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The survival strategies of *Acacia decurrens, Acacia melanoxylon* and *Populus alba* in Vaalwater, Waterberg Biosphere Reserve, Limpopo Province, South Africa

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Dissertation submitted in fulfilment of the requirement of

Master of Science Degree in Botany

In the

School of Mathematical and Natural Sciences

University of Venda

Thohoyandou, Limpopo

South Africa

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January 2021

DECLARATION

I, Vanessa Matukana [11564729], declare that this thesis is my original work and has not been submitted for any degree at any other university or institution. This thesis does not contain any other persons' writing unless specifically acknowledged and referenced accordingly.

Signed (Student): **Date: 25/01/2021**

DEDICATION

I would like to dedicate this dissertation to my family and parents for their unconditional support and courage they continued to give me throughout my studies.

ACKNOWLEDGEMENTS

I would love to thank the most-High God for the strength and good health He gave me throughout the duration of my studies.

I thank my husband Dalton Masia for the support he gave me when looking after my children and taking care of the rest of the family during my studies. I will never forget my children Zwavhudi Masia, Hulisani Masia and Lushaka Masia for their love, support and understanding they gave me during this time, as I spent little time with them.

I am grateful to the Centre for Invasion Biology (CIB) and the University of Venda for the use of their facilities and for financial support.

I also want to thank my supervisor Mr. Maanda Hadzhi Ligavha-Mbelengwa for his support and inspiration he gave me. He encouraged me to put more effort on this work and made me have more interest in invasion biology studies. I also want to thank my co-supervisor Professor Peter Tshisikhawe for his time and advice throughout this study. I cannot thank him enough for the inspiration.

A lot of people have supported me along the way. I thank Dr. Colin Schoeman, and the late Professor RB Bhat, may is soul rest in peace, for their support throughout my study.

Finally, my gratitude goes to University of Venda, Botany third year students in particular for their time and support and for helping with field work.

ABSTRACT

Invasive alien plants use survival strategies to outcompete native plants. Invasive alien plants occurring next to water bodies consume lot of water and are difficult to control and remove within their area of existence. Government uses public funds to control and remove invasive alien plants and use different methods to control them. Mechanical control can only be used for specific plants, not for all invasive alien plants existing in field. Only three species of invasive alien plants were sampled in this study, namely; *Acacia decurrens, Acacia melanoxylon* and *Populus alba.* Two sites were sampled, one away from the water body and the other site next to the river. Twenty quadrats were sampled per site and trees were controlled through mechanical method of digging the roots and cutting at the ankle and knee height size within the quadrats. Over 18 months monitoring was conducted to check the response of these plants. The results show that, out of twenty quadrats sampled per site, the response of sprouts next to the water body was very successful. All stumps cut at knee level next to the river had sprouts and root suckering was observed more on trees that were closer to the river, especially on *Populus alba* and *Acacia decurrens*. This study emphasizes the need to consider the impact of survival strategies of invasive alien plants when controlling them.

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
PCA	-	Principal Component Analysis
DWA	-	Department of Water Affairs
NEMBA	-	National Environmental Management Biodiversity Act
CARA	-	Conservation of Agricultural Resource Act
km	-	kilometre
km^2	-	Square Kilometre
N	-	Nitrogen
cm	-	centimetre
%	-	Percentage
mm	-	millimetre
M	-	Mean
M	-	metre
sd	-	Standard Deviation
^oC	-	Degrees Celsius
^{o}	-	Degrees
E	-	East
S	-	South

CHAPTER 1

INTRUDUCTION

1.1 Background of the study

Invasions by alien species are considered one of the largest threats to ecosystems and the services that they provide to humanity (Gaertner *et al*., 2009; Vilà *et al*., 2011). Invasive alien plant species cost South Africa an estimated R6.5 billion every year. Understanding the survival strategies of some invasive alien species is vital in informing land use management. Some alien tree species used in commercial forestry and agroforestry cause major problems as invaders of natural and semi-natural ecosystems (Semenya *et al*., 2012). The magnitude of the problem has increased significantly over the past few decades, with a rapid increase in afforestation and changes in land use (Van Kleunen *et al*., 2010; Richardson, 2011).

Even though human induced factors affect the establishment and spread of alien species (Pyšek and Richardson, 2007; Pyšek *et al*., 2010), plant characteristics structures are important in their establishment. Invasive plants alter natural communities by competing with and displacing indigenous plants (Vitousek and Walker, 1989) and cause economic loss (Pimtel *et al*., 2000). Rapid invasion is made possible by the greater reproductive potential of the invading species than those in a community being invaded. Many invasive plants produce prodigious quantities of seeds, which are often retained in the soil as seed banks and may be much larger than those of natives (Holmes *et al.*, 2005).

The species that cause the greatest problems are those that have been planted most widely and for the longest time. In these cases, plantation forestry has unavoidable negative impacts, with alien species spilling over into areas set aside for conservation and water production (Richardson, 1998). Invasive alien plants represent a recurrent and ubiquitous threat to agriculture and biodiversity directly by displacement of flora and fauna, or directly through placing natural resource under strain (Buhler *et al.,* 2000). Invasive alien plants pose the most threats to the natural vegetation. They are likely to be problematic because they do not have natural enemies and have not co-evolved with the indigenous plant species. Thus, alien plant species can interfere strongly with indigenous species and as a result they tend to dominate and even displace the native species (Pimentel *et al*., 2005; Vilà *et al*., 2011).

Invasions are found in all areas of South Africa where the annual rainfall exceeds 500 mm. The provinces mostly affected are the Western Cape, Eastern Cape, KwaZulu-Natal and Mpumalanga, but parts of the Free State, Gauteng and Limpopo Provinces are also affected (Mcdonald *et al*., 2003). In Africa studies in Kenya and Tanzania prove the impact of alien invasion plants (Swallow and Mwangi, 2008; Wakabira and Mhaya, 2002).

Invasive alien plant species have numerous deleterious effects on the environment, usually outperform co-occurring plants because they can survive, reproduce and spread unaided. By so doing they cause detrimental effect on the growth of the indigenous tree species and giving rise to management problems (Ahimbisiwe, 2000; Van Wilgen *et al*., 2001). Invasive alien plants cause economic loss (Pimentel *et al.*, 2000). Plant invasion can be viewed in the context of global change as they have considerable impact on biodiversity (Chapin *et al.,* 2000). Alien plants alter, degrade and deplete nutrients, water and organisms within the soil that also cause soil erosion and degrade terrestrial habitats. In addition to reducing ecosystems productivity and stability, the invasion of ecosystem by alien plants may simultaneously increase susceptibility of ecosystems to further invasion (Reed, 2007).

In invasion ecology, identifying traits correlated with invasiveness is a central goal, the success of which has direct application for the prediction and prevention of future invasions (Hulme, 2006). Acacia species have several reproductive traits that may also contribute to their invasiveness, such as massive, attractive and long-lasting floral displays, generalist pollination, self-pollinate and to reproduce vegetative (Gibson *et al*., 2011). Below are the characteristics of three Acacia species which the study focused on:

1.2 Species of interest

1.2.1 *Acacia decurrens* (Green Wattle)

It belongs to Acacia section Botrycephalae, a group of 44 mostly arborescent species characterized by having bipinnate adult foliage and flower heads normally arranged in elongated racemes (Orchard and Wilson, 2001). These species predominate in temperate areas. Maslin *et al*. (2003) suggested that species of section Botrycephalae are most closely related to certain racemose species of section phyllodineae. It has been widely cultivated as an ornamental and has become naturalized in many areas. It is endemic in New South Wales, where it occurs chiefly on the coast and table lands from capital territory.

The green wattle is a tree that reaches a height of between 6 and 20 m. It originates from southeast Australia and Tasmania. In addition, many green wattle woodlots provide rural communities with firewood. It produces copious amounts of hard-coated seeds which are relatively long lived and are spread readily down water courses and through the movement of soil. There are many benefits associated with green wattles in South Africa. Many of these arise from formal plantations, but some (including firewood, charcoal and building materials) are also derived from stands of invading plants. Similarly, there are a range of negative impacts that can be attributed to both wattle plantations and invasions for example, reduce surface runoff and affect water availability, and impact on biodiversity (Dogra *et al*., 2010).

Acacia decurrens is shapely erect 5-10 m tall but sometimes attaining 20-22 m height (Boland, 1987). It is commonly with single, straight main stems, and strong, shallow lateral root development. Its bark is smooth but may become fissured on main trunks or mature plants and turn dark grey to almost black in colour. *Acacia decurrens* mostly flowers between July and early September but this may vary with seasonal conditions, locality and altitude. Flowering can extend to November (Kodela and Tindale, 2001). Time between flowering and pod maturation is 5-6 months (Boland, 1987) with seeds being present from November to January, but pods are not produced every year. It is a relatively short-lived species, which declines in vigour after 10-15 years (Pryor and Banks, 1991). Green wattle has the potential to produce clear, straight stems when close-grown and it regenerates via seedling recruitment.

1.2.2 *Acacia melanoxylon* (Black wood)

Acacia melanoyxlon commonly known as Black wood, lightwood, or hickory is native to eastern Australia. It is a member of the family Fabaceae*,* clade Mimosoideae (Searle, 2000). *A. melanoxylon* was introduced in South Africa in 1850 as a shade and ornamental tree. Its best development, in terms of superior growth and form, is found in cool temperate environments with deep soils, especially in tall forests of Tasmania and Victoria (Searle, 2000). This tree species grows fast and tall, and can reach a height of 45 m. It has a wide range of ecological tolerance, occurs over an extensive range of soils and climatic conditions but develops better in colder conditions.

The main source of Blackwood is native forest logging in Tasmania and western Victoria, although small quantities come from plantation-based resources in New Zealand, South Africa and Brazil. Across its natural distribution, there are three forest types; swamp, wet sclerophyll and riverine that support the production of high-quality timber (Searle, 2000). Hence there are conditions that lead to an earlier change of growth habits from leaves to phyllodes. Under some conditions this phase change may not occur or is reversed, following a change from exposed to shaded conditions. Factors other than light intensity may also trigger phase change. Reproductive traits are crucial for the establishment and maintenance of populations in a new area (Suetsugu *et al.,* 2012; Bezeng *et al.,* 2013). *A. melanoxylon* produce many seeds leading to large seed bank. Like many legumes, black wood forms a symbiotic relationship with a nitrogen-fixing bacterium that induces nodule formation on their roots. The bacteria provide nitrogen (N) to the plant in return for carbohydrate. Regarding the physiology of Blackwood root nodules, light environment, nutrition and water availability may affect nodulation.

Seeds of *A. melanoxylon* are widely dispersed by the birds, once the birds become adapted to feeding on the pink red aril around the seeds. They germinate widely when soaked in hot water over night, or when soil stored seeds are heated by the sun or after fire. Boiling water is poured over the seeds at volume five times the volume of the seeds. The seeds must be stirred gently during the 2-5 minutes hot water soak. *A. melanoxylon* reproduces prolifically after fire. It can also multiply by vegetative methods where coppice shoots develop from cut and damaged stems, and from damaged roots (Hussain *et al*., 2020).

1.2.3 *Populous alba* (White poplar)

White poplar was first introduced to North America in 1748 and has a long history in cultivation. *Populus alba* is a tall member of the willow family Salicaceae that at maturity may reach 21 m or more in height. White poplar is native to central and southern Europe, North Africa and western and central Asia. It was introduced in the United States as a shade and ornamental tree. White poplar can form large clonal communities that can exclude native species and degrade natural areas (Remaley and Swearingen, 1998). Its attractive leaves of contrasting colours make it a good ornamental species (i.e., green above, white below). It has escaped and spread widely from many original planting sites. Because it is susceptible to a wide variety of pest insects and diseases, and is easily damaged by storms and wind, the ornamental value of white poplar is low. Poplars are the modest number of species in diverse groups, general abundance, quick growth, ready vegetative propagation, easy cultivation, ability to flower and set seed on exercised branches (Dickmann, 2001).

Populus alba is a dioecious species and female mature trees produce large seed crops. It spreads to new locations when mature trees release thousands of wind-dispersed seeds that may be carried long distances. It is an especially strong competitor because it can grow in a variety of soils and sprout easily in response to damage. Local spread of male and female trees occurs through vegetative mechanism *via* root suckers (Mbedzi *et al*., 2019).

