Seed bank distribution and viability of selected *Vachellia* and *Acacia* species in KwaZulu-Natal, South Africa

Submitted in fulfilment of the requirements for the degree of

Masters of Science at the University of KwaZulu-Natal

by

Amy Frances Webster

Discipline of Geography

School of Agricultural, Earth and Environmental Sciences

College of Agricultural, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

November 2015

FRONTISPIECE

ABSTRACT

There is increasing concern regarding the impact of invasive alien plants (IAPs), where their spread is a serious threat to both the structure and functionality of ecosystems, which causes the loss of biodiversity. Approximately 10 million hectares is currently covered by IAPs in South Africa, with programs such as Working for Water (WFW) having been implemented in an attempt to manage them. This research investigated the seed soil distribution and viability of selected indigenous (*Vachellia*) and exotic invasive *Acacia* species in KwaZulu-Natal, South Africa. In this study, the seed banks of four tree species were sampled; *Vachellia karroo* Hayne, *Vachellia nilotica (L.) P.J.H. Hurter & Mabb*, *Acacia mearnsii* De Wild. (black wattle) and *Acacia dealbata* Link (silver wattle). The first two species are indigenous and the latter two are exotic. The selected invasive species are both classified as Category 2 species by the National Environmental Management: Biodiversity Act of 2004.

The soil seed banks were determined, using a set sampling strategy of six pits at three depths for twelve selected trees per species. Seeds were removed from the soil, using soil sieves, and they were counted and tested for viability, using the tetrazolium chloride (TTZ) test. The majority of methods replicated those of Witkowski and Garner (2000). There was a high variability in seed numbers between different species and individual trees of the same species. Soil seed densities were greater in the *Acacia* species, compared to those of the *Vachellia* species. *Acacia dealbata* had the largest seed density, with the highest number of seeds in the top layer between 0-2 cm. Soil seed density declined with increasing distance from the trunk and with soil depth. The species with the greatest number of viable seeds in the seed bank was *A. dealbata*, followed by *A. mearnsii.* There was no significant difference ($\alpha = 0.05$) in viability between the depths. The *Acacia* species had an advantage over the *Vachellia* species, with a higher soil seed bank density and seed viability. An improved knowledge of the seed banks can assist in providing evidence-based recommendations to improve the effectiveness of current methods for the removal of IAPs, which focus predominantly on 'above-ground material'.

DECLARATION

This document was submitted in fulfilment of a Master of Science Degree. The thesis represents the original work of the author and any literature used is properly acknowledged, both in the text and the reference chapter.

…………………………

Miss Amy Webster

…………………………...

Professor Trevor Hill

ACKNOWLEDGEMENTS

The author would like to thank the following people:

- Professor Trevor Hill, for his patience, guidance, support, immense knowledge, supervision and advice throughout this process.
- The National Research Foundation (NRF), for their financial assistance;
- Bonamanzi and Sierra Ranch, for access to their property to conduct research.
- Craig Houston and Martin Arnold for their enthusiasm and willingness to have me on their property.
- Tristan Duthie and Ntombi Ngoloyi for their field assistance and their company in the laboratory.
- Mr Craig Morris for his guidance with data analysis.
- Victor Bangamwabo and Brice Gijsbertsen, for their help with the GPS, GIS and maps.
- Lindy and Kerrine for their support, love, care and understanding during this long process.
- My boyfriend, Pascal, for his patience and support.
- My family Jane, Barry and David, for their encouraging support.
- Last, but not least, my dear parents, for their understanding and support during this "never ending progress".

DEDICATION

To all individuals who suffer from any form of learning disability, severe or mild.

Progress might be slow but, goals can be achieved.

Do not allow others to define you.

TABLE OF CONTENTS

CHAPTER FOUR: RESULTS

CHAPTER FIVE: DISCUSSION

CHAPTER SIX: CONCLUSION

APPENDIXES

List of Figures

List of Tables

List of Plates

CHAPTER ONE

INTRODUCTION

"The spread of Invasive Alien Species is now recognised as one of the greatest threats to the ecological and economic wellbeing of the planet" (McNeely *et al*., 2001: viii).

1.1 Introduction

Invasive Alien Plants (IAPs) are a global problem, defined by Pejchar and Mooney (2009: 497) as "non-native species that threaten ecosystems and habitats, and are key drivers of human-caused global environmental change." These IAPs are a major threat to biodiversity, human livelihoods and economic development. They invade the natural environment, dominate the landscape, alter the functioning of ecosystems and negatively impact ecosystem functionality (Walker and Smith, 1997). They are therefore, one of the greatest threats to ecosystems (Kaiser, 1999), with international scientists coming together for the Millennium Ecosystem Assessment (MEA) to formulate a plan of action. The 2005 MEA Report used scientific information to put forward recommendations and provide guidance on the sustainable use and conservation of ecosystems (MEA, 2005a; 2005b). De Groot *et al.,* (2010) noted that, there has been an increased interest in the science of ecosystem functioning and goods and services since the release of the MEA.

The spread of IAPs has a negative impact on biodiversity, which led to The Convention on Biological Diversity (CBD) addressing the loss of global biodiversity (Hågvar, 1998). Global institutions created and adopted biological and ecological frameworks that actively sought to conserve and safeguard global biodiversity (Biggs *et al*., 2008). The CBD required countries to develop national strategies for the safeguarding of, and a reduction in, the rate of loss of biodiversity. This included extensive conservation strategies, the fair and equitable benefit sharing of biological resources and the sustainable use of local biodiversity components (UN, 1992; Hågvar, 1998; Biggs *et al*., 2008). The critical importance of biodiversity is becoming increasingly recognized, with the UN and European Union declaring this period (2011—2020) the decade of biodiversity, with the goal of redirecting biodiversity loss and ecosystem services degradation, and to restoring 15% of spoiled ecosystems by 2020 (Tscharntke *et al.*, 2012).

IAPs have the ability to change the composition of plant community, in particular densely populated areas, by displacing other species and negatively impacting on indigenous species (Woods, 1997). The impacts of IAPs are not only limited to environmental losses but also include economic losses. Well-functioning ecosystems are vital to any country; in particular a developing one, such as South Africa, providing a variety of benefits and goods; fisheries, agricultural and forestry products all rely heavily on healthy, functioning ecosystems. These systems, provide services, such as clean drinking water, climate stability, a pollution-free environment, recreation and cultural benefits, to society (Pejchar and Mooney, 2009; van Wilgen and Richardson, 2012). Attempts to quantify the value and importance of biodiversity and ecosystem goods and services are challenging, since biodiversity is of infinite value to the global economy (Costanza *et al.*, 1997). The value in today's global society, dominated by economics, means that 'value' mostly corresponds to financial worth and 'importance' is therefore associated with it. Therefore, for the global economy to understand the importance of biodiversity and ecosystem goods and services, it is necessary to place a financial value on them. There is a need to quantify the effect of IAPs invading grasslands, which can decrease the agricultural potential and grazing capacity and which, in turn, has a direct negative impact on the economy. Similarly, in water-stressed areas where water shortages are exacerbated by IAPs, water availability may potentially decline, with subsequent financial impacts on human residents. This economic focus helps to justify the costs for the removal and management of IAPs. Costanza *et al.* (1997) were some of the earliest authors to place a value on the world's ecosystem goods and services, at an estimated US $16-54 trillion per annum. Owing to global land use changes between 1997—2011, a loss of ecosystem services was estimated to be between $4.3—$20.2 trillion annually. Costanza *et al*., (2014) believes these estimates are conservative. This value to the global economy is large and is expected to increase, as biodiversity is placed under increasing pressure.

South Africa is particularly vulnerable to biodiversity loss due to a high degree of endemism, with approximately 21 137 (80%) of its vascular plants being endemic (Carling and Hilton-Taylor, 1994).Of concern in South Africa, is that 8 750 species have been recorded as having been introduced, of which 161 are regarded as invasive (van Wilgen *et al*., 2001). Many of the contemporary environmental infestations today are as a consequence of the escape or spread of exotic plants from commercial afforestation - a common practice in South Africa. The impacts of IAPs are often felt in areas far removed from the plantations, and the people most affected are often not the people who benefited from the initial plantations (van Wilgen and Richardson, 2012; Richardson *et al.*, 2015).

Although IAPs can have a negative impact on the environment, some are of economic importance, for example, the studied Australian *Acacia* species used in commercial forestry. South Africa produces approximately 45 000 tons of bark extract annually (Chan *et al*., 2015). Land owners use these IAP species for shade, building material and fuel wood.

IAPs are the second largest agent of biodiversity endangerment and extinction after habitat destruction (Pejchar and Mooney, 2009), therefore research into the dynamics of IAPs is critical. The South African government acknowledges the need to manage IAPs. However, despite efforts at clearing stands of invasive *Vachellia* (*Acacia*) species in South Africa, there has been insufficient attention paid to understanding the role that seed production and storage in seed banks may play, with regard to invasiveness and the long-term persistence of IAPs (Richardson and Kluge, 2008). Indeed, there is a gap in the literature on seed bank distribution and the number of IAPs. Current removal techniques tend to focus more on above-ground material and less on seed numbers and distribution (Van Wilgen *et al.*, 1992).

An issue with most seed banks is that their estimates are imprecise (Bigwood and Inouye 1988). Behenna *et al*., 2008 stated the need for more research in the role of soil-stored seed banks, and in the recovery of natural vegetation in the grassy fynbos and its riparian areas after clearing mature stands of woody, invasive plants. Therefore, using a method adopted from Witkowski and Garner (2000), this research measured seed numbers and determined seed viability of selected species. The seed bank needs to be considered when removing *A. mearnsii and A. dealbata* as this impacts its regeneration ability and the control of it.

The four species selected were *Vachellia karroo* Hayne, *V. nilotica* (L.) *P.J.H. Hurter & Mabb (Acacia nilotica)* (L.), *Acacia mearnsii* De Wild. and *A. dealbata* Link. The latter two, commonly known as ‘wattle’, are exotic species. *Acacia mearnsii* and *A. dealbata* were selected as they are considered invasive, vigorous and difficult to control (de Wit *et al.*, 2001).

1.2 Research Aim and Objectives

To measure and describe seed bank distribution and seed viability of selected *Vachellia* and *Acacia* species in KwaZulu-Natal, South Africa. This will be achieved by focusing on the following objectives, namely:

(a) To describe seed bank distribution and quantify the seed numbers of selected *Acacia* and *Vachellia* species;

(b) to measure seed viability of the selected *Acacia* and *Vachellia* species; and

(c) to provide management recommendations for the control of selected *Acacia* species.

This research will assist in the understanding of how IAPs propagate and it will add to the body of knowledge on *Acacia* seed banks and their dynamics, which is crucial for effective management. There is a scarcity of knowledge regarding the seed distribution and volume of seeds in the soil bank. Therefore, a study to investigate and describe the seed distribution and viability of different *Acacia* species was undertaken. *Vachellia* and *Acacia* species were included in this study; however, the focus remains the *Acacia* species. This differs from a similar study undertaken by Witkowski and Garner (2000), in which only indigenous species were selected.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Although the scientific literature regarding the effective control of invasive alien plants (IAPs) is growing, IAPs remain a global problem. The introduction of IAPs has caused the fragmentation of habitats, the loss of biodiversity, and the disruption of fundamental ecological processes (Le Maitre *et al.*, 2000; Kyle and Duncan, 2012). IAPs are non-native species, which do not occur naturally in a region and are translocated either by natural or anthropogenic means, and result in changing the nature of ecosystems and the landscape of a host area (Enright, 2000). The two main agents of species endangerment and extinction are that of habitat destruction and IAPs (Pejchar and Mooney, 2009).

It is estimated that water runoff has been reduced by 7% as a result of IAPs. This impacts upon water availability and the functionality of the ecosystem, due to a reduced streamflow. (Le Maitre *et al.*, 2000). South Africa is a water-scarce country. In KwaZulu-Natal, IAPs use approximately 576 million m^3 of water per annum more than the natural vegetation they have invaded and replaced (Way, 2015). More than 80 Australian *Acacia* species were introduced and spread throughout South Africa over the past 150 years (Poynton, 2009; Le Roux *et al.*, 2011; Richardson *et al.*, 2011). Fourteen Australian *Acacias* that are currently invasive in South Africa have been present in the country for similar lengths of time, although the extents of their invasiveness differ (van Wilgen *et al.*, 2001; Donaldson *et al.*, 2014).

Despite the negative impacts, many of these IAPs can be described as paradox species, in that 38% of the area invaded by exotic species in South Africa is in the form of commercial forestry plantations, grown for economic gain (Nyoka, 2003). In 2001, over 100 000 km^2 was invaded by invasive alien tree species, approximately 8% of South Africa’s total area (van Wilgen *et al.*, 2001). Furthermore, in 2011, South Africa, exported 330 000 tons of *A. mearnsii* De Wild. bark with a gross value of approximately US $10.40 million (DAFF, 2013). In 2014, 110 000 ha of land was covered by black wattle cultivated plantations (Chan *et al*., 2015). *Acacia mearnsii*, followed by *A. dealbata*, have the greatest invasive range in South Africa (Donaldson *et al*., 2014).

There has been an increase in the area occupied by *Acacias* over the past 50 years (de Neergaard *et al.*, 2005), which has led to changes in the availability of natural resources. The commercial value of wattle has varied over time, ranging from being deemed an asset, to being deemed a liability. This concept is well-illustrated by Richardson *et al*., (2015:34) (Figure 2.1). The three possible paths that *A. mearnsii* could follow in the future are illustrated below (Richardson *et al.*, 2015).

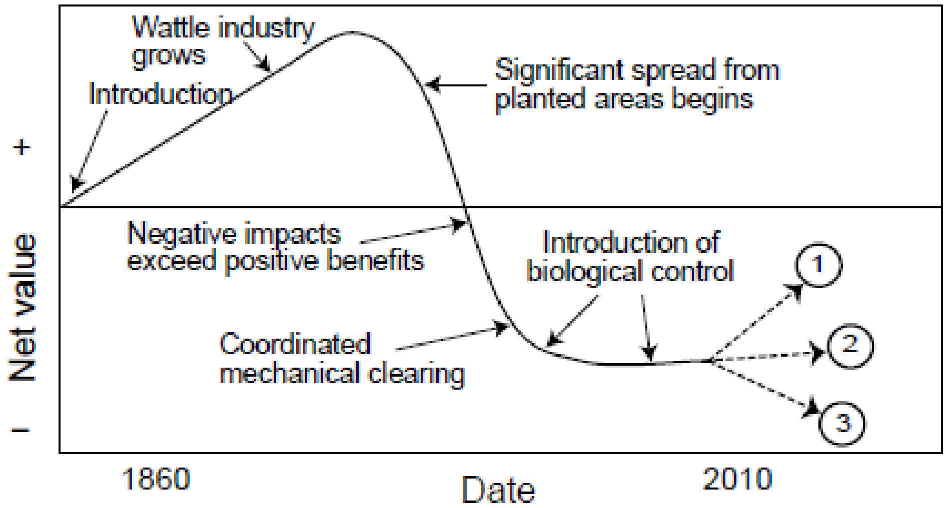


Figure 2.1 The net value of *Acacia mearnsii* 1860-2010 (adopted from Richardson *et al.*, 2015).

[1] The optimum combination of management practices is fully implemented, and practices are effective

[2] Maintenance of the status quo, where the implementation of management practices is incomplete, not fully coordinated and sustained, or partially ineffective

[3] The worst-case scenario, where key management practices are either not implemented or fail.

Acacia mearnsii, is grown for its bark which contains high-grade tannin. This tannin content is used to produce tannin extracts and adhesives, and the wood is used as pulp in the paper industry (Beck-Pay, 2013; Chan *et al*., 2015). *Acacia mearnsii* and *A. dealbata* are commonly used as a primary heat source and as building material for marginalised communities in rural areas.

2.2 Impact of IAPs

IAPs have many impacts on the environment that have a knock on effect which, in turn, impacts the economy. The Food and Agriculture Organization of the United Nations (FAO) emphasised that a reduction in streamflow and available water, as well as and the loss of productive agriculture land, are the consequences of IAPs. The ecological assault by IAPs on indigenous species has resulted in attempts to safeguard endemic and native biodiversity. Recently, stringent efforts at eradicating problematic ‘pest’ species have resulted in IAPs being perceived in an increasingly negative light (Kull and Rangan, 2008). IAPs increase the cost of fire protection, and the damage caused by wild fires. In addition, they increase the potential of soil erosion following fires, and the loss of biodiversity, and they may change the biomass and overall habitat for native animal species (Nyoka, 2003).

2.3 *Acacia* Name Change

The classification of plants and their nomenclature can differ from one place to another, some plants have many common names, and they provide a historical continuity and familiarity of relationships with others (Kull and Ranagn, 2012). However, a universal name is needed to classify them. Ideally, plant names should have minimal change, so as to avoid confusion and mistakes.

If a species has been named more than once with different names, then the *rule of priority* is used i.e. whichever name is the oldest, is used. For example, black wattle was known as *Acacia decurrens* var. *mollies* or *Acacia mollissima* during the 19th and early 20th century as described in European Herbaria. The name was changed after an American naturalist Edgar A. Mearns, documented it while collecting specimens in Kenya. Mearns passed away in 1916 before he was able to process his findings however his African botany collection reached the National Botanical Gardens in Brussels. Here, Émile de Wildman, the director at the time, published Mearns’ species description, honouring his name. This achieved taxonomic priority as the older scientific names for black wattle were found to be invalid (Kull and Ranagn, 2012). The full scientific name for black wattle is *Acacia mearnsii* De Wild.

Yet, all this has been overshadowed in the 21st century by an interesting and somewhat controversial naming process. In 2003 a proposal was put forward to conserve the name

Acacia for an Australian type specimen. Much debate followed with it going to a vote at the International Botanical Congress in Vienna in 2005. In July 2011 it was concluded that the name *Acacia* would be used exclusively for Australian species (Boatwright *et al.*, 2014). This was a significant step in splitting the genus into five separate genera as it allowed most of the species to keep the original name *Acacia*, in particular those in Australia. The remaining approximately 400 species were categorised into four new genera; *Vachellia*, *Senegalia*, *Acaciella* and *Mariousousa*. For example the African *Vachellia karroo* (Sweet Thorn) was named *Acacic karroo* and *Vachellia nilotica* (Scented Thorn) was classified as *Acacia nilotica* (SANA, 2015). The *Acacia dealbata* and *Acacia mearnsii* names remained unchanged as they are Australian species.

2.4 Selected Species

Vachellia karroo (previously known as *Acacia karroo*) and *V. nilotica* (previously known as *Acacia nilotica*) are associated with bush encroachment and thicket formation in African savannas (Garner and Witkowski, 1997; Radford *et al*., 2001; Munker, 2009). Bush encroachment, is defined as a process of increase in woody plant density, where the tree volume increases in savannah ecosystems, due to overgrazing and/or fire (Bond, 2008). *Vachellia nilotica* is common in semi-arid savannah areas and found in clay soils, while in the coastal areas, it tends to prefer sandy alluvial soils. The species is widespread across KwaZulu-Natal (Smit, 1999).

The natural distribution of *A. mearnsii* and *A. dealbata* is south-eastern Australia. Both are pioneering species in Australia and invade several biomes in South Africa, including grasslands, savannah, forest and fynbos (Nyoka, 2003). They favour areas of higher soil moisture availability and a warm, humid climate, although they are rarely distributed in areas where the temperature exceeds 38°C (Searle, 1997).

Acacia mearnsii is classified as one of the 'top 10' invading species in South Africa, and has invaded an area of 2.5 million ha (Le Maitre *et al*., 2000), whilst *A. dealbata* is classified within the 'top 25'. Both species are classified as Category 2 plants by the National Environmental Management: Biodiversity Act [No. 10 of 2004] updated in the Government Gazette, 1 August 2014, are regarded as highly invasive (Beck-Pay, 2013) and are thought to produce a high number of viable seeds. The Department of Environmental Affairs and Tourism (DEAT) is currently hosting countrywide workshops, explaining the new regulations of National Environment Management Biodiversity Act (NEM: BA) Invasive Species Regulations. For example, if a person's land contains IAPs, estate agents are unable to sell a property without an invasive species compliance certificate. All municipalities and large land owners, by law, need to develop an invasive species management plan by 1 August 2017.

2.4.1 The history of *Acacia* (wattle)

Wattle has an interesting history in South Africa. *Acacia mearnsii* seeds were introduced in South Africa from Australia in the early 19th century. John Vanderplank planted the first recorded wattle seeds on his farm for shelter in Camperdown, KwaZulu-Natal (Lighton, 1958). The most commonly held wisdom is that travellers who passed Vanderplank's farm collected seeds and thus the exotic species spread inland (Lighton, 1958).

In the 1870s, Mr. George Sutton is believed to have been the first person in South Africa to plant a black wattle plantation in Howick, KwaZulu-Natal (Scotney, 2010). Sutton sent samples to be tested for the tannin content, with successful results, and the wattle industry boomed. The first wattle bark factory was constructed in Pietermaritzburg in 1915, and in 1941 the Wattle Research Institution was established (Sherry, 1971).

2.4.2 Ecology of *Acacias*

Black wattle (*A. mearnsii*) plantations in South Africa are predominantly found between 27° and 30° East and 25° and 33° South, which includes the provinces of the Eastern Cape, Mpumalanga and KwaZulu-Natal (Chaunbi, 1997). *Acacia mearnsii* is a pioneer species that has a relatively short life (15–20 years). The species is a fast-growing, evergreen, leguminous shrub or small tree. At maturity, this species ranges in height from 5–15 m, with a diameter at breast height (dbh) ranging from 10–35 cm (Searle, 1997). It generally takes two to three years before it first flowers and it will be seed-bearing in its fourth to fifth year as a crop (in plantations) in South Africa (Nyoka, 2003). The major limiting factor to cultivation is rainfall. Plantations are predominately in summer rainfall regions, with an average annual precipitation of between 870–1050 mm (Chaunbi, 1997). The ideal soils for plantations are those with high organic matter content, good permeability and water-holding capacity, and a depth of approximately 40–150 cm. In the native Quercus robur forest in North West Spain the *Acacia dealbata* invasion has modified the biotic and the abiotic component of the ecosystem and decreased the species richness of the soil seedbank (González-Muñoz *et al*., 2012).

Within an *A. mearnsii* jungle[*] stand, generally the largest trees are to be found where there is increased soil moisture availability, usually along water courses or in deep alluvial soils (Searle, 1997). Growth is poorer in shallow soils, in particular if there is a large amount of quartz (Chaunbi, 1997). *Acacia mearnsii* and *A. dealbata* predominately invade riparian zones (Le Maitre *et al*., 2000).

Germination depends on the breakdown of the seed coat generally over a period of a year or more (Keeley *et al*., 2012). Heat treatment destroys the impermeability of the seed, which suggests that there could potentially be a mass germination of seeds after a fire (Keeley *et al*., 2012). However, several fires will destroy the seeds and they will no longer be viable. After a fire or land clearing, the germination of seeds is vigorous, creating even-aged stands. Similar to most *Acacia* species, the seed has a hard coat and is impervious to water (Searle, 1997). The size of the invasive *Acacia* species stand is determined by the extent of the disruption and the germination ability of viable seeds (Searle, 1997), with density of the stand decreasing with time as competition for the site increases and environmental hazards, insects and fungal infestations take their toll on the trees. The wattle stand continues to decline in vigour and density until there is a further disturbance on the site (Searle, 1997), thus stimulating the seed bed to germinate, creating a new generation.

2.4.3 Ecology of *Vachellias*

Vachellia species are not grown for commercial use, but occur naturally in South Africa. *Vachellia karroo* is a small-to medium-size tree, sometimes deciduous (Pooley, 1993). It is the most wide spread *Vachellia* species in South Africa; drought-and frost-resistant, ranging in habitat from desert to floodplains, montane environments to grasslands (Smit,1999). It grows rapidly in any soil type and height ranges from 4-7 m but it can reach up to 20 m. Flowering occurs from two to three years of age and trees can flower up to four times a year, depending on rainfall (Pooley, 1993). The species occurs widely in KwaZulu-Natal, growing in most soil types and is often associated with heavy clay soils on the banks of rivers and streams (Smit, 1999).

---

[*] Jungle wattle refers to wattle that grows wild, no longer in controlled plantations.

Vachellia nilotica is a small tree found predominantly in KwaZulu-Natal below the Drakensberg mountain range, particularly in bushveld and dry valleys (Pooley, 1993). The most favourable conditions are high rainfall grasslands (Pooley, 1993). The height of *V. nilotica* ranges from 3-6 m, with a flattened crown (Smit, 1999). Flowers are scented round yellow balls with up to eight per node (Pooley, 1993).

2.4.4 Environmental and economic impact of IAPs

It is estimated that these IAPs use approximately 7% of total mean surface water runoff in South Africa, which places *A. mearnsii* and *A. dealbata* first and third, respectively, amongst the IAPs for causing water loss (Le Maitre *et al.*, 2000). The economic value of the 5-13% reduction in stream flow caused by *A. mearnsii* (Le Maitre *et al.*, 2000) was estimated at US $ 1.4 billion (de Wit *et al*., 2001). Once an area has been burnt, soil erosion can be a problem as there is little vegetation to hold the topsoil, and so IAPs can indirectly increase soil erosion.

Biodiversity is critical for food security and nutrition and many species make up a vital web of biodiversity within the ecosystems on which global food production depend, (FAO, 2015) yet these IAPs occupy previously indigenous ecosystems. 8 750 species have been recorded as being introduced into South Africa, of these, 161 are regarded as invasive species (van Wilgen *et al.*, 2001). The South Africa government is aware of the impact IAPs have on the economy and food security and, through legislation, is responding to the need to manage these, both harmful and beneficial, species.

2.5 Legislative Framework in South Africa

South Africa has a long history of IAP management, being one of the first countries in Africa to use biological control (Henderson, 2007). Indeed, South Africa is one of only a few countries in Africa that contribute substantial resources towards addressing IAPs and the country has leading legislation with regards to IAPs. Two Acts, in particular, consider the management and control of IAPs, (i) Conservation of Agricultural Resources Act of 1983 (CARA), and (ii) National Environmental Management: Biodiversity Act of 2004 (NEM: BA). Furthermore Working for Water (WFW), a pioneering program founded in 1995, is a social upliftment program of the former Department of Water Affairs, the aim of which to remove IAPs.

2.5.1 Conservation of Agriculture Resources Act of 1983 (CARA)

The Conservation of Agriculture Resources Act of 1983 (CARA) considers 'problematic' plants species. In 1983, 56 alien plant species were listed as weeds or invaders (Henderson, 2007). Regulations 15 and 16 aim to address the accelerating deterioration of South Africa's natural resource base due to IAPs (ARC, 2010; SANA, 2012), CARA of 1983 was updated in March 2001, and has categorised alien invasive species into three categories, based on their invasiveness and commercial value, with Category 1 being most serious and Category 3 being the least serious. If a species is categorised as Category 1, it is a weed of no value, and must be removed and destroyed immediately (where possible) or controlled, and trade in these species are banned. Category 2 species are recognised as invaders with commercial value and they (and their products) may be traded and grown under permit conditions only and landowners are required to take steps to limit their spread. Category 3 species may no longer be planted, and are recognised as invaders with ornamental but no commercial value. Steps are required to limit the spread of these species, further plantings are banned and the sale of these plants and their products are prohibited (DAFF; 1983; ARC, 2010; SANA, 2012). *Acacia dealbata* is classified as Category 1 in the Western Cape and as Category 2 in the remainder of South Africa (Environment, 2013), whilst *A. mearnsii* is classified as Category 2 throughout South Africa.

All relevant species listed in CARA have now been incorporated into the interim regulations in terms of NEM: BA which was published in February 2014 (Government Gazette Vol. 584, no. 37320 of 12 February 2014). The regulations include 11 lists of alien species that require management in South Africa (Henderson, 2007). The South African government is fully supportive of commercial forestry based on these species and recognizes the important contribution that these IAPs make to the South African economy and the welfare of its people (SANA,2012). The Conservation of Agricultural Resources Act states that no area can be demarcated for the growing of Category 2 plants unless the land user is able to ensure that the invader plants shall be confined to the area and that the cultivation of the invader plants shall be strictly controlled (SANA, 2012). In terms of demarcation, any area where a water use license for stream flow reduction activities has been issued (in terms of section 36 of the National Water Act, 36 of 1998) is deemed to be demarcated under the terms of CARA, an example is a registered timber plantation.

