Determine area characteristics in the Upper Kromme River Catchment to compare indigenous and invasive species

Locally-based and field-based study in a management perspective

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Presence
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Transnational ecosystem-based Water Management
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Comparison of soil and water characteristics between native and non-native species in the Kromme River Catchment

Locally-based and field-based study in a management perspective

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Research project supporting

Knowledge and management on alien invasions, focused on *Acacia mearnsii*

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Preface

The study Transnational ecosystem-based Water Management is a two year master study at Radboud University Nijmegen in the Netherlands and the University of Duisburg-Essen in Germany.
The final task of the study is to do a last research and to write a master thesis about it. This master thesis has been prepared in South Africa in collaboration with the non-profit organization, Living Lands and the overarching PRESENCE. PRESENCE stands for Participatory Restoration of Ecosystem SErvices and Natural Capital, Eastern Cape. This organization is working on conserving and restoring living landscapes. A living landscape consists of a variety of healthy ecosystems and land uses. It is also home to ecological, agricultural, and social systems, which are managed to be sustainable. This ensures that natural and cultural resources are available for future generations and that the system is resilient for adaptation to climate change.

About six months prior to the start of my master thesis, I started to make contact with Living Lands and with Marijn Zwinkels via e-mail and Skype. I was able to do my master thesis at the PRESENCE learning village. The thesis is about the comparison between area characteristics of invaded areas with *Acacia mearnsii* and the area characteristics of Wetland areas with native species, *Prionium serratum,* in the Kromme river catchment.

This master thesis will be the end product of the study Transnational ecosystem-based Water Management, to obtain the double degree;

Master of Science in Transnational ecosystem-based Water Management (TWM) at University of Duisburg-Essen
Master of Science in Biology, Master track TWM at Radboud University Nijmegen

This report is the result of the study performed in South Africa for the period of January until July 2014. I hope this study will contain to a sustainable living landscape in the Kromme river catchment.
I also hope that you will enjoy reading this report.

Yours sincerely,

Sharon van Rossum, 2014

Acknowledgement

Firstly, I would like to thank the whole Living Lands team for giving me the opportunity to do this thesis and for making me feel part of the PRESENCE learning village family. The six months I have stayed here were a great experience and I feel like I learned what is important in nature conservation.

I would like to thank Marijn Zwinkels for his supervision during my work within Living Lands and PRESENCE learning village and for providing me with contact details from the local people in the Kromme river catchment that I should get into contact with gathering information about the Kromme river catchment and the characteristics of *Acacia mearnsii* and the native species.

Furthermore I would like to say thank you to; Eberhard Ernst van der Merwe, for arranging my stay at the PRESENCE learning village, Zandile Naka, who arranged my stay in Port Elizabeth when I arrived in South Africa on the 17th of January 2014 and provided me with information and reports from other students and Julia Glenday for providing me some of the equipment to work with during the fieldwork of my thesis.

A big thank you go to; the landowners for helping me gathering information about the Black Wattle and helping me finding the areas along the Kromme river catchment to perform my fieldwork and I would also like to say thanks to Sam van der Merwe from the Department of Agriculture and Rural development for welcoming me in the Kromme catchment and getting me into contact with local people in the upper Kromme river catchment.

Dr Derek Du Preez provided me with the equipment for my fieldwork and the laboratorial work. Also he provided me with very valuable information about how to do analysis of soil samples and he also provided me with some literature, which I could use for my analysis, for this I would like to thank him.

Also I would like to thank the department of Environmental Affairs and the Department of Water affairs and Forestry for answering questions regarding the management of Black Wattle and its area characteristics and for providing me with literature about the management approach of the Working for Water program.

Although they were not in South Africa, my supervisors at the University of Duisburg-Essen and Radboud University Nijmegen, Christian Feld and Wouter de Groot offered me great help in giving structure to this research and for helping me writing this final thesis.

Last but not least I would like to thank my family and friends for supporting me in the journey to my stay and my stay at PRESENCE learning village Living Lands, South Africa.

Summary

Invasive alien species are a big threat to among others the South African economy, biodiversity, water security and ecological functioning.