Profuse suckers from the "mother" plant will form large vegetative colonies. Being dioecious, cottonwood trees are either male or female in both sexes, the flowers are clustered in catkins, which tend to be borne in the upper tree crown. Male and female catkins are readily distinguished from one another, as male catkins are smaller and reddish-purple, whereas female flowers and catkins are significantly larger and greenish in appearance. Males commonly initiate flowering before females and both sexes flower approximately 1-2 weeks. *Populus alba* start to bloom during the early spring seasons, and as a perennial plant it stays green throughout the year. The development of seeds capsules normally occurs quite rapidly following effective pollination and fertilization, when fertilization is effective, fruits maturation occurs within 2-3 weeks. *Populus alba* produces more fruits which results in the production of numerous seeds which are dispersed by the animals; it is not easy for the wind to disperse most of the seeds. The fruit period begins during the spring season and ends on the spring season of the coming year (Dickmann, 2001).

1.3 Statement of the problem

The South African government has proved to be serious about addressing the negative impacts of alien invading species on the natural resources of the country. However, the approach so far has concentrated on using physical methods such as mechanical and chemical control and biological control of alien plants, utilizing public funds to clear invasive stands.

Limpopo Province is one of the provinces that are mostly invaded by alien plants. Waterberg District is particularly susceptible to invasive alien plant species and where this has taken place, it almost results in the complete replacement of the indigenous vegetation. Invasive alien plants use several strategies to survive and out-compete indigenous plants (Milton, 2004).

This study focusses on the establishment and survival strategies of invasive alien plants. Control and eradication of invasive plants must be carried out by means of methods that are appropriate for the species concerned and the environment in which it occurs. These plants are sampled in the area where they occur in abundance and they are sampled through the method of random sampling, through roots digging and cutting. This study focusses only on few species dominating in the Waterberg District, such as green wattle, black wood and white poplar. Any action taken to control and eradicate a listed invasive species must be executed with caution and in a manner that may cause the least possible harm to biodiversity and damage to the environment.

The methods employed to control and eradicate a listed invasive species must also be directed at offspring, propagating material and regrowth of such invasive species in order to prevent such species from producing more offspring, seeds, regenerating or re- establishing itself in any manner.

1.4 Research Justification

Invasive alien plants have invaded the Limpopo Province and they are destroying the biodiversity and displacing indigenous plants. The introduction of alien plants is a prerequisite to formulation of effective management of alien plant invasion. Management strategies that can control the spread of alien plant species will also be suggested or developed. Three species selected *Acacia decurrens*, *Acacia melanoxylon* and *Populus alba* are classified as Category 2 listed invasive species which required permit to carry out a restricted activity within an area, according to section 70(1)a of the National Environmental Management: Biodiversity Act (Act NO.

10 of 2004). This mean that these species cannot be planted without a permit and all species that occurs in riparian areas must be managed according to regulation 3 (Henderson, 2020).

Invasive alien plants pose a direct threat not only to South Africa's biological diversity, but to water security, the ecological functioning of natural systems and the productive use of land. They intensify the impact of fires and floods and increase soil erosion. Invasive alien plants can divert enormous amounts of water from more productive uses and such as the water hyacinth, effect agriculture, fisheries, transport, recreation and water supply (DWA, 2012). It is necessary to undertake projects like this in order to identify alien plants and finding out the best strategy to control alien invasive plants.

1.5 Aim and objectives

An assessment of the survival strategies of the three species in South Africa is necessary. Therefore, the study aim was to investigate the survival strategies of three invasive alien plants in Vaalwater, Waterberg Biosphere Reserve, Limpopo Province, South Africa. The following objectives were investigated into order to achieve the aim:

- i Determine the survival strategies of *A. decurrens*, *A. melanoxylon* and *P. alba*
- ii Investigate the most suitable level of cutting control method of a stump.
- iii Determine if digging is the feasible control method of invasive alien plants.

1.6 Hypothesis

Invasive alien plants have survival strategies which enable them to survive.

Invasive alien plants that grow closer to water sources are more likely to be successful.

Due to stored resources juvenile plants respond by regrow to cutting faster than adult plants.

1.7 Structure of dissertation

The dissertation is written in the form of a unitary scientific report. Chapter one deals with introduction of the survival strategies of invasive alien plants. Characteristics of the three invasive alien plants are discussed and their potential invasiveness. The problem statement of the study is outlined with aims and the objectives of the study. Chapter two outlines the literature review of invasive alien plants species on their development management, nature of the problem, modes of invasion and alien invasion process. Methodology and study area are described in chapter three and random sampling was the sampling method explained. Chapter four explains the results in forms of tables and graphs and later discussed in chapter five which is the discussion. Summary, recommendations and conclusions are made in chapter six.

CHAPTER 2

LITERATURE REVIEW

2.1 Invasive alien plant species development and management

In South Africa invasive alien plant species spread at an average rate of 1% per annum (Enright, 2000). The process of invasion follows three phases: arrival, establishment and spread. The knowledge of the processes that take place within each stage in terms of plant ecology, human activities and stochastic events is therefore of fundamental importance in management of plant invasion. Eradication is possible in a few instances, but only at great expense and effort. Others may not be controllable by any practical means (Enright, 2000). However, understanding the survival strategies of alien plant species is essential, because for eradication to be successful plant ecology of these species must be understood. With the effect of climate change more invasion is more likely to occur. Invasive alien plant species display extensive recruitment into native plant communities without human intervention. Various invasive alien plants are known to alter the rate of nutrient cycling (Liao *et al*., 2008; Ehrenfeld, 2010), decrease local plant species diversity (Vila` *et al*., 2006; Gaertner *et al*., 2009; Hejda *et al*., 2009; Powell *et al*., 2011).

Witkowski and Wilson (2001), noted that invasive alien plant species have higher growth rates which enable them to survive, and produce more seeds (Richardson and Kluge, 2008) and have led to some Acacia species becoming worst invaders.

However, these Australian acacias remain as small populations within limited ranges but have the potential to spread widely (Zenni *et al*., 2009; Van Wilgen *et al*., 2011; Wilson *et al*., 2011). In the three species this research focused on *A. decurrens* and *A. melanoxylon* are legumes while *P. alba* is not. Their ability to fix nitrogen make them drought resistance and enable them to disperse quicker, which makes them the second most important agricultural plant family after grasses (Graham and Vance, 2003). Legumes are also popular in horticulture for their showy flowers, hardiness and ability to thrive in nutrient-poor soils. For these reasons, and because of the long seed dormancy in many species, legumes are among the most notorious contributors to the naturalised flora of the world (Paynter *et al*., 2003; Pyšek, 1998; Richardson and Rejmánek, 2011). Henderson (2007), noted that legumes make up 18% of the declared weeds in the Conservation of Agricultural Resources Act (CARA), and top the lists of invasive alien species in most biomes.

2.2. Nature of the problem

Invasion has been defined as the introduction, establishment and expansion of new species in a community in which it was previously absent (Mack, 1985). Invasion is a process distinguished from colonization based on the bio geographical origin of the invading species and the detrimental effects that its expansion has on the new community (Mack, 1996).

2.4 Modes of invasion

An increase in global change effect is becoming more important than ever, and to understand how human activities are altering biodiversity and ecosystem functioning is even more vital (Tylianakis *et al*., 2008). Alien plants are introduced in many ways, some are brought into the country for practical purposes such as forestry plantation and some are introduced unintentionally by road transport, wind, floods and sea transport. Invasion by alien plants causes major problems in most regions of the world (Poynton, 2009).

2.5 Effects of invasive alien plants

Invasive alien plants are amongst the most ecological and economic problems (Cohen, 2002). In South Africa invasive alien plants have become one of the most serious threats to native species natural community processes (Cassey *et al.,* 2005). Introduction of these species was supported by human activities, which includes species from other continents as well as species native to neighbouring regions.

Alien plants cause enormous damage to biodiversity and the valuable natural agricultural system upon which we depend on. Baskin (2002) suggests that invasive species are increasingly recognized as having important impacts on landscape, ecosystem and level of biodiversity. Among many plant species introduced, some have displayed unexpected growth tendencies, while many of these plants do not persist in the wild. Some are readily invading natural habitats (Daehler, 2001). The total area invaded by alien plants in South Africa is over 100 000 km, which is over 8% of the country's total area, the most invaded area is along the riparian zones (Van Wilgen *et al.*, 2001).

Plant invasion can be viewed in the context of global change, as they have a considerable impact on biodiversity (Chapin *et al*., 2000). Invasive plants pose the biggest threat to the long-term integrity of Limpopo Province. Alien plants are more likely to be problematic, because they often grow without their natural enemies and co-evolved with indigenous plants. Alien plants represent a recurrent and ubiquitous threat to agriculture and biodiversity directly by displacing of flora, or indirectly through placing natural resources under strain (Buhler *et al*., 2000).

2.6 Survival strategies of invasive alien plants

There are many characteristics of invasive plants, which aid them in their survival. Most alien plants depend on seed dispersal to occupy different areas. Invasive alien plants are good competitors in their new environment and successful invaders that often share new traits that allow them to out-compete indigenous plants (Gould, 2000). Invasive plants often produce large quantities of fruits and seeds, which means that they have more offspring which can establish and occupy the area. Some invasive plants have propagules that help to colonize the area, some also have lignotubers that store food during the seasons and photosynthesize using branches and stems when leaves are shed off. Seeds of most invasive plants are easily transported by people, wind, water, birds or wildlife. They can establish in new locations faster than their parent plants.

2.7 Alien invasion process

The introduction of invasive plants involves the translocation of alien plant species from one place to another either accidentally or intentionally in fulfilment of human needs. When an ecosystem is disturbed it is either by natural processes or due to some anthropogenic factors. Habitat disturbance also provides a kind of invasion window to alien propagules. Gradually it overcomes the environmental, reproductive and dispersal barriers and expands its population (Raizada, 2007).

Some of the propagating structures may be carried away by running water during rainy seasons, some are transported by birds. After introduction, they adapt to a new geographical area, expand their population and create a mono specific thicket. These species affect ecosystem processes, biodiversity patterns and community structure. They are also able to use resources previously unavailable to native species, such as deep-water because some of them consists of deep tap roots and ability to live on previously uninhabited soil types (Raizada, 2007).

2.8 Alien plant species as a threat to biodiversity

South Africa is one of the countries invaded by most alien plant invaders (Richardson *et al*., 2004). South Africa has long history of problems, rating among the worst in the world, associated with invasion by alien trees and such is continuously having a large negative effect on riparian vegetation throughout the country. The replacement of indigenous plants `by alien invasive plants leads to an increased transpiration and reduction in water flow owing to the larger biomass of the alien plants compared to the indigenous vegetation (Holmes *et al*., 2005).

Invasion by alien plants indeed is a serious threat to biodiversity following direct habitat destruction. They may lead to a greater continuing threat to biodiversity especially rare plant species, if allowed to persist and spread to their greater extent (Magoba, 2005). Invasion of alien species can affect the entire community and transform the structure and species composition of ecosystem or displace native species by out-competing them for resources or directly by changing the way nutrients are cycled through the ecosystem.

Chapter 3

STUDY AREA, MATERIALS AND METHODS

3.1 Description of the Study Area

The study site (Figure 3.1) is located in Mokgotopong, Waterberg District, Limpopo Province South Africa, in Marken Farms (24^0 17' 45" S, 28^0 26' 20" E). Marken Farms cover a huge area occupied with alien plants. There are main river catchment areas which provide water to an area of over 40 000 km^2. It is an area consisting of low mountain ranges and escarpment with poor soils and a relatively low level of economic activities (Scholes and Walker, 2004).

The vegetation is dominated by different veld types, the two dominant forms being sour Bushveld and mixed Bushveld which are typical savanna vegetation types, as well as the Waterberg Moist Mountain Bushveld. The Mountain sour veld in the Northern Eastern of the Waterberg is the most threatened veld type in Limpopo. Sour Bushveld is dominated by Transvaal beech (*Faurea saligna*), common Hookthorn (*Acacia caffra*), Wild Seringa (*Burkea africana*), Sliver Cluster-leaf (*Terminalia sericea*) and African Wattle *(Peltophorum africanum*). On the sandy areas, steep slopes and bare rock consists of trees including Velvet bushwillow (*Combretum molle*). On the river bank and fresh water habitats the vegetation is characterized by Common Wild

Fig (*Ficus thonningii*) and Transvaal red milkwood (*Mimisopus zeyheri*) (Scholes and Walker, 2004).

