langmuir Scholarship 2017.

Lastly, I like to thank the Ntuli family, Omphemba oNdlela KaSompisi, special thanks to Nompumelelo Nah Ntuli and oXolo oMthusi particularly Nomsa Xolo, Musa Xolo, Nosipho Xolo and Bonginkosi Xolo, for continuous love and support. Shoutout to my SWART-TEAM, Tirbo, Mjozi, C’tolo and Da, family over everything zinjazam.

DEDICATION

I dedicate this work to my three sons, Luthando Malishe, Ndabenhle Malishe and Zanokuhle Mbonambi. Love and peace.

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CHAPTER 1: GENERAL INTRODUCTION AND OVERVIEW

1.1 Background to the study

The increase of human population on earth has negatively affected most of the natural ecosystems (Chen et al., 2018; Xiang et al., 2018). Amongst other factors, the conversion of natural ecosystems for other uses is one of the most significant causes of biodiversity loss (Hobbs and Harris, 2001). Land-cover change destroys natural habitat, frequently with secondary consequences of degradation and fragmentation of remaining habitats, all of which result in loss of biodiversity (Tilman and Lehman, 2001). Loss and degradation of natural habitat, particularly natural forests, is the biggest cause of biodiversity loss and decline in the terrestrial environment (Tilman and Lehman, 2001).

Much of the natural forest of the world have been substantially cleared and converted for other anthropogenic land use activities. Human settlements and agriculture have taken a large portion of earth's land surface and currently only few pristine ecosystems remain undisturbed by some form of human activities (Bowen et al., 2007). Extensive areas of native forest ecosystems have been cleared to make way for agriculture and city developments primarily to accommodate an increasing human population (Cunningham et al., 2015).

Despite all the goods and services that forests provide, they continue to decline. Between years 1990 - 2015, the world's forest area decreased from 31.6% to 30.6% of the global land area (FAO, 2015). Approximately 129 million hectares of forest have been lost since 1990, this is an area almost equivalent in size to South Africa (FAO, 2015). The remaining natural forests are still under pressure to deliver ecosystem services, while suffering from the stress of climate change (FAO, 2018). Globally, agriculture remains the main driver of deforestation (Chomitz et al., 2007). Deforestation resulting from the conversion of forests to agriculture pose threats to livelihoods of foresters, forest communities and indigenous peoples, and substantially affect the variety of life on our planet (Gomes et al., 2014; Shepherd et al., 2013).

While the crisis of deforestation should not be understated, there are also some positive restoration efforts underway. Restoration of forests and landscapes is part of global efforts to reverse loss of forest globally (Evans et al., 2018; Dougherty et al., 2015; Bowen et al., 2007). Lately, reforestation and restoration processes have gained momentum across the world and have been the topic of much research (Hobbs, 2016). In this context, restoration refers to action taken as means to assist the recovery of an ecosystem that has been degraded or damaged (Piper et al., 2009), while reforestation refers to the replanting of trees on landscape that previously had trees but used for other purposes other than natural forestlands (Zhou et al., 2008). Ecological restoration is increasingly recognized as a solution to the current global biodiversity crisis (Hobbs and Cramer, 2008). Species conservation within expanded reserve areas is essential however, many native fauna species occupy modified landscapes outside the formal reserve system (Bowen et al., 2007). This is why fragmented ecosystems should be prioritized for some form of restoration (Bowen et al., 2007). Restoration of degraded ecosystems is recognised as critical to the protection of both biodiversity and ecosystem services in this period of strong human alteration of ecosystems (Hobbs and Harris, 2001).

Restoration of forestlands particularly, has been implemented for several reasons, including refuges for biodiversity (Lamb et al., 2005), to reduce greenhouse gases emissions (Singh and Gupta, 2016) and carbon sinks (Van Rooyen et al., 2012), timber (Montes-Londoño et al., 2018), to reduce stream pollution, and upland plantings to reduce soil erosion and salinity (Cunningham et al., 2015). New forests can restore links among existing forest patch remnants, increase movement, increase gene flow and substantially increase effective population sizes of native species (Cunningham et al., 2015). Reforestation alone can restore biogeochemical cycling of carbon, oxygen, and nutrients, improve biodiversity, which can lead to increased primary production, reduced susceptibility to invasion by exotic species, and increase ecological resilience to pressures such as climate change (Van Rooyen et al., 2012). Trees sequester and retain more atmospheric carbon in their biomass than do crops or pastures, hence, reforestation can directly mitigate climate change by sequestering atmospheric carbon, both above and below ground (Cunningham et al., 2015).

There are several successful restoration and reforestation projects that have been initiated around the world over the past decades. For example, restoration of rainforest ecosystem in areas formerly deforested in Costa Rica, was initiated in order to increase the area of valuable habitat, and to provide important functions such as ensuring clean water supply (Janzen, 1988). Restoring surface-mined areas in forests in south-western Australia was implemented to return a forest ecosystem to the area and at the same time protect drinking water supplies and other functions essential in multiple-use forests (Koch and Vohland, 2004). There are numerous projects in which restoration and reforestation has being attempted around Africa, e.g.

restoration in Mount Elgon National Park in Uganda (Mupada, 1997); landscape approach to forest restoration and conservation in Rwanda; Community based rangeland rehabilitation for Carbon sequestration in Sudan (Dougherty et al., 2001); and the Participatory Environmental Management Programme (PEMA) in Tanzania (Scurrah-Ehrhart, 2006). There are also numerous projects in South Africa, e.g. Rehabilitation of coastal dunes and riparian areas at Port St John (King et al., 2005); habitat rehabilitation on coastal dune forest in northern KwaZulu-Natal (Van Aarde et al., 1996); rehabilitation of riparian areas in Letaba river (King et al., 2005); Platbos indigenous forest (Pepin, 2017); Buffelsdraai community reforestation project (Douwes et al., 2015); and KwaNibela Sandforest Reforestation Programme (DEA, 2019). These projects contribute to an understanding of how climate change might be stabilised, while boosting local biodiversity, and ensuring improved resilience of landscapes and people (Douwes et al., 2015).

To ensure that reforestation initiatives are achieving the intended goals, mostly being to recovery biodiversity loss, such initiatives need to be monitored (Kanowski et al., 2008). The monitoring of areas in process of forest recovery can be an important tool in the identification of ongoing human induced threats, therefore consistent monitoring of reforested landscapes measures the success of restoration subsequently after the restoration (Gerlach et al., 2013). However, there is a need to identify taxa suitable to use for monitoring of biodiversity recovery and the state of reforestation over time.

Invertebrates have been used extensively as bioindicator of restoration success as they are widely recognised in the context of detecting ecological change associated with human land use (Andersen et al., 2002).

1.2 Invertebrates as bioindicators of ecological restoration

Bioindicators commonly reflect the state of the environment (McGeoch 2007). These taxa or functional groups may act as early warning indicators of any environmental change to the local environment, or used to monitor a specific ecosystem stress, or used to indicate the levels of taxonomic diversity at a site (McGeoch, 2007; 1998). Bioindicators are also used for conservation prioritisation, monitoring of ecosystem recovery, or response to management (Gerlach et al., 2013). Invertebrates as bioindicators may reflect trends in species richness and community composition more accurately than vertebrates, as they are more diverse and abundant (Gerlach et al., 2013). Moreover, they may often be good environmental and ecological bioindicators as their small size makes them sensitive to local conditions, while their mobility enables them to move in response to changing conditions (Majer, 1983). Invertebrates constitute a substantial amount of species biodiversity and are also a functionally significant component of biodiversity (Chomicki and Renner, 2017; Andersen and Majer, 2004). Although invertebrates have been historically neglected in conservation and monitoring strategies (Cardoso et al., 2011), they are now becoming an important asset in the landscape ecology and conservation planning (McGeoch et al., 2011), and they have recently gained momentum as ecological bioindicators (Jamison et al., 2016).

Ants (Hymenoptera: Formicidae) in particular, are among the most diverse group of insects in the terrestrial ecosystem, and they have some of the highest number of species and biomass among invertebrates (Ward, 2007). Ants are good ecological bioindicators because of their diversity and functional importance (Del Toro et al., 2012). They perform important functions in ecosystems including nutrient cycling and biotic interactions, and they occupy many trophic levels ranging from predators and scavengers, to herbivores and omnivores (Del Toro et al., 2012). They are easy to collect and identify, they can be resampled due to stationary nesting habit and they respond quickly to habitat changes (Alonso and Agosti, 2000). Ants occur in high numbers across terrestrial environments, and due to their increasing knowledge of their taxonomy, they are widely recognised as bioindicator of ecological change associated with human land use (Costa-Milanez et al., 2015; Del Toro et al., 2012; Alonso and Agosti, 2000).

Over the past decades, ants have been used as indicators of restoration success by mining industry in various countries including Australia (Majer et al., 1984), Brazil (Majer, 1992), and South Africa (Majer and de Kock, 1992; Van Hamburg et al., 2004). They have been used as indicators of off-site mining impacts (Andersen et al., 2002) and other land uses such as commercial forestry (Andersen, 1997). They have been used to indicate disturbance levels (Paolucci et al., 2010; Thompson and McLachlan, 2007), rehabilitation success (Jamison et al., 2016), and management success (Souza et al., 2010). Furthermore, they may indicate invasive species (Yemshanov et al., 2011) and pollution (Pereira et al., 2010). Many other studies (Andersen and Majer, 2004; Adams and Fiedler, 2016) indicated that species richness, community structure and composition, of ants can be used as response variables in environmental monitoring, since they are sensitive to human activities, including agricultural practices and reforestation. Therefore, the study of ants is useful to assess the success of forest restoration practices (Gomes et al., 2014).

Although using ants as monitoring taxa is not a new approach, it has not yet gained momentum and recognition by policymakers and stakeholders to be considered among the priority taxa in conservation programmes in South Africa. Nonetheless, there are ongoing projects that have made contributions using ants in ecosystem monitoring in South Africa, such as Iimbovane Outreach Project (Braschler, 2009), western Soutpansberg Mountains (Munyai and Foord, 2012) and Rietvlei Nature Reserve (Jamison et al., 2016).

1.3 Study site description

Responses to the loss of biodiversity and ecosystem health include measures that aim to conserve biodiversity, and to ensure the sustainable use and equitable sharing of natural resources (Macfarlane et al., 2010). In response to biodiversity loss in South Africa, there has been several ongoing projects focus on restoring habitat loss, with the goal of returning or recovering of biodiversity loss. These projects include practical measures such as reforestation (Mugwedi et al., 2017), re-vegetation (Van den Berg, 2005), agroforestry (Sileshi et al., 2007), sustainable agriculture (Mpepereki et al., 2000) and other land management (Landman, 2004). The Buffelsdraai Landfill Site Community Reforestation Project is the example of a large, ongoing restoration project taking place outside the city of Durban in South Africa (Mugwedi et al., 2017; Douwes et al., 2015).

Durban is situated in one of the world's 35 Global Biodiversity Hotspots, namely the Maputaland-Pondoland-Albany corridor, and contains a variety of forest types including Northern Coastal Forest, Swamp Forest, Mangrove Forest, Eastern Scarp Forest, and Dune Forest (Douwes et al., 2015; Shih and Mabon, 2017). Therefore, interventions that would ensure full protection of elements of this hotspot and restoration of forests are essential, specifically for the recovery of lost biodiversity and sustainability of existing biodiversity.

The eThekwini Municipality implemented the Buffelsdraai Landfill Site Community Reforestation Project which is a flagship project that demonstrates numerous adaptation and mitigation co-benefits (Mugwedi et al., 2017). The Reforestation Project was initiated in 2008 with the action plan to alleviate the climate change impacts of hosting the Durban-based elements of the 2010 FIFA™ World Cup (Mugwedi et al., 2017; Douwes et al., 2015). The Buffelsdraai project area is situated largely within a Biodiversity Priority Area. The restoration of forest ecosystems was identified as a way of absorbing event-related greenhouse gas emissions, while enhancing the capacity of people and biodiversity to adapt to the inevitable effects of climate change (CCBA_PDD, 2011). The project offers new perspectives on how best to foster systemic and transformative change, through improved equity, social legitimacy and environmental sustainability in the climate-stressed cities of the 21st Century (Douwes et al., 2015).

Reforestation of the Buffelsdraai Landfill Site buffer zone took place on old agricultural lands, historically farmed (for over 100 years) with sugarcane **(**Mugwedi et al., 2017). Of the 787ha landfill site buffer zone, only some 580 ha under reforestation. Historically, the buffer area would have comprised a mixture of forest, grasslands, woodlands, wetlands and riparian areas (Mucina and Rutherford, 2006). Many of these original ecosystems are being restored, but it is acknowledged that it will be impossible to recreate the exact network of ecosystems that previously occurred on the site.

The project has already demonstrated that forest restoration, motivated by climate mitigation objectives, can provide direct socioeconomic benefits to surrounding communities, as well as enhanced ecosystem functioning (Douwes et al., 2015). The ecosystem services derived from the restored forests will also produce benefits such as enhancement of biodiversity refuges, and water quality, river flow regulation, flood mitigation, sediment control, improved visual amenity and fire risk reduction (CCBA_PDD, 2011). Such services enhance the long-term climate change adaptation benefits derived by local communities, as well as short-term resilience to dangerous weather patterns (Douwes et al., 2015).

1.4 Aims and objectives

This thesis aims to address three main objectives along a reforestation gradient that included sugarcane plantation (the recent landuse), and three states of reforestation progress (short, medium and long-term), as well as two reference habitats, natural grassland and natural forest: 1) To provide Checklist of epigaeic ants in a reforested landscape of Buffesldraai Landfill Conservancy, South Africa, 2) To determine how species diversity and composition differs along a reforestation gradient and 3) To identify which factors might underlie differences in ant diversity and composition along the reforestation gradient.

1.5 Thesis structure

This dissertation comprises of four chapters:

Chapter 1 (this chapter) is the general introduction with aims and objectives of the thesis and background information about the study area, Buffelsdraai Landfill Conservancy.

Chapter 2 provides the checklist of ground-dwelling ant species found in restored sites and reference sites. This checklist should serve as a baseline for monitoring the recovery of ant assemblages following a reforestation process.

Chapter 3 focuses on monitoring the response of ant species to reforestation, and describes the environmental variables driving the ant community structure found in Buffesldraai Landfill Conservancy. It also identifies the indicator species for different habitats sampled.

Chapter 4 is the final chapter, providing general discussion and conclusions, as well as recommendations.

Chapter 2 and 3 are intended for publication as peer-reviewed papers, and, as such, there is a degree of repetition in the thesis, as these have to stand alone for publication.

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CHAPTER 2: CHECKLIST OF EPIGAEIC ANTS IN BUFFESLDRAAI LANDFILL CONSERVANCY, SOUTH AFRICA

2.1 Abstract

Restoration of reclaimed land can provide a vehicle in the recovery of lost biodiversity. Inventories provide the basis to assess the relative success of restoration initiatives. Here we provide a checklist of ants sampled along a restoration gradient at the Buffesldraai Landfill Conservancy, KwaZulu-Natal Province in South Africa. Ants were sampled at eight sites along a restoration gradient which included sugarcane plantation (young and matured), natural grassland, and scarp forest and three different age restored sites, short-term (0-2 years), medium-term (3-5 years) and long-term (6-8 years). A total of 27 439 ant specimens comprising of 96 species in 31 genera, belonging to six subfamilies, were collected. Sample coverage estimator was higher than 0.97, indicating that inventory completion approximated most of the ant assemblages found in the study area. The most frequent subfamilies were Myrmicinae, Ponerinae and Formicinae and the most common genera were *Tetramorium*, *Pheidole* and *Monomorium* as the most species-rich genera. The most numerically dominant species were *Pheidole megacephala* species group (*Pheidole* UKZN_06 and *Pheidole* UKZN_11) and *Anoplolepis custodiens*. There was a higher number of predatory (35%) and honeydews (26%) foraging guilds present in the study site. The highest number of species were restricted to restored sites, followed by grassland and forest habitats.Respectively, this checklist provides baseline for monitoring the recovery of ant assemblages following a reforestation process.

Keywords: Reforestation, Ants (Hymenoptera: Formicidae), Epigeal, Inventory, Checklist, Invertebrates

2.2 Introduction

Reforestation of many degraded forested environments remain essential in the conservation of biodiversity and is considered both ecologically and economically valuable, worldwide. So far, the success of forest restoration practice has gained strong momentum in Australia (Majer et al., 2004; Andersen, 1993), and has been partially explored in South Africa **(**Pepin, 2017; Douwes et al., 2015; King et al., 2005). Forest restoration is vital especially in the African continent, where agricultural activities are perceived as a source of income and are continuously practised (Cunningham et al., 2015). Reforestation of previously cleared land has been perceived as the most promising practical solution by which biodiversity loss can be recovered (Hobbs and Harris, 2001). Following reforestation and restoration processes, these tree-dominated landscapes should be subjected to adequate monitoring, to measure restoration success and biodiversity recovery status (Gerlach et al., 2013). Therefore, there is a need for species inventories and checklists in reforested and restored areas that aid in monitoring and measuring the success of forest restoration practices.

The Buffelsdraai Landfill Conservancy Community Reforestation Project is an example of an ongoing restoration project, taking place in Durban, KwaZulu-Natal. The vegetation of the project belongs to the KwaZulu-Natal Coastal Belt (Mucina and Rutherford, 2006). The reforestation project was initiated by the eThekwini Municipality in 2008, as part of an action plan to alleviate the climate change impacts of hosting the Durban-based activities of the 2010 FIFA™ World Cup (Macfarlane et al., 2010). The project aims to offset carbon emissions over a 20-year period and increase climate change adaptation through biodiversity and ecosystem services restoration and employment creation (Mugwedi et al., 2017; Douwes et al., 2015). A large portion of the Buffelsdraai buffer zone that was under sugarcane cultivation, is currently rehabilitated from sugarcane lands to their original forested state (CCBA_PDD, 2011). The goal of the project is to establish a functioning, and indigenous woodland that would sequester atmospheric carbon over time and enhance the ecosystem functioning of the landfill site buffer zone (Macfarlane et al., 2010). This project provides an opportunity to investigate the fauna assemblage re/colonizing the reforested area and how the fauna respond to reforested habitats.

It is essential to have prior information about species involved in an area worth conserving before conservation measures can be practically implemented (Whitmore et al., 2002). If there is insufficient information about species involved then conservation measures put into place are not meaningful (De Wet and Shoonbee, 1991). Such insight can be obtained through inventories (Balmford and Gaston, 1999). Species inventories have been identified as crucial elements in identifying which species should be conserved (Venter and Conradie, 2015; Engelbrecht, 2010) and to synthesize biodiversity information (Aplin et al., 2001). Inventories would therefore contribute strongly to sustainable reforestation strategies.

Our knowledge of the South African invertebrate fauna is limited to a few contemporary contributions Mkambati Nature Reserve (Hamer and Slotow 2017), spider checklists from

Mkhambati Nature Reserve (Dippenaar-Schoeman et al., 2011), Polokwane Nature Reserve (Dippenaar et al., 2008) and Mountain Zebra National Park (Dippenaar-Schoeman, 2006), Ndumo Game Reserve (Haddad et al., 2006), Makalali Private Game Reserve (Whitmore et al., 2002) and Western Soutpansberg (Foord et al., 2002). Despite the dominance of epigeal ant fauna, very few checklists exist for ground-dwelling ants in South Africa, limited to the Limpopo Province, in the western Soutpansberg Mountain (Munyai and Foord, 2015) and in Marakele National Park (Schoeman and Foord, 2012). It is, therefore, the aim of this study to provide a checklist of epigaeic ant species in a reforested landscape of Buffesldraai Landfill Conservancy, KwaZulu-Natal Province, South Africa. This checklist should serve as a baseline for monitoring the recovery of ant assemblages following a reforestation process.

