An investigation of the social impact of *Solanum mauritianum* (Bugweed) on Gauteng Farmers, and the geographical distribution of Bugweed in Gauteng

By Tshuxekani Maluleke

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PREFACE

The experimental work described in this research report was carried out in the school of Animal, Plant and Environmental sciences, University of Witwatersrand, Johannesburg, from February 2016 to January 2018, under the supervision of Professor M.J Byrne and Professor E.T.F Witkowski (school of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg) . These studies represent original work of the author and have not been submitted in any form for any degree or diploma.

Signed:

T Maluleke (Candidate)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

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Date:

08 August 2018

PLAGARISM DECLARATION

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ABSTRACT

Bugweed (*Solanum mauritianum* Scop. Solanaceae) is a NEMBA category 1b, alien invasive plant species that originates from South America. In South Africa Bugweed is abundant in the eastern part of the country, especially where rainfall is high. Previous studies have focused mainly on the ecological and economic impacts as well as the control of alien invasive plants including Bugweed in South Africa. However, these studies have not addressed the social impact of the weed on the various stakeholders including farmers. The understanding of the social impact of Bugweed on farmers will enable us to quantify the amount of damage caused by this weed at a social level, and also to explore potential benefits that could be derived from the infestation. The study also sought to determine the geographic distribution of Bugweed within Gauteng using remote sensing. This will form part of an integrative approach towards combating the negative impacts of Bugweed invasion.

Interviews were conducted across five of the areas that are regarded as agricultural hubs in the Gauteng Province. A total of 50 farmers were interviewed. The interviews were aimed at assessing the farmers' sources of information regarding Bugweed and other invasive alien plants (IAP), their level of knowledge regarding Bugweed, and lastly their perceptions regarding Bugweed. Farmers Organisations were identified as the main source of information farmers are exposed to. Only 38% of the participants (farmers) knew Bugweed. The level of knowledge amongst the participants regarding Bugweed is surprisingly low, and it is very difficult to assess people's perceptions about something they are not familiar with. However, there are those participants who are familiar with the weed who do not regard it as a pest. Bugweed does not appear to have any social impact on the majority of the participants.

The study also explored the feasibility of applying remote sensing to discriminate Bugweed from coexisting plant species within the Gauteng Province, using both field spectroscopy (ASD) and satellite imagery for the purpose of mapping and monitoring. The discrimination of Bugweed from other plant species within the Gauteng Province is possible, and thus the use of remote sensing to monitor Bugweed within the Gauteng

Province should be encouraged. In order to improve the results, it is recommended that satellite imagery of a higher spectral resolution (hyperspectral imagery) must be used, and most importantly the number of the co-existing plant samples and classes should be increased.

LIST OF ABBREVIATIONS

NEMBA	: National Environmental Management Biodiversity Act
ASD	: Analytical Spectral Device
DF	: Degrees of Freedom
IAP	: Invasive Alien Plants
SVM	: Support Vector Machine
WWF	: World Wide Fund (For Sustainable Agriculture)
GDARD	: Gauteng Department of Agriculture and Rural Development
SCHOOL OF APES	: School of Animal, Plant and Environmental Sciences
PDA	: Personal Digital Assistant
X^2	: Chi-squared value

SOIL TYPES ABBREVIATIONS

Ab	: Dolomite, chert, shale and quartzite of the Chuniespoort Group, Transvaal Sequence.
Ba	: Shale, quartzite, siltstone, chert and hornfels of the Silverton, Daspoort and Timeball Hill Formations (Transvaal Sequence) and diabase.
Bb	: Granite and migmatite of the Halfway House Intrusion and quartzite, shale and siltstone of the Pretoria Group, andesite of the Hekpoort Formation, diabase and some occurrence of dolomite and chert.

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CHAPTER 1: GENERAL INTRODUCTION

1. *Problem Statement*

Solanum mauritianum (Bugweed) is an Invasive Alien Plant (IAP) that has the ability to aggressively invade lands, particularly disturbed agricultural lands. This increases the running costs of farming. Bugweed is also believed to nurture the Natal Fruit fly populations during winter months, and this enables the fruit flies to thrive (Devillers, Hattingh and Kriticos 2013). The Natal fruit fly is a pest of economic importance, and should be controlled. The prevailing perceptions regarding Bugweed and other IAPs are generally negative. They can be narrowed down to the following statements; IAPs are dangerous, destructive and they are responsible for displacing indigenous plant species, and thus they should be eliminated (Smith *et al.* 2006). IAP's such as Bugweed have been in the country for over 100 years, and as such there are people who might regard them as indigenous plants. It is possible that some people might have even developed some uses for these plants, and the plants may have been incorporated in the local people's culture and tradition. IAP's such as *Parthenium hysterophorus* (famine weed) and *Opuntia stricta* (prickly pear) have been proven to have both positive and negative impacts on the environment and the people's way of life. This complicates the issue of IAP because there are alien species that serve as both a pest while also serving as a resource to others, nonetheless control of these plant species is of paramount importance.

The control of IAP is largely centred on control methods/measures i.e. chemical, mechanical and biological control methods, however the first step is to "locate" the IAP. Locating and mapping was previously based on ground based data collection. This type of method can be very costly since it involves driving around in search of IAPs. It is also limited in effectiveness because many areas are inaccessible, compared to using free satellite imagery that can cover enormous spatial areas. The use of remote sensing techniques to detect weeds has been gaining traction over the past years. The study will enable us to check whether remote sensing has a role to play in the control of Bugweed within the Gauteng Province. Remote sensing might provide us with the opportunity to develop proactive control measures rather than the expensive reactive control measures. This information can be used when deciding on the most effective control measures. Chemical based control measures usually have negative impacts on the environment, because they contain poisonous chemicals. It is important to be precise when working with such measures in order to avoid polluting or contaminating the environment unnecessarily. The overall study will form part of an integrative approach towards understanding and controlling Bugweed.

2. Literature Review

2.1 Invasive Alien Species

Invasive Alien Plant (IAP) species result from the ongoing re-distribution of species for reasons such as, to support agriculture, forestry, mari-culture, horticulture etc. (Van Wilgen *et al.* 2008). In some instances, IAPs are introduced accidentally, in other cases humans serve as vectors (Van Wilgen *et al.* 2008). Among many types of biological invasions, they include insects and diseases of agricultural weeds. The introduction of IAP in new ecosystems is regarded as a complex problem which threatens the delivery of ecosystem services such as, water purification, soil generation, nutrient cycling and waste decomposition (Van Wilgen *et al*. 2008). These services are necessary for human survival (Le Maitre *et al.* 2004). The absence of natural enemies in the new environment enables the invasive plants to flourish and spread aggressively (Marais and Wannenburgh 2008).

The severity of this challenge is increasing as a result of globalisation (Van Wilgen *et al.* 2008). Globalization refers to the free movement of goods, capital, services, people, technology and information. Alien invasions have financial implications that result from the cost of managing them in areas where they are deemed problematic, and most importantly the loss of land that has agricultural potential. The global cost of managing and controlling IAP was estimated to be at US$314 billion in 2004 (Le Maitre *et al.* 2004). In South Africa billions of Rands are lost annually, due to the loss of agricultural productivity and weed control costs. This cost is expected to increase over the next coming years.

There are a number of alien invasive plant species that have been brought to South African shores over the last century, either deliberately as commercial plants, ornamental garden plants or accidentally. An estimated 70% of the plant species that are invading the country are originally from South America or Australia. This is because the ecological and climatic conditions of these continents are similar to the conditions in southern Africa (Marais and Wannenburgh 2008). By the beginning of the new millennium Gauteng province was estimated to have at least 0.8% of its land surface area invaded by invasive species (Enright 1999). One of the most problematic alien invasive plants in Gauteng is *Solanum mauritianum* (Bugweed) (www.jhbcityparks.com).

2.2 Solanum mauritianum (Bugweed)

Solanum mauritianum is a NEMBA category 1b alien invasive species commonly known as Bugweed (English), Luisboom (Afrikaans) and Bonga-Bonga (Zulu). It originates from South America. Bugweed belongs to the genus *Solanum*, and the species within the genus *Solanum* belong to the family Solanaeceae (Symon 1981). The family Solanaeceae is important in the agricultural sector because it includes *Solanum tuberosum* (potatoes), *Solanum lycopersicum* (tomatoes) and *Solanum melongena* (brinjals), and these species are cultivated worldwide for human consumption. It is believed that Bugweed was first introduced in Africa in the 1600's. According to Anon (1984) Bugweed became more widespread in the 18th century (Wright 1904). According to a study by Harding (1938) the weed was publically announced as a noxious weed.

Bugweed is a tree or shrub that forms dense stands in agricultural lands, rural and urban areas (Henderson 2001). Bugweed is a thorn-less perennial shrub, with large leaves that appear dull green and velvety from above (Henderson 2001). The leaves produce a strong odour when crushed. Bugweed has purple flowers and produces fruits that are poisonous when unripe (Figure 1). The fruits bear large number of seeds that are spread by birds and forms soil-stored seed banks (Witkowski and Garner 2008; Goodall *et al*. 2017). The fruits are also believed to sustain the Natal Fruit Fly populations during cold winter months (Annecke and Moran 1982). Bugweed grows fast and in areas where it is growing alongside pines, it usually outcompetes them resulting in stem deformation and inhibited growth of the pines (Le Roux 1982).

In South Africa Bugweed is abundant in the eastern part of the country, especially where rainfall is high (Witkowski and Garner 2008). Bugweed threatens sectors such as: agriculture, forestry, biodiversity as well as human health by affecting ecosystem services (Atkinson 2012). Bugweed has generated a lot of interest from scholars, and as a result it became the subject of choice for many scientific studies. This is due to its ability to transform habitats, and the impact that it has on the forestry sector in the country specifically in KwaZulu Natal.

According to Samways *et al.* (1996) Bugweed infestation can impact negatively on the diversity and assemblage of invertebrate fauna. Bugweed's success as a weed stems from its reproductive capacity (it produces large numbers of seeds), long-range seed dispersal with the aid of birds and its ability to store seeds in the ground (Witkowski and Garner 2008).

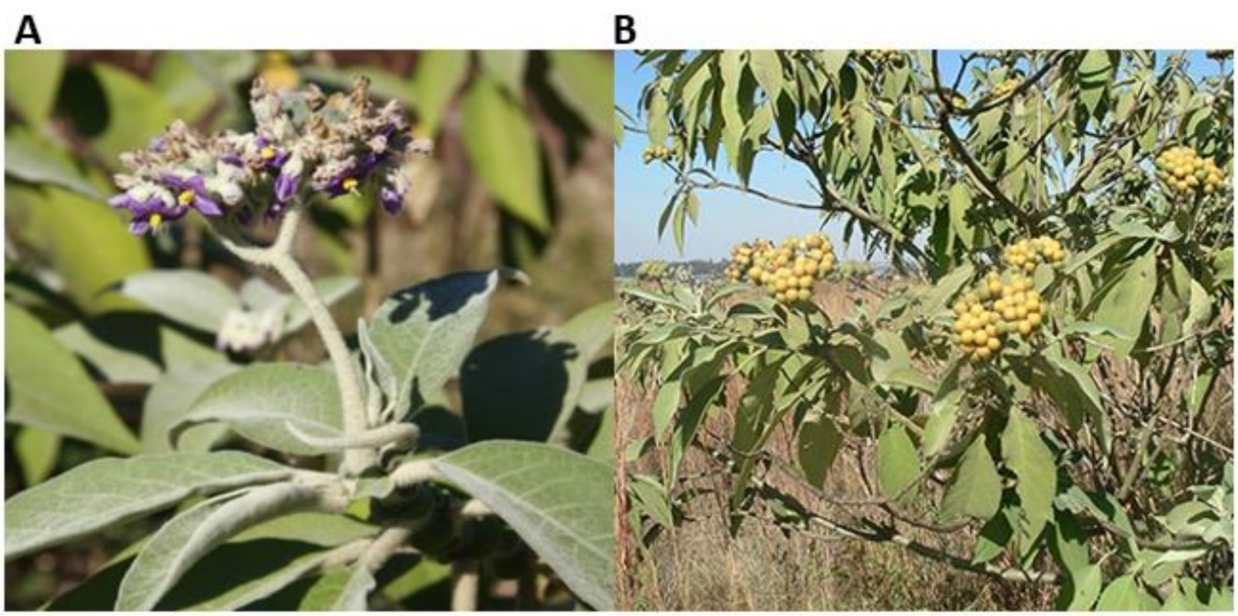


Figure 1: Solanum mauritianum (Bugweed) *shrub, displaying the flowers, broad hairy leaves and fruits.*

2.3 South African Environmental Legal Institutions regarding Bugweed

The legal guidelines that govern the management of alien invasive species are in the Constitution of the Republic of South Africa, 1996 (Act 108 of 1996). Section 24 of the South African Constitution "provides for the right of every South African citizen to a healthy environment, and protects the environment for the benefit of present and future generations through reasonable legislation and other measures that prevent pollution and ecological degradation, promote conservation and secure ecologically sustainable and social development" (South Africa, 1996).

According to the National Environmental Management: Biodiversity Act of 2003, (NEMBA) Bugweed is a declared category 1b invader weed. Therefore, one of the directives of NEMBA regarding the control of category 1b invader weeds is that, these plants require compulsory control as part of an invasive species control programme. NEMBA thus imposes a legal obligation upon all landowners to actively locate and regulate the predominance and limit the spreading of category 1b species such as Bugweed occurring on their land. The Government is obliged by section 24 to pass legislation to protect the environment, to prevent pollution and ecological degradation and to secure sustainable development (Mashiloane 2011). Municipal Weed Inspectors are authorised to visit any property at random at a reasonable time in order to inspect it for the presence of any declared weeds or invasive plants.

2.4 Control of Bugweed

The control of Bugweed has been a challenge, various methods such as chemical, mechanical and biological control measures are currently being used in an attempt to control it. However, a combination of mechanical and chemical methods usually yield the best results. When using the mechanical method (cutting), if the plant is not completely removed from the ground, the remaining part can re-sprout and grow more vigorously (Witkowski and Garner 2008). Mechanical removal of Bugweed is a labour intensive and time consuming process (Witkowski and Garner 2008). Bugweed has a tendency to grow in agricultural lands, and this makes the use of chemicals (Herbicides) difficult because those herbicides do not target Bugweed specifically and can destroy commercially important crops resulting in financial loses.

2.5 Biological control of Bugweed

Due to the ineffectiveness and cost implications of chemical and mechanical control methods (Hakizimana 2011), the biological control of Bugweed in the country was initiated in 1984. Biological control of Bugweed faced a number of challenges, which included host specificity testing of the imported agents (Witkowski and Garner 2008). Bugweed is closely related to commercially important crops such as tomatoes, Brinjals and potatoes, these crops became targets of the biological agents causing major financial loses. The biological agents also struggled in acclimatising to the climatic conditions of South Africa (Witkowski and Garner 2008), however there are some promising results (Olckers 2011; Olckers and Borea 2009). Currently there are two species of insects that are being tested as biological agents against Bugweed, they include the lace bug (*Gargaphia decoris)* Drake (Tingidae) and the flower-feeding weevil *Anthonomus santacruzi* Hustache (Anthonomini) (Olckers 2003; Cowie *et al.* 2017).

Gargaphia decoris was first released against Bugweed about 16 years ago in Kwa-Zulu Natal, Limpopo province and Mpumalanga province (Klein 2011). *Gargaphia decoris* feeds on the leaf sap of Bugweed, which results in extensive damage to the leaf and ultimately reducing the plants ability to photosynthesize (Olckers 2000). *Gargaphia decoris* struggles to establish on the plant during the cold winter months, and it is also prayed on by other insects such as ants (Barker and Byrne 2005).

Anthonomus santacruzi adults target the flowers and the larvae target the buds, and this cripples the weed's ability to bear fruit (Olckers 2003; Witkowski and Garner 2008). Further studies need to be conducted to test the effectiveness of *Anthonomus santacruzi,* it has been established that the weevil is currently limited by its sensitivity to low humidity (Cowie *et al.* 2016). The control of invasive species such as Bugweed requires accurate mapping of the distribution and modelling of the extent of invasion (Le Maitre *et al.* 1996; Underwood *et al.* 2003).

2.6 Detection and mapping of alien invasive plants using Remote Sensing

Traditionally the estimation of the extent of occurrence (invaded area) and mapping of alien invasive species was dependent upon the generation of costly ground based survey methods (Jensen and Lulla 1987;Peerbhay *et al.* 2016). These methods are generally technically and logistically impractical (Lawrence *et al* 2006). The technology applied in remote sensing sciences provides a rapid source of data over a broad spatial extent, and this is a perfect alternative to ground based survey methods (Kerr and Ostrovsky 2003). Remote sensing refers to the scanning of the earth using sensors to monitor the reflection of electromagnetic waves from the target (Thorp and Tian 2004). The sensors detect electromagnetic radiation (Lillesand and Kiefer 2000).

The electromagnetic radiation reflected off each plant species is based on the plant's unique biochemical and biophysical properties (Datt 1999; Cho *et al.* 2012). These properties are responsible for plant species being able to absorb certain colours of the electromagnetic spectra while reflecting others, and thus giving a plant its spectral reflectance signature (Datt 1999; Asner and Martin 2009). The application of remote sensing technologies to identify and map invasive species in commercial forest has been limited thus far, mainly because farm managers still really on physical searching and locating alien plants (Atkinson *et al.* 2014; Peerbhay *et al.* 2016). Thorp and Tian (2004) noted that the use of remote sensing for weed detection was limited at the time of the study.

However, with improved technology, the use of remote sensing technology has been on the rise, and several studies that are more recent have utilized remote sensing to detect and monitor weeds in natural and semi-natural ecosystems (Andrew and Ustin 2008). Remote sensing simplifies the process of determining the geographic distribution of weeds in agricultural fields, and the data can be used to map the distribution.

A study was conducted in KwaZulu Natal and it was able to produce results that proved that Bugweed could be detected and mapped with reasonable accuracy in a complex commercial forest environment (Peerbhay *et al* 2016). Previous studies have focussed mainly on the ecological and economic impacts as well as the control of alien invasive plants including Bugweed in South Africa (Sharp, Larson and Green 2011). However, these studies have not addressed the social impact of the weed on the various stakeholders including farmers (Sharp, Larson and Green 2011).

2.7 Social impact

As human beings we are involved, to some degree in the entire invasive process. We sometimes serve as vectors for introductions of IAP and ultimately we are often the worst affected (Gracia-Llorente *et al.* 2008). Fortunately, humans have the capacity to make decisions that might help alleviate the infestations (Gracia-Llorente *et al.* 2008). Perrings *et al.* (2000) framed the challenge of invasive species as socio-economic issue which requires solutions from economics, ecology, sociology and biology.

Studies on IAP's have normally concentrated on the biological aspect of the problem, and have failed to adequately focus on the social aspect of the problem (Garcia-Llorente *et al.* 2008). An in-depth understanding of the social/human aspect of the problem will enable a holistic approach towards effectively managing the problem. Within the context of controlling invasive species in farms, the effective control of alien invasive plants is also dependent on the farmer's perceptions. The farmers should perceive management of invasive species as aiming for socio-economic and ecological sustainability (Bardsley and Jones 2006), and then encourage participation.

The fact that some IAP are economically important makes the problem more complicated (Kendle and Rose, 2000; Bardsley and Jones 2006). Invasive species often benefit some sectors while disadvantaging other sectors of the economy (Baskin, 2002). Some invasive alien species are socio-economically important such as cactus *Opuntia ficus-indica* (used to make fruit jam), *Acacia mearnsii* (used for firewood) and Eucalyptus species (used to as a medicinal plant amongst other uses) (Shackleton *et al., 2007*). Thus is important to consider both social and economic aspects of the problem (Zavaleta *et al.* 2001). Human beings play a crucial role in the introduction of alien invasive species, and this may happen intentionally (garden plants, commercial trees etc.) or accidently as a result of globalisation (Garcia-Llorente *et al* 2008). Human beings are also responsible for making decisions regarding the control and management of invasive species.

According to Vaske (2008), "Environmental values measure broad ecological worldviews or basic beliefs about human interaction with the natural world that are relatively stable and immutable". Worldview refers to the way someone thinks about the world. Environmental values are influenced by environmental attitudes. People's attitudes are not fixed, they change all the time (Williams *et al.* 2002). Attitudes play a major role in influencing behaviour, and they may determine how people behave towards invasive plants (Fishbein and Manfredo 2002).

Alien invasive species such as Bugweed need to be viewed through various lenses such as scientific, sociological and economic disciplines, so that inclusive solutions may be generated. Few studies on invasive species have quantified the costs caused by invasive species, and in their control (e.g. Perrings *et al* 2002).

The knowledge base on the social dimensions and the management of alien invasive species would be increased if additional research was conducted, and this would increase stakeholder participation (White *et al.* 2008). Acknowledging the role that people play in the distribution and control of invasive populations is very important (Larson and Green 2011). Studies have shown that Public awareness and support can determine success in controlling alien invasive species (Andreu *et al.* 2009), however public opinion continues to be ignored (Garcia-Llorente *et al.* 2008).