A land user has to ensure that steps are taken to limit the spread of propagating material of the IAPs to land and inland water surfaces outside the demarcated areas (WFW, 2015). These species are regarded as weeds outside of these demarcated areas, and landowners are required to control the species where they occur on their properties. Working for Water will help remove the initial stand but, without adequate seed bed knowledge and control, the long-term management is likely to be inadequate.

2.5.2 National Environmental Management Act: Biodiversity of 2004

The National Environmental Management Act: Biodiversity of 2004 (NEM: BA) states that the aim of the Act is:

"To provide for the management and conservation of South Africa's biodiversity within the framework of the National Environmental Management Act, 1998; the protection of species and ecosystems that warrant national protection; the sustainable use of indigenous biological resources; the fair and equitable sharing the benefits arising from bioprospecting involving indigenous biological resources; the establishment and function of a South African National Biodiversity Institute; and for matters connected therewith" (Proc. No. R47, Gazette No. 26887 dated 8 October 2004).

Objectives stated directly from the Act are:

(a) Within the framework of the National Environmental Management Act of 2004, to provide for:
   - (i) the management and conservation of biological diversity within the Republic and of the components of such biological diversity;
   - (ii) the use of indigenous biological resources in a sustainable manner; and
   - (iii) the fair and equitable sharing among stakeholders of benefits arising from bioprospecting involving indigenous biological resources;

(b) to give effect to ratified international agreements relating to biodiversity which are binding on the Republic;

(c) to provide for co-operative governance in biodiversity management and conservation;

(d) to provide for a South African National Biodiversity Institute to assist in achieving the objectives of this Act.

The National Environmental Management: Biodiversity Act of 2004 (NEM: BA) refers to IAP's and their management and control (ARC, 2010; SANA, 2012). IAPs are categorised, depending on their invasiveness. *Acacia mearnsii* and *Acacia dealbata* are both classified as Category 2 species in the National List of Invasive Species in terms section 70(1)(A), published by the National Environmental Management: Biodiversity Act [No. 10 of 2004] updated in the Government Gazette, 1 August 2014. Despite the negative impact of IAPs', some have considerable value. In some cases, commercial species become invasive and spread beyond the areas in which they are cultivated (van Wilgen *et al.*, 2001).

A conflict of interest between commercial wattle growers and environmentalists has caused much debate, which arose from the classification of *A. mearnsii* as Category 2, from initially not allowing biological control in the provinces of KwaZulu-Natal and Mpumalanga (Nyoka, 2003). These conflicts have to be dealt with in a sensitive manner, if progress is to be made in reducing the significant negative impacts of IAPs and satisfying all interested parties (van Wilgen *et al.*, 2001). *Acacia mearnsii* is exempt from the provisions of section 71(3) prohibition in terms of section 71A (1) if *A. mearnsii* is part of an existing plantation.

2.5.3 Working for Water (WFW)

Working for Water (WFW) is a pioneering programme established in 1995 and has been successful in combining ecological concerns with social development benefits (de Neergaard *et al.*, 2005). In 1995, WFW was allocated R25 million (CAB, 2001), but by the 2013/2014 financial year, it had grown to R1.28 billion (WFW, historical expenditure, http://sites.google.com/site/wfwplanning). WFW contributes to poverty alleviation and controlling IAPs and is globally recognised as an outstanding environmental conservation initiative (WFW, 2004). This labour-intensive program provides employment for marginalized sectors of South African society (Ntshotsho *et al.,* 2015). However, leading authors have questioned if the money 'is being spent effectively?' For example it has been stated that the current rates and approaches to clearing are not sufficient to bring the problem of IAPs in South Africa under control (van Wilgen *et al*., 2012a; Ntshotsho *et al*., 2015).

The WFW estimates that IAPs in South Africa are currently consuming 3.3 billion m^3 of water per year above the levels required by indigenous flora. This represents approximately

6.7% of the annual runoff (Preston, 2003). Between 2002 and 2003, 23 105 ha of IAPs were cleared, however no seed treatment was used (WFW, 2004). Working for Water estimates that, with the current rates of clearing using physical and chemical methods, it will take 31 years to clear invasive *Acacia* species. Other studies (van Wilgen *et al.*, 2012a) have shown that depending on the species, it could take up to 83 years to clear the most important species, assuming that no further spread would take place during this time. This would involve more than just the initial ‘cut and go’. Maintenance and seed management would form a vital link in the control chain. In a circular, dated July 2008, WFW shifted their approach, suggesting that private land owners manage IAPs themselves with penalties and incentives in place. This would require landowners to manage seeds and their viability, in order to break the cycle of endless clearing. The implementation process of clearing these species is extremely costly and it is estimated that between 1995 and 2008, WFW spent R 561.9 million (~US $ 66.1 million) on *A. mearnsii* and R 79.3 million (~US $ 9.2 million) on *A. dealbata* removal (van Wilgen *et al.*, 2012a).

There is a growing concern that, after 20 years of WFW implementation, the area covered by IAPs continues to grow, despite the amount of money being spent on eradication. The costs of controlling invasive species increases exponentially based on the size of area infested (Rejmánek and Pitcairn, 2002). It should be noted that projects controlling IAPs are potentially unsustainable as they often rely heavily on external funding (de Neergaard *et al.*, 2005). The WFW programme was administrated by the Department of Water Affairs, until a shift in government departments, when it was transferred to the Department of Environmental Affairs and Tourism. This has allowed for an increase in funding opportunities for the scientific community to research improvements in ecosystem management (van Wilgen *et al.*, 2012b).

McConnachie *et al*., (2012) state that WFW only records plant cover in areas that have been treated and costs of specific sites where contracts are awarded to work. Only the input variables (money spent, area cleared, and jobs created) are recorded. Therefore there is no actual assessment of the effectiveness of the work done, and McConnachie *et al*., (2012:129). asks “How can one measure WFW effectiveness in terms of progress towards the goal of restoring ecosystem health?” Van Wilgen *et al*., (2012a) found that, despite substantial spending on control operations of R 3.2 billion (~US $370 million), the extent of invaded areas in South Africa had grown since the inception of WFW in 1995. Furthermore, the Working for Water program tends to focus on the above-ground plant material, and uses mechanical or chemical methods for removal of IAPs (Van Wigen *et al.*, 1992). These methods require follow-up procedures, to ensure the long-term or permanent removal of these alien species.

2.6 Control Methods

There are a number of techniques to control IAPs, all requiring at least three phases, namely: (a) the initial control; (b) the follow up control of seedlings, coppice growth and root suckers; and (c) the annual maintenance control (DWA, 2015), for which seedbank information is necessary.

WFW currently uses four methods to remove IAPs during the initial phase. Each method used separately and/or integrated is species-and site-specific. Trees can be felled by hand-saw or power-saw. Felling followed by painting prevents regrowth and injecting chemicals into larger trees is used where this is easier than cutting the tree. A less labour-intensive method which does kill the tree is ring barking, where a cut around the base of the tree is used. Small seedlings can be hand-pulled (Conservation at Work, 2015). Fire is used strategically in areas that are too dense or inaccessible to use other methods. In this way areas are segmented and then subjected to controlled burns. Finally, herbicides can be sprayed on young saplings.

In addition, the Plant Protection Research Institute includes a variety of techniques, namely, biological control, chemical control, bioherbicides and integrated control, to manage the emergence and spread of IAPs (Henderson, 2014)

Biological control methods are a lengthy process as the potential introduction needs to be fully screened before it is implemented. Extreme care has to be taken to ensure there are no unwanted side effects associated with the use of biological control agents (Nyoka, 2003). The impact of biological control agents takes a long time to be seen compared to conventional methods. Biological control in South Africa has been used since 1913, however public concerns over long-term safety are still an issue (Zimmermann *et al*., 2004). These concerns appear not to be justified by evidence, as more than 350 biological control agents have been released worldwide and only eight instances of non-target damage have been reported, over the past100 years (WFW, 2004).

There are a limited number of species that are suitable for biological control work in South Africa. The Acacia Seed Weevil (*Melanterius maculatus*) is a seed feeder. It does not harm the tree but damages the seeds and therefore reduces seedbank viability and regrowth. It is currently being used on *A. mearnsii* (ARC, 2015), for example in the Golden Gate Highlands National Park where 3 000 weevils were released on approximately 12ha area of *A. mearnsii* in November 2014 (ARC, 2015).

The main advantage of biological control is that it is more cost-effective and less resource-intense and hazardous, than manual and chemical methods. It is economically and environmentally sustainable. However, its main limitation is the extended time period for its establishment and success (WFW, 2004). South Africa has released 106 biological control agent species for the control of 48 IAPs (Henderson, 2007). Despite the cost of introducing biological control agents, this cost is substantially less than the benefit to the ecosystem being protected (Henderson, 2007).

In the future, biological control may be incorporated, together with other methods. Research to breed a sterile *A. mearnsii* tree has been on-going (Beck and Fossey, 2007). According to Chan *et al*., (2015), this research was stopped at the end of 2012. This type of research emphasises the serious need to control the seed production and to balance the need of wattles' valuable products versus its problems as an invader. Comprehensive methods are needed with quantitive information on all aspects of control. Here, seedbank and viability information is required. Strydom *et al.,* (2012), showed that *Acacia saligna* still presents serious challenges for managers as a significant number of seeds are still present in the upper soil layers despite 20 years of destructive biological control (*Uromycladium tepperianum*) agents being introduced.

South Africa has applied substantial funds and effort in its attempt to control its IAPs. Most of the effort has been on the visible, above-ground material. Without an integrated multi-disciplinary approach, the results will be inadequate. South Africa is forced to incur the costs of removal now, or face an even worse scenario of the growing impacts in the future (van Wilgen *et al*., 2001).

2.7 Plant Regeneration

Acacia species can regenerate both asexually and sexually. Asexual reproduction occurs through coppicing (Plate 2.1), and sexual reproduction occurs through the production of seeds (Fenner and Thompson, 2005). Many *Acacia* trees are able to re-sprout after damage from grazing herbivores, fire or human interference (Bond, 2008). There are four types of spouting, sprouting from the base of the trunk, underground stems, roots and from layered branches (Del Tredicic, 2001). This type of reproduction helps to preserve this species in an environment where seed based regeneration is limited by competition from grasses (Bond and Midgley, 2001).

Seed production is an important regeneration mechanism for *Vachellia* tree species such as *V. karroo,* and *V. nilotica* (Munkert, 2009). Several of the *Acacias* (notably *A. mearnsii, A. melanoxylon* and *A. saligna*) re-sprout vigorously from roots after mechanical clearing, further complicating control (van Wilgen *et al.*, 1992).

An impermeable seed coat will prevent water from being imbibed, until surrounding conditions are favourable for seedling growth (van Staden *et al.*, 1989). *Acacia* seeds that have been kept dry are able to remain dormant for up to 50 years (Farrell and Ashton, 1978; Tybrik *et al.*, 1994).

A study conducted by Donaldson *et al*., (2014) on *A. elata* (introduced into South Africa for forestry and dune stabilization), recorded a mean seed rain of 767 seeds per m^2. These results are within the range of *A. saligna* (530 seeds/m^2) and *A. cyclops* (1 197 seeds/m^2) (Milton and Hall, 1981), Donaldson *et al*.'s (2014) estimate of the annual seed production of individual *A. salingna* trees (10 000–50 000 seeds annually) is similar to those estimated by Milton and Hall (1981) for Australian *Acacia* seed production in the Western Cape (9 500–48 000 seeds per year).

Plate 2.1 Trees coppicing after being cut. (a) *V. karroo* in Weenen. (b,c) *A. mearnsii* coppicing after two or more cut back, illustrating their ability to regenerate.

2.7.1 Seed dispersal

Seed dispersal is the spatial pattern of seeds in the soil and is a response to the spatial pattern of the parent trees (Witkowski and Garner, 2000). It is used primarily to avoid natural enemies and sibling interactions and to locate a site physically suitable for the successful establishment of the next generation. There are many factors that can affect seed dispersal dynamics (Green, 1983). The four main factors for spatial patterns are the spatial pattern of parent trees, the agents of seed dispersal, predominant winds and runoff water. Other factors are the dynamics of seed in the soil, and the physical removal of seeds by insects and animals (Witkowski and Garner, 2000).

Natural seed distribution is limited by distance, thus for seeds to reach greater distances secondary dispersal pathways are required. These include wind, water, animals and humans. The wind direction and strength will increase seed distribution, and dominant wind direction has been shown to influence seed dispersal (Marchante *et al*., 2010). The patterns of rainfall and water flow will also affect seed dispersal (Wilson and Traveset, 2000). Buoyant pods potentially transported downstream by water are of the greatest concern to IAP management as a mode of dispersal. *Acacia implexa* of the Western Cape was shown to disperse over long distances along a river course (Kaplan *et al*., 2014). If *Acacia* pods are consumed by animals before seeds or pods are dispersed, there is a possibility that a significant proportion of seeds will evade infestation by some of their natural enemies, such as beetles (Kriticos *et al*., 1999). Kaplan *et al*. (2014) study on anthropogenic seed dispersal on *A. stricta* found that human activity of road graders and plantation mechanical equipment played a significant role in dispersing seeds. These secondary dispersal methods will ultimately play a greater role in the overall spread of the species (Donaldson *et al*., 2014).

2.7.2 Soil seed bank

Soil seed banks are defined by Simpson *et al*. (1989) as all the viable seeds found in and on the soil or in associated leaf litter, and they consist of dormant seeds that have the potential to replace adult plants in a population. Soil seed banks of *Vachellias* (*Acacias*) are highly multi-layered systems (Tybrik *et al.,* 1994). There are gaps in the understanding of seed bank dynamics. Understanding these processes will provide an explanation to the process of bush encroachment (Garner and Witkowski, 1997), as well as that of IAPs.

The seeds that tend to remain in the soil for long periods of time are often those that are compact, small and smooth, and that have specific requirements for germination (Thompson, 1987). These seeds remain dormant until they have met their requirements for germination. Farrell and Ashton (1978) explain that the seeds of Australian *Acacia* species can remain viable for up to 50 years. Concern still remains regarding the soil-stored seed bank and inadequate knowledge of seed bank status and dynamics, and these factors are crucial for the effective management of IAPs (Strydom *et al*., 2012).

In a study of *Acacia saligna*, in South Africa, seed production of between 2 000 and 212 000 seeds per m^2 has been measured (Morris, 1999; 1997). However, one must note that the number of seeds in the seed bank does not accurately reflect the number of seedlings that will emerge after germination as the number of seedlings is only a small portion of the seeds initially present in the soil (Witkowski and Wilson, 2001). Knowing the size and composition of the seed bank is essential in reflecting the past, present and future state of the ecosystem

(Solomon *et al.*, 2006). The highest recorded seed number for *A. mearnsii* is 5 314/m^2 (Pieterse, 1997). The highest seed viability for *A. mearnsii* is 83% (Milton and Hall, 1981).

Kaplan *et al*.'s (2014) study on *A. stricta* measured a seed bank under a canopy of ~ 1 000 seeds per m^2. The seed number does not necessarily mean that all the seeds will germinate, because the seed viability rate needs to be factored in. Kaplan *et al*. (2014) used the TTZ (Tetrazolium chloride) test to ascertain seed viability of *A. stricta*. A sample of 200 seeds were stained using a 1 % 3, 5-triphenyl tetrazolium chloride solution.

2.8 Conclusion

Australian *Acacias* have played a significant role in habitat destruction in South Africa. The *Acacia'*s ability to regenerate sexually and asexually makes them a highly invasive species, which impacts on the natural balance in the ecosystems, impacting the indigenous species and results in a loss of biodiversity. The water consumption of IAPs is greater than that of indigenous species, reducing water flow and having negative consequences. The South African government is aware of the problem and has frameworks in place to control IAPs, in particular NEM: BA and WFW, which have operated for the last 20 years. Various control methods such as biological control need to be integrated to control and combat the IAPs.

The hidden threat of the seed bank and highly effective seed dispersal need to be incorporated into IAPs management plans. These seeds can remain dormant until they have met their requirements for germination. If not controlled, the problem will become unmanageable and the ecological damage irreversible. Some IAPs have a commercial value, which complicates the situation, and therefore the management of IAPs is complex.

CHAPTER THREE

METHODS

3.1 Introduction

The primary focus of this research was to investigate the seed distribution and viability of four selected tree species. The research was carried out at three study sites in KwaZulu-Natal, South Africa (Figure 3.1). Twelve seed-bearing trees of each of the four species were sampled. The field work was undertaken from November 2013 to June 2014.

3.2 Study Sites

The study sites were selected to fulfil the criteria of stand-alone trees, where there was no cross-contamination of species, nor interference of the geographical isolation, of an individual tree. This was to ensure that the seeds found were from that specific individual specimen. Each species was sampled after pods had developed and fallen. The species were not statistically compared between sites and species due to the geographical differences and varying environmental factors.

3.2.1 Weenen

Weenen is located on the R74 between Greytown and Ladysmith. The Weenen area has rocky rugged slopes, with trees of short to medium height. The area is classified as *Thukela Valley Bushveld*, under the sub-escarpment savannah bioregion (Mucina and Rutherford, 2011). Weenen receives 550-850 mm rainfall per year, predominantly in summer. *Vachellia karroo* and *V. nilotica* dominate the Thorn Veld (61%) (Mucina and Rutherford, 2011).

3.2.2 Hluhluwe

Bonamanzi Game Farm is located near the town of Hluhluwe, northern KwaZulu-Natal. This site has extensive flat plains to undulating slopes, dominated by woodlands with grassy undergrowth. The bioregion is classified as *Tembe Sandy Bushveld.* The area receives 550 – 800 mm of rainfall per year (Mucina and Rutherford, 2011).

3.2.3 Mooi River

Mooi River is located adjacent to the N3 freeway between Estcourt and Howick. It is classified as *Mooi River Highland Grasslands*, under the sub-escarpment grasslands bioregion (Mucina and Rutherford, 2011). The area receives approximately 785 mm per year predominately in summer.

Mooi River was chosen as the main site for invasive *A. dealbata* and *A. mearnsii* because the *Acacias* occur as 'jungle wattle' stands in the region.

.

Figure 3.1 Map of the study sites.

3.3 Species Descriptions

The genus *Acacia* (Fabaceae) is considered to be one of the most invasive taxa in the world, especially most of the Australian species (Turner and Pharo, 2005; Inderjit *et al*., 2011). African *Acacia* species (*Vachellia*) are major contributors to bush encroachment and increase the woody component of savannah and grasslands (Walters and Milton, 2003). They produce large amounts of seed and may have large soil seed banks (Walters and Milton, 2003). Exotic species produce copious numbers of hard-coated seeds which are stored in the soil, resulting in them thriving in a non-native environment (Dean *et al*., 1986).

3.3.1 *Vachellia karroo* Hayne *(Acacia karroo)*

Vachellia karroo is a small to medium-sized tree, generally single-stemmed with a rounded spreading crown (Plate 3.1a). Trees reach heights of between 5 to 12 m. Seeding occurs from March to September (Smit, 1999), with sickle-shaped pods which are green and mostly hairless and mature to brown (Plate 3.1b). Bright yellow flowers (Plate 3.1c), occur from late November to March (Smit, 1999), while seeds are a light green colour with a brown inner circle (Plate 3.5).

The leaves are dark green and dense. The new young shoots are smooth, usually hairless and are green to reddish brown and covered with small reddish sessile glands. Their distinct thorns are straight and occur in pairs at the nodes. These thorns are white (Plate 3.1d) or greyish in colour with an average length of 4 cm (Smit, 1999). The mature bark on the *V. karroo* is blackish grey with horizontal cracking.

Plate 3.1 Field images of *Vachellia karroo*: (a) a stand-alone specimen; (b) seed pods (c)yellow flowers; and (d) stems with white thorns and leaves.

3.3.2 *Vachellia nilotica* (L.) *P.J.H. Hurter & Mabb (Acacia nilotica)*

Vachellia nilotica is a small to medium-sized single-stemmed tree of 5 to 6 m, with a compact rounded or flattened crown (Plate 3.2a). Young shoots are green and covered with a thin layer of short, whitish hair. Thorns are straight or slightly curved, and appear in pairs at the nodes (Smit, 1999). Pods have a beaded appearance and hang down (Plate 3.2b). While the pods are still young and green, they have a peachy smell (personal observation). Flowering generally occurs from early November to late January (Smit, 1999), and flowers are bright yellow (Plate 3.2c). Seeds occur from February to late August (Smit, 1999). The bark of mature trees is very distinct, namely, blackish with longitudinal fissures (Plate 3.2d), while seeds are a circular shape and a dark brown colour (Plate 3.5). The seeds pods are single or in clusters (Pooley, 1993).

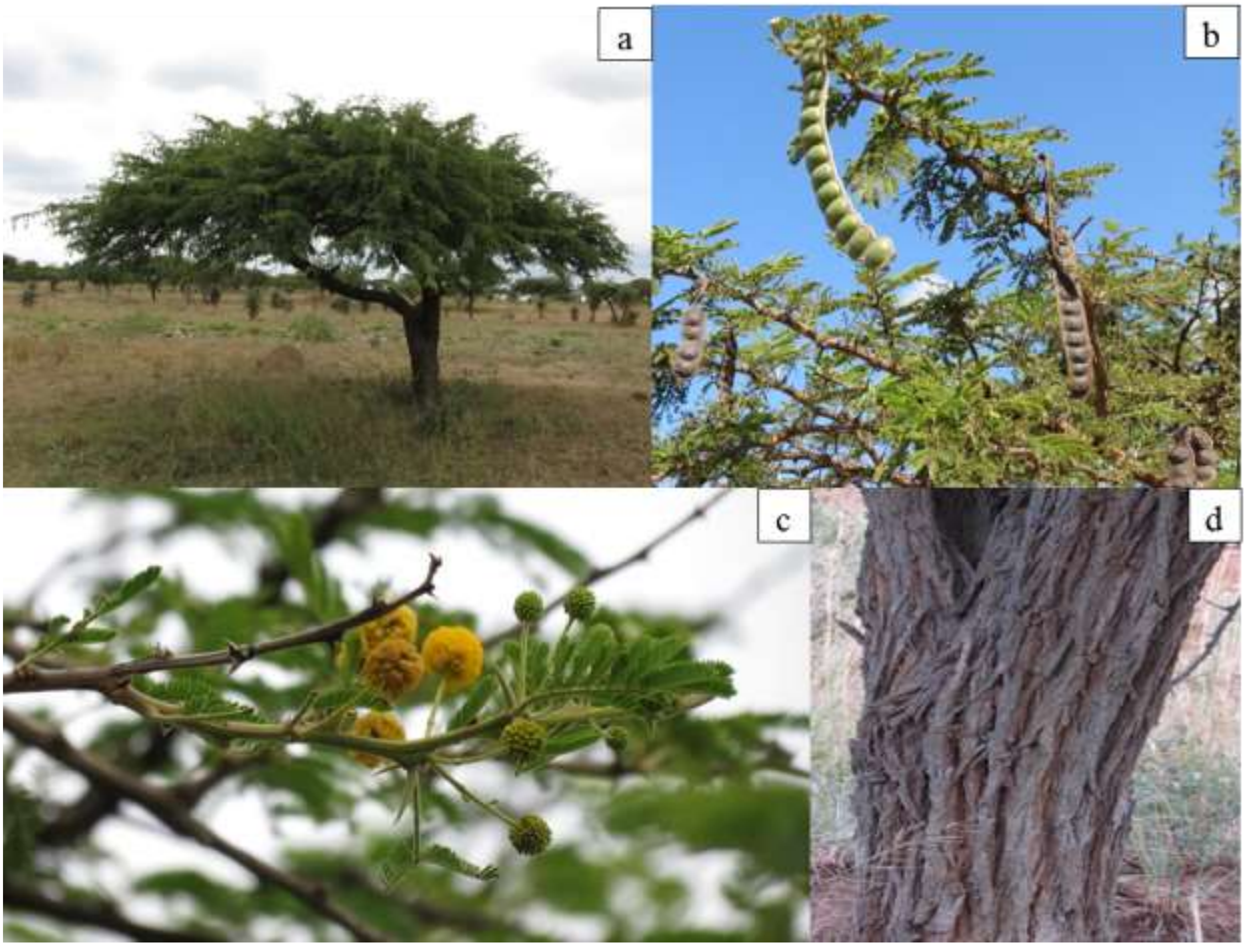


Plate 3.2 Field images of *Vachellia nilotica*: (a) a stand-alone specimen; (b) seed pods; (c) yellow flowers; and (d) tree bark with longitudinal fissures.

3.3.3 *Acacia mearnsii* De Wild.

The species flowers in the summer months between October and December, and approximately 8 to 10 weeks after floral initiation the first visible racemes appear (Moncur *et al.*, 1988). The flowers are a pale yellow (de Beer, 1986) (Plate 3.3c). The proportion of male flowers may be determined by environmental factors during the development of the flowers (Moncur *et al.*, 1988). Flower heads contain both staminate and bisexual flowers, hence not all flowers have the ability to produce seeds. The seed pods are straight or slightly curved (Plate 3.3b). The leaves are green in colour and each pinna is subdivided into many leaflets approximately 4 mm long (Plate 3.3d).

Plate 3.3 Field images of *Acacia mearnsii*: (a) a stand-alone specimen; (b) seed pods containing seeds; (c) yellow flowers; and (d) leaves.

3.3.4 *Acacia dealbata* Link

Acacia dealbata occurs predominantly in montane areas, and moist upland areas such as the Drakensberg and mist-belt of KwaZulu-Natal. The main difference between *Acacia dealbata* and *A. mearnsii* is their leaf colour. The leaves of *A. dealbata* are silver-grey to light green, with finely-haired short leaflets and each pinna is subdivided into many leaflets. The young bark has a distinct silver tinge (personal observation). The stems grow in any direction, thus being able to find tree canopies at different heights (González-Muñoz et al., 2012). *Acacia dealbata* shrub or tree reaches heights of 20 m, with a conical or rounded crown (Plate 3.4a). Pods are flat and brown in colour, 30-80 mm long (Plate 3.4b). Flowers are pale to bright yellow, (Plate 3.4c) with flowering occurring from July to August (Smit, 1999). The compound leaves are divided into 14-21 pairs of pinna, subdivided into many leaflets approximately 4 mm long (Plate 3.4d).