Acacia mearnsii is such an invasive species in South Africa and it causes societal, economic and ecological problems in the Kromme river catchment, located in the Eastern Cape of South Africa. This catchment is a very important water resource for the Nelson Mandela Bay Municipality. The degradation of the catchment by among others *Acacia mearnsii* causes a threat to the water availability, livelihood of people and biodiversity in the area.

The tree outcompetes the native wetland species in the area, altering the species composition and biodiversity. Furthermore, these wetland species are very important in the storage of water and purification of water in the catchment. These important functions of this wetland are reasons why a clearing program is implemented by the Working for Water program and why rehabilitation of the area by the Working for Wetland program is needed and already started.

This thesis aims at defining area characteristics that determine the growth of this invasive species and that determine the problems of clearing the Kromme river catchment and of the problems with the growth of native wetland species, such as *Prionium serratum*, in the area. The methods to collect data about these aspects is a local knowledge study and a field-based empirical study. The first method makes use of the knowledge of landowners living and working in the Kromme river catchment and expert working in this field of work. The local landowners and experts were asked what they know about the area characteristics of *Acacia mearnsii* and of the native counterpart, *Prionium serratum*. Almost every respondent mentioned a problem with erosion at places where *Acacia mearnsii* is growing. Furthermore the landowners and experts mentioned that the tree changes soil moisture and that it has a possible tolerance for soil organisms, creating problems for other plant species to grow and develop. Also tannin production by *Acacia mearnsii* was mentioned as being a problem. Those factors are very important in the degradation of the Kromme river catchment and the problems in growth of native species, according to the local people.

The second method, the field-based empirical study is about gathering data on the area characteristics by taking samples and performing field measurements. A difference in water content and Ortho-Phosphate content was found between invaded and non-invaded sites. Furthermore a difference in

diversity of plants was found in the area and also this thesis focused on the abundance of each found species by calculating the Shannon-Wiener index.

The results of these two types of studies were used to make suggestions to the current management approach of the clearing of *Acacia mearnsii*.

The current management strategy is to clear the tree, mainly by felling them, but also by the usage of herbicides or by introducing bio-control agents. Currently the felled trees are often left on the field, which is causing problems with erosion and clogging. For this the tree should be removed and preferably used for one of its original purposes, construction wood, fire wood etc., but it is dependent on the costs and market if this is successful or not.

Furthermore, a follow-up is needed to be implemented by the Working for Water program and the landowners. A follow-up is done after the initial clearing of the tree, to clear newly germinated trees. This should be done to make sure no new seeds are produced and the seed bank is reducing. After removal of the invasive tree, restoration or rehabilitation of the area can be implemented.

Furthermore some more detailed research on the soil could be done to see whether or not there is an important factor in the growth of the tree, which can be used and possibly be the key to successfully remove the tree in the most efficient way.

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Chapter 1
Introduction

Alien (or non-native) species are species introduced to regions or sites outside its native distribution range. These species may become invasive, which is defined as species whose establishment and dispersal modifies ecosystems, habitats, or other species (Middleton and Bailey, 2011).

Human communities and natural ecosystems worldwide are under siege from a growing number of invasive alien species (including; disease organisms, agricultural weeds, and insect pests). These species can have a severe impact on the natural capital, for example, on ecosystem stability, and even on economic productivity (Richardson and Wilgen, 2004).

Most invasive species transform ecosystems by making use of excessive amounts of resources (water, light, oxygen), by adding resources, for example by N_2 fixation, by promoting or suppressing fires, by stabilizing sand movement and/or promoting erosion and/or by accumulating litter (Richardson and Wilgen 2004; Ehrenfeld, 2003). Such changes potentially alter flow, availability or quality of nutrient resources, physical resources (living places or habitat, sediment, light and water) and the invaders alter trophic resources within food webs (Richardson and Wilgen, 2004).

Invasive species, like *Acacia* species (Mill. 1754) (Wattle) also have an influence on riparian areas. *''Riparian areas are the three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width''* (Wagner and Hagan, 2000). Ecotones are the transitional areas between two different ecological communities (Naudé, 2012).

Riparian areas are relatively small components of a landscape, but they are very important in many biological, physical, chemical and socio-economic roles as riparian zones are; habitats for plants and animals, natural filters of sediment, providing good water quality, retaining water, a connectivity to other landscapes, water, food and recreation for human use, a harbour of biotic diversity etc. (Esler et al., 2008).