A study by Sharp, Larson and Green (2008) proved that public opinion with regard to the control of alien invasive species continues to be ignored by scientists and policy makers, and recommend that studies need to be done to determine the public's acceptance of policies and management of invasive species. In South Africa a top-down approach was noted when it comes to the management of areas within and around protected areas and this created problems between land managers and the local people (Anthony *et al.* 2011). Studies have been conducted to assess the social impact of invasive species such as *Parthenium hysterophorus* and *Lantana camara* by Kohli *et* *al* (2006). The impacts of *Parthenium hysterophorus* were found to be multi-faceted, because it affects human health and biodiversity, economy crop production and animal husbandry. The understanding of the social impact of Bugweed on farmers will enable us to quantify the amount of damage caused by this weed at a social level, and possibly shed light on the possible positive benefits that may be derived from the presence of Bugweed. This will form part of an integrative approach towards combating the negative impacts of Bugweed invasion.

An integrative approach towards combating Bugweed will draw the various disciplines and expertise towards helping to frame the infestation challenge properly, and thus help derive effective control methods. The disciplines will include ecology, entomology, social sciences, Geographic information systems (GIS), and remote sensing.

The human dimension must not be underestimated because humans are both the cause of invasions and can be part of the solution (Le Maitre *et al.* 2004). The understanding of the farmer's levels of knowledge and perceptions towards Bugweed is important when quantifying the magnitude of the impact of Bugweed within Gauteng Province. This approach will help increase the Province's knowledge regarding Bugweed and also control Bugweed by increasing stakeholder participation.

3. Aims and Objectives

Solanum mauritianum (Bugweed) was introduced into South Africa more than a 400 years ago, and as a result local frugivorous bird species have become accustomed to the taste of Bugweed fruits (Mokotjomela, Musil and Esler 2015). Human beings and other animal species tend to develop relationships with plants species that grow around them, i.e. the plant species may be used as food, medicine, building or crafting material, and such plants are said to have ethnobotanical value. As a result plant species tend to have a social impact because they influence how we do certain things in life. Given the fact that Bugweed has been in the country for a very long time, it is fair to assume that Bugweed may have some sort of social impact on the various stakeholders within the country. The potential social impact may be more evident in those areas where Bugweed is very abundant. The impact of Bugweed is innately known to be negative given the fact that it is an IAP. However there could be some benefits that can be derived from the plant i.e. that might have some ethno-botanical value.

Hence a study was designed to firstly determine the geographic distribution of Bugweed within the Gauteng province. This would assist us in estimating/ quantifying the extent of infestation within the Gauteng Province, using remote sensing techniques. Secondly a survey was designed to engage with farmers. This study gave us the opportunity to ask farmers questions regarding Bugweed in an attempt to assess their knowledge and attitudes regarding Bugweed. These would enable us to uncover some of the information regarding Bugweed's social impact on the farmers or the people.

The research report consists of an introductory chapter (Chapter 1), and the introduction is then followed by (Chapter 2) which has information about the study area, experimental design and methodology. The social impact of Bugweed on farmers in Gauteng is thoroughly discussed in Chapter 3. Chapter 4 focusses on the geographic distribution of Bugweed within Gauteng Province. Chapters 3 and 4 both have a Problem statement, Background, Purpose of study, Materials and methods, Results and Discussion sections. The overall findings of the study are summarised in the last chapter (Chapter 5).

CHAPTER 2: DESCRIPTION OF THE STUDY AREA

1. *Study Area*

The study was conducted in the Gauteng Province. The province is the smallest province in South Africa in terms of surface area, it covers an estimated 1.5% of the country's surface area. The province serves as the country's economic hub, with a gross domestic product (GDP) of about 34%. The altitude in the Gauteng Province ranges between 1081m to 1899 m above sea level. The average temperature in Gauteng is 25.6 ºC in summer and 13.8 ºC in winter (Grobler, Bredenkam and Brown 2002). The average annual rain in the province is estimated to be 670mm/year, with most of the rainfall falling in the summer months. The province tends to experience the highest average rainfall during January, and the second highest average monthly rainfall is December (Dyson 2009).

2. *Geology and Soils*

The Gauteng province has a unique geological composition. The area is composed of the following rock types; chert, dolomite, shale, quartzite, andesitic lava, granite and diabase. The Province has about three land type units that are regarded as important namely; Ab, Ba & Bb. These land type units are linked with the flat or slightly undulating landscapes, while the ridge areas are associated with the Ib land type unit (Grobler, Bredenkam and Brown 2002). The soil types that are mainly found within the Gauteng Province are the Mispah and Glenrosa.

3. *Vegetation Types:*

The Gauteng Province is dominated by the Grassland biome with patches of woodland vegetation on hillslopes and rocky outcrops within the various veld types. The areas in the north side of the Magaliesberg Mountain are located in the savanna biome (Rutherford & Wesffall 1986). The Province has three veld types namely, Sour Bushveld, Bankenveld and the Sourish Mixed Bushveld. The Mixed Bushveld, Moist Cool Highveld Grassland and Rocky Highveld Grassland are the main vegetation types within the province. The province is characterized by Rocky Highveld Grassland Vegetation (Bredenkamp & Van Rooyen 1996a). This vegetation type usually has open and closed woodland patches, these patches closely resemble the ones that are seen in the Waterberg Moist Mountain Bushveld (Bredenkamp & Van Rooyen 1996b; Mucina and Rutherford 2004) (Figure 2).

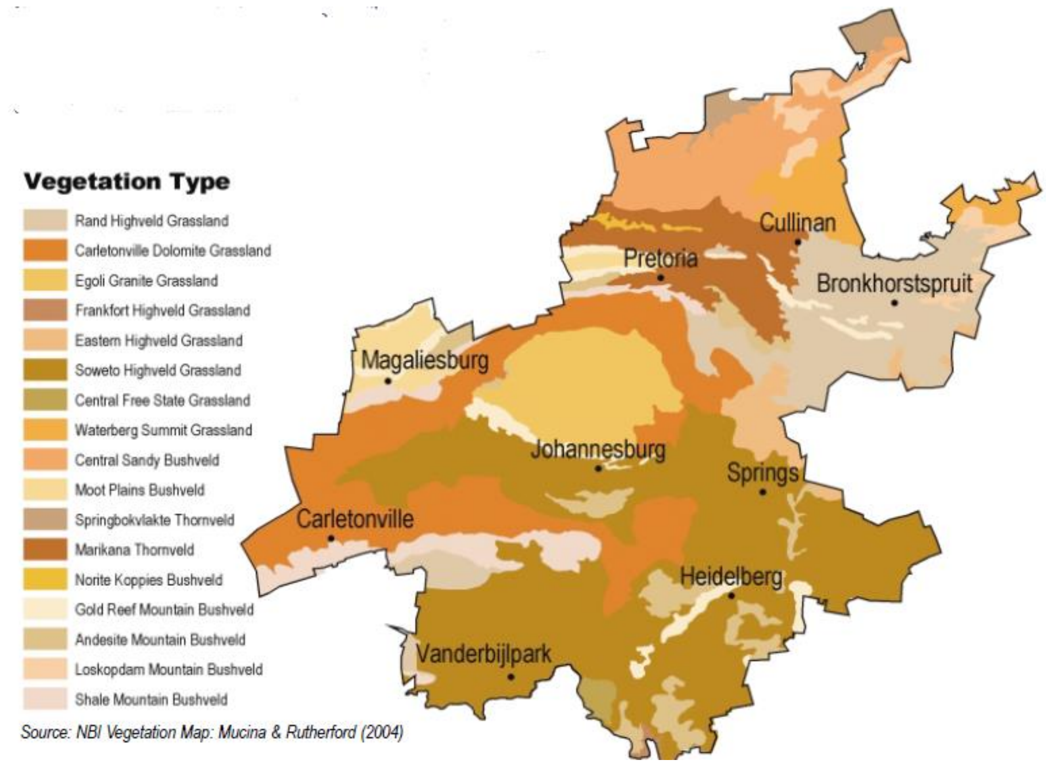


Figure 2: Gauteng Province Vegetation map (Courtesy of Mucina & Rutherford)

4. Drainage

The Gauteng Province consists of two major catchments namely; the Crocodile River and Vaal River. The Crocodile River feeds into the east coast, and the Vaal River feeds into the west coast. The province serves as a major water shed (Figure 3).

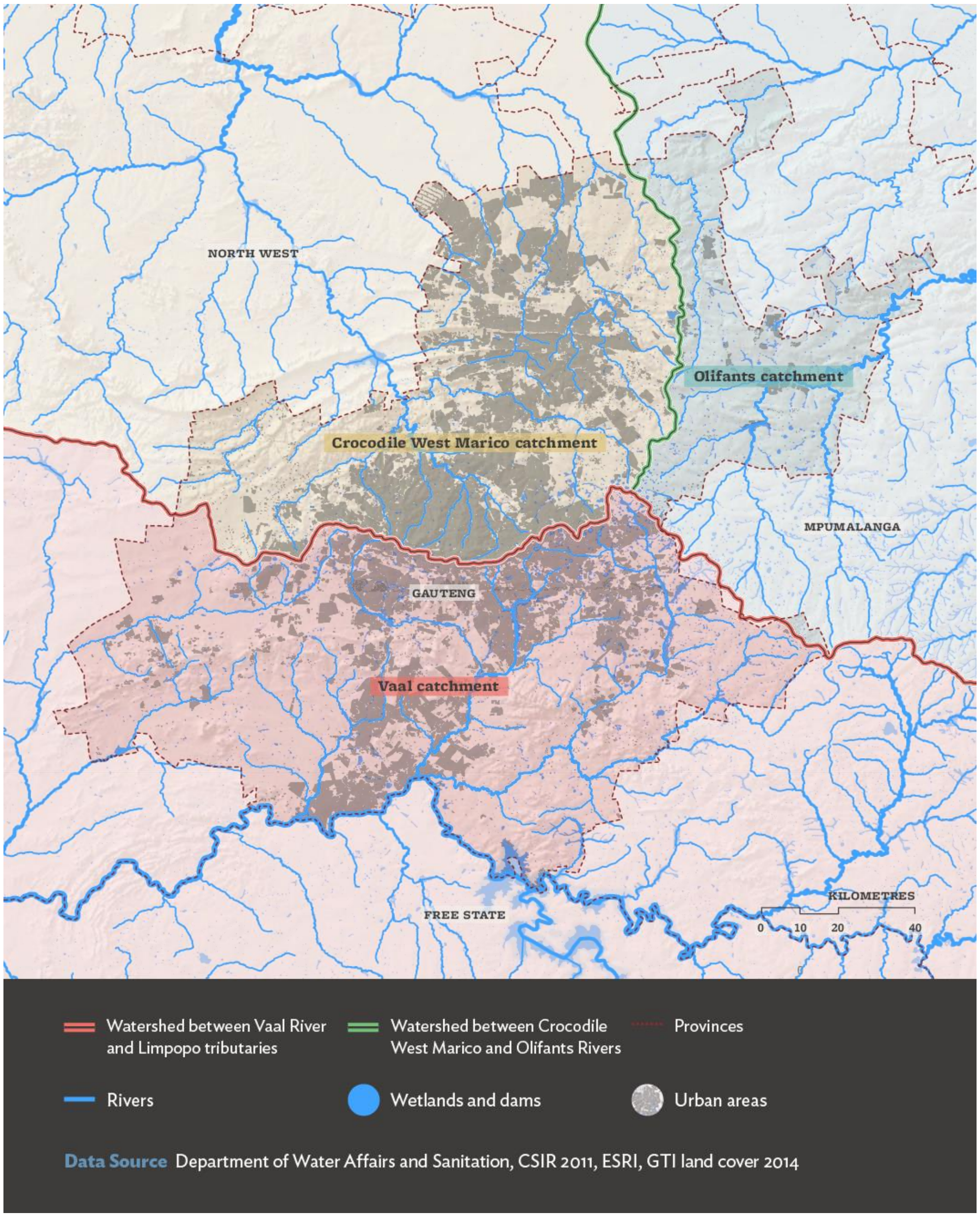


Figure 3: Drainage of the Gauteng Province (Courtesy of GCRO: http://www.gcro.ac.za/outputs/map-of-the-month/detail/watershed-boundaries-of-the-gcr).

5. *Agriculture*

The development of emerging economies is very much dependent on the agricultural sector (WWF, Agriculture and Biodiversity Initiative, 2008). The sector enables the country to be in a position to feed its residents, while also contributing towards economic growth. The industry/sector plays an important role towards food security, social welfare, job creation, ecotourism. The country is divided into different farming regions. The farming activities range from intensive crop production in winter rainfall and high summer rainfall areas, to cattle ranching in the Bushveld and sheep farming in the more arid regions. (WWF, Agriculture and Biodiversity Initiative, 2008).

South Africa is believed to have an estimated 12% of its arable land being used for the production of rain fed crops. The country has a limited amount of fertile land, the land available is estimated at $\leq$ 3% of the total land surface area. The bulk of the land (69%) is highly suitable for livestock farming, due to its ability to support grazing. This could explain why livestock farming is the largest type of farming activity within the country.

The Gauteng Province is no exception to this, it does participate in agricultural activities. The Province is very active in food production through agriculture, and the umbrella body that is responsible for controlling and regulating all the commercial agricultural activities within the province is the Gauteng Department of Agriculture and Rural Development (GDARD). The province has designated certain areas as agricultural hubs. Agricultural hubs are responsible for the advancement of agricultural activity and agro-related economic activities in the province. The overall aim of the agricultural hub is to strengthen the rural economy within the province. The province is involved in a variety of farming activities,

The north eastern, south eastern and south western hubs are responsible for livestock farming particularly cattle farming. The Central part is responsible for the Grain Production. The West Rand is responsible for a variety of agricultural activities that span through the whole value chain of agriculture.

CHAPTER 3: DETERMINING THE SOCIAL IMPACT OF BUGWEED ON THE FARMERS IN THE GAUTENG PROVINCE

Summary

Solanum mauritianum (Bugweed) is a NEMBA category 1b, alien invasive plant that originates from South America. It is a tree or shrub that forms dense stands in agricultural lands, rural and urban areas. Previous studies have focussed mainly on the ecological and economic impacts as well as the control of Bugweed in South Africa. However, these studies have not addressed the potential social impact of the weed to various stakeholders including farmers, considering the fact that the plant has been in the country for more than 400 years. The understanding of the social impact of Bugweed will enable us to quantify the amount of damage caused by this weed and also explore if there are any benefits that could be derived from the presence of Bugweed i.e. medicinal properties. A survey was conducted across five of the areas that are regarded as agricultural hubs. A total of 50 farmers were interviewed.

The interviews were aimed at assessing the farmers' sources of information regarding Bugweed and other IAP, their level of knowledge regarding Bugweed, and lastly their perceptions regarding Bugweed. Only 38% of the participants (farmers) knew Bugweed and the rest of the participants (62%) did not know Bugweed. A 2x2 contingency Chi-squared test revealed a significant association Chi $P<0.0084$ between the different races, when comparing those who knew versus those who did not know Bugweed. Similar tests were conducted based on Gender and Farmers organisation affiliation status, and there was a significant association ($P<0.0312$) between farmers organization affiliates and non-affiliates. The association were insignificant ($P=0.5186$) between female and male participants. Farmers associations were identified as the main source of information to farmers, even though only 30% of the participants were affiliates. A large majority of those who were able to recognise Bugweed (69%) regarded it as a pest, however there were a few participants who indicated that they use Bugweed as a medicinal plant and/or as an ornamental plant.

In conclusion, the level of knowledge amongst the participants regarding Bugweed is surprisingly low, and it is very difficult to assess people's perceptions about something they are not familiar with. There needs to be more awareness programs to help increase people's knowledge regarding Bugweed and other important IAP that are prevalent in Gauteng. This will help encourage compliance with the directives of NEMBA.

Keywords: Agricultural hub, Farmers associations, Invasive alien plant species, NEMBA Participant, Social Impact

1. Introduction

1.1 Problem statement

Studies on IAP in South Africa and abroad have focused predominately on their negative impacts on the environment (Shackleton, Kirby and Gambiza 2011). These studies have thoroughly documented the impacts of IAP on ecosystems and the economy. However there is a serious lack of knowledge regarding the social impact of important IAP's such as Bugweed. There are potential social impacts on the various stakeholders such as farmers and also on informal economic activities that might arise from the presence of Bugweed or other IAP.

The survival of human beings and other fauna is highly dependent upon the presence of flora on the planet. Throughout the history of humanity, human beings have always interacted with plant species, and this interaction has led to the discovery of edible plant species, medicinal plant species, poisonous and ornamental plant species (Van deer Veen 2014). Plants have and will always play a pivotal role in human culture and physical development. The plants may be indigenous or alien plants. The nature or magnitude of influence they might have on human beings is determined by a variety of factors such as the physical and chemical properties of the plant.

Plants have always influenced human activity, and thus it is evident that certain plant species have a social impact on human life. IAP's are usually regarded as weeds, and weeds by their nature are associated with human activity, i.e. human disturbance on the earth usually creates suitable habitats for weeds to invade and thrive. A classic example is seen in the former agricultural lands that are infested by IAP. Human beings and IAP (weeds) have a long history together. According to Pollan (1989) “the decision to cultivate also meant to have weeds”.

1.2 Social Impact

Social impact is defined as the effect an organization or object’s action have on the wellbeing of the community, or significant positive/ negative change that addresses or causes a social challenge (Epstein and Buhovac 2014). Social impact has also been defined as the effect of an activity on the social fabric of the community and wellbeing of the individuals (Helliwell, and Putnam 2004). Plant species have various degrees of social impacts on humanity. The impacts may be positive or negative i.e. some IAP threaten the livelihoods of people, while others may actually improve people’s livelihoods by serving as supplementary sources of income, medication and food.

1.3 Social Impacts of Invasive Alien Plant Species

Pfeiffer & Voeks, (2008) documented that people in communities sometimes adapt to changes in biodiversity that result from the introduction of non-native plant species changes, through incorporating those particular plant species into their way of life. Macdonald *et al.* (1986) estimated that at least 50 invasive plant species that were prominent at the time (1986 and before) resulted from deliberate introduction as a result of various reasons such as for fodder plants, fruits, agroforestry and dune stabilisers.

Some IAP have the potential to serve as resource/s which may contribute towards improving the livelihoods of the vulnerable (Shackleton *et al.* 2007). Studies have also demonstrated that locally there are some people who do not perceive IAP as a separate entity, but rather they are perceived as being part of the landscape. This observation could be directly linked to people’s level of knowledge regarding IAP (Shackleton, Kirby and Gambiza 2011). The knowledge base regarding the contributions towards livelihoods that are made by indigenous plants is continually growing, and this is important for encouraging the conservation of indigenous plant species. However there is a serious shortage of knowledge regarding the contributions of IAP towards the informal economies and poor people's livelihoods (Shackleton and Shackleton 2004). There is a possibility that Bugweed could be of importance to some people within the Gauteng Province, including the farmers.

1.4 Positive Social Impacts of Invasive Alien Plants

There are IAP that have managed to form part of both the informal and formal economies. In South Africa the *Opuntia stricta* (prickly pear) is an example of an IAP that has a dual impact. It is used to create many commercial and non-market products such as fruits, jams, syrups, medicine. While on the other hand it is an aggressive invader of habitats (Shackleton, Kirby and Gambiza 2011). IAP species such as *Tamarix usnoides* (Tamarix) and *Eichhornia crassipes* (Water hyacinth) play an important role in phyto-remediation in mines, helping reduce the effects of acid mine drainage on the water systems (Weiersbye *et al.* 2006). They are capable of absorbing minerals that are released during the mining process and storing them.

1.5 Negative Social Impacts:

IAP have the potential to transform habitats through the disruption of ecosystems in areas where they colonize. The disturbance caused IAP can be translated into various facets of human livelihood and Biodiversity threats. A brief summary of the negative impacts of IAP is discussed below:

(a) Alien Plants and Food Security

The vast majority of people in rural areas rely on subsistence farming to supplement food sources and income, and thus improve livelihood. Some IAP invade and reduce habitats that have been set aside to be used as agricultural spaces, reducing crop yields (Pejchar and Mooney 2009). Some IAP species can also outcompete grass species that form a key role in feeding livestock such as cattle, i.e. *Campulcoclinium macrocephalum* (Pompom) weed, and this reduces the food that is available for livestock, and hence exacerbates food security (Daily *et al.* 1997; Goodall *et al.* 2011; Goodall *et al.* 2012).

There are IAP species that are known to be poisonous or have allergens that sometimes impact negatively on livestock, for instance Bugweed produces fruits that are very poisonous when unripe. In drought stricken areas livestock may be tempted to consume Bugweed fruits.

IAP such as *Eucalyptus* species and *Tamarix* species use a lot of water through transpiration and thus decrease the availability of water in an area (Pyšek and Richardson, 2010). In such areas people can spend more time searching for water as streams dry up earlier in autumn/winter. Aggressive invasions can block existing foot paths resulting in less accessibility and possible injuries. There are cases of impoverished subsistence farmers being forced to abandon their farms due to high infestations and as a result increased difficulty to cultivate. The limited space can result in conflict between farmers and also migration to otherwise less favourable areas.