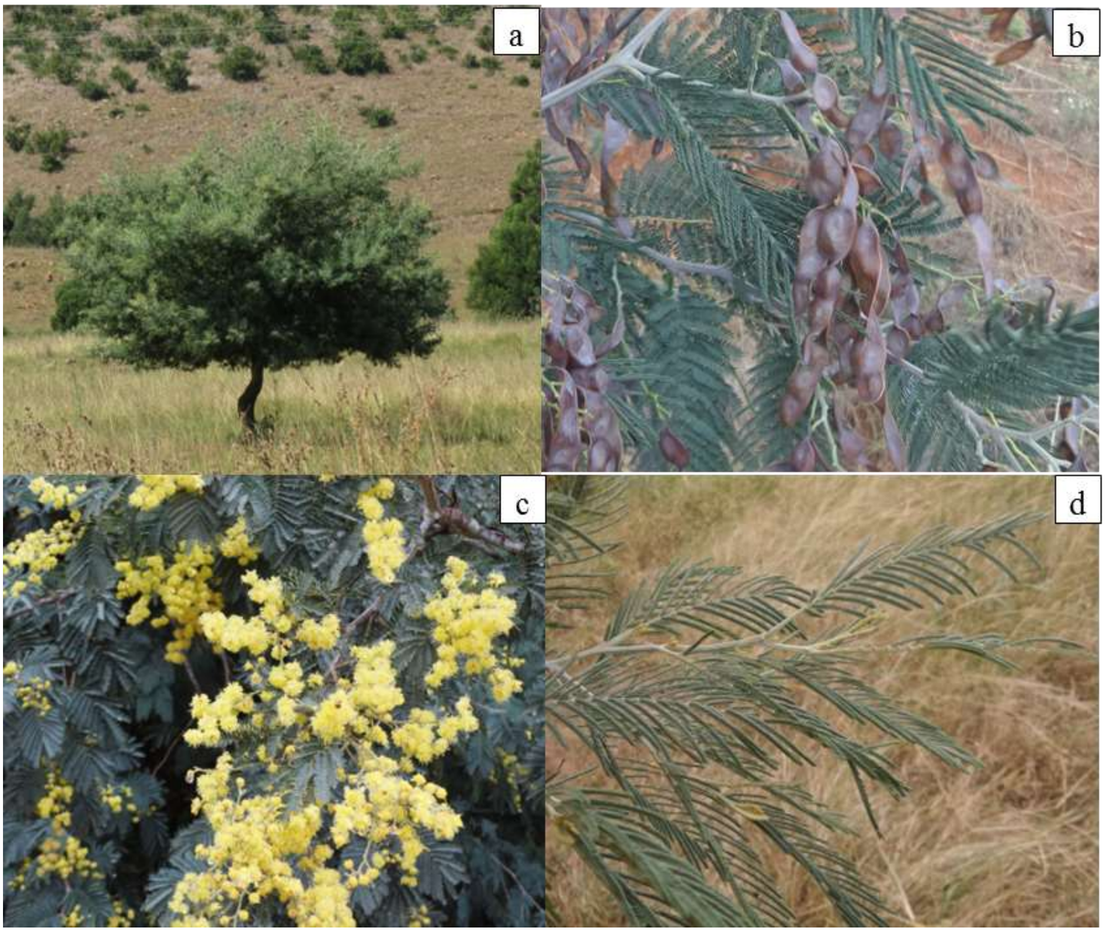


Plate 3.4 Field images of *Acacia dealbata*: (a) a stand-alone specimen; (b) seed pod; (c) pale yellow flowers; and (d) leaves.

3.4 Data Collection

Individual trees were selected, based on the criteria set out in Table 3.1.

Table 3.1 All sampled trees fulfilled the following criteria:

	Term	**Explanation**
i	'Stand-alone'	There were no younger trees under or next to the canopy. Therefore it can be assumed that the seeds directly below the canopy were those of the individual tree.
ii	Mature tree	Before sampling, confirmation that the tree was of seed-bearing age was determined by observing seeds either on the ground or tree.
iii	Canopy intact	On-site inspection confirmed that no branches had been harvested or broken. This was to ensure that the sample represented a true reflection of the canopy size.
iv	No interference	Sampled trees were inspected to ensure no interference of roads, rivers or other obvious obstructions.

3.4.1 Tree density and size

For each tree, the following measurements were calculated: the tree height (Plate 3.6a); and the longest canopy diameter (d_1) were measured with a ranging rod (Plate 3.6b); the canopy diameter perpendicular to the longest axis (d_2) was calculated as: π (d_1/2) x (d_2/2). Volume was calculated as (4/3) x π x (d_1/2) x (d_2/2) x (Height/2) (Witkowski and Garner, 2000).

A diameter of approximately 1.3 m, at breast height (dbh), was measured (Purser, 1999). For multi-stemmed trees, each stem circumference was measured and the mean calculated. The measurements were kept on field work sheets (Appendix 2). The canopy volume and seed number will be compared through regression analysis, which is a statistical process for estimating the relationships among variables.

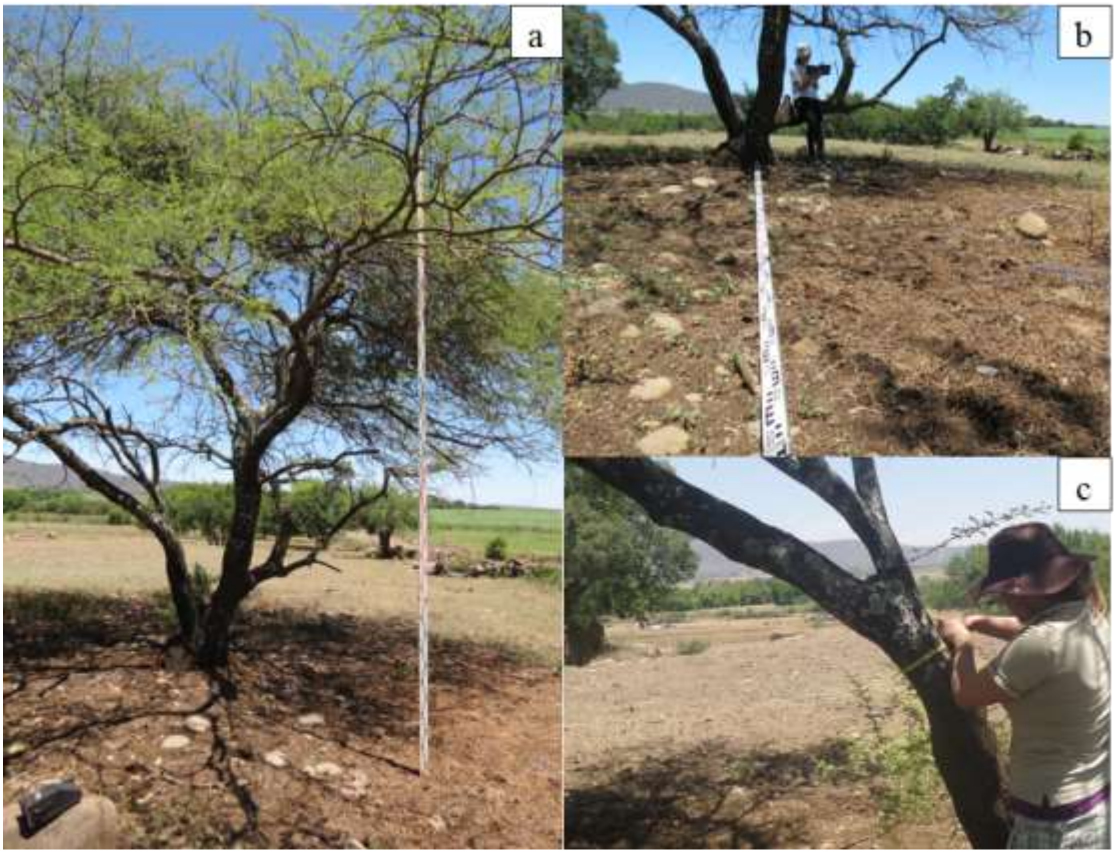


Plate 3.5 Field images of tree measurements of *Vachellia karroo*: (a) measuring tree height; (b) measuring longest canopy; and (c) measuring diameter at breast height.

3.4.2 Seed bank sampling

Twelve trees per species were sampled. Each tree was of seed-bearing age and greater than one meter in height. This was confirmed with a ranging rod, adapted from Witkowski and Garner (2000). Seed collection was undertaken after seed dispersal, although less than 1% were still attached during the field work.

Soil sampling was adapted from Witkowski and Garner, (2000). Soil samples were taken at three locations (1) 'Under', (2) 'Middle', and (3) 'Periphery', along the north/south or up-slope/down-slope axis. The 'under' samples were taken under the canopy 30 cm from the trunk; 'middle' samples were taken mid-way between the canopy dripline and trunk; and 'periphery' samples were taken 1 m beyond the edge of the canopy. If the tree was on a slope, the samples were taken up-slope and down-slope (Figure 3.2), and if the tree was on flat terrain, then samples were taken on the north/south axis.

At each site, slope was measured to investigate the impact that gradient could have on seed distribution in the seed bank. If there was an obvious slope, this dictated the axis for the micro-sites. Slopes that were between 0-3° were classified as flat, 4-10° as gentle, and a slope greater than 10° was classified as steep.

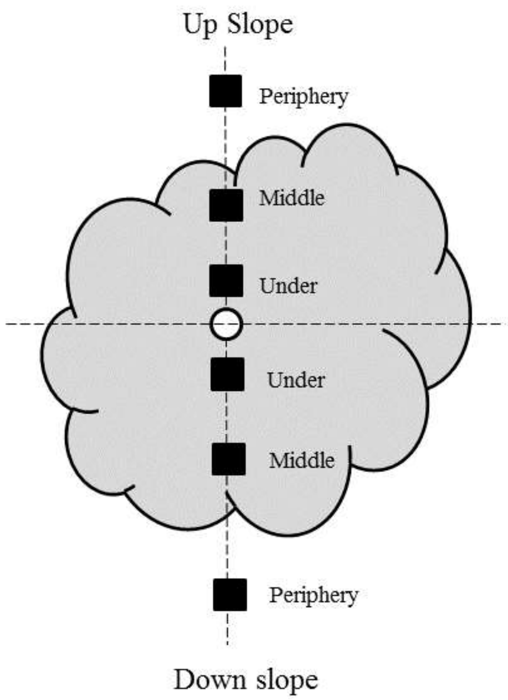


Figure 3.2 Seed sampling: Illustrating the tree canopy and the three locations of sampled points on the up-slope and down-slope axis adopted from Witkowski and Garner, (2000).

Research undertaken by Morris, (1999) and Strydom *et al.*, (2012) on *Vachellia* in the Northern Province of South Africa suggested that the majority of the seeds are located in the upper portion of the soil profile (0 to 10 cm). Therefore, in this study, seeds were not sampled (method adapted from Witkowski and Garner, 2000) from deeper than 10 cm below the soil surface. Three different depths, 0-2 cm 2-4 cm and 4-10 cm, were used. Samples were taken from six pits, at three different depths, for all 12 individual trees per species.

Each pit was demarcated by a steel quadrat 30 cm x 30 cm. Soil from the depth of 0-2 cm, 2-4 cm and 4-10 cm, respectively, was removed and sieved (Figure 3.3). Each sample was sieved through a 4 mm and 1 mm sieve. The seeds were removed from the sieves in direct sunlight, using tweezers, and they were counted. The soil was stored in paper bags and the seeds in labelled paper envelopes. No seeds were removed from the tree for sampling, only from soil samples. Seed density was calculated (length x breath x height)

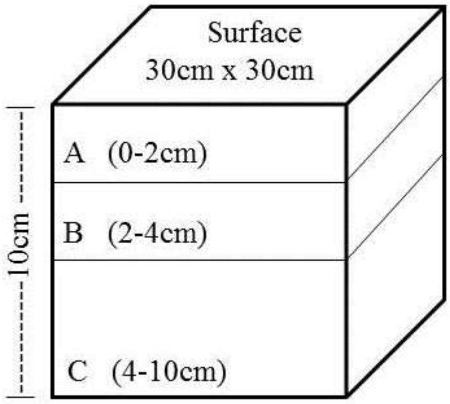


Figure 3.3 Soil sample diagram: A-0-2 cm, B-2-4 cm and C-4-10 cm (adopted from Witkowski and Garner, 2000).

Plate 3.6 Field images of soil sampling: (a) before soil collection; (b) 0-2 cm soil sample; (c) 2- 4 cm soil sample; and (d) 4-10 cm soil sample.

Plate 3.7 Seeds of the four selected species: (a) *Acacia mearnsii*; (b) *A. dealbata*; (c) *Vachellia karroo*; and (d) *V. nilotica*.

Plate 3.8 Size comparison of four tree species, from left to right: *Acacia mearnsii*, *A. dealbata*, *Vachellia karroo* and *V. nilotica*.

3.4.3 Seed viability

Viability of intact seeds was determined using (TTZ) tetrazolium chloride in the laboratory (Appendix 3). The TTZ test was a rapid test, taking 48 hours to indicate seed viability, thus many seeds could be tested in a manageable time period. The TTZ test is a biochemical test, which distinguishes between viable and dead tissue based on red staining of viable tissue (Guzman *et al*., 2011). Tri-phenyl tetrazolium chloride was reduced by terminal oxidase systems in living plant tissue, from a colourless solution to a red, water-insoluble formazan compound which was precipitated within living cells, while dead cells showed no reaction and they remained colourless (Perry, 1981). The development of red colour on the respiring tissue is based on whether the seed is alive or not (Guzman *et al*., 2011). All seeds found during sampling were tested for viability, unless there was visible insect damage.

3.5 Soil Analysis

The seeds were removed from the soil, and the remaining soil from each depth was mixed and tested for pH and soil organic matter (SOM) measured. Soil colour was determined in the field using the Munsell Chart Soil Colour Chart.

3.5.1 Soil Organic matter (SOM)

Soil organic matter was determined as loss-on-ignition of a 20 g sample at 600°C for 6 hours.

The following method (adapted from Reddy, 2015) was used in the laboratory:

The soil samples were left to dry overnight,

1) Dry soil samples were weighed and placed in crucibles (Om)
2) The soil samples were placed in a muffle furnace, increasing the temperature until it reached 600^{0} C, and left for 6 hours.
3) The soil samples were removed from the furnace and placed in a desiccator and reweighed (Do)
4) The following formula was used to calculate organic matter: $OM = \frac{Om}{Do}\ x100$

3.5.2 Soil pH

The soil pH values were measured using an YSI Professional Plus handheld multipara meter, calibrated prior to each measurement. One-third of the soil sample was mixed with two-thirds distilled water. The pH values were classified from extremely acid to strongly alkaline according to USDA (USDA, 1998).

3.6 Statistical and Quantitative Analysis

Analysis of Variance (ANOVA) techniques are used for a set of statistical problems in which one is interested in the effect of one or more non-metric variables on a single dependant variable. For an ANOVA, a hypothesis is formulated about the means of the groups on the dependant variable and then differences, in terms of the respective groups, are tested for statistical significance (Hinkle *et al*, 1979).

3.7 Conclusion

The majority of the methods replicated those of Witkowski and Garner (2000). Their methods were the most appropriate for achieving the aim and objectives of this research and allowing for replication and comparison. This project consisted of field work (Appendix 4 and Appendix 5) and laboratory work, with the aim being to quantify seed distribution and viability of four selected tree species.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents graphical summaries and description of the data to address the research aim and objectives.

4.2 Tree Characteristics

Mean tree height, canopy area and canopy volume of the selected species were assessed. *Vachellia karroo* tended to have a smaller canopy area, compared to *A. dealbata, V. nilotica* and *A. mearnsii* (Table 4.1)

Table 4.1 Tree height, canopy area and canopy volume of the selected species

Species	Mean	Standard Deviation (SD)
Tree height (m)		
V. karroo	4.2	± 1.3
V. nilotica	3.2	± 0.7
A. mearnsii	6.8	± 2.0
A. dealbata	6.3	± 1.5
Canopy area (m^2)		
V. karroo	8.8	± 6.4
V. nilotica	10.9	± 5.2
A. mearnsii	16.2	± 13.7
A. dealbata	17.2	± 7.6
Canopy volume (m^3)		
V. karroo	25.0	± 18.9
V. nilotica	24.0	± 13.1
A. mearnsii	89.2	± 100.5
A. dealbata	72.8	± 55.3

4.3 Seed Bank Distribution

4.3.1 Seed numbers

Total seed numbers collected for each tree (from all micro-sites and depths) are shown in Table 4.2 (Appendix 6). The mean seeds collected from *V. karroo* was 85 (variation: 3-235) and for *V. nilotica* it was 9 (variation: 0-27). The invasive *Acacia* species mean seeds were higher than the *Vachellia*. The mean seed collected for *A. mearnsii* was 286 (variation: 15-709) and *A. dealbata* was 1 605 (variation: 3-11 175). There was a wide range in seed numbers between different species as well as individual trees of the same species (Table 4.2).

Table 4.2 Total seed numbers per sampled tree and the seed mean compared to mean canopy volume

	Indigenous		**Exotic**	
Tree Number	*V. karroo*	*V. nilotica*	*A. mearnsii*	*A. dealbata*
1	261	0	709	706
2	189	1	96	162
3	8	25	42	167
4	15	1	406	3
5	3	1	94	11 175
6	38	4	603	3 283
7	196	0	197	288
8	235	27	176	1 935
9	7	12	357	856
10	97	0	15	180
11	3	22	191	318
12	58	12	546	183
Mean	85	9	286	1 605
Mean canopy volume (m^3)	25	24	89	73

A regression analysis of canopy volume and seed number provided no clear trend (Figure 4.1). There was a large variation per tree although but providing the mean value is of little relevance.

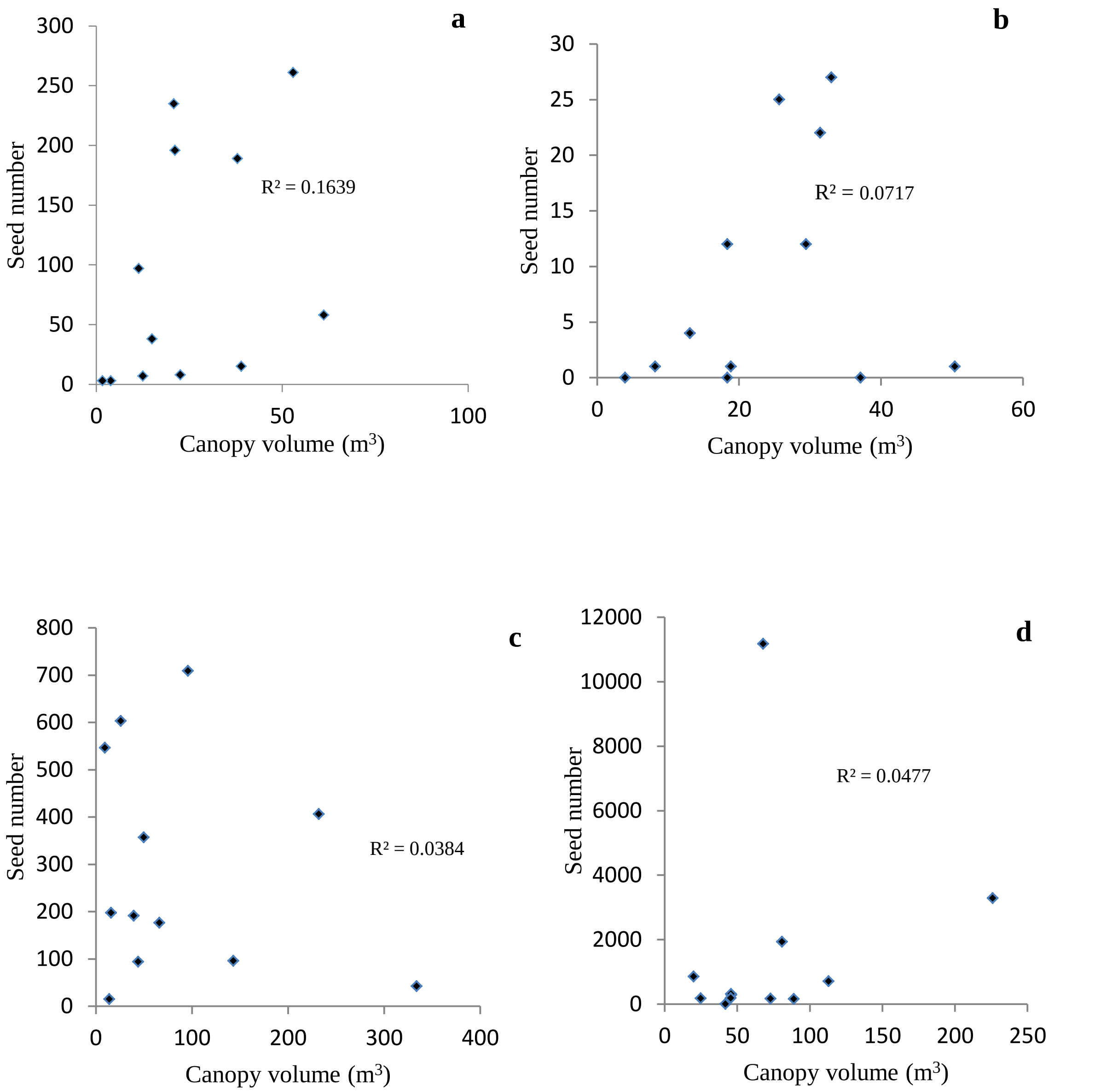


Figure 4.1 Canopy volume and seed number of selected tree species. (a) *V. karroo* (b) *V. nilotica* (c) *A. mearnsii* (d) *A. dealbata.*

4.3.2 Seed distribution

Seed numbers declined with distance outwards from the trunk. *Vachellia karroo* at a depth of 0-2 cm had total seed numbers of 110, 99 and 84 for 'under', 'middle' and 'periphery' micro-sites respectively on the down-slope. On the upslope, *V. karroo* total seed numbers were 116, 64 and 19 for 'under', 'middle' and 'periphery' micro-sites respectively at 0-2 cm (Table 4.3).

Seed numbers declined with soil depth with highest seed densities predominantly in the 0-2 cm layer of soil. In the micro-site 'under' on the downslope, mean seed numbers decreased with depth from 110, 48 to 29 for *V. karroo*. *Vachellia nilotica* total seed number decreased from 38 to 5 to 0 for the downslope micro-site 'under'. *Acacia mearnsii* total seed numbers increased slightly from 428 to 500, dropping to 35. *Acacia dealbata* seed numbers decreased from 4 118, 2 386 to 932, following the general trend.

Table 4.3 The total seed number per species on two different axes (up-slope and down-slope), at three different micro-sites (under, middle, and periphery), at three different depths (0-2 cm, 2-4 cm and 4-10 cm)

Upslope/North									
Species	Under			Middle			Periphery		
	0-2	2-4	4-10	0-2	2-4	4-10	0-2	2-4	4-10
V. karroo	116	87	77	64	51	34	19	17	8
V. nilotica	38	5	0	5	1	0	0	0	0
A. mearnsii	772	117	56	457	136	145	28	19	37
A. dealbata	2 141	1 165	842	1 575	360	210	20	124	76
Downslope/South									
Species	Under			Middle			Periphery		
	0-2	2-4	4-10	0-2	2-4	4-10	0-2	2-4	4-10
V. karroo	110	48	29	99	94	65	84	72	36
V. nilotica	32	8	0	14	0	0	1	1	0
A. mearnsii	428	210	180	500	170	94	35	27	21
A. dealbata	4 118	2 386	932	3 744	964	374	166	34	25

4.3.3 Seed density

Soil seed density in the soil is greater in the invasive *Acacia* species compared to that of *Vachellia* species. The mean seed density in the soil for *A. dealbata* was 1 448/m^3 (±3 356.1) in the 'under' micro-site, compared to *V. nilotica* that was 10/m^3 (±15.4) (Table 4.4). *Vachellia karroo* mean seed density in the 'periphery' micro-site was 30/m^3 (±53.1) compared to *A. mearnsii* 220/m^3 (±252.5).

Seed density declined with increasing distance from the trunk for all species. *Acacia dealbata* seed density decreased from 1 448/m^3 (under) to 903/m^3 (middle) to 13/m^3 (periphery) (Table 4.4). *Vachellia karroo* seed density decreased from 58/m^3 (under) to 51/m^3 (middle) to 30/m^3 (periphery).

Table 4.4 Seed number and seed density (m^3), the mean and standard deviation (SD) of species at different points associated with the canopy at different micro-sites

		Total seed number		**Seed density (m^3)**	
	Micro-site	Mean	SD	Mean	SD
V. karroo	Under	6.5	± 7.0	58.4	±63.2
	Middle	5.7	± 7.7	50.9	±69.7
	Periphery	3.3	±5.9	29.5	±53.1
V. nilotica	Under	1.2	±1.7	10.4	±15.4
	Middle	0.3	±0.8	2.5	±7.0
	Periphery	0.0	±0.1	0.2	±0.8
A. mearnsii	Under	24.5	±28.1	220.4	±252.5
	Middle	20.9	±19.5	187.8	±175.2
	Periphery	2.3	±3.6	20.8	±32.2
A. dealbata	Under	160.9	±380.9	1 448.0	±3 356.1
	Middle	100.4	±198.2	903.4	±1 783.8
	Periphery	6.2	±55.6	13.3	±119.3

4.3.4 Slope

There was no clear pattern of total seeds on the down-slope compared to the up-slope (Table 4.5). Slopes that were between 0-3° were classified as flat, 4-10° as gentle, and a slope greater than 10° was classified as steep. When combining all micro-sites and depths, there were more seeds downslope than upslope, for most selected *Acacia*. The indigenous *V. karroo* had 46% of the seeds upslope/North and 54% seeds of the downslope/South. *Vachellia nilotica* had 47% of the seeds upslope/North and 53% of the seeds downslope/South. The exotic species *A. dealbata* had 33% of the seeds upslope and 67% downslope. *Acacia mearnsii* had more seeds upslope 51%, compared to downslope 49% and 50% of the sampled area was on sleep slopes (Table 4.5).

Table 4.5 Percentage of trees sampled on steepness and seeds percentage on the upslope and downslope

Species	Steepness (%)			Seed number (%)	
	Flat (0-3°)	Gentle (4-10°)	Steep (>10°)	Up-slope	Down-slope
V. karroo	58	25	17	46	54
V. nilotica	100	0	0	47	53
A. mearnsii	25	25	50	51	49
A. dealbata	50	9	41	33	67

4.4 Seed Viability

A total of 23 715 seeds found from all micro-sites and depths from the four selected *Acacia* species were sampled for viability (96 were classified as non-viable because of visible insect damage). *Acacia dealbata* and *A. mearnsii* had a high percentage of seed viability (95.6% and 92.5%, respectively). *Vachellia nilotica* had the lowest seed viability 33.7% and *V. karroo* had 77.7% (Table 4.6).

Table 4.6 Percentage viability of selected *Acacia* species

Species	Viability (%)
V. karroo	77.7%
V. nilotica	33.7%
A. mearnsii	92.5%
A. dealbata	95.6%

The viability range was relativity small for *A. mearnsii* (82-90%) and *A. dealbata* (90-100 %) but larger for *V. nilotica* (5-83%) and *V. karroo* (63-89 %) (Figure 4.2).

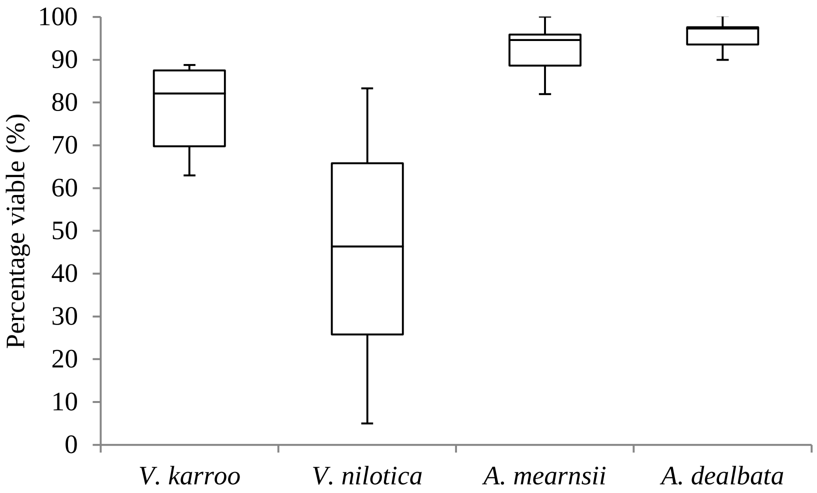


Figure 4.2 Seed viability percentage of four tree species

4.4.1 Seed viability and depth

There is no significant difference (α = 0.05) between seed viability and the sampled depth of the *Acacia* species (Table 4.11). *Acacia mearnsii* seeds were most viable at a 0-2 cm depth for all micro-sites (96%, 94% and 100%), followed by 4-10 cm (85%, 95% and 98%) (Table 4.6). For *A. dealbata*, seeds for all micro-sites at a depth of 2-4 cm were the most viable (97%, 93% and 99%), followed by those at 4-10 cm for all micro-sites (97%, 90%, and 100). *Vachellia karroo*, 4-10 cm for all micro-sites (89%, 89%, and 73%) was most viable, followed by 2-4 cm at all micro-sites (82%, 88%, and 84%). *Vachellia nilotica* had the lowest viability rate of the species (Figure 4.3).

4.4.2 Seed viability and distance

There is no significant difference (α = 0.05) between seed viability and the sampled distance of the species (Table 4.11). For *V. karroo* at a depth of 0-2 cm, the seed viability percentage decreased with distances from the trunk, from 70% to 69% to 63%. *Acacia mearnsii* at a depth of 2-4 cm seed viability percentage increased with distance from the trunk from 82% to 89% to 96% (Table 4.7).