Also these areas are vulnerable to invasions by alien plants, since this ecotone is disturbed by floods and other associated hydrological impacts. In such areas *Acacia* spp. like *Acacia mearnsii* (De Wild. 1925) (Black Wattle), are important in altering the environment. *Acacia* species cause transformations in vegetation and microbial communities, microclimates, soil nutrient level and moisture regimes (Naudé, 2012).

1.1 Situation of *Acacia* species in the world

Acacia species are widely distributed invader species. Only in Australia (New South Wales, Queensland, Victoria and Tasmania) it is a native species (distribution shown in green in Figure 1.1). It has been introduced throughout the tropics and subtropics, where the plant became invasive in the areas. The large plantations and the resulting, major invasions are found in southern and eastern Africa, (Kenya, Madagascar, South Africa and Zimbabwe) New Zealand, the Western Part of the United States of America, parts of South America, Japan and Spain (Jansen and Cardon, 2005; http://academic.sun.ac.za/cib/team/academic/gthompson.asp).

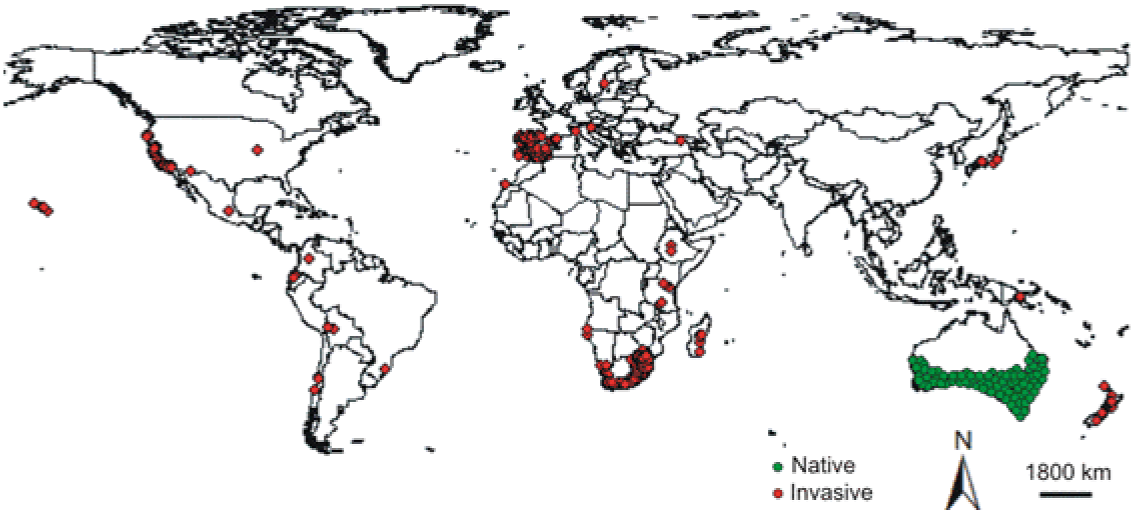

Figure 1.1: Global distribution of nine major Acacia species (*A. baileyana*, *A. cyclops*, *A. dealbata*, *A. decurrens*, *A. longifolia*, *A. mearnsii*, *A. melanoxylon*, *A. pycnantha* and *A. saligna*) *classified as a major invader in South Africa (http://academic.sun.ac.za/cib/team/academic/gthompson.asp).*

1.1.1 Invasion of *Acacia mearnsii* in South Africa

South Africa has a long history of problems with invasive alien species, and of research and management of invasions (Richardson and Wilgen, 2004). *Acacia mearnsii* has already invaded over 2.5 million ha in South Africa (Moyo and Fatunbi, 2010).

The species was introduced to South Africa in the mid-nineteenth century (1850) and was grown in plantation for timber and fuel wood. The bark was used for tannin production, suitable for the manufacture of heavy leather goods. It can also be used for local construction material; mine props, wooden tools, joinery, flooring, and hardboard and to produce paper pulp (Jansen and Carbon, 2005; Wilgen et al., 2011).

The seeds of *A. mearnsii* spread and create dense patches in the surrounding landscapes of plantations. Especially when an industry collapses, the management and control of tree growth stops and the tree can easily spread towards abandoned fields and into the natural vegetation (Wilson et al., 2011).