(b) Health Impact

The floating moat of water hyacinth is known to harbour mosquitoes (Ofulla *et al*. 2010). A challenge arises when medically important plants are outcompeted by IAP for the space and resources. This situation becomes problematic when the IAP has allelopathic properties, resulting in the inhibition of the growth of medicinal plants. There are communities that are highly dependent on traditional medicinal plants for their primary healthcare (Williams *et al*. 2000; Luoga *et al.* 2000). The hairy substance found on Bugweed leaves and stem can cause respiratory issues in humans if inhaled, can irritate the skin causing itching and also affect the eyes if blown into the face by the wind.

(c) Impact on Women and Children

Removing IAP in poor countries is usually performed by the woman and children especially if the infestation is within the yard or areas that are used by the family to farm. This can result in lost time that was supposed to be used for more productive duties.

2. *Purpose of study*

Aim

The aim of the study was to investigate the social impact of *Solanum mauritianum* (Bugweed) on the farmers in Gauteng Province. The study was designed to fully explore the various possible ways Bugweed could be impacting on the farmers.

Objectives

a) To assess the farmers level of knowledge with regard to Bugweed.
b) To assess the perceptions of farmers regarding the infestation of Bugweed.
c) To investigate the sources of information farmers are exposed to or employ.

3. *Methods*

3.1 Study Site

The study was conducted across the agricultural hubs of the Gauteng Province, South Africa (Figure 4).

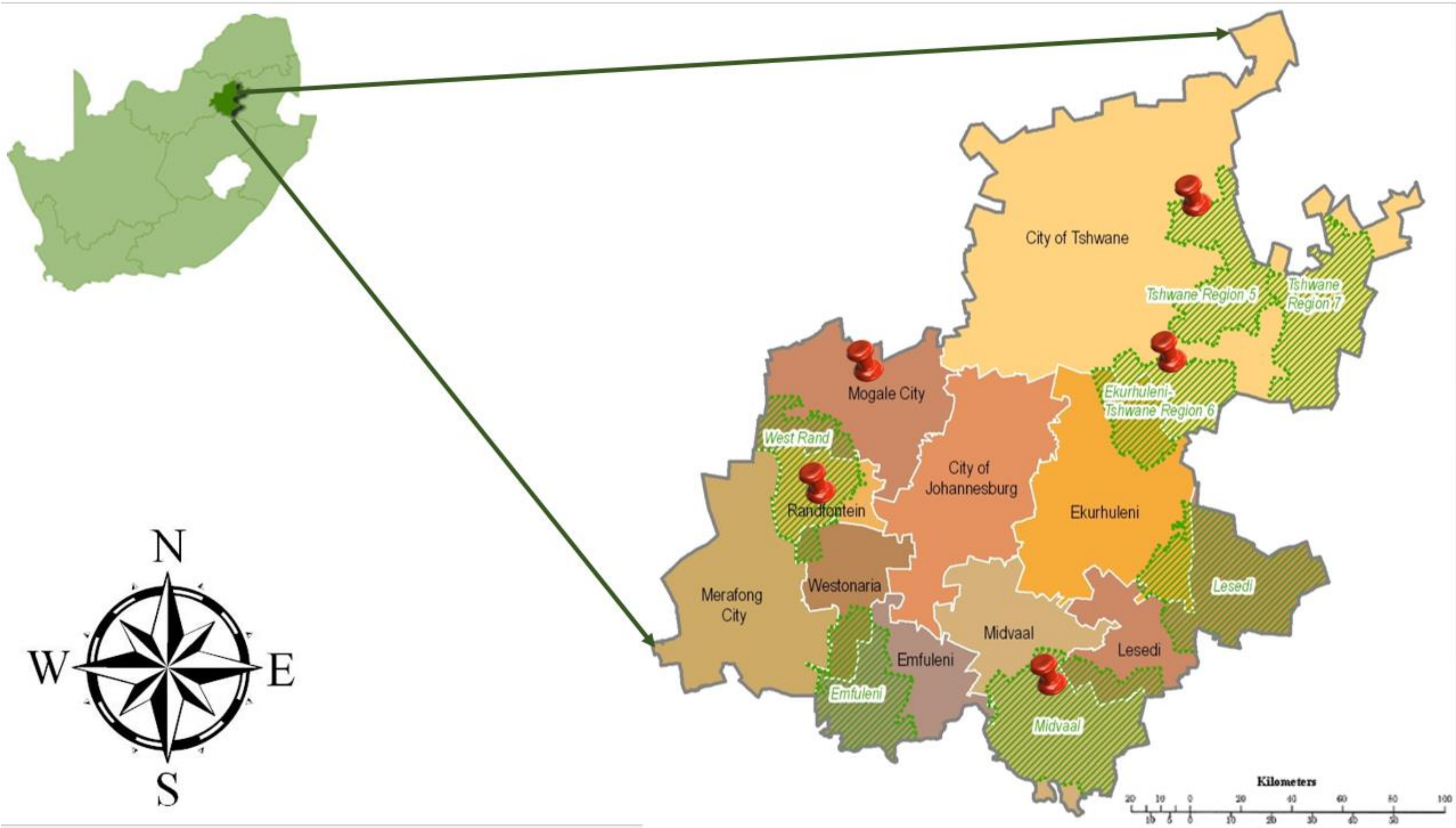


Figure 4: Map of the Gauteng Province, South Africa. Depicting the agricultural hubs of the province which served as the study areas for this study

3.2 Data Collection:

(a) Questionnaire design

A detailed questionnaire (Appendix A) was designed to achieve the above mentioned objectives. The questionnaire was reviewed by the Wits Human Ethics Committee to ensure that it was met all required human ethical standards. Upon completion of the review process, ethics clearance was granted (Appendix B). The questionnaire served as the main guide for the semi-structured interviews. In order to obtain as much information as possible from the participants (farmers), the questions were open ended to avoid limiting the responses of the participants. In addition to assessing the farmer's level of knowledge, perceptions and sources of information regarding Bugweed were also examined. The questionnaire was also used to gather additional information such as (age, gender, and level of education, number of years on the property and farmer affiliations) of the participants.

(b) Field Sampling

Farmers were interviewed from the 01/10/2016- 18/11/2016, and each farmer was interviewed for at least 10- 15 minutes. I used the questionnaire in appendix A to ask the participants questions while I personally wrote down the responses in the questionnaire, while also using it as a guide during the interview. In order to try and get the most from the participants the interviews were not very formal, they were more like conversations. The farmers interviewed were initially randomly chosen across the agricultural hubs, and then the snowball sampling method was use to access the remaining farmers in each agricultural hub. A minimum of 5 farmers were interviewed in each agricultural hub regardless of their farming specialty. Before the interviews could take place, participants were required to give consent in the form of their signature on the consent form, and in some cases verbal consent was also accepted (Appendix E).

The interviews took place on the farmers' properties (Figure 5). The interviews were not very formal in order to create a relaxed atmosphere so that they may share as much information as possible. I travelled with a live Bugweed plant sample in a pot, as well as a hard copy picture and a digital picture on a 10" tablet, to ensure that the participants were able to observe the plant species clearly.

Figure 5: An Interview with one of the farmers from Randfontein.

A total of 50 participants (farmers) were interviewed across the Gauteng Province, particularly in five of the areas that are designated as the agricultural hubs of the province. All the agricultural hubs were visited and an average of 10 participants (farmers) were interviewed per agricultural hub (refer to Table 1).

Table 1: Representing the overall number, average, minimum and maximum of participants in the agricultural hubs

Summary	***Number***
Total Agricultural hubs (study sites)	*5*
Total number of participants	*50*
Average number of participants/per agricultural hub	*10*
Minimum	*6*
Maximum	*18*

The majority of the farmers who participated in the study came from the Tshwane municipality (36%), and Mogale City (24%). The number of participants from Ekurhuleni and Sedibeng were almost equal, each contributing 14%. The least represented agricultural hub was Randfontein with 12% of the participants (Figure 6 A&B).

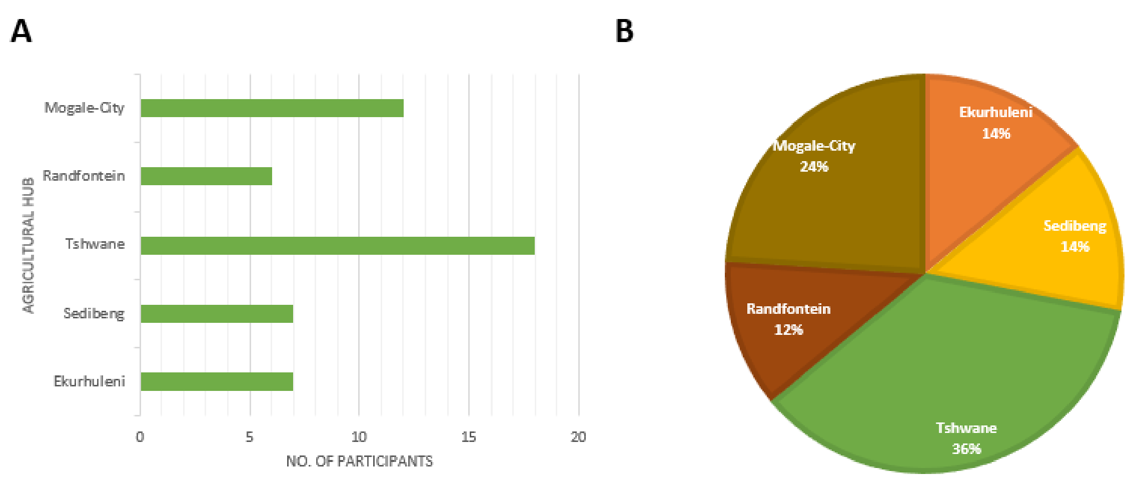


Figure 6: Number of participants (farmers) in each study area (A) and the percentages of the participants in each study area (Agricultural hub) (B).

The Tshwane region recorded the highest female participants when compared to the other agricultural hubs (Figure 7). The study focused on mainly on commercial farmers in Gauteng, and hence the majority of the participants were males.

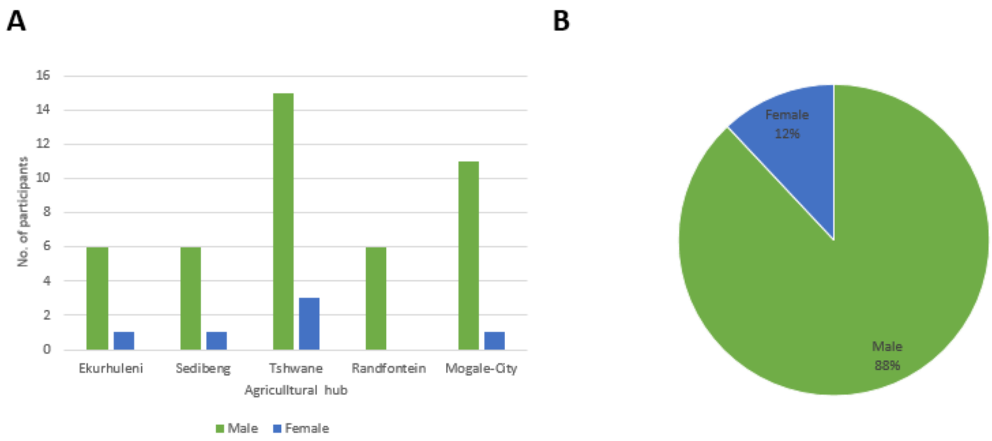


Figure 7: Male versus female Participants across the agricultural hubs (A), and the overall comparison of both male and female (B).

The farmers who participated in the survey came from various different backgrounds. The highest number of African participants was recorded in Tshwane, while the highest number of participants of European descent came from the Mogale-City areas (Figure 8(A)).The overall number of farmers who were of African descent was almost equal to the number of farmers who were of European descent (Figures 9(B)).

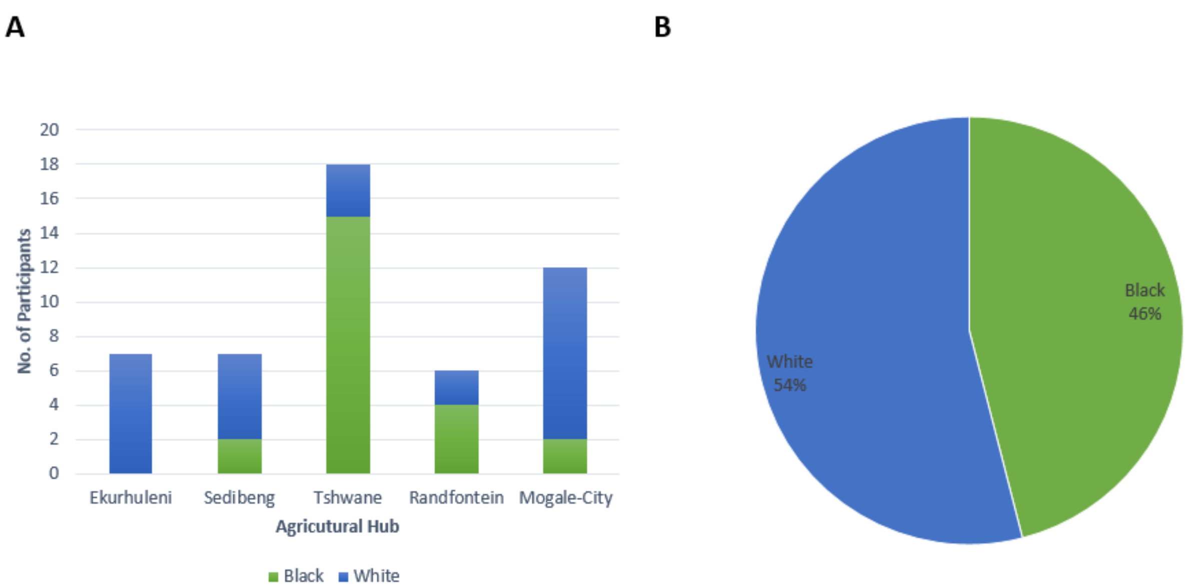


Figure 8: The racial profiles of the participants in each agricultural hub (A), and the overall percentages of the participants in terms of their race (B).

The participants had an average of 18 years of farming experience in each agricultural hub, with the highest average farming being seen in Sedibeng (Figure 9).

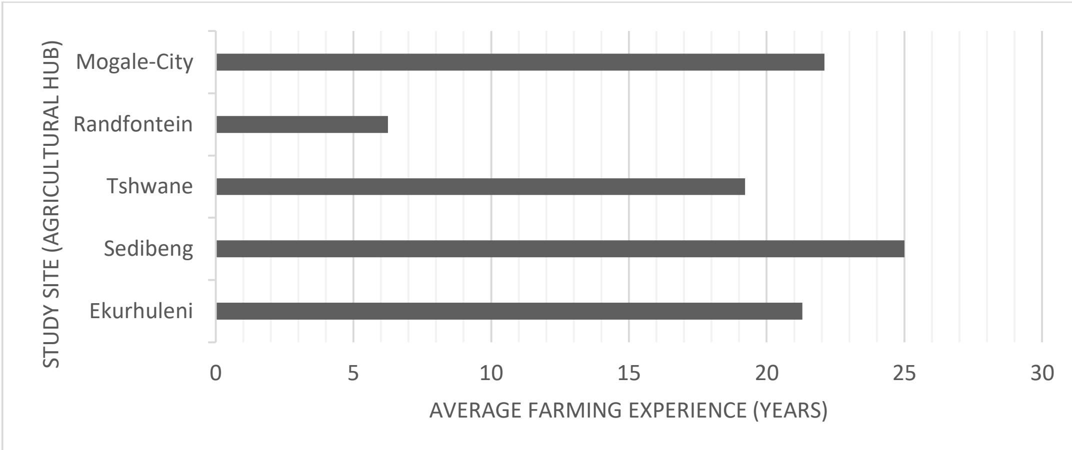


Figure 9: Average farming experience per agricultural hub.

The farmers who were interviewed specialize in various agricultural fields, with the majority of participants specializing in vegetable farming, particularly in the Mogale-City Local Municipality area (Figure 10).

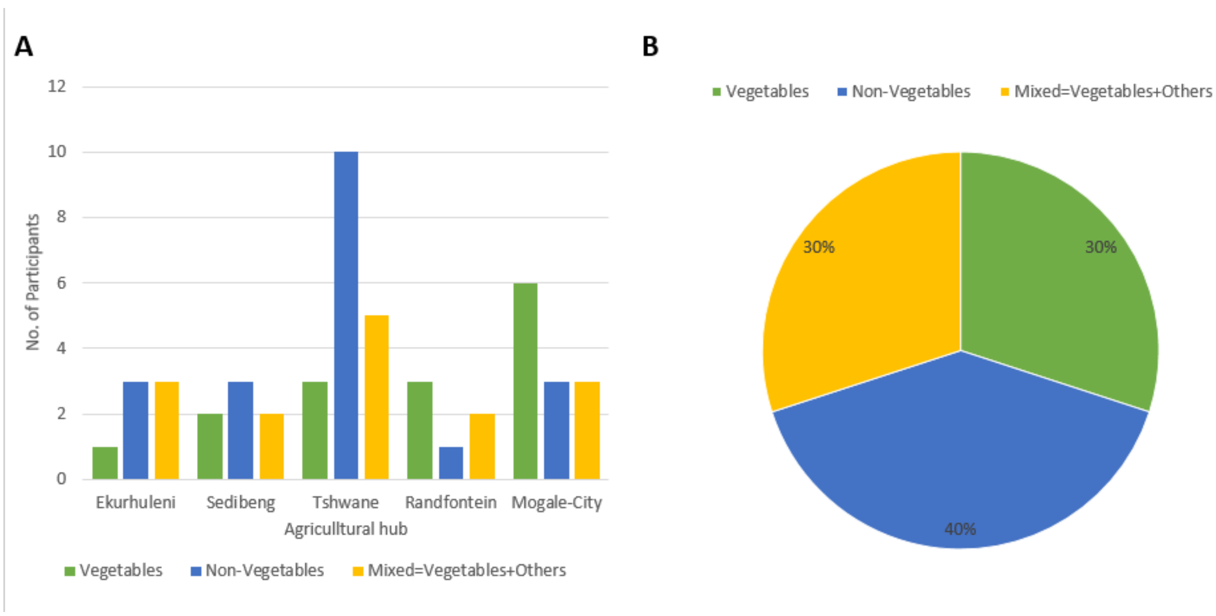


Figure 10: Summary of the farming specialty of the participants in each agricultural hub (A), and the overall farming specialties of the participants (B.)

3.3 Pre-processing and analysis

(a) Pre-processing

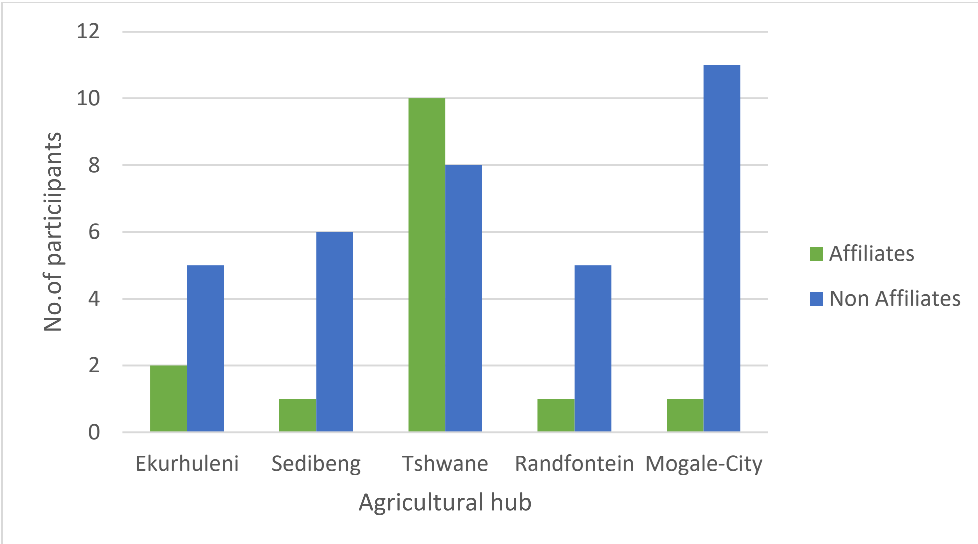
The data from the questionnaires was decoded from the questionnaires onto an excel spreadsheet, for analysis. The qualitative data was then grouped into the relevant objectives namely; Knowledge, Perceptions and Sources of Information. The quantity and quality of information that could be retrieved from each participant (farmer) was dependent on the farmer's ability to recognise the Bugweed plant sample along with the other supporting material that were carried around to all the interviews, and the ability to link the relevant information that might be associated with the plant. The answer to the first question on the questionnaire determined whether there would be subsequent information that would be retrieved from the participant or not, i.e. farmers who were unable to recognize the plant sample were automatically unable to be assessed for their knowledge and perception regarding the plant sample.