Table 4.7 Percentage (%) of viable seeds sampled from varying depths in the soil at different categories of micro-sites for *Vachellia karroo, V. nilotica, Acacia mearnsii* and *A. dealbata.* The total number of seeds sampled per micro-site per species is in brackets next to the percentages

	V. karroo	*V. nilotica*	*A. mearnsii*	*A. dealbata*
		Under		
0-2 cm	70 (226)	33 (70)	96 (1200)	97 (6259)
2-4 cm	82 (135)	83 (13)	82 (327)	97 (3551)
4-10 cm	89 (106)	0 (0)	85 (236)	97 (1774)
		Middle		
0-2 cm	69 (163)	60 (19)	94 (957)	93 (5319)
2-4 cm	88 (145)	0 (1)	89 (306)	93 (1324)
4-10 cm	89 (99)	0 (0)	95 (239)	90 (584)
		Periphery		
0-2 cm	63 (103)	0 (1)	100 (63)	95 (186)
2-4 cm	84 (89)	0 (1)	96 (46)	99 (158)
4-10 cm	73 (44)	0 (0)	98 (58)	100 (101)

The viability range was relativity large for the indigenous species, *Vachellia nilotica* (0-100%) at a depth of 2-4 cm (Figure 4.3).

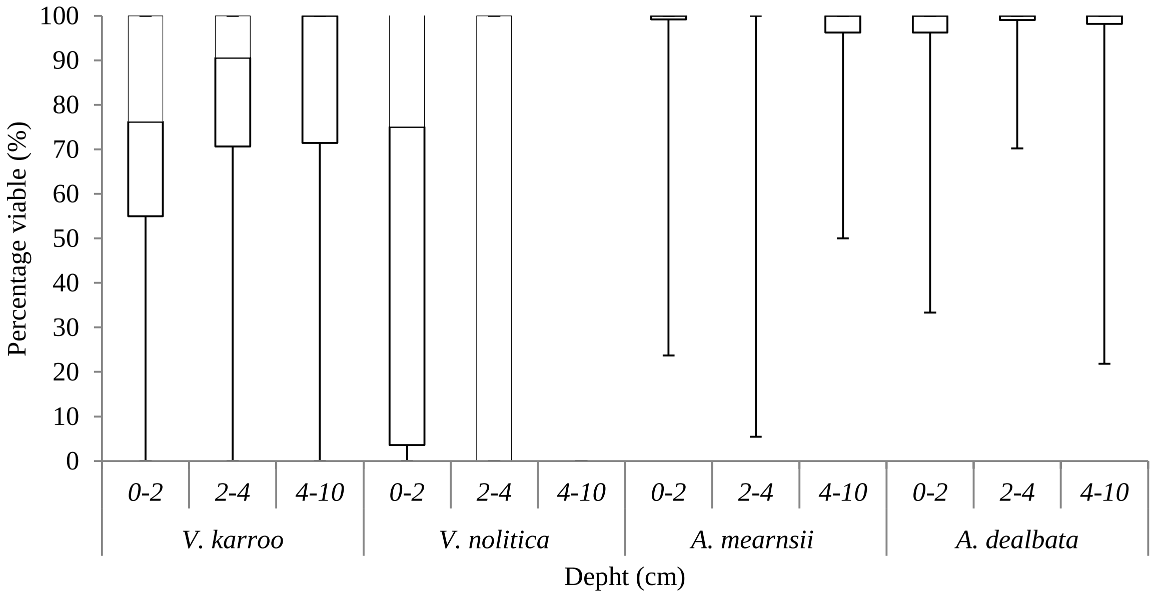


Figure 4.3 Seed viability percentage at different depths for species

With varying distances, the viability range was large for all species (Figure 4.4). *Vachellia karroo* viability ranged from (0-100%) for ‘under’, (0-100%) for ‘middle’ and (44-100%) for the ‘periphery’. *Vachellia nilotica* viability ranged from (0-100%) for ‘under’, (0-100%) for ‘middle’ and (0%) for the ‘periphery’. The exotic species *A. mearnsii* viability ranged from (33-100%) for ‘under’, (38-100%) for ‘middle’ and (94-100%) for the ‘periphery’. *Acacia dealbata* viability ranged from (88-100%) for ‘under’, (33-100%) for ‘middle’ and (93-100%) for the ‘periphery’.

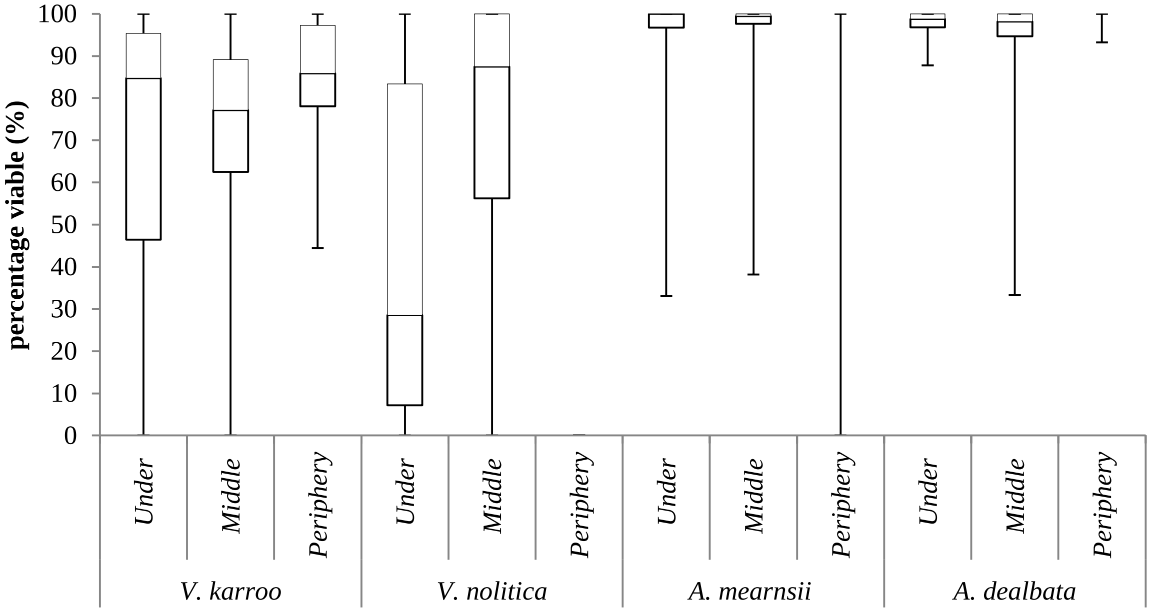


Figure 4.4 Seed viability percentage at different micro-sites for the species

Vachellia karroo (8.1%) and *V. nilotica* (5.9%) had a greater percentage insect damage compared to those of the invasive *Acacia* species *A. mearnsii* (0%) and *A. dealbata* (0%) (Table 4.8). Most of the insect damage for both *Vachellia* species was in the upper layer (0-2 cm) nearest the trunk (Appendix 7).

Table 4.8 Seed predation

Species	Insect damage (%)	Physical damage (%)	Total
V. karroo	8.1	0.9	1 109
V. nilotica	5.9	0.0	101
A. mearnsii	0.0	0.1	3 432
A. dealbata	0.0	0.0	19 256

4.5 Soil Analysis

4.5.1 pH values

The pH of the soil sample ranged from 6.1-8.5. *Vachellia karroo* had highest pH value and *A. dealbata* had the lowest (Table 4.9). (Details can be found in Appendix 8).

Table 4.9 The mean soil pH values of each species at each micro-site

	pH values			
	Micro-site	**Mean**	**SD**	**Classified***
V. karroo	Under	7.6	±0.4	Slightly alkaline
	Middle	7.8	±3.3	Slightly alkaline
	Periphery	7.5	±3.7	Slightly alkaline
V. nilotica	Under	6.7	±0.4	Neutral
	Middle	6.8	±0.6	Neutral
	Periphery	6.8	±0.6	Neutral
A. mearnsii	Under	6.3	±0.6	Slight acid
	Middle	6.3	±0.5	Slight acid
	Periphery	6.4	±0.5	Slight acid
A. dealbata	Under	6.1	±1.4	Slight acid
	Middle	6.1	±1.8	Slight acid
	Periphery	6.1	±2.1	Slight acid

*Classified according to (USDA, 1998)

4.5.2 Soil organic matter

Soil Organic Matter (SOM) for *V. karroo* ranged from 0.8–41.8%, while that for *V. nilotica* was 3.2– 70.3%, *A. mearnsii* was 2.3–33.6% and *A. dealbata* was 1.7–23.3% (Table 4.10) (Appendix 9).

Table 4.10 The Soil Organic Matter percentage values of each species at each micro-site

	Soil Organic Matter		
	Micro-site	**Mean (%)**	**SD**
V. karroo	Under	12.8	± 6.8
	Middle	15.3	± 10.1
	Periphery	16.6	± 11.1
V. nilotica	Under	4.6	± 25.4
	Middle	5.6	± 20.2
	Periphery	4.1	± 18.6
A. mearnsii	Under	13.6	± 11.5
	Middle	12.3	± 9.5
	Periphery	12.3	± 8.4
A. dealbata	Under	1.8	± 6.5
	Middle	1.8	± 7.5
	Periphery	0.1	±7.9

4.5.3 Soil colour and texture

The *V. nilotica* soil samples were predominantly very dark grey, clayey soils, according to the common Munsell Chart codes 5YR 3/1. *Vachellia karroo* soils varied in colour from purple grey blue to very dark grey brown, while the soil texture varied from sandy, clay to shale sand and Munsell Chart codes were unique for most samples. *Acacia mearnsii* soil samples were clayey and dark reddish brown in colour and clayey soils and Munsell Chart codes were generally 7.5 YR. *Acacia dealbata* soil colours were variations of brown, while the texture was sandy and clayey and the Munsell Chart codes varied between 10 YR and 5 YR (Appendix 5).

4.6 Statistical and Quantitative Analysis

The following hypotheses were tested:

1) $H_{o:}$ There is no significant difference ($\alpha = 0.05$) between the sampled depths and seed numbers for - [a] *Vachellia karroo;* [b]*V. nilotica;* [c]*Acacia. mearnsii;* [d]*A. dealbata.*

2) $H_{o:}$ There is no significant difference ($\alpha = 0.05$) between the distance and seed numbers for - [a] *Vachellia karroo;* [b]*V. nilotica;* [c]*Acacia. mearnsii;* [d]*A. dealbata.*

3) H_o: There is no significant difference ($\alpha = 0.05$) between the sampled depths and seed viability for- [a] *Vachellia karroo;* [b]*V. nilotica;* [c]*Acacia. mearnsii;* [d]*A. dealbata.*

4) H_o: There is no significant difference ($\alpha = 0.05$) between the distance from trunk and seed viability for- [a] *Vachellia karroo;* [b]*V. nilotica;* [c]*Acacia. mearnsii;* [d]*A. dealbata.*

Since $F < F_{crit}$ it is concluded that we accept the null hypothesis at a 0.5% level of significance and if the P-value is 0.05 or smaller.

Table 4.11 Summary of the results from ANOVA

	F	*P-value*	*F crit*	*df*	total *df*
1[a]	0.878	0.425	3.285	2	33
1[b*]	**5.535**	**0.008**	**3.288**	**2**	**33**
1[c*]	**7.758**	**0.002**	**3.285**	**2**	**33**
1[d]	1.156	0.327	3.285	2	33
2[a]	0.652	0.528	3.285	2	33
2[b]	0.971	0.389	3.285	2	33
2[c*]	**5.117**	**0.012**	**3.285**	**2**	**33**
2[d]	1.820	0.178	3.285	2	33
3[a]	0.137	0.872	3.328	2	31
3[b]	0.001	0.992	4.965	1	11
3[c]	0.016	0.983	3.285	2	33
3[d]	0.370	0.694	3.295	2	32
4[a]	1.020	0.373	3.328	2	29
4[b]	0.785	0.475	3.739	2	14
4[c]	1.090	0.349	3.295	2	32
4[d]	2.300	0.117	3.305	2	31

* Accept null hypothesis

Details of the ANOVA can be found in Appendix 10. There were significant differences for three of the tested hypotheses.

4.7 Summary

The results aimed to meet research objectives, understand the soil seed distribution and viability. Tree height, canopy area and canopy volume were measured. To understand the dynamics of seed bank distribution for *Vachellia* and *Acacia* species, seed numbers, seed distribution and seed density were examined. The seed viability was measured and compared to depth and distance outwards from trunk. Soil analysis was measured through pH values and soil organic matter, while soil colour and texture were described. Statistical and quantitative analysis was conducted through ANOVA where possible, to compare with similar previous studies

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter discusses results from the current study and compares them to relevant case studies and literature. In addition, recommendations for future research are provided.

5.2 Tree Characteristics

The scientific literature regarding tree height, canopy size and seed production is limited for jungle wattle, which is why this study focused on these aspects where only jungle wattle specimens were included.

The median height, canopy area and canopy volume of the *Acacia* was greater than *Vachellia* species. The standard deviation was greater for the *Acacia* than that of the *Vachellia* species. Seed number and canopy volume were plotted against each other (Figure 4.1) where *A. karroo* (R^2 = 0.1639) had the highest R^2 value compared to *A. nilotica* (R^2 = 0.0717) which had the smallest. The tree canopy size had a weak correlation with seed production; however other factors such as rainfall and flowering can affect seed production, especially if only one sample is conducted. However Witkowski and Garner's, (2000) had a higher R^2 value with total seed number associated with canopy area for *A. nilotica* (R^2 = 0.50 reserve) and (R^2 = 0.46 farm). Therefore in this study canopy volume and seed number are not directly linked, in contrast to the results of Witkowski and Garner's, (2000) study on indigenous *Vachellia* species where soil seed store per parent tree was positively related to canopy area of sampled trees. A possible explanation for these dissimilar results was that the current study used stand-alone trees.

5.3 Seed Bank Distribution

5.3.1 Seed number

The mean seed numbers were less for the *Vachellia* species compared to the invasive *Acacia* species. The mean seed number per tree for invasive *Acacia* species *A. dealbata* (1 605) and *A. mearnsii* (286), were higher than *V. nilotica* (9) and *V. karroo* (85). The results of

González-Muñoz *et al*. (2012) showed greater seed numbers produced by *A. dealbata* in comparison to indigenous Spanish Quercus robur forests, similar results to this study. *Vachellia karroo* had a greater total seed number than that of *V. nilotica*. This is similar to a study by Walters and Milton (2003), where the total seed production of *V. karroo* produced 1.6 times more seeds than *V. nilotica*. This study had 10.57 times more *V. karroo* total seeds than *V. nilotica*. Results from O'Connor *et al*., (2010) noted seed numbers of *V. karroo* in the province of Eastern Cape, South Africa, did not exceed 18 seeds/m^2, while another study showed 14 seeds/m^2 for *V. nilotica* (Tybrik, 1994). In this study a different sampling strategy (including three depths) was used but the mean seed density showed a similar outcome with *V. karroo* (58.4 m^3) and *V. nilotica* (10.4 m^3) for the micro-sites nearest the trunk (Table 4.3).

5.3.2 Seed distribution

Seeds were distributed within all micro-sites and depths in this study, with the exception of *V. nilotica*, where no seeds were found at a depth of 4-10 cm for all sampled trees (Table 4.4). In general, seed numbers decreased with depth. There was a significant difference ($\alpha = 0.05$) between the sampled depths and seed numbers for only *V. nilotica* and *A. mearnsii* (Table 4.10).

The greatest number of seeds were found nearest the trunk and decreased outwards. There was a significant difference ($\alpha = 0.05$) between distance from the trunk and seed numbers for *A. mearnsii* (Table 4.10). *Acacia dealbata* seed density decreased from 1 448.0/m^3 to 903.4/m^3 to 13.3/m^3 for micro-sites 'under', 'middle', and 'periphery' respectively (Table 4.3). These findings were similar to a study by Donaldson *et al*. (2014) which showed exotic *A. elata* had the greatest seed density directly under the canopy close to the trunk. A study on *V. karroo* and *V. nilotica* in Umfolozi Game Reserve in KwaZulu-Natal showed a decrease in seeds, with the increasing distance from the tree base (Walters and Milton, 2003). Similarly, Witkowski and Garner (2000) showed that seed bank densities differed greatly between micro-sites, generally decreasing outwards from the trunk. Wilson and Traveset (2000) described the "seed number/distance relationship as leptokurtic (with a higher peak and longer tail than a normal distribution) from the peak outward, seed numbers are generally considered to decrease monotonically, fitting a negative exponential curve" (Wilson and Traveset, 2000: 86), similar to the findings in this study. Smaller seeds flow more easily, while larger seeds tend to be spherical in form, which favours them rolling down the slope (Cerda` and Garc´ıa-

Fayos, 2002). Smaller seeds can fall into soil cracks and, because they are lighter, they can be transported further in surface wash. The *Acacia* have smaller seeds compared to the *Vachellia* species (Plates 3.7 and 3.8).

5.3.3 Slope

In this study some sampled trees were on slopes, where there was little difference found between seed percentages on the up and downslope (Appendix 6). *Vachellia nilotica* samples were taken on a flat area with 47% of seeds located upslope/North and 53% downslope/South. *Acacia dealbata* results showed the downslope to be 33%, compared to the upslope 67%. *Acacia mearnsii* was the only sampled species to have a total greater number on the upslope (51%) and (49%), 50% of the sampled area was on sleep slopes (Table 4.5). Surface wash is likely to be the reason for the greater number of seeds on the down slope. Surface wash is determined by factors such as slope angle, rainfall intensity, surface roughness and vegetation cover (Cerda`and Garcı´a-Fayos, 2002). Seeds that would have fallen on the ground up-slope of the trunk may have been washed down slope, therefore wash is potentially the reason for higher seed numbers on the down slope. Although surface wash and slope had previously been thought to be an important factor, in this study, there was no significant difference ($\alpha = 0.05$) between the up-and down slope when comparing seed density (Table 4.10).

Witkowski and Garner (2000), showed no significant differences in the seed densities between north and south aspects, for any of the species for *V. nilotica* within any micro-site, where statistical analyses could be performed. This study did not include aspect but focused on slope. Seeds on the north aspect within the edge and beyond the sample sites may be more successful, as light intensity is greater. In the event of tree death, seedling regeneration is likely to be high in response to the large number of stored seeds.

5.3.4 Herbivory

This study did not measure the impact of herbivores directly. However, it should be noted that animals play a role in seed distribution (Miller, 1996:1994). Prior to sampling, seeds of *V. nilotica* may have been consumed from the ground or off the tree as the sample was from a private game farm.

Miller (1996) notes that *V. nilotica* seeds in a South African savannah ecosystem were dispersed by giraffe (*Giffaffa camelopardalis*) and Stelli, (2011), extracted *V. nilotica* (15 seeds) from wildebeest (*Connochaetes taurnus*) dung. Some seed pods are ingested by browsers on the tree, while other pods and/or seeds may be eaten on the ground by herbivores such as kudu (*Tragelaphus imberbis*) (Miller, 1994). This may be a reason for the lower number of seeds found for *V. nilotica*. Walters and Milton, (2003) stated that very few pods were produced from *V. nilotica* in Umfolozi Game Reserve in KwaZulu-Natal. However, that study, like this study, was only conducted during one season, and the result may have been impacted by unfavourable environmental conditions.

5.4 Seed Viability

Acacia species had a higher percentage viability compared to the *Vachellia* species: *V. karroo* (77.7%) *V. nilotica* (33.7%) *A. dealbata* (95.6%) *A. mearnsii* (92.5%). Similar results from Witkowski and Garner, (2000) present a viability for *V. nilotica* of 77% (reserve) and 68% (farm) for two different sites. A study undertaken in the province of Eastern Cape, South Africa, where seeds were tested for viability using tetrazolium chloride showed 98-99 % viability for *V. karroo* (O'Connor *et al*., 2010). Kaplan *et al*., (2014) found a viability rate of 6% for *A. stricta,* thus there may be a correlation between seed viability and the area invaded. The percentage viability has an impact on the invasiveness of a species. *Acacia stricta* has a much smaller invasive range compared to other *Acacia* species. In this study the viability of *A. dealbata* (95.6%) and *A. mearnsii* (92.5%) are higher than other species.

5.4.1 Seed viability and depth

There were generally no significant differences ($\alpha = 0.05$) of seed viability and soil depth, although the seed viability percentage of *V. karroo* showed an increase at micro-sites with increasing soil depths (70%, 82%, 89%) (Table 4.7). *Acacia* species' viability differed at each micro-site. *Acacia mearnsii* had the highest seed viability percentage (100%) at the 0-2 cm depth for 'under' and 'periphery' micro-sites. Results from *A. mearnsii* do not show an increase of seed viability with depth. The only micro-site that showed an increase with depth for *A. dealbata* was the periphery micro–site. The number of seeds tested for viability would have impacted the viability percentage. In another study on indigenous *Vachellia* seed viability tended to increase with depth, with one exception of *V. nilotica* (Witkowski and Garner, 2000).

5.4.2 Seed viability and distance

There is no significant difference between (α = 0.05) the distance from trunk and seed viability. The highest seed viability of *V. karroo* was at the 'middle' (69%, 88%, 89%) micro-site, followed by the 'under' (70%, 82%, 89%) and 'periphery' (63%, 84%, 73%) micro-sites. *Vachellia nilotica* seed viability decreased with distance outwards as no seeds were found in the 'periphery' micro-site. Witkowski and Garner (2000) noted no consistent differences between seed viability and distances for *V. nilotica* and *V. tortilis*. In this study the highest number of viable seeds for all species was that of *A. dealbata* at the 'under' micro-site where 97 % were viable. However, Witkowski and Garner (2000) had a slightly different definition of where the furthest soil samples were mid-point between the canopy edge and their nearest neighbours.

5.4.3 Seed predation

The *Acacia* species appear to have limited native enemies, for example insects, to damage their seeds. The most insect damage was on the *V. karroo*, with 10 seeds out of 1 109, which represents 0.9% of the sampled seeds. Most of the insect damage for both indigenous species was at 0-2 cm nearest the trunk (Appendix 7). A similar finding by Walters and Milton, (2003) showed Bruchid damage of *V. karroo* had a very low infestation. In contrast, another study by Miller (1996) had rates of 40% for *V. karroo.* These damaged seeds were tested for viability and were classified as non-viable. Infestation of seeds within pods was greater on the ground in the canopy (Miller, 1996). This study classified seeds with visible insect damage as non-viable.

5.5 Soil Analysis

Soil pH value is important because it impacts the solubility of nutrients and the activity of micro-organisms breaking down the organic matter, allowing chemical transformation in the soil (USDA, 1998). The most favourable pH value for plant growth is between 6 to 7 because nutrients are readily available (USDA, 1998). The pH values for all species in this study had a narrow mean range (6.1-7.8). *Vachellia nilotica* had slightly alkaline soils and *V. karroo* had neutral soils. The exotic species had slightly acid soils, *A. dealbata* had a constant mean pH value (6.1) at all micro-sites. González-Muñoz *et al*. (2012) research in Spain also showed *A. dealbata* to have acidic soils in the Spanish Quercus robur forests. *Acacia dealbata* has the ability to severely impact the soil properties and vegetation of native forests (González-

Muñoz *et al*., 2012). In the Witkowski and Garner (2000) study, the soil pH values for their indigenous *Vachellia* species ranged (5.1–5.6) from strong acid to moderately acid soils. Witkowski and Garner (2000) had no differences in pH concentrations between sites and micro-sites, similar to this study. Generally the invasive *Acacia* species in this study had more acid soils compared to the indigenous *Vachellia* soil samples.

Vachellia karroo had the highest SOM, which increased with distances outwards from trunk (12.8%) 'under' (15.3%) 'middle' and (16.6%) for the 'periphery'. *Vachellia karroo* soil was samples where cattle had access to the trees and used them as shade, this may account for the high SOM from the dung. The SOM of *A. dealbata* was the lowest 1.8% 'under', for 'middle' and 0.1% for the 'periphery'. However, González-Muñoz *et al*., (2012) results showed the percentage of organic matter was higher under *A. dealbata* canopies compared to the Spanish indigenous canopies. The differences may be because many of *A. dealbata* soil samples were taken from badly eroded and overgrazed areas. Witkowski and Garner (2000) SOM results were generally lower than this study for the reserve (1.11%, 1.17%) and farm (1.04%, 1.62%). They stated organic matter was higher and pH tended to be lower under trees, otherwise there were no differences between sub-canopy and open micro-sites.

.

5.6 IAPs Management Recommendations

Zavaleta *et al*., (2001) state that the challenge of clearing programmes is to prevent infestation of IAPs from seed banks, while promoting growth of native vegetation and preventing soil erosion. *Acacia* species are challenging to control and remove as they can regenerate through coppicing and sexually through the production of seeds. Currently, there are a number of techniques used to control IAPs; these methods need to be adapted to include the removal and management of seeds. Trees that have been felled and chemically treated/painted/injected with chemical may be killed or prevented from regrowth. However, this does not control the potential regeneration of the seeds. Burning of jungle stands potentially kills the trees but assists with germination of the seed bank (Keeley *et al*., 2012). *Acacia longifolia* seeds had increased germination under simulated fire, and could remain viable, even when exposed to temperatures in excess of 120°C for several minutes (Behenna *et al*., 2008). Ideally young saplings should be sprayed with herbicides before they seed.

Biological control agents can affect seed viability if used correctly, for example, the Acacia Seed Weevil (*Melanterius maculatus*) is a seed feeder used as a biological control agent. There are a limited number of species that are suitable for biological control (Zimmermann *et al*., 2004).

It must be noted that if the seed bank is not controlled correctly, removing the above-ground material is worthless. This study supports the conclusions of van Wilgen *et al.* (2001), who stated that South Africa must control IAPs, or an even worse scenario of the growing impacts will be encountered in the future. For example the mean number of seeds at the 0-2 cm (30 cm x 30 cm) layer of the 'under' micro-site of *A. dealbata* were 521.5 with a 97 % viability rate. This gives a potential of 505 IAP seedlings per tree. The total seed density, together with seed viability, gives an indication of the potential of the species to propagate. One tree killed could potentially be replaced by 505 more.

5.7 Future Studies

It is recommended that each tree be felled, in all future studies, and that tree ring analysis be used, to confirm the age of each tree. Isotope analysis may enhance the accuracy of tree age but would increase the cost.

It is recommended that the trees studied are equally accessible to animals, or that they are fenced off before the season, or that cameras are installed, to remotely monitor and note the activities of animals at the study site. It would be advisable to sample the indigenous and exotic species within the same geographical area in order to statistically analyse the results. However this must not compromise the stand alone criterion.

In addition to the TTZ test, it would be an added value to conduct germination trials for multiple seasons. More information could be obtained by including dung samples, in order to examine scarification of seeds and to note the viability percentage. In future studies it would be recommended that pH and soil organic matter of each depth be recorded to see if there are changes with depth and distances from trunk.

CHAPTER SIX

CONCLUSION

6.1 Introduction

Witkowski, (1991) stated that exotic *Acacias* are pre-adapted to nutrient-poor soils and excessive seed output. When control efforts focus on the above-ground material, it is the seed bank that can pose the greatest hurdle to successful control. The abundance of viable seeds in the soil determines the likelihood of future outbreaks (Alexandria and Antonio, 2003). Therefore, the formation of large seed banks is potentially problematic for control efforts.

6.2 Discussion

This research set out to improve the understanding of seed bank distribution for selected *Vachellia* and invasive *Acacia* species using recognised techniques as outlined by Witkowski and Garner (2000). Allowing for comparison with previous studies, the results suggest that the invasive species have an advantage over the indigenous, in terms of both seed numbers and seed viability. A better knowledge of *Acacia* seed bank dynamics is crucial for the effective management of IAPs.

The aim of this research was achieved by quantifying and describing seed bank distribution and seed viability of selected *Vachellia* and *Acacia* species in KwaZulu-Natal, South Africa.

The first objective was to describe seed bank distribution of selected species. This goal was achieved by quantifying the selected species seed bank distribution and density. The *Acacias* had a greater seed density compared *Vachellia*. For all the species seed density generally decreased with soil depth and distance from trunk. The results of other studies were similar to this one.