The climate of the Waterberg District varies from a hot and semi-arid in the northern and western regions to more humid and somewhat cooler in the southern and eastern areas. Average maximum temperatures range from 33.0 ºC in January to 23.4 ºC in Lephalale, with average daily minima ranging from 20.4 ºC in January to 6.7 ºC in June. In Bela-Bela lower temperatures are recorded with average maximum temperature range from 29.9 ºC in January to 20.8 ºC in June. The Waterberg District experience marked seasonality of rainfall with cool, dry winters and hot, wet summers. The mean annually rainfall in the northern and western areas is approximately 400 mm, increasing to the south and east to approximately 600 mm. Isolated high line areas receive in excess 600 mm rainfall per annum (Kupchella and Hyland, 1993).

Limpopo Province is the second province that is experiencing the problem of invasion by alien plants in South Africa and as is one of the countries most affected by alien plant invasion (Richardson *et al*., 2004).

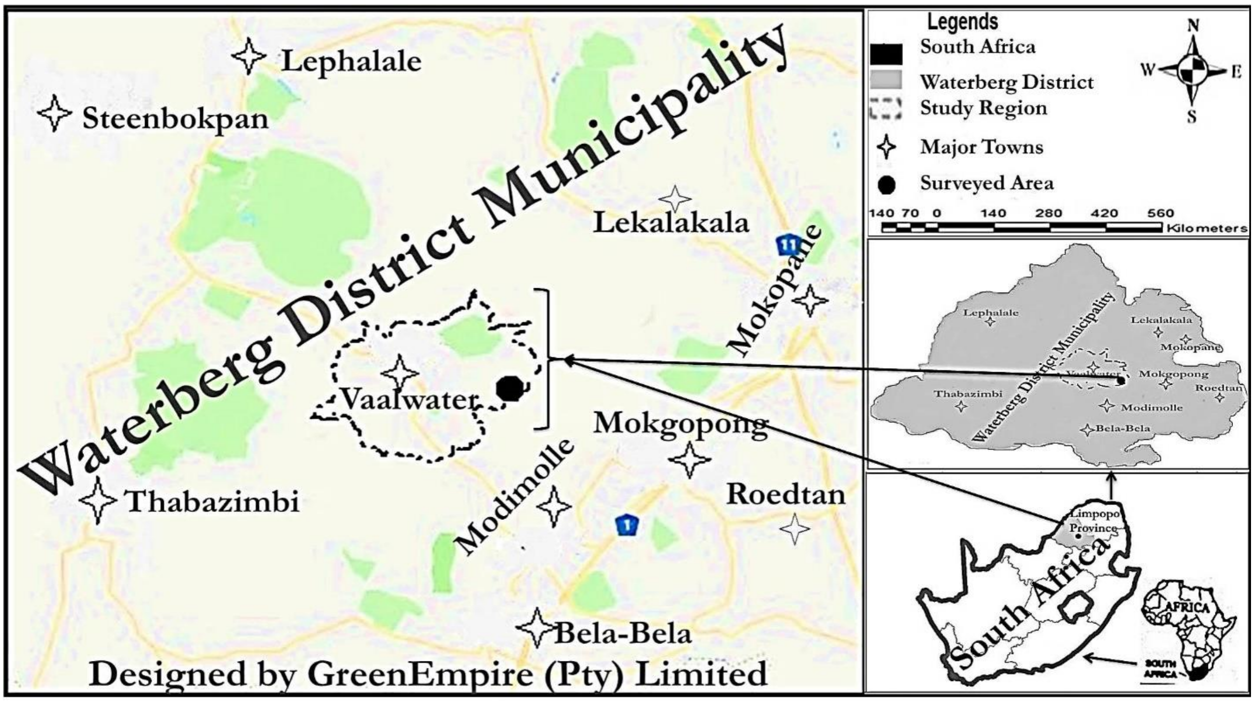


Figure 3.1: Map of the Waterberg District Municipality showing the study area in the Limpopo Province.

Since the availability of water is the most crucially limiting resources for Limpopo Province, the natural environment and human population suffer as a result of serious shortage of water. Waterberg District is one of the districts affected by alien invasive plants. As such water as a resource is constantly under pressure. The rivers flowing in the district drain in the north-western direction to the Limpopo River that in turn has a direct influence on South African neighbouring countries (Scholes and Walker, 2004).

The environmental sensitive areas within the district are mainly the wetland habitat that includes rivers and riverine vegetation. The Nyl flood plain which covers an area of 16 000 hectares is situated in the district with the Nylsvlei nature reserve which encompasses only 10% of the flood plain and was registered in February 1998 as a Ramsar site (Scholes and Walker, 2004).

3.2 Methodology

3.2.1 Root suckering experiment

Two sites were sampled; one site next to the river and the other site 150 m away from the river. These two sites were divided into four plots. Two sampling techniques, which was digging and cutting in the two sites were established. As a basis of this study, three different plant species, namely; *Acacia decurrens*, *Acacia melenoxylon* and *Populus alba* were sampled randomly to determine their survival strategies in Vaalwater, Marken Farm.

The random sampling method is a method in which all individuals of a group have an equal and independent chance of being selected in this method, one takes a manageable area of known size and identifies, counts, and usually measures all individuals contained within it. This sampling procedure is then repeated for several plots to obtain an adequate representation of the community. Random sampling is used for accuracy and unbiased application of plot sampling, samples must be randomly distributed. This method is applied in dense areas or transitional environments (Bourdeau, 1953).

The aim of digging was to determine if the three species can grow through the root suckers. Four plots were established as follows:

i. Plot 1 was constructed next to the river. In plot 1, 40 adult and juvenile trees were sampled randomly by the method of digging.
ii. Plot 2 was 150 m away from the river and 40 adult and juvenile trees were sampled randomly by the method of digging.

Forty adult and juvenile trees whose roots were dug for root suckering experiments per species (*A. decurrens, A. melanoxylon* and *P. alba*), and number of trees that were found root suckering were counted. Root suckering is a vegetative method used by plants to survive. Plants such as *P. alba* use root suckering to share and transport nutrients to one another and produce new shoots.

3.2.2 Stem cutting experiment

The aim of cutting was to determine how they can respond to cutting. Four plots were established as follows:

i. Plot 3 (next to the river) was also sampled randomly by selecting 40 adults and 40 juvenile trees. In 40 adult trees selected, 20 were cut at ground level and 20 were cut at knee level (50 cm above the ground), also the same was done on juvenile trees.
ii. Plot 4 had 40 adult trees that were selected 150 m away from the river and 20 of them were cut at ground level while 20 were cut at knee level. The same was done on juveniles.

Observation started after three months following cutting and continued each season. Monitoring if the stump has new nodes and sprouts, if present number of nodes and sprouts were counted and the length of sprouts measured. The results were recorded each season.

3.2.3 Data analysis

Within the study plot, all data collected were analysed with descriptive approach. During all seasons results were analysed of all three species (*A. decurrens, A. melanoxylon* and *P. alba*), specifically the number of nodes, length of the sprouts and root suckering. Analysis of variance (ANOVA) one way and chi-square were used to get the level of significance between these alien plants in their study sites. Student t-test was also be used to compare the length of sprouts, number of nodes, between three invasive alien plants in two sites.

CHAPTER 4

RESULTS

4.1 Determining the survival strategies of *Acacia decurrens*, *Acacia melanoxylon* and *Populus alba*

4.1.1 Root suckering as survival strategy

All species responded differently to root suckering, *Populus alba* has 99%; *Acacia. melanoxylon* 16%; *Acacia decurrens* 8% and except for *Acacia decurrens* that was sampled 150 m away from the river which responded negatively with 0% of root suckering (Figure 4.1.1).

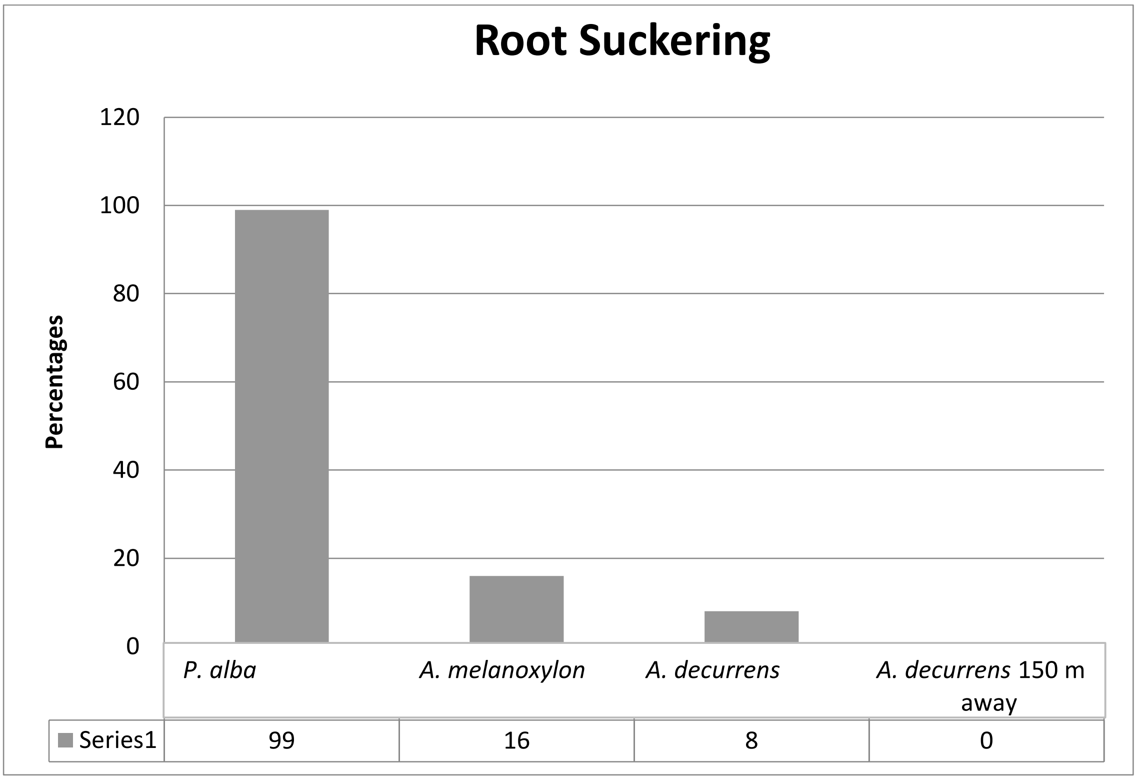


Figure 4.1: Percentages on root suckering per species.

4.1. 2 Resprouting as survival strategy

There was no significant difference between the number of sprouts and their length between all three species (Table 4.1)

Table 4.1: Results of variation between *Acacia melanoxylon*, *Acacia decurrens, Populus alba* and *Acacia decurrens* 150 m away from the river.

Grouped species	**N**	**Mean**	**Variance**
Populus alba	780	1.02	0.020
Acacia melanoxylon	779	1.00	0.000
Acacia decurrens	772	1.40	0.240
Acacia decurrens 150 m away	780	1.56	0.246
Total	3111	1.25	0.185

Results indicates that *Populus alba* (white poplar) was seen responding positively to cutting by producing 79.3% sprouts. *Acacia melanoxylon* responded positively at 100% of sprouting after cutting at all level of cutting. *Acacia decurrens* (green wattle) responded well at 72.1% and 60.5% of sprouting of *Acacia decurrens* sampled 150 m away from the river (Figure 4.2).