2.3 Methods and materials

2.3.1 Study area

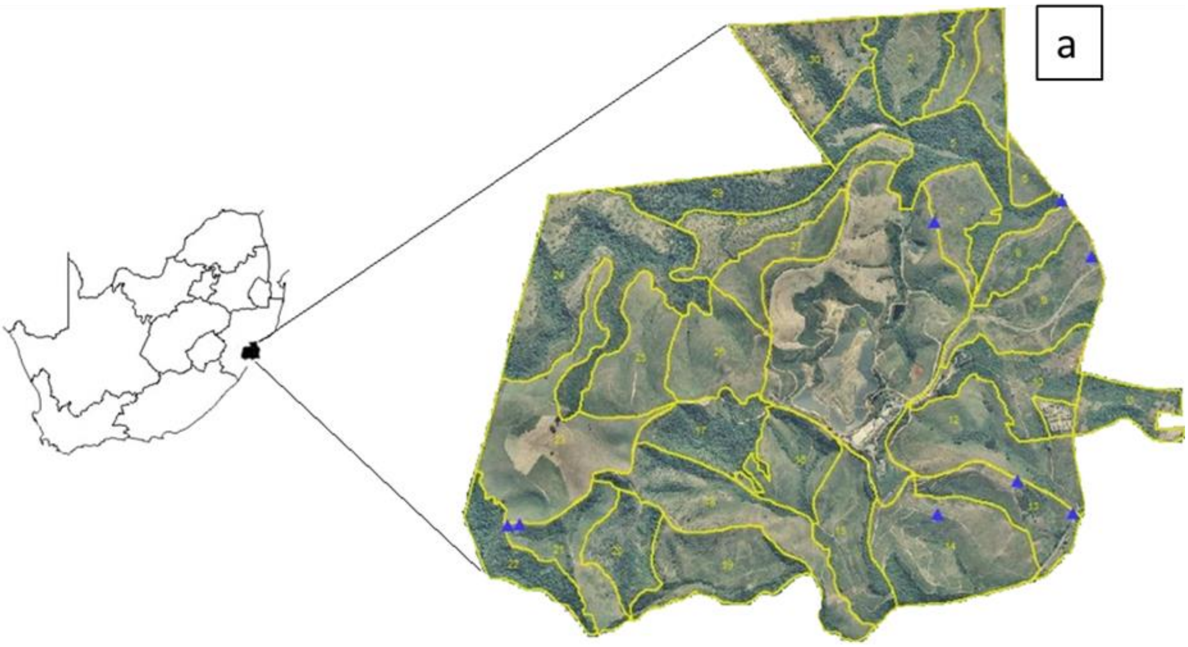
The study was conducted within Buffelsdraai Landfill Conservancy (29°38.068’S, 30°59.420’E), a regional waste landfill site owned and managed by the eThekwini Municipality, which is located 5 km west of Verulam and 25 km north of Durban, in KwaZulu-Natal South Africa (CCBA_PDD, 2011). Historically, the site was used for sugarcane production (Mugwedi et al., 2017; Douwes et al., 2015). The project area of 520.6 ha is in the buffer zone of the eThekwini Municipality owned Buffelsdraai Landfill Conservancy (CCBA_PDD, 2011). The zone around the project area includes commercial sugarcane operations, to the north while peri-urban communities occur to the west, south, and east of the Buffelsdraai Landfill Conservancy Community Reforestation Project area (Macfarlane et al., 2010).

2.3.2 Description of the study area

Annual rainfall in Verulam average at 766 mm per year, with most rainfall concentrated within a summer wet season (EPCPD, 2011) and peaks in the month of February. Temperatures average at 22.2°C in the winter months to 27.4°C in February (EPCPD, 2011). The forest type of the site is described as Coastal scarp and Dry Valley Thicket (EPCPD, 2011). Vegetation is broadly described as belonging to the KwaZulu-Natal Coastal Belt (Mucina and Rutherford, 2006). This is a highly transformed and fragmented vegetation type, with very little of the vegetation type formally protected (Macfarlane et al., 2010). Within the study area, vegetation varies considerably, with much of the area previously converted to sugarcane lands. Forest patches do still occur along south-facing slopes, while remnants of riparian forest occur along many of the drainage lines (Mucina and Rutherford, 2006). Some areas of woodland and grassland remained, but are highly restricted in their distribution (Mucina and Rutherford, 2006).

Geology in the study area is dominated by Dwyka Tillite deposited in a glacial environment by retreating ice sheets about 300 million years ago (Macfarlane et al., 2010). Soil is highly variable, ranging from deep, well drained red Hutton soil forms to shallow, poorly-drained Glenrosa soil forms (Water Research Commission, 1995). Topography is also highly variable, with a large stream, the Black Mhlasini, flowing through the northern section of the site and the White Mhlasini River flowing along the southern boundary. Between these rivers, elevations rise from 200-m, to 325-m above sea level along the ridge lines.

Eight sites, ranging from open grassland habitat to closed forest habitat were selected (Figure 1.1; 1.2). Site description are summarized in Table 1.1. Three sites represented a chronosequence of time since restoration (short- 0-2 years, medium- 3-5 years, and long-term 6-8 years). We included a mature scarp forest site, a natural grassland site as reference, and three transformed sites, young sugarcane (six months), mature sugarcane (over 8 years) and mature sugarcane invaded by indigenous trees (over 5 years).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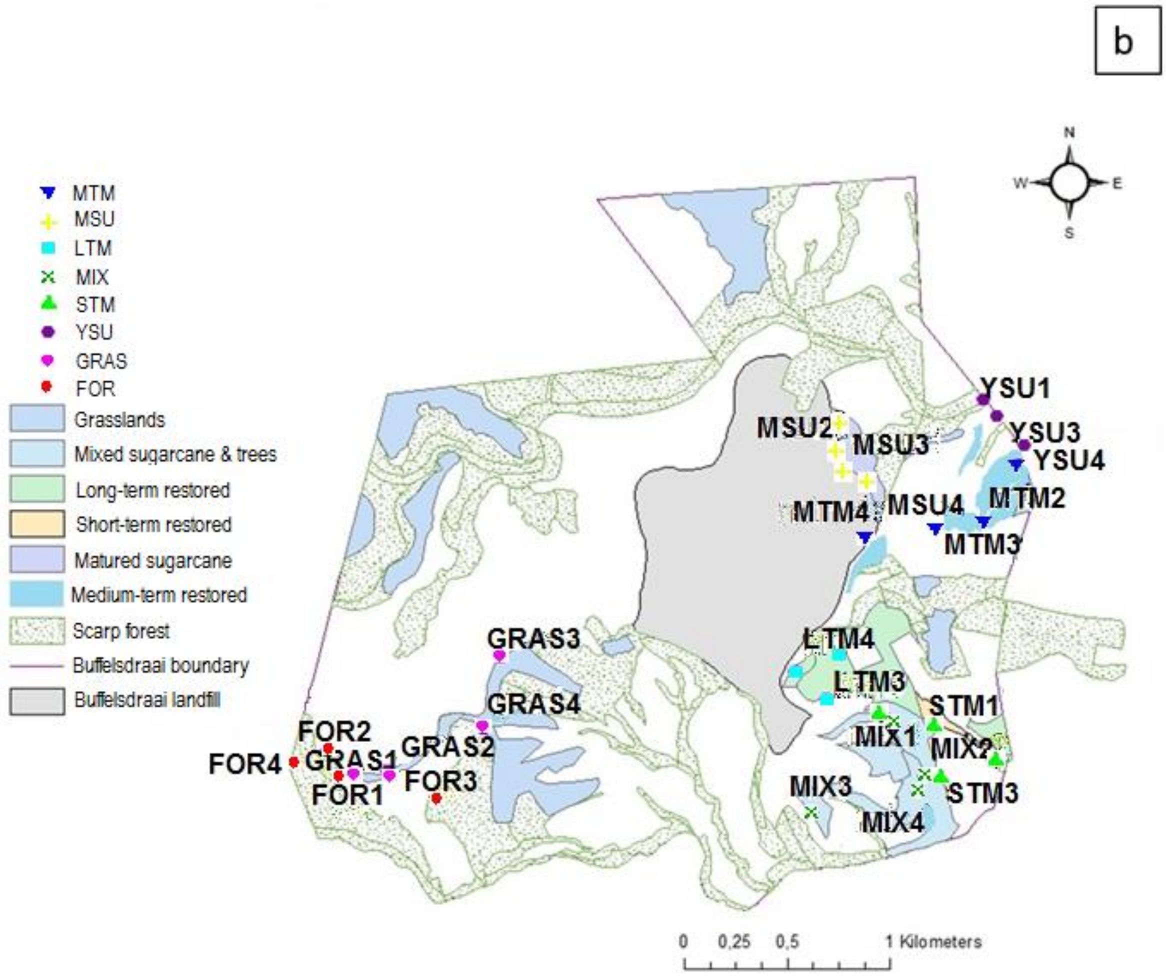

Figure 1.1 a) Map of South Africa showing position of Buffelsdraai Landfill Conservancy and map of Buffelsdraai Landfill Conservancy showing the eight selected sites (b) Map showing location of replicates for each sampled site. STM - Short-term; MTM - Medium-term; LTM – Long-term restored; FOR – Forest; GRAS – Grassland; MSU – Mature-sugarcane; YSU – Young-sugarcane; MIX – Mixed stands of sugarcane and trees.

2.3.3 Ant sampling

Ant sampling was conducted during two sampling periods, April-May 2017 (early dry season) and December 2017 (wet season). In each sampling period, ground-dwelling ants were sampled at the eight sites using standardized pitfall trapping method (Munyai and Foord, 2012; Agosti and Alonso, 2000). This method is easy and effective for ants sampling and can be used by non-specialists (Parr and Chown, 2001; Andersen, 1991). Four replicates, separated by at least 300 m, were set out within each of the eight sites. Within each replicate, 10 pitfall traps (50 mm diameter plastic jars) were laid out in a 2 X 5 grid with 10 m spacing in-between traps, totalling 40 pitfalls per site. These pitfall traps were partly filled with a 50% solution of propylene glycol as a preservative and killing agent. Pitfall traps were kept open for five consecutive days in the field, which is presume enough to allow sampling of representative ants (Lasmar et al., 2017; Munyai and Foord, 2012), and after five days trap catches were collected.

All specimens were sorted, enumerated and identified to species level where possible by the fourth author. Other species were identified to genus level and then assigned to morphospecies. Valid ant genera names were confirmed using Fisher and Bolton (2016). All voucher specimens were preserved in 70% ethanol and later pinned. A full collection of voucher specimens is held at the School of Life Sciences at the University of KwaZulu-Natal, Pietermaritzburg campus.

Table 1.1 Eight sampled sites with habitat description along with dominated vegetation type and their geographical coordinates and elevation observed in Buffelsdraai Landfill Conservancy during April-May and December 2017.

Sites	Habitat description	Dominant vegetation type (CCBA_PDD, 2011)	GPS: deg. S	GPS: deg. E	Elevation (m)
Short-term restored	Newly reforested site which is 0-2, dominated by indigenous tree species with pioneer species and some understorey species.	*Acacia karoo*, *Acacia robusta*, *Acacia sieberiana*, *Brachylaena discolor*, *Bridelia micrantha*, *Dalbergia obvata*, *Erythrina lysistemon*, *Ficus sur*, *Grewia occidentalis*, *Harpephyllum caffrum*, *Heteropyxis natalensis*, *Protorhus longfolia*, *Millettia grandis*, *Strelittia nicolai*, *Syzygium cordatum*, *Trichilia dregeana*, and *Ziziphus mucronata*.	29°38.068'	30°59.421'	173
Medium-term restored	Medium reforested site which is 3-5 years, dominated by indigenous tree species with understorey species.	*Acacia natalitia*, *Acacia nilotica*, *Agapanthus praecox subsp*. *Orientalis*, *Baphia racemosa*, *Bauhinia tormentosa*, *Chrysanthemoides monilifera*, *Clerodendrum glabrum*, *Combretum edwardsii*, *Croton sylvaticus*, *Dalbergia armata*, *Ficus glumosa*, *Maytenus peduncularis*, *Sclerocroton integerrimum* and *Succulent schefflera*.	29°37.382'	30°59.680'	155
Long-term restored	Oldest reforested site which is 6-8 years, dominated by indigenous tree species with understorey species and climax tree species	*Albizia adianthifolia var*. *adianthifolia*, *Sclerocarya birrea*, *Dombeya rotundifolia*, *Schotia brachypetala*, *Tabernaemontana ventricosa*, *Tecomaria capensis subsp*. *Infausta*, *Kigelia africana*, and *Scolopia zeyheri*.	29°38.163'	30°59.612'	134
Forest	Original Scarp forest dominated by climax tree species, this act as a reference site for the reforested sites.	*Albizia adianthifolia*, *Antidesma venosum*, *Burchellia bubalina*, *Calodendrum capens*, *Carissa bispinosa*, *Gardenia thunbergia*, *Schotia brachypetala*, *Vepris lanceolata*, *Maytenus heterophylla* and *Ochna natalitia*.	29°38.202'	30°57.641'	299

Young sugarcane	Reference site which is dominated by sprouting sugarcane, this is cut, burnt and grown every year.	Monoculture sugarcane plantation which is over six months.	29°37.212'	30°59.576'	140
Mature sugarcane	Reference site which is dominated by senescent sugarcane and alien species, this was last disturbed in 2006.	Very old sugarcane which is over eight years.	29°37.278'	30°59.128'	219
Mixed stands	Reference site which is dominated by a mixed senescent sugarcane and tree species	Mature sugarcane invaded by indigenous trees which is over five years.	29°38.166'	30°59.140'	210
Grasslands	Reference site which is an open grassland with rocky ridge, scattered shrubs and small trees.	*Themeda triandra* and *Aristida junciformis*.	29°38.196'	30°57.682'	309

A. Original scarp forest

B. Short-term restored

C. Medium-term restored

D. Long-term restored

E. Young sugarcane

F. Mature sugarcane

G. Mixed sugarcane and tree

H. Grassland

Figure 1.2. Eight selected sample sites in Buffelsdraai Landfill Conservancy. Images represent: (A) Original scarp forest; typical chronosequence of restoration: (B) short-term restored (0-2 years), (C) medium-term restored (3-5 years) and (D) long-term restored site (6-8 years). Unrestored reference sites: (E) young sugarcane (0-6 months); (F) mature sugarcane (> 8 years); (G) mature sugarcane invaded by indigenous trees (> 5 years) and (H) a natural grassland site.

2.3.4 Data analysis

To assess the inventory completeness within each of the eight sites, we used the sample coverage estimator (coverage-based rarefaction/extrapolation) described in Chao and Jost (2012), and the iNEXT online software program was used to run the analysis (Chao et al., 2016; Hsieh et al., 2013). Sample coverage measures sample completeness. Sample completeness is defined as the total relative abundances of the observed species, or equivalently, the proportion of the total number of individuals in an assemblage that belong to species represented in the sample (Chao et al., 2014). Chao and Jost (2012) suggested plotting rarefaction and extrapolation curves with respect to sample coverage rather than with respect to sample size because the expected species richness for equal sample coverage satisfies a replication principle or doubling property, which the expected species richness for equal sample size does not obey.

Ant species were assigned into different foraging guilds or foraging habits as described by Tshiguvho et al. (1999) and Mauda et al. (2018), and the following guilds were used: predators, scavengers, granivores (i.e. seed-collectors), honeydew and nectarivores (Simberloff and Dayan,1991; Lanan, 2014). These guilds were determined by a thorough inspection of mandibular morphology and through the knowledge of foraging strategy for the different genera (Mauda et al., 2018).

2.4 RESULTS AND DISCUSSION

In total, 27 439 ant specimens comprising of 96 species in 31 genera, belonging to 6 subfamilies, were collected (Table 1.2). Sample coverage was larger than 0.97, showing that the sample size was sufficient to represent the study site's ant communities (Figure 1.3; Table 1.4).

Myrmicinae was the most abundant and species rich subfamily, with 87% of the total abundance, 48 species (50%) of the total number of species, and 37% of the total number of genera (Table 1.2). The second most diverse subfamilies were Ponerinae, followed by Formicinae with 21% and 18%, respectively. The rarest subfamily was Pseudomyrmicinae with just one species and a single specimen.

Table 1.2 Checklist of ground-dwelling ants and each taxon abundance in Buffelsdraai Landfill Conservancy, KwaZulu-Natal province, South Africa. Msu – Mature-sugarcane; Ysu – Young-sugarcane; Mix – Mixed stands of sugarcane and trees; Stm - Short-term; Mtm - Medium-term; Ltm – Long-term restored; and Gra – Grassland.

Subfamily	Species / Morphospecies	Specimens collected per site							
		MSU	YSU	MIX	STM	MTM	LTM	GRAS	FOR
Dolichoderinae	*Tapinoma* UKZN_01	-	-	-	-	-	-	2	-
	Technomyrmex pallipes (F. Smith, 1876)	-	1	3	7	-	1	1	-
	Technomyrmex UKZN_01	15	3	3	4	1	2	8	9
Dorylinae	*Aenictus rotundatus* (Mayr, 1901)	-	-	150	11	-	-	-	-
	Dorylus helvolus (Linnaeus, 1764)	-	-	12	2	-	-	1	2
	Parasyscia UKZN_01	1	-	-	-	1	-	4	-
	Parasyscia UKZN_02	-	-	-	-	1	-	1	-
	Parasyscia UKZN_03	-	-	2	-	-	-	1	-
Formicinae	*Anoplolepis custodiens* (F. Smith, 1858)	57	36	-	-	308	-	862	-
	Camponotus maculatus (Fabricius, 1782)	2	3	-	1	3	4	3	-
	Camponotus UKZN_03	-	-	-	7	-	-	-	-
	Camponotus cintellus (Gerstaecker, 1859)	14	51	12	41	54	69	15	25
	Camponotus rufoglacus (Jerdon, 1851)	-	-	-	-	1	-	-	-
	Lepisiota UKZN_02 *(spinosior* gp.*)* (Forel, 1913)	-	1	1	6	1	1	1	-
	Lepisiota capensis (Mayr, 1862)	-	3	36	12	1	5	52	1
	Lepisiota crinite (Mayr, 1895)	-	-	-	5	-	-	-	-
	Lepisiota UKZN_01 *(capensis* gp.*)* (Mayr, 1862)	5	-	2	54	8	27	-	12

	Lepisiota UKZN_03 *(spinosior* gp.*)* (Forel, 1913)	-	-	-	-	2	4	-	-
	Lepisiota spinosior (Forel, 1913)	1	-	-	10	1	-	3	-
	Lepisiota UKZN_04 *(spinosior* gp.*)* (Forel, 1913)	-	-	-	-	-	-	1	-
	Nylanderia natalensis (Forel, 1915)	74	16	115	255	105	318	108	5
	Plagiolepis UKZN_02	-	-	-	6	-	1	4	-
	Plagiolepis UKZN_03	3	-	3	-	-	-	8	-
	Plagiolepis UKZN_04	-	1	-	-	-	-	-	-
	Polyrhachis (Myrmia) *schistacea* (Gerstaecker, 1859)	4	1	4	13	3	7	1	-
Myrmicinae	*Cardiocondyla* UKZN_03	1	-	-	13	5	5	3	-
	Carebara UKZN_01	-	-	-	1	2	-	-	-
	Crematogaster rectinota (Forel, 1913)	1	1	46	162	56	85	66	1
	Crematogaster UKZN_05	3	-	-	-	8	-	-	-
	Crematogaster castanea (Smith, F, 1858)	1	-	-	-	2	-	-	-
	Crematogaster UKZN_10	-	-	15	-	-	-	2	3
	Meranoplus UKZN_03	-	1	-	-	-	-	-	-
	Monomorium damarense (Forel, 1910)	2	5	11	17	25	8	12	-
	Monomorium UKZN_08	1	3	1	11	2	3	1	1
	Monomorium cf. drapenum (Bolton, 1987)	1	-	1	3	-	-	-	-
	Monomorium junodi (Forel, 1910)	14	32	65	47	149	63	100	23
	Monomorium UKZN_04	-	-	-	-	-	-	1	-
	Monomorium UKZN_08	-	1	-	-	-	-	-	-
	Monomorium UKZN_09	-	-	-	5	4	3	-	-
	Myrmicaria UKZN_01	25	203	14	6	1	1	-	4
	Nesomyrmex UKZN_01	-	-	-	-	2	-	-	-

Nesomyrmex UKZN_02	-	-	-	-	1	1	-	-
Nesomyrmex UKZN_03	-	-	-	-	-	-	-	1
Pheidole crassinoda (Emery, 1895)	-	2	-	-	41	1	1	9
Pheidole UKZN_06 *(megacephala* gp.*)* (Fabricius, 1793)	269	284	2294	5250	1335	6053	2076	-
Pheidole UKZN_07	17	65	41	140	130	117	452	152
Pheidole UKZN_08	8	32	30	39	79	23	4	-
Pheidole UKZN_09	3	16	36	26	62	32	-	8
Pheidole UKZN_10 *(liengmei* gp.*)* (Forel, 1894)	-	-	14	-	-	-	223	106
Pheidole UKZN_11 *(megacephala* gp.*)* (Fabricius, 1793)	-	-	-	10	-	-	45	1588
Pheidole UKZN_9	-	-	-	-	-	-	-	4
Solenopsis UKZN_01	8	2	5	61	52	66	7	1
Solenopsis UKZN_02	6	-	38	-	-	-	111	89
Strumigenys nr. *Faurei* (Arnold, 1948)	-	-	3	5	-	1	-	-
Tetramorium UKZN_04 *(squaminode* gp.*)*	2	1	-	-	2	-	54	56
Tetramorium UKZN_06 *(gabonense* gp.*)* (Andre, 1892)	-	92	-	-	14	1	102	-
Tetramorium UKZN_08 *(gabonense* gp.*)* (Andre, 1892) (Santschi, 1911)	-	-	-	-	17	-	-	-
Tetramorium UKZN_13	-	1	8	-	-	-	-	-
Tetramorium UKZN_19 *(squaminode* gp.*)* (Santschi, 1911)	-	-	-	2	-	8	16	-
Tetramorium notiale (Bolton, 1980)	3	8	13	23	25	14	23	1
Tetramorium setigerum (Santschi, 1918)	-	-	2	53	1	55	-	15
Tetramorium UKZN_02 *(sericeiventre* gp.*)* (Emery, 1877)	-	4	-	4	25	-	20	-
Tetramorium UKZN_07 *(simillimum* gp.*)* (F. Smith, 1851)	-	-	2	5	-	5	2	20