The farms (properties) and surrounding areas were also surveyed for the presence of Bugweed plants along with the surrounding areas, as a way of verifying whether or not the plant is a pest in the respective agricultural hubs. Certain questions representing key objectives were selected and assessed in order to determine the required objectives on excel, i.e. the ability to recognise the Bugweed plant sample can be attributed to the farmer's knowledge regarding Bugweed, regardless of the limitations i.e. inability to assess the depth of that particular knowledge. The farmers who were able to recognise the plant sample, and had some knowledge about the plant qualified to be assessed for their perceptions regarding Bugweed.

Sources of information

Farmers association/organizations were identified as the main source of information farmers are exposed to. They serve as a medium where farmers are able to exchange information, and bargain as a collective for various reasons or agendas. The majority (70%) of the farmers who were interviewed are not affiliated to any of the existing farmer's association/organizations within the province. Tshwane appears to have more participants who are affiliated to farmer's organizations (Figure 11A &B).

A



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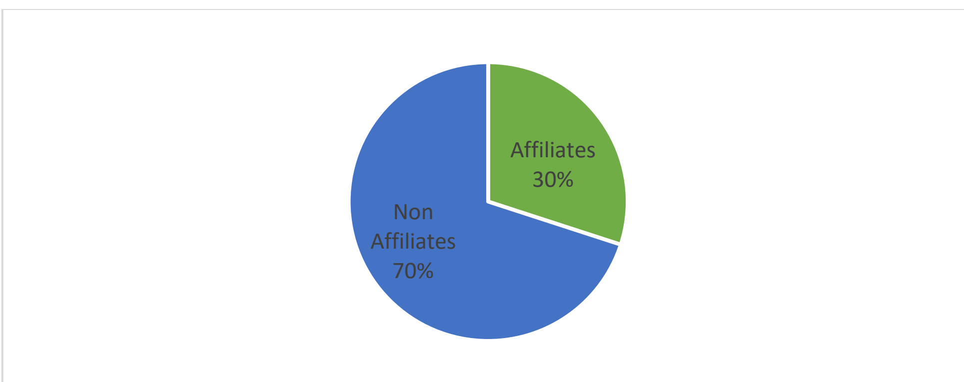


Figure 11: Comparison of affiliates versus non affiliates per agricultural hub (A), overall for all agricultural hub (B).

(b) Data Analysis

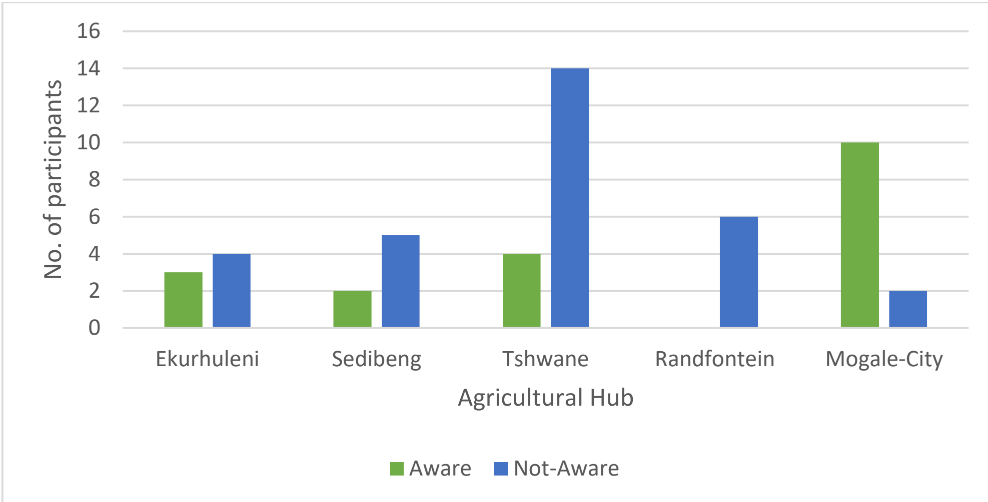
The qualitative data were converted to quantitative data by scoring each participants' responses, i.e. the ability to recognize the plant sample was 1 and inability was 0. A similar procedure was done for the other objectives using the relevant responses to the questions on the questionnaire. Contingency tables (2×2) were created and chi-squared tests performed where appropriate to test for an association’s between the categories. For instance, comparison between Female and male participants who are familiar with Bugweed versus those who are not familiar with it.

4. Results

4.1 Farmer’s Knowledge Regarding Bugweed

The participant’s level of knowledge regarding Bugweed was tested, beginning with a simple test of determining whether they are able to recognize Bugweed. The majority (62%) of participants were unable to recognize Bugweed, and this implied that they did not know or were aware of this species, and it was possibly not very apparent on their farms (Figure 12). A 5x2 contingency table revealed a significant difference between the farmers who were able to recognise Bugweed and those who were unable to across the agricultural hub (X^2=16.38,DF=4 & P=0.0025). The differences between the number of those participants who were able to recognize Bugweed, from the different ethnic/racial was tested. A Chi-squared test revealed a significant association (*P =0.056, DF=1, &* X^2*=7.678*) in the awareness between white and black farmers. The test also revealed no significant association (P= 0.5186, DF=1 & X^2=0.4167) between and males and females who were able to recognize Bugweed versus does who were unable to. There is a significant association between affiliates and non-affiliates who were able to recognize Bugweed and those who were unable to (P=0.0312, DF=1 & X^2=4.641) well as between affiliates and non-affiliates of farming organizations (Figure 13 & Table 2).

A



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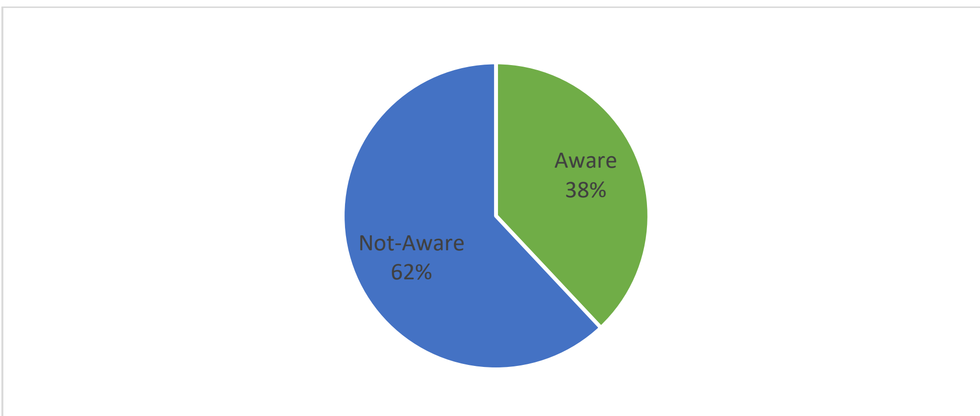


Figure 12: Number of participants who were able to recognize Bugweed per agricultural hub(X^2=16.38,DF=4 & P=0.0025) (A), and overall for the all the agricultural hubs (B).

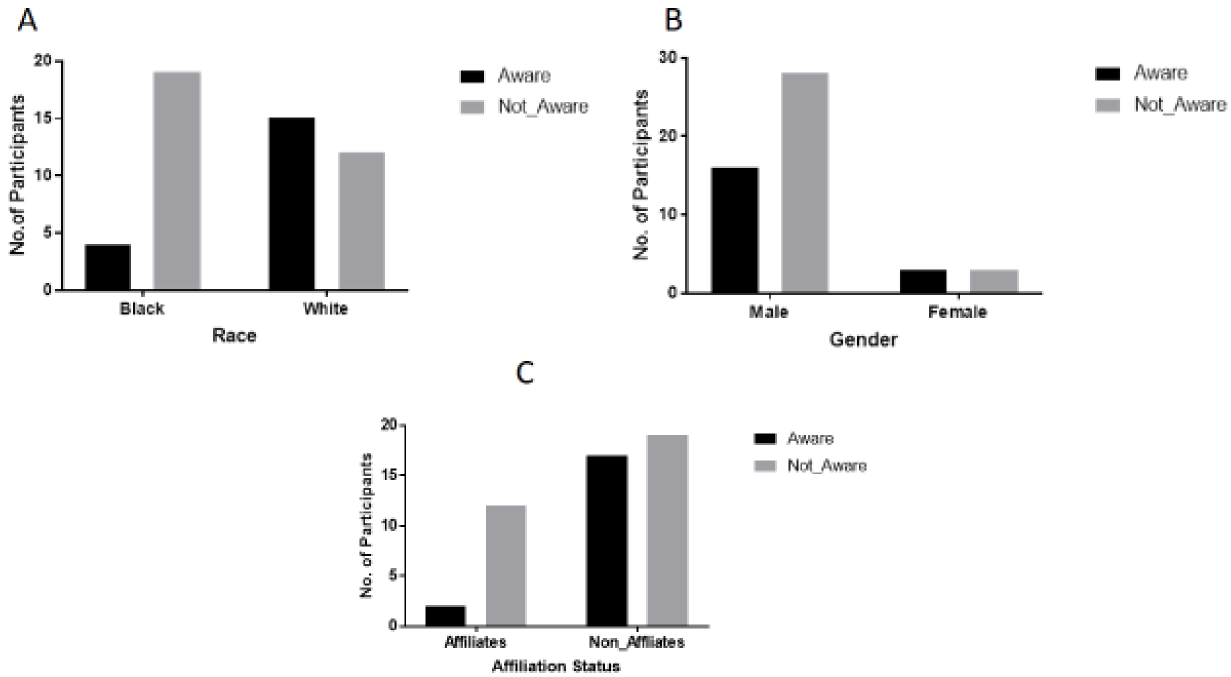


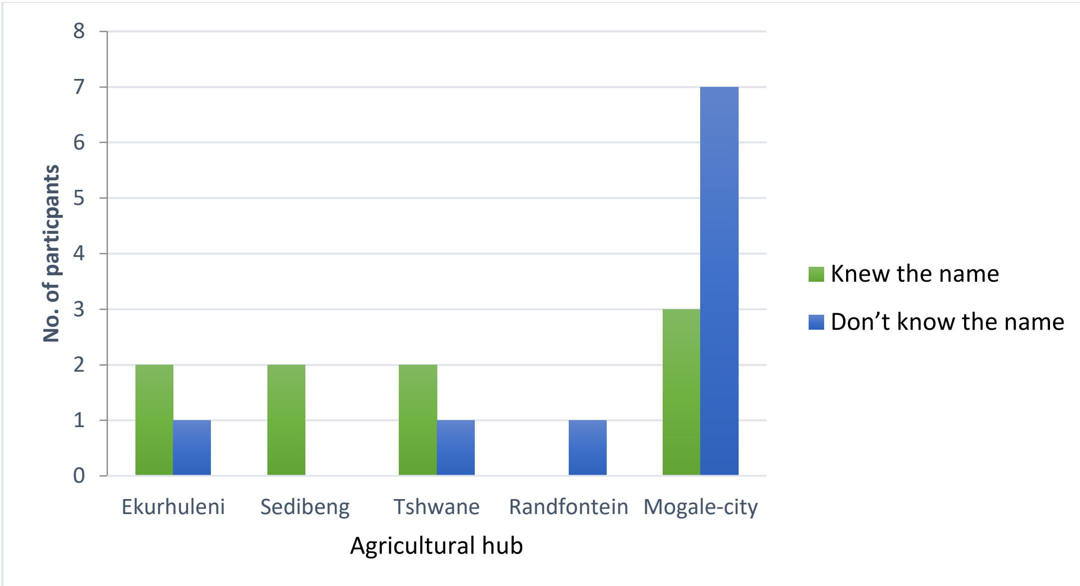
*Figure 13: Comparison of the ability to recognize (Aware versus Not Aware) Bugweed between white and black participants (P =0.0056) (**A**), male and female participants (P=0.5186) (**B**), and the participants who are affiliated versus those who are not affiliated (P < 0.0312) (**C**).*

Table 2: The results of three, 2x2 contingency table Chi squared tests of the data shown in Figure 14 (above), for parts A (white versus black participants), B (male versus female participants) and C (affiliated versus not affiliated), in each case in relation to whether the respondents were aware versus not aware of Bugweed.

Summary	**Race**	**Gender**	**Affiliation Status (Farm's organization)**
Degrees of freedom	1	1	1
P Value	0.0056	0.5186	0.0312
Chi-Squared Value	7.678	0.4167	4.641
Statistical significance (Yes/No)	Yes	No	Yes

The participants who indicated that they are aware of Bugweed were then asked to provide the name of the plant species in front of them. Of those that recognized the species, 53% did not know the name of Bugweed, and the highest number of participant who knew the name of Bugweed came from the Mogale-City (Figure 14).

A



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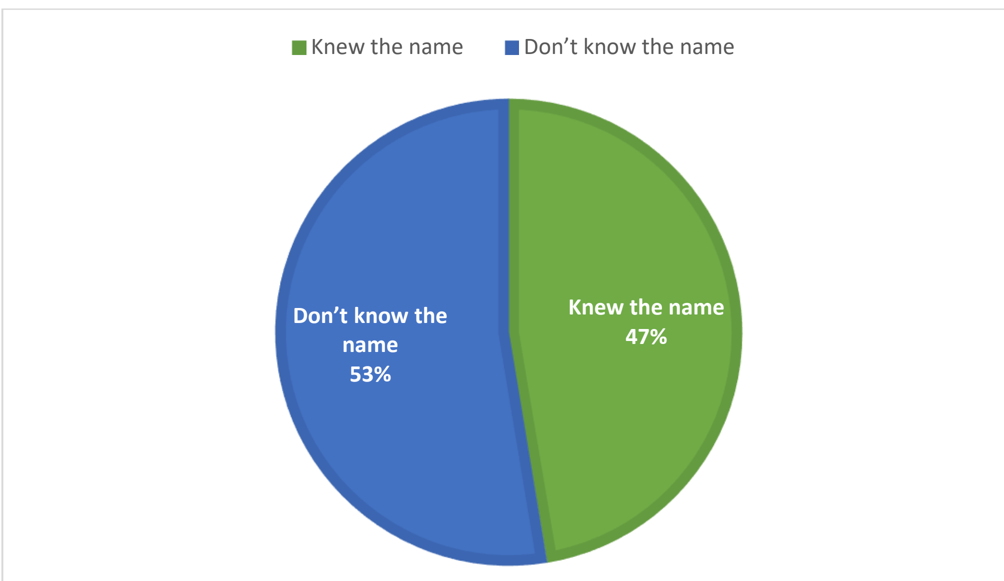
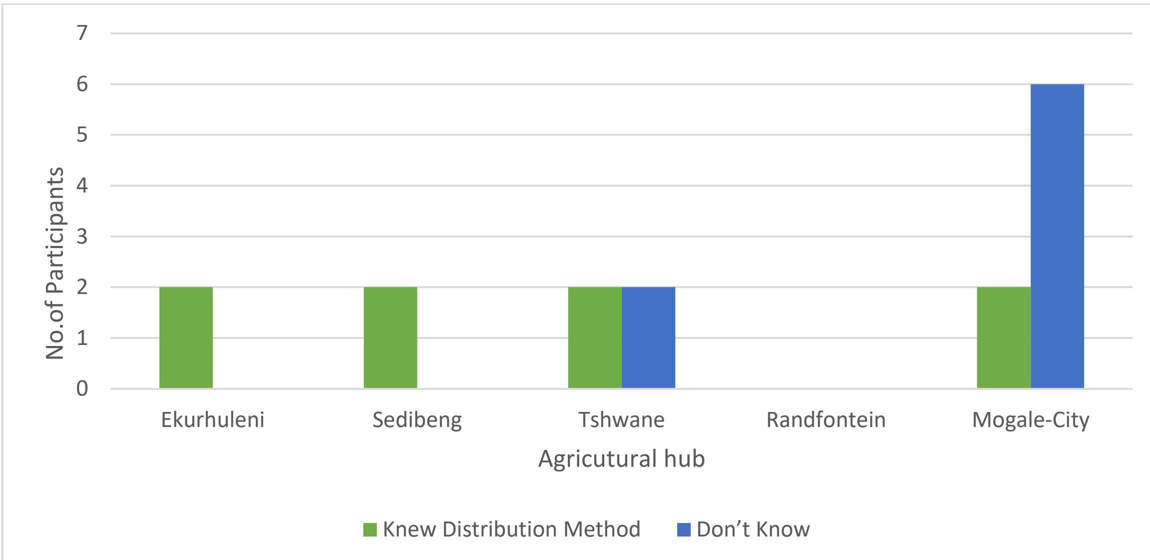


Figure 14: Number of participants who knew the name of Bugweed versus those who did not per agricultural hub (A), and the overall for all the combined agricultural hub.

The participants who indicated that they know Bugweed, were asked further questions to determine whether they knew of the basic information about Bugweed, i.e. the most common method used by Bugweed to spread or disperse. The number of participants who had an idea about how Bugweed is dispersed was equal across the agricultural hubs, however the Mogale City- areas had the highest number of participants who did not know how Bugweed is dispersed (Figure 15).

A



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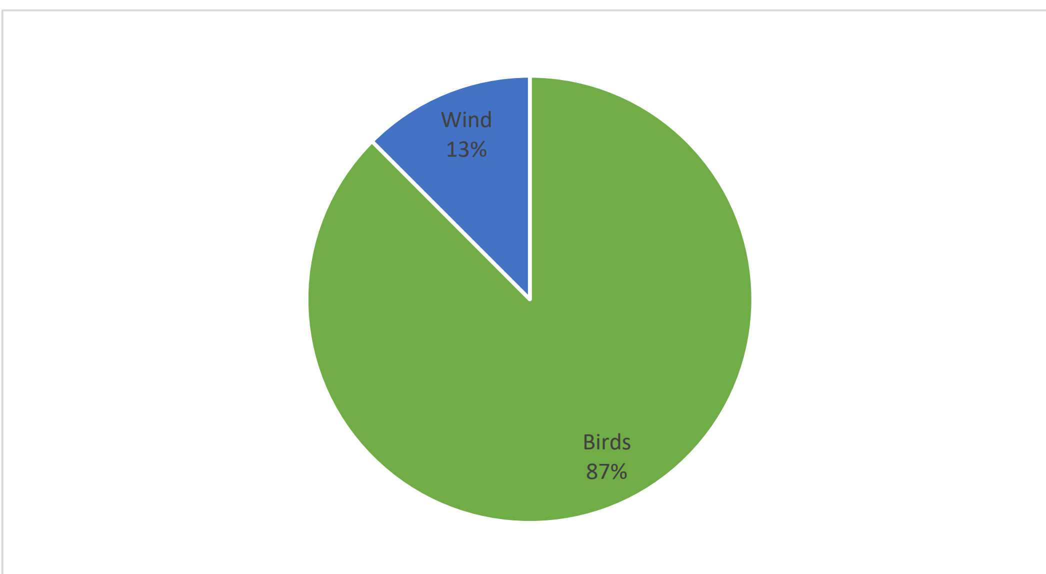
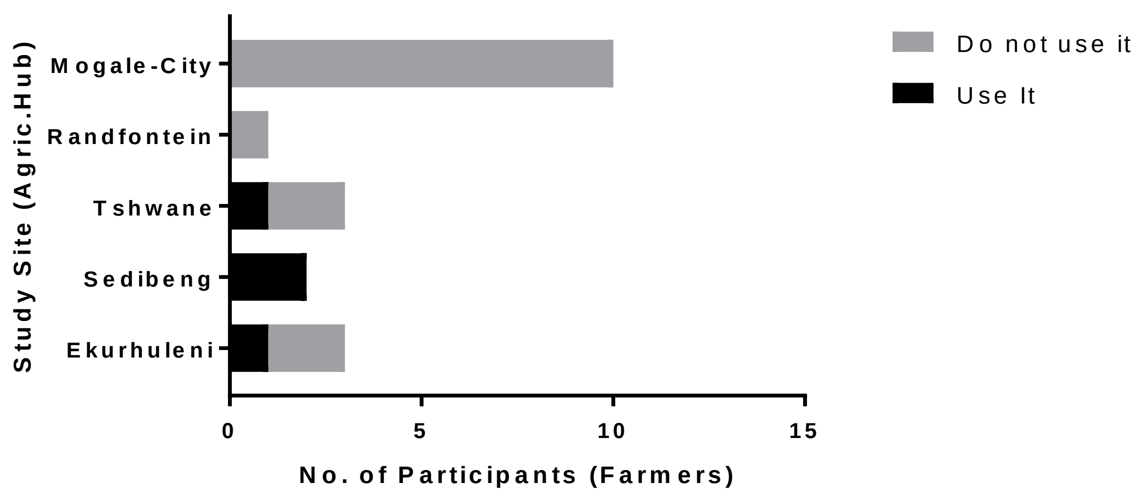


Figure 15: Number of participants who knew versus did not know how Bugweed is dispersed per agricultural hub (A), and overall for all hubs combined (B).

4.2 Farmer's perceptions towards Bugweed

Only 4 of the nineteen participants (or 21%) who indicated that they know Bugweed stated that they have uses for Bugweed, while the rest of the participants indicated that they do not have any uses for the plant (Figure 16).