A second objective was to test seed viability of the selected species. This goal was achieved by using the TTZ test. Exotic species had higher seed viability than indigenous. It is important to take into account the number of seeds found, which will give an indication of a species' potential to invade.

The final objective was to provide management recommendations for control of selected *Acacia* species. Using the results for this study, it is vital that further management plans include removal of *A. mearnsii* and *A. dealbata* seeds.

In this study, more seeds were found from the invasive *Acacia* species than the indigenous *Vachellia* species. There was a wide range of seed numbers between the individual trees of the same species. In general, seed density decreased with distance from the trunk and with depth. Although slope was thought to play a role in seed bank distribution from surface wash, there was no clear pattern in mean seed density. Tree canopy size had no clear pattern. The indigenous trees tended to be smaller than the exotic trees. Exotic species had a higher percentage viability compared to the indigenous species. There were no significant differences ($\alpha = 0.05$) between seed viability and soil depth and distance from the trunk. With regard to seed predation, indigenous seeds had more insect damage than exotic seeds.

6.3 Outlook

Seed viability is an indication of the potential for future generations. However the data of seed viability must not be viewed in isolation. Richardson *et al*. (2015) offered three scenarios post-2010 for the future management of IAPs. In the best case scenario the optimum combination would be management practices being fully implemented, and effectively fulfilled. The second best scenario would be the maintenance of the status quo, where the implementation of management practices is incomplete, not fully coordinated and sustained, or partially ineffective. While in the worst-case scenario, key management practices are either not implemented or fail (Richardson *et al*., 2015).

The future depends on which scenario dominates. At present we are working on the tip of the iceberg, scratching the surface, while what lies beneath may be more dangerous.

.

References

Agricultural Research Council (ARC)., 2010. *Legal obligations regarding invasive alien plants in South Africa*. [online] Available from: http://www.arc.agric.za/arc-ppri/Pages/Weeds%20Research/Legalobligations-regarding-invasive-alien-plants-in-South-Africa-.aspx. [Accessed 1/04/2015].

Agriculture Research Institute (ARC)., 2015. *The acacia seed weevils*. [online] No 7. Available from: http://www.arc.agric.za/arcppri/Leaflets%20Library/Melanterius%20species.pdf#search=The%20acacia%20seed%20weevils%2E. [Accessed 3/04/2015].

Alexandra, J.M and Antonio, C.M.D., 2003. Seed bank dynamics of French brew in coastal California grasslands: effects of standard age and prescriptive burning on control and restoration. *Restoration ecology*, 11 (2), 185–197.

Beck, S.L and Fossey, A., 2007. Investigation and optimization of gamma irradiation to sterility or seedlessness in black wattle (*Acacia mearnsii*). *Seed Science and Technology*, 35, 351–359.

Beck-Pay, S.L., 2013. Confirmation of cytotype stability in autotetraploid black wattle (*Acacia mearnsii*) trees using flow cytometry and size differences of the reproductive gametes. *Southern Forests: a Journal of Forest Science*, 75 (1), 1–6.

Behenna, M., Vetter, S. and Fourie, S., 2008. Viability of alien and native seed banks after slash and burn: Effects of soil. *South African Journal of Botany*, 74, 454–462.

Biggs, R., Simons, H., Bakkenes, M., Scholes, R. J., Eickhout, B., van Vuuren, D. and Alkemade, R., 2008. Scenarios of biodiversity loss in southern Africa in the 21st century. *Global Environmental Change*, 18, 296–309.

Bigwood, D. W. and Inouye, D. W., 1988. Spatial Pattern Analysis of Seed Banks: An Improved Method and Optimized Sampling. *Ecology*, 69,497–507.

Boatwright, J.S., van der Bank, M. and Maurin, O., 2014. Name change in African Acacia species. *Veld & Fora*, 100 (1), 33.

Bond, W.J. and Midgley, J.M., 2001. The persistence niche: ecology of sprouting in woody plants. *Trends in Ecology and Evolution*, 16, 45–51.

Bond, W.J., 2008. What limits trees in C4 grasslands and savannas? *Annual Review of Ecology, Evolution and Systematic*, 39, 641–659.

CAB International., 2001. *Social and Environmental Benefits of the Fynbos Working for Water Programme. Global Invasive Species Programme On-line Toolkit*. [online] Case Study 5.33 - Published on behalf of GISP. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.115.4342&rep=rep1&type=pdf. [Accessed 2/04/2015].

Carling, R. M. and Hilton-Taylor, C., 1994. Patterns of plant diversity and endemism in Southern Africa: an overview. *In:* B.J. Huntley, eds. *Botanical diversity in Southern Africa*. Pretoria: National botanical Institute, 31–52.

Cerda`., A. and Garcı´a-Fayos, P., 2002. The influence of seed size and shape on their removal by water erosion. *Catena*, 48, 293– 301.

Chan, J. M., Day, P. Feely, J. Thompson, R. Little, K.M. and Norris, C.H., 2015. *Acacia mearnsii* industry overview: current status, key research and development issues, *Southern Forests: a Journal of Forest Science*, 77(1), 19–30.

Chaunbi, G., 1997. Black Wattle Plantations in South Africa: Introduction, Silviculture and Management. *In:*

A.G Brown, & Ho Chin Ko, eds. *Black Wattle and its Utilisation.* Barton: Rural Industries Research and Development Corporation Publication, 28–38.

Conservation at work., 2015. *Best Practice Guideline: alien vegetation management*. [online].Available from: http://www.conservationatwork.co.za/sites/default/files/conservationguidelines/BPG%20Alien%20Vegt%20Mngmnt_0.pdf. [Accessed 03/09/2015].

Costanza, R., d'Arge, R., de Groot, R., Farberk, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Suttonkk, P. and van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387, 253–260.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S. and Kerry, R.T., 2014. Changes in the global value of ecosystem services. *Global Environmental Change*, 26, 152–158.

de Beer, H.,1986. *Black Wattle. Plant protection research institute*. [online]. Department of Agriculture and Water Supply. Pretoria. Available from: http://www.arc.agric.za/arc-ppri/Leaflets%20Library/Blackwattle.pdf. [Accessed10/02/2015].

de Groot, R. S., Alkemade, R., Braat, L., Hein, L. and Willeman, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision-making. *Ecological Complexity*, 7, 26–272.

de Neergaard, A., Saarnak, C., Hill, T., Khanyile, M., MartinezBerzosa, A. and Birch-Thomsen, T., 2005. Australian wattle species in the Drakensberg region of South Africa-An invasive alien or a natural resource? *Agriculture Systems*, 86, 216–233.

de Wit, M.P., Crookes, D. J. and van Wilgen, B. W., 2001. Conflicts of interest in environmental management: Estimating the costs and benefits of a tree invasion. *Biological Invasions*, 3, 167–178.

Dean, S.J., Holmes, P.M. and Weiss, P.W., 1986. Seed biology of invasive alien plants in South Africa and Namibia. *In:* AW. Macdonald, FJ. Kruger, A. Ferrar, eds. *The ecology and management of biological invasions in southern Africa*. Cape Town: Oxford University Press, 157–170.

Del Tredici, P., 2001. Sprouting in temperate trees: a morphological and ecological review. *Botanical Reviews*, 67, 121–140.

Department of Agriculture, Forestry and Fisheries (DAFF)., 1983. *Conservation of Agricultural Resources Act, 1983 (Act No. 43 of 1983).* Government Printer. Republic of South Africa.

Department of Agriculture, Forestry and Fisheries (DAFF)., 2013. *Abstract of Agriculture Statics 2013.* [online]. Available from: http://www.nda.agric.za/docs/statsinfo/Abstact2013.pdf [Accessed 2/04/2015].

Department of Water Affairs (DWA)., 2015. *Management of invasive alien plants*. [online]. Available from: https://www.dwaf.gov.za/wfw/Control/. [Accessed 2/04/2015].

Donaldson, J.E., Richardson, D.M. and Wilson, J.R.U., 2014. The seed ecology of an ornamental wattle in South Africa — Why has Acacia elata not invaded a greater area? *South African Journal of Botany*, 94, 40–45.

Enright, W.D., 2000.The effect of terrestrial invasive alien plants on water scarcity in South Africa. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere,* 25 (3), 237–242.

Environment., 2013. *Alien Invasive Plants List for South Africa*. [online]. Available from: http://www.environment.co.za/weeds-invaders-alien-vegetation/alien-invasive-plants-list-for-south-africa. [Accessed 8/05/2015].

Farrell, T.P. and Ashton, D.H., 1978. Population studies on *Acacia melanoxylon* R. Br. I. Variation in seed and vegetative characteristics. *Australian Journal of Botany*, 26, 365–379.

Fenner, M. and Thompson, K., 2005. *The Ecology of Seeds*. Cambridge: Cambridge University Press.

Food and Agriculture Organization of the United Nations (FAO), 2015., *Biodiversity*. [online] Available from: http://www.fao.org/biodiversity/en/. [Accessed 9/04/2015].

Garner, R.D. and Witkowski, E.T.F., 1997. Variations on seed size and shape in relation to depth of burial in the soil and pre-dispersal predation in *Acacia nilotica*, *A. tortilis* and *Dichrostachys cinerea*. *South African Journal of Botany*, 63 (6), 371–377.

González-Muñoz, N., Costa-Tenorio, M. and Espigares, T., 2012. Invasion of alien Acacia dealbata on Spanish Quercus Robur forests: Impact on soils and vegetation. *Forest Ecology and Management*, 269, 214–221.

Government Gazette., 2014. *Notice 3: National list of invasive species in terms section 70(1)(A) 1* August 2014. No. 37886. Government Printers, Pretoria.

Green, D.S., 1983. The efficacy of dispersal in relation to safe site density. *Oecologia*, 56, 356-358.

Guzman, L.E.P., Zamora, O.B., Borromeo, T.H., Sta Cruz, P.C. and Mendoza, T.C., 2011.Seed viability and vigor testing of *Jatropha curcas* L. *Philippine Journal of crop science*, 36 (3), 10–18.

Hågvar, S., 1998. The relevance of the Rio-Convention on biodiversity to conserving the biodiversity of soils. *Applied Soil Ecology*, 9, 1–7.

Henderson, L., 2014. *Newsletter of the Southern African Plant Invaders Atlas, an initiative of the Weeds Programme of the Plant Protection Research Institute, within the Agricultural Research Council (ARC).*[online]. Plant Protection Research Institute. v31. Available from: http://www.arc.agric .za/arcppri/Newsletter%20Library. [Accessed 2/01/2015].

Henderson, L., 2007. Invasive, naturalized and casual alien plants in southern Africa: a summary based on the Southern African Plant Invaders Atlas (SAPIA). *Bothalia*, 37 (2) 215–248.

Hinkle, D.E., Wiersma, W. and Jurs, S.G., 1979. *Applied statistics for the behavioural sciences*. Boston: Houghton Muffin Co.

Inderjit, S., Wardle, D.A., Karban, R. and Callaway, R.M., 2011. The ecosystem and evolutionary contexts of allelopathy. *Trends Ecol Evol*, 26, 655–662.

Kaiser, J., 1999. Stemming the tide of invasive species. *Science*, 285, 1836–1841.

Kaplan, H., van Niekerk, A., Le Roux, J.J., Richardson, D.M. and Wilson, J.R.U., 2014. Incorporating risk mapping at multiple spatial scales into eradication management plans. *Biological Invasion*, 16, 691–703.

Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G., Rundel., P.W., 2012. *Fire in Mediterranean ecosystems*. Cambridge: Cambridge University Press.

Kriticos, D., Brown, J., Radford, I. and Nicholas, M., 1999. Commentary: Plant Population Ecology and Biological Control: *Acacia nilotica* as a Case Study. *Biological Control*, 16, 230–239.

Kull, C. A. and Rangan, H., 2008. Acacia exchanges: wattles, thorn trees, and the study of plant movements. *Geoforum*, 39, 1258–1272.

Kull, C.A. and Rangan, H., 2012. Science, sentiment and territorial chauvinism in the acacia name change debate. In S.G. Haberle and B. David, eds., *Peopled Landscapes. Terra Australis 34*. Canberra: ANU E-Press, 197–219.

Kyle, G. and Duncan, D.H., 2012. Arresting the rate of land clearing: Change in woody native vegetation cover in a changing agricultural landscape. *Landscape and Urban Planning*, 106, 165–173.

Le Maitre, D., Verfeld, D. and Chapman, R. A., 2000. The impact of invading alien plants on surface water resources in South Africa: a review of the inaugural symposium of Working for water program. South Africa. *Journal of science*, 100, 21–26.

Le Roux, J.J., Brown, G.K., Bryne, M., Ndlovu, J., Richardson, D.M., Thompson, G.D. and Wilson, J.R.U., 2011. Phylogeographic consequences of different introduction histories of invasive Australian Acacia species and Paraseriantheslophantha (Fabaceae) in South Africa. *Diversity and Distributions*, 17, 861–871.

Lighton, C.,1958. Magic with tree seeds. *In*: ED, R. Ed. *Sisters of the South*. Cape Town:Howard Timmins

Marchante, H., Freitas, H. and Hoffmann, J.H., 2010. Seed ecology of an invasive alien species, Acacia longifolia (Fabaceae), in Portuguese dune ecosystems. *American Journal of Botany*, 11, 1780–1790.

McConnachie, M.M., Cowling, R.M., van Wilgen, B.W. and McConnachie, D.A., 2012. Evaluating the cost-effectiveness of invasive alien plant clearing: A case study from South Africa. *Biological Conservation*, 155, 128–135.

McNeely, J.A., Mooney H.A., Neville, L.E., Schei, P. and Waage J.K., 2001. *A Global Strategy on Invasive Alien Species*. [online]. Global invasive species programme. Available from: http://www.issg.org/pdf/publications/GISP/Resources/McNeeley-etal-EN.pdf. [Accessed 2/02/2015].

Millennium Ecosystem Assessment (MEA). 2005b. *Ecosystems and Human Well-Being: Synthesis*. Washington: Island Press.

Millennium Ecosystems Assessment (MEA). 2005a. *Ecosystems and Human Well-being: Biodiversity Synthesis*. Washington: World Resources Institute.

Miller, M.F., 1994. Large African herbivores, bruchid beetles and their interactions with Acacia seeds. *Oecologia*, 97 (2) 265–270.

Miller, M.F., 1996. Acacia seed predation by bruchids in an African savanna ecosystem. *Journal of Applied Ecology*, 33, 1137–1144.

Milton, S. J. and Hall, A. V., 1981. Reproductive biology of Australian Acacias in the south-western Cape Province, South Africa. *Transactions of the Royal Society of South Africa*, 44, 465–485.

Moncur, M.W., Moran, G.F., Boland, D. and Turner, J., 1988. Floral morphology and breeding systems of Acacia Mearnsii. *De Wild*. *In:* Chinese Academy of forestry and ACIAR, Proceedings of the use of Australian seeds and China workshop. December 1988. Guangzhou, China, 12.

Morris, M.J., 1997. Impact of the gall-forming rust fungus *Uromycladium tepperianum* on the invasive tree *Acacia saligna* in South Africa. *Biological Control*, 10, 75–82.

Morris, M.J., 1999. The contribution of the gall forming rust fungus *Uronmycladiumtepperiamum* (Sacc.) McAlp. to the biological control of *Acacias saligna* (LAbill.) Wendl. (Fababceae) in South Africa. *African entomology Memoir*, 1, 125–128.

Mucina, L. and Rutherford, M.C., (eds)., 2011. *The vegetation of South Africa, Lesotho and Swaziland*. Pretoria: South African National Biodiversity Institute.

Munkert, H.C., 2009. Sexual and vegetative regeneration of three leguminous tree species in South African savannas. *South African Journal of Botany*, 75(3), 606–610.

Murry, D.R., 1986. *Seed dispersal*. North Ryde: Academic Press Australia.

Ntshotsho. P, Prozesky H.E, Esler K. J. and Reyers B., 2015. What drives the use of scientific evidence in decision making? The case of the South African Working for Water program. *Biological Conservation*, 184, 136–144.

Nyoka, B.I., 2003. *Biosecurity in forestry: A case study on the status of invasive forest species in Southern Africa*. [online]. Forest Biosecurity working paper FBS/1E. Forestry Department. FAO. Rome. Available from: http://www.fao.org/docrep/005/ac846e/ac846e06.htm. [Accessed 1/04/2015].

O'Connor, T. G., de Ridder, C. H. and Hobson, F. O., 2010. Aspects of the seed ecology of Acacia karroo in the Eastern Cape, South Africa, *African Journal of Range & Forage Science*, 27 (2), 77–87.

Pejchar, L. and Mooney, H.A., 2009. Invasive species, ecosystem services and human well-being. *Trends in Ecology and Evolution*, 24 (9), 497–504.

Perry, D. A., 1981. Seedling growth and evaluation tests. *In:* D.A., Perry, *Handbook of Vigour test methods*. Zurich: The international Seed Testing Association.

Pieterse, P.J., 1997. *Biological studies on woody leguminous invaders with special reference to Acacia mearnsii, A. melanoxylon and Paraseriantheslophanhtha*. Thesis (D. Phil), University of Stellenbosch, Stellenbosch.

Pooley, E., 1993. *The complete field guide to trees of Natal, Zululand & Transkei. Durban*: Natal Flora publications trust.

Poynton, R.J., 2009. *Tree Planting in Southern Africa*, Volume 3. Pretoria: Department of Agriculture, Forestry and Fisheries.

Preston, G., 2003. *Invasive Alien Plans and Protected Areas in South Africa*. [online] World Parks Congress, Durban, South Africa. 13 September 2003. Available from: http://www.dwaf.gov.za/wfw/Docs [Accessed 1/04/2015].

Purser, P., 1999. *Timber measurement manual: Standard Procedures for the Measurement of Round Timber for Sale Purposes in Ireland*. [online].Republic of Ireland, Forest Service in the Department of the Marine & Natural Resources. Available from: http://www.coford.ie/media/coford/content/publications TimberMeasurementManual.pdf. [Accessed 10/02/2015].

Radford, I.J., Nicholas, M.D. and Brown, J.R., 2001. Impacts of prescribed burning on *Acacia nilotica* seed banks and seedlings in the Astrebla grasslands of northern Australia. *Journal of Arid Environments*, 49, 795–807.

Reddy, K., 2015. *Experiment 2 Organic Matter Determination* .University of Illinois at Chicago. [online]. Available from: http://www.uic.edu/classes/cemm/cemmlab/Experiment%202-Organic%20Content.pdf [Accessed 10/04/ 2015].

Rejmánek, M. and Pitcairn, M.J., 2002. When is eradication of exotic pest plants a realistic goal? *In:* Vietch, C.R., Clout, M.N., Eds, *Turning the tide: the eradication of island invasive*. Auckland: The World Conservation Union, 249–253.

Republic of South Africa (RSA), Department: Environmental Affairs., 2014. *A National Strategy for dealing with Biological Invasions in South Africa*. 25 March 2014. Cape Town.

Republic of South Africa (RSA)., 2004. *National Environmental Management: Biodiversity Act No 10*. Government Printers, Vol. 467 No. 26436. Cape Town.

Richardson, D. M. and Kluge, R. L., 2008. Seed banks of invasive Australian Acacia species in South Africa: Role in invasiveness and options for management. *Perspectives in Plant Ecology, Evolution and systematics,* 10 (3), 161–177.

Richardson, D. M., Le Roux, J.J. and Wilson, J.R.U., 2015. Australian acacias as invasive species: lessons to be learnt from regions with long planting histories, *Southern Forests: a Journal of Forest Science*, 77 (1), 31–39.

Richardson, D.M. and Rejmánek, M., 2011. Trees and shrubs as invasive alien species – a global review. *Diversity and Distributions,* 17, 788–809.

Richardson, D.M., Carruthers, J., Hui, C., Impson, F.A.C., Miller, J.T., Robertson, M.P., Rouget, M., Le Roux, J.J. and Wilson, J.R.U., 2011. Human-mediated introductions of Australian acacias – a global experiment in biogeography. *Diversity and Distributions*, 17, 771–787.

Scotney, P., 2010. *Sutton Diaries*. Port Elizabeth: Privately published by Pearl Scotney.

Searle, S.D., 1997. Acacia mearnsii *De Wild*. (Black Wattle) in Australia. *In:* Brown, A.G and Chin Ko, H., 1997. *Black Wattle and its utilization.* Kingston: *Rural Industries Research & Development Corporation*, 2-13.

Sherry, S. P., 1971. *The black wattle (Acacia mearnsii de wild.)*. Pietermaritzburg: University of Natal Press.

Simpson, R.L., Leek, M.A. and Parker, V.T., 1989. Seed Banks: General Concepts and Methodological Issues. *In:* M.A. Leek, V.T. Parker, and R.L. Simpson, Eds. *Ecology of Soil Seed Banks*. London: Academic Press Limited, 3-9.

Smit, N., 1999 .*Guide to the acacias of South Africa*. Cape Town: Briza publications.

Solomon, T.B., Snyman. H.A. and Smit, G.N., 2006. Soil seed bank characteristics in relation to land use systems and distance from water in a semi-arid rangeland of southern Ethiopia. *South African Journal of Botany*, 72, 263 – 271.

South Africa Nursery Association (SANA)., 2015. *Acacia Species Name change*. [online]. Available from: http://www.sana.co.za/pdf/Acacia-Species-Name-Change.pdf. [Accessed 10/05/2015].

South African Nursery Association (SANA)., 2012. *Alien Invasive Plants – NEM: BA and CARA list*. [online]. Available from: http://www.sana.co.za/Alien-Invasive-Plants/. [Accessed 6/06/2014].

Stelli, S. A., 2011. *Seed fate and density of soil seed banks of four Acacia species in the Kruger National Park, South Africa*. Thesis (MSc). Faculty of Science, University of the Witwatersrand. Johannesburg.

Strydom, M., Esler, K.J. and Wood, A.R., 2012. *Acacia saligna* seed banks: sampling methods and dynamics, Western Cape, South Africa. *South African Journal of Botany*, 79, 140–147.

The U. S. Department of Agriculture (USDA), 1998., *Natural Resources Conservation Service: Soil Quality Indicators: pH.* [online] Available from: http://www.nrcs.usda.gov/Internet/FSEDOCUMENTS/ nrcs142p2052208.pdf [Accessed 10/02/2015].

The United Nations (UN)., 1992. *Convention on Biodiversity*. [online]. Available from: http://www.cbd.int/doc/legal/cbd-en.pdf. [Accessed 30/03/2015].

Thompson, K., 1987. Seeds and seed banks. *New Phytologist*, 103, 23–34.

Tscharntke, T., Clough, Y., Wagner, T. C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J. and Whitbread, A., 2012. Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation*, 151, 53–59.

Turner, P. and Pharo, E., 2005. Influence of substrate type and forest age on bryophyte species distribution in Tasmanian mixed forest. *Bryologist*, 108, 67–85.

Tybirk, K., Schmidt, L.H. and Hauser, T., 1992. Notes and Records. *African Journal of Ecology*, 32, 327–330.

Tybrik, K., Schmidt, L.H. and Hauser, T., 1994. Notes on soil seed banks of African acacias. *African journal of Ecolocogy*, 27, 1–184.

United Nations Environment Programme (UNEP). 2006. *Africa Environment Outlook2 – Human Well-Being and Livelihoods*. [online]. Available from: http://www.unep.org/dewa/Africa/publications/AEO-2/content/017.htm. [Accessed 30/03/2015].

Van Staden, J., Manning, J.C. and Kelly, K.M., 1989. Legume Seeds-the Structure: Function Equation. *In:* C.H. Stirton, & J.L. Zarucchi, Eds. *Advances in Legume.* New York: CABI publishing, 417–450.

van Wilgen, B. W., Forsyth, G.G., Le Maitre , D. C., Wannenburgh, A., Kotzé, J.D.F., van den Berg, E. and Henderson, L., 2012a. An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. *Biological Conservation*, 148, 28–38.

van Wilgen, B.W. and Richardson, D.M., 2012. Three centuries of managing introduced conifers in South Africa: benefits, impacts, changing perceptions and conflict resolution. J*ournal of Environmental Management*, 106, 56–68.

van Wilgen, B.W., Bond, W.J. and Richardson, D.M., 1992. Ecosystem management. In: R.M. Cowling, Ed., *The Ecology of Fynbos: Nutrients, Fire and Diversity*. Cape Town: Oxford University Press, 345–371.

van Wilgen, B.W., Cowling, R. M., Marais, C., Esler, K.J., McConnachie, M. and Sharp, D., 2012b. Challenges in invasive alien plant control in South Africa. *South African Journal of Science,* 108, 11–12.

van Wilgen, B.W., Richardson, D. M., Le Maitre, D.C. and Magadlela, D., 2001. The economic consequences of alien invasion: examples of intact and approaches to sustainable management in South Africa. *Environment, development and sustainability*, 3, 145–168.

Walker, L.R. and Smith, W.A., 1997. Impacts of invasive plants on community and ecosystem properties. *In:* J.O. Luken and J.W. Thieret, Eds. *Assessment and Management of Plant Invasions*. New York: Springer-Verlag, 69–85.

Walters, M. and Milton, S.J., 2003. The production, storage and viability of seeds of Acacia karroo and A. nilotica in a grassy savanna in KwaZulu-Natal, South Africa. *African Journal of Ecology*, 41, 211–217.

Way, J., 2015. *Alien plant impact*: *What impact are invasive alien plants having on EKZNW protected areas?* [online]. Available from: http://www.kznwildlife.com/alien-plant-impact.html. [Accessed 10/02/2015].

Wilson, M.F. and Traveset, A., 2000. The Ecology of Seed Dispersal Seeds. *In:* M. Fenne, Eds. *Seeds: The Ecology of Regeneration in Plant Communities, 2nd edition*. Wallingford: CABI Publishing, 85–110.

Witkowski, E.T.F and R. D. Garner., 2000. Spatial distribution of soil seed banks of three African savanna woody species at two contrasting sites. *Plant Ecology*, 149, 91–106.

Witkowski, E.T.F. and Wilson, M., 2001. Changes in density, biomass, seed production and soil seed banks of the non-native invasive plant, Chromolaena odorata, along a 15-year chronosequence. *Plant Ecology*, 152, 13–27.

Witkowski, E.T.F., 1991.Nutrient limitation of inflorescence and seed production in Leucospermum parile (Proteaceae) in the Cape fynbos. *Journal of Applied Ecology*, 27, 148-158.

Woods, K. D., 1997. Community Response to Plant Invasion. *In:* J.O. Luken and J.W. Thieret, Eds. *Assessment and Management of Plant Invasions*. New York: Springer-Verlag, 56–68.