	Tetramorium UKZN_11 *(similimum* gp.*)* (F. Smith, 1851)	3	7	2	13	7	5	3	2
	Tetramorium erectum (Emery, 1895*)*	1	-	-	8	4	-	-	28
	Tetramorium UKZN_24 *(squaminode* gp.*)* (Santschi, 1911)	-	-	-	-	-	2	-	-
	Tetramorium UKZN_25 *(solidum* gp.*)*	-	-	-	1	-	-	2	1
	Tetramorium UKZN_26 *(squaminode* gp.*)* (Santschi, 1911)	-	-	-	-	-	-	-	2
	Tetramorium UKZN_27 *(squaminode* gp.*)* (Santschi, 1911)	-	-	3	-	-	-	-	4
	Tetramorium UKZN_28 *(setigerum* gp.*)* (Mayr, 1901)	-	-	-	-	-	-	-	92
	Tetramorium UKZN_29	-	1	2	-	-	-	-	-
	Tetramorium UKZN_30	1	-	5	-	-	-	2	-
	Tetramorium UKZN_31	-	-	-	1	-	-	1	-
	Tetramorium UKZN_33	1	-	-	-	-	-	-	-
Ponerinae	*Anochectus* UKZN_03	-	-	-	1	-	-	1	0
	Bothroponera cavernosa (Roger, 1860)	4	-	-	-	-	-	1	2
	Bothroponera UKZN_02	3	-	-	-	-	-	-	-
	Hagensia UKZN_01	-	-	-	-	-	-	1	-
	Hypoponera UKZN_01	-	-	-	2	-	-	-	-
	Hypoponera UKZN_02	1	-	-	-	-	-	-	-
	Hypoponera UKZN_03	-	-	4	-	-	-	-	-
	Leptogenys UKZN_01	8	-	34	8	6	59	29	30
	Leptogenys attenuate (Smith, F, 1858)	1	-	7	1	8	3	6	49
	Leptogenys intermedia (Emery, 1902)	1	1	-	-	-	-	-	-
	Leptogenys castanea (Mayr, 1862)	-	1	2	-	-	-	3	1
	Leptogenys UKZN_05	-	-	-	-	-	-	10	-
	Mesoponera caffraria (Smith, F., 1858)	26	-	-	1	37	5	3	3
	Mesoponera UKZN_01	18	6	11	7	8	-	6	-

	Mesoponera UKZN_01	-	-	-	-	-	2	-	-
	Mesoponera nr *sharpi*	-	-	-	2	2	-	-	-
	Mesoponera UKZN_06	-	-	-	1	-	2	-	-
	Mesoponera UKZN_07	1	-	6	-	-	-	2	-
	Paltothyreus UKZN_02	-	-	-	-	-	-	-	10
	Plectroctena mandibularis (F. Smith, 1858)	-	-	1	-	-	-	-	1
	Mesoponera UKZN_02	7	3	1	3	8	3	5	-
Pseudomyrmicinae	*Tetraponera natalensis* (F. Smith, 1858)	-	-	-	-	-	1	-	-
Activity		**617**	**886**	**3060**	**6367**	**2610**	**7066**	**4472**	**2361**
Richness_ S		**41**	**33**	**43**	**49**	**46**	**40**	**54**	**37**

Table 1.3 Species richness and abundance of ant subfamilies collected at the Buffelsdraai Landfill Conservancy, KwaZulu-Natal province, South Africa during April-May and December 2017.

Subfamily	Genera	Species	Richness (%)	Abundance (%)
Dolichoderinae	2	3	3	0.2
Dorylinae	3	6	6	0.7
Formicinae	6	17	18	11
Myrmicinae	11	49	51	87
Ponerinae	8	20	21	2
Pseudomyrmicinae	1	1	1	0.004

Table 1.4 Observed number of species (O_{bs}), individuals (activity), and sample coverage for each of eight sites sampled in Buffelsdraai Landfill Conservancy.

Sites	Obs	Activity	Sample coverage
Mature sugarcane	41	617	0.997
Young sugarcane	33	886	0.997
Mixed sugarcane and trees	43	3060	0.998
Short-term restored	49	6367	0.998
Med-term restored	46	2610	0.976
Long-term restored	40	7066	0.998
Grassland	54	4472	0.996
Forest	37	2361	0.996

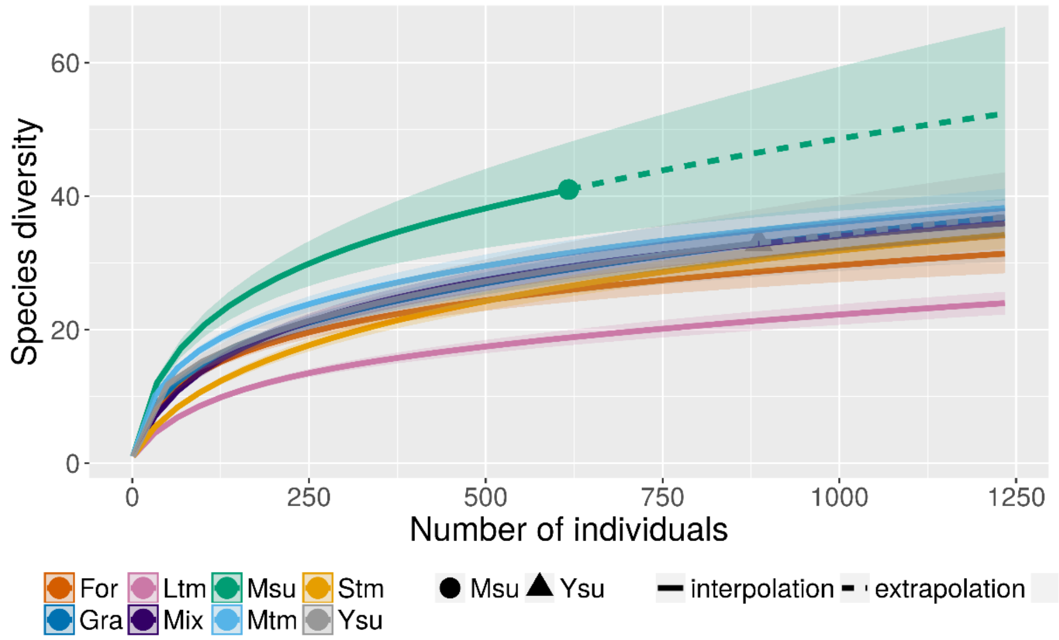

Figure 1.3 Sample-size based rarefaction (interpolation) curve indicating ant sample size coverage based on 8 sites sampled in Buffelsdraai landfill Conservancy in December 2017. For – Forest; Ltm – Long-term restored; Msu – Mature-sugarcane; Stm - Short-term; Gra – Grassland; Mix – Mixed stands of sugarcane and trees; Mtm - Medium-term; Ysu – Young-sugarcane.

SUBFAMILY DOLICHODERINAE

Commonly known as smelly odorous ants (Slingsby, 2017) and makes up to six percent of the known ant genera world-wide (Bolton, 2018). This subfamily consists of a small number of ground dwelling ants, but most species are associated with plants, and they nest and forage on leaf litter (Fisher and Bolton, 2016). Of the five genera recorded in South Africa, two (*Tapinoma* and *Technomyrmex*) were collected in this study.

Technomyrmex pallipes (Smith, 1876)

In KwaZulu-Natal, *Technomyrmex pallipes* has been recorded from Margate, Pietermaritzburg, Durban and Richards Bay (Bolton, 2018). The two species found in this study, *T. UKZN_01* and *T. pallipes*, occurred in almost all the habitat types sampled. *Technomyrmex pallipes*

(Pallid-footed ants), is referred to as a tramp species (Fernández and Guerrero, 2008) and is widespread (Bolton 2007). Species are differentiated by the bristles or setae position on the body. *Technomyrmex pallipes* is jet black, pale yellow legs with proportionally long and pointed gasters that hide the petiole (Slingsby, 2017). Antennae are filiform and petiole nodiform (Arnold, 1924). It has been collected in Escort, Hluhluwe and Boston in KwaZulu-Natal (AntWeb, 2018). *Technomyrmex pallipes* is indigenous in our region (Slingsby, 2017). They are known to colonize highly disturbed areas and predominate in plantations of tree and shrub crops (AntWeb, 2018). In this study it occurred in high abundant across all the sites sampled (Appendix A) but dominate in matured sugarcane and forest sites (Table 1.2).

SUBFAMILY DORYLINAE

Dorylines are a primitive ant sub-family (Fisher and Bolton, 2016) and are commonly known as Army ants, Driver ants, and Legionary ants (Slingsby, 2017) and they are almost entirely carnivorous (Borowiec, 2016). Doryline ants are characterized by their predation on other social insects which no permanent nests and colonies (Borowiec, 2016). Most species are hypogeic or cryptic, nesting and foraging in leaf litter, soil, wood and they also prey on social insects (Fisher and Bolton, 2016). Three genera *Aenictus*, *Dorylus* and *Parasycia* were observed in this study, and dominant taxa include: *Aenictus rotundatus* and *Dorylus helvolus*.

Aenictus rotundatus (Mayr, 1901)

Aenictus species are described as the true army ants (Borowiec, 2016), and are specialized predators of other ants (Dean and Turner, 1991). Of the species recorded in South Africa, *Aenictus rotundatus* (golden raider ant) was the only species found in this study. The body colour is golden red, and very shiny, with a pale gaster. The antennae are ten-segmented, with a shortened curved scape. This species has a long, yellowish pilosity on the petiole and gaster, and it is less regular and scantier on the head, scape and alitrunk (Slingsby, 2017). In KZN, this species has been collected in Ashburton, Nhlabane and Mkuze (AntWeb, 2018). *Aenictus* *rotundatus* preferred mixed stands of sugarcane and tree site, but also occurred in the short-term restored site (Table 1.2).

Dorylus helvolus (Linnaeus, 1764)

Dorylus has eleven species that have been recorded in South Africa, *Dorylus helvolu* was the only species collected in this study. *Dorylus helvolus* (the red driver ant) is bright red to orange-red in colour and is blind and aggressive (Slingsby, 2017). Apterous, mandibles are narrow edentate and antennae with 11 segments (Arnold, 1924). This species has been reported as the most abundant predator of cereal stemborers in South Africa (Kfir, 1997). It has been recorded in different areas around KZN including, Port Shepstone, Kokstad, Underberg, Boston, Mpophomeni, Ashburton, New Hanover, Mkuze, Mtunzini, and Richards Bay (AntWeb, 2018). *Dorylus helvolus* lives in large colonies with several individuals and known to invade domestic compost heaps (Slingsby, 2017). They are commonly found in montane rainforest, grassland and Afromontane forest edges (Bolton, 2018). It can be collected under stones, leaf litter and rotten log. Few individuals of this species were sampled in the forest, grassland, short-term restored sites but they preferred mixed sugarcane and trees (Table 1.2; Appendix A).

SUBFAMILY FORMICINAE

They are distributed across Afro-tropical Region (Bolton, 2018). Genera in this group consist of ants with nest-weaving behaviour (Johnson et al., 2003). Species are commonly found in the leaf litter and on low vegetation, and they nest in hollow stems, rotten wood, and in burrows of other insects (Fisher and Bolton, 2016). The current study collected six genera from this subfamily: *Anoplolepis*, *Camponotus*, *Lepisiota*, *Nylanderia*, *Plagiolepsis* and *Polyrhachis*.

Anoplolepis custodiens (Smith, 1858)

Seven species are known from South Africa but only *Anoplolepis custodiens* (pugnacious ant) was collected in the study. *Anoplolepis custodiens* has dark brick red sienna with dark brown gasters and silky reflective pubescence over all parts of the body (Slingsby, 2017). Gaster has five rows of hairs piled in different directions, refracting light and giving the gaster a bright appearance (Slingsby, 2017). *Anoplolepis custodiens* occurs very widely across southern Africa and may be the most abundant Camponotine species in South Africa (Steyn, 1954). In

KZN, *A. custodiens* has been collected in kokstad, Ixopo, Howick, Mkhomazi, Durban, Escourt, Nkandla and Mkuze (AntWeb, 2018). In the current study, this species was abundant in all the sites especially in medium-restored and grassland sites (Appendix A; Table 1.2). *A. custodiens* is a very aggressive ant and a major predator of indigenous insects (Addison and Samways, 2006). Parr (2008) reported *A. custodiens* as one of the dominant species that control ant assemblage in the Kruger National Park. It is also known to exhibit extreme dominance over other ant species especially in agricultural landscapes (Samways, 1999). In its natural habitat in the southern Karoo, this ant nests in open, well insulated soil and feeds on dead and live animal matter as well as honeydew and nectar (Dean, 1992). It is native to sub-Saharan Africa where it is considered a major indigenous pest in crop lands and orchards (Addison and Samways, 2006).

Camponotus cinctellus (Gerstaecker, 1859)

Componotus contains medium-sized to large, polymorphic ants (Koch and Vohland, 2004). They are reddish brown with shining pilosity on the gaster. *Componotus cintellus* (shiny sugar ant) is black with gaster that has dense and long pale golden pubescence present in uneven pattern (Slingsby, 2017). It has been collected in KwaZulu-Natal in areas such as Mkhambati, Port Edward, Margate, Harding, Boston, Impophomen, Durban, Mtunzini, Mkuze and St Lucia (AntWeb, 2018). It has also been collected in grasslands, Eastern Coastal Belt Forest, Savannah, savannah woodland and montane rainforest (Bolton, 2018). In the present study, *C. cintellus* occurred across all habitat types (Appendix A), but dominated in young sugarcane, medium-term and long-term restored sites (Table 1.2).

Lepisiota capensis (Mayr, 1862)

This species is widely distributed in Afro-tropical Region: Ghana, South Africa, and Zimbabwe (Bolton, 2018). Of the 14 known species from genus *Lepisiota* in South Africa five species occurs in KZN: *Lepisiota capensis*, *Lepisiota crinita*, *Lepisiota incisa*, *Lepisiota spinosior* and *Lepisiota spinosior natalensis*. *L. capensis* (small black sugar ant) species are small, all shiny black and their antenna are dark brown. First joint of flagellum is longer than the second (Slingsby, 2017). They have blunt spines on the propodeum (Arnold, 1924). *Lepisiota capensis* occurrence has been sampled in KZN areas such as Kokstad, Bulwer, Howick and Escourt

(AntWeb, 2018). *Lepisiota capensis* is a ficus tree species (Schatz et al., 2008), and is considered as an occasional pest in urban and agricultural areas of Southern Africa (Prins et al., 1990). It is described as nectarivore and scavenger (Tshiguvho et al., 1999). It is commonly found in grassland, bushveld, woodland and thornveld (Bolton, 2018). It nests under stones, leaf litter and foraging on the ground. *Lepisiota capensis* was present in almost all the sites except for the matured-sugarcane site and was mostly abundant in the grassland site (Appendix A; Table 1.2).

Nylanderia natalensis (Forel, 1915)

Nylanderia species are found throughout Africa and most species in the equatorial rainforests (LaPolla et al., 2011). *Nylanderia boltoni* and *Nylanderia natalensis* are two species collected in South Africa (AntWeb, 2018). *Nylanderia natalensis* is overall brown, cuticle smooth and shining, covered with dense pubescence, but mesopleuron and propodeum with sparser pubescence (Arnold, 1924). *Nylanderia natalensis* was collected in this study and has also been recorded in Durban, Umtamvuna Nature Reserve and Port Edward in KZN (LaPolla et al., 2011). This species is very abundant across all sites in Buffelsdraai but mostly in all the restored sites and grassland (Appendix A; Table 1.2).

SUBFAMILY MYRMICINAE

The Myrmicines are the largest ant subfamily (Slingsby, 2017; Fisher and Bolton, 2016). Most species from this subfamily are considered generalist omnivores, however some have become specialized as predators, granivores, or fungus-growers. They are distributed across Afro-tropical Region (Bolton, 2018). The study sampled 10 genera belonging to this subfamily: *Cardiocondyla*, *Carebara*, *Crematogaster*, *Meranoplus*, *Monomorium, Myrmicaria*, *Pheidole*, *Solenopsis*, *Strumigenys* and *Tetramorium*. Some of the notable collected species and genera collected in this subfamily include: *Monomorium junodi*, *Myrmicaria natalensis*, *Pheidole*, and *Tetramorium*

Monomorium junodi (Forel, 1910)

This species is distributed in Southern Africa (Botswana, South Africa, and Zimbabwe). Its distribution in South Africa includes Mpumalanga, Limpopo and Gauteng (AntWeb, 2018).

Monomorium Junodi (Junod's pharaoh ant) is dark brown with pale legs. May be distinguished from *M. albopilosum* by the thicker fist node and short peduncle (Arnold, 1924). It has no spines on the propodeum. It has a shining gaster with fine white pilosity (Arnold, 1924). This species has not been collected in KZN, and is only found in Mpumalanga. It nests in the ground under a large, low mound (Slingsby, 2017). It is commonly collected in grassland, open woodland, dry forest, savanna, acacia Thicket, and closed forest. This species occurred in high numbers across all sites (Appendix A) and was very abundant in restored and grassland sites (Table 1.2).

Myrmicaria natalensis (Smith, 1858)

Myrmicaria natalensis (Natal droptail ant) is shiny with dark brown antennae, gaster and legs (Slingsby, 2017). *Myrmicaria natalensis* has seven antennae. Head, thorax and petiole dark red to brownish red; gaster, legs and antennae darker brown to almost black and shiny. It has double-jointed petiole and hanging gaster (Arnold, 1924). It is very aggressive and live in large underground nests (Slingsby, 2017). In KZN it has been collected in areas such as Durban, Richards Bay and Hluhluwe (AntWeb, 2018). *Myrmicaria natalensis* is a savannah ant and tend to have very large colonies (Slingsby, 2017). This species is highly predaceous and is reported to attack insect pests such as *Heliothis armigera* (Samways, 1982). This might explain its dominance in the sugarcane plantation and complete absence in the grassland site (Appendix A; Table 1.2). *Myrmicaria natalensis* usually builds nests of large size which are beneficial to the species, as the nearby nests of competitive species are smothered by continual dumping of soil particles by workers of this species (Samways, 1982).

Pheidole

Pheidole is a world-wide genus that probably includes over a thousand species (Bolton, 2018). The genus is easily recognized by the presence of huge-headed major workers. Most species are predators in this genus, but they also feed on honeydew. They tend to be dominant over other species (Parr and Chown, 2001; Parr, 2008). The most common and troublesome species group is *Pheidole megacephala*. This species group was the most dominant in all sites and was present in high numbers compared to all other species. Species from this group tend to be more common in open and disturbed habitats (mostly heavily disturbed anthropic areas) with weedy vegetation that can support high densities of the plant-feeding Hemiptera that ants tend to use for honeydew scale insects and aphids. *Pheidole Megacephala* species are reddish brown with darker gaster and two yellowish spots on either side of the first gaster segment. They are very aggressive towards other ant species and have a major impact on indigenous insects (Hoffmann and Parr, 2008). Colonies of *P. megacephala* are strongly territorial and exclude other dominant territorial ants (Wetterer, 2007). *Pheidole Megacephala* species spread by colony-budding, leading to huge, interconnected nests that overwhelm most other ant species (Lawes et al., 2017). *Pheidole Megacephala* species can be an important agricultural pest of many crops, including pineapple, sugarcane, bananas, coffee and coconuts through enhancing populations of the plant-feeding Hemiptera such as mealybugs **(**Goebel et al., 1999). *Pheidole* UKZN_06 (*megacephala* gp.) and *Pheidole* UKZN_11 (*megacephala* gp.) were the two species collected in the current study. Surprisingly, *Pheidole* UKZN_06 (*megacephala* gp.) dominated all the sites but was completely absent from the forest site while *Pheidole* UKZN_11 (*megacephala* gp.) and *Pheidole* UKZN_10 (*liengmei* gp.) only dominated the forest habitat (Appendix A; Table 1.2). Other *Pheidole* species such as *Pheidole* UKZN_07, were very abundant across all the sites. The dominant species from this genus are known to control ant assemblages in the habitats that they occupy (Parr, 2008).

Tetramorium

It is one of the world's largest genera of ants (Slingsby, 2017), and it is the most speciose genus in the present study. Most *Tetramorium* species are small and obscure ants with 11 or 12 segmented antennae and at least one pair of spines on the propodeum. They have a distinctly thickened first or second petiole node (Arnold, 1924). *Tetramorium* species are collected in different habitats, including Afrotropical forest, arid savanna and desert (Slingsby, 2017). Their nests are common in the ground, forest litter, and under bark (Slingsby, 2017). Species ranges from carnivorous hunters or scavengers to granivores (Slingsby, 2017). There are over 80 species collected in South Africa from this genus (AntWeb, 2018) including the three species found in this study: *Tetramorium erectum* (forest fierce ant), *Tetramorium notiale* (southern fierce ant) and *Tetramorium setigerum* (hairy fierce ant). *Tetramorium erectum* is uniform dark with pale appendages and dorsum with strong hairs. *Tetramorium notiale* is uniform bright yellow or orange brown, lighter gaster, with head and body dorsum with long hair. *T. setigerum* is uniform dark brown with distinct shallow scrobes. In this study, *Tetramorium* species were not dominant in any of the habitats, and only occurred in few numbers in different habitats (Appendix A; Table 1.2).