Invasive alien plants, such as *Acacia mearnsii* (Black Wattle)*,* have replaced (and continue to replace) native riparian vegetation along a lot of water courses in south western and south eastern parts of South Africa. The species grows fast when water is available and a result is the invasion of river systems (Marchante, 2010a; Jansen and Cardon, 2005). The invasive species threaten natural capital, ecosystem stability, agricultural activities and forestry activities. The second largest global threat, after habitat destruction is the threat to biodiversity (Richardson and Wilgen, 2004).

1.2 Economic impacts of *Acacia* species in South Africa

Invasive plants, for example *Acacia* spp*.* are causing a lot of damage to the South African economy every year. Invasions have reduced the value of Fynbos ecosystems by over US$ 11.75 billion. A Fynbos ecosystem is the natural shrub land or heathland vegetation occurring in a small belt of the Western Cape and parts of the Eastern Cape of South Africa. The total cost of invasion would be about US$ 3.2 billion on the Agulhas plain alone (located in the Western Cape of South Africa), the net present cost of invasion by *Acacia mearnsii* (Black Wattle) is about US$ 1.4 billion and the cost to clear the alien plant invasions in South Africa will be about US$ 1.2 billion (Wilgen et al., 2001).

In general *A. mearnsii* outweigh the benefits by more than 2.5 times (Wit et al., 2001; Shackleton et al., 2006). The benefits-costs ratio is based upon the negative impacts of *Acacia mearnsii* and benefits associated with *Acacia mearnsii* in South Africa. For this analysis were conducted on six different steps according to the paper written by Wit et al., 2001;

- Economic (including the cost of labour) and ecological impacts of Black Wattle were identified.
- Impacts were prioritized, and the most severe impacts were identified.
- Alternative crops to replace *Acacia mearnsii*, or substitutes for their products were identified.
- The costs and benefits of *Acacia mearnsii* and the alternative crops or products were quantified.
- The distribution of costs and benefits was evaluated.

- Scenarios for mitigation of costs and benefits were formulated and subjected to sensitivity analysis on key uncertainties.

In the table below (Table 1.1) the costs and benefits (millions of US$), associated with the 'do nothing' scenario is shown. 'Do nothing' scenario means that commercial activities around the growing of Black Wattle continued, and no attempts were made to control the invasive plants that continue to spread around the country (Wit et al., 2001). The calculation is done by making use of the six steps above, altered for this specific example, resulting in a benefits-cost ratio of 0.4 (Wit et al., 2001).

Table 1.1: The costs and benefits (millions of US$) with regard to the management of Acacia mearnsii in South Africa (Wit et al., 2001).

	Benefits to commercial growers	Benefits to rural users	Benefits from carbon storage	Cost of lost streamflow	Cost of increased fire hazard	Benefit–cost ratio
1998 values	30.7	14.2	1.8	78.7	0.03	0.6
Average annual value over 20 years	39.3	17.3	2.5	158.5	0.15	0.4
Net present value	363	149.3	24	1370.8	1.1	0.4

Only quantifiable costs and benefits were considered. An 8% discount rate was used to calculate net present value.

1.3 Problem statement

In the Kromme river catchment, a catchment located in the Eastern Cape, South Africa (more information in chapter 2 ''study area''), invasive *Acacia mearnsii* creates ecological, economic and social problems. All of this has to do with the fact that *A. mearnsii* is among others a heavily water consuming tree and this characteristic of the plants causes problems in for example water availability, erosion, but also problems for other species to grow, mainly native species in wetlands. Wetlands are under threat by, among others this invasive species. Another important aspect of this species is the conflict of interest, as there are beneficiaries and non-beneficiaries of this specific tree and of the way the landscape is functioning. All of the factors are important in successfully trying to find a balance between invasiveness and control or eradication of the plant in invaded areas and in this case the Kromme river catchment (Shackleton et al., 2006; Rebelo, 2012; Dye and Jarmain, 2004).

The importance of gathering knowledge about this tree is the aim of this research, which will focus on this specific *Acacia mearnsii* invaded areas and Wetland areas or non-invaded areas. The knowledge will be gathered by an opinion-driven and empirical field research.

Also is focused on the management strategies to control/eradicate this tree species. The information for this will be gathered on the one hand by the local community, in a similar approach as the opinion-driven research to gather knowledge about the area characteristics of the tree. On the other hand reports written by the Working for Water team are used.