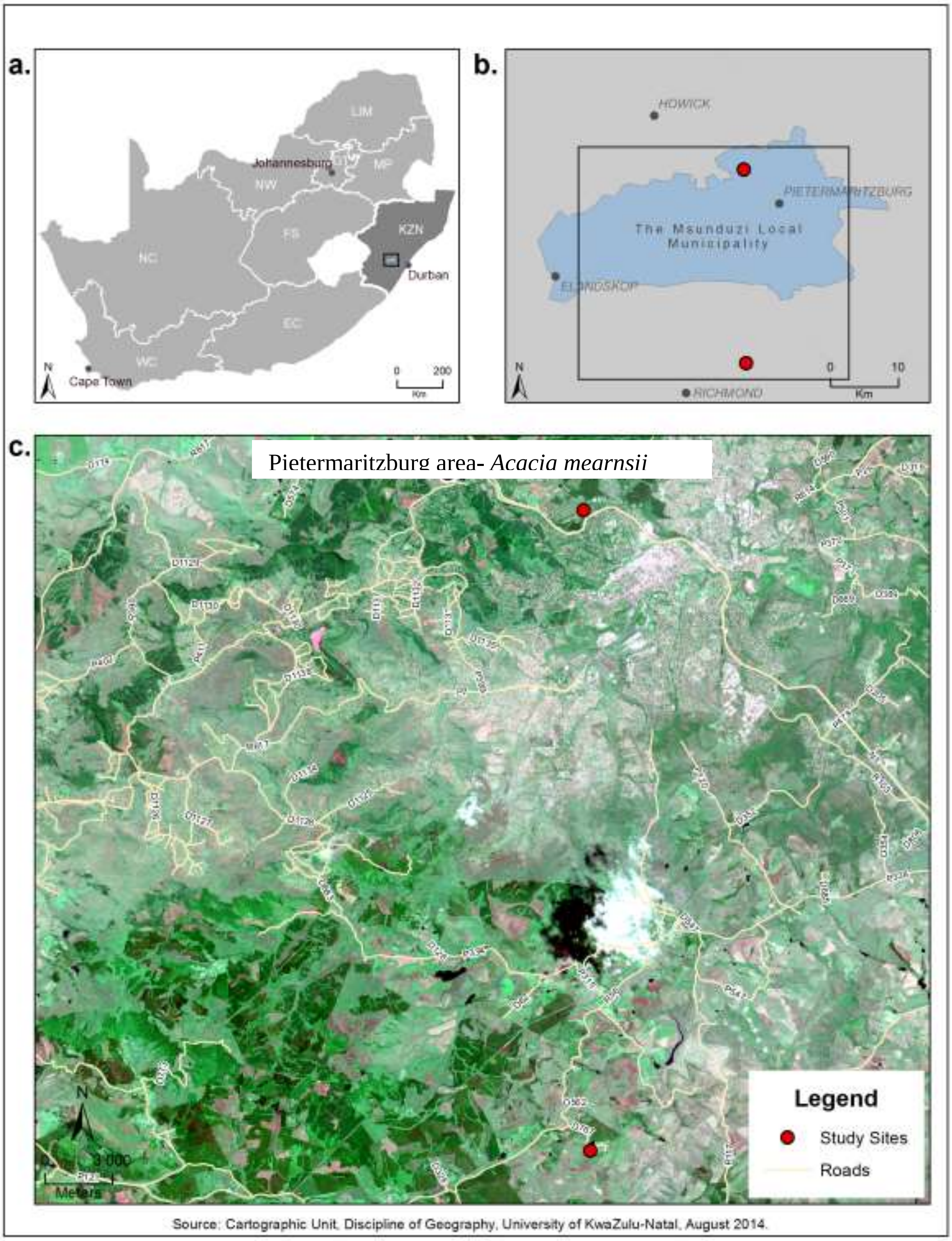
Working for Water (WFW)., 2004. *Annual Report 2003/04. Working for Water: A South African Sustainability Case*. [online]. Available from: http://www.dwaf.gov.za/wfw/AnnualReports/Archives/2003-2004/Default.asp. (Accessed 10/02/2015).

Zavaleta, E.S., Hobbs, R.J., Mooney, H.A., 2001. Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology and Evolution*, 16, 454–459.

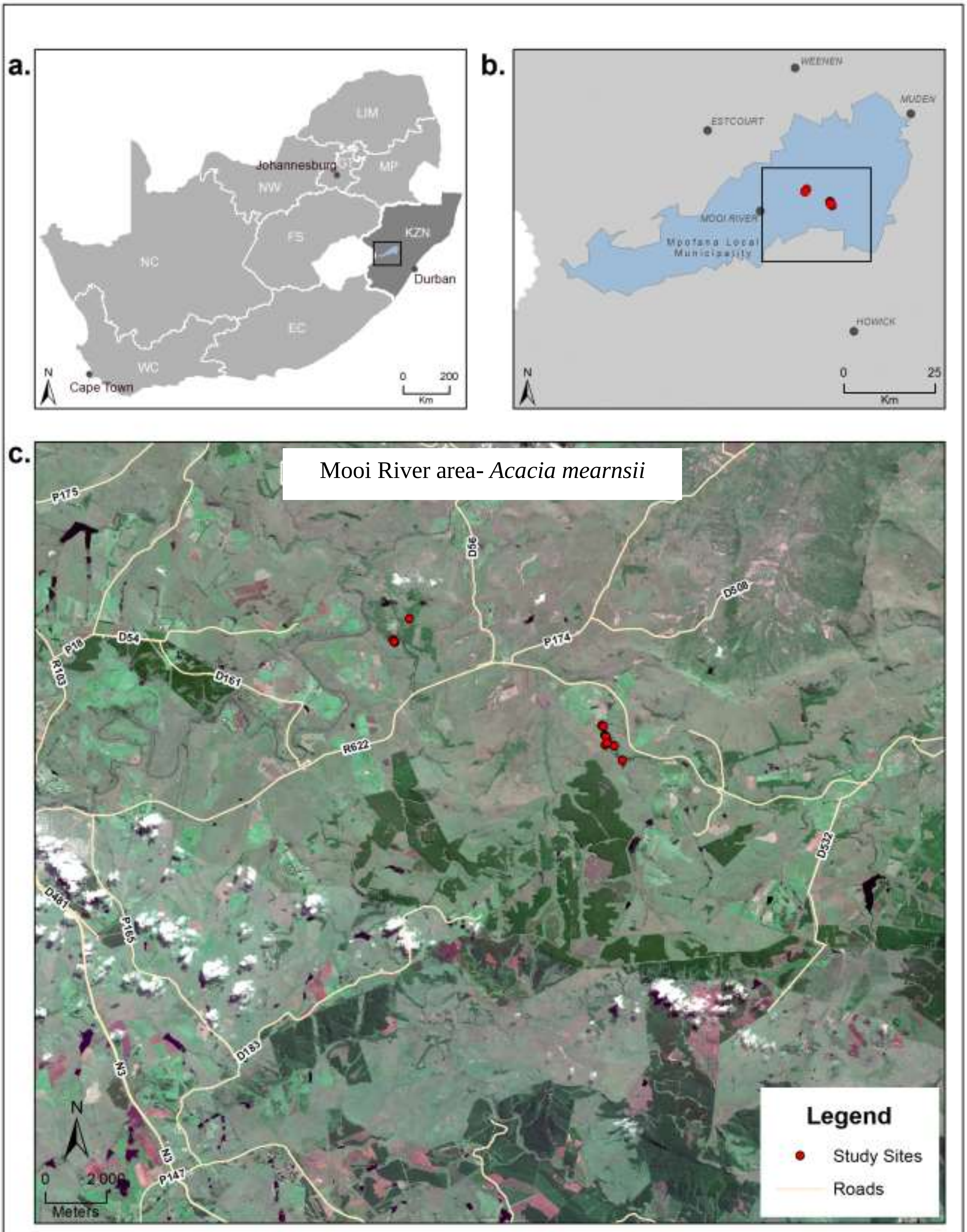
Zimmermann, H.G., Moran, V.C. and Hoffmann, J.H., 2004. Biological control in the management of invasive alien plants in South Africa, and the role of the Working for Water Programme: working for water. *South African Journal of Science*, 100, 34–40.

Appendices

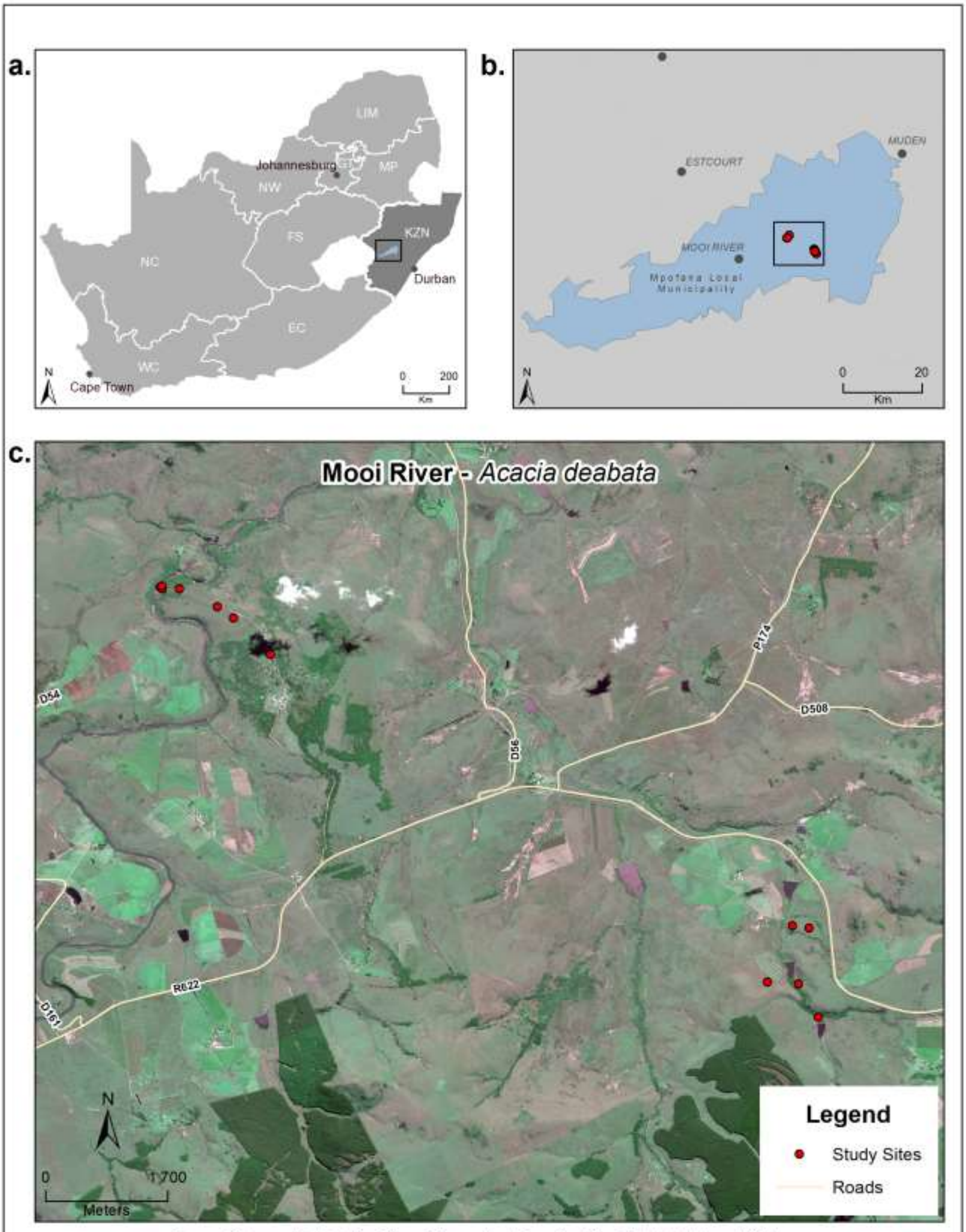
Appendix 1. Maps of the studied area



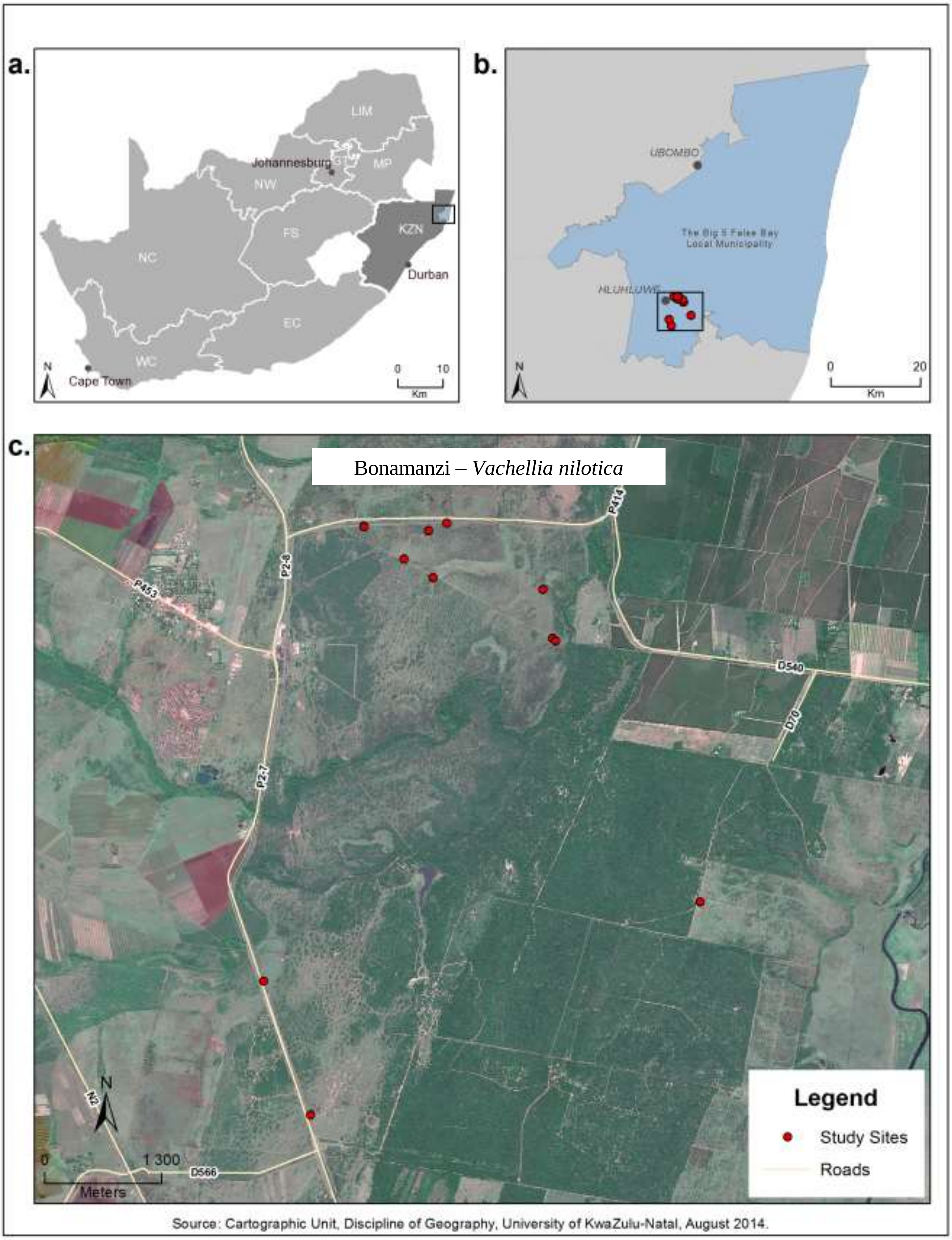
Source: Cartographic Unit, Discipline of Geography, University of KwaZulu-Natal, August 2014.



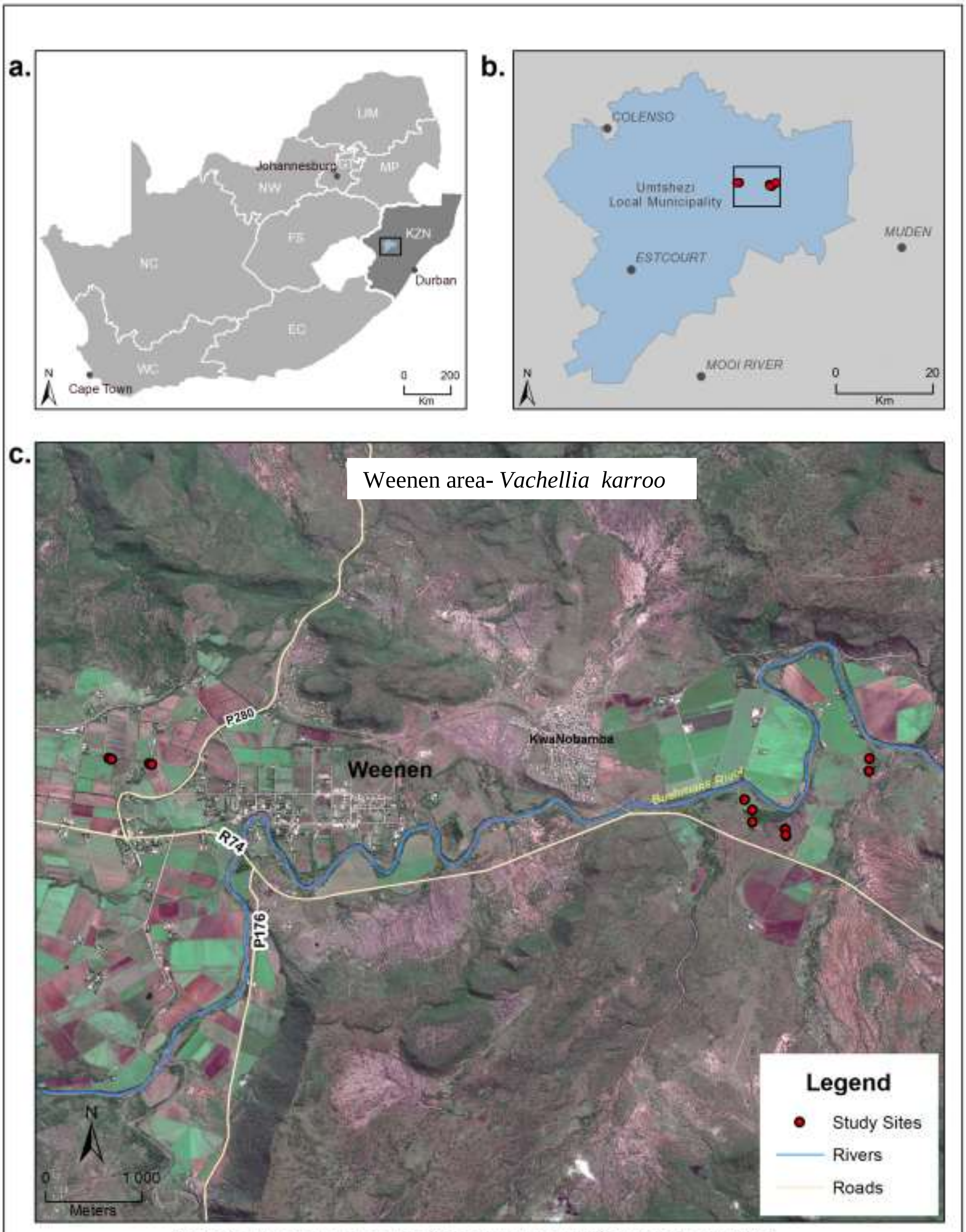
Source: Cartographic Unit, Discipline of Geography, University of KwaZulu-Natal, August 2014.



Source: Cartographic Unit, Discipline of Geography, University of KwaZulu-Natal, August 2014.



Source: Cartographic Unit, Discipline of Geography, University of KwaZulu-Natal, August 2014.



Source: Cartographic Unit, Discipline of Geography, University of KwaZulu-Natal, August 2014.

Appendix 2. Sample of field data sheet

Field Data Sheet

Sheet #............................... Date…………………………. Name……………………

Location …………………. GPS points ....……………S …..…………………………..E

Tree Species……………… Photo #……………………… DBH (cm).......................

Slope……………………… Elevation (m)……………….. Other……………….

Tree height (m)			
Manual height	Distances from tree (X)	Angle of tree height	True Height

Canopy (m)			
Length of longest Canopy (X)	Length of Canopy axis 90°C to X(Y)	Area π (d1/2)x(d2/2)	Volume (4/3) π (d1/2)x (d2/2)x (height/2)

Soil Properties				
Upslope/ North				
#	PH	Soil texture	Soil colour	Comments
1 Under				
2 Middle				
3 Periphery				
Downslope/South				
4 Under				
5 Middle				
6 Periphery				

Site Description
………
……………..……………………………………………………………………………………………
………

Appendix 3. Tetrazolium test method

The following method was used, adapted from Perry, (1981):

1) A solution of 1.0% TTC was prepared (1g of Tetrazolium and 100 ml of distilled water), stored in a dark container and kept and used for several months while remaining refrigerated at 5°C.

2) Each sample of seeds was placed in a beaker which was three-quarters filled with water. It was then stirred to release air bubbles and ensure the seeds were submerged. These seeds were left soaking overnight at room temperature to allow them to soften.

3) The following day, once the seeds had softened, a scalpel was used on each seed, in order to make a slight cut into the hard outer coat, enabling the solution to penetrate.

4) These seeds were then placed in labelled beakers, and Tetrazolium solution was poured over the seeds until all were covered.

5) Cling wrap was used to cover each beaker which was then placed in an oven at 35°C for 24 hours.

6) After 24 hours, each seed was removed with tweezers and dipped on blotting paper, until excess solution was removed.

7) Then each seed had the outer layer removed and was split with the scalpel to examine the embryo and cotyledon.

Seeds were categorized as either viable or non-viable (Plate B and Plate C). Non-viable seeds were sub-divided into five categories depending on the percentage of seed not stained <10%, 25%, 50%, 75%, 100% (Plate A). This was dependant on where the seed was stained, for example, if the cotyledon was not stained, but the rest of the seed was, it would still be classified as non-viable. Older seeds that were not viable were classified into two groups as black (B) or dark brown (DB). Seed predation through insect damage or other means was noted as the last category.

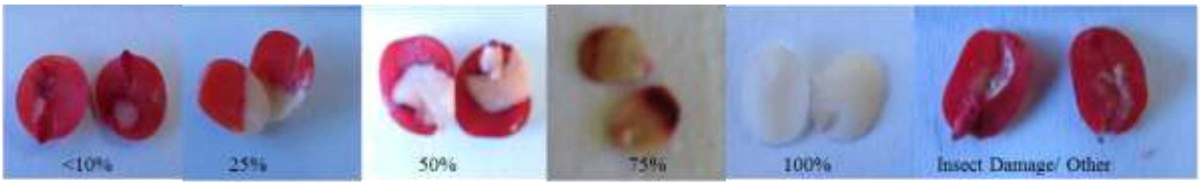


Plate A. *Vachellia karroo* seeds after being stained; from left to right from < 10% to 100% tissue not stained.

Plate B. *Vachellia karroo* seeds; (A) original seed, (B) Seed cut in top left corner, (C) seed after soaking in TZ solution, (D) Cross section of seed that has been stained (E) Seed with insect damage classified as non-viable.

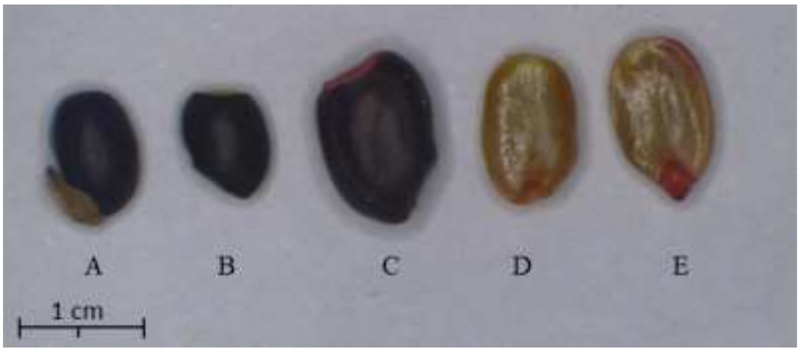


Plate C. *Acacia mearnsii* seeds; (A) original seed, (B) Seed cut in across the top, (C) seed after soaking in TZ solution, red tissues visible (D) Cross section of seed that has been stained and classified as non-viable (E) cotyledon stained therefore classified as viable.

Appendix 4. Field work details

Tree	Date	Location	South	East	Elevation (m)	Slope (°)	
Vachellia karroo							
1	2013/11/18	Weenen	28° 50' 818"	30° 04' 239"	884	0	
2	2013/11/18	Weenen	28° 50' 823"	30° 04' 350"	876	30	
3	2013/11/19	Weenen HS	28° 51' 021"	30° 07' 701"	843	0	
4	2013/11/19	Weenen HS	28° 51' 077"	30° 07' 744"	837	0	
5	2013/11/19	Weenen HS	28° 51' 147"	30° 07' 745"	845	15	
6	2013/11/19	Weenen HS	28° 50' 788"	30° 08' 405"	847	0	
7	2013/11/19	Weenen HS	28° 50' 787"	30° 04' 107"	876	0	
8	2013/11/19	Weenen	28° 50' 792"	30° 04' 124"	874	0	
9	2013/11/20	Weenen HS	28° 51' 189"	30° 07' 930"	843	5	
10	2013/11/20	Weenen HS	28° 51' 225"	30° 07' 935"	847	2	
11	2013/11/20	Weenen HS	28° 51' 218"	30° 07' 931"	847	2	
12	2013/11/20	Weenen HS	28° 50' 858"	30° 08' 403"	830	0	
Vachellia nilotica							
1	2014/01/05	Bonamanzi	28° 02' 908"	32° 10' 303"	-	2	
2	2014/02/05	Bonamanzi	28° 04' 191"	32° 16' 959"	-	0	
3	2014/02/05	Bonamanzi	28° 03' 386"	32° 16' 674"	-	0	
4	2014/02/05	Bonamanzi	28° 00' 956"	32° 17' 696"	-	0	
5	2014/02/05	Bonamanzi	28° 00' 626"	32° 17' 778"	-	0	
6	2014/02/05	Bonamanzi	28° 00' 674"	32° 17' 669"	-	0	
7	2014/03/05	Bonamanzi	28° 00' 843"	32° 17' 519"	-	0	
8	2014/03/05	Bonamanzi	28° 01' 321"	32° 18' 414"	-	0	
9	2014/03/05	Bonamanzi	28° 01' 336"	32° 18' 433"	-	0	
10	2014/03/05	Bonamanzi	28° 01' 028"	32° 18' 357"	-	0	
11	2014/03/05	Bonamanzi	28° 00' 644"	32° 17' 277"	-	0	
12	2014/03/05	Bonamanzi	28° 00' 648"	32° 17' 278"	-	0	
Acacia mearnsii							
1	2014/01/29	Houston	29° 11' 389"	30° 10' 594"	1423	4	
2	2014/01/29	Houston	29° 11' 335"	30° 10' 470"	1427	21	
3	2014/07/03	PMB	29° 34' 548"	30° 21' 102"	715	9	
4	2014/03/16	Thornville	29° 11' 336"	30° 10' 473"	-	1	
5	2014/03/30	Houston	29° 11' 032"	30° 10' 376"	1408	2	
6	2014/03/30	Houston	29° 11' 047"	30° 10' 406"	1404	4	
7	2014/03/30	Houston	29° 11' 643"	30° 10' 738"	1437	3	
8	2014/04/06	Houston	29° 11' 197"	30° 10' 428"	1432	12	
9	2014/04/06	Houston	29° 11' 370"	30° 10' 433"	1445	14	
10	2014/04/06	Houston	29° 11' 288"	30° 10' 442"	1415	18	
11	2014/06/14	Sierra Ranch	29° 09' 557"	30° 06' 716"	1411	20	
12	2014/06/14	Sierra Ranch	29° 09' 542"	30° 06' 703"	1421	20	
Acacia dealbata							
1	2014/01/29	Houston	29° 11' 393"	30° 10' 586"	1422	25	
2	2014/03/30	Houston	29° 11' 643"	30° 10' 736"	1420	0	
3	2014/04/06	Houston	29° 11' 379"	30° 10' 354"	1454	20	
4	2014/04/06	Houston	29° 10' 974"	30° 10' 664"	1417	0	
5	2014/04/06	Houston	29° 10' 956"	30° 10' 539"	1396	5	
6	2014/06/13	Sierra Ranch	28° 00' 646"	32° 17' 278"	1306	2	
7	2014/06/13	Sierra Ranch	29° 08' 422"	30° 05' 805"	1309	3	
8	2014/06/13	Sierra Ranch	29° 08' 412"	30° 05' 786"	1310	0	
9	2014/06/13	Sierra Ranch	20° 08' 424"	30° 05' 932"	1320	2&20	
10	2014/06/13	Sierra Ranch	29° 08' 560"	30° 06' 218"	1362	16	
11	2014/06/13	Sierra Ranch	29° 08' 641"	30° 06' 340"	1375	15	

Appendix 5. Tree measurements and soil characteristics

Vachellia nilotica							
	Tree Measurements				**Soil**		
Tree	**DBH** (cm)	**High** (m)	**Area** (m^2)	**Volume** (m^3)	**Colour**	**Texture**	**Code**
1	61	4.5	12.4	37.1	Dark Brown	Sandy	10 YR 3/3
2	93	3.5	21.6	50.4	Very Dark grey	Clay	5 YR 3/1
3	88	3.5	11.01	25.65	Black	Clay	5 YR 2.5/1
4	54	2.5	4.9	8.18	Black	Clay	5 YR 2.5/1
5	48	3	9.42	18.85	Very Dark grey	Clay	5 YR 3/1
6	57	2.5	7.85	13.09	Dark Reddish brown	Clay	5YR 2/1
7	63	2.5	11.01	18.33	Black	Clay	5YR2.5/1
8	87	4	12.37	32.99	Very Dark grey	Clay	7.5 YR 3/1
9	67	2.5	17.67	29.45	Very Dark grey	Clay	7.5 YR 3/1
10	43	2.5	2.36	3.93	Black	Clay	10YR 2/1
11	79	4	11.78	31.42	Very Dark grey	Clay	5YR 3/1
12	68	3.5	7.9	18.33	Very Dark grey	Clay	5 YR 3/1
Vachellia karroo							
1	75	6	23.6	53	Very dark Greyish Brown	Sandy	10 YR 3/2
2	35	5.2	11	38	Very dark Greyish Brown	Sandy	2.5 Y 3/2
3	33	4.5	7.5	22.6	Light Olive Brown	Sandy	2.5 Y 5/4
4	58	5.3	11	39	Brown	Sandy	7.5 5/4
5	32	2.5	2	3.9	Purple grey blue	Shale Sand	Gley2 5/5h
6	40	3.2	7	15	Very dark Greyish Brown	Clay	2.5 Y 3/2
7	45	4.5	7	21.2	Brown	Clay	10 YR 4/3
8	46	5	6.2	20.9	Dark Yellowish Brown	Clay	10 YR 4/4
9	45	3.2	5.8	12.5	Dark Blueish Grey	Shale Sand	Gley2 4/5B
10	70	3.5	4.9	11.4	Dark Grey	Shale Sand	2.5 Y 4/1
11	19	1.8	1.4	1.7	Dark Blueish Grey	Shale Sand	Gley24/10B
12	68	5.2	17.6	61.2	Reddish Brown	Clay	5 YR 4/3

Acacia mearnsii							
	Tree Measurements				**Soil**		
Tree	**DBH** (cm)	**High** (m)	**Area** (m^2)	**Volume** (m^3)	**Colour**	**Texture**	**Code**
1	140	7	20	96	Dark Reddish Brown	Clayey	2.5 YR 313
2	169	6.5	33	143	Very dusty red	Clayey	2.5 YR 2.5/2
3	141	12	43	334	Dark Reddish Brown	Clayey	-
4	54	8.5	36	232	Dark Reddish Brown	Clayey	5 YR 3/4
5	74	6	11	44	Dark Brown	Clayey	7.5 YR 3/3
6	64	5.5	7	26	Very dark greyish brown		10YR 3/2
7	43	5	5	16	Dark Reddish Brown		5YR
8	107	7.5	13	66	Dark yellowish Brown	Clayey	10 YR 4/4
9	73	8	9	50	Dark Reddish		5 YR 2.5/2
10	37	5.5	4	14	Very Dark Brown		7.5 YR 3/2
11	86	6	9.9	39.6	Dark Brown	Clayey	7.5 YR 3/4
12	68	4.3	3.3	9.45	Brown		7.5 YR 2/4
Acacia dealbata							
1	74*	6	28	113	Dark reddish brown	Clayey	2.5 YR 2.5/3
2	86	8	12	89	Dark yellowish Brown	Clayey	10 YR 3/4
3	62	5.5	20	73	Red darkish brown	Clayey	2.5 YR 3/4
4	69	5	13	42	Very dark greyish brown	Clayey	10 YR 3/4
5	93*	5.2	20	68	Dark greyish brown	Clayey	10 YR 4/2
6	182	10.2	33	226	Dark reddish brown	Clayey	5 YR 3/3
7	84	7.3	9.4	45.9	Dark brown	Clayey	7.5 4/3
8	89	6.2	19.6	81	Brown	Sandy	7.5 YR 4/4
9	74	6	18.8	20	Dark brown	Sandy	2.5 YR 4/3
10	70*	5	7.5	24.9	Reddish brown	Clayey	5 YR 4/4
11	80	5.1	13.4	45.8	Grey	Shale	10 YR 6/1
12	100	5.8	11.7	45.5	Brown	Clayey	7.5 YR 3/4

(*) multi stemmed

Appendix 6. Seed numbers

Total seed collected from *Vachellia karroo* on two different axes (up-slope and down-slope), at three different micro-sites (under, middle, and periphery), at three different depths (0-2 cm, 2-4 cm and 4-10 cm).