SUBFAMILY PONERINAE

Ponerine is a diverse group of ants and is distributed in the tropics. Species from this sub-family show predatory habits although few others are also scavengers. They are distributed across Afrotropical Region (AntWeb, 2018). Ponerine ants are usually large and mostly carnivorous. They tend to hunt on other insects and small invertebrates (Slingsby, 2017). In South Africa, 18 genera had been collected and 13 occurs in KZN (AntWeb, 2018). The current study collected 9 genera belonging to this subfamily: *Anochectus*, *Bothroponera*, *Hagensia*, *Hypoponera*, *Leptogenys*, *Mesoponera*, *Paltothyreus*, *Plectroctena*, and *Pseudoponera*. The following species were collected in this subfamily and some had significant influence on ant assemblages of the study.

Leptogenys attenuata (Smith, 1858)

Leptogenys attenuata (blue razor jaw ant*)* are specialist predator of termites, earthworms, and isopods (Slingsby, 2017). It is black with blue reflections, with narrow or elongated mandibles, crossing each other and enclosing a large space between them and the clypeus (Arnold, 1924). It has been collected in Hilton and Escourt in KZN (AntWeb, 2018). This species was abundant in forest site and declined in sugarcane sites. *Leptogenys* UKZN_01 was also abundant in forest and mixed sugarcane and trees and only few individuals were found in other sites (Table 1.2; Appendix A).

Mesoponera caffraria (Smith, 1858)

There are only four species collected in South Africa *Viz*. *Mesoponera ambigua*, *Mesoponera caffraria*, *Mesoponera elisae* and *Mesoponera elisae rotundata* (AntWeb, 2018). This study collected *Mesoponera caffraria* and *Mesoponera* UKZN_01 (Table 1.2). *Mesoponera caffraria* (small foul ringbum ant) is long with a dull black body, with dark red mandibles and large stings (Slingsby, 2017). Mesonotum and scutellum are together. Dordum of epinotus are short not as long as scutellum (Anorld, 1924). Species of this genus are commonly found in small colonies nesting in the ground, under the tree bark and leaf litter (Slingsby, 2017). *Mesoponera* *caffraria* has been collected in Bulwer, Ixopo, Durban and Mkhomazi in KZN (AntWeb, 2018). Based on the current study, species from this genus tend to prefer sugarcane plantation over other habitats (Table 1.2; Appendix A). One individual of *M. caffraria* was only collected in Young sugarcane while *Mesoponera* UKZN_01 dominated Matured sugarcane (Table 1.2).

SUBFAMILY PSEUDOMYRMECINAE

They are distributed in Afrotropical Region (Bolton, 2018). Most species have generalized twig nesting habits, occupying dead stems and branches of many kinds of plants (Ward and Downie, 2005). Most species of this subfamily prefer forested environment and open fynbos (Slingsby, 2017). *Tetraponera* is the only genus collected in South Africa and has been collected in areas such as Port Edward, Durban, Escourt, Mtubatuba, St Lucia, Hluhluwe, Richards Bay and Mbazwana in KZN (AntWeb, 2018). We found one species belonging to this genus:

Tetraponera natalensis (Smith, 1858)

Tetraponera natalensis (Natal slender ant) is yellow or red with darker apex to gaster (Slingsby, 2017). It has large eyes set slightly behind the midline of the head. The thoracic area has a distinct margin (Arnold, 1924). It is recognised by the sharp margination on the pronotum, which extends to the propodeum and petiole. It has the medium notch on the posteroventral margin (Philips, 2006). In South Africa, *T. natalensis* is distributed in Western Cape, Eastern Cape, KwaZulu-Natal, Mpumalanga, and Limpopo (AntWeb, 2018). It has been collected mainly in Durban, Richards Bay and Hluhluwe in KZN (AntWeb, 2018). This species is common in savanna woodland and usually nests in dead twigs (Slingsby, 2017). We only found one individual which occurred in Long-term restored site.

Diversity patterns

Eleven ant species out of the 96 were found in all eight habitats types. These species were: *Camponotus cintellus*, *Crematogaster rectinota*, *Monomorium junodi*, *Monomorium* UKZN_08, *Myrmicaria natalensis*, *Nylanderia* UKZN_02, *Pheidole* UKZN_07, *Solenopsis* UKZN_01, *Tetramorium notiale*, *Tetramorium* UKZN_11 (*similimum* gp.) and *Technomyrmex pallipes* (Appendix B). The most species-rich genera were *Tetramorium* (20 species), *Pheidole* (8 species), and *Monomorium* (7 species). The most numerically dominant species were

Pheidole megacephala species group e.g. *Pheidole* UKZN_06 (*megacephala* gp.) (64% of the total abundance), *Pheidole* UKZN_11 (*megacephala* gp.) (6% of the total abundance) and *Anoplolepis custodiens* (4.5% of total abundance). Amongst all other species, two *Pheidole* species (*megacephala* gp.) were noticeably abundant almost across all sites (Appendix B). For instance, the dominant Myrmicinae *Pheidole* UKZN_11 (*megacephala* gp.) accounted for 67% of the total pitfall catches in the forest habitat. Although *Pheidole* UKZN_06 (*megacephala* gp.) was not found in the forest habitat, this species was present in all other sites. This species alone represented a total abundance of 83% in short-term, 51% in medium-term and 86% in long-term restored sites. In sugarcane plantation it accounted for 44% and 32% in mature and young sugarcane while in other reference sites this species represented a total catch of 76% in mixed sugarcane and trees, and 46% in grassland.

We found five species that were restricted to grassland habitat, namely: *Hagensia* UKZN_01, *Lepisiota* UKZN_04 (*spinosior* gp.), *Leptogenys* UKZN_05, *Monomorium* UKZN_04 (*salomonis* gp.) and *Tapinoma* UKZN_01. This was followed by forest habitat with four species: *Nesomyrmex* UKZN_03, *Paltothyreus* UKZN_02, *Tetramorium* UKZN_26 (*squaminode* gp.) and *Tetramorium* UKZN_28 (*setigerum* gp.). Of the eight species found only in restored sites, three species were found only in short-term restored: *Camponotus* UKZN_03, *Hypoponera* UKZN_01, *Lepisiota crinita*; three species in medium-term restored: *Camponotus rufoglacus*, *Nesomyrmex* UKZN_01 and *Tetramorium* UKZN_08 (*gabonense* gp.); and two species in long-term restored site: *Tetraponera natalensis* and *Tetramorium* UKZN_24 (*squaminode* gp.). Matured sugarcane had three species found only there: *Bothroponera* UKZN_05, *Hypoponera* UKZN_02 and *Tetramorium* UKZN_33; while young sugarcane site also had two unique species: *Meranoplus* UKZN_03, *Plagiolepis* UKZN_04. Mixed sugarcane and tree species had one species, *Hypoponera* UKZN_03. There was a considerable amount of predatory species (35%) followed by honeydews (26%) while scavengers, granivores and nectarivores had relatively equal propositional representation (Appendix B).

There are nine ant subfamilies and 89 genera that have been collected in South Africa (AntWeb, 2018; Bolton, 2018). In this study, we found six subfamilies. Three subfamilies, Myrmicinae, Ponerinae, and Formicinae made up the most ant species richness and abundance found in Buffelsdraai Landfill Conservancy. Likewise, the three most common subfamilies in the present study, Myrmicinae, Ponerinae, and Formicinae, are the most frequent and comparable to studies conducted in South Africa. Schoeman and Foord (2012) collected 87% ant abundance and 61% of all species in subfamily Mymicinae, and 18% of the total species richness in Formicinae. Munyai and Foord (2015) reported similar results where Mymicinae was the richest subfamily comprising 86% of the total abundance with 72 species of the 133 total numbers of species. This was followed by Formicinae with 27 species. Myrmicinae and Formicinae are the largest ant subfamilies, and the dominant ant groups in most terrestrial habitats (Marsh, 1986). Myrmicinae alone contributed 87% of the total abundance and 51% of the total species richness and the three most species-rich genera (*Tetramorium*, *Pheidole* and *Monomorium*) were from this group. Across various habitat types in South Africa, Mymicinae is the most abundant and diverse subfamily (Munyai and Foord, 2012; Majer and De Kock, 1992; Marsh, 1986). Most ants from this subfamily have the advantage of having a wide variety of feeding and nesting habitats (Slingsby, 2017; Soares et al., 2013).

Anoplolepis custodiens and *Pheidole* species are among the other dominant species identified by Parr (2008), as the behavioural and numerical dominant and they are known to exhibit extreme dominance over other ant species (Samways, 1999). With their aggressive behaviour, large colonies and nest, these dominant species are known to out-compete and control ant assemblage species richness in the habitats they occupy (Parr, 2008). Both species are thought to have played a major role in structuring ant assemblages in Buffelsdraai. Our results also showed that *Pheidole* was most abundant and this conforms to the findings by Wilkie et al. (2010) who reported *Pheidole* as the most diverse genus on the ground which is driven by the availability of nesting sites.

There are several factors that could explain the distribution and restriction of some species to particular habitats which includes habitat resources and nesting areas available and intensity of competition from dominant species. For example, most species which were found in sugarcane plantations are mainly predatory species (e.g. *Anoplolepis custodiens*, *Mesoponera caffraria*, *Myrmicaria natalensis*, and *Pheidole* species) and sugar ants (*Camponotus* and *Nylanderia* species), this could indicate that food resources were the main drivers of the ant species to sugarcane plantation. Moreover, the higher number of predators in Buffeldraai could potential indicate that the vegetation structure and arthropod fauna, has reached the degree of establishment necessary to support the specialized diet of these predators (Jamison et al., 2016). The latter has been noted by various ecological studies (Mauda et al., 2018; Hoffman and Andersen, 2003) that predators are likely to be among the last colonizer species due to their diet. However, this study mainly focusses on the checklist of ground-dwelling ant species and not underlying factors and variables which govern differences in the ant patterns and restriction of certain species to different habitats.

Our results provide a first checklist of ant species composition in a reforested landscape under eThekwini Municipality in Durban. This checklist serves as a solid basis of knowledge on the distribution of ant fauna and it provides a useful taxonomic tool for future biodiversity monitoring and for any follow up future research on the success of reforestation in the study area.

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CHAPTER 3: RESPONSE OF ANT ASSEMBLAGES TO A REFORESTATION GRADIENT IN BUFFELSDRAAI LANDFILL CONSERVANCY, KWAZULU-NATAL

3.1 Abstract

There is a growing interest in the potential of reforestation to support the recovery of biodiversity. Studies examining how biodiversity responds following restoration may provide guidelines towards a successful recovery process. This study was conducted in Buffelsdraai Landfill Conservancy, a landscape historically used for sugarcane production that has been reclaimed for restoration. The main objective of the project is that of Carbon sequestration, however it simultaneously ensures the recovery of biodiversity loss during land-use change. There is conflict that needs to be explored between reforestation for carbon sequestration and/or for biodiversity conservation. Using a standardised pitfall survey, we assessed how ants responded to reforested habitats of different ages, relative to natural grassland, forest and different sugarcane stands, as well as to determine the environmental variables which underlie differences in ant diversity and composition along the reforestation gradient. Surveys of structure and soil were conducted at each replicate/grid. Species richness significantly decreased with increasing bare-ground cover. Both species richness and abundance were lowest in sugarcane plantation and forest sites and highest in restored and grasslands sites. Ant assemblages differed significantly across all sites, with forests having the most distinct assemblages. Four predictor variables (leaf litter, vegetation structure, canopy cover and bare ground cover) had major influences on ant assemblage structure. Four forest indicator taxa were identified (*Pheidole* UKZN_11 (*megacephala* gp.), *Tetramorium* UKZN_04 (*squaminode* gp.), *Tetramorium* UKZN_28 (*setigerum* gp.) and *Leptogenys attenuate*), and one indicator for grassland (*Lepisiota capensis*). No indicators were found for sugarcane sites. However, *Solenopsis* UKZN_01 and *Pheidole* UKZN_09 were potential indicators for restored sites. The restoration sites were transitioning from sugarcane plantation, and were drawing most of their colonisation from grasslands. Our results showed that biodiversity benefits can be increased more if the restoration sites are kept as open woodlands with grass later in between them. Importantly, we demonstrated the importance of grasslands as a source of diversity to colonise the restored habitats.

Keywords: Restoration, Biodiversity, Bioindicators, Invertebrates, Ants, Pitfall

3.2 Introduction

Well-functioning ecosystem can ensure continuous provisioning of services to people, such as economic (e.g. timber, fuelwood, food and bio-products), socio-cultural (e.g. homes to human, recreation, and tourism), and ecological (e.g. carbon storage and sequestration, conservation of biodiversity, nutrient cycling, water and air purification) services (FAO, 2018).

Finding a practical solution to climate changes and biodiversity loss is the topic of interest so far (Beaudrot et al., 2016). Restoration of a degraded ecosystem is viewed as viable solution from which these issues can be resolved (Hall et al., 2012; Strassburg et al., 2010). Reforestation of previously cleared land particularly, has the potential to mitigate climate change by reducing greenhouse gas emissions (Singh and Gupta, 2016; FAO, 2018), and simultaneously conserving biodiversity (Lamb et al., 2005). However, there is conflict between reforestation for biodiversity conservation and for carbon storage. For instance, Dybala et al. (2018) found that biomass carbon stocks positively related to high stand density from which bird's density and diversity suffers greatly. Cunningham et al. (2015) also reported a positive relationship between biomass carbon stock and stand densities. However, there is reduced habitat quality at high stand densities (Horner et al., 2010). Beaudrot et al. (2016) found that carbon stocks were not a significant predictor of any diversity measures. Biodiversity benefits would not be maximized through projects that prioritize carbon stocks alone, unless biodiversity is explicitly considered, and vice versa (Beaudrot et al., 2016). Therefore, reforestation projects that aim to address both climate change and biodiversity loss should pay attention to the design of the project to avoid the trade-off between the two ecosystem services, carbon sequestration and biodiversity.

EThekwini Municipality, South Africa, initiated the Community Reforestation Project in 2008 at the Buffelsdraai Landfill Conservancy. Reforestation of the Buffelsdraai Landfill buffer zone took place on old agricultural lands, historically planted with sugarcane for over 100 years (Macfarlane et al., 2010). Historically, the buffer area would have comprised a mixture of forest, grasslands, woodlands, wetlands and riparian areas (Mugwedi et al., 2017; Douwes et al., 2015). Many of these original ecosystems are in the process of restoration, but it is acknowledged that it will be impossible to recreate the exact network of ecosystems that previously occurred on the site (CCBA_PDD, 2011). The project was implemented mainly to alleviate the climate change impacts of hosting the Durban-based elements of the 2010 FIFA™

World Cup (Macfarlane et al., 2010). The restoration of forest ecosystems was identified as a way of absorbing event-related greenhouse gas emissions, while enhancing the capacity of people and biodiversity to adapt to the inevitable effects of climate change (CCBA_PDD, 2011). The Buffelsdraai project area is situated largely within a biodiversity priority area (Macfarlane et al., 2010), hence, it also provides an opportunity to investigate the response of fauna assemblage restoration initiatives.

There is a growing interest in the potential for reforestation to assist in the recovery of faunal biodiversity (Piper et al., 2009; Bowen et al., 2007). Although recent reforestation developments of degraded forestlands are largely implemented as way to mitigate climate changes (Canadell et al., 2008), they may also be used as a practical way to recover and protect biodiversity (Hobbs and Harris, 2001; Hobbs and Cramer, 2008). They can prevent further loss of species caused by deforestation, while simultaneously ensuring the improved supply of ecosystem services (Bremer and Farley, 2010).

Studies showing how biodiversity responds following restoration are needed, as they may serve as a guideline towards a successful ongoing recovery process (Segat et al., 2017). The responses of particular species may be useful as this may reflect the state of ecological changes associated with disturbance, and these species could be used as bioindicators (McGeoch, 2007; 1998). Invertebrates are potential bioindicator of restoration success as they are broadly used for monitoring ecological change associated with human land use (Andersen et al., 2002). Ants (Hymenoptera: Formicidae) particularly, are an ecologically dominant faunal group, and are widely advocated as ecological indicators (Lawes et al., 2017). The importance of ants in ecosystems is well recognized, they have repeatedly been used as indicator of restoration success in the mining industry in different part of the world, including Australia (Majer et al., 1984), Brazil (Majer, 1992) and South Africa (Majer and de Kock 1992, Van Hamburg et al., 2004). They have also been used in other land uses such as forestry (Andersen, 1997).

Here we investigated the trade-off between a focus on carbon sequestration and biodiversity in remnant and reforested landscape of Buffelsdraai Landfill Conservancy, South Africa. Specifically, we want to know what impact reforestation, with the main focus on carbon sequestration, has on biodiversity. We used ants to measure and monitor the extent to which reforestation can support fauna diversity. The present study aimed to address the following objectives: (1) to determine how ant species diversity and composition differ along a reforestation gradient, relative to reference natural grassland and forest, and to different stages of sugarcane production; and (2) to determine the environmental variables which underlie differences in ant diversity and composition along this reforestation gradient.

3.3 Materials and methods

3.3.1 Study area

The study was conducted within Buffelsdraai Landfill Conservancy (29°38.068'S, 30°59.420'E), a regional waste landfill site owned and managed by eThekwini Municipality, which is located 5 km west of Verulam and 25km north of Durban, in KwaZulu-Natal South Africa (CCBA_PDD, 2011). Historically, the site was used for sugarcane production (Mugwedi et al., 2017; Douwes et al., 2015). The project area of 520.6 ha is in the buffer zone of the eThekwini Municipality owned Buffelsdraai Landfill Conservancy (CCBA_PDD, 2011). The zone around the project area includes commercial sugarcane operations, to the north while peri-urban communities occur to the west, south and east of the Buffelsdraai Landfill Conservancy Community Reforestation Project area (Macfarlane et al., 2010).

3.3.2 Description of the study area

Annual rainfall in Verulam average at 766 mm per year, with most rainfall concentrated within a summer wet season (EPCPD, 2011) and peaks in the month of February. Temperatures average at 22.2°C in the winter months to 27.4°C in February (EPCPD, 2011). The forest type of the site is described as Coastal scarp and Dry Valley Thicket (EPCPD, 2011). Vegetation is broadly described as belonging to the KwaZulu-Natal Coastal Belt (Mucina and Rutherford, 2006). This is a highly transformed and fragmented vegetation type, with very little of the vegetation type formally protected (Macfarlane et al., 2010). Within the study area, vegetation varies considerably, with much of the area previously converted to sugarcane lands. Forest patches do still occur along south-facing slopes, while remnants of riparian forest occur along many of the drainage lines (Mucina and Rutherford, 2006). Some areas of woodland and grassland remained, but are highly restricted in their distribution (Mucina and Rutherford, 2006).

Geology in the study area is dominated by Dwyka Tillite deposited in a glacial environment by retreating ice sheets about 300 million years ago (Macfarlane et al., 2010). Soils are highly variable, ranging from deep, well drained red hutton soil forms, to shallow, poorly-drained Glenrosa soil forms (Water Research Commission, 1995). Topography is also highly variable, with a large stream, the Black Mhlasini, flowing through the northern section of the site and the White Mhlasini River flowing along the southern boundary. Between these rivers, elevations rise some 200-m, to 325-m above sea level along the ridge lines.

Eight sites, ranging from open grassland habitat to closed forest habitat were selected (Figure 1.1; 1.2). Site description are summarized in Table 1.1. Three sites represented a chronosequence of time since restoration (short- 0-2 years, medium- 3-5 years, and long-term 6-8 years). We included a mature scarp forest site, a natural grassland site as reference, and three transformed sites, young sugarcane (six months), mature sugarcane (over 8 years) and mature sugarcane invaded by indigenous trees (over 5 years).

3.3.3 **Ant sampling**

Ant sampling was conducted during two sampling periods, April-May 2017 (early dry season) and December 2017 (wet season). In each sampling period, ground-dwelling ants were sampled at the eight sites using standardized pitfall trapping method (Munyai and Foord, 2012; Agosti and Alonso, 2000). This method is easy and effective in ants sampling and can be used by non-specialists (Parr and Chown, 2001; Andersen, 1991). Four replicates, separated by at least 300 m, were set out within each of the eight sites. Within each replicate, 10 pitfall traps (50 mm diameter plastic jars) were laid out in a 2 X 5 grid with 10-m spacing in-between traps, totalling 40 pitfalls per site. These pitfall traps were partly filled with a 50% solution of propylene glycol as a preservative and killing agent. Pitfall traps were kept open for five consecutive days in the field, which is presume enough to allow sampling of representative ants (Lasmar et al., 2017;

Munyai and Foord, 2012) and trap catches were collected after five days. The pooled weekly sample from a set of pitfall traps was treated as one sample.