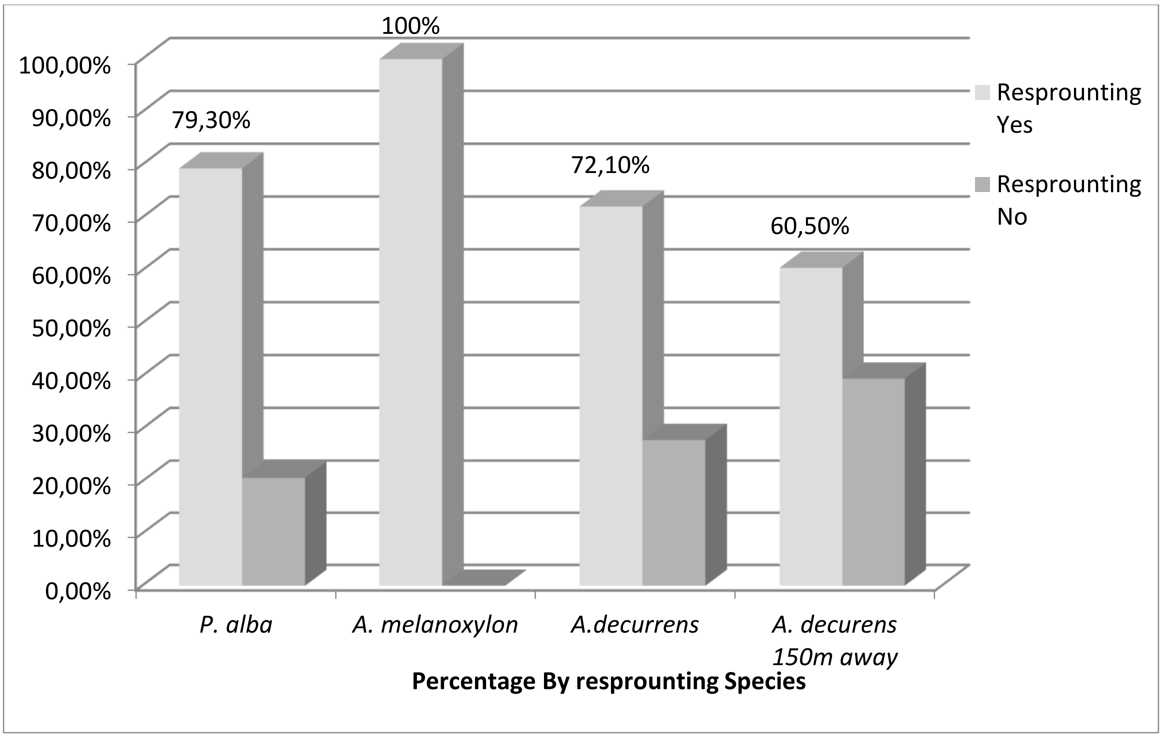


Figure 4.2: Percentages resprouting of adult plants cut at all levels of cutting.

There were no significant differences between the number of resprouts and the length of sprouts in all species. *A. melanoxylon* produce higher average number of sprouts (992) than other species). *A. decurrens* along the river had few average numbers of sprouts than *A. decurrens* 150 m away from the river (Table 4.2).

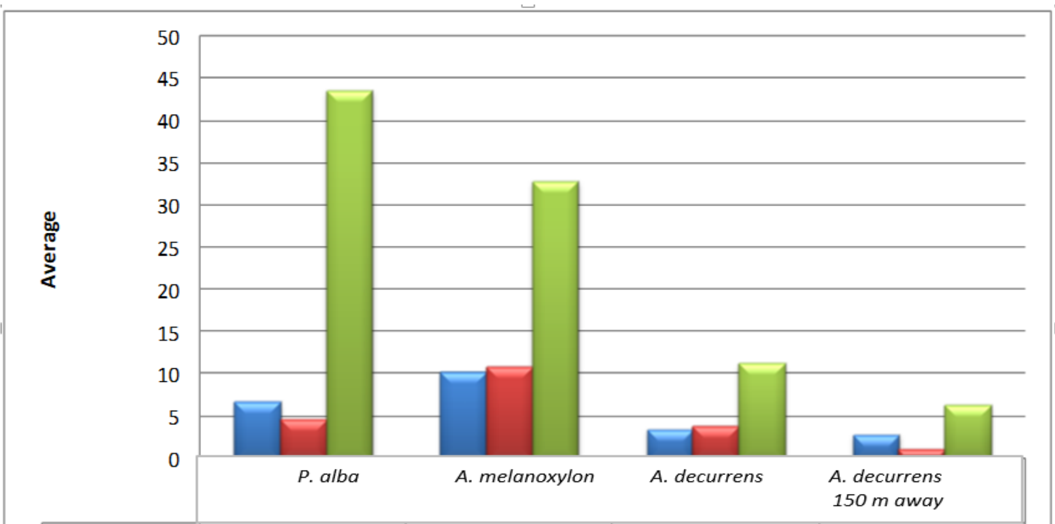
Table 4.2: Indicates the number of sprouts that have been sampled per species.

Case Summaries

Grouped species		**No. sprouts**	**of Length (cm)**	**Average No. of sprouts**
P. alba	N	880	78	880
	Mean	4.673	43.70	2.568
	Std. Deviation	1.7529	18.62	2.0291
A. melanoxylon	N	992	73	992
	Mean	10.959	32.892	4.683
	Std. Deviation	7.3550	18.4976	2.5097
A. decurrens	N	772	22	772
	Mean	3.960	11.267	1.440
	Std. Deviation	6.7823	14.2258	1.8710
A. decurrens 150 m away	N	620	18	780
	Mean	1.197	6.429	0.679
	Std. Deviation	1.5844	9.0144	0.8432

The results show that *P. alba* had the longest sprouts, with *A. decurrens* 150 m away from the river with the short length of sprouts and *A. melanoxylon* had the highest number of nodes than other species (Figure 4.3).

Average no: of length, sprouts and nodes per species



	P. alba	*A. melanoxylon*	*A. decurrens*	*A. decurrens 150 m away*
No of nodes	6.692	10.288	3.518	2.894
No of sprouts	4.673	10.959	3.96	1.197
Length cm	43.706	32.892	11.267	6.429

Figure 4.3: Average number of length (cm), sprouts and nodes per species counted during the time of observation and the height of the highest sprout that was measured.

The graph below indicates the percentages of sprouting between adults and juvenile trees. This graph simply shows juvenile trees sprout faster than adults (39.2%) and adults (36.3%). (Figure 4.4).

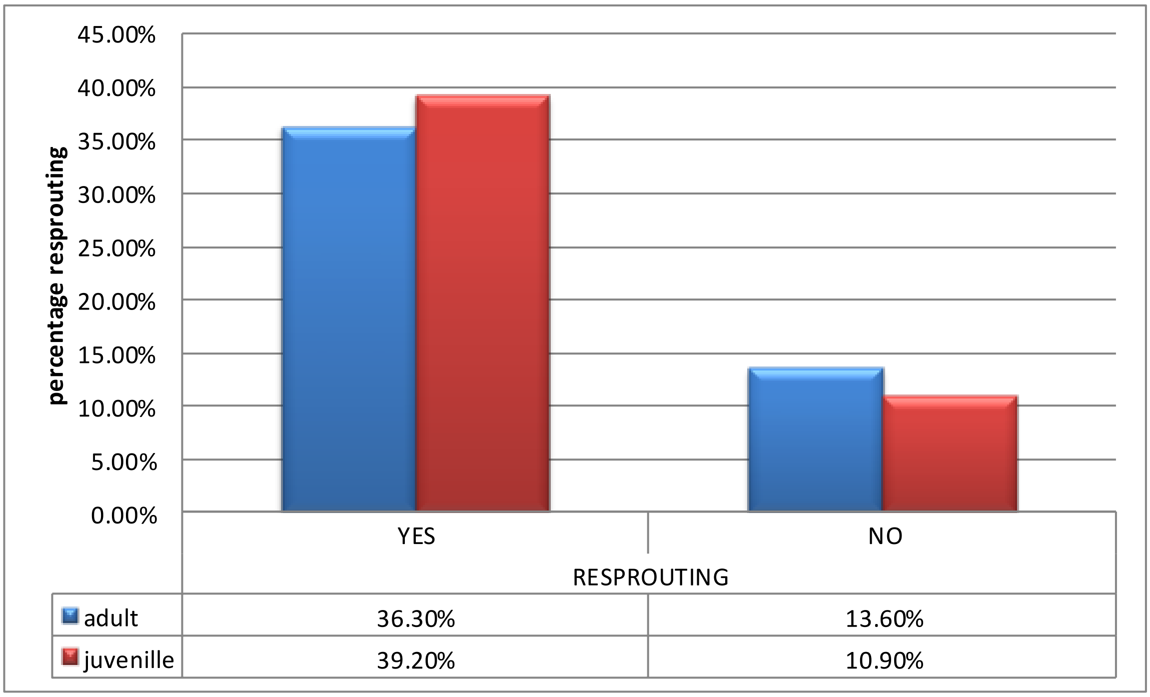


Figure 4.4: The difference between adult and juvenile plants of the three alien species (*P. alba, A. melanoxylon* and *A. decurrens*) respond to cutting, in terms of sprouting.

4.2 Stump removal experiments

For all three invasive alien species cut at knee level had higher number of resprouts (1258) which counted for 40% resprouting than those cut at ground level (1090) which counted for 35%, and the resprouts count for a total of 75% resprouts (Table 4.3).

Table 4.3: Total number of resprouts at ground and knee level after cutting

Level			**RESPROUTING**		**Total**
			YES	NO	
	Ground	Count	1090	464	1554
		% of Total	35.0%	14.9%	50.0%
	Knee	Count	1258	299	1557
		% of Total	40.4%	9.6%	50.0%
Total		Count	2348	763	3111
		% of Total	75.5%	24.5%	100.0%

The graph indicates adult *A. melanoxylon* plants cut at ground level had the greatest number of nodes (3.215) than juveniles and a smaller number of sprouts (3.776) than juvenile which had (4.558). However, the length of the sprouts on juveniles were higher (20.596) than that of adults and the average number of sprouts were higher in juvenile than adults (Figure 4.5).

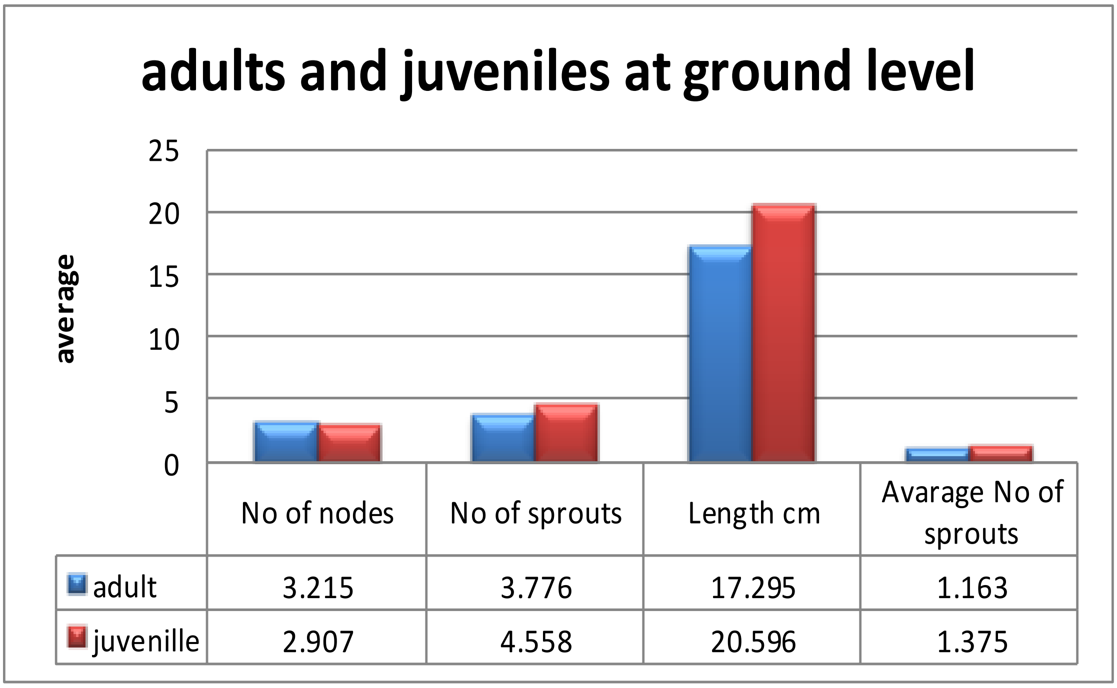


Figure 4.5: Adults and juveniles responded after cutting at ground level.

This graph indicates that trees cut at the knee level responded at 40.4% resprouting following cutting than those trees cut at the ground level at 35% (Figure 4.6).