A



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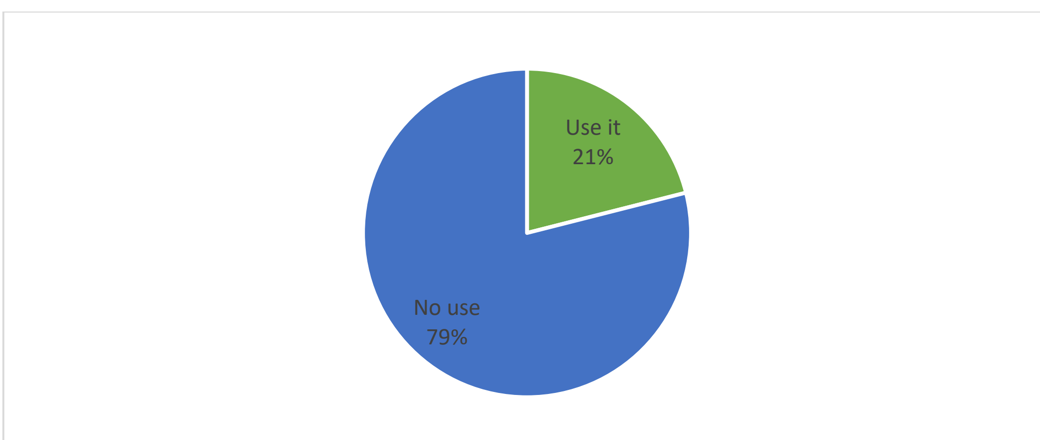


Figure 16: Number of participants who use versus those who do not use Bugweed per agricultural hub (A) and the overall for all hubs combined.

The plant is mainly used as an ornamental plant in urban areas (n=3 participants), because of the beautiful purple flowers it produces. It is also used as a medicinal plant, mainly as a laxative by one participant only (Figure 17).

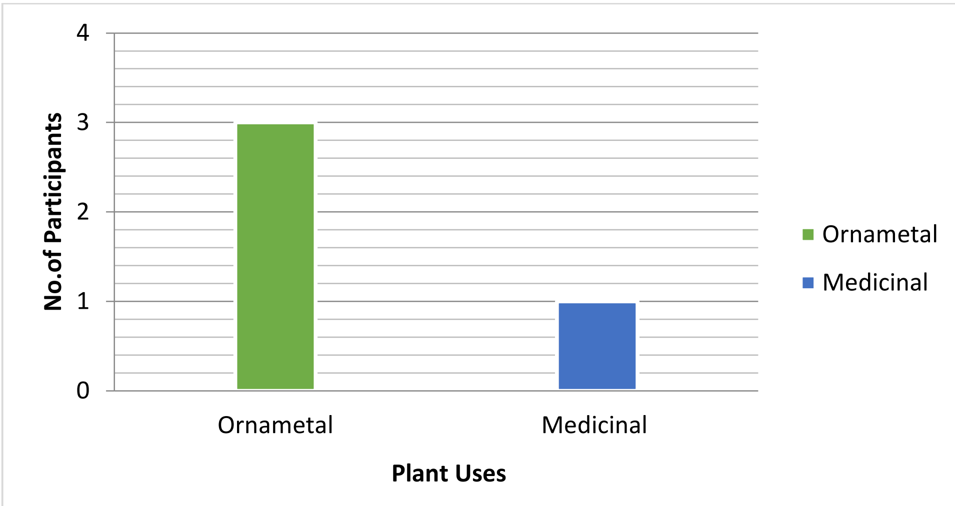
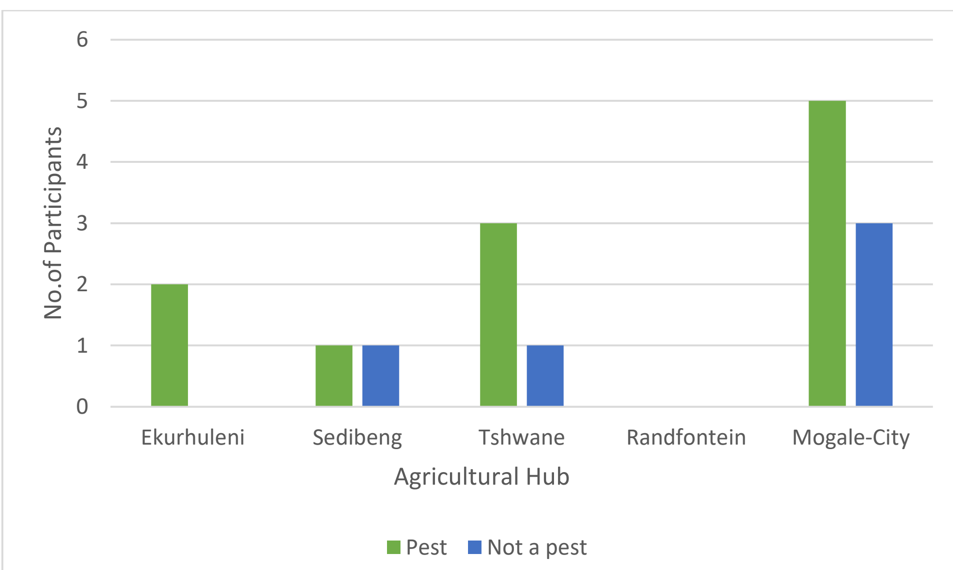


Figure 17: Different uses of Bugweed as indicated by the participants who stated that they use Bugweed.

The majority of the participants who indicated that they knew Bugweed regard Bugweed regard it as a pest. The majority of the participants across the agricultural hubs regard Bugweed as a pest (Figures 18 A and B).

A



B

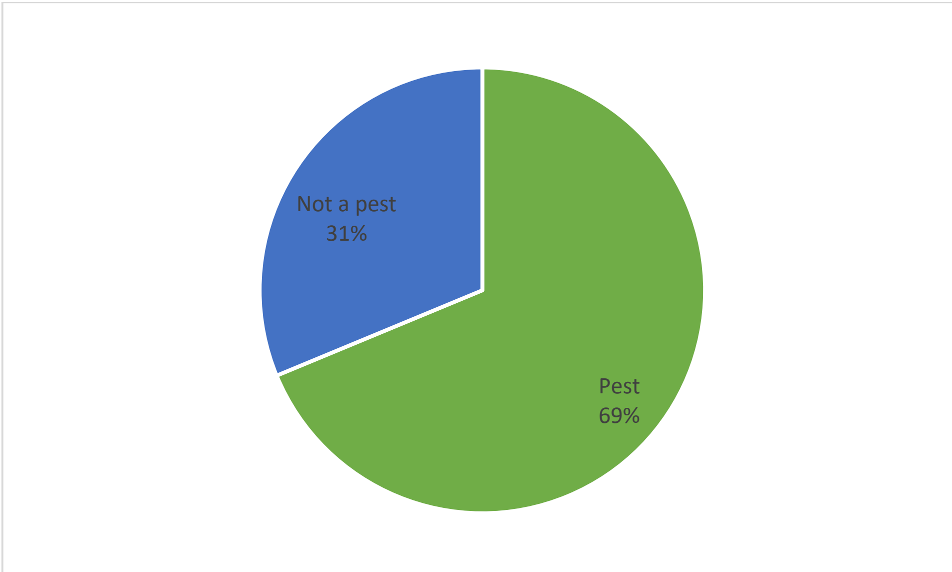


Figure 18: The number of participants who perceive Bugweed as a pest in each study area (A), and the overall comparisons of participants who perceive Bugweed as a pest versus those who do not.

While other reasons for perceiving Bugweed as a pest were split between "It harbours snakes" and "It is poisonous" (Figure 19).

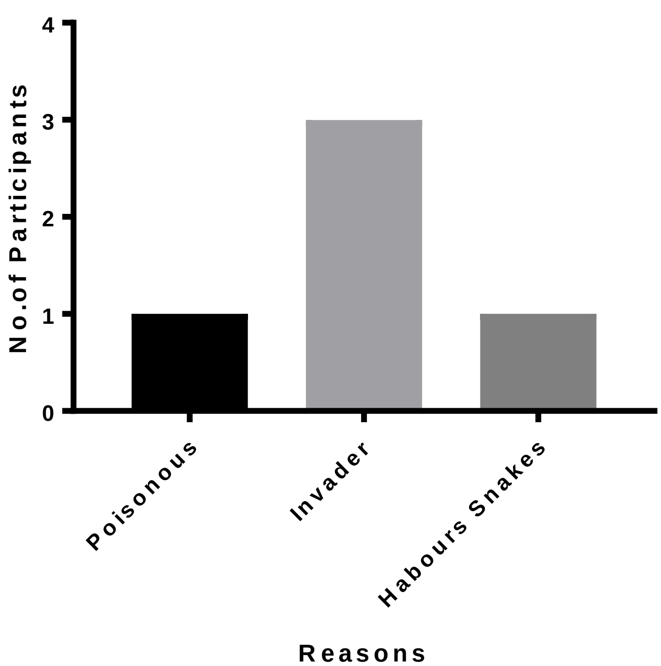
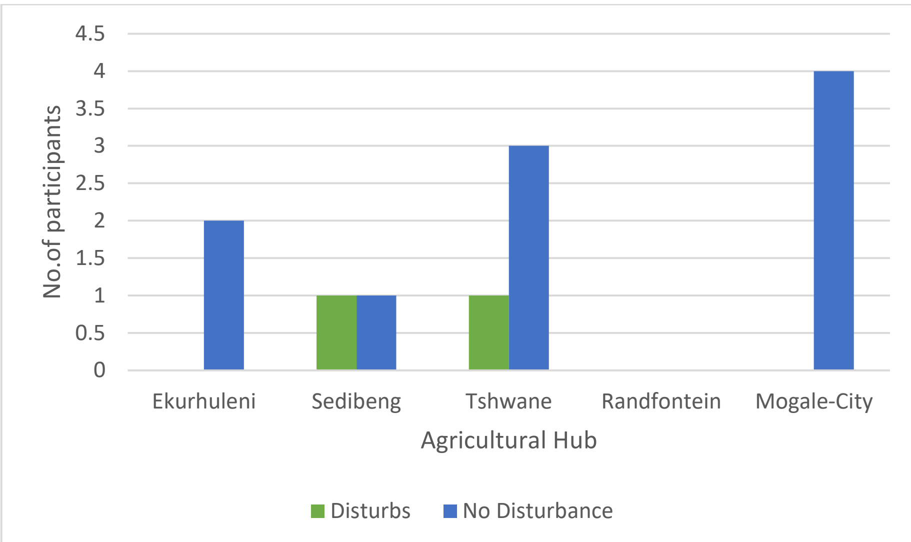


Figure 19: Reasons behind the perception of the participants who regard Bugweed to be a pest.

Across the agricultural hubs (study areas) the number of participants who indicated that they believed that Bugweed interferes in some way with their farming activities, i.e. the possibility of Bugweed competing with their crops for space, or the poisoning of livestock by Bugweed fruits was very low (Figure 20) with only 20% regarding Bugweed as a nuisance or what we would generally call a weed.

A



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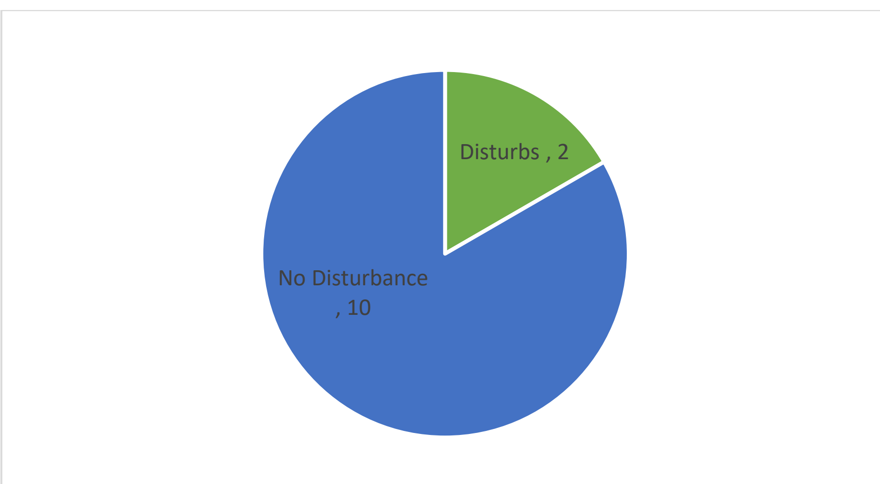

Figure 20: Comparison of participants who believe that Bugweed interferes in some way with their farming activities in each agricultural hub versus those who do not (A), and the comparison overall of number of participants who perceive Bugweed as a disturbance to their farming activities versus those who do not (B).

5. *Discussion*

Three of the main points to emerge from this study were that: (a) there is a great need to raise awareness amongst farmers regarding the importance of Bugweed and other IAP within the Gauteng Province; (b) that the number of farmers (participants) who are familiar with Bugweed is significantly low, which may indicate low levels of awareness of alien weed in general, and (c) that the participants do not generally perceive Bugweed as a pest or a weed on their farms.

Sources of information

The study identified Farmers association/organizations as the main source of information, however a significant number of the participants indicated that they were not affiliated to any of these organisations. One would assume that affiliates are more likely to know about Bugweed or other alien invasive plant species, however the study revealed that non affiliates were more familiar with Bugweed than affiliates. The highest number of affiliates was observed amongst the African (black) farmers, and this may stem from the fact that most black emerging farmers require a lot of assistance in the form of information and other resources, which may be supplied by associations. Amongst the more experienced farmers (Mogale-City), Famer associations may not be perceived as a source of information, rather as a bargaining forum for their produce.

A bargaining forum is responsible for making and enforcing collective agreements in an organization. None of the farmers mentioned anything about farmer's day events, which play a pivotal role in sharing relevant information amongst farmers and other stakeholders. Farmers occasionally meet in formal gatherings where information regarding agriculture is shared, and products that might have value to help solve some of the problems farmers encounter on a daily basis are marketed and sold. Such occasions are formally referred to as "Farmers Days". Farmer's days are an excellent platform that can be used to raise awareness about Bugweed and other alien invasive species. Information about various problematic IAP is also included in the well-known "Famers Weekly" magazine. The information is aimed at informing and updating farmers about the latest control measures and programs that are currently being used.

None of the participants mentioned this weekly magazine as a source of information and hence it is unlikely that they read it or have access to it.

Farmer's Knowledge regarding Bugweed

The overall knowledge of Bugweed amongst participants is low, although the number of participants who were familiar with Bugweed varies across the five agricultural hubs that were visited. The reason behind this might stem from the fact that farmers tend to be familiar with plants that pose a direct threat to their farming activities or are beneficial, and in this case Bugweed does not pose a direct threat nor is it beneficial to the majority of the participants. In fact in one of the agricultural hubs (Tshwane) this was also confirmed by an official from the Agricultural Research Council (ARC) who is responsible for monitoring IAP in that area.

Sedibeng and Ekurhuleni also had a low number of participants' who were able recognize Bugweed, and this is a problem because these areas specialize in growing peaches and it is believed that Bugweed nurtures the Natal Fruit Fly populations during the winter months in its fruits (Olckers and Hulley 1991). The fruit fly is a pest of note, which can attack peaches, and it is highly destructive. It is important for farmers to know the link between Bugweed and the fruit fly so as they may assist in controlling this plant. The threat may be indirect but it is important for farmers to know about it.

Farmers' Perceptions regarding Bugweed

The 19 participants who indicated that that they knew Bugweed were asked further questions to determine their perceptions regarding Bugweed. 21% of the 19 participants (n=4) indicated that they have uses for the plant while the majority did not have any uses. From my own personnel observations, Bugweed is not that common in agricultural areas across the various agricultural hubs, it is actually more abundant in within and close to urban areas within the Province. If by some chance it is found in the farms, it usually grows along the fence due to the birds perching along the fence and the seeds being deposited in their faeces while they roost on the fence (Figure 21).

Figure 21: Bugweed shrub spotted along the fence of a farm in Magaliesburg (taken 11/18/2016 11:30AM).

Those who indicated that they are using Bugweed, specified that it was used in their gardens as an ornamental plant in their other properties. The two participants who specified that they use Bugweed as a medicinal plant are originally from KwaZulu Natal and the other from Mpumalanga. This makes sense because both these provinces have a high infestation of Bugweed, and it is possible that the people maybe have developed certain uses for the plant and thus giving it ethnobotanical value. In KwaZulu Natal Bugweed as known as "Bonga-Bonga".

Actually 69% of the participants who indicated that they knew Bugweed perceived it to be a pest, and the reasons for that were mainly because it was an invader. While the others regard Bugweed as a pest because it is believed to "harbour snakes" and it is poisonous. However, the majority of the participants indicated that they do not believe that Bugweed has an impact on their farming activity. If these farmers had been aware of the relationship it has with the Natal Fruit fly (Figure 22), their perceptions would probably be different, especially those farmers in Ekurhuleni and Sedibeng who invested in peach farming, as well as vegetable farming. Perceptions are also linked to the level of knowledge, and given the fact that knowledge regarding Bugweed is limited amongst the participants, these results are not surprising. Hence overall, only a limited amount of information could be derived from the participants regarding their perceptions on Bugweed.

Figure 22: The Natal Fruit Fly is believed to be nurtured by Bugweed fruits during the cold winter months.

However there are other weeds that were mentioned by the participants that would require a reactive approach to help control them. Mexican poppy (*Argemone mexicana)* was listed as one of the most problematic alien invasive plant species affecting planted crops, especially amongst emerging farmers (Figure 23). Furthermore, the farmers who are active in the livestock sector indicated that they are having challenges with Bankrupt bush (*Seriphium plumosum*), this plant species usually increases are years of poor veld management, particularly overgrazing as a results of overstocking (Jordaan 2009) (Figure 24).

Figure 23: Maize farm in Mogale-City that has been infested by Argemone mexicana.

Figure 24: Bankrupt bush infestation observed in one of the properties that was visited in Randfontein. The plant was pointed out by the owner of the property as the main invasive plant problem on the property.

6. Conclusion and Recommendation

The study sought to investigate the social impact of Bugweed on the farmers in the Gauteng Province, through the interrogation of the farmer's knowledge and perceptions regarding Bugweed. In conclusion, it is evident that the farmer's level of knowledge regarding Bugweed is very limited. It is very difficult or almost impossible to assess people's perceptions towards something they are not familiar with. It can be concluded that Bugweed does not have a negative social impact on the farmers in the Province in general. On the other hand, a few farmers actually indicated that they use Bugweed as an ornamental or as a medicinal plant. However, it is important to note that in the Gauteng Province the use of Bugweed is not a common practice. Although this might not be the case in the eastern high rainfall regions of the country, since Bugweed is more prolific in those areas. The relationship that Bugweed shares with the Natal fruit fly is also not known to the farmers interviewed. Unlike other IAP, Bugweed does not contribute towards informal economies, unlike the prickly pear cactus that has been "naturalized" for its prolific tasty fruit that are sold on roadsides and also in supermarkets. The impact of Bugweed is very limited or near non-existent to these farmers.

It is however recommended that awareness campaigns be initiated to help inform farmers about Bugweed and other IAPs so as they may also play a role in controlling them. This will also enable farmers to comply with the directives of the NEMBA, which states that all land owners are obliged to actively locate and regulate the predominance and regulate the spreading of category 1b species occurring on their land.

CHAPTER 4: DETERMINING THE GEOGRAPHIC DISTRIBUTION OF BUGWEED USING REMOTE SENSING IN GAUTENG PROVINCE

Summary

The study explored the feasibility of applying remote sensing to discriminate Bugweed from coexisting plant species within the Gauteng Province, using both field spectroscopy (ASD) and satellite imagery (Landsat and Worldview-2). The use of satellite imagery was able to discriminate Bugweed from other land cover (classes) with a reasonable amount of accuracy. The study proved that the higher the resolution of the image, the higher the accuracy (Landsat= ~69% accurate and Worldview-2=~75%). The spectral reflectance signatures of Bugweed and 8 co-existing plant species that were generated using the ASD were significantly different from each other ($P<0.0001$).

The discrimination of Bugweed from other co-occurring plant species within the Gauteng Province is possible, and thus the use of remote sensing to monitor Bugweed within the Province should be encouraged. In order to improve the results, it is recommended that satellite imagery of a higher spectral resolution (Hyperspectral Imagery) must be used. To improve accuracy of the discrimination process it is important to increase the number of classes for the classification process, and each class must have a larger sample size. Increasing the number of classes will enable the inclusion of other land cover uses that may have been neglected in this study.