All specimens were sorted and enumerated and the fourth author identified them to species level where possible. Other species were identified to genus level and then assigned to morphospecies. Valid ant genera names were confirmed using Fisher and Bolton (2016). All voucher specimens were preserved in 70% ethanol and later pinned. A full collection of voucher specimens is held at the School of Life Sciences at the University of KwaZulu-Natal, Pietermaritzburg campus.

3.3.3.1 Environmental variables and soil analysis

Ant composition can be better explained by the specific characteristics of the microhabitat in which ants live or forage (De Queiroz et al., 2013). Hence, the present study measured the vegetation habitat structure and soil as predictor variables related to the microhabitat.

3.3.3.1.1 Vegetation habitat structure

Vegetation structure (vertical and horizontal) was quantified in both surveys following methods used by Botes et al. (2006) and Munyai and Foord (2015). Vertical distribution was measured by placing a 1.5 m rod marked at 25 cm height intervals: 0-25; 25-50; 50-75; 75-100; 100-125; 125-150 and 150+ cm (canopy cover) at four points on 1.5 m radius centred on each pitfall trap. The number of foliage hits at 25 cm intervals were recorded and averaged for each replicate. Horizontal vegetation complexity which included percentage of exposed rock, bare ground, vegetation cover, and percentage litter cover, was measured using a one m^2 grid quadrat (Munyai and Foord, 2012; 2015; Figure 2.1). Average values of horizontal and vertical vegetation structure are presented in Appendix C.

Figure 2.1 Illustration of how vertical and horizontal vegetation structure were quantified in one m^2 grid and pitfall in the centre in Buffelsdraai Landfill Conservancy.

3.3.3.1.2 Soil analysis

Soil samples were collected of Buffelsdraai Landfill Conservancy in December 2017. Using a soil auger, ten soil samples were randomly collected and were pooled together into one bag for each replicate. The soil analyses were performed by KZN Agriculture and Rural Development, Cedara College of Agriculture, Pietermaritzburg, South Africa. Soil samples were dried and analysed for soil texture using three fractions (sand, silt and clay), and soil fertility incorporated the following elements: P, K, Ca, Mg, Exch. Acidity, pH, Zn, Mn, Cu, (Estimates: Org. C, N, Clay) (Appendix D).

3.3.4 **Data analysis**

Prior to analyses, the pitfall samples for each survey within a plot were pooled, this represented one community. Species richness and composition at each site were determined by compiling records from each trap. Hence, species richness was measured as the number of species recorded, activity as the total number of individuals collected at trap per site. We considered the number of ants caught in pitfall traps as a reflection of ant activity, which is the incidences or occurrences of how many times the different morphospecies were registered in the pitfall traps. In the case of ants, the number of individuals collected cannot be used to determine ant abundance because the individual unit is the colony, therefore ant individuals would be incidences (Gotelli and Colwell, 2001). Ant data were square root transformed to reduce the impact of the abundant species.

Species richness and ant activity was modelled using Generalized Linear Model (GLM). As species counts are discrete values, we treated ant richness as count data and we modelled its response to the explanatory variables using Generalized Linear Mixed Models (GLMM) with Poisson distributions. Fixed factors that were included in the model were soil characteristics and habitat structure (vertical and horizontal) and replicates were nested within the sites which were included as a random variable. The GLMM (Bolker et al. 2009) and GLM analysis were performed using R (R Core Team, 2017) and lme4 package (Bates et al., 2015).

To assess differences in communities across sites, we constructed a similarity matrix based on Bray–Curtis similarity measure, followed by analysis of similarity (ANOSIM) and non-metric multi-dimensional scaling (nMDS) plots. ANOSIM generates a Global R statistic which serves as an indication of average dissimilarity between the groups or assemblages being compared, R value close to 1 indicates distinct differences and R value close to 0 indicates high levels of similarity in composition (Jamison et al., 2016). In this study, groups that had $R > 0.75$ for ANOSIM pair-wise comparison, were treated as well separated groups; those with $R > 0.5$, were overlapping but clearly different and groups with $R < 0.5$, were treated as barely separable groups (Hamer and Slotow, 2017; Clarke and Gorley 2001).

We used permutational multivariate analysis of variance (PERMANOVA, Anderson, 2001) to test if there were any differences in ant assemblages between seasons (dry and wet season), among sites and among replicates. Distance-based test for homogeneity of multivariate dispersions (PERMDISP) was used to test for homogeneity of dispersion among the groups (Anderson, 2006).

Indicator species for each habitat type were identified using the indicator value (IndVal) method (Dufrêne and Legendre, 1997). IndVal measures the degree to which each species fulfils the criteria of specificity (uniqueness to a particular site), and fidelity (frequency within that habitat type) for each habitat cluster compared with all other habitats (Van Rensburg et al., 1999). A species with higher IndVal value (%) is regarded as a reliable indicator species because it has higher probability of being sampled in the habitat type during monitoring and assessment (McGeoch and Chown, 1998). For this study, species with IndVal values of significantly greater than 70% across the two sampling periods significant were regarded as indicator species for the habitat type. Detector species had significant IndVals smaller than 70% and larger than 50%. For restored sites we identified potential indicator/detector species for those species that had significant IndVal score of greater than 50% (McGeoch, 1998). The above-mentioned analyses were run in the R environment for statistical computing (R Core Team 2017, version 3.4.3) using the vegan package 2.5-3 (Oksanen et al., 2013).

The distance-based linear model (DistLM) (Legendre and Anderson, 1999) analysis was carried out to investigate the influence of the measured environmental variables on ant assemblage structure. A step-wise selection procedure based on Akaike's bias corrected information criterion (AICc) was used to determine which variables were potentially predictors of variation in ant community structure (Legendre and Anderson, 1999). Marginal tests were then used to test if there were significant correlation between the ant community and each of the environmental variables on its own. To visualize the DISTLM results we used a distance-based redundancy analysis (dbRDA) (Legendre and Anderson, 1999). All analyses were conducted using Primer version 6 (Clarke, 1993).

We applied a canonical correlation analysis (CCA) using Canoco version 4.5 (Ter Braak and Similauer, 2002) to correlate ant community composition with the best environmental predictors. We examined the significance of the first CCA axis, the full model and each environmental variable by using 499 Monte Carlo permutations.

3.4 Results

A total of 27 439 ant specimens were collected for this study (Table 1.2). Species richness was significantly higher in grasslands and short-term restored sites and richness peaked in the wet season (Table 2.1). Our studies indicated a humpback (unimodal) richness-curve response, as richness was low in matured sugarcane and forest (at both extremes), but peaked up in restore sites and grasslands (Figure 2.2). Patterns of species richness was significantly explained by bare-ground cover, with species richness decreasing with increasing bare-ground cover (Table 2.3). Leaf litter and canopy cover also had a negative relationship with richness, while vegetation cover indicated a positive relationship with species richness (Appendix E) but these variables were not significant ($p>0.05$) in explaining variation in species richness (Table 2.3). Ant activity was significant higher in grassland, short- and long-term restored sites and low in sugarcane and forest (Figure 2.2) and ant activity peaked in wet season (Table 2.2). Interestingly, medium-term restored site had low ant activity but showed high species richness (Figure 2.2). Species evenness based on Shannon diversity index ranged from 0.066 to 0.376, indicating uneven spread of abundance across species (Appendix F).

The PERMANOVA results indicated that there were significant differences between the sites (Pseudo F = 9.2092, p = 0.0001; Table 2.4). Forest sites were different from the short- (t = 3.81, p = 0.02), medium- (t = 2.99, p = 0.02), and long-term sites (t = 3.87, p = 0.01; Appendix G).

Table 2.1 Summary of general linear models for species richness as observed in Buffelsdraai in 2017.

Factors	Estimated Std.	Error	z value	Pr(>|z|)
Intercept	2.64268	0.10210	25.883	< 2e-16 ***
Grassland	0.30888	0.12852	2.403	0.01624 *
Long-term	0.19023	0.13190	1.442	0.14925
Matured sugarcane	-0.05884	0.14009	-0.420	0.67447
Medium-term	0.23639	0.13055	1.811	0.07018
Mixed sugarcane	0.15006	0.13312	1.127	0.25963
Short-term	0.32965	0.12796	2.576	0.00999 **
Young sugarcane	-0.16532	0.14408	-1.147	0.25121
SeasonWet	-0.14131	0.06458	-2.188	0.02865 *

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 2.2 Generalized Linear Model (GLM) table for species abundance showing fixed factors summary result (sites and seasons).

Factors	Estimated Std.	Error	z value	Pr(>|z|)
Intercept	5.92836	0.16476	35.981	< 2e-16 ***
Grassland	0.65566	0.23246	2.821	0.00479 **
Long-term	1.02321	0.23234	4.404	1.06e-05***
Matured sugarcane	-1.42549	0.23614	-6.037	1.57e-09***
Medium-term	0.07327	0.23289	0.315	0.75305
Mixed sugarcane	0.23827	0.23274	1.024	0.30594
Short-term	1.00785	0.23231	4.338	1.44e-05***
Young sugarcane	-0.97863	0.23453	-4.173	3.01e-05***
SeasonWet	-0.64848	0.01271	-51.017	<2e-16***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 2.3 Generalized Linear Mixed Model (GLMM) table for species richness showing fixed factors summary result (sites and seasons).

Predictor variables	Estimated Std.	Error	z value	Pr(>|z|)
Intercept	2.819233	0.055197	51.076	< 2e-16 ***
Bare ground	-0.007557	0.003030	-2.395	0.0166 *
Leaf litter	-0.001665	0.002879	-0.578	0.5632
150 hits (Canopy cover)	-0.032538	0.050939	-0.639	0.5230
Vegetation	0.001990	0.003026	0.658	0.5111

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

ANOSIM indicated that ant assemblages differed significantly among the sites (ANOSIM, Global R = 0.664, p = 0.001, no. of permutations = 999). The ant assemblage associated with the forest were distinct, this was clearly shown by the nMDS plot (Figure 2.3; Appendix H). Restored sites had similar assemblages to each other and to grassland as well (Figure 2.3; Appendix H and I). The sugarcane sites also had similar assemblages but differed significantly from short- and medium-term and grasslands (Figure 2.3; Appendix I). PERMDISP results inferred that plots differed significantly in their dispersion (F7, 24 = 4.4184, p = 0.0292), but difference among the groups was weak (Appendix J). Groups that showed significant difference in dispersion were: medium term and long-term; long-term and forest; long-term and matured sugarcane; forest and young sugarcane.

Table 2.4. PERMANOVA analysis of ground-dwelling ant assemblages across a reforested landscape, based on square-root transformed abundances and S17 Bray-Curtis similarity. Listed are the degrees of freedom (df), sum of squares (SS), mean of squares (MS), Pseudo F and *p* statistics value. Pseudo F statistics were calculated for each term using direct analogues to univariate expectations of mean squares (EMS). P-values were obtained using 9999 permutations. * indicates significant differences at p < 0.05.

Source	df	SS	MS	Pseudo F	p (perm)	Unique perms
Replicate	3	5715.7	1905.2	1.0704	0.3586	9881
Sites	7	62960	8994.3	9.2092	0.0001*	9882
Season	1	7003.4	7003.4	2.906	0.0201*	9873
Residual	21	20510	976.66			
Total	63	1.5309E5				

Forest had the largest number of indicator species, namely *Pheidole* UKZN_11 (*megacephala* gp.), *Tetramorium* UKZN_28 (*setigerum* gp.), *Tetramorium* UKZN_04 (*squaminode* gp.) and *Leptogenys attenuate* and two detector species, *Solenopsis* UKZN_02, *Tetramorium setigerum* (Table 2.5). *Lepisiota capensis* was the only grassland indicator species, with *Pheidole* UKZN_10 (*liengmei* gp.) and *Crematogaster rectinota* as detector species. None of three restored nor sugarcane sites had any indicator species (Table 2.5).

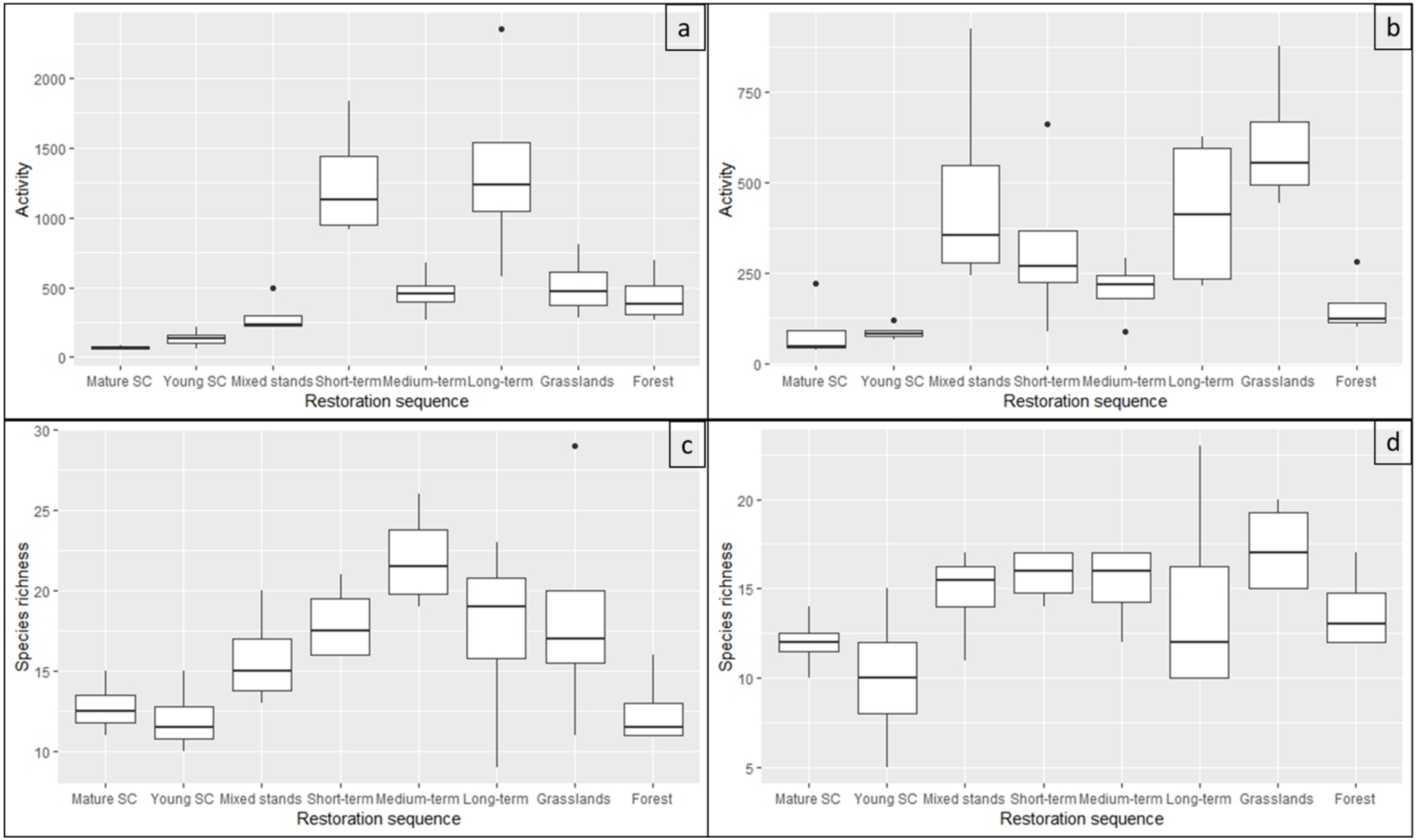

Figure 2.2. Ant species activity and observed species richness across eight sites in Buffelsdraai Landfill Conservancy during the dry and wet season in 2017. A = ant activity in dry season, b = ant activity in wet season, c = species richness in dry season, d = species richness in wet season.

Sugarcane did not have a single species that had a significant IndVal value while *Pheidole* UKZN_09 and *Solenopsis* UKZN_01 were the two detector species for restored sites.

Canonical Correspondence Analysis (CCA) model was significant ($F = 5.407$, $p < 0.01$), and presented five environmental factors that significantly explained the variation within ant community composition of Buffelsdraai Landfill Conservancy: vegetation, bare ground, pH, leaf litter and 150 + hits (canopy cover) (Figure 2.4). The first two principal axes explained the 52.7% of the cumulative variance. Leaf litter cover and canopy cover were strongly correlated to each other and were associated with forest species such as *Nesomyrmex* UKZN_03 (84), *Leptogenys attenuate* (34), *Paltothyreus* UKZN_02 (35), *Pheidole* UKZN_11 (*megacephala* gp.) (85), and *Tetramorium* UKZN_28 (*setigerum* gp.) (83). Most ant assemblages in Buffelsdraai Landfill Conservancy were more sensitive to average vegetation ground-cover which appeared to be most common in sites with low leaf litter and soil pH level. Most species composition found in the young sugarcane plantation site, especially *Meranoplus* UKZN_03 (14), *Myrmicaria natalensis* (71), *Tetramorium* UKZN_06 (*gabonense* gp.) (74), and *Camponotus cintellus* (55), were strongly correlated with bare ground and high acidic soil (Figure 2.4).

The distance-based linear model (DistLM), based on Akaike's bias corrected information criterion (AICc), explained 31.7% of the variation in the ant species assemblages (Table 2.6). The percentage of variation explained by the individual variable indicated that bare ground, vegetation, and leaf litter contributed the highest percentage (54.06%, 27.18% and 9.44%), while 150 + hits and clay percentage were the lowest contributors (Table 2.6; Appendix K).

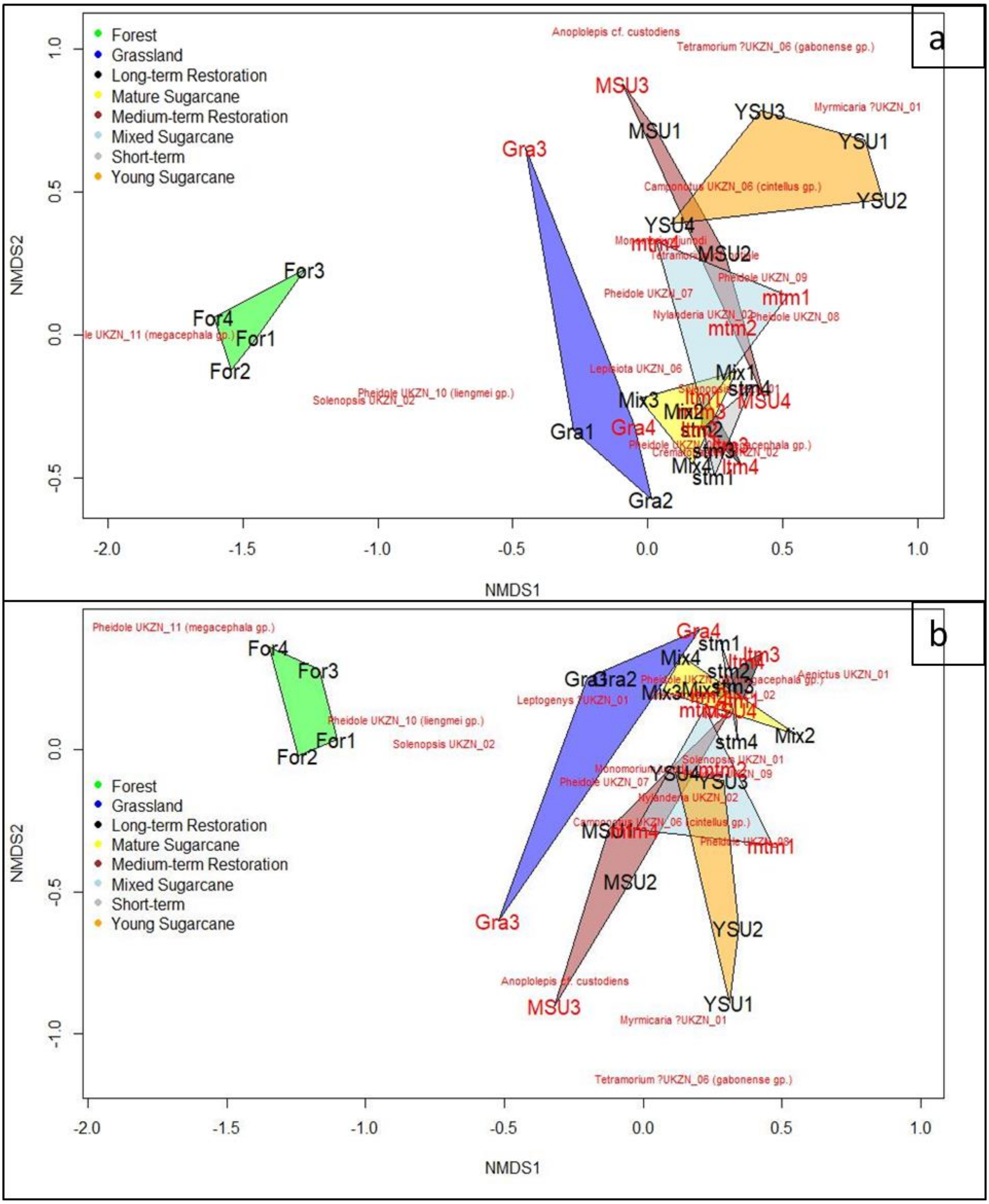

Figure 2.3 Non-metric multidimensional scaling (NDMS) plot indicating community composition patterns among sites selected in Buffelsdraai landfill Conservancy in dry (a) and wet season (b) in 2017.