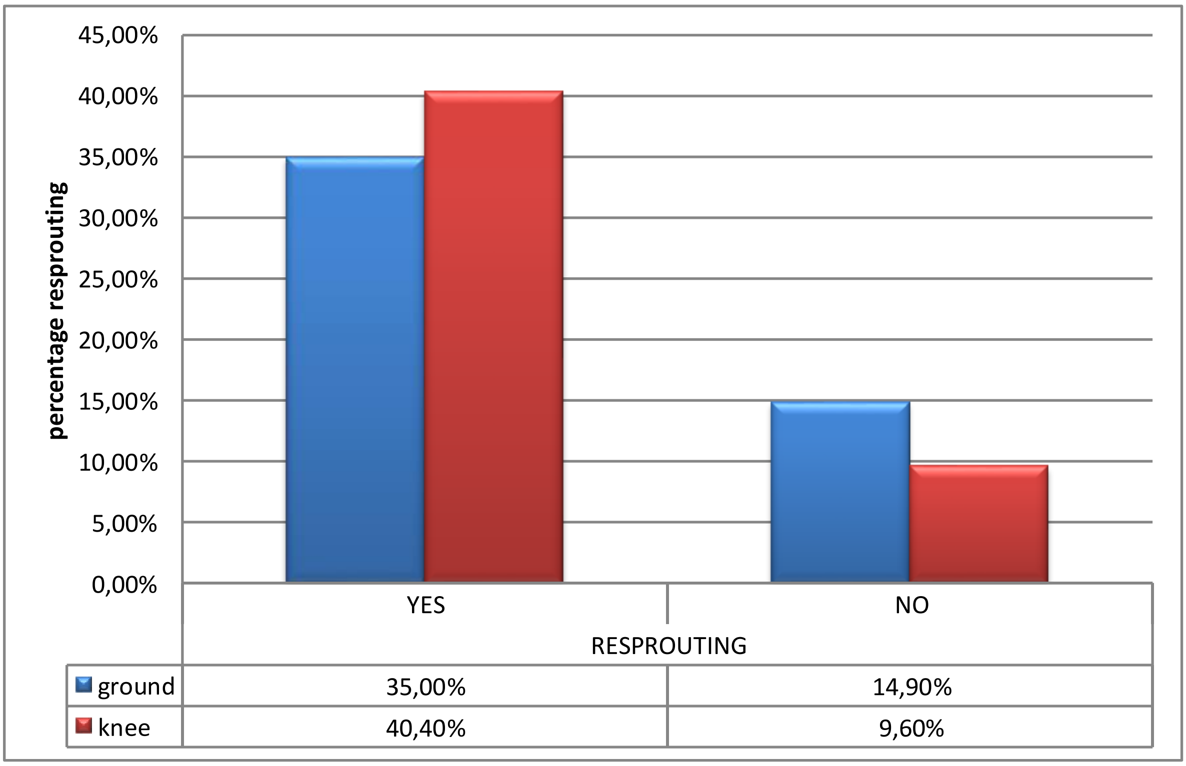


Figure 4.6: The percentages of sprouting between ground and knee level for all species.

Populus alba produced the longest sprout of 43.7 cm, followed by *Acacia melanoxylon* which produced the sprout of 32. 8 cm. *Acacia decurrens* produced sprouts that were short of 11.2 cm and not too many. More especially the sprouts of plants that were found 150 m away from the river measured up to 6.4 cm (Figure 4.7).

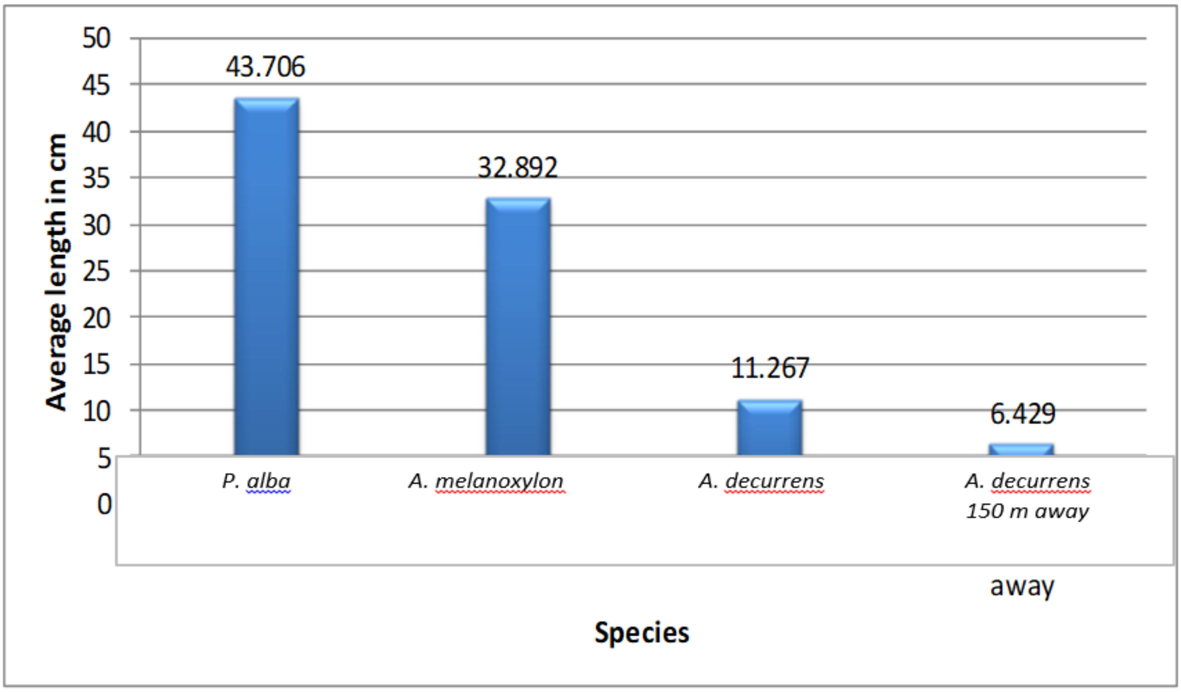


Figure 4.7: Average length of the sprouts per species.

Analysis of variance (ANOVA) was used to analyze the differences between group means and their associates (number of sprouts, number of nodes, length of sprouts and productive nodes) and separates the total variability found within data set into two components. The table below indicates that there is a difference between the three species, which means that there is a significant difference between the groups. The significant group difference can be determined by examining the means plot and identifying the intervals that do not overlap (Table 4.4).

Table 4.4: The standard deviation of *P. alba*, A*. melanoxylon* and *A. decurrens* with number of sprouts, length of sprouts and number of nodes

Descriptives		**N**	**Mean**	**Std. Deviation**	**Std. Error**
No of sprouts	*P. alba*	780	4.673	1.7529	0.0628
	A. melanoxylon	780	10.959	7.3550	0.34
	A. decurrens	772	3.960	6.7823	0.2441
	A. decurrens 150 m *away*	780	1.197	1.5844	0.0567
	Total	3112	5.201	6.2552	0.1121
Length (cm)	*P. alba*	780	43.706	18.6201	0.6667
	A. melanoxylon	780	32.892	18.4976	0.6623
	A. decurrens	772	11.267	14.2258	0.5120
	A. decurrens 150 m *away*	780	6.429	9.0144	0.3228
	Total	3112	23.605	21.8556	0.3918
No of nodes	*P. alba*	780	6.692	4.2554	0.1524
	A. melanoxylon	780	10.288	6.3960	0.2290
	A. decurrens	772	3.518	3.4110	0.1228
	A. decurrens 150 m *away*	780	2.894	1.5536	0.0556

	Total	3112	5.854	5.1888	0.0930
	P. alba	780	6.106	3.4039	0.1219
	A. melanoxylon	780	7.065	4.0894	0.1464
Productive nodes	*A. decurrens*	772	2.299	3.1097	0.1119
	A. decurrens 150 m *aways*	780	.974	1.2975	0.0465
	Total	3112	4.116	4.0466	0.0725

Analysis of variance to analyse the differences between group means of the seasons and their associates (number of sprouts, number of nodes, length of sprouts and productive nodes) and also separates the total variability it indicates that there is a difference between the seasons depending on the growth of the species, which means that there is a significant difference between the groups of the seasons. There is more variation between these species based on how they respond to cutting. There is a significant difference between almost categories of all the species, the p value is less than 0. 05 (p<0. 05) (Table 4.5).

Table 4.5: The significance difference between number of sprouts, length of sprouts, number of nodes and productive nodes.

ANOVA

		Sig.
No of sprouts	Between Groups	0.000
	Within Groups	
	Total	
Length (cm)	Between Groups	0.000
	Within Groups	
	Total	
No of nodes	Between Groups	0.000
	Within Groups	
	Total	
Productive nodes	Between Groups	0.000
	Within Groups	
	Total	

4.3 Management strategies for controlling invasive alien plants

Populus alba shows a big difference compared to *A. decurrens* and *A. melanoxylon* which were similar in terms of its response to cutting. *P. alba* had higher growth rate than all the Acacia species (Figure 4.8).

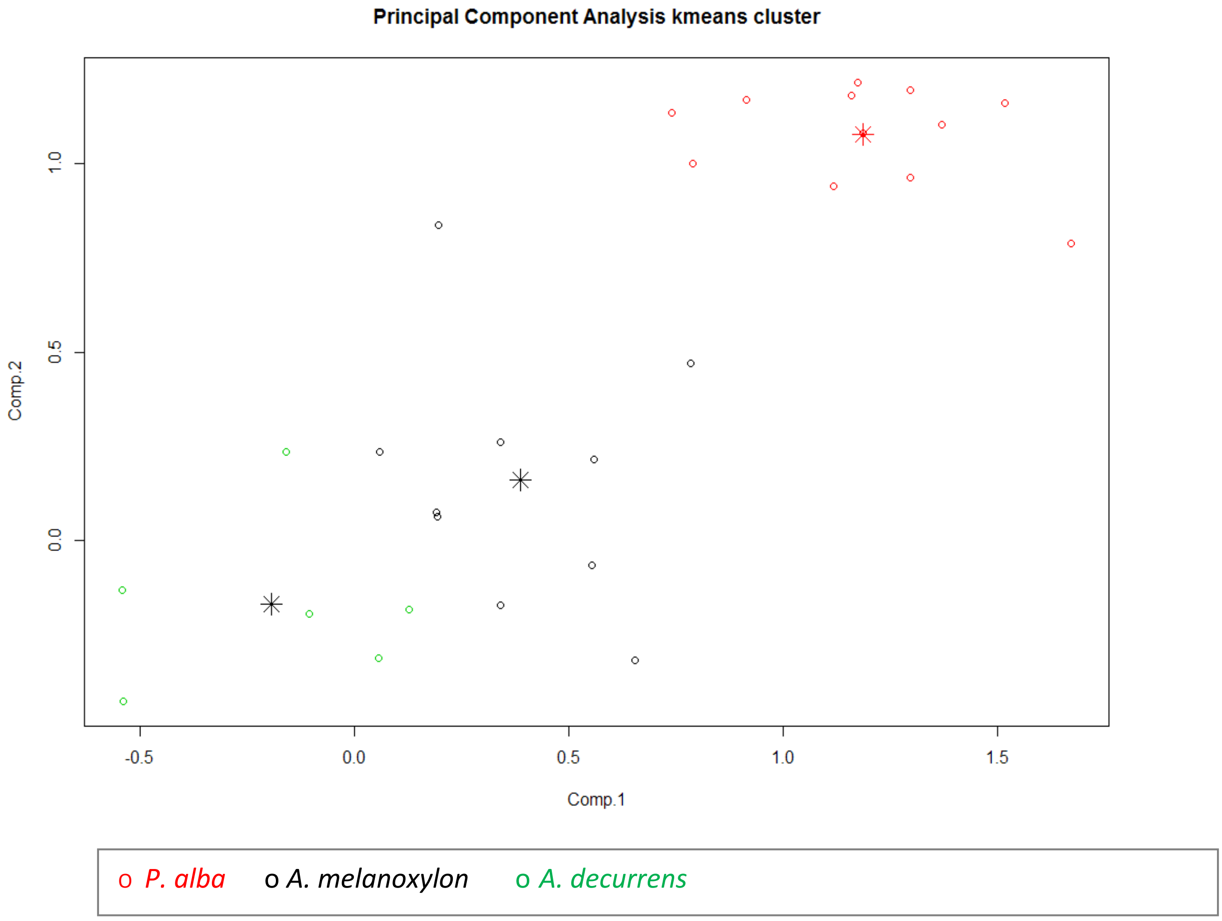


Figure 4.8: Principal component analysis (PCA) cluster shows the difference between the three species in terms of their growth rate after cutting.

All species responded well in summer but in winter *A. decurrens* 150 m away from the river had very few resprouts (117). In spring *A. decurrens* 150 m away from the river had the highest number of sprouts (195). There was no much difference in resprouts in autumn and winter (Figure 4.9).