1.4 Hypothesis

The main objective of this study is to find and show important factors that promote the growth and invasion of *Acacia mearnsii* and undermining the growth of wetland species in the Kromme river catchment.

Research about *Acacia mearnsii* is done in different areas already and some key factors are described, like the ability to fixate Nitrogen and the water use of the tree, but as the Kromme river catchment is a unique, but degraded wetland system and a very important water resource for the Nelson Mandela Bay Municipality in the Eastern Cape, research in specifically this area is important to contribute to management strategy of this area. Specific knowledge about this area can help to create a suited management strategy, which is very important in restoring the Kromme river catchment towards a more productive ecosystem in the sense of for example the storage of water.
To make a comparison also key factors in which native species, like *Prionium serratum* ((L.f.)) Drège ex E.Mey. 1843) (Palmiet), grows are gathered.

The factors that are looked at are; soil characteristics (nutrients, pH, electric conductivity, water content and organic matter content), biodiversity of plant species, riverbed erosion along the Kromme river, weather conditions (rainfall) and the effect of floods and fire on the growth of *Acacia mearnsii* and the native counterpart. To guide and structure the research, the following hypothesis were defined:

- Available nutrient concentrations (NO_3, NH_4, and PO_4) will be lower in non-invaded sites (wetland sites) than in invaded sites with *Acacia mearnsii*. The invasive tree is able to fixate Nitrogen and mineralize Phosphorus, which could increase the amount of these nutrients in the soil (Naudé, 2012; Waal, 2009; Zahran, 1999)
- The pH will be lower in non-invaded sites than in invaded sites with *Acacia mearnsii*, because the soil in non-invaded sites consists of peat, which is in general acidic soil, while invaded sites do not contain peat in the soil and for this it is possibly less acidic (Czeglédi, 2013).

- The electric conductivity will be higher in the non-invaded sites than in invaded sites with *Acacia mearnsii*. Electric conductivity is related to the organic matter of the soil and peat consists of a high organic matter, contributing to a higher electric conductivity (USDA, 2011).
- The water content will be higher in non-invaded areas than in invaded sites with *Acacia mearnsii*, because the invasive species is a high water consuming tree and for this dryer soils will be found underneath *Acacia mearnsii* (Rebelo, 2012).
- The organic matter content will be higher in non-invaded sites than in invaded sites with *Acacia mearnsii*, because peat, which is build up in the wetlands, contains a high amount of organic matter, while *Acacia mearnsii* degrades the wetlands and the peat layer, resulting in lower organic matter content (Nsor and Gambiza, 2013).
- More riverbed erosion happens in invaded sites than in non-invaded sites, because *Acacia mearnsii* has in comparison to the native counterpart very shallow root system and is easily ripped out and taken with the water, causing riverbed erosion (Rebelo et al., 2012).
- The impact of fire in the area will be more in invaded sites than in non-invaded sites. The invasive species contains more fuel and the fires are hotter, affecting the soil and native species in the area, as they are not adapted to these hot fires (Weis et al., 2002).
- The impact of flood in the area will be higher in invaded sites than in non-invaded sites. Floods cause a lot of damage to the riverbed at invaded sites as *Acacia mearnsii* has a shallow root system and it does not anchor the soil properly, causing trees being ripped out and erosion (Rebelo et al., 2012)
- Rainfall and extreme rainfall events will have more impact in the invaded sites than in the non-invaded sites in the Kromme river catchment, because less water is retained in the invaded sites, which makes the water have more impact on the area. Extreme rainfall event will cause a bigger impact of floods because of this storage problem (Jong, 2012).
- The diversity in plants will be higher in the non-invaded sites than in the invaded sites with *Acacia mearnsii*. This invasive tree is able to change the habitat in which the native species used to live, by for example changing soil nutrient status (Higgins et al., 1999; Weis et al., 2002).

Furthermore, the following research questions for the management strategy of the Kromme river catchment are formulated;

What is the current management strategy for the removal of invasive plants (or to be more explicit: of *A. mearnsii*)?

> Could management of *A. mearnsii* be rethought by making use of the key factors for growth of the tree, gathered during this research?
>
> Could a change of land use be a way to better control the growth of the plant?
>
> Could the usage of animals to graze the young *Acacia mearnsii* be a new strategy to control the plant?