Keywords: Analytical Spectral Device (ASD), Co-existing plant species, infested land, Landsat-Image *Solanum mauritianum* Spectral Reflectance Signature, Worldview-2-Image, Support Vector Machine, Phenology

1. Introduction

1.1 Problem Statement

Bugweed (*Solanum mauritianum*) has the ability to outcompete indigenous plant species (Witkowski & Garner 2008 ;). It is an invasive alien plant (IAP) that serves as a serious threat to the agricultural and forestry industries within South Africa. It is believed to harbour the notorious Natal fruit fly (*Ceratitis rosa*), while also invading croplands (Devillers, Hattingh and Kriticos 2013). This results in a decrease in agricultural productivity, and a loss of ecosystem services. This is all possible due to the fact that Bugweed is highly resilient, very opportunistic and it also has allelopathic properties (Richardson *et al.* 1996). All of these characteristics enable Bugweed to have a high invasion potential, and as such the National Environmental Management Biodiversity Act: Biodiversity Act of 2003 (NEMBA), makes the control/removal of Bugweed compulsory (Atkinson *et al.* 2014). It is very important to develop efficient methods of controlling IAP such as Bugweed within Gauteng and other provinces where the weed is known to thrive, in order to protect both ecosystem services and biodiversity. According to Anderson *et al.* (1993) "there is a great need to develop accurate and spatially explicit techniques for early weed detection, mapping and monitoring at various stages of occurrence is a priority particularly in the commercial forests". The inability to detect or predict early invasions has rendered the current control methods against IAP such as Bugweed ineffective, mainly because of well-established invasions that have numerous mature plants (Cowie *et al.* 2017). Remote sensing can help with early detection of IAP and also provide site specific data (Kganyago *et al.* 2017). The use of remote sensing techniques has been gaining traction lately mainly because of their ability to provide rapid site specific information, and thus enabling the development of proactive responses rather than reactive responses.

1.2 Detection and Mapping of Alien Invasive Plants Using Remote Sensing

Remote sensing acquires data through the use of satellites which are based in space, sensors mounted on aircrafts, or the use of hand held devices that are capable of scanning objects at close range (Datt B1999; Adam and Mutanga, 2009). The sensor is responsible for capturing data regarding an object or scene without making any physical contact (Xie, Sha and Yu 2008). The Analytical Spectral Device (ASD) is used to collect data from objects that are at close range, preferably on the ground. It is a handheld device that can be easily carried around due to its size (Figure 26). The device can be used to discriminate between various plant species based on the manner in which they respond to the electromagnetic radiation.

The electromagnetic radiation reflected off each plant species is based on the plant's unique biochemical and biophysical properties (Jensen and Lulla 1987;Cho *et al.* 2012). These properties are responsible for plant species being able to absorb certain colours of the electromagnetic spectra while reflecting others and, thus giving a plant its spectral signature (Asner and Martin 2009).

1.3 Spectral Reflectance Signature

The spectral reflectance signature of a plant can be measured from both the canopy and leaf levels. Canopies consist of a dense arrangement of leaves and the leaves of different plant species have different reflectance signatures. At leaf level the differences are based on the internal leaf structure, leaf surface features such as hairs or waxes and physiological disturbances (Grant 1987). However, the primary factors that influence spectral reflectance are the leaf surface and the geometry of the internal structures. The physiology of the plant also plays a role in determining its own unique spectral reflectance signature

Spectral reflectance signatures can be used to identify different plant species, and a study by Durgante *et al.* (2013) showed that spectral signatures can be used to discriminate between closely related plant species. Thus spectral reflectance signatures can also be used in Taxonomy to classify plant species. Plant species identification as an alternative to other existing methods. The spectral reflectance signatures can be superimposed onto a satellite image to discriminate between plant species.

1.4 Satellite Images

Remote sensing can be used to provide data that is vital for visual interpretation such as satellite imagery. The satellite images that are generated with the different sensors have different resolutions. Low spectral resolution images derived from sensors that are located in space such as, Quickbird, Landsat and SPOT, usually have limited remote sensing capabilities (Cho *et al.* 2012). The limited availability of high spectral resolution sensors (Hyperspectral) has been a limiting factor to the detection of plant species (Huang and Asner 2009). There are several studies that have been conducted that have proven the efficacy of hyperspectral data in detecting and discriminating problematic IAP along with their co-existing plant species i.e. *Eichhornia crassipes* (Water hyacinth) (Everitt 2010).

However, the application of remote sensing technologies to identify and map invasive species in commercial forests has been limited thus far (Atkinson *et al* 2014; Peerbhay *et al* 2016). Thorp and Tian (2004) showed that detection of weeds using remote sensing technologies was limited. However, the technology is rapidly improving with higher resolution data being generated, and the potential for expanding the capabilities of remote sensing has been improving with time.

The most commonly utilised remote sensing approach for detecting weeds is high-resolution spatial imagery such as aerial photography (Huang and Asner 2009). According to Everitt *et al.* (1995) studies have utilised aerial photography to monitor *Euphorbia esula* and *Tamarix chinesis*. Aerial photography is limited to weeds that have a unique growth pattern, and this shortfall can be corrected by using multispectral remote sensing (Huang and Asner 2009). Colour Aerial photos are only RGB (Red, Green & Blue), and the bands cannot be manipulated. The older aerial photos were in black and white, they relied heavily upon the use of texture, context and shape to interpret them.

Multispectral remote sensing is an upgrade of the aerial photography method, because it has the ability to record data in a wider range of wavelengths, across the electromagnetic spectrum (Mundt *et al.* 2005). Multispectral remote sensing has been previously used to map *Melaleuca quinquenervia* (Paper bark), with aid of IKONOS, a commercial earth observation satellite capable of producing a 3.2 m multispectral and Near Infrared image.

Hyperspectral remote sensing is even more advanced when compared to multispectral remote sensing, as it has a better resolution (Glenn *et al.* 2005). Hyperspectral remote sensing has the ability to capture data from hundreds of narrow wavebands, and thus providing a full spectral curve for each pixel (Peerbhay *et al.* 2016). A pixel refers to the smallest unit of information in an image. It has the ability to distinguish native from non-native plant species, as a result of its ability to generate detailed spectral profiles (Huang and Asner 2009). Hyperspectral remote sensing consists of a number of satellite sensors that are capable of collecting data with various resolutions.

The use of hyperspectral images may enable us to delineate the spatial extent and to ascertain the severity or intensity of the invasion of Bugweed within the Gauteng province. Given the fact that Bugweed tends to grow in commercial forest plantations, Hyperspectral images are ideal for the detection of Bugweed, because they allow for the discrimination of subtler differences between individual species (Atkinson, Ismail and Robertson 2014). Hyperspectral images were successfully used to monitor and map Bugweed in a commercial forest in KwaZulu Natal Province. The information was used to improve the management of Bugweed within the forest and thus reducing the loss of habitat (Atkinson, Ismail and Robertson 2014). A similar study was also conducted in KwaZulu Natal, and it was also able to produce results that showed that Bugweed could be detected and mapped with reasonable accuracy in a commercial forest environment (Peerbhay *et al.* 2016).

1.5 Case Studies Documenting The Successful Use Of Remote Sensing In Monitoring And Mapping Both Indigenous Plant Species And Invasive Alien Plant Species

The effective management of water and terrestrial resources is based on early detection of invasions. Early detection enables rapid response to invasions, and thus increasing the chances of eradication. Remote sensing is currently the best tool that can be used to rapidly detect invasions. Remote sensing is specifically ideal for both detection and identification. In order to have an effective invasive alien plant management plant programme, it is important to have up-to-date spatial information about the magnitude and the quality of vegetation cover in order to initiate vegetation protection and restoration programme (He *et al.*, 2005).

Below are cases the illustrate the role of remote in the control of IAPs, and the general identification of vegetation in both terrestrial and wetland resources;

Wetland case studies

Wetland vegetation plays a crucial role in maintaining the natural integrity of ecological functions (Adam, Mutanga and Regege 2009). The presence of wetland IAPs may disrupt this ecological integrity, resulting in a loss of ecosystem services. A study was conducted in the United States of America in California's Sacramento-San Joaquin River Delta by Hestir *et al*., (2008). The study successfully mapped the following IAPs; *Lepidium latifolium* (Perennial pepperweed), and *Eichhornia crassipes* (water hyacinth) distribution in an aquatic setup. During the experiment it was also noted that the phenological stages of the plant species influenced the rates of detection. Water hyacinth was mapped with modest accuracies, and Pernnial pepperweed was mapped with high accuracies. Perennial pepperweed and water hyacinth both exhibited significant spectral variation related to plant phenology. Such variation must be accounted for in order to optimally map these species, and this was done for the water hyacinth case study (Hestir *et al*., 2008).

The use of multi-temporal satellite imagery, field spectral data (ASD)and LiDAR was employed in mapping and classifying the most common plant communities in the Connecticut River by Gilmore *et al*., 2008. The study used Visible to near-infrared (VNIR) reflectance spectra to assess the phenological differences of the dominant marsh plant species i.e *Phragmites australis* and *Typha* spp. *Phragmites* was best distinguished from other species by its high NIR response late in the growing season. *Typha* spp. had a high red/green ratio and *S. patens* had a unique green/blue ratio relative to other species throughout the bulk of the growing season (Gilmore *et al.* 2008).

The study produced a remarkable 97% accuracy during the classification process. Overall maximum fuzzy accuracy for the classification was 97% for *Phragmites*, 63% for *Typha* spp. and 80% for *S. patens* meadows and improved to 97%, 76%, and 92%, respectively, using a fuzzy acceptable match measure. This study demonstrated the importance of the timing of image acquisition for the identification of targeted plant species in a heterogeneous marsh (Gilmore *et al.* 2008).

Terrestrial Cases

A study conducted in Southwest Sydney, Australia determined whether satellite imagery was an effective tool for mapping and examining the distribution of the invasive species *Olea europaea* L. ssp. *cuspidata* at a regional landscape scale. The study focused on a total area of 1907 ha of dense African Olive infestation was identified, with an omission error of 7.5% and a commission error of 5.4%. African Olive was found to occur on the steepest slopes (mean slope 14.3°) of the vegetation classes examined, with aspect analysis identifying a high prevalence on south- and southwest-facing slopes. The analysis also quantified the level of African Olive infestation in endangered ecological communities, with Western Sydney Dry Rainforest (25% affected) and Moist Shale Woodland (28% affected) identified as most vulnerable to African Olive invasion. The distribution of African Olive can be efficiently mapped at a landscape scale (Cuneo, Jacobson and Leishman 2009).

In South Africa a study examined the efficacy of mapping savanna tree species using the Carnegie Airborne Observatory (CAO) hyperspectral data, WorldView-2 imagery and Quickbird multispectral spectral data. The data was then used to map seven of the most common savanna tree species in the Sabi Sands Reserve and communal lands adjacent to Kruger National Park, South Africa. Seven savanna tree species were mapped with an overall accuracy of 79% WorldView-2 is adequate for mapping savanna tree species with big crowns (≥ 6 m).

2. Purpose Of Study

Aim

The aim of this study was to determine whether it is possible to use remote sensing to map the geographical distribution of Bugweed within Gauteng Province.

Objectives

a) To determine the spectral signature of Bugweed and the predominant coexisting plant species within the province.
b) To discriminate between Bugweed and these co-existing plant species using spectral reflectance signatures.
c) To discriminate Bugweed from non-Bugweed plant species and other landcover on two different types of satellite imagery covering of Johannesburg.

3. Methods

3.1 Study Site

The study was conducted in the City of Johannesburg, Gauteng Province. Two sites that are highly infested with Bugweed were selected, a vacant piece of land near the Chinese shops at Bruma (26°11’17.31”S 28°01’14.88”E) and another site in Braamfontein within the Egoli Gas property (26°10’38.37”S 28°01’14.88”E). The “Egoli Gas” site has a perimeter of approximately 2 km and an area covering 0.23 km^2. While Bruma has a perimeter of about 0.36 km and 7,015 m^2 respectively. Both sites are highly disturbed by anthropogenic activities, and are infested with a number of invasive alien plant species. They are both within Johannesburg approximately 5 km apart from each other, and thus share the same climatic conditions, rainfall patterns and geology (refer to Chapter 2 for more information regarding the study area).

3.2 Data collection

3.2.1 Leaf level reflectance measurements

The sites that were infested with Bugweed were located, and also surveyed for the presence of other coexisting plant species before collecting samples of these plant species for spectral reflectance determination. The coexisting plant species were determined through observation, while driving across the province searching for Bugweed plant samples. A minimum of 25 fresh leaf samples per tree for each plant species (Bugweed and Co-existing species) were detached from their petioles, and then placed inside labelled zip lock bags. Each bag contaminated 25 leaf samples from the same tree, collected from different branches. The ziplock bags were transported to the University of the Witwatersrand, Johannesburg and stored in a cold room (temperature set at 4 ^{o}C) in the Biology Building (School of APES) to keep them well preserved.

The leaf samples within the ziplock bags were then taken to the University of Johannesburg (UJ) (Geography Department) within 48 hours of being stored in the cold room. Upon arrival at UJ, the plant samples were scanned indoors in the laboratory with the aid of an internal light source on the leaf clipper, instead of sunlight serving as the source of light/energy. The spectral reflectance signatures of the Bugweed leaves along with eight of the most common coexisting plant species were determined using an ASD machine (Spectral Evolution SR-3501 spectrodiameter) (Figure 26). The Spectral Evolution SR-3501 spectrodiameter (Spectral Evolution, Inc. ©2014) has a spectral range of 280-2500nm (Figure 25). The device can provide a uniform visible spectrum (400 to 700nm), near infrared (750-950nm) and shortwave infrared (950-2500nm) across the solar irradiance spectrum (Spectral Evolution, Inc. ©2014). This Analytical Spectral Device (ASD) consisted of a portable Personal Digital Assistant (PDA) (Handheld Computer) and optic fibre cable.

Figure 25: Spectral Evolution SR-3501 spectrodiameter machine with leaf clip apparatus for leaf level Spectral signature determination.

A PDA Is a small portable computer that is able to connect to the ASD machine via Bluetooth or Wi-Fi, it is was used to indicate the curves of plant species that were scanned. The leaves were scanned at least 3 times and the average was used for further analyses (Table 3). To improve the accuracy, the device was constantly being calibrated while scanning the plants. For example, it was recalibrated whenever a different species was scanned.

Table 3: Summary of the number of plant species collected and scanned

PLANT SPECIES	***NO. OF SAMPLES***	***NO. OF REPLICATES***	***NO. OF SPECTRAL OBSERVATIONS (N)***
S. mauritianum_Bruma_site	25	3	75
S. mauritianum_Egoli_site	25	3	75
SPECIES 1	25	3	75
SPECIES 2	25	3	75
SPECIES 3	25	3	75
SPECIES 4	25	3	75
SPECIES 5	25	3	75
SPECIES 6	25	3	75
SPECIES 7	25	3	75
SPECIES 8	25	3	75
TOTAL	250	30	750

3.2.2 *Image Acquisition and Classification*

Two satellite images covering a section of the City of Johannesburg in the Gauteng Province were acquired. A worldview-2 and a Landsat images were utilized for the project. The Landsat was acquired from the USGS website (https://landsatlook.usgs.gov/viewer.html.). The Landsat image was taken on the 19 October 2016 via a satellite sensor. The USGS operates the Landsat satellites, and serves as one of the major world sources of remote sensing data that can be used for various application such as monitoring of global agricultural, vegetation, and assessing impacts of natural disasters. Like other satellite sensors, Landsat is able to measure reflected light in the visible and infrared wavelength. The information that is acquired usually provides detailed information covering a large spatial area, and the data can be interpreted to assess cases of ecological infestation by IAP or degradation.

A worldview-2 imagery was acquired using a satellite sensor. DigitalGlobe's WorldView-2 satellite sensor, launched October 8, 2009, provides 0.46 m panchromatic (B&W) mono and stereo satellite image data. The WorldView-2 sensor provides a high resolution panchromatic band and eight (8) multispectral bands; four (4) standard colours (red, green, blue, and near-infrared 1) and four (4) new bands (coastal, yellow, red edge, and near-infrared 2), full-colour images for enhanced spectral analysis, mapping and monitoring applications, land-use planning, disaster relief, exploration, defence and intelligence, and visualization and simulation environments. With its improved agility, WorldView-2 is able to act like a paintbrush, sweeping back and forth to collect very large areas of multispectral imagery in a single pass.

Both images were then atmospherically corrected to reduce the impacts of cloud cover using ENVI. The GPS coordinates of Bugweed trees that have a canopy that is above 2 m in diameter were noted using a Handheld Garmin GPS device with ± 3 m accuracy. The accuracy of those points was improved on Google Earth by creating points on the exact location of the tree as illustrated in Figure 27. This procedure was also used to increase the number of points that were available. These GPS coordinates were noted for the purpose of classifying the Satellite image on ENVI. The summary of the procedure that was followed is illustrated in Figure 26.

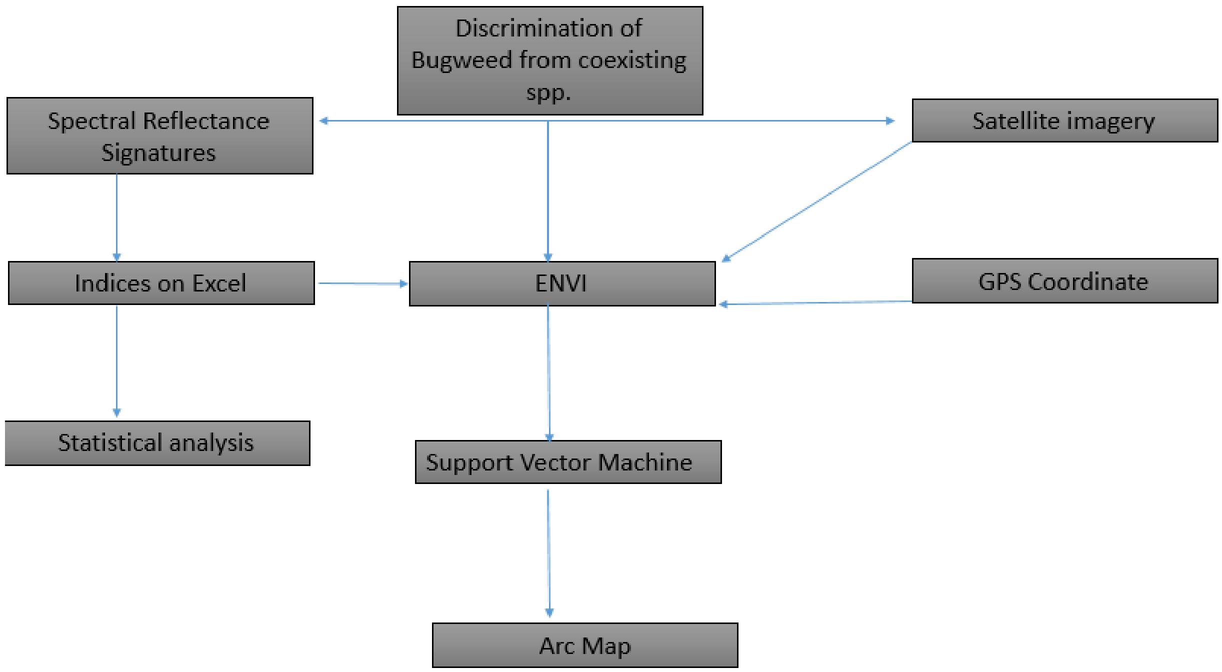

Figure 26: Summary of the Methodology that was used for data collection, and the classification process for the discrimination of the plant species.

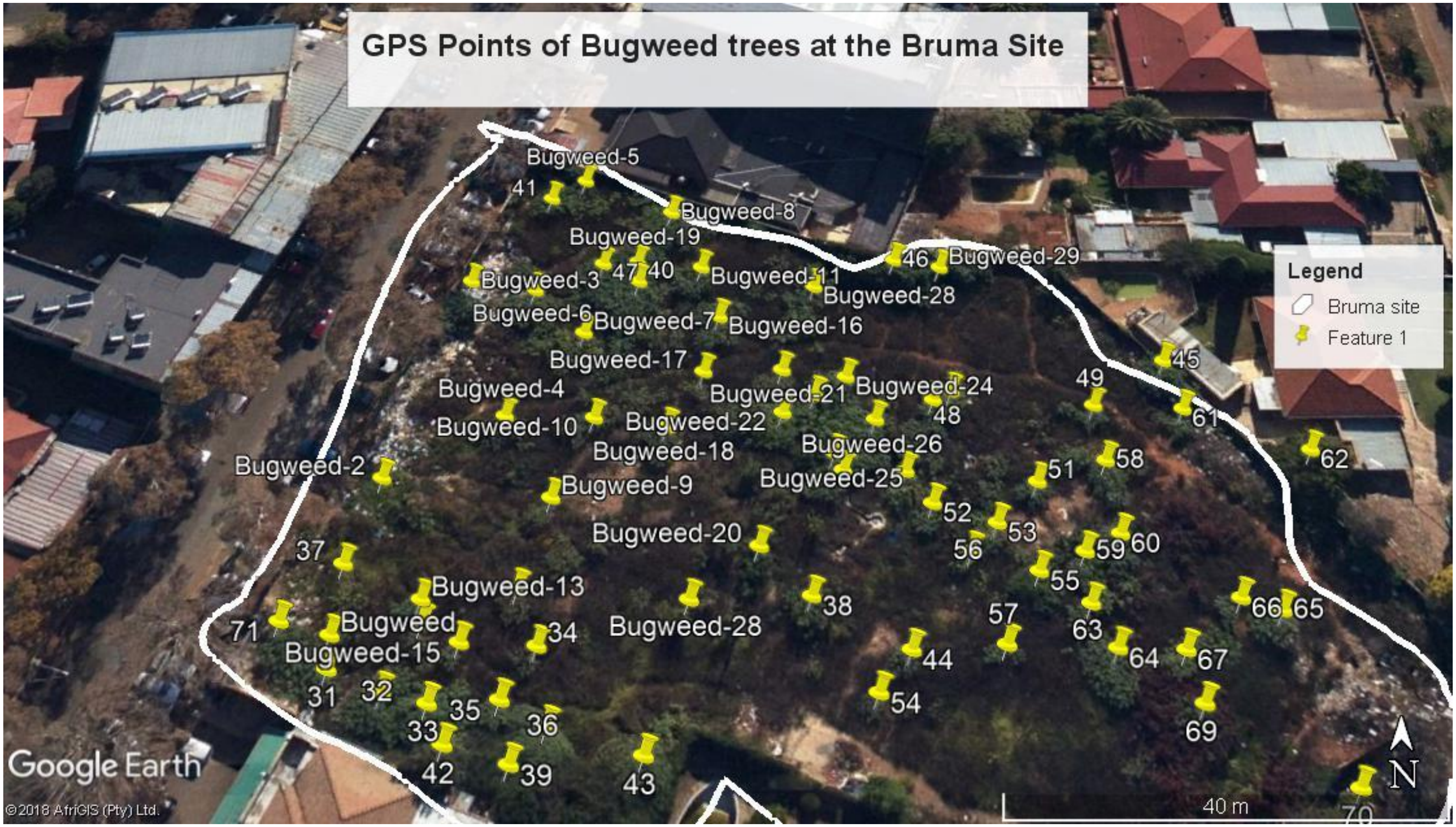

Figure 27: A google earth image of a section/portion of the areas that were sampled in City of Johannesburg, displaying the positions of some of the Bugweed trees that were used during the classification of the satellite image

3.3 Pre-processing and Analysis

3.3.1 Bugweed Reference Data

(i) ASD-Field Spectroscopy

The spectral signatures of Bugweed and Coexisting plant species were arranged in an excel spreadsheet. The spectral signatures of the plants were averaged and plotted graphically to observe the differences in how to they react to light (Figure 28-29).