Vachellia karroo										
Upslope or North Slope										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
1	17	12	14	6	26	11	2	1	3	**92**
2[*ii]	11	30	32	3	6	4	2	9	4	**101**
3	3	2	0	0	0	1	0	0	0	**6**
4	3	1	2	1	0	0	0	0	0	**7**
5[*ii]	0	1	0	0	0	0	0	0	0	**1**
6	9	2	3	3	0	0	3	1	0	**21**
7	8	16	7	22	8	0	11	4	1	**77**
8	27	12	6	5	3	11	1	2	0	**67**
9[*i]	1	0	0	1	2	0	0	0	0	**4**
10	29	9	5	19	5	0	0	0	0	**67**
11	2	0	0	0	0	0	0	0	0	**2**
12	6	2	8	4	1	7	0	0	0	**28**
Total	**116**	**87**	**77**	**64**	**51**	**34**	**19**	**17**	**8**	**473**
Downslope or South										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
1	16	26	5	17	34	33	13	19	6	**169**
2[*ii]	5	0	2	15	23	14	21	8	0	**88**
3	0	1	0	0	0	1	0	0	0	**2**
4	3	1	1	3	0	0	0	0	0	**8**
5[*ii]	1	1	0	0	0	0	0	0	0	**2**
6	8	3	2	4	0	0	0	0	0	**17**
7	11	0	0	17	25	5	21	25	15	**119**
8	48	6	3	37	9	11	24	17	13	**168**
9[*i]	0	0	0	1	0	0	2	0	0	**3**
10	12	7	2	2	0	0	2	3	2	**30**
11	1	0	0	0	0	0	0	0	0	**1**
12	5	3	14	3	3	1	1	0	0	**30**
Total	**110**	**48**	**29**	**99**	**94**	**65**	**84**	**72**	**36**	**637**

*Trees that were sampled on [i]gentle or [ii]steep slopes.

Total seed collected from *Vachellia nilotica* on two different axes (up-slope and down-slope), at three different micro-sites (under, middle, and periphery), at three different depths (0-2 cm, 2-4 cm and 4-10 cm)

Vachellia nilotica										
Upslope or North Slope										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
AN 1	0	0	0	0	0	0	0	0	0	**0**
AN 2	1	0	0	0	0	0	0	0	0	**1**
AN 3	7	0	0	0	0	0	0	0	0	**7**
AN 4	0	0	0	0	0	0	0	0	0	**0**
AN 5	0	0	0	0	0	0	0	0	0	**0**
AN 6	1	0	0	1	1	0	0	0	0	**3**
AN 7	0	0	0	0	0	0	0	0	0	**0**
AN 8	9	0	0	0	0	0	0	0	0	**9**
AN 9	12	0	0	0	0	0	0	0	0	**12**
AN 10	0	0	0	0	0	0	0	0	0	**0**
AN 11	2	2	0	4	0	0	0	0	0	**8**
AN 12	6	3	0	0	0	0	0	0	0	**9**
Total	**38**	**5**	**0**	**5**	**1**	**0**	**0**	**0**	**0**	**49**
Downslope or South										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
AN 1	0	0	0	0	0	0	0	0	0	**0**
AN 2	0	0	0	0	0	0	0	0	0	**0**
AN 3	7	0	0	11	0	0	0	0	0	**18**
AN 4	0	0	0	1	0	0	0	0	0	**1**
AN 5	0	0	0	0	0	0	0	1	0	**1**
AN 6	0	1	0	0	0	0	0	0	0	**1**
AN 7	0	0	0	0	0	0	0	0	0	**0**
AN 8	18	0	0	0	0	0	0	0	0	**18**
AN 9	0	0	0	0	0	0	0	0	0	**0**
AN 10	0	0	0	0	0	0	0	0	0	**0**
AN 11	6	6	0	2	0	0	0	0	0	**14**
AN 12	1	1	0	0	0	0	1	0	0	**3**
Total	**32**	**8**	**0**	**14**	**0**	**0**	**1**	**1**	**0**	**56**

Total seed collected from *Acacia mearnsii* on two different axes (up-slope and down-slope), at three different micro-sites (under, middle, and periphery), at three different depths (0-2 cm, 2-4 cm and 4-10 cm).

Acacia mearnsii										
Seed Numbers Upslope or North Slope										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
AM 1*[i]	266	17	11	23	13	49	0	0	0	**379**
AM 2	6	3	2	6	1	0	2	0	0	**20**
AM 3*[i]	11	9	1	4	3	2	0	0	0	**30**
AM 4	100	37	7	48	2	7	10	0	0	**211**
AM 5	43	3	2	9	0	0	3	0	0	**60**
AM 6*[i]	3	0	0	147	39	9	7	6	3	**214**
AM 7	46	5	0	34	25	7	0	0	0	**117**
AM 8*[ii]	38	8	3	20	5	1	0	0	0	**75**
AM 9*[ii]	13	5	3	73	15	25	1	0	0	**135**
AM 10*[ii]	4	1	2	1	1	1	1	0	0	**11**
AM 11*[ii]	9	15	16	3	7	18	2	13	34	**117**
AM 12*[ii]	233	14	9	89	25	26	2	0	0	**398**
Total	**772**	**117**	**56**	**457**	**136**	**145**	**28**	**19**	**37**	**1 767**
Downslope or South										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
AM 1*[i]	38	55	107	72	48	8	1	0	1	**330**
AM 2	23	9	5	29	5	5	0	0	0	**76**
AM 3*[i]	6	1	0	0	0	0	2	3	0	**12**
AM 4	65	21	16	48	29	9	1	6	0	**195**
AM 5	4	2	0	20	0	0	3	3	2	**34**
AM 6*[i]	132	29	25	139	30	29	5	0	0	**389**
AM 7	13	5	0	34	16	6	2	3	1	**80**
AM 8*[ii]	10	11	0	64	7	3	5	1	0	**101**
AM 9*[ii]	83	24	12	61	15	21	1	5	0	**222**
AM 10*[ii]	4	0	0	0	0	0	0	0	0	**4**
AM 11*[ii]	20	6	6	11	7	0	10	0	14	**74**
AM 12*[ii]	30	47	9	22	13	13	5	6	3	**148**
Total	**428**	**210**	**180**	**500**	**170**	**94**	**35**	**27**	**21**	**1 665**

*Trees that were sampled on [i]gentle or [ii]steep slopes.

Total seed collected from *Acacia dealbata* on two different axes (up-slope and down-slope), at three different micro-sites (under, middle, and periphery), at three different depths (0-2 cm, 2-4 cm and 4-10 cm).

Acacia dealbata										
Upslope or North Slope										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
AD 1*[ii]	67	21	38	3	3	0	0	0	0	**132**
AD 2	31	16	2	3	0	0	0	0	0	**52**
AD 3*[ii]	12	3	0	6	9	0	3	1	0	**34**
AD 4	0	0	0	0	0	0	0	0	0	**0**
AD 5*[i]	1339	217	223	1036	113	56	8	4	0	**2 996**
AD 6	246	395	248	150	122	55	2	2	0	**1 220**
AD 7	4	7	12	4	11	15	4	101	76	**234**
AD 8	266	185	153	271	86	54	1	4	0	**1 020**
AD 9*[ii]	114	257	151	67	4	26	1	1	0	**621**
AD 10*[ii]	5	5	8	7	4	0	1	7	0	**37**
AD 11*[ii]	38	51	4	13	4	3	0	2	0	**115**
AD 12	19	8	3	15	4	1	0	2	0	**52**
Total	**2 141**	**1 165**	**842**	**1 575**	**360**	**210**	**20**	**124**	**76**	**6 513**
Downslope or South										
Tree number	**Under**			**Middle**			**Periphery**			**Total**
	0-2	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	**0-2**	**2-4**	**4-10**	
AD 1*[ii]	38	34	13	333	84	58	7	4	3	**574**
AD 2	64	13	8	14	2	7	1	1	0	**110**
AD 3*[ii]	2	1	0	85	23	22	0	0	0	**133**
AD 4	0	1	0	0	0	2	0	0	0	**3**
AD 5*[i]	2 537	2 133	758	2 306	373	37	28	5	2	**8 179**
AD 6	980	79	96	635	125	76	56	6	10	**2 063**
AD 7	1	1	3	8	10	21	4	4	2	**54**
AD 8	314	67	27	170	151	121	52	12	1	**915**
AD 9*[ii]	101	34	15	15	67	3	0	0	0	**235**
AD 10*[ii]	27	3	2	29	39	18	17	1	7	**143**
AD 11*[ii]	17	1	0	106	75	4	0	0	0	**203**
AD 12	37	19	10	43	15	5	1	1	0	**131**
Total	**4 118**	**2 386**	**932**	**3 744**	**964**	**374**	**166**	**34**	**25**	**12 743**

*Trees that were sampled on [i]gentle or [ii]steep slopes.

Appendix 7. Seed viability

Only samples that had seeds are reflected in the tables below.

Vachellia karroo												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
AK1-N-1a	15	2	1								1	
Ak1-N-1b	11	1		1								
Ak1-N-1c	14	0										
Ak1-N-2a	6	0										
Ak1-N-2b	24	2			2							
Ak1-N-2c	11	0										
Ak1-N-3a	2	0										
Ak1-N-3b	1	0										
Ak1-N-3c	2	1							1			
Ak1-S-1a	16	0										
Ak1-S-1b	24	2			1						1	
Ak1-S-1c	5	0										
Ak1-S-2a	14	3			2	1						
Ak1-S-2b	33	1		1								
Ak1-S-2c	31	2	1	1								
Ak1-S-3a	10	3			1				2			
Ak1-S-3b	17	2					1		1			
Ak1-S-3c	6	0										
Ak2-U-1a	7	4									4	
Ak2-U-1b	26	4		1	2					1		
Ak2-U-1c	28	4	3	1								
Ak2-U-2a	3	0										
Ak2-U-2b	6	0										
Ak2-U-2c	4	0										
Ak2-U-3a	2	0										
Ak2-U-3b	8	1	1									
Ak2-U-3c	4	0										
Ak2-D-1a	3	2		1						1		
Ak2-D-1c	2	0										
Ak2-D-2a	11	4	1						1	2		
Ak2-D-2b	19	4	2	2								
Ak2-D-2c	10	4	1		1		1	1				
Ak2-D-3a	16	5	1						2	2		
Ak2-D-3b	7	1		1								
Ak3-N-1a	1	2								2		
Ak3-N-1b	1	1		1								
Ak3-N-2c	0	1					1					
Ak3-S-1b	0	1								1		
Ak3-S-2c	0	1								1		
Ak4-N-1a	0	3								3		
Ak4-N-1b	1	0										
Ak4-N-1c	1	1	1									
Ak4-N-2a	1	0										
Ak4-S-1a	2	1								1		
Ak4-S-1b	1	0										
Ak4-S-1c	1	0										
Ak4-S-2a	2	1								1		
Ak5-U-1b	0	1								1		
Ak5-D-1a	1	0										
Ak5-D-1b	0	1								1		

B-Black DB- Dark brown Bl Bu-bug damage Ger- Germinated

Vachellia karroo

Code	Viable	Non-Viable	>10	25	50	75	100	B	DB	Bl	Bu	Ger
Ak6-N-1a	6	3					2			1		
Ak6-N-1b	2	0										
Ak6-N-1c	3	0										
Ak6-N-2a	2	1								1		
Ak6-N-3a	1	2								2		
Ak6-N-3b	1	0										
Ak6-S-1a	7	1								1		
Ak6-S-1b	2	1	1									
Ak6-S-1c	2	0										
Ak6-S-2a	3	1	1									
Ak7-N-1a	8	0										
Ak7-N-1b	15	1								1		
Ak7-N-1c	7	0										
Ak7-N-2a	16	6			2				2	2		
Ak7-N-2b	6	2	1	1								
Ak7-N-3a	5	6		1		1			1	3		
Ak7-N-3b	4	0										
Ak7-N-3c	1	0										
Ak7-S-1a	11	0										
Ak7-S-2a	13	4					1			3		
Ak7-S-2b	21	4		1	1	1				1		
Ak7-S-2c	5	0										
Ak7-S-3a	9	12		3	3		1			5		
Ak7-S-3b	18	7	2	3		1				1		
Ak7-S-3c	6	9	3	2						4		
Ak8-U-1a	21	6		2						4		
Ak8-U-1b	12	0										
Ak8-U-1c	6	0										
Ak8-U-2a	4	1			1							
Ak8-U-2b	3	0										
Ak8-U-2c	9	2		1	1							
Ak8-U-3a	1	0										
Ak8-U-3b	2	0										
Ak8-D-1a	35	13	5	2	1	2			1	2		
Ak8-D-1b	5	1				1						
Ak8-D-1c	3	0										
Ak8-D-2a	30	7		2		1			2	2		
Ak8-D-2b	8	1		1								
Ak8-D-2c	11	0										
Ak8-D-3a	15	9	2	2					2	3		
Ak8-D-3b	16	1		1								
Ak8-D-3c	12	1		1								
Ak9-U-1a	1	0										
Ak9-U-2a	0	1					1					
Ak9-U-2b	2	0										
Ak9-D-2a	1	0										
Ak9-D-3a	2	0										
Ak10-U-1a	6	23	3		5		2	1	4	5	3	
Ak10-U-1b	5	4			1		1			2		
Ak10-U-1c	1	4		1						3		
Ak10-U-2a	2	17		3	1	1				12		
Ak10-U-2b	1	4			2					1	1	
Ak10-D-1a	6	6							3	3		
Ak10-D-1b	2	5	1	1			1			2		
Ak10-D-1c	1	1								1		
Ak10-D-2a	1	1	1									
Ak10-D-3a	1	1								1		
Ak10-D-3b	1	2								2		
Ak10-D-3c	1	1							1			

Vachellia karroo												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
AK11-U-1a	0	1		1								
AK11-D-1a	1	0										
AK12-N-1a	6	0										
AK12-N-1b	2	0										
AK12-N-1c	8	0										
AK12-N-2a	2	2								2		
AK12-N-2b	1	0										
AK12-N-2c	6	1								1		
AK12-S-1a	4	1								1		
AK12-S-1b	2	1	1									
AK12-S-1c	12	2	2									
AK12-S-2a	2	1								1		
AK12-S-2b	3	0										
AK12-S-2c	1	0										
AK12-S-3a	1	0										

Vachellia nilotica												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
AN2-N-1a	1	0										
AN3-N-1a	1	6				1	1	2	2			
AN3-S-1a	2	5		4	1							
AN3-S-2a	0	11			1			10				
AN4-S-2a	1	0										
AN5-S-3a	0	1			1							
AN6-N-1a	1	0										
AN6-N-2a	1	0										
AN6-N-2b	0	1							1			
AN6-S-1b	0	1							1			
AN8-N-1a	0	9					3			6		
AN8-S-1a	0	19	1	2	3	5	5	3				
AN9-N-1a	3	9					6		3			
AN11-N-1a	5	1		1								
AN11-N-1b	2	0										
AN11-N-2a	2	0										
AN11-S-1a	3	1		1								
AN11-S-2a	3	1				1						
AN12-N-1a	5	0										
AN12-N-1b	3	0										
AN12-S-1a	1	0										
AN12-S-1b	0	1					1					
AN12-S-3a	0	1					1					

Acacia mearnsii												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
BW 1-U-1a	259	7	3	2	1	1					1	
BW 1-U-1b	17	0										
BW 1-U-1c	11	0										
BW 1-U-2a	23	0										
BW 1-U-2b	13	0										
BW 1-U-2c	45	4	1		1	2						
BW1-D-1a	9	29	4	5	6	7	4	3				
BW1-D-1b	3	52	8	5	2	9	27	1				
BW1-D-1c	75	32	10	9	4	7	2					
BW1-D-2a	24	48	17	15	5	7	3			1		
BW1-D-2b	15	33	7	6	5	4	11					
BW1-D-2c	4	4		1	1		2					
BW1-D-3a	1	0										
BW1-D-3c	1	0										
BW 2-U-1a	6	0										
BW 2-U-1b	3	0										
BW 2-U-1c	2	0										
BW 2-U-2a	6	0										
BW 2-U-2b	1	0										
BW 2-U-3a	2	0										
BW 2-D-1a	23	0										
BW 2-D-1b	9	0										
BW 2-D-1c	5	0										
BW 2-D-2a	29	0										
BW 2-D-2b	5	0										
BW 2-D-2c	5	0										
BW 3-U-1a	11	0										
BW 3-U-1b	9	0										
BW 3-U-1c	1	0										
BW 3-U-2a	4	0										
BW 3-U-2b	3	0										
BW 3-U-2c	2	0										
BW 3-D-1a	6	0										
BW 3-D-1b	1	0										
BW 3-D-3a	2	0										
BW 3-D-3b	3	0										
BW 4-U-1a	98	2	1	1								
BW 4-U-1b	37	0										
BW 4-U-1c	7	0										
BW 4-U-2a	48	0									1	
BW 4-U-2b	2	0										
BW 4-U-2c	7	0										
BW 4-U-3a	10	0										
BW 4-D-1a	65	0										
BW 4-D-1b	20	1	1									
BW 4-D-1c	16	0										
BW 4-D-2a	48	0										
BW 4-D-2b	29	0										
BW 4-D-2c	8	1		1								
BW 4-D-3a	1	0										
BW 4-D-3b	6	0										
BW 5-U-1a	41	2		2								
BW 5-U-1b	3	0										
BW 5-U-1c	2	0										
BW 5-U-2a	9	0										

Acacia mearnsii												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
BW 5-U-3a	3	0										
BW 5-D-1a	4	0										
BW 5-D-1b	2	0										
BW 5-D-2a	20	0										
BW 5-D-3a	3	0										
BW 5-D-3b	3	0										
BW 5-D-3c	2	0										
BW 6-U-1a	3	0										
BW 6-U-2a	145	2	2									
BW 6-U-2b	38	1				1						
BW 6-U-2c	9	0										
BW 6-U-3a	7	0										
BW 6-U-3b	6	0										
BW 6-U-3c	3	0										
BW 6-D-1a	130	2		1		1						
BW 6-D-1b	28	1		1								
BW 6-D-1c	24	1	1									
BW 6-D-2a	138	1	1									
BW 6-D-2b	29	1		1								
BW 6-D-2c	29	0										
BW 6-D-3a	5	0										
BW 7-U-1a	46	0										
BW 7-U-1b	5	0										
BW 7-U-2a	34	0										
BW 7-U-2b	25	0										
BW 7-U-2c	7	0										
BW 7-D-1a	13	0										
BW 7-D-1b	5	0										
BW 7-D-2a	34	0										
BW 7-D-2b	16	0										
BW 7-D-2c	6	0										
BW 7-D-3a	2	0										
BW 7-D-3b	3	0										
BW 7-D-3c	1	0										
BW 8-U-1a	36	2				1			1			
BW 8-U-1b	7	1		1								
BW 8-U-1c	3	0										
BW 8-U-2a	19	1					1					
BW 8-U-2b	5	0										
BW 8-U-2c	1	0										
BW 8-D-1a	10	0										
BW 8-D-1b	11	0										
BW 8-D-2a	62	2		1			1					
BW 8-D-2b	7	0										
BW 8-D-2c	3	0										
BW 8-D-3a	5	0										
BW 8-D-3b	1	0										
BW 9-U-1a	13	0										
BW 9-U-1b	5	0										
BW 9-U-1c	3	0										
BW 9-U-2a	69	4	1	3								
BW 9-U-2b	15	0										
BW 9-U-2c	25	0										
BW 9-U-3a	1	0										

Acacia mearnsii												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
BW 9-D-1a	82	1	1									
BW 9-D-1b	21	3				2	1					
BW 9-D-1c	12	0										
BW 9-D-2a	58	3				2	1					
BW 9-D-2b	15	0										
BW 9-D-2c	20	1		1								
BW 9-D-3a	1	0										
BW 9-D-3b	5	0										
BW 10-U-1a	4	0										
BW 10-U-1b	1	0										
BW 10-U-1c	2	0										
BW 10-U-2a	1	0										
BW 10-U-2b	1	0										
BW 10-U-2c	1	0										
BW 10-U-3a	1	0										
BW 10-D-1a	4	0										
BW 11-U-1a	8	1					1					
BW 11-U-1b	14	1				1						
BW 11-U-1c	15	1				1						
BW 11-U-2a	3	0										
BW 11-U-2b	7	0										
BW 11-U-2c	16	2						2				
BW 11-U-3a	2	0										
BW 11-U-3b	11	2				1	1					
BW 11-U-3c	33	1					1					
BW 11-D-1a	20	0										
BW 11-D-1b	6	0										
BW 11-D-1c	6	0										
BW 11-D-2a	11	0										
BW 11-D-2b	7	0										
BW 11-D-3a	10	0										
BW 11-D-3c	14	0										
BW 12-U-1a	230	3				1	2					
BW 12-U-1b	14	0										
BW 12-U-1c	8	1					1					
BW 12-U-2a	89	0										
BW 12-U-2b	25	0										
BW 12-U-2c	26	0										
BW 12-U-3a	2	0										
BW 12-D-1a	29	1		1								
BW 12-D-1b	47	0										
BW 12-D-1c	8	1					1					
BW 12-D-2a	22	0										
BW 12-D-2b	13	0										
BW 12-D-2c	12	1			1							
BW 12-D-3a	5	0										
BW 12-D-3b	6	0										
BW 12-D-3c	3	0										

Acacia dealbata												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
SW 1-U-1a	64	3	1	2								
SW 1-U-1a	21	0										
SW 1-U-1c	35	3	2	1								
SW 1-U-2a	3	0										
SW 1-U-2b	3	0										
SW 1-D-1a	37	1								1		
SW 1-D-1b	31	3	1	2								
SW 1-D-1c	13	0										
SW 1-D-2a	317	16	4	3	6					3		
SW 1-D-2b	78	6	1		3	1				1		10
SW 1-D-2c	56	2	2									
SW 1-D-3a	7	0										1
SW 1-D-3b	4	0										1
SW 1-D-3c	3	0										1
SW 2-U-1a	31	0										
SW 2-U-1b	16	0										
SW 2-U-1c	2	0										
SW 2-U-2a	1	2	1			1						
SW 2-D-1a	60	4	1	2		1						
SW 2-D-1b	13	0										
SW 2-D-1c	8	0										
SW 2-D-2a	14	0										
SW 2-D-2b	2	0										
SW 2-D-2c	7	0										
SW 3-D-3a	1	0										
SW 2-D-3b	1	0										
SW 2-D-3c	0	0										
SW 3-U-1a	12	0										
SW 3-U-1b	3	0										
SW 3-U-2a	6	0										
SW 3-U-2b	8	1		1								
SW 3-U-3a	3	0										
SW 3-U-3b	1	0										
SW 3-D-1a	2	0										
SW 3-D-1b	1	0										
SW 3-D-2a	81	4		1	2		1					
SW 3-D-2b	21	2	1				1					
SW 3-D-2c	22	0										
SW 4-D-1b	1	0										
SW 4-D-2c	2	0										
SW 5-U-1a	1329	10	1	5	3	1						
SW 5-U-1b	205	12	2	5	3	2						
SW 5-U-1c	222	1						1				
SW 5-U-2a	1022	14	1	5	6	1		1				
SW 5-U-2b	108	5		2	3							
SW 5-U-2c	50	6	1	3	2							
SW 5-U-3a	8	0										
SW 5-U-3b	4	0										
SW 5-D-1a	2476	61	4	11	15	21	10					
SW 5-D-1b	2113	20	2	11	5	2						
SW 5-D-1c	741	17	2	8	4	3						
SW 5-D-2a	2095	211	23	63	49	43	33					4
SW 5-D-2b	353	20	1	5	5	6	3					
SW 5-D-2c	35	2		2								
SW 5-D-3a	23	5		2	1	2						
SW 5-D-3b	5	0										
SW 5-D-3c	2	0										