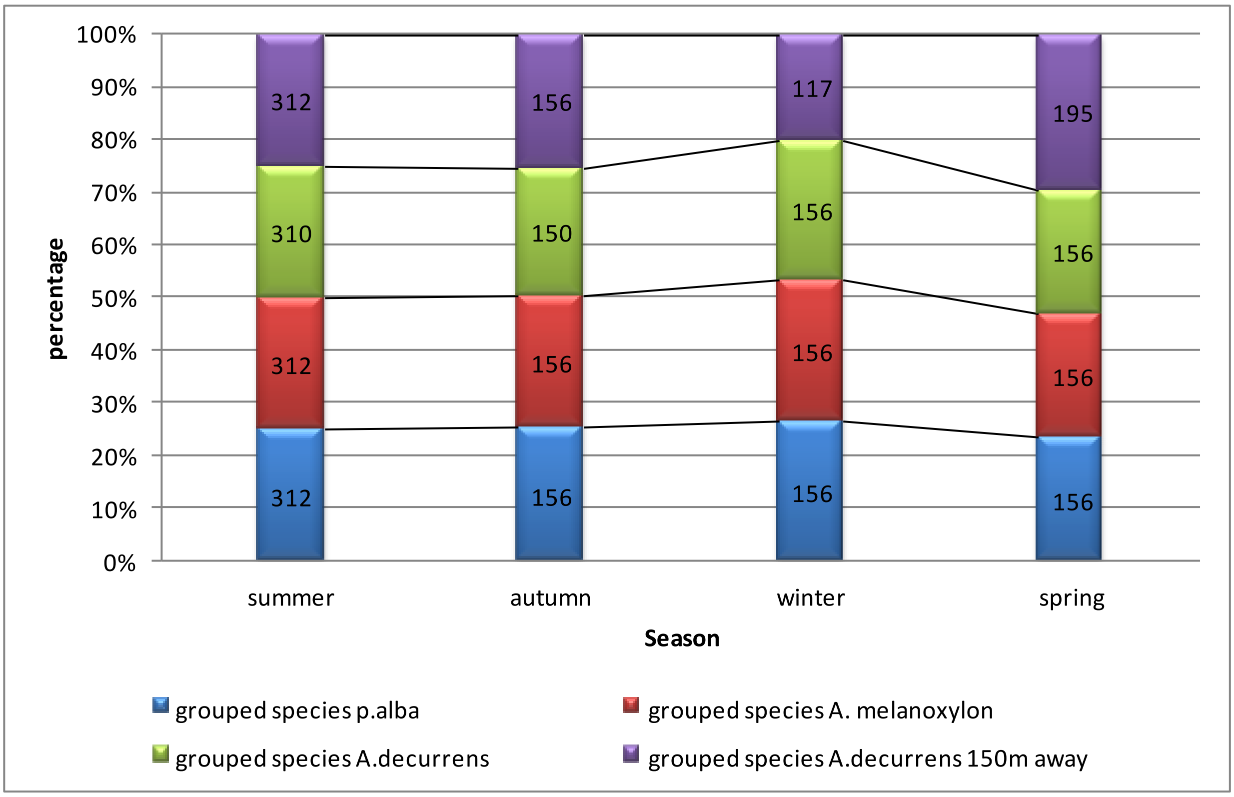


Figure 4.9: The percentages pattern of how *P alba, A decurrens, A melanoxylon* and *A decurrens* 150 m away from the river responded to cutting throughout all the seasons

The longest average length of sprouts of 38.3 cm was recorded in autumn, while the shortest length of 18 cm was recorded in winter (Figure 4.10).

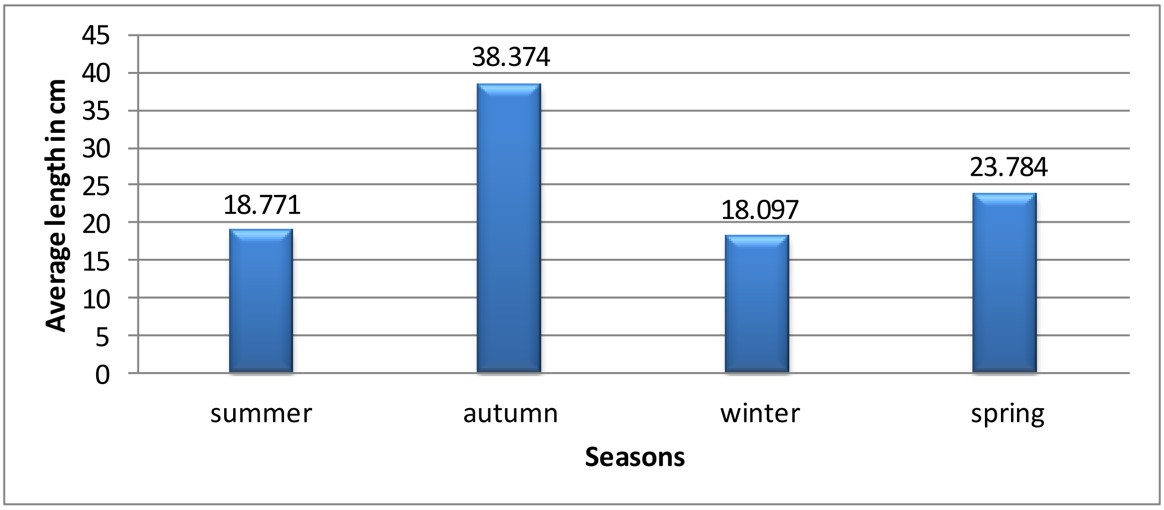


Figure 4.10: The average length of sprouts per seasons of all species.

CHAPTER 5

DISCUSSIONS

Eradication of invasive alien species is one of the methods used as indicator for biodiversity improvement (McGeoch *et al*., 2010), where eradication is defined as the elimination of every single individual of a species from an area to a point at which re-colonization is unlikely to occur (Myers *et al*., 1998). However, invasive alien plants tend to have survival strategies which enable them to survive and compete with indigenous plants. The relative competitive performance of native against invasive species depends on environmental conditions (Daehler, 2001).

5.1 Survival strategies through root suckering

Root suckering allows persistence and resilience to any disturbances (Wakeling and Bond, 2007). However, root suckering has not been previously considered in either the spread or management strategies for controlling invasive alien plants. Root suckers were observed in all invasive alien species with *Populus alba* with 99% (Fig. 4.1). Results revealed that on average IAP have different survival strategies from root suckering to resprouting in different seasons. Of all sampled species there is a mechanism of root suckering observed, except for the *Acacia decurrens* that was sampled 150 m away from the water resource. *Populus alba* shows a big difference compared to the other two species in terms of its response.

The survival strategies of IAP in both adult and juveniles differed. Such gives advantage to alien species survival and making eradicating very difficult. *Acacia decurrens* 150 m away from the river had no root suckers. Wiehle *et al*. (2009) found that *Populus euphratica* growing away from the riparian zone had fewer root suckers, therefore root growth depends on water availability. Gavin and Peart (1999) mention soil disturbances and floods enhance root suckers. Britez *et al*. (2020) confirm that it is more likely that sprouts from root sucker survive than those from the high up the stump.

5.2 Importance of sprouts in invasive alien plants

In trees, sprouting is the process through which replacement trunks develop after the original stem has been cut or suffered damage (Tredici, 2001). In the current study *A. melanoxylon* responded positively (100%) (Fig. 4.2) While *A. melanoxylon* is known to form persistent seed banks that require a heat stimulus for germination to occur (Richardson and Kluge, 2008), its response to cutting at ground level showed high survival strategies. This is further supported by the small proportion and limited distribution of seedlings within populations. For example, *Robinia pseudoacacia* regenerates asexually after cutting through adventitious buds and induce growth on stumps and roots (Iliev *et al*., 2005). Based on this study, *Acacia decurrens* are also difficult to control because they respond very fast to cutting (Fig. 4.2). This might be a basis for natural selection in response to new weeding techniques (Neve *et al*., 2009). *Acacia decurrens* that was sampled along the river was resprouting at 72 % whilst the other sampled at 150 m away from the river was resprouting at 60.5% this clearly indicates that availability of water underground played a role (Wiehle *et al*., 2009).

Based on the results, trees cut at the knee level responded by 40.4% resprouting after cutting than trees cut at the ground level which responded by 35 % (Fig 4.3). Contrary, Oliver *et al*. (2020), found that cutting tree at ground level in *Impatiens glandulifera* had resprouts than high cutting (knee level). The early regenerative stage has been recommended as an optimum time for cutting *I. glandulifera* (Helmisaari, 2010). If cut as juveniles, they may start to regrow and produce seeds after cutting (Jernelöv, 2017).

All trees cut at ground and knee level were resprouting in all the two sites (Fig. 4.4). This clearly indicates that this plant depends on coppicing or sprouting for survival apparently by cutting down the trees and applying herbicides correctly on the cut stump might suppress the growing of these plants. Resprouting of woody plants after cutting is a common trait in African savannas and forests (Luoga *et al*., 2002; Mwavu and Witkowski, 2008). The effect of cutting height on the subsequent height of the coppice growth differed between the three species. In the case of *A. melanoxylon* the total height of the coppice growth, during all five seasons, differed significantly ($P< 0.001$) between plants that were cut at different heights. The significance of the differences decreased slightly over time. If the objective for cutting trees is to increase the amount of browsable leaves at low browsing levels a cutting height above 5 cm is recommended, but there appears to be little advantage of a cutting height above 30 cm (Smit, 2003).

The difference in response to cutting in adult and juvenile trees at ground level is indicated in (Fig 4.5). Adult trees cut at ground level produce more nodes than juveniles, but juveniles had greater number of sprouts and longest sprout was recorded at ground level. Adult tree had average number of nodes this could be because adult trees has a big circumference than juveniles and (Fig 4.6) shows the percentages of trees cut at the knee level responded at 40.4% resprouting, following cutting than those trees cut at the ground level at 35%. As sprouters have lower biomass than nonsprouters of the same age, growth is a function of whole-plant allocation. The important implication is that plants with similar leaf properties might have widely divergent growth rates depending on the reserves allocated for resprouting (Kobe, 1997).

Fig 4.7 shows that *P. alba* produced the longest sprout of 43.7 cm and *A decurrens* had short average length of sprout 11.2 cm next to river. However, 6.4 cm average sprout was recorded for *A. decurrens* that was 50 cm away from the river. One of the finding in this study revealed that the growth of *A. decurrens* sprouts next to the river was higher than those found 50 m away from the river. This could be because *A decurrens* next to the river has access to water while the *A decurrens* that is 50 m away from the river has limited water resource. As discussed above, Table 4.2, also indicates that *P. alba* has the longest sprout recorded. Sprouting ability is an important, but neglected, consideration for conservation and management of plant species. Nonsprouters will be more vulnerable to recruitment failure after severe disturbance. Sprouting behaviour is a key trait for persistence influencing the ecology of individuals, populations and communities (Higgins, 2000).

Acacia decurrens and *A. melanoxylon* are similar in terms of their response to cutting as they seem to somehow overlap in their response (Fig. 4.8). Species of related taxa with morphological and ecological characteristics are more likely to response the same, in terms of invasion success (Pyšek *et al*., 2003; Pyšek and Richardson, 2007). Acacia species had a high adaptation and fast growth (i.e. diameter and height) which was better than the other species. Changing tree community's basal area in early succession stage are driven, in absolute and relative scales, by tree growth more than mortality and recruitment (Breugel *et al*., 2007).

A. decurrens and *A. melanoxylon* are legumes and their nitrogen-fixing ability, and drought resistance (Graham and Vance, 2003). An assessment of invasiveness and feasibility of eradication, based on a species 'biology and population dynamics, will provide a good indication of the risk posed by a species and inform plans for the species' management (Zenni *et al*., 2009). All species responded well in summer than in winter. In spring *A. decurrens* close to the river had the highest number of sprouts with 195 shoots (Figure 4.9). The dormancy of vegetative traits depends on meristem activities in most perennial plants (Rohde and Bhalerao, 2007).

All species cut at both ground and knee level had resprouts, however trees cut at knee level produced more sprouts, 5% more than trees cut at ground level. The density in the successional changes might indicate the potential for density, both in trees and the regenerating seedlings and saplings, depending on the effects of mortality, growth and recruitment (Uriarte *et al*., 2004). The average length of sprouts per season of all species was recorded in autumn and the shortest length was recorded in winter

(Figure 4.10). This could be because winter is a dormant season where plants reserve their energy for the next growing season.