Chapter 2
Study area

In this research the study area is a part of the Kromme river catchment. This catchment (Figure 2.1) is located in the Eastern Cape province of South Africa. The Kromme river is about 100 km in length and the total area of the Kromme Catchment is about 1556 km^2. The river drains the Kouga mountains (altitude of 550 m above sea level), which is the eastern part of the inter-montane valley within the Cape Fold Belt, following the valley around the town of Kareedouw. Then it flows eastwards into the Indian Ocean via Humansdorp and St. Francis Bay. The Kromme river catchment has two impoundments; the Churchill Dam and the Impofu Dam to ensure water availability for the downstream areas, the Nelson Mandela Bay Municipality. It supplies to Port Elizabeth, Humansdorp, Jeffreys Bay and some smaller towns (IWR, 2005; Nsor and Gambiza, 2013; Rebelo; 2012; Jong, 2012). Currently the Kromme river catchment is the most important water resource for the Nelson Mandela Metropole. Impofu dam is delivering 10,314,000 m^3 and Churchill dam is delivering 25,234,000 m^3 annually. This is about 55% of the entire water demand of this Metropole (IWR, 2005).

The research area is the part of the Kromme river upstream from the Churchill Dam. In Figure 2.1 the upper Kromme Catchment is indicated as K90A and K90B. This part of the catchment is approximately 365 km^2. In the catchment only one town is located; Kareedouw (Jong, 2012).

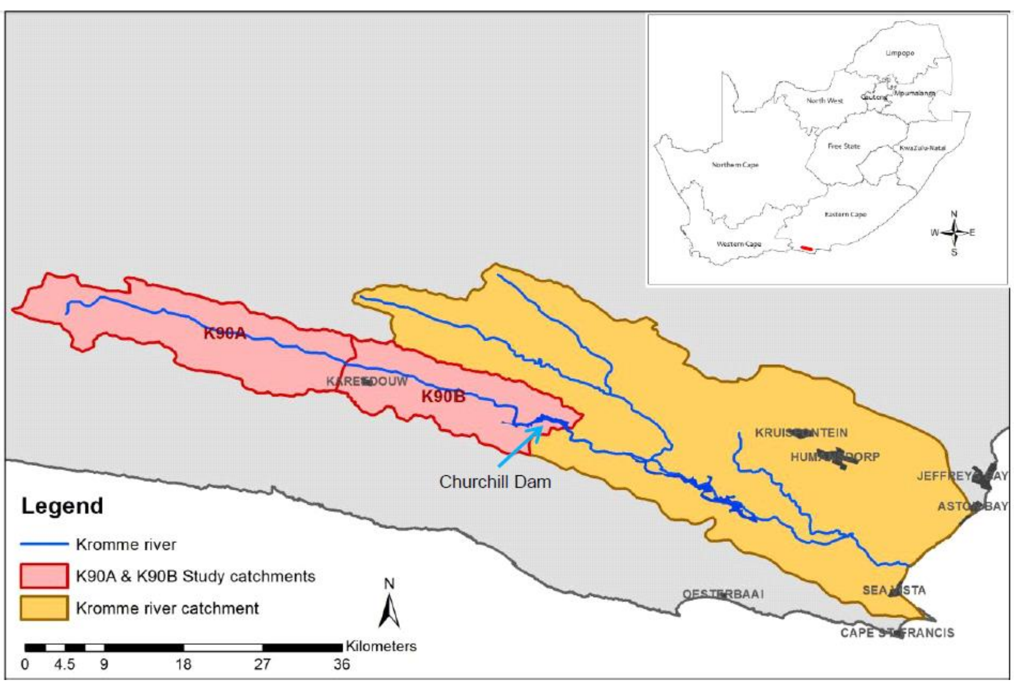

Figure 2.1: Kromme river catchment (the study area consist of the catchments K90A and K90B) (Jong, 2012).

2.1 Development of the catchment over the last century

In former times the Kromme river catchment was overgrown with *Prionium serratum* (Palmiet), which is a wetland species in the Fynbos ecosystem. The Kromme river is a Palmiet river, in which the floodplain and the actual river are entirely covered with wetlands and the key species *Prionium serratum* (Palmiet) (Rebelo, 2012).