Table 2.5 Indicator Value Analysis results for ants' species in eight selected sites both in dry and wet season. All species fulfilling the criteria (IndVal > 70%, p < 0.05) were identified as indicator species.

season		**Stat**	
Dry	**Habitat type and species**	**IndVal (%)**	***p*-value**
	Forest		
	Pheidole UKZN_11 (*megacephala* gp.)	97.30	0.001*
	Tetramorium UKZN_28 (*setigerum* gp.)	75.00	0.002*
	Solenopsis UKZN_02	58.18	0.007*
	Tetramorium UKZN_26 (*squaminode* gp.)	50.00	0.028
	Tetramorium UKZN_27 (*squaminode* gp.)	50.00	0.023
	Tetramorium UKZN_04 (*squaminode* gp.)	41.86	0.027
	Grassland		
	Lepisiota capensis	73.47	0.002*
	Pheidole UKZN_10 (*liengmei* gp.)	68.57	0.003*
	Leptogenys UKZN_01	49.09	0.027
	Plagiolepis UKZN_03	40.00	0.043
	Tetramorium UKZN_19 (*squaminode* gp.)	40.00	0.030
	Restored (short-, medium-, long-term)		
	Pheidole UKZN_09	56.52	0.006*
	Solenopsis UKZN_01	52.87	0.024*
	Nylanderia natalensis	49.31	0.001
	Pheidole UKZN_06 (*megacephala* gp.)	44.21	0.002
	Forest		
	Pheidole UKZN_11 (*megacephala* gp.)	99.01	0.001*
	Tetramorium UKZN_04 (*squaminode* gp.)	77.42	0.003*
Wet	*Leptogenys attenuate*	72.73	0.002*
	Tetramorium setigerum	58.18	0.010*
	Leptogenys UKZN_01	48.00	0.020
	Pheidole UKZN_10 (*liengmei* gp.)	44.44	0.031
	Pheidole UKZN_09	40.00	0.047
	Camponotus cintellus	39.02	0.014
	Grassland		
	Lepisiota capensis	73.47	0.001*
	Crematogaster rectinota	53.33	0.032*
	Pheidole UKZN_07	44.64	0.049
	Restored (short-, medium-, long-term)		
	Solenopsis UKZN_01	52.27	0.011*
	Nylanderia natalensis	46.79	0.012
	Pheidole UKZN_06 (*megacephala* gp.)	42.65	0.004

*****Indicate significance of indicator and detector species.

Table 2.6 Best model of the distance-based linear model (DistLM), using a step-wise selection procedure based on Akaike's bias corrected information criterion (AICc), and the percentage of variation explained by individual variable based on distance-based linear model analysis.

	% Explained variation (fitted model)		% Explained variation (total)	
Criterion	**Individual**	**Cumulative**	**Individual**	**Cumulative**
AICc	**R^2**	**RSS**	**No. variables**	**Selections**
245.46	0.31677	42464	5*	2-4, 11, 25
245.89	0.30759	43035	5*	2-4,19,23
246.52	0.29388	43887	5*	1,3,11,23,25
Axis				
% Bare ground	54.06	54.06	17.13	17.13
% Vegetation	27.18	81.24	8.61	25.73
% Leaf litter	9.44	90.68	2.99	28.72
150 + hits	6.11	96.79	1.93	30.66
% Clay	3.21	100	1.02	31.68

* Predictor variables: 1, % rock; 2, % bare-ground; 3, % Vegetation; 4, % Leaf-litter; 5, 0-25 hits; 6, 26-50 hits; 7, 51-75 hits; 8, 76-100 hits; 9, 101-125 hits; 10, 126-150 hits; 11, 150+ hits;12, P mg/L; 13, k mg/L; 14, Ca mg/L; 15 Mg mg/L; 16, Exch. Acidity cmol/L; 17, Total cations cmol/L; 18, % Acid sat.; 19, pH (KCI); 20, Zn mg/L; 21, Mn mg/L; 22, Cu mg/L; 23, org. content; 24, % N; 25, % Clay.

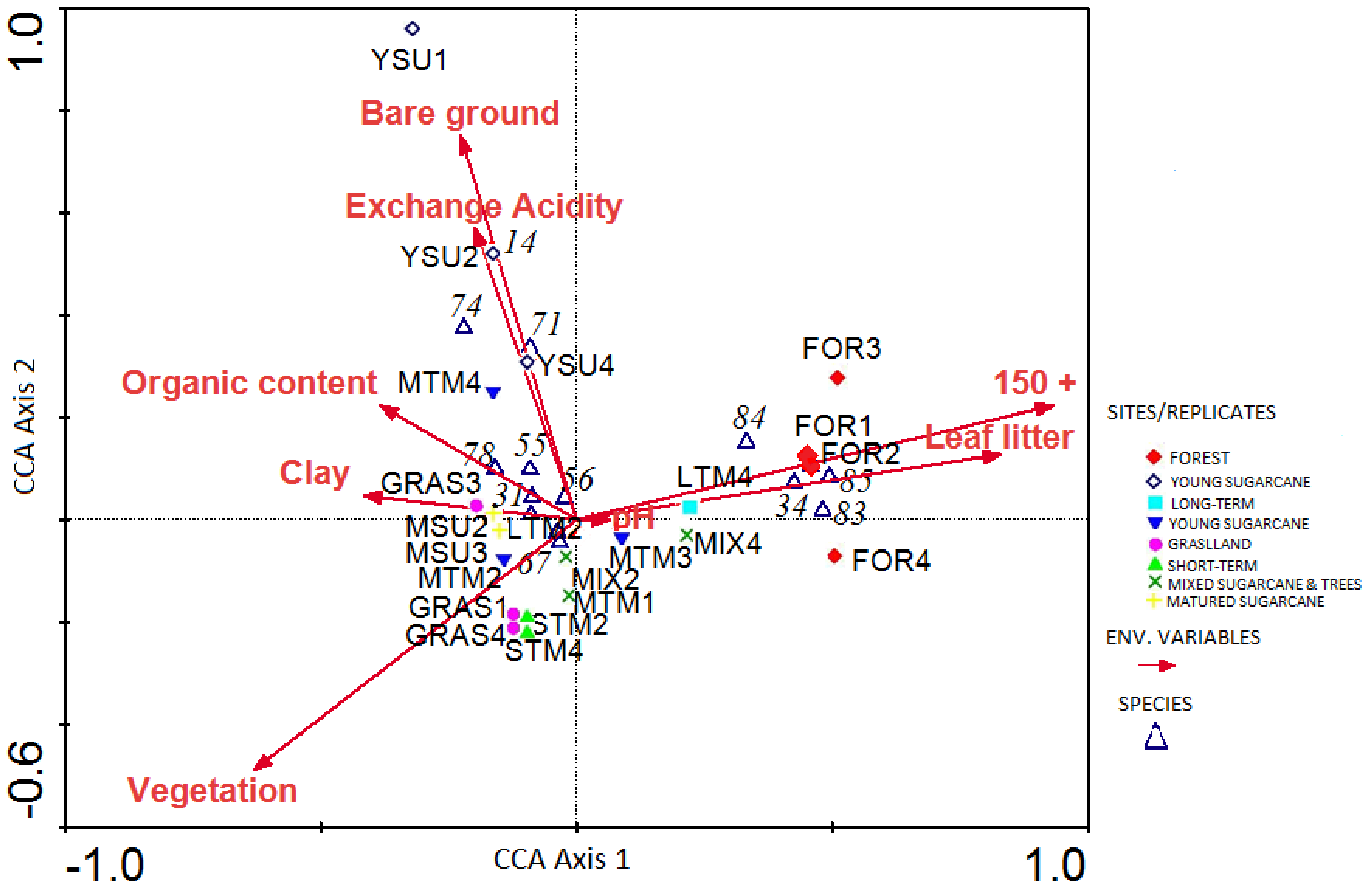

Figure 2.4. Canonical correspondence analysis (CCA) ordination graph with fitted environmental variables and four replicates for each of the eight sites sampled with relative species in Buffeldraai Landfill Conservancy in 2017. Arrows represent environmental variables that were most significantly ($p \leq 0.05$) related to ordination: bare-ground (%); Vegetation (%); Leaf-litter (%); 150+ hits; Exch. Acidity cmol/L; pH (KCl); Org. content; Clay %. Sites: STM - short-term; MTM - medium-term; LTM – long-term restored; FOR – forest; GRAS – grassland; MSU – mature-sugarcane; YSU – young-sugarcane; MIX – mixed stands of sugarcane and trees. Numbers represent dominant species associated with a particular site and variable i.e. Meranoplus UKZN_03 (14), Leptogenys attenuate (34), Paltothyreus UKZN_02 (35), Camponotus cintellus (55), Myrmicaria natalensis (71), Tetramorium UKZN_06 (gabonense gp.) (74), Tetramorium UKZN_28 (setigerum gp.) (83), Nesomyrmex UKZN_03 (84), and Pheidole UKZN_11 (megacephala gp.) (85).

3.5 Discussion

Our results indicated that patterns of species richness were significantly associated with bare-ground cover. Species richness decreased with increasing bare-ground cover. Forest resembled distinctive ant assemblage and indicator taxa were associated with forest and grassland. Bare-ground, leaf litter and vegetation cover were important in structuring the ant assemblages found in the study site.

Species richness indicated a humpback response, as species richness was low for the mature sugarcane and low for the forest but peaked up in the intermediate sites (i.e. restored and grassland sites). Richness response model showed a significant negative relationship between species richness and bare-ground cover. Both matured sugarcane and forest were associated with increased bare-ground cover, hence richness was low at both extremes. Our results are consistent with the study of other studies (Graham and Duda, 2011; Graham et al., 2009; Mackey and Currie, 2001), that reported humpback species richness response as common in terrestrial invertebrates, and ants in particular and that humpbacked diversity pattern in local ant communities have mainly been observed for disturbance (Majer, 1985; Gallé, 1991) and stress (Andersen, 1992) in particular. Ground-dwelling ants are reported as closely related to the ground surface resources especially leaf litter (de Queiroz et al., 2013; Mauda et al., 2018). However, the present study found a negative relationship between leaf litter and canopy cover, and only vegetation cover increased linearly with richness, but there were no significant correlations.

Species richness was significantly lowest in forest and sugarcane plantation. Our results showed that forests do not support high ant diversity, instead open woodlands (restored sites) and grasslands had high ant diversity. A study by Munyai and Foord (2015) in Soutpansberg Mountain, found that open woodlands on the arid north had significantly more ant species than the south which included forest and thickets sites. Increase diversity in open habitat has been reported in plant species as well (Dorji et al., 2014). Most ant species tend to favour open habitats over closed canopy habitats as they are thermophilic (Hoffmann, 2010; Hoffmann and Andersen, 2003). As indicated by our results, high species diversity is associated with open habitats (i.e. grassland and medium-term restored) characterized by high rock and vegetation cover, but low bare-ground and leaf litter cover. It is possible that ant species are influenced by high quality food and nesting sites provided by a heterogeneous environment found in restored and grasslands sites.

Ant species richness tends to be low in cultivated areas (Souza et al., 2010), and is nearly always lower in farmland environments than in naturally vegetated areas (De Bruyn, 1990). Our results indicated that sugarcane sites were associated with high bare-ground cover. Ants generally, nest in soil and are directly affected by severe soil disruption such as ploughing (Evans et al., 2011) and mining (van Hamburg et al., 2004). De Bruyn (1990) mentioned three common explanations for the loss of species in agricultural environments: changes in microclimate conditions poorly affect development of larvae and pupae, foraging activity and nesting places; agrochemicals such as fertilizer and pesticides, reduce food availability and there is reduction in litter and soil organic matter; and altered interaction affect community structure. Therefore, low species richness might be due to limited habitat resources such as nesting sites in sugarcane plantation.

For ant composition, forests had the most distinct assemblages restricted to them and most indicator taxa were found in forests followed by grasslands. Distinct species community in forest is common, Hill et al. (2008) reported that ground-dwelling ant communities in forest may seem similar even between different forest types. They are responsive to wide range of environmental variables such as soil texture or moisture (Kaspari and Weiser, 2000), woody debris, and litter cover (Wilson and Holldobler, 2005), rather than tree community composition (Staab et al., 2014). However, primary forests tend to support a more species-rich and distinct species community than secondary forests (Vasconcelos, 1999). The present study show that forests were characterised by high leaf litter which is related to copy cover. The degree of canopy cover affects ground temperature and therefore ant foraging (Kaspari et al., 2000). Light availability and moisture have strong influences on ant communities (Veldman et al., 2015). Dense tree cover limits the productivity and richness of light-demanding species, while reducing habitat for animals adapted to open environments (Veldman et al., 2015). Therefore, cooler temperatures in forest favour ants adapted to cooler and more stable temperatures.

Four indicator species, *Pheidole* UKZN_11 (*megacephala* gp.); *Tetramorium* UKZN_04 (*squaminode* gp.); *Tetramorium* UKZN_28 (*setigerum* gp.); and *Leptogenys attenuate*, were identified as forest indicators and *Solenopsis* UKZN_02, and *Tetramorium setigerum* as detector species for forest habitats. These indicator species distinguished forest habitat from the natural grasslands. For grassland, *Lepisiota capensis* was an indicator species with two detector species, *Pheidole* UKZN_10 (*liengmei* gp.) and *Crematogaster rectinota*. These species were also important in showing the differences of grassland habitat from the natural forest and from other habitats of this study. Although there were clear differences between the restored habitats and sugarcane plantation habitats no species were found meeting the IndVal criteria and reliably considered as indicators or detector species of restored or sugarcane sites. However, the IndVal results showed that two species, *Solenopsis* UKZN_01 and *Pheidole* UKZN_09, are very likely to come out as potential indicator species for restored sites. These potential species indicate that restored sites are becoming different to sugarcane and this is becoming detectable. Although their indicator ability seems weak at this stage, given more time and with intense sampling, these species would clearly distinguish restored sites from sugarcane sites and could be used as indicators of progress in restoration.

On the other hand, ant assemblage which were associated with sugarcane plantations were mostly nectar feeders and sugar ants e.g. *Camponotus* and *Nylanderia* species, and predatory species e.g. *Anoplolepis custodiens, Mesoponera caffraria*, *Myrmicaria natalensis* and some species in genus *Pheidole*. Therefore, food source plays a major role as a driver of ants in sugarcane sites. Some studies (De Oliveira et al., 2012; Fernandes et al., 1994) have indicated some ant species can be key generalist of crop pest. For example, Goebel et al., (1999) reported that *Pheidole megacephala* is an important predator of the stem borer. *Chilo sacchariphagus* (Bojer), in sugarcane plantation; *Myrmicaria natalensis* is highly predacious and known to attack insect pest such as *Heliothis armigera* (Samways, 1982). Nevertheless, none of these species were strictly associated with sugarcane sites.

The four environmental variables (leaf litter, vegetation structure, canopy cover and bare ground cover) explained 32 % variation in ant assemblages. This indicated that there might be other factors that played a key role in structuring the ant composition in this area which may have not been measured in this study. It might also just be as a result of our sampling technique or random processes. One aspect is the potential source of pool of species. Species pool allows the examination of large-scale effect on the diversity, composition and phylogenetic structure of local communities (Cornell and Harrison, 2014). This includes effect that can arise from geographic area. The influence of species pool is important when local communities are not strongly and predictably structure by environmental variables or by species interaction under disturbance (Cornell and Harrison, 2014). As shown by present study, environmental variables may explain some effect in the structure of local communities, but biogeographic ones e.g. barriers to dispersal and distance from source, may explain a substantial part of the balance and biological effect (nesting sites, food source, etc.) could explain the rest (Novotny et al., 2007; Sundermann et al., 2011).

Ant species in these restoration sites appeared to have been colonized by ant species from adjacent sites or sugarcane plantation, but not from forest sites. This is not the issue of dispersal limitation but environmental filtering one. The restoration sites are open habitats and are just not environmentally suitable for the forest species. Notably, the trees species used for restoration in Buffelsdraai are mostly savanna species e.g. *Bridelia micrantha, Erythrina lysistemon, Millettia grandis* and *Vachellia natalitia*. Therefore, it is convenient to retain the grass layer in between these tree species and make the area structurally complex, this would allow for more variation in temperature and a much higher diversity of species (Parr, 2008; Veldman et al., 2015). From an invertebrate diversity perspective, if the restoration project in Buffelsdraai Landfill Conservancy wishes to increase species diversity and to have potentially more biodiversity benefits, eThekwini Municipality restoration should refrain from completely restoring it to a forest, and maintain it as savanna woodlands. A mosaic of habitats may be most advantageous. Importantly, we demonstrated the importance of a source of diversity from nearby grassland to colonise the restored habitats, as the environmental conditions are more similar than to those of the target forest habitat.

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CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

4.1 Introduction

It is widely recognized that high biodiversity enhances ecosystem functioning and services, and biodiversity loss is associated closely with ecosystem change. Deforestation and human induced land use change is as bad as planting forests where they did not historically occur (Veldman et al., 2015a; Veldman et al., 2015b). Generally, replacing one biome with a different one is bad for the environment and for biodiversity (Veldman et al., 2015b). The relationships between species diversity and environmental conditions is very crucial in ecology. The issue of how species respond to disturbance such as landcover change or modifications of habitat structure such as reforestation, has long been investigated (Gerlach et al., 2013; McGeoch, 2007). Species response and species assemblages' structure is mostly influenced by numerous variables. Some species may decline in abundance because of the lack of vital habitat components, such as foraging and breeding resources (Waltert et al., 2005; Waltert et al., 2004; Grove, 2002). If for instance, landcover change was so intense such that it caused major soil disruption ant species would decline as most of their nests are above the ground (Hoffmann and Andersen, 2003). While other species may benefit from the altered habitat conditions through the increase in diversity and distribution due to increase in habitat resources. Factors that drives species richness over space and time are still poorly understood (Munyai and Foord 2015). Understanding the factors that drives species richness and composition at multiple scales is of crucial importance for conservation (Pacheco and Vasconcelos, 2012).

4.2 Revisiting the aims and objectives

The first objective of the study was to provide a checklist of epigaeic ants in a reforested landscape of Buffesldraai Landfill Conservancy. This study provided a checklist of ground-dwelling ants sampled along a restoration gradient at the Buffesldraai Landfill Conservancy. The checklist consisted of the three most diverse subfamilies (Myrmicinae, Ponerinae, and Formicinae) that are commonly found by other studies (Schoeman and Foord, 2012; Munyai and Foord, 2015) conducted in South Africa. This checklist contributes to the limited number of studies that are using ants for monitoring ecological changes in South Africa, and it should serve as a foundation for monitoring the recovery of ant assemblages following a reforestation process. The second and third objectives were to determine how species diversity and composition differs along a reforestation gradient, and to identify which factors might underlie differences in ant diversity and composition. Results showed that both species richness and ant activity was lowest in forest and sugarcane plantation, but highest in grasslands and restored sites. Sugarcane sites had limited resources to support high ant diversity. Species richness responded with humpback response, as richness decreased with increasing bare-ground cover. High ant diversity was associated with open woodland habitats in contrast to closed-canopy habitats. Forest had the most distinct ant assemblages and had most indicator taxa followed by grassland habitats. Four predictor variables, leaf litter, vegetation structure, canopy cover and bare ground cover, have had major influences on ant assemblage structure. Restored sites are using grassland as source of species colonisation. This study concluded that open woodland restored sites are ideal habitats for increasing species diversity as they provide a complex habitat for species.

4.3 Contributions of the study

This study is one of the very few that have been conducted around the world focusing on the value of species composition rather than only the numbers of species in a reforested landscape. It is the very first study of highly diversity species and composition found in a reforestation aimed for carbon sequestration rather than for biodiversity benefits.

A trade-off between reforestation for carbon sequestration and biodiversity has been explored (Hall et al., 2012). Beaudrot et al. (2016) argued that biodiversity benefits is unlikely to be increased through projects that prioritize carbon stocks alone. In order to yields co-benefits, both biodiversity and carbon storage ecosystem services should be explicitly considered during the initial design of the project (Strassburg et al., 2010; Beaudrot et al., 2016). However, findings of this study showed that reforestation for carbon dioxide can have co-benefits for biodiversity and there would potentially be more benefits if biodiversity as well is accounted for in the in initial design of the reforestation project.