(ii) Satellite imagery

The second method used GPS coordinates of Bugweed plants to create a classification system which was then used to create an algorithm for detecting or discriminating Bugweed on the satellite images. A purposive sampling approach was used for the identification of Bugweed within the City of Johannesburg using high resolution colour (RGB) imagery (Atkinson, Ismail and Robertson 2014). The occurrence of Bugweed was based on photographic interpretation of the satellite imagery, by classifying the image. The classification process was *68.19%* accurate in distinguishing Bugweed from non-Bugweed plant species and the other features.

A total of 104 (*n*) Bugweed GPS coordinates were collected along with 60 (*n*) positions of the predominant coexisting plant species, 60 (*n)* Infrastructure/building structures and lastly 60 (*n)* roads. The points were extracted on ARC-MAP and fed into ENVI for classification. A portion of the data (30%) was used to train the model in ENVI and the remaining 70% was used to test the model.

3.3.2 ASD-Leaf level measurements-Pre-processing

The ASD had a 350-2500nm spectral range. In order to reduce errors these data were cleaned, and the following "noisy bands" were removed: 350-399 nm; 1350-1465 nm, 1790-1960 nm, and 2350-2500 nm (Figure 28 and 30) (Thenkabbail *et al.* 2004).

3.4 Data Analysis:

3.4.1 Random Forest (RF) Package

Random Forest can also be viewed as a non-parametric statistical method which classifies the data by splitting it up in a sequential approach (Breiman, 1984). The spectral signatures were split into five regions namely green (450-549 nm), blue (350-449 nm) red-edge (650-749 nm), infrared (1300-2500 nm) and near infrared (750-1299 nm). To determine the confidence level at 95%, a parametric test, ANOVA was undertaken. This method measures the variables of importance to create a ranking classifier decision tree and chooses the attributes (Lin *et al*. 2011). This classification method is excellent at avoiding the selection of new features that will result in the duplication of the information.

3.4.2 First derivative (Leaf Level Spectral Signatures)

The spectral data were magnified through the use of the first derivative indices, in order to further identify the spectral differences between Bugweed and its coexisting plant species (Laba *et al.* 2005). This was achieved by focusing on the absorption features of the red edge region, and then enhancing it to discriminate between the different species. The difference arise from the chemical composition of the leaf structure, which influences how it absorbs and reflects light (Kumar and Skidmore, 1998). The red edge position (REP) was used to measure the first order derivative with an interval of 670 to 800 nm. The Red Edge is the area with the highest spectral reflectance where chlorophyll absorbs light mostly in the red band.

3.4.3 Support Vector Machines (Classification of Satellite Imagery)

Support Vector Machine (SVM) is a supervised learning technique that is, used to classify a satellite imagery. The technique is based on a statistical theory (Vapnik, 1998). It classifies an image by identifying the optimal separation surfaces between the classes (Bugweed, Buildings, Roads and Co-existing plant species) by finding the most representative training samples, or support vectors on either side of the hyperplane (Mercier and Lenon, 2003). The optimal hyperplane is therefore the one that separates the classes with the maximum distance between the separating margin and the data points (support vectors) on the plane with least generalization error and is known as the optimum separating hyperplane (Huang *et al.* 2002).

4. Results

4.1 Leaf level measurements-Pre-processing

The spectral signatures were loaded on excel for pre-processing. The mean spectral signatures of the plant species were determined on Microsoft Excel, and compared graphically). The two Bugweed samples that were collected from different sites were also compared graphically and statistically (Figure 28). A t-test was performed to test for differences between the spectral signatures of the two Bugweed samples. The mean spectral signatures were found to be not significantly different (*P=0.6004, DF=198, t=0.5247*). The graphical representation of Bugweed and the most coexisting plant species is illustrated in figure 29.

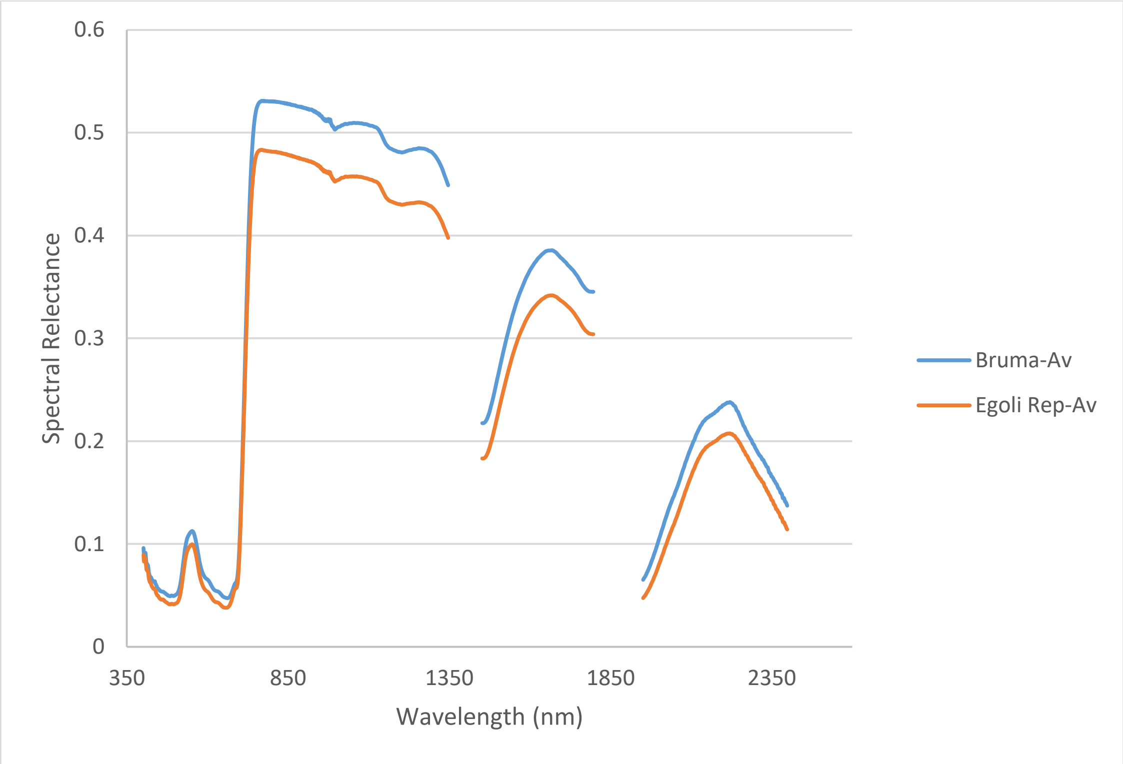

Figure 28: Spectral reflectance (Pre-processed) curves of the two Bugweed samples collected from both Bruma and Egoli Gas property in the City of Johannesburg.

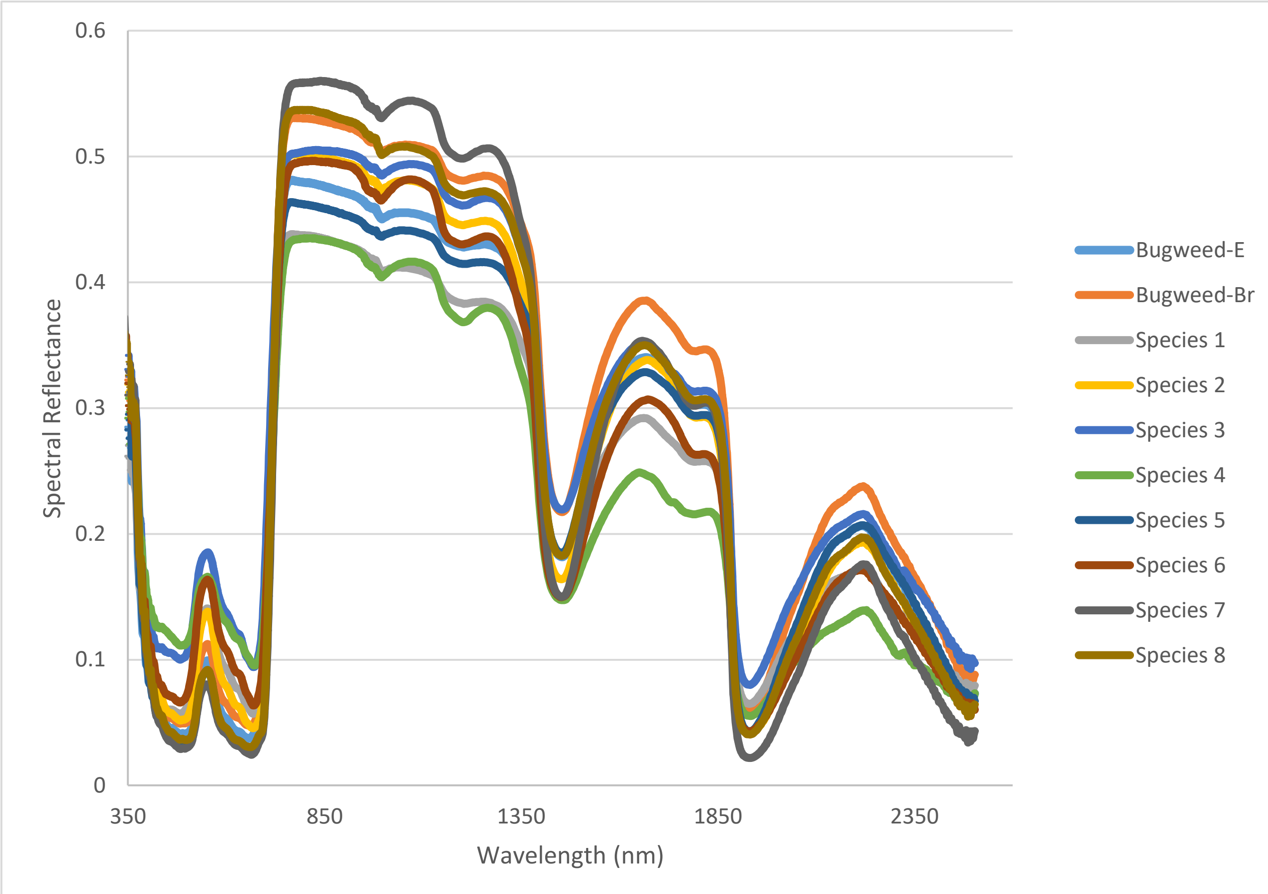

Figure 29: The spectral signatures of Bugweed and the most common co-existing plant species from the City of Johannesburg prior to being Pre-processed.

The mean spectral signatures of all the plant species were also compared statistically using the (non-parametric) Friedman's test, and there were significant differences between the differen.t plant species ($F=19.06$, $P<0.0001$, and $R^2=0.9272$). The different. Plant species can be disguised from each using spectral reflectance signatures (Figure 30 & 31).

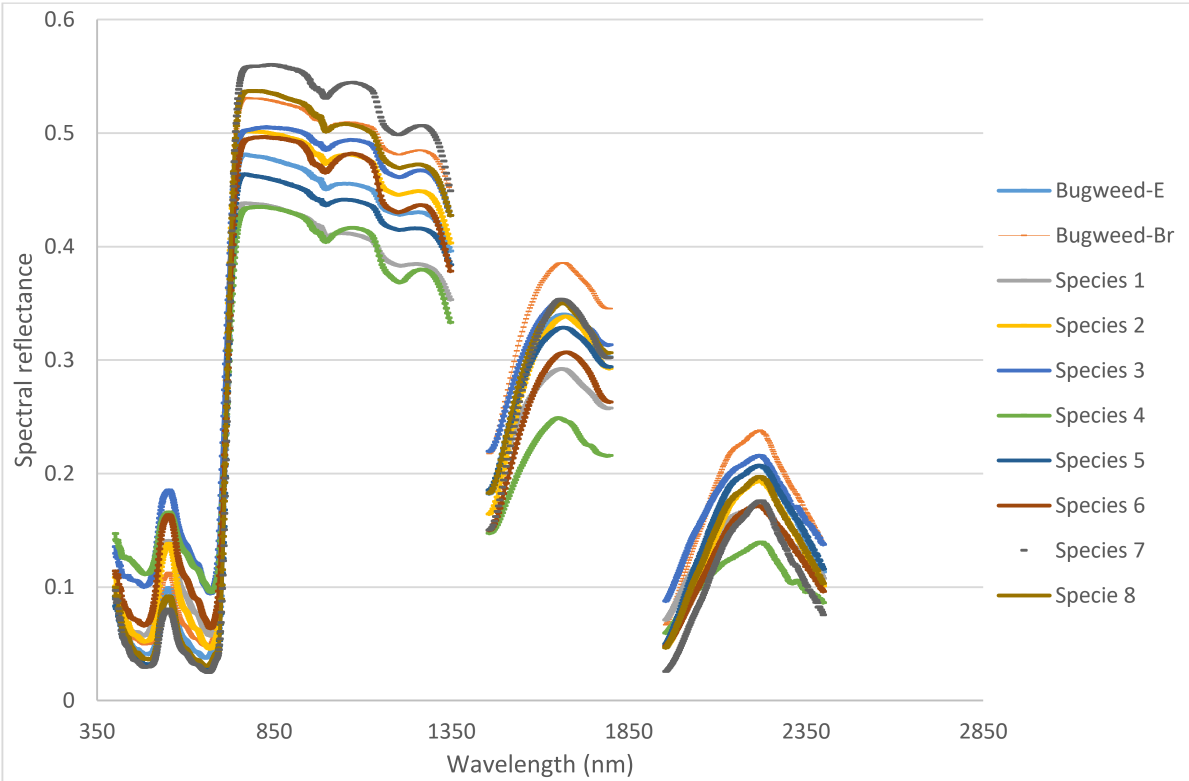

Figure 30: Mean spectral signatures for Solanum mauritianum *and the predominant coexisting plant species without the 'noisy spectral bands' ((350-399 nm; 1350-1465 nm, 1790-1960 nm, and 2350-2500 nm). The mean spectral reflectance signatures of the samples were significantly different from each other (P<0, 0001)*

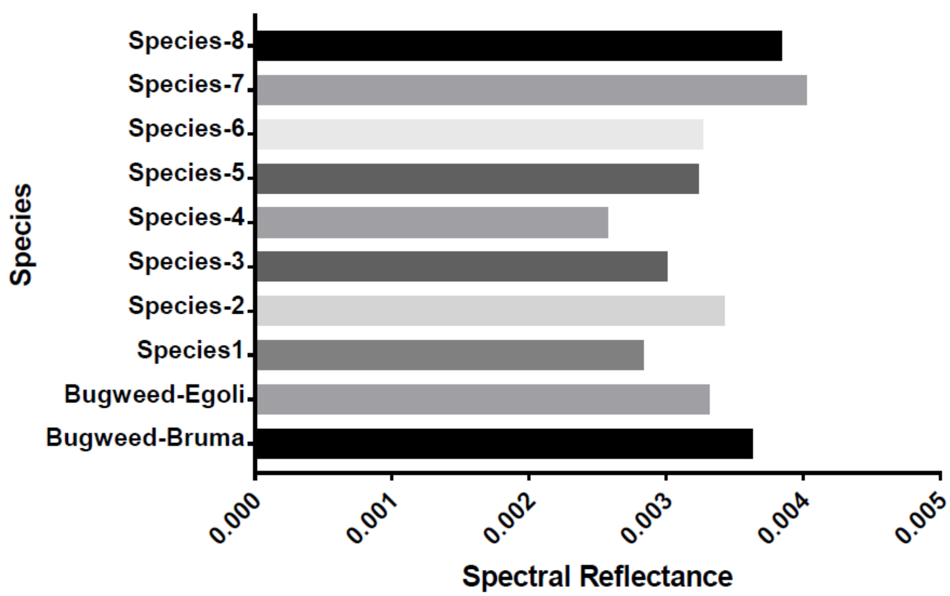

Figure 31: Comparison of the mean values of the spectral reflectance signatures of Bugweed and the non-Bugweed plant species (P<0.0001)

4.2 First order derivative

The Red Edge of the spectral signatures was analysed further to test whether the plant species can be distinguished from each other (Figure 32). The red edge is typical used to assess the health of the plants.

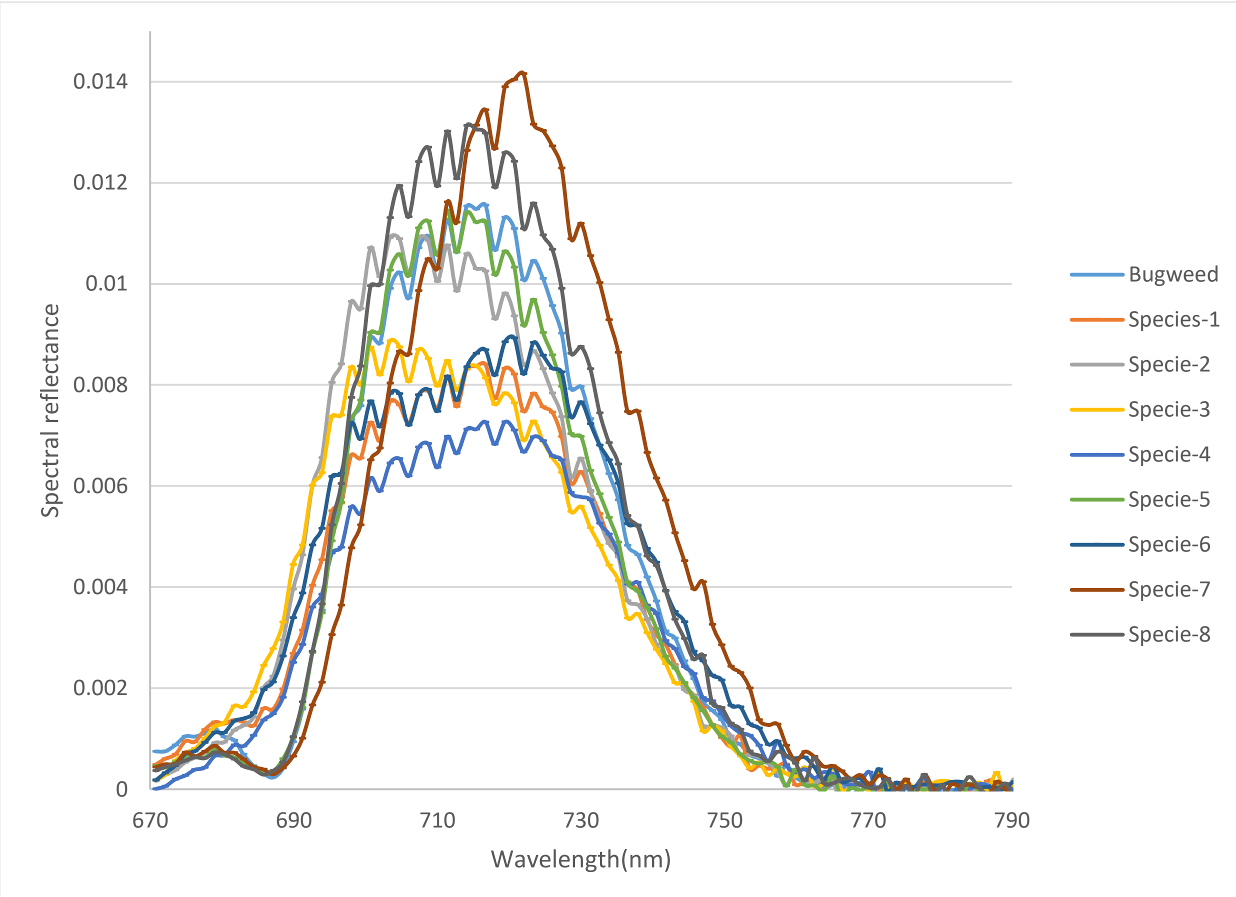

Figure 32: Leaf level comparison for the first order derivative average measured at a range of 670-800 nm

4.3 Support Vector Machine

The two satellite images were classified using Support Vector Machine. The classification check whether it was possible to detect Bugweed from the co-existing plant species, infrastructure (build-up) and roads (Figure 33). The classification process had an accuracy of 68%. The confusion matrix revealed that out of the 261 GPS coordinate representing the individual classes, 178 were accurately classified. An estimated 83 Points were not classified accurately. The classification consisted of four classes namely; Bugweed, Non-Bugweed Plant species, Roads and Build-up. Approximately 59.68% of the GPS coordinates representing "Build-up" were classified accurately, and this represented the lowest accuracy percentage. Bugweed was 79.49% classified accurately (Table 4). A similar classification was conducted on a Worldview-2 image of the same area, and the accuracy of the classification improved from ~69% to ~75% (Table 5). The main reason behind using two satellite images with different spectral resolution was to compare their effectiveness by focussing on their accuracies during the classification process. The classification process used the same quality and quantity of variables for both satellite images i.e. same number of classes hence the comparison was a good indication that a satellite image with a higher resolution will always produce good results when compared to a lower resolution satellite image under the same circumstances.