Chapter 6

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

This study investigated the survival strategies of *Acacia decurrens*, *Acacia melanoxylon* and *Populus alba* in the Waterberg District savanna site in South Africa, with the aim of improving our understanding of the range of survival strategies used by Invasive alien plant species (IAP). The traits of IAP were investigated as well as their regrowth after cutting. This was to demonstrate a data-driven approach to identifying survival strategies as a step towards integrating information across a range of different invasive alien plants. In order to investigate survival strategies of invasive alien plant species, three common alien invasive species were selected, surveyed, roots were exposed, cut and monitored over 12 months. *Popolus alba* can regrow faster through root sucker than *A. decurrens* and *A. melanoxylon*. It was evident that species cut during growing season as there were less resprouting at this period. It is important that during eradication to focus more on adult individuals as they have low respond of sprouts. Ecological studies of this type are needed to elucidate the underlying mechanisms behind invasions.

Different survival strategies were observed on all three invasive alien plants *A. decurrens*, *A. melanoxylon* and *P. alba* after cutting and digging disturbance. The level of invasion varies as per resource availability (Davis *et al*., 2000) and management factors. Resources and the fluctuation in their availability can also play a role in the invasion process (Davis, *et al*., 2000). Once a species becomes established in a new region considerable time may pass before there is a noticeable increase in the population size (Crooks, 2005).

This study will provide the basis for the establishment of a national level invasive species management programme. In terms of National Environmental Management Biodiversity Act (NEMBA), Section 75 (4). It will constitute an invasive species control and eradication strategy as envisaged in section 8 (2) (a) of the NEMBA regulations. Simultaneously it should be realised that failure to invest in intensive management of alien invasive plant will have detrimental effect on South Africa economy which my lead to severe long-term economic consequences and affect numerous livelihoods particularly in resource poor communities.

6.2 Conclusion

Most of the studies in alien plant invasion are based on observation without further experimental testing (Fuentes-Ramirez *et al*., 2011), which is the case in this study. It will be important to conduct herbarium or field experiment in order to include other environmental factors involved. Cutting of invasive alien plant at a knee level is not a good way of controlling method because more shoots resprout are formed from the stump as a survival strategy. Otherwise cut stump at a ground level can be the most suitable cutting method to control alien invasive plants, as fewer resprouts were formed at a ground level compared to knee level. Sprouting ability is an important, but neglected, consideration for conservation and management of plant species

6.3 Recommendations

Cutting alone is not effective in controlling the invasion of alien plant it is therefore recommend that herbicide be applied according to the herbicide species list. From the results species growing way from the river produce less sprouts, it will therefore be a good idea to focus on populations which are close to the river as it also recommended by working for water. The implementation of strategy requires national management and coordination and the cooperation and commitment of all stakeholders. It is an expensive operation to control alien invasive plants and it will only be worth the investment if it is granted sustained high-level funding on pre-determined time scale.

The potential impact of invading invasive alien woody plants on water resources was known to be serious but there has been no information available evaluate significance of these water losses across the whole country and finally, the findings are very important for future consideration because they also serve as the scheme for the policy makers and new compatible management of invasive alien plants in the country and provide recommendation for national management strategies.

References

Ahimbisiwe, B.P. 2000. A socio-economic assessment of the impact of invasive alien plant species on forestry production; the case study of *Senna spectabilis* in Budongo Forest River, Uganda. MSc Thesis, University of Pretoria, Pretoria, South Africa.

Baskin, Y. 2002. A plague of rats and rubber vines: the growing threat of species invasion. Island Press. Washington DC, United States of America.

Bezeng, B.S., Savolainen, V., Yaessoufou, K., Papadopulos, A.S.T., Maurin, O. and van der Bank, M. 2013. A phylogenetic approach towards understanding the drives of plants invasiveness on Robben Island, South Africa. *Botanical Journal of the Linnean Society* **172**: 142-152.

Blossey, B. and Notzold, R. 1995. Evolution of increased competitive ability in invasive nonindigenous plants—a hypothesis. *Journal Ecology* **83**: 887-889.

Boland, D.J. 1987. Genetic resources and utilisation of Australian bipinnate acacias (Botrycephalae). In: Turnbull, J.W. (ed) Australian Acacias in Developing Countries. Proceedings of an International Workshop held at the Forestry Training Centre, Gympie, Qld, Australia, 4–7 August 1986. Australian Centre for International Agricultural Research, *Proceedings* No. **16**: 29-37.

Bourdeau, P.F. 1953. A Test of Random Versus Systematic Ecological Sampling. *Ecology* **34**(3): 499-512.

Breugel, M.V., Martínez-Ramos, M. and Bongers, F. 2006. Community dynamics during early secondary succession in Mexican tropical rain forests. *Journal of Tropical Ecology* **22**: 663-674.

Britez D.D., Claudia Romero, C., Francis E. and Putz (Jack), F.E. 2020. Coppicing of two native but invasive oak species in Florida. *Forest Ecology and Management* 477.118487.

Buhler, D.D., Liebman, M. and Obryck, J.J. 2000. Theoretical and practical challenges to an IPM approach to weed management. *Weed Science* **48**: 274-280.

Buhler, D.D., Liebman, M. and Obryck, J.J. 2000. Theoretical and practical challenges to an IPM approach to weed management. *Weed Science* **48**: 274-280.

Cassey, P.T., Blackburn, M., Duncan, R.P. and Chrown, S.L. 2005. Concerning invasive species: reply to Brown and Sax. *Australian Ecology* **30**: 475-480.

Chapin, F.S., Zavaleta, W.S., Eviner, T.V., Naylor, R.L., Vitousek, O.M., Reynold, H.L., Hooper, D.U., Lavovel, S., O.E., Hobbie, S.E., Mack M.C. and Plaz. S. 2000. Consequences of changing biodiversity. *Nature* **405**: 234-241.

Chapin, F.S., Zavaleta, W.S., Eviner, T.V., Naylor, R.L., Vitousek, O.M., Reynold, H.L., Hooper, D.U., Lavovel, S., O.E., Hobbie, S.E., Mack, M.C. and Plaz, S. 2000. Consequences of changing biodiversity. *Nature* **405**: 234-241.

Cohen, A.N. 2002. Success factors in the establishment of human-dispersed organisms. In: Bullock, J.M., Kenward, R.E., Hails, R.S (Eds), Dispersal Ecology. Blackwell Science Ltd, Oxford, pp. 374-394.

Crooks, J.A. 2005. Lag times and exotic species: The ecology and management of biological invasions in slow–motion1. *Ecoscience* **12**(13): 316-329.

Daehler, J. 2001. Alien plant control guide. Rennies Wetland Projects, South Africa.

Davis, M.A., Grime, P. and Thompson, K. 2000. Fluctuating resources in plant communities: *A* general theory of invisibility. *Ecology* **88**: 528-532.

Department of Water Affairs, Working for Water, Annual Report, 2012/13.

Dickmann, D.I. 2001. An overview of the genus Populus, In: Poplar Culture in North America, Dickmann, D.I., Isebrands, J.G., Eckenwalder, J.E., Richardson, J., (Ed.), pp. 1-42, NRC Research Press, Ottawa, Ontario, Canada.

Dogra, K.S., Sood, S.K., Dobhal, P.K. and Sharma, S. 2010. Alien plant invasion and their impact on indigenous species diversity at global scale: A review of *Journal of Ecology and the Natural Environment* **2**:175-186.

Ehrenfeld, J.G. 2010. Ecosystem consequences of biological invasions. *Annual Review Ecology Evolution and Systematic* **41**: 59-80.

Elliott, K.J., Boring, L.R. and Swank, W.T. 1998. Changes in vegetation structure and diversity after grass-to-forest succession in a Southern Appalachian watershed. *The American Midland Naturalist* **140**: 219-232.

Enright, W.D. 2000. The effect invasive alien plants on water scarcity in South Africa. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere* **25**(30): 237-242.

Fuentes-Ramires, A., Pauchard, A., Cavieres, L.A. and Garcia, R.A. 2011. Survival and growth of *Acacia delbata* vs. native trees across an invasion front in south-central Chile. *Forest Ecology and Management* **261**: 1003-1009.

Gaertner, M., Breeyen, A.D., Hui, C. and Richardson, D.M. 2009. Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: a meta-analysis. *Progressive, Physiology and Geography* **33**: 319-338.

Gaertner, M., Breeyen, A.D., Hui, C. and Richardson, D.M. 2009. Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: a metaanalysis. *Progressive Physiology and Geography* **33**: 319-338.

Gibson, M., Richardson, D.M., Marchante, E., Marchante, H., Rodger, J.G., Stone, G.N., Byrne, M., Fuentes-Ramírez, A., George, N., Harris, C., Johnson, S.D., Le Roux, J.J., Murphy, D.J., Pauw, A., Prescott, M.N., Wandrag, E.M. and Wilson, J.R.U. 2011. Reproductive ecology of Australian acacias: fundamental mediator of invasive success? *Diversity and Distributions* **17**, 911-933.

Gould, A. 2000. Out of Eden: An odyssey of ecological invasion. Farrar Straus and Giroux. New York, United States of America.

Graham, P.H. and Vance, C.P. 2003. Legumes: importance and constraints to greater use. *Plant Physiology* **131**: 872-877.

Graham, P.H. and Vance, C.P. 2003. Legumes: importance and constraints to greater use. *Plant Physiology* **131**: 872-877.

Gyokusen, K., Iijima, Y. and Yahata, H. 1991. Spatial distribution and morphological features of root sprouts in Niseakashia (*Robinia pseudo-acacia L*.) growing under a coastal black pine forest [*Pinus thunbergii*] forest. *Bulletin of the Kyushu University Forests* **54**:13-28.

Hejda, M., Pyšek P. and Jarošík, V. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of Ecology* **97**(3): 393-403.

Helmisaari, H. 2010. Invasive Alien Species Fact Sheet—*Impatiens glandulifera*. Online Database of the European Network on Invasive Alien Species—NOBANIS. www.nobanis.org. Accessed: September 12, 2019.

Henderson, L. 2020. Invasive Alien Plants in South Africa: a complete guide to declared weeds and invaders in South Africa. Plant Protection Research Institute Handbook No. 21, Plant Protection Research Institute. Agricultural Research Council, South Africa, pp. 1-384. Pretoria.

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

Henderson, L. 2001. Alien weeds and invasive plants: a complete guide to declared weeds and invaders in South Africa. Plant Protection Research Institute Handbook No. 12, Plant Protection Research Institute. Agricultural Research Council, South Africa, pp. 1-300. Pretoria.

Higgins, S.I., Pickett, S.T.A. and Bond W.J. 2000. Predicting extinction risks for plants: environmental stochasticity can save declining populations. *Trends in Ecology and Evolution* **15**(12): 516-520.

Hobbs, R.J. and Hunneke, L.F. 1992. Disturbance, diversity and invasion. Implications for conservation. *Conservation Biology* **6**: 324-337.

Holmes, P.M., Richardson, D.M., Esler, K.J., Witkowski, E.T.F. and Urie, S. 2005. A decision-making framework for restoring riparian zones regarded by invasive alien plants in South Africa. *South African Journal of Science* **101**: 553-564.

Holmes, P.M., Richardson, D.M., Esler, K.J., Witkowski, E.T.F. and Urie, S. 2005. A decision-making framework for restoring riparian zones regarded by invasive alien plants in South Africa. *South African Journal of Science* **101**: 553-564.

Hulme, P.E. 2006. Beyond control: wider implications for the management of biological invasions. *Journal of Application Ecology* **43**: 835-847.

Hussain, M.I., El-Sheikh, M.A. and Reigosa M.J. 2020. Allelopathic Potential of Aqueous Extract from *Acacia melanoxylon* R. Br. On *Lactuca sativa*. *Plants* **9** (9): 1228.

Iliev, N., Iliev, I. and Park, Y. 2005. Black locust (*Robinia pseudoacacia* L.) in Bulgaria. *Journal Korean Forestry Society* **94**: 291-301.

Jernelöv, A. 2017. Himalayan balsamin Europe. Pages 39-54 in Jernelöv A. The Long-Term Fate of Invasive Species: Aliens Forever or Integrated Immigrants with Time? Cham, Switzerland: Springer International.