This study also presented natural forest as of high conservation value as they preserved the most distinct ant species community (Sutton and Collins, 1991; Staab et al., 2014). This is important because natural forestlands are under threat of being heavily exploited by human activities. The current study findings encourage indigenous tree plantation by local communities for protection and conservation of biodiversity. As it has been noted by Cunningham et al. (2015), forests offer far beyond support to poor people particularly those residing in rural areas because they are highly dependent on it for their basic needs. For example, natural forest offers ecosystem goods and services to people, this includes food, wood, fibre and medicine, and it provide protection from natural disasters such as floods and landslides through soil stabilisation (King et al., 2005). Moreover, the outputs of this research are beneficial to local potential stakeholders such as eThekwini Municipality and government as they require such studies as evidence that the capital invested in protecting local biodiversity is effectively and bearing productive information.

Furthermore, the conservation status and value of invertebrates, (ants in particularly), is poorly known (McGeoch et al., 2011), and in South Africa there are still limited number of studies that have contributed to the conservation of ants. This project provides an ant inventory which covers the ant diversity of the Buffelsdraai Landfill Conservancy. This knowledge of ant diversity in restored landscape can result in a great deal of information that can be useful for conservation planning in South Africa especially for open woodland habitats (savanna) as they are under threat of transformation to support agrarian such as farming (Mauda et al., 2018). The project further indicated that ants are robust bioindicators of ecological changes, and can be resampled for continuous monitoring of ecological changes in the terrestrial environments. Inclusion of ants into biodiversity programs can provide a global database profile that can be used by ecologist and taxonomist for further research in ecosystem monitoring and conservation (Agosti et al., 2000).

4.4 Challenges

It is evident from the current study that restoration programs are doing remarkable work in ensuring a secured future for biodiversity. However, there are still very low chances for biodiversity to effectively reach fully recovery and persist from land-use change because the amount of agricultural land under active management is higher that restoration lands (Le et al., 2014). Currently, there is less evidence available to show that forestlands are potentially great competitors to agricultural land use (Le et al., 2014). As much as sugarcane production contributes significantly to the economy of South Africa, we must not overlook the fact that our biodiversity is severely affected by land-use change to support agricultural activities. If need be, we need to strike a balance between agricultural production and protected areas for biodiversity.

On the other hand, land owners strongly prefer the idea of small-scale tree plantings on their marginally productive land and are less likely to be willing to consider larger scale afforestation, particularly on their productive land (Schirmer and Bull, 2014). This suggests that land owners seek to place afforestation at the margins of their enterprise where it will not interfere with existing agricultural production, or views about acceptable use of agricultural land, and where afforestation thus presents less economic or social risk to the land-holder. Land-holders will accept afforestation only if its design enables them to minimize the opportunity cost of afforestation, and to continue their existing land management activities and socio-economic relations with little disturbance (Schirmer and Bull, 2014).

4.5 Future possibilities

As ant communities commonly vary in composition along environmental gradients, relationships between functional diversity and the environment are expected in most of the world's principal terrestrial ecosystems (Arnan et al., 2014). It is therefore important to analyse how the functional traits found in ant communities vary along reforested gradients, and agroecosystem. Moreover, much of the literature has documented most of alpha-diversity and have rarely explore beta diversity especially in the tropical forests (Condit et al., 2002). Analysing the patterns of animal beta diversity along a variable environmental affected by human impacts would offer important insights about how conservation measures should be put in place. Studies conducted to measure beta diversity can result in a richer analysis of biological patterns, and this can results in a great deal of information that can support conservation and management decisions (Bush et al., 2016). Moreover, biodiversity conservation planning should also focus on the phylogenic diversity contributions of geographic localities (Faith and Baker, 2006). Lastly, more studies are needed that would monitor the diversity of savanna in contrast to forest habitats, this would emphasize the importance of conserving savanna as much as of forest.

4.6 Final comments and summary conclusions

Reforestation and restoration of ecosystem is adopted as a feasible practical solution to mitigate climate change and recover biodiversity loss. This study has revealed that reforestation can yield co-benefits for both carbon sequestration and biodiversity.

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4.7 Appendix

Appendix A. Subfamilies and ant species collected in different habitat type along Buffelsdraai Landfill Conservancy during April-May and December 2017. AP = all present, FOR = forest, GRAS = grassland, LTM = long-term restored, MIX = mixed sugarcane and trees, MSU = matured sugarcane, MTM = medium-term restored, STM = short-term restored, and YSU = young sugarcane.

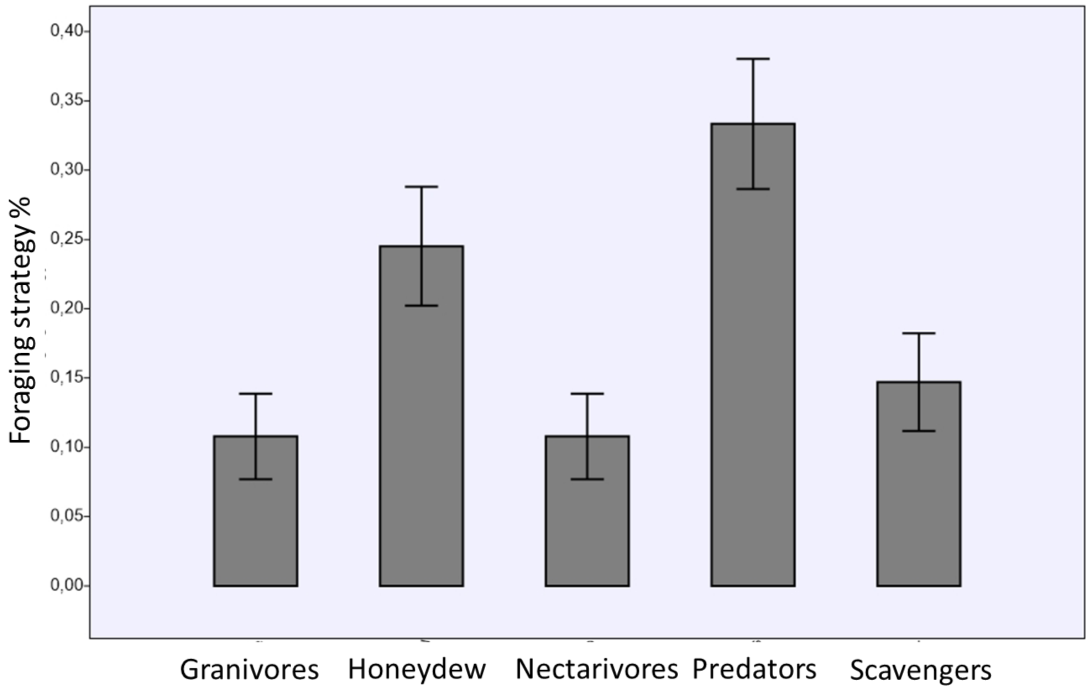
Subfamily and species	Foraging strategy	Abundance	Habitat type
Dolichoderinae			
Tapinoma UKZN_01	honeydew	2	GRAS
Technomyrmex pallipes (F. Smith, 1876)	honeydew	13	GRA,LTM,MIX,STM,YSU
Technomyrmex UKZN_01	honeydew	45	AP
Dorylinae			
Aenictus rotundatus (Mayr, 1901)	predators	161	MIX, STM
Dorylus helvolus (Linnaeus, 1764)	predators	2	GRAS,STM
Parasyscia UKZN_01	predators	17	FOR,GRAS,MIX,STM
Parasyscia UKZN_02	predators	6	GRAS,MSU,MTM
Parasyscia UKZN_03	predators	2	GRAS,MTM
Aenictus rotundatus (Mayr, 1901)	predators	3	GRAS,MIX
Formicinae			
Anoplolepis custodiens (F. Smith, 1858)	predator	1263	GRA,MSU,MTM,YSU
Camponotus maculatus (Fabricius, 1782)	honeydew	16	GRA,LTM,MSU,MTM,STM,YSU
Camponotus UKZN_03	honeydew	7	STM
Camponotus cintellus (Gerstaecker, 1859)	honeydew	281	ALL
Camponotus rufoglacus (Jerdon, 1851)	honeydew	1	MTM

Lepisiota UKZN_02 *(spinosior* gp.*)* (Forel, 1913)	honeydew	11	GRA,LTM,MTM,MIX,STM
Lepisiota capensis (Mayr, 1862)	honeydew	110	FOR,GRAS,LTM,MTM,MIX,STM,YSU
Lepisiota crinite (Mayr, 1895)	honeydew	5	STM
Lepisiota UKZN_01 *(capensis* gp.*)* (Mayr, 1862)	honeydew	108	FOR,LTM,MSU,MTM,MIX,STM
Lepisiota UKZN_03 *(spinosior* gp.*)* (Forel, 1913)	honeydew	6	LTM,MTM
Lepisiota spinosior (Forel, 1913)	honeydew	15	GRAS,MSU,MTM,STM
Lepisiota UKZN_04 *(spinosior* gp.*)* (Forel, 1913)	honeydew	1	GRAS
Nylanderia UKZN_01	nectarivores	996	AP
Plagiolepis UKZN_02	nectarivores	11	GRAS,LTM,STM
Plagiolepis UKZN_03	nectarivores	14	GRA,MSU,MIX
Plagiolepis UKZN_04	honeydew	1	YSU
Polyrhachis (Myrmia) *schistacea* (Gerstaecker, 1859)	nectarivores	33	GRAS,MSU,LTM,MTM,MIX,STM,YSU
Myrmicinae			
Cardiocondyla UKZN_03	granivores	27	GRAS,LTM,MSU,MTM,STM
Carebara UKZN_01	predators	3	MTM,STM
Crematogaster rectinota (Forel, 1913)	honeydew	418	AP
Crematogaster UKZN_05	honeydew	11	MSU,MTM
Crematogaster castanea (Smith, F, 1858)	honeydew	3	MSU,MTM
Crematogaster UKZN_10	honeydew	20	FOR,GRAS,MIX
Meranoplus UKZN_03	honeydew	1	YSU
Monomorium damarense (Forel, 1910)	granivores	80	GRAS,MSU,LTM,MTM,MIX,STM,YSU
Monomorium UKZN_08	granivores	22	AP

Monomorium cf. drapenum (Bolton, 1987)	nectarivores	5	MSU,MIX,STM
Monomorium junodi (Forel, 1910)	nectarivores	493	AP
Monomorium UKZN_04	granivores	1	GRAS
Monomorium UKZN_08	granivores	1	YSU
Monomorium UKZN_09	granivores	12	LTM,MTM,STM
Myrmicaria UKZN_01	scavengers	254	AP
Nesomyrmex UKZN_01	Predators	2	MTM,
Nesomyrmex UKZN_02	Predators	2	LTM,MTM
Nesomyrmex UKZN_03	Predators	1	FOR
Pheidole crassinoda (Emery, 1895)	Granivores	54	FOR,GRAS,LTM,MTM,YSU
Pheidole UKZN_06 *(megacephala* gp.*)* (Fabricius, 1793)	honeydew	17561	GRAS,MSU,LTM,MTM,MIX,STM,YSU
Pheidole UKZN_07	honeydew	1114	AP
Pheidole UKZN_08	honeydew	215	GRAS,MSU,LTM,MTM,MIX,STM,YSU
Pheidole UKZN_09	Predator	183	FOR,MSU,LTM,MTM,MIX,STM,YSU
Pheidole UKZN_10 *(liengmei* gp.*)* (Forel, 1894)	Granivores	343	FOR,GRA,MIX
Pheidole UKZN_11 *(megacephala* gp.*)* (Fabricius, 1793)	honeydew	1643	FOR,GRA,STM
Pheidole UKZN_9	Predator	4	FOR
Solenopsis UKZN_01	scavengers	202	AP
Solenopsis UKZN_02	scavengers	244	FOR,GRAS,MSU,MIX
Strumigenys nr. *Faurei* (Arnold, 1948)	predators	9	LTM,MIX,STM
Tetramorium UKZN_04 *(squaminode* gp.*)*	honeydew	115	FOR,GRAS,MSU,MTM,YSU
Tetramorium UKZN_06 *(gabonense* gp.*)* (Andre, 1892)	honeydew	209	GRAS,LTM,MTM,YSU

Tetramorium UKZN_08 *(gabonense* gp.*)* (Andre, 1892) (Santschi, 1911)	honeydew	17	MTM
Tetramorium UKZN_13	scavengers	9	MIX,YSU
Tetramorium UKZN_19 *(squaminode* gp.*)* (Santschi, 1911)	honeydew	26	GRAS,LTM,STM
Tetramorium notiale (Bolton, 1980)	granivores	110	AP
Tetramorium setigerum (Santschi, 1918)	granivores	126	FOR,LTM,MTM,MIX,STM
Tetramorium UKZN_02 *(sericeiventre* gp.*)* (Emery, 1877)	honeydew	53	GRAS,MTM,STM,YSU
Tetramorium UKZN_07 *(simillimum* gp.*)* (F. Smith, 1851)	honeydew	34	FOR,GRAS,LTM,MIX,STM
Tetramorium UKZN_11 *(similimum* gp.*)* (F. Smith, 1851)	honeydew	42	AP
Tetramorium erectum (Emery, 1895*)*	scavengers	41	FOR,MSU,MTM,STM
Tetramorium UKZN_24 *(squaminode* gp.*)* (Santschi, 1911)	scavengers	2	LTM
Tetramorium UKZN_25 *(solidum* gp.*)*	scavengers	4	FOR,GRAS,STM
Tetramorium UKZN_26 *(squaminode* gp.*)* (Santschi, 1911)	scavengers	2	FOR
Tetramorium UKZN_27 *(squaminode* gp.*)* (Santschi, 1911)	scavengers	7	FOR,MIX
Tetramorium UKZN_28 *(setigerum* gp.*)* (Mayr, 1901)	scavengers	92	FOR
Tetramorium UKZN_29	scavengers	3	MIX,YSU
Tetramorium UKZN_30	scavengers	8	GRAS,MSU,MIX
Tetramorium UKZN_31	scavengers	2	GRAS,STM
Tetramorium UKZN_33	scavengers	1	MSU
Ponerinae			

Anochectus UKZN_03			
Bothroponera cavernosa (Roger, 1860)	predators	7	FOR,GRAS,MSU
Bothroponera UKZN_02	predators	3	MSU
Hagensia UKZN_01	predators	1	GRAS
Hypoponera UKZN_01	predators	2	STM
Hypoponera UKZN_02	predators	1	MSU
Hypoponera UKZN_03	predators	4	MIX
Leptogenys UKZN_01	predators	174	FOR,GRAS,MSU,LTM,MTM,MIX,STM
Leptogenys attenuate (Smith, F, 1858)	predators	75	FOR,GRAS,MSU,LTM,MTM,MIX,STM
Leptogenys intermedia (Emery, 1902)	predators	2	MSU,YSU
Leptogenys castanea (Mayr, 1862)	predators	7	FOR,GRAS,MIX,YSU
Leptogenys UKZN_05	predators	10	GRAS
Mesoponera caffraria (Smith, F., 1858)	predators	75	FOR,GRAS,LTM,MSU,MTM,STM
Mesoponera UKZN_01	predators	56	GRAS,MSU,MTM,MIX,STM,YSU
Mesoponera UKZN_01	predators	2	LTM
Mesoponera nr *sharpi*	predators	4	MTM,STM
Mesoponera UKZN_06	predators	3	LTM,STM
Mesoponera UKZN_07	predators	9	GRAS,MSU,MIX
Paltothyreus UKZN_02	predators	10	FOR
Plectroctena mandibularis (F. Smith, 1858)	predators	2	FOR,MIX
Mesoponera UKZN_02	predators	30	GRAS,MSU,LTM,MTM,MIX,STM,YSU
Pseudomyrmicinae			
Tetraponera natalensis (F. Smith, 1858)	scavengers	1	LTM



Appendix B. Foraging guild for ant composition observed during April-May and December 2017 in Buffelsdraai Landfill Conservancy.

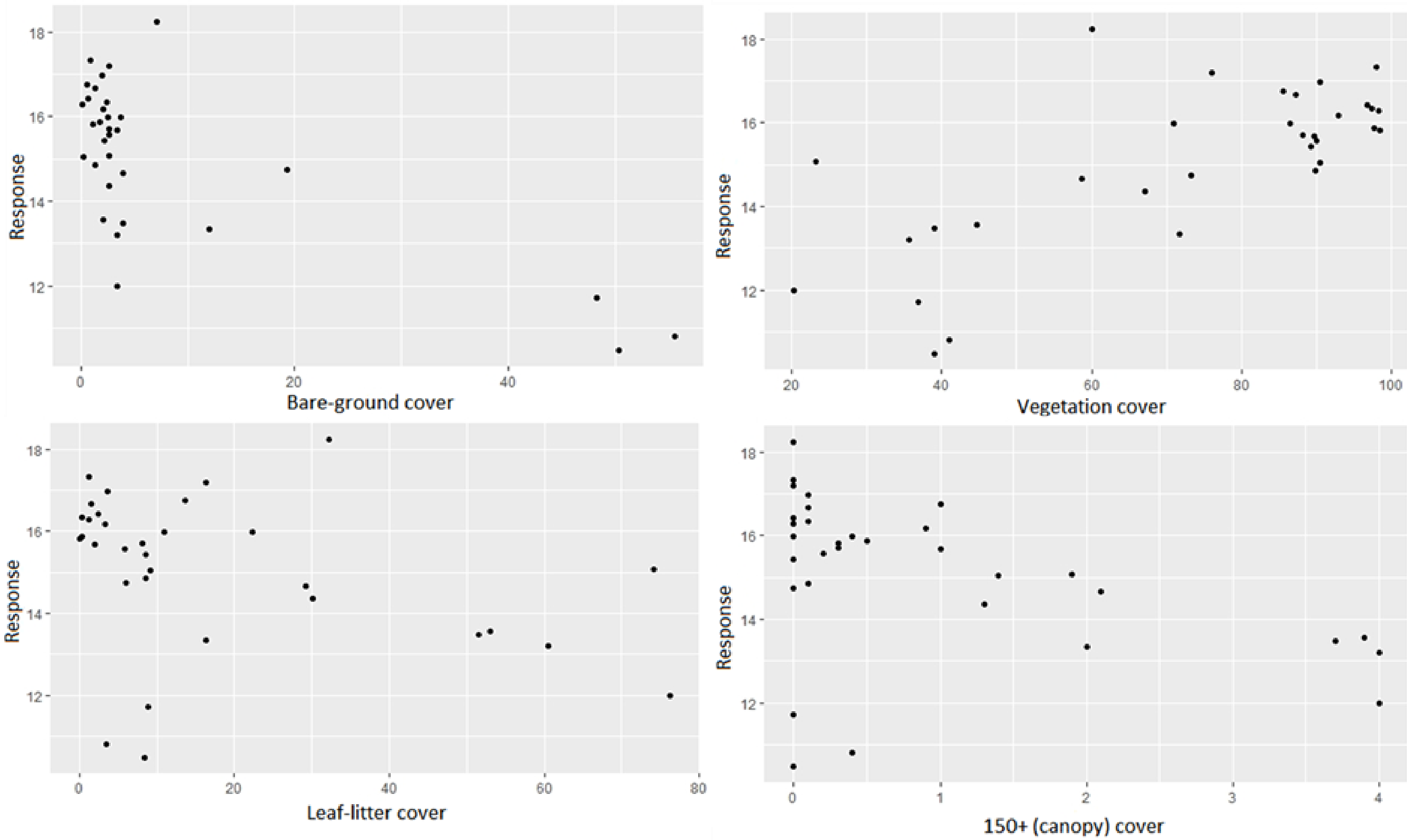
Appendix C. Vegetation habitat structure collected in each site per replicate in Buffelsdraai Landfill Conservancy during April-May and December 2017. STM - Short-term; MTM - Medium-term; LTM – Long-term restored; FOR – Forest; GRAS – Grassland; MSU – Mature-sugarcane; YSU – Young-sugarcane; MIX – Mixed stands of sugarcane and trees.