Table 4: The accuracy of the classification process for the Landsat image

Confusion Matrix					
Overall Accuracy= (178/261) 68.1992%					
Kappa Coefficient= 0.5717					
	Ground Truth (Pixels)				
Class	**Buildup**	**Roads**	**Non_BugweedEVF**	**Layer:d**	**Total**
Unclassified	0	0	0	0	0
Buildup	37	8	4	5	54
Roads	16	42	5	4	67
Non_Bugweed	0	1	37	7	45
EVF:Layer:d	9	10	14	62	95
Total	62	61	60	78	261
	Ground Truth (Percent)				
Class	**Buildup**	**Roads**	**Non_BugweedEVF**	**Layer:d**	**Total**
Unclassified	0.00	0.00	0.00	0.00	0.00
Buildup	59.68	13.11	6.67	6.41	20.69

Roads	25.81	68.85	8.33	5.13	25.67
Non_Bugweed	0.00	1.64	61.67	8.97	17.24
EVF:Layer:d	14.52	16.39	23.33	79.49	36.40
Total	100.00	100.00	100.00	100.00	100.00

Table 5: Accuracy assessment of the classification of worldview-2 image

Confusion Matrix and Statistics				
	Reference			
Prediction	**Bugweed**	**Buildup**	**Non_Bugweed Plant_spp**	**Roads**
Bugweed	18	3	4	0
Buildup	1	7	0	1
Non_Bugweed_Plant_Spp	1	2	8	0
Roads	2	1	0	11
Overall Statistics				
Accuracy :07458 95%CI :(0.6156, 0.8502) No information Rate : 0.3729 P-value [ACC>NIR] : 6.369e-09 Kappa :0.648 Mcnemar’s Test P-value :NA				

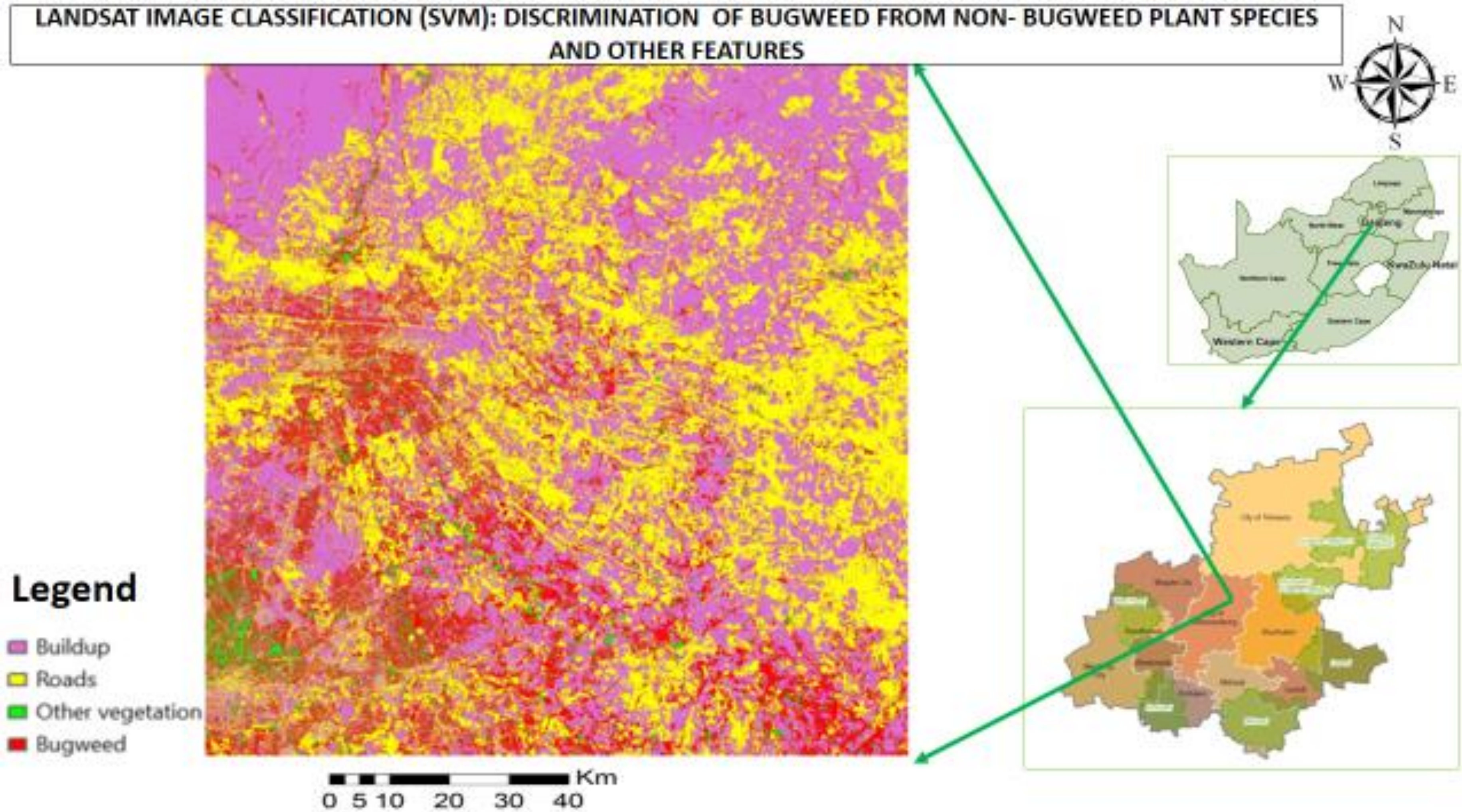

Figure 33: Classification results of a Landsat image of a section of Johannesburg, the classification discriminates Bugweed from non Bugweed plant species and other land cover features. The classification is 69% accurate

5. Discussion

The three important findings are (a) Spectral Reflectance Signatures of Bugweed samples collected from two different sites are not significantly different from each other, even though the sites have varying amounts of water, sunlight, exposure and level of herbivory (insects); (b) The spectral signatures of Bugweed and the coexisting plant species were significantly different from each other; and (c) Landsat Images and Worldview-2 satellite imagery can be used to discriminate Bugweed from other land cover uses and other plant species.

Leaf level measurements

The two Bugweed samples from both the Bruma and Egoli sites were not significantly different from each other, even though they are growing under different conditions. The leaf samples from the two sites (Bruma and Egoli sites) had slight differences in their colours, the leaves from the Egoli site were greener than the leaves from Bruma. The Egoli site is dominated by large eucalyptus trees, which creates shady conditions. The site also has a lot of moisture coming from a pipe, providing water to area invaded by Bugweed.

The Bruma site is located on an abandoned property, which is used as a dumping site. The site is dryer than Egoli, and the plants are exposed to direct sunlight, not shade. The difference in the amount of water on site, sunlight and maybe the exposure to herbivorous insect's results in different physiological responses of the plant, yet nonetheless did not have much of an impact on the Spectral reflectance signatures of both Bugweed samples. This is important mainly because it implies that a plant species are able to maintain their spectral signatures regardless of subtle differences in their immediate environments/habitats.

This means that the spectral signature of Bugweed is consistent throughout, and thus Bugweed samples collected from part can be used to derive spectral signatures that can be used to identify Bugweed in another area. Equally the subtle differences in spectral signatures can be used to compare overall health of the same plant species that grow in different places, by focusing on water content, chlorophyll and Nitrogen content (Kokaly 2001)

Bugweed and the 8 coexisting plant species can be discriminated using remote sensing at leaf level. Some of the species have spectral reflectance signatures that resemble each other (see Figures 30 & 32), however the statistical tests revealed that they are distinct from each other ($P<0.0001$). The spectral reflectance signatures are highly influenced by components such as chlorophyll content and other molecules within the leaf which constitute the biochemical components of the plant (Blackburn, 2007). Species 7 had the highest spectral reflectance peak at 850 nm, and the lowest spectral reflectance peak was seen on Species 4. As leaves and plant species vary in the concentration of their biochemical constitutes, the reflectance spectra vary as well. It is expected that variations in spectral signatures (shape and the depth of the shape) should be found across environmental gradients or taxonomic lines (Kokaly *et al.*, 2009; Ustin *et al.*, 2009)

This information is the right step towards early detection and mapping of the extent of rapidly spreading invasive populations such as Bugweed, and will be critical for informing management priorities, including eradication efforts (Rochini, Neteler and Nagendra 2011).

First Order Derivative Curve

The red edge refers to the region between 670-800 nm on the spectral reflectance curve, it is characterized a by rapid change in reflectance of vegetation in the near infrared rage of the electromagnetic spectrum (Ceccalo *et al.*2001). This region can be used to extract a lot of information regarding the plant i.e. health of the plant. The red edge closely examines the chlorophyll content of the plant species that are being examined. The average spectral measurements of the red edge are visually different (Figure 33). The data were then used to create the 1st order derivative (vegetative index) to help enhance the discrimination between the individual spectral signatures of the plants. The

1st order derivative (FD) averaged reluctance shows a clearly distinctive difference between the species spectral signatures.

Support Vector Machine

A Landsat image was classified in ENVI, the classification process had an accuracy of 68.199% (refer to Table 3). The classification system consisted of 4 different factors including Bugweed, namely; Roads, Build-up (infrastructure) and other coexisting plant species/non-Bugweed plants. The data was split into two groups, one for training the algorithm and the other group used for testing the algorithm. The classification had a Kappa coefficient 0.5717.

The accuracy can be improved by either using an image with a higher resolution or increasing the classification factors. A larger sample size provides the algorithm with enough data to train it and afterwards test it. An image with a higher resolution is ideal in stances where the spatial extent of invasion is small relative to imagery with lower spatial resolution (e.g. Landsat), and thus higher resolution imagery increases the odds of detecting the species of interest from the image (Dubula, Tesfamichel and Rampedi 2016).

6. Conclusion and Recommendations

The study sought to prove that it is possible to map the geographic distribution of Bugweed in the Gauteng Province. The discrimination of Bugweed from coexisting plant species is possible using a field spectroscopy (ASD). It is also possible to discriminate Bugweed from non-Bugweed species, Roads and Infrastructure using a Landsat satellite image and a Worldview-2 image with reasonable accuracy. Furthermore, the spectral signature can be analysed to reveal the differences between the species using models such as Random Forest and Resampling. Remote sensing can definitely enable us to monitor and map Bugweed within the Gauteng Province. It can also enable early detection of new Bugweed infestations.

In order to improve accuracy when monitoring and detecting Bugweed, I recommend the use of satellite images taken with a sensor that has a higher resolution imagery. Hyperspectral sensors such as Hyperion, Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), Compact Airborne Spectrographic Imager (CASI), Airborne Imaging Spectroradiometer for Applications (AISA) and HyMap (from HyVista, Castle Hill, Australia). All of these sensors have been used to detect invaders at the species level (Clark *et al.*, 2005; Andrew & Ustin, 2006, 2008, 2009; Bradley 2014) The image must be classified with more classes and each class must have a larger sample size. This will help improve accuracy when mapping the distribution of Bugweed and other IAP.

CHAPTER 5: GENERAL CONCLUSION AND RECOMMENDATIONS

The main aim of the study was to initiate the development of an integrative approach towards controlling and understanding Bugweed. The rich body of knowledge regarding Bugweed is mainly based on the ecological and economic impacts of Bugweed. The study sought to check whether Bugweed had a social impact on the farmers in the Gauteng Province, in an attempt to expand on the current body of knowledge regarding Bugweed. The social aspect of the study was aimed at uncovering unknown information regarding the impacts of Bugweed, both negative and potentially positive impacts. Some participants shed some new knowledge on the potential use of Bugweed as a medicinal plant, although this notion needs further investigation because it is not common practice within the Gauteng Province. It can be concluded that Bugweed does not have a significant social impact on the majority of the participants in terms of affecting their farming operations, even though it is believed to nurture the Natal fruit fly during the winter months. Furthermore, Bugweed is a poisonous plant species (. Fruit and vegetable farmers do have a serious problem with the Natal fruit fly, and thus raising awareness about Bugweed should enable farmers to indirectly control fruit flies in winter by removing the Bugweed tree/ shrubs on their farms. There is a great need to educate farmers about IAPs such as Bugweed, so that they may take part in controlling the weed. This education must include the latest and most efficient control measures i.e. cutting the tree as low as possible and then applying herbicide (see Witkowski & Garner 2008).

The other aspect of the study was to investigate the potential application of remote sensing on the mapping and monitoring of Bugweed in the province. The study revealed that it is indeed possible to discriminate Bugweed from other coexisting plant species using both field spectroscopy and satellite imagery. The ability to discriminate means it can be mapped and monitored. The ability to monitor and map, will definitely aid in developing rapid responses that are aimed at tackling the infestation issues. This information can help the authorities (GDARD) in the decision making process, when designing, planning and carrying out IAP control Management Programmes. This knowledge may enable the development of proactive control measures, provided that Bugweed can be detected from all its growth stages. Increasing this knowledge base may also help develop models that can predict infestations while they are still only at a small scale, hence saving on costs over the long term. This will save the country a lot of money.

I recommend that the use of free satellite imagery such as Landsat be improved in order to increase the accuracy during the classification process. This will also reduce the cost of monitoring Bugweed using remote sensing, since satellite imagery with a higher spatial resolution can be very expensive.

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APPENDICES

Appendix A: Questionnaire

Impact of Bugweed on Gauteng farmers

Personal information
Date:
Name:
Gender:
Race:
Age:
Farm size:
Do you own the farm or you renting it?
How many years have you been on the farm?
What do you farm?
Are you part of a farmers organization, if so which one?

1. Do you know this plant?
2. Does this plant grow on your farm?
3. What do you call it?
4. Do you have any uses for this plant?
5. Do you see it as a pest? If so why?

6. Describe the conditions where this plant grows the most.
7. Do you know how it spreads? If so how?
8. Does it disturb the growth of your crops/trees? If so, how?
9. Have you tried to get rid of it?
10. If so, how?
11. How many times have you tried to get rid of this plant?
12. Are you willing to spend money on controlling Bugweed?
13. If so, have you spent any money recently to control this weed?
14. How much do you spend on controlling Bugweed?
15. Have you heard of other methods of controlling this weed? If so please name or describe them?
16. Have you ever heard of Biological control?
17. If so are you willing to use Biological control on your farm?
18. Have you received any information regarding this plant?
19. What kind of information? From where?

THANK YOU

Appendix B: Ethical Clarence Certificate

School of Animal, Plant & Environmental Sciences
The Biology of a Changing World: Conserving African Biodiversity

Private Bag 3, Wits 2050, South Africa • Enquiries Tel: +27 (0)11 717-6404 • Fax: +27 (0)11 403-1429
E-mail: apesinfo@gecko.biol.wits.ac.za

Prof M Sanders
Tel: (011) 717-6481
Martie.Sanders@wits.ac.za
7 September 2016

Animal, Plant and Environmental Sciences Human Research (Non-medical) Ethics Committee

ETHICS CLEARANCE CERTIFICATE

Protocol number:	HA1609
Project title:	An investigation of the social impact of *Solanum mauritianum* (bugweed) on Gautong farmers, and the geographical distribution of bugweed in Gauteng.
Researcher:	Tshuxekani Maluleke
Student number:	362334
School:	Animal, Plant and Environmental Sciences
Degree:	MSc (research report)
Date of issue:	7 September 2016

The certificate is valid until **December 30th 2017** and covers only the research for the project for your Masters (by research report) degree.

Martie Sanders
Chairman of the *AP&ES Human Ethics (Non-medical) Ethics Committee*

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions.

Signature

07, 09, 2016
Date

Appendix C: Information letter

University of the Witwatersrand

Private Bag 3 2050

Tshuxekani Maluleke

071 2082 364

Supervisor: marcus.byrne@wits.ac.za

Greetings

My name is Tshuxekani Maluleke from the University of the Witwatersrand. I am currently doing a master's degree in Environmental Sciences. I will be doing my research project in Gauteng, and I will be focussing on the impact of bugweed/luisboom on the farming activities. *Solanum mauritianum* (bugweed) is a National Environmental Management: Biodiversity Act (NEMBA) category 1b, alien invasive plant that comes from South America. It is a tree or shrub that forms dense stands in agricultural lands, rural and urban areas. Bugweed is a problem to agriculture, forestry, biodiversity as well as human health.

Previous scientific studies have focussed mainly on the environmental and economic impacts as well as the control of bugweed in South Africa, but however, these studies have not addressed the impact of the weed to the various stakeholders, including farmers. For instance some weeds are known to have impacts on peoples culture, they are used a medicinal plants. The understanding of the impact of bugweed will enable us to quantify the amount of damage and possible benefits caused by this weed.

In order to achieve this I need to interview farmers. The interviews will take at least 15 minutes. This interviews will take place during the month of July and August. The interviews are entirely voluntarily, and if you do agree to be interviewed you may skip questions you are not comfortable with, and you may stop the interview at any point if you do not want to continue. The interviews will be recorded using an audio recording device, if and only if the participant is comfortable with that. When I report my results I will not use your name.

Your cooperation would be highly appreciated

Kind regards

Appendix D: Afrikaans Information Sheet

University of the Witwatersrand

Private Bag 3 2050

Tshuxekani Maluleke

071 2082 364

Goeie dag

My naam is Tshuxekani Maluleke en ek is ‘n student by die Universiteit van die Witwatersand. Ek doen my meesters graad in Omgewengings wetenskap en my projek ondersoek die impak van luisboom op landbou in Gauteng. Luisboom is a uitheemse indringende plant wat oorspronklik van Suid Amerika af kom. Dit kan of a boom of ‘n bos wees, en hulle grooi in dik erwe op plase en in dorpe en word as n onkruid geklasifiseer. Luisboom veroorsak ‘n verskeidenheid probleme in landbou, bosbou, biodiversiteit, ~~en~~ sowel as menslike gesondheid.

Voorige studies het meestal op die impak van luisboom op die omgewing en ekonomie gevokus, sowel as die beheer van luisboom in Suid Afrika, maar nie een van die studies het gekyk hoe die onkruid verskuie belanghebbendes, ~~veraal~~ veral plaas boere, beinvloed nie. Plante het n verskuie invloede op mense, byvoorbeeld in sekere kulture word ontkruie as medisyne gebruik. Om die rede will ons graag die invloed van luisboom op mense verstaan, omdat dit ons help om sodat ons die skade en voordele van die plant kan kwantifiseer. ??? Rather “ons wil graag …”

Om dit te kan doen wil ons graag onderhoude met plaasboere doen. Invite Die onderhoud sal min of meer 15 minute lank wees en sal September or Oktober gedoen word. Die onderhoude word vrywillig gedoen en U mag geduurend die onderhoud enige vrag los wat U nie wil Verder mag U ook op enige punt gedurend die onderhoud vra om nie meer die onderhou te doen nie. Indien U toestemming gee, sal die hele onderhou afgeneem word met n bandopnemer. U ~~se~~ naam sal nie in my verslag gebruik word.

U samewerking sal baie waardeer word.

Appendix E: Consent form

CONSENT FORM

I confirm that I have been told about Mr Maluleke's research project and have had the opportunity to ask questions. I have been told that

- my participation is voluntary
- I am free to withdraw at any time,
- And that my name will not be used in the report.

I agree to be interviewed as part of this study.

____________________	____________________	____________________
Signature:	Contact Details (cell number)	Date