Kobe, R.K. 1997. Carbohydrate allocation to storage as a basis of interspecific variation in sapling survivorship and growth. *Oikos* **80**: 226-233.

Kodela, P.G. and Tindale, M.D. 2001. Acacia subg. Acacia. *Flora of Australia* **11A**: Mimosaceae.196-207.

Kowarik, I. 1995. Time lags in biological invasions with regard to the success and failure of alien species. Plant invasions: general aspects and special problems, 15-38.

Kupchella, C.E. and Hyland, M.C. 1993. Environmental Science. Living within the system of nature. Prentice Hall. New Jersey, United States of America.

Liao, C., Peng, R., Luo, Y., Zhou, X., Wu, X., Fang, C., Chen, J. and Li, B. 2008. Altered ecosystem carbon and nitrogen cycles by plant invasion: a meta-analysis. *New Phytologist* **177**, 706-714.

Luoga, E.J., Witkowski, E.T.F. and Balkwill, K. 2002. Harvested and standing wood stock in protected and communal miombo woodlands of eastern Tanzania. *Forest Ecology and Management* **164**: 15-30.

Macdonald, I.A.W., Reaser, J.K., Bright, C., Neville, L.E., Howard, G.W., Murphy, S.J. and Preston. G. 2003. Invasive alien species in southern Africa: National reports and directory of resources. Global Invasive Species Programme, Cape Town, South Africa.

Mack, R.N. 1985. Invading plants, their potential contribution to population biology. In studies on plant demography, Academic Press, New York, pp. 127-142.

Mack, R.N. 1996. Predicting the identity and fate of plants invader, emergent and emerging approaches. *Biological Conservation* **78**: 107-142.

Magoba, R.N.N. 2005. Effect of invasion and clearing of alien riparian vegetation on benthic macro invertebrate and adult Odonota assemblages in Soutpansberg Rivers, Unpublished MSc thesis. University of Stellenbosch. Stellenbosch, South Africa.

Martı´nkova´, J., Klimesˇova´, J. and Mihulka, S. 2008. Compensation of seed production after severe injury in the short-lived herb *Barbarea vulgaris*. *Basic Applied Ecology* **9**: 44–54.

Maslin, B.R., Orchard, A.E. and West, J.G. 2003. Nomenclatural and classification history of Acacia (Leguminosae: Mimosoideae), and the implications on generic subdivision. WorldWideWattle. 2003

Mbedzi, M., Tshisikhawe, P., Sinthumule, I. and Rahlao, S. 2019. The rate of recolonization by native plant species after the Eradication of the invasive alien plant species (*Populus alba* L.) in the Limpopo Province, South Africa. *Ecology, Environment and Conservation* **25**(4): 1672-1678.

McGeoch, M.A., Butchart, S.H.M., Spear, D., Marais, E., Kleynhans, E.J., Symes, A., Chanson, J. and Hoffmann, M. 2010. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. *Diversity and Distributions* **16**: 95-108.

Milton, S.J. 2004. Grasses as invasive alien plants in South Africa. *South African Journal of Science* **100**(1-2), 69-75.

Mwavu, E.N. and Witkowski, E.T.F. 2008. Sprouting of woody species following cutting and tree fall in a low land semi-deciduous tropical rainforest, North-Weastern Uganda. *Forest Ecology and Management* **225**: 982-992.

Myers, J.H., Savoie, A. and van Randen, E. 1998. Eradication and pest management. *Annual Review of Entomology* **43**: 471-491.

Neve, P., Vila-Aiub, M. and Roux, F. 2009. Evolutionary thinking in agricultural weed management. *New Phytologist* **184**: 783-793.

Oliver, B.W., Berge, T.W., Solhaug, K.A. and Fløistad, I.S. 2020. Hot water and cutting for control of *Impatiens glandulifera*. *Invasive Plant Science Management* **13**: 84-93.

Orchard, A.E. and Wilson, A.J.G. 2001. Flora of Australia, Volume 11A, Mimosaceae,

Paynter, Q., Csurhes, S.M., Heard, T.A., Ireson, J., Julien, M.H., Lloyd, J., Lonsdale, W.M., Palmer, W.A., Sheppard, A.W. and van Klinken, R.D. 2003. Worth the risk? Introduction of legumes can cause more harm than good: an Australian perspective. *Australian Systematic Botany* **16**: 81-88.

Peiterse, P.J. 1998. Seed damage by indigenous Alydidae (Heteroptera) on the exotic *Acacia implexa* (Fabaceae). *African Plant Protection* **4**(1): 11-13.

Pimentel, D., Zuniga, R. and Morrison, D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* **52**, 273-288. Acacia Part 1.

Pimentel, D., Lach, L., Zuniga, R. and Morrison, D. 2000. Environmental and economic costs of non-indigenous plants in the United State. *Biological Science* **50**: 53-56.

Powell, K.I., Chase, J.M. and Knight, T.M. 2011. A synthesis of plant invasion effects on biodiversity across spatial scales. *American Journal of Botany* **98**: 539-548.

Poynton, R.J. 2009. Tree planting in southern Africa. Volume 3: Other genera, Department of Agriculture, Forestry and Fisheries, Pretoria.

Pryor, L.D. and Banks J.C.G. 1991. Trees. Australian Capital Territo" Canberra. ACT Parks and Conservation Service.

Pyšek, P. 1998. Alien and native species in Central European urban floras: a quantitative comparison. *Journal of Biogeography* **25**(1): 155-163.

Pyšek, P. and Richardson, D.M. 2007. Traits associated with invasiveness in alien plants: Where do we stand? Biological invasions (ed. W. Nentwig), pp 97-126. Springer-Verlag, Berlin.

Pyšek, P. and Richardson, D.M. 2007. Traits associated with invasiveness in alien plants: Where do we stand? Biological invasions (ed. W. Nentwig), pp 97-126. Springer-Verlag, Berlin, Germany.

Pyšek, P., Jarošík, V. and Kučera, T. 2003. Inclusion of native and alien species temperate nature reserves: an historical study from Central Europe. *Conservation Biology* **17**(5): 1414-1424.

Pyšek, P., Jarošík, V., Hulme, P.E., Kuhn, I., Wild, J., Arianoutsou, M., Bacher, S., Chiron, F., Didziulis, V., Essl, F., Genovesi, P., Gherardi, F., Hejda, M., Kark, S., Lambdon, P.W., Desprez-Loustau, A.M., Nentwig, W., Pergl, J., Poboljsaj, K., Rabitsch, W., Roques, A., Roy, D.B., Solarz, W., Vilà, M. and Winter, M. 2010. Disentangling the role of environmental and human pressure on biological invasions across Europe. *Proceedings of the National Academy of Sciences of the United State of America* **107**: 12157-12162.

Raizada, P. 2007. Invasive species: the concept, invasion and impact management of invaders. Environmental News of newsletter of ISEB India 3: 1-4.

Reed, E.B. 2007. Does the scale of alien plant invasive affect native insects communities? MSc thesis, University of Delaware. Newark, United State of America.

Remaley, T. and Sewaringen, J.M. 1998. White poplar, Populus alba fact sheet. Alien plant invaders of natural areas. htttp://www.nps.gov/plants/alien/fact/poal l.htm (Accessed 10 November 2014).

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

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

Richardson, D.M. 1998. Forestry trees as invasive aliens. *Conservation Biology* **12**: 18-26.

Richardson, D.M. 2011. Forestry and agroforestry. In: Encyclopedia of Biological Invasions (eds D. Simberloff and M. Rejmánek) pp. 241–8. University of California Press, Berkeley, United States of America.

Richardson, D.M., Macdonald, I.A.W. and Van Wilgen, B.M. 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? *African Journal of Science* **100**: 42-52.

Richardson, D.M., Macdonald, I.A.W. and Van Wilgen, B.M. 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? *African Journal of Science* **100**: 42-52.

Rohde, A. and Bhalerao, R.P. 2007. Plant dormancy in perennial context. *Trends in Plant Science* **12**: 217-223.

Ruskin, F.R. 1983. *Acacia mangium* and other fast growing, Acacias for humid tropical Region National Academy Press. Washington D.C., United States of America.

Uriarte, M., Canham, C.D., Thompson, J. and Zimmerman, J.K. 2004. A neighbourhood analysis of tree growth and survival in a Hurricane-Driven Tropical Forest. *Ecological Monographs* **74**: 591-614.

Scholes, R.J. and Walker, B.H. 2004. An African savanna: Synthesis of the Nylsvley study. Cambridge University Press. Cambridge. United Kingdom.

Searle, S.D. 2000. *Acacia melanoxylon* – A review of variation among planted trees. *Australian trees* **63**(2): 79-85.

Semenya, S.S., Tshisikhawe, M.P. and Potgieter, M.T. 2012. Invasive alien plant species: A case study of their use in the Thulamela Local Municipality, Limpopo Province, South Africa. *Scientific Research and Essays* **7**(27): 2363-2369.

Suetsugu, K., Takeuchi, Y., Futal, K. and Kato, M. 2012. Host selectivity haustorial anatomy and impact of the invasive parasite *Parentusellia viscosa* on floodplain vegetative communities in Japan. *Botanical Journal of the Linnean Society* **170**: 69-78.

Swallow, B. and Mwangi, E. 2008. *Prosopis juriflora* invasion in rural livelihoods in the Lake Baringo area of Kenya. *Conservation Society* **6**: 130-140.

Tredici, P. 2001. Sprouting in temperate trees: a morphological and ecological review. *Botany Review* **67**: 121-140.

Tylianakis, J.M., Didham, R.K., Bascompte, J. and Wardle D.A. 2008. Global change and species interactions in terrestrial ecosystems. *Ecology Letters* **11**(12): 1351-1363.

Van Kleunen, M., Weber, E. and Fischer, M. 2010. A meta-analysis of trait differences between invasive and non-invasive species. *Ecology Letters* **13**: 235-245.

Van Wilgen, B.W., Dyer, C., Hoffmann, J.H., Ivey, P., Maitre, D.C.L., Moore, J.L., Richardson, D.M., Rouget, M., Wannenburgh, A. and Wilson, J.R.U. 2011. National-scale strategic approaches for managing introduced plants: insights from Australian acacias in South Africa. *Diversity and Distributions* **17**: 1060-1075.

Van Wilgen, B.W., Richardson, D.M., Le Maitre D.C., Marais C. and Magadlela D. 2001. The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa. *Environment Development and Sustainability* **3**: 145-168.

Van Wilgen, B.W., Richardson, D.N., Le Maitre, D.C., Marais, C. and Magadlela, D. 2001. The economic consequences of alien plant invasion: examples of impacts and approaches to sustainable management in South Africa. *Environment, Development and Sustainability* **3**(2): 145-168.

Vilà, M., Espina, J.L., Hejda, M., Hulme, P.E, Jarošík, V., Maron, J.L., Pergl, J., Schaffner, U., Sun, Y. and Pyšek, P. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. *Ecology Letters* **14**: 702-708.

Vilà, M., Tessier, M., Suehs, C.M., Brundu, G., Carta, L., Galanidis, A., Lambdon, P., Manca, M., Medail, F., Moragues, E., Treveset, A., Troumbis, A.Y. and Hulme, P.E. 2006. Local and regional assessment of the impacts of plant invaders on vegetation structure and soil properties of Mediterranean islands. *Journal Biogeography* **33**: 853-861.

Wakabira, V.J. and Mhaya, J.B. 2002. Possible control *Senna spectabilis* (Caesalpininiaceae), an invasive tree in Mahale Mountains National Park, Tanzania. *Oryx - International Journal of Conservation* **36**(4): 357-363.

Wilson, J.R.U., Gairifo, C., Gibson, M.R., Arianoutsou, M., Bakar, B.B., Baret, S., Celesti-Grapow, L., Dufour-Dror, J.M., Kueffer, C., Kull, C.A., Hoffmann, J.H., Impson, F.A.C., Loope, L.L., Marchante, E., Marchante, H., Moore, J.L., Murphy,D., Pauchard, A., Tassin,J., Witt, A., Zenni, R.D. and Richardson, D.M. 2011. Risk assessment, eradication, containment, and biological control: global efforts to manage Australian acacias before they become widespread invaders. *Diversity and Distributions* **17**: 1030-1046.

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

Zenni, R.D., Wilson, J.R.U., Le Roux, J.J. and Richardson, D.M. 2009. Evaluating the invasiveness of *Acacia paradoxa* in South Africa. *South African Journal of Botany* **75**: 485-496.*y*