Site	Bare ground (%)	Leaf litter (%)	Rock (%)	Vegetation (%)	0-25 hits	26-50 hits	51-75 hits	76-100 hits	101-125 hits	126-150 hits	150 + hits
STM1	7.1	32.2	0.7	60	3.9	0.9	0.1	0.4	0.4	0	0
STM2	2.6	16.3	5.1	76	4	0.9	0.2	0.2	0	0	0
STM3	2.5	10.9	0.1	86.5	4	0.5	0.3	0	0	0	0
STM4	0.9	1.2	0	97.9	4	3.2	2.3	1.3	0.2	0	0
MTM1	1.1	0.1	0.4	98.4	4	3.1	2	0.9	0.5	0	0.3
MTM2	2.4	0.3	0	97.3	4	3.2	2.1	1.1	0.2	0	0.1
MTM3	0.3	9.2	0	90.5	4	3.7	3.5	2.4	2.1	1.1	1.4
MTM4	2.1	3.3	1.7	92.9	4	0.3	0.1	0.3	0.5	0.4	0.9
LTM1	1.8	0.3	0.2	97.7	4	2.1	0.9	0.4	0.4	0	0.5
LTM2	3.4	2	4.9	89.7	4	2.8	2.5	2.1	1.7	1	1
LTM3	0.6	13.7	0.2	85.5	3.9	2.1	0.2	0.2	0.2	0.2	1
LTM4	4	29.3	8	58.7	4	2.2	0.8	0.6	1.3	0.8	2.1
FOR1	2.1	53.1	0.1	44.7	3.9	2.4	1.5	1.4	1.4	1.1	3.9
FOR2	3.4	60.5	0.4	35.7	3.7	1.8	1.9	1.4	1.5	1.4	4
FOR3	3.4	76.2	0	20.4	4	1	1.2	0.8	0.5	1.1	4
FOR4	4	51.5	5.5	39	4	1.5	1	0.9	0.8	1.2	3.7
GRAS1	0.7	2.5	0	96.8	3.9	3.8	3.5	2	1.2	0.3	0
GRAS2	2.6	8.1	1.2	88.1	4	3.5	2.9	1.6	1.2	0.8	0.3
GRAS3	2	3.7	3.9	90.4	4	3.6	2.6	1.1	0.4	0.2	0.1
GRAS4	1.3	1.5	10	87.2	4	2.6	0.9	0	0	0.2	0.1
MSU1	0.2	1.2	0.3	98.3	4	3.8	2.8	2.7	2	2.1	0
MSU2	2.2	8.5	0	89.3	4	3.6	2.5	2.2	1.4	1.4	0
MSU3	1.4	8.6	0.2	89.8	4	3.2	2.5	1.2	0.8	0.9	0.1
MSU4	2.7	30.1	0	67.2	4	3.1	2.8	2.8	2.9	3.1	1.3
MIX1	12	16.3	0	71.7	4	2.1	1.6	1	1.5	1.1	2
MIX2	3.7	22.4	3	70.9	4	2.3	1.9	1.5	1.4	1.3	0.4
MIX3	2.6	5.9	1.5	90	4	3.4	2.3	1.1	0.6	0.3	0.2
MIX4	2.6	74.1	0.1	23.2	4	2.7	2.5	2.3	1.9	2	1.9
YSU1	50.3	8.4	2.3	39	1.7	2.1	1.6	1	0.4	0.2	0
YSU2	55.5	3.5	0	41	3.7	2.3	2.7	2.8	2.3	1.6	0.4
YSU3	19.3	6	1.4	73.3	3.8	1.7	1.8	0.8	0.4	0.2	0
YSU4	48.2	8.9	6	36.9	2.4	2.1	2.1	2.2	1.6	1.1	0

Appendix D. Soil properties measured for each replicate of the eight sites. Soil samples collected and analysed in December 2017. STM - Short-term; MTM - Medium-term; LTM – Long-term restored; FOR – Forest; GRAS – Grassland; MSU – Mature-sugarcane; YSU – Young-sugarcane; MIX – Mixed stands of sugarcane and trees.

Site/ Replicate	P mg/L	K mg/L	Ca mg/L	Mg mg/L	Exch. Acidity cmol/L	Total cations cmol/L	Acid sat. %	pH (KCl)	Zn mg/L	Mn mg/L	Cu mg/L	Org. content	N %	Clay %	Soil classification	Moisture (%)
STM1	28	404	779	622	0,92	10,96	8	3,92	1,9	28	2,8	3,5	0,45	51	Clay	2.40
STM2	16	306	1429	703	0,25	13,95	2	4,2	1,2	19	6,4	1,7	0,18	31	Clay	2.74
STM3	21	183	654	306	0,69	6,94	10	3,93	1,4	14	0,7	3,4	0,24	18	Sandy Clay	1.77
STM4	22	440	581	375	0.53	7.64	7	4.02	14.9	11	2.5	1.9	0.15	35	Clay Loam	2.50
MTM1	57	348	926	383	0.30	8.96	3	4.16	2.7	16	3.8	2.2	0.21	24	Sandy Clay	0.38
MTM2	46	509	1176	430	0.39	11.10	4	4.22	1.8	12	4.6	3.5	0.40	39	Silty Clay	2.35
MTM3	11	216	545	348	0.70	6.84	10	4.01	0.8	8	2.0	2.2	0.16	22	Clay	2.79
MTM4	20	398	1530	960	0.17	16.72	1	4.84	3.4	15	4.1	3.5	0.41	45	Clay Loam	2.16
LTM1	57	598	1007	504	0.19	10.89	2	4.39	4.2	14	4.0	4.4	0.49	42	Clay	3.48
LTM2	17	351	953	412	0.30	9.34	3	4.28	1.7	22	6.1	2.4	0.21	34	Sandy Clay	1.04
LTM3	13	206	1273	578	0.55	12.19	5	4.12	2.1	47	12.3	3.4	0.34	48	Clay Loam	2.37
LTM4	12	244	703	394	0.26	7.63	3	4.35	0.6	5	2.5	2.5	0.17	32	Clay	2.58
FOR1	34	395	784	300	0.20	7.59	3	4.37	1.4	15	3.3	1.5	0.12	29	Clay Loam	2.41
FOR2	11	239	647	381	0.51	7.49	7	4.23	0.5	8	1.9	2.8	0.22	31	Sandy Clay	1.53
FOR3	23	149	967	223	0.22	7.26	3	4.41	2.3	12	0.9	3.0	0.26	15	Clay Loam	2.05
FOR4	23	374	931	375	0.59	9.28	6	3.97	1.2	79	5.6	1.7	0.08	28	Clay Loam	2.62
GRAS1	57	148	522	208	0.51	5.21	10	4.04	17.9	22	4.1	0.7	0.06	21	Sandy	1.27
GRAS2	31	291	239	83	0.64	3.26	20	3.99	1.2	80	1.9	0.6	0.05	15	Sandy Loam	0.86
GRAS3	24	310	1485	763	0.13	14.61	1	4.55	3.3	19	9.9	4.0	0.40	44	Clay	3.00
GRAS4	26	509	1125	628	0.42	12.50	3	4.19	2.8	17	6.5	4.5	0.48	43	Loam	1.73

MSU1	28	215	1117	425	0.68	10.30	7	3.98	2.6	35	9.1	2.5	0.27	37	Sandy Clay	2.02
MSU2	25	164	611	385	1.32	7.96	17	3.86	1.2	24	3.5	3.3	0.30	31	Sandy Clay	1.84
MSU3	38	129	812	252	1.05	7.51	14	3.87	2.9	43	1.3	4.6	0.35	26	Clay Loam	2.89
MSU4	12	247	750	374	0.23	7.68	3	4.32	1.4	9	2.6	2.8	0.21	26	Clay Loam	0.97
MIX1	40	304	840	479	0.93	9.84	9	3.93	2.3	12	3.8	4.0	0.46	38	Sandy Loam	1.31
MIX2	15	234	1236	627	0.29	12.22	2	4.18	2.7	37	9.5	3.7	0.38	40	Clay	3.47
MIX3	22	231	677	380	0.44	7.54	6	4.11	1.5	28	4.5	1.6	0.17	23	Clay	3.33
MIX4	17	296	667	442	1.59	9.31	17	3.82	1.0	90	5.2	2.9	0.33	39	Sandy Clay	1.66
YSU1	32	189	478	309	3.66	9.07	40	3.64	1.4	11	2.7	3.9	0.41	36	Clay	2.64
YSU2	24	156	929	375	1.65	9.77	17	3.76	2.3	68	15.9	3.0	0.27	48	Clay	3.28
YSU3	53	658	1519	777	0.51	16.17	3	4.01	2.7	100	7.5	3.3	0.42	51	Clay	2.77
YSU4	10	198	1162	521	0.38	10.97	3	4.12	1.9	54	15.8	2.8	0.24	46	Silty Clay	2.85



Appendix E. Species richness response to predictor variables. Ant species richness as a function of each of the five predictor variables included in the model of ant species richness.

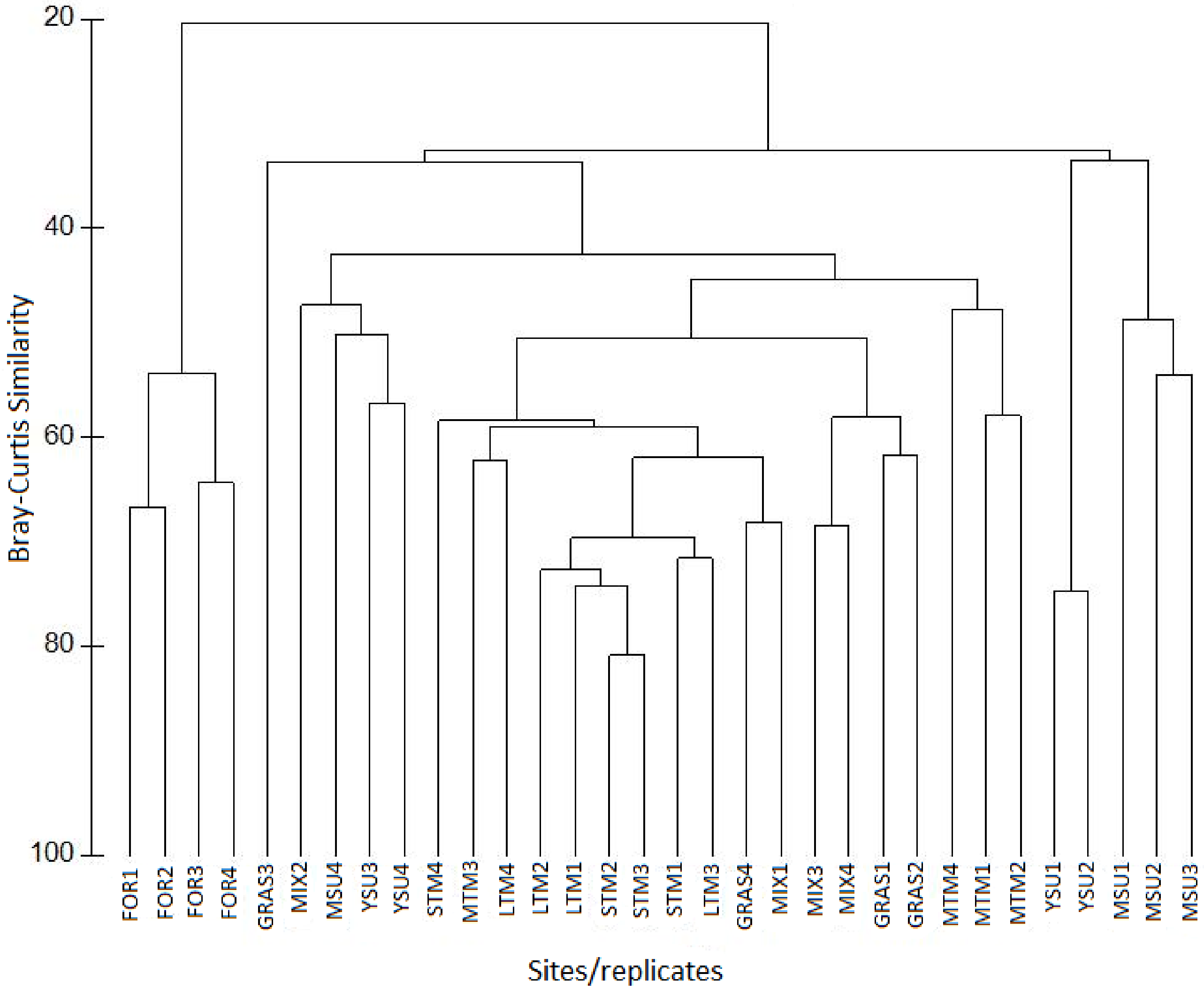
Appendix F. Abundance, observed species richness (S_{obs} = number of species observed) and diversity measure indexes (Dominance_D, Simpson_1-D, Shannon_H, Evenness_e^H/S) calculated over the period of the study.

Season and Site	Abundance	S_{obs}	Dominance_D	Simpson_1-D	Shannon_H	Evenness_e^H/S
DRY						
Forest	1730	29	0.576	0.423	1.162	0.110
Grassland	2040	41	0.229	0.771	2.056	0.190
Long-term	5401	33	0.721	0.278	0.783	0.066
Matured Sugarcane	265	28	0.150	0.849	2.355	0.376
Medium-term	1839	39	0.284	0.715	2.037	0.196
Mixed Sugarcane & Trees	1179	34	0.487	0.512	1.474	0.128
Short-term	5023	34	0.708	0.291	0.838	0.068
Young Sugarcane	540	27	0.161	0.838	2.276	0.360
WET						
Forest	757	32	0.186	0.813	2.264	0.300
Grassland	2491	38	0.306	0.693	1.725	0.147
Long-term	1725	35	0.734	0.265	0.827	0.065
Matured Sugarcane	356	26	0.335	0.665	1.883	0.252
Medium-term	824	30	0.269	0.730	1.964	0.237
Mixed Sugarcane & Trees	1902	33	0.611	0.388	1.081	0.089
Short-term	1400	42	0.548	0.451	1.416	0.098
Young Sugarcane	366	26	0.340	0.659	1.772	0.226

Appendix G. Pairwise comparison using PERMANOVA of ant assemblages sampled in the eight sites of Buffelsdraai Landfill Conservancy. STM - Short-term; MTM - Medium-term; LTM – Long-term restored; FOR – Forest; GRAS – Grassland; MSU – Mature-sugarcane; YSU – Young-sugarcane; MIX – Mixed stands of sugarcane and trees.

Groups	t	p
STM, MTM	1.5409	0.050
STM, LTM	0.88443	0.730
STM, FOR	3.8105	0.020*
STM, GRAS	1.7184	0.047
STM, MSU	2.6534	0.003*
STM, MIX	1.7952	0.025*
STM, YSU	2.1321	0.025*
MTM, LTM	1.594	0.022*
MTM, FOR	2.9932	0.019*
MTM, GRAS	1.4133	0.063
MTM, MSU	1.4533	0.069
MTM, MIX	1.5975	0.016*
MTM, YSU	1.6854	0.002*
LTM, FOR	3.8795	0.011*
LTM, GRAS	1.8057	0.022*
LTM, MSU	2.66	0.005*
LTM, MIX	1.6881	0.042*
LTM, YSU	2.5887	0.003*
FOR, GRAS	2.3724	0.028*
FOR, MSU	2.9716	0.006*
FOR, MIX	3.1654	0.012*
FOR, YSU	2.8515	0.016*
GRAS, MSU	2.1034	0.005*
GRAS, MIX	1.1561	0.191
GRAS, YSU	1.8164	0.021*
MSU, MIX	1.7547	0.026*
MSU, YSU	1.303	0.161
MIX, YSU	1.9473	0.008*

*Indicate significance at $p < 0.05$



Appendix H. Bray–Curtis similarity matrix comparing the similarity between ant communities from different replicates of different sites. Sites: STM - short-term; MTM - medium-term; LTM – long-term restored; FOR – forest; GRAS – grassland; MSU – mature-sugarcane; YSU – young-sugarcane; MIX – mixed stands of sugarcane and trees.

Appendix I. Pair-wise comparison using ANOSIM of ant assemblages sampled in the eight sites of Buffelsdraai Landfill Conservancy. STM - short-term; MTM - medium-term; LTM – Long-term restored; FOR – Forest; GRAS – Grassland; MSU – Mature-sugarcane; YSU – young-sugarcane; MIX – mixed stands of sugarcane and trees. Groups with R > 0.75 were treated as well separated groups; R > 0.5, overlapping but clearly different and R < 0.5, were barely separable groups (Hamer and Slotow, 2017; Clarke and Gorley 2001).

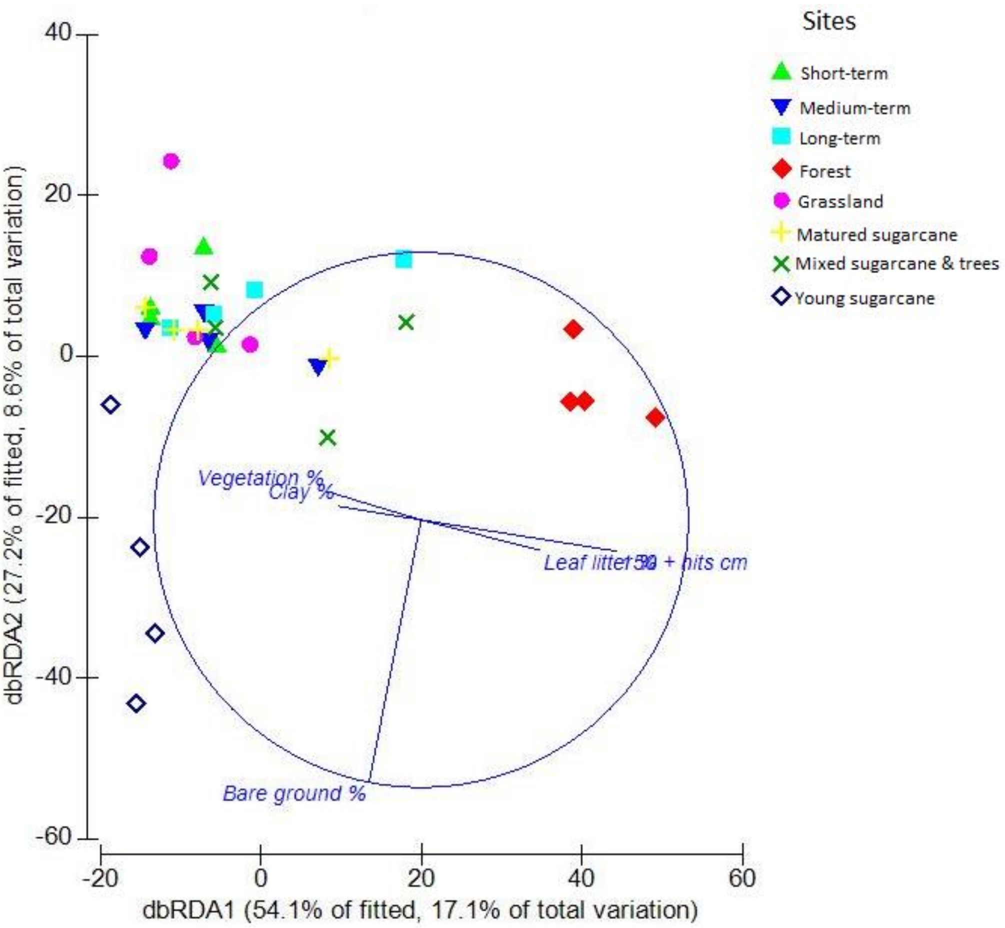
ANOSIM summaries		
Groups	**R**	**Significance level %**
STM, MTM	0.417	5.7
STM, LTM	-0.104	80
STM, FOR	1	2.9*
STM, GRAS	0.49	2.9
STM, MSU	0.906	2.9*
STM, MIX	0.531	2.9
STM, YSU	0.76	2.9*
MTM, LTM	0.479	2.9
MTM, FOR	1	2.9*
MTM, GRAS	0.479	5.7
MTM, MSU	0.615	5.7
MTM, MIX	0.542	2.9
MTM, YSU	0.385	5.7
LTM, FOR	1	2.9*
LTM, GRAS	0.594	2.9
LTM, MSU	0.875	2.9*
LTM, MIX	0.542	5.7
LTM, YSU	0.781	2.9*
FOR, GRAS	0.938	2.9*
FOR, MSU	1	2.9*
FOR, MIX	1	2.9*
FOR, YSU	1	2.9*
GRAS, MSU	0.823	2.9*
GRAS, MIX	0.052	40
GRAS, YSU	0.76	2.9*
MSU, MIX	0.75	2.9*
MSU, YSU	0.375	5.7
MIX, YSU	0.677	2.9

*Indicate well separated groups

Appendix J. Pairwise comparisons of groups using PERMDISP based on square-root transformed abundances and S17 Bray-Curtis similarity. P-values were obtained using 9999 permutations.

Groups	t	P(perm)
STM,MTM	2.6624	0.091
STM,LTM	0.55498	0.738
STM,FOR	1.8157	0.232
STM,GRAS	2.4697	0.116
STM,MSU	3.0138	0.056
STM,MIX	1.7502	0.256
STM,YSU	2.9608	0.058
MTM,LTM	3.8818	0.029*
MTM,FOR	2.3176	0.085
MTM,GRAS	0.4553	0.744
MTM,MSU	0.93446	0.384
MTM,MIX	1.3537	0.288
MTM,YSU	0.99156	0.344
LTM,FOR	2.9258	0.029*
LTM,GRAS	2.7369	0.057
LTM,MSU	3.8076	0.028*
LTM,MIX	2.089	0.142
LTM,YSU	3.5324	0.027*
FOR,GRAS	1.6368	0.169
FOR,MSU	2.5741	0.028*
FOR,MIX	0.26644	0.806
FOR,YSU	2.3934	0.027*
GRAS,MSU	0.26341	0.882
GRAS,MIX	1.3069	0.459
GRAS,YSU	0.36752	0.721
MSU,MIX	1.9405	0.087
MSU,YSU	0.13769	0.845
MIX,YSU	1.8992	0.115

*Indicate significance at $p < 0.05$



Appendix K. Distance-based redundancy analysis (dbRDA) plot showing the five-selected significant environmental variables which significantly explained the variation in ant community.