Acacia dealbata												
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
SW 6-U-1a	212	34	11	13	7		3					
SW 6-U-1b	340	55	28	13	2		11	1				
SW 6-U-1c	226	22	13	2			5	2				
SW 6-U-2a	104	46	22	13	7	4						
SW 6-U-2b	115	7	3	2		2						
SW 6-U-2c	12	43	5	20			17	1				
SW 6-U-3a	2	0										
SW 6-U-3b	2	0										
SW 6-D-1a	949	31	3	7	2		18	1				
SW 6-D-1b	73	6	2	1	1	2						
SW 6-D-1c	96	0										
SW 6-D-2a	631	4				4						
SW 6-D-2b	125	0										
SW 6-D-2c	72	4			3	1						
SW 6-D-3a	54	2			1	1						
SW 6-D-3b	5	1				1						
SW 6-D-3c	10	0										
SW 7-U-1a	4	0										
SW 7-U-1b	7	0										
SW 7-U-1c	11	1			1							
SW 7-U-2a	4	0										
SW 7-U-2b	11	0										
SW 7-U-2c	15	0										
SW 7-U-3a	4	0										
SW 7-U-3b	100	1		1								
SW 7-U-3c	76	0										
SW 7-D-1a	1	0										
SW 7-D-1b	1	0										
SW 7-D-1c	3	0										
SW 7-D-2a	8	0										
SW 7-D-2b	10	0										
SW 7-D-2c	21	0										
SW 7-D-3a	4	0										
SW 7-D-3b	4	0										
SW 7-D-3c	2	0										
SW 8-U-1a	261	5	3	1		1						
SW 8-U-1b	184	1	1									
SW 8-U-1c	152	1			1							
SW 8-U-2a	271	0										
SW 8-U-2b	86	0										
SW 8-U-2c	53	1		1								
SW 8-U-3a	1	0										
SW 8-U-3b	4	0										
SW 8-D-1a	308	6				1	2	3				
SW 8-D-1b	67	0										
SW 8-D-1c	27	0										
SW 8-D-2a	112	58	13	17	16	2	10					
SW 8-D-2b	106	45	10	12		9	14					
SW 8-D-2c	120	1	1									
SW 8-D-3a	50	2		1	1							
SW 8-D-3b	12	0										
SW 8-D-3c	1	0										
SW 9-U-1a	103	11	4		1	5	1					
SW 9-U-1b	249	8	1	1	2	2	2					

Acacia dealbata													
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
SW 9-U-1c	150	1			1							
SW 9-U-2a	67	0										
SW 9-U-2b	4	0										
SW 9-U-2c	26	0										
SW 9-U-3a	1	0										
SW 9-U-3b	1	0										
SW 9-U-3c	0	0										
SW 9-D-1a	94	7	3	1	2	1						
SW 9-D-1b	34	0										
SW 9-D-1c	15	0										
SW 9-D-2a	15	0										
SW 9-D-2b	62	5	1	1		3						
SW 9-D-2c	3	0										
SW 9-D-3a	0	0										
SW 9-D-3b	0	0										
SW 9-D-3c	0	0										
SW 10-U-1a	4	1		1								
SW 10-U-1b	5	0										
SW 10-U-1c	7	1				1						
SW 10-U-2a	7	0										
SW 10-U-2b	4	0										
SW 10-U-2c	0	0										
SW 10-U-3a	1	0										
SW 10-U-3b	7	0										
SW 10-D-1a	26	1						1				
SW 10-D-1b	3	0										
SW 10-D-1c	2	0										
SW 10-D-2a	29	0										
SW 10-D-2b	39	0										
SW 10-D-2c	17	1					1					
SW 10-D-3a	17	0										
SW 10-D-3b	1	0										
SW 10-D-3c	7	0										
SW 11-U-1a	38	0										
SW 11-U-1b	51	0										
SW 11-U-1c	4	0										
SW 11-U-2a	13	0										
SW 11-U-2b	4	0										
SW 11-U-2c	3	0										
SW 11-U-3b	2	0										
SW 11-D-1a	17	0										
SW 11-D-1b	1	0										
SW 11-D-2a	106	0										
SW 11-D-2b	75	0										
SW 11-D-2c	4	0										
SW 12-U-1a	19	0										
SW 12-U-1b	8	0										
SW 12-U-1c	3	0										
SW 12-U-2a	14	1				1						
SW 12-U-2b	4	0										
SW 12-U-2c	1	0										
SW 12-U-3b	2	0										
SW 12-D-1a	37	0										

Acacia dealbata													
Code	**Viable**	**Non-Viable**	**>10**	**25**	**50**	**75**	**100**	**B**	**DB**	**Bl**	**Bu**	**Ger**
SW 12-D-1b	19	0										
SW 12-D-1c	10	0										
SW 12-D-2a	42	1				1						
SW 12-D-2b	15	0										
SW 12-D-2c	5	0										
SW 12-D-3a	1	0										
SW 12-D-3b	1	0										

Appendix 8. Soil pH values

V. karroo		*V. nilotica*		*A. mearnsii*		*A. dealbata*	
Code	pH value	Code	pH value	Code	pH value	Code	pH value
AK 1-N-1	8.34	AN1-U-1	6.5	BW 1-U-1	7.49	SW 1-U-1	6.27
AK 1-N-2	7.95	AN1-U-2	6.68	BW 1-U-2	6.33	SW 1-U-2	5.93
AK 1-N-3	7.55	AN1-U-3	6.52	BW 1-U-3	7.16	SW 1-U-3	6.69
AK 1-S-1	7.61	AN1-D-1	6.55	BW 1-D-1	6.6	SW 1-D-1	6.2
AK 1-S-2	8.84	AN1-D-2	6.48	BW 1-D-2	6.49	SW 1-D-2	6.54
AK1 -S-3	7.52	AN1-D-3	6.56	BW 1-D-3	6.41	SW 1-D-3	6.74
AK 2-U-1	6.92	AN2-N-1	6.82	BW 2-U-1	6.26	SW 2-U-1	7.07
AK 2-U-2	7.23	AN2-N-2	6.72	BW 2-U-2	6.57	SW 2-U-2	7.1
AK 2-U-3	7.3	AN2-N-3	6.7	BW 2-U-3	5.94	SW 2-U-3	7.13
AK 2-D-1	7.38	AN2-S-1	6.75	BW 2-D-1	6.22	SW 2-D-1	7.12
AK 2-D-2	7.02	AN2-S-2	6.52	BW 2-D-2	6.42	SW 2-D-2	6.97
AK 2-D-3	-	AN2-S-3	6.5	BW 2-D-3	6.62	SW 2-D-3	7.07
AK 3-N-1	7.38	AN3-N-1	6.42	BW 3-U-1	6.5	SW 3-U-1	6.12
AK 3-N-2	7.21	AN3-N-2	6.63	BW 3-U-2	6.73	SW 3-U-2	6.29
AK 3-N-3	7.1	AN3-N-3	6.73	BW 3-U-3	6.79	SW 3-U-3	6.34
AK 3-S-1	7.64	AN3-S-1	6.61	BW 3-D-1	6.68	SW 3-D-1	6.42
AK 3-S-2	7.4	AN3-S-2	6.64	BW 3-D-2	6.57	SW 3-D-2	6.6
AK 3-S-3	7.03	AN3-S-3	6.92	BW 3-D-3	6.63	SW 3-D-3	6.44
AK 4-N-1	7	AN4-N-1	6.57	BW 4-U-1	6.75	SW 4-U-1	6.07
AK 4-N-2	7.52	AN4-N-2	6.35	BW 4-U-2	6.91	SW 4-U-2	6.14
AK 4-N-3	7.26	AN4-N-3	6.51	BW 4-U-3	6.85	SW 4-U-3	6.31
AK 4-S-1	7.18	AN4-S-1	6.56	BW 4-D-1	7.3	SW 4-D-1	6.51
AK 4-S-2	7.46	AN4-S-2	6.64	BW 4-D-2	6.52	SW 4-D-2	6.26
AK 4-S-3	7.56	AN4-S-3	6.57	BW 4-D-3	7	SW 4-D-3	6.33
AK 5-N-1	7.19	AN5-N-1	6.09	BW 5-U-1	5.76	SW 5-U-1	5.83
AK 5-N-2	-	AN5-N-2	6.12	BW 5-U-2	6.02	SW 5-U-2	5.64
AK 5-N-3	-	AN5-N-3	6.57	BW 5-U-3	6.32	SW 5-U-3	6.33
AK 5-S-1	7.08	AN5-S-1	6.42	BW 5-D-1	6.28	SW 5-D-1	5.9
AK 5-S-2	-	AN5-S-2	6.64	BW 5-D-2	6.37	SW 5-D-2	6.06
AK 5-S-3	-	AN5-S-3	6.35	BW 5-D-3	6.51	SW 5-D-3	5.95
AK 6-N-1	7.02	AN6-N-1	6.27	BW 6-U-1	6.43	SW 6-U-1	6.93
AK 6-N-2	6.28	AN6-N-2	6.2	BW 6-U-2	6.67	SW 6-U-2	-
AK 6-N-3	5.89	AN6-N-3	6.18	BW 6-U-3	6.74	SW 6-U-3	7.14
AK 6-S-1	8	AN6-S-1	6.55	BW 6-D-1	6.64	SW 6-U-1	6.71
AK 6-S-2	8.23	AN6-S-2	6.35	BW 6-D-2	6.62	SW 6-U-2	5.89
AK 6-S-3	8.12	AN6-S-3	6.12	BW 6-D-3	6.66	SW 6-U-3	-
AK 7-N-1	7.94	AN7-N-1	7.09	BW 7-U-1	7.07	SW 7-U-1	5.92
AK 7-N-2	9.5	AN7-N-2	7.1	BW 7-U-2	6.97	SW 7-U-2	5.86
AK 7-N-3	7.85	AN7-N-3	7.13	BW 7-U-3	7.09	SW 7-U-3	5.73
AK 7-S-1	8.42	AN7-S-1	6.88	BW 7-D-1	7.12	SW 7-D-1	5.53
AK 7-S-2	8.54	AN7-S-2	6.95	BW 7-D-2	7.1	SW 7-D-2	5.67
AK 7-S-3	8.16	AN7-S-3	6.93	BW 7-D-3	7.06	SW 7-D-3	5.98

V. karroo		*V. nilotica*		*A. mearnsii*		*A. dealbata*	
Code	**pH value**	**Code**	**pH value**	**Code**	**pH value**	**Code**	**pH value**
AK 8-U-1	8	AN8-N-1	6.84	BW 8-U-1	6.12	SW 8-U-1	5.72
AK 8-U-2	7.88	AN8-N-2	6.64	BW 8-U-2	6.1	SW 8-U-2	6.01
AK 8-U-3	8	AN8-N-3	6.97	BW 8-U-3	5.8	SW 8-U-3	6.27
AK 8-D-1	8.1	AN8-S-1	6.56	BW 8-D-1	5.75	SW 8-D-1	6.07
AK 8-D-2	8.57	AN8-S-2	6.52	BW 8-D-2	5.96	SW 8-D-2	6.02
AK 8-D-3	8.67	AN8-S-3	6.47	BW 8-D-3	6.1	SW 8-D-3	6.05
AK 9-U-1	7.9	AN9-N-1	6.98	BW-9-U-1	5.97	SW 9-U-1	6.04
AK 9-U-2	-	AN9-N-2	8.14	BW-9-U-2	5.98	SW 9-U-2	5.9
AK 9-U-3	-	AN9-N-3	8.33	BW-9-U-3	6.47	SW 9-U-3	5.88
AK 9-D-1	7.95	AN9-S-1	8.14	BW-9-D-1	6.05	SW 9-D-1	5.75
AK 9-D-2	-	AN9-S-2	8.17	BW-9-D-2	6.37	SW 9-D-2	5.78
AK 9-D-3	-	AN9-S-3	8	BW-9-D-3	6.52	SW 9-D-3	5.84
AK 10-N-1	7.35	AN10-N-1	6.48	BW 10-U-1	6.7	SW 10-U-1	5.71
AK 10-N-2	7.67	AN10-N-2	7.74	BW 10-U-2	6.21	SW 10-U-2	5.65
AK 10-N-3	-	AN10-N-3	7.89	BW 10-U-3	5.98	SW 10-U-3	5.9
AK 10-S-1	7.36	AN10-S-1	7.51	BW 10-D-1	6.05	SW 10-D-1	-
AK 10-S-2	7.5	AN10-S-2	7.48	BW 10-D-2	6.15	SW 10-D-2	-
AK 10-S-3	7.78	AN10-S-3	7.44	BW 10-D-3	6.17	SW 10-D-3	5.89
AK 11-U-1	7.5	AN11-N-1	6.87	BW 11-U-1	5.98	SW 11-U-1	6.34
AK 11-U-2	-	AN11-N-2	6.56	BW 11-U-2	5.65	SW 11-U-2	6.21
AK 11-U-3	-	AN11-N-3	6.6	BW 11-U-3	5.5	SW 11-U-3	6.19
AK 11-D-1	7.45	AN11-S-1	6.41	BW 11-D-1	5.4	SW 11-D-1	5.72
AK 11-D-2	7.56	AN11-S-2	6.18	BW 11-D-2	5.44	SW 11-D-2	6.01
AK 11-D-3	-	AN11-S-3	6.05	BW 11-D-3	5.25	SW 11-D-3	-
AK 12-N-1	7.56	AN12-N-1	6.18	BW 12-U-1	5.47	SW 12-U-1	5.91
AK 12-N-2	7.58	AN12-N-2	6.37	BW 12-U-2	5.59	SW 12-U-2	5.82
AK 12-N-3	7.5	AN12-N-3	6.68	BW 12-U-3	5.56	SW 12-U-3	5.38
AK 12-S-1	7.36	AN12-S-1	6.58	BW 12-D-1	5.54	SW 12-D-1	4.71
AK 12-S-2	7.45	AN12-S-2	6.49	BW 12-D-2	5.47	SW 12-D-2	4.98
AK 12-S-3	7.3	AN12-S-3	6.57	BW 12-D-3	5.57	SW 12-D-3	5.34

Appendix 9. Soil Organic matter

V. karroo		*V. nilotica*		*A. mearnsii*		*A. dealbata*	
Code	**SOM (%)**	**Code**	**SOM (%)**	**Code**	**SOM (%)**	**Code**	**SOM (%)**
AK 1-N-1	12.53	AN1-U-1	3.02	BW 1-U-1	23.90	SW 1-U-1	18.00
AK 1-N-2	9.04	AN1-U-2	3.08	BW 1-U-2	13.15	SW 1-U-2	17.15
AK 1-N-3	21.30	AN1-U-3	2.49	BW 1-U-3	11.70	SW 1-U-3	17.30
AK 1-S-1	15.60	AN1-D-1	3.12	BW 1-D-1	22.45	SW 1-D-1	17.55
AK 1-S-2	13.85	AN1-D-2	4.47	BW 1-D-2	17.10	SW 1-D-2	19.20
AK1 -S-3	15.11	AN1-D-3	2.34	BW 1-D-3	11.70	SW 1-D-3	23.30
AK 2-U-1	8.34	AN2-N-1	16.32	BW 2-U-1	14.55	SW 2-U-1	3.10
AK 2-U-2	6.21	AN2-N-2	13.29	BW 2-U-2	14.10	SW 2-U-2	4.14
AK 2-U-3	9.12	AN2-N-3	14.19	BW 2-U-3	19.15	SW 2-U-3	2.14
AK 2-D-1	4.91	AN2-S-1	15.85	BW 2-D-1	19.85	SW 2-D-1	5.17
AK 2-D-2	2.31	AN2-S-2	8.27	BW 2-D-2	16.45	SW 2-D-2	2.92
AK 2-D-3	_	AN2-S-3	27.64	BW 2-D-3	17.60	SW 2-D-3	3.42
AK 3-N-1	8.95	AN3-N-1	70.27	BW 3-U-1	17.90	SW 3-U-1	3.32
AK 3-N-2	8.40	AN3-N-2	51.16	BW 3-U-2	21.45	SW 3-U-2	3.65
AK 3-N-3	5.80	AN3-N-3	53.79	BW 3-U-3	15.45	SW 3-U-3	3.35
AK 3-S-1	0.75	AN3-S-1	60.81	BW 3-D-1	33.60	SW 3-D-1	4.06
AK 3-S-2	13.45	AN3-S-2	47.67	BW 3-D-2	29.45	SW 3-D-2	3.76
AK 3-S-3	-	AN3-S-3	31.11	BW 3-D-3	30.05	SW 3-D-3	3.87
AK 4-N-1	13.80	AN4-N-1	3.78	BW 4-U-1	30.25	SW 4-U-1	2.43
AK 4-N-2	12.10	AN4-N-2	3.43	BW 4-U-2	26.90	SW 4-U-2	2.59
AK 4-N-3	7.85	AN4-N-3	16.52	BW 4-U-3	23.80	SW 4-U-3	1.72
AK 4-S-1	12.25	AN4-S-1	19.87	BW 4-D-1	32.50	SW 4-D-1	1.93
AK 4-S-2	11.90	AN4-S-2	27.47	BW 4-D-2	25.35	SW 4-D-2	3.67
AK 4-S-3	11.60	AN4-S-3	18.09	BW 4-D-3	22.30	SW 4-D-3	4.56
AK 5-N-1	8.43	AN5-N-1	9.29	BW 5-U-1	11.33	SW 5-U-1	2.11
AK 5-N-2	_	AN5-N-2	8.93	BW 5-U-2	6.05	SW 5-U-2	2.05
AK 5-N-3	_	AN5-N-3	8.02	BW 5-U-3	6.68	SW 5-U-3	2.17
AK 5-S-1	12.42	AN5-S-1	11.45	BW 5-D-1	5.66	SW 5-D-1	4.40
AK 5-S-2	_	AN5-S-2	21.88	BW 5-D-2	5.24	SW 5-D-2	2.66
AK 5-S-3	_	AN5-S-3	9.24	BW 5-D-3	6.51	SW 5-D-3	2.65
AK 6-N-1	14.25	AN6-N-1	11.43	BW 6-U-1	7.53	SW 6-U-1	5.32
AK 6-N-2	13.45	AN6-N-2	11.81	BW 6-U-2	10.12	SW 6-U-2	-
AK 6-N-3	12.60	AN6-N-3	8.77	BW 6-U-3	9.76	SW 6-U-3	4.71
AK 6-S-1	9.30	AN6-S-1	13.10	BW 6-D-1	9.59	SW 6-U-1	4.41
AK 6-S-2	12.70	AN6-S-2	12.17	BW 6-D-2	9.80	SW 6-U-2	2.02
AK 6-S-3	11.55	AN6-S-3	14.71	BW 6-D-3	6.44	SW 6-U-3	-
AK 7-N-1	13.55	AN7-N-1	13.89	BW 7-U-1	31.73	SW 7-U-1	6.63
AK 7-N-2	22.50	AN7-N-2	12.40	BW 7-U-2	19.06	SW 7-U-2	5.69
AK 7-N-3	22.95	AN7-N-3	10.70	BW 7-U-3	13.50	SW 7-U-3	5.91
AK 7-S-1	9.35	AN7-S-1	14.84	BW 7-D-1	10.16	SW 7-D-1	5.38
AK 7-S-2	11.35	AN7-S-2	15.67	BW 7-D-2	13.14	SW 7-D-2	5.84
AK 7-S-3	7.75	AN7-S-3	13.19	BW 7-D-3	13.55	SW 7-D-3	5.59

V. karroo		*V. nilotica*		*A. mearnsii*		*A. dealbata*	
Code	**SOM (%)**	**Code**	**SOM (%)**	**Code**	**SOM (%)**	**Code**	**SOM (%)**
AK 8-U-1	32.30	AN8-N-1	24.50	BW 8-U-1	2.76	SW 8-U-1	3.57
AK 8-U-2	35.10	AN8-N-2	19.36	BW 8-U-2	2.61	SW 8-U-2	3.50
AK 8-U-3	41.80	AN8-N-3	14.96	BW 8-U-3	2.68	SW 8-U-3	4.13
AK 8-D-1	28.04	AN8-S-1	25.74	BW 8-D-1	2.31	SW 8-D-1	4.62
AK 8-D-2	37.21	AN8-S-2	27.16	BW 8-D-2	2.75	SW 8-D-2	4.33
AK 8-D-3	29.21	AN8-S-3	19.20	BW 8-D-3	10.10	SW 8-D-3	3.80
AK 9-U-1	10.32	AN9-N-1	29.03	BW-9-U-1	16.60	SW 9-U-1	5.48
AK 9-U-2	-	AN9-N-2	15.28	BW-9-U-2	18.30	SW 9-U-2	6.07
AK 9-U-3	_-	AN9-N-3	15.94	BW-9-U-3	20.45	SW 9-U-3	5.68
Ak 9-D-1	8.21	AN9-S-1	18.80	BW-9-D-1	17.85	SW 9-D-1	6.70
Ak 9-D-2	_-	AN9-S-2	18.47	BW-9-D-2	19.80	SW 9-D-2	7.00
Ak 9-D-3	-	AN9-S-3	14.02	BW-9-D-3	12.40	SW 9-D-3	5.82
AK 10-N-1	17.02	AN10-N-1	31.32	BW 10-U-1	5.62	SW 10-U-1	4.32
AK 10-N-2	15.51	AN10-N-2	21.40	BW 10-U-2	7.21	SW 10-U-2	5.48
AK 10-N-3	_-	AN10-N-3	25.30	BW 10-U-3	12.08	SW 10-U-3	6.21
AK 10-S-1	11.23	AN10-S-1	29.46	BW 10-D-1	5.16	SW 10-D-1	-
AK 10-S-2	19.01	AN10-S-2	27.70	BW 10-D-2	6.98	SW 10-D-2	-
AK 10-S-3	18.20	AN10-S-3	20.91	BW 10-D-3	9.76	SW 10-D-3	16.01
AK 11-U-1	7.32	AN11-N-1	6.23	BW 11-U-1	2.96	SW 11-U-1	3.91
AK 11-U-2	-	AN11-N-2	4.88	BW 11-U-2	2.75	SW 11-U-2	3.36
AK 11-U-3	-	AN11-N-3	5.20	BW 11-U-3	3.47	SW 11-U-3	3.08
AK 11-D-1	17.20	AN11-S-1	5.40	BW 11-D-1	3.53	SW 11-D-1	3.96
AK 11-D-2	19.90	AN11-S-2	5.41	BW 11-D-2	3.60	SW 11-D-2	3.79
AK 11-D-3	-	AN11-S-3	6.32	BW 11-D-3	2.93	SW 11-D-3	-
AK 12-N-1	20.85	AN12-N-1	5.89	BW 12-U-1	5.43	SW 12-U-1	4.08
AK 12-N-2	8.30	AN12-N-2	4.27	BW 12-U-2	18.21	SW 12-U-2	3.98
AK 12-N-3	12.80	AN12-N-3	5.07	BW 12-U-3	21.03	SW 12-U-3	3.41
AK 12-S-1	10.30	AN12-S-1	5.01	BW 12-D-1	15.78	SW 12-D-1	4.21
AK 12-S-2	17.90	AN12-S-2	4.95	BW 12-D-2	8.75	SW 12-D-2	18.56
AK 12-S-3	21.20	AN12-S-3	3.18	BW 12-D-3	10.20	SW 12-D-3	2.99

Appendix 10. ANOVA tables

1a) Seed numbers and depth (*Vachellia karroo*)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
a	12	81.96667	6.830556	54.79807
b	12	61.5	5.125	44.32386
c	12	41.5	3.458333	17.40467

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	68.23432	2	34.11716	0.878353	0.424955	3.284918
Within Groups	1281.793	33	38.8422			
Total	1350.027	35				

1b) Seed numbers and depth (*Vachellia nilotica*)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
a	12	15	1.25	2.75
b	12	2.5	0.208333	0.167298
c	12	0	0	0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.76389	2	5.381944	5.534516	0.008458	3.284918
Within Groups	32.09028	33	0.972433			
Total	42.85417	35				

1c) Seed numbers and depth (*Acacia mearnsii*)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
a	12	370	30.83333	656.3182
b	12	113.1667	9.430556	53.3407
c	12	88.83333	7.402778	72.3912

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4044.727	2	2022.363	7.757931	0.001731	3.284918
Within Groups	8602.551	33	260.6834			
Total	12647.28	35				

1d) Seed numbers and depth (*Acacia dealbata*)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
a	12	1960.667	163.3889	118403
b	12	838.8333	69.90278	17592.36
c	12	409.8333	34.15278	2741.265

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	106878.8	2	53439.38	1.155558	0.327296	3.284918
Within Groups	1526102	33	46245.53			
Total	1632981	35				

2a) Seed number and distance (*Vachellia karroo*)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	12	58.5	4.875	22.46023
Middle	12	58.5	4.875	49.41477
Periphery	12	32	2.666667	17.92424

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	39.01389	2	19.50694	0.651685	0.527744	3.284918
Within Groups	987.7917	33	29.93308			
Total	1026.806	35				

2b) Seed number and distance (*Vachellia nilotica*)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	12	3	0.25	0.386364
Middle	12	3	0.25	0.386364
Periphery	12	0	0	0

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.5	2	0.25	0.970588	0.389413	3.284918
Within Groups	8.5	33	0.257576			
Total	9	35				

2c) Seed number and distance (*Acacia mearnsii*)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	12	163	13.58333	175.1288
Middle	12	175.5	14.625	168.8693
Periphery	12	22	1.833333	11.01515

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1211.097	2	605.5486	5.117121	0.011596	3.284918
Within Groups	3905.146	33	118.3378			
Total	5116.243	35				

2d) Seed number and distance (*Acacia dealbata*)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	12	21	1.75	3.659091
Middle	12	613	51.08333	5774.447
Periphery	12	1657.5	138.125	88491.14

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	114432.7	2	57216.34	1.820838	0.177782	3.284918
Within Groups	1036962	33	31423.08			
Total	1151394	35				

3a) Seed viability of *Vachellia karroo* at different depths

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
a	12	873.9096	72.8258	445.5852
b	11	816.8189	74.25626	1358.251
c	9	717.8571	79.7619	1186.224

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	264.5887	2	132.2943	0.137148	0.872404	3.327654
Within Groups	27973.74	29	964.6117			
Total	28238.33	31				

3b) Seed viability of *Vachellia nilotica* at different depth

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
a	9	447.5952	49.7328	1718.172
b	3	150	50	2500

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.160635	1	0.160635	8.57E-05	0.992796	4.964603
Within Groups	18745.38	10	1874.538			
Total	18745.54	11				

3c) Seed viability of *Acacia mearnsii* at different depths

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
a	12	1161.264	96.77198	98.70711
b	12	1163.061	96.92174	97.68247
c	12	1168.677	97.38977	32.80534

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.492549	2	1.246274	0.016313	0.983827	3.284918
Within Groups	2521.144	33	76.39831			
Total	2523.637	35				

3d) Seed viability of *Acacia dealbata* different depths

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
a	11	1082.576	98.41601	6.491322
b	12	1189.135	99.09458	2.793329
c	12	1181.255	98.43795	5.111471

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.512321	2	1.756161	0.370044	0.693621	3.294537
Within Groups	151.866	32	4.745813			
Total	155.3784	34				

4a) Seed viability and distance of *Vachellia karroo*

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	12	855.1490633	71.26242	504.8629
Middle	12	800.4142034	66.70118	505.4587
Periphery	8	640.8501732	80.10627	173.5074

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	867.3522	2	433.6761	1.020159	0.373114	3.327654
Within Groups	12328.09	29	425.1065			
Total	13195.44	31				

4b) Seed viability and distance of *Vachellia nilotica*

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	11	484.5238	44.04762	1683.107
Middle	6	425	70.83333	1604.167
Periphery	0	0	#DIV/0!	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2785.489	2	1392.745	0.784585	0.475377	3.738892
Within Groups	24851.9	14	1775.136			
Total	27637.39	16				

4c) Seed viability and distance of *Acacia mearnsii*

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	12	1146.697	95.55806	86.22796
Middle	12	1151.37	95.94747	72.88929
Periphery	11	1096.946	99.72234	0.848067

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	119.7663	2	59.88317	1.089546	0.348523	3.294537
Within Groups	1758.77	32	54.96158			
Total	1878.537	34				

4d) Seed viability and distance of *Acacia dealbata*

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Under	12	1171.94	97.66164	6.85683
Middle	12	1124.015	93.66794	107.1975
Periphery	10	993.4858	99.34858	4.010682

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	191.4882	2	95.74412	2.299592	0.117162	3.304817
Within Groups	1290.693	31	41.63527			
Total	1482.182	33				