There was almost no surface water in the area as the water was mainly stored in the soil. In 1905, the first farming activities were taking place (Rebelo, 2012). And in between 1930 and 1940 the farming region changed to the more fertile floodplains, which had previously been part of the wetlands. In 1931, a massive flood ripped out orchards and caused severe erosion.

After 1940 the farming activities changed towards dairy and sheep farming. This caused a lot of overgrazing and bare soil. In the period of 1954 until 2003 the Kromme river straightened and the area was deteriorating heavily (Rebelo, 2012). *Acacia mearnsii* (Black Wattle) has spread all along the Kromme river catchment and the agricultural activities were intensive as well (Rebelo, 2012).

In 1996 a 'Working for Water' program, launched in 1995, started to clear the invasive tree species, but the spreading of the species continued. During the implementation of the program the damage to the wetland was revealed, including the widespread occurrence of river bank erosion. Rehabilitation by 'Working for Wetland' was necessary and performed at a small part of the Kromme river catchment. At the moment only one place is still a productive and functional wetland with a lot of stored water in the peat of this wetland (Rebelo, 2012). In figure 2.2 a map is shown where the natural vegetation still exist in the area.

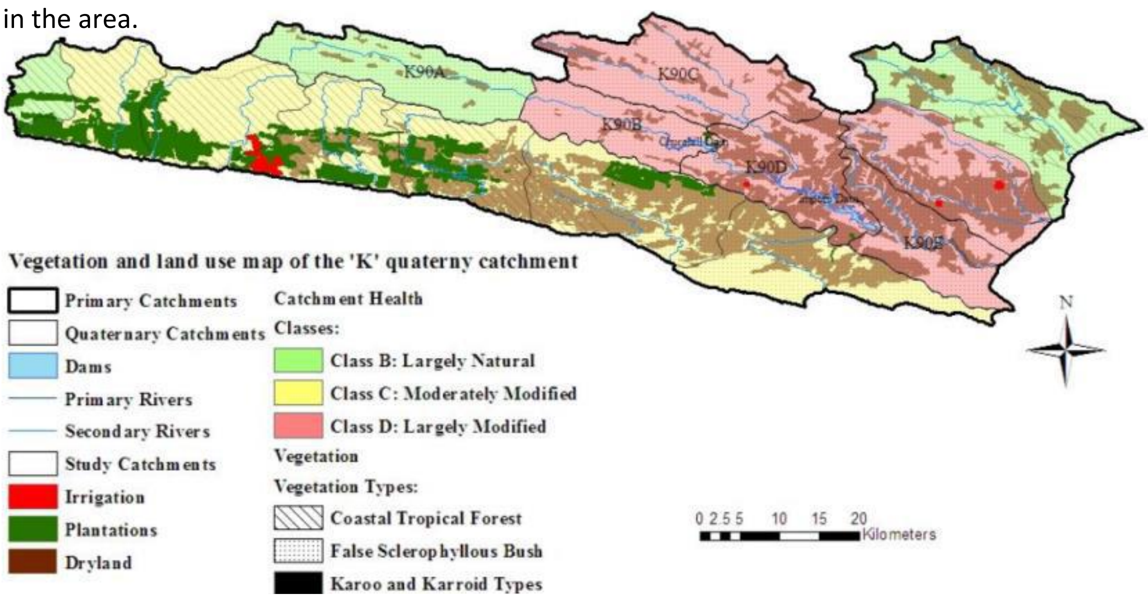

Figure 2.2: The vegetation and land use of the Kromme Catchment is showed (Middleton and Bailey, 2011a).

2.2 Rainfall and Evaporation

Rainfall in the Kromme river catchment is not uniformly distributed. The north east experiences lower rainfall than the south and south west. In the upper Kromme river catchment (K90A and K90B) the rainfall is relatively high. The mean annual rainfall in the area, measured in Kareedouw, is about 700 mm. This amount can vary per region and per year. In some years the rainfall can be up to 1200 mm while in other years there is only 400 mm (Kotze and Ellery, 2009). The average annual rainfall is showed in Figure 2.3.

The mean annual evaporation, shown in Figure 2.4 is between 1400 mm and 1800 mm. In the upper Kromme river catchment the average is about 1700 mm (Middleton and Bailey, 2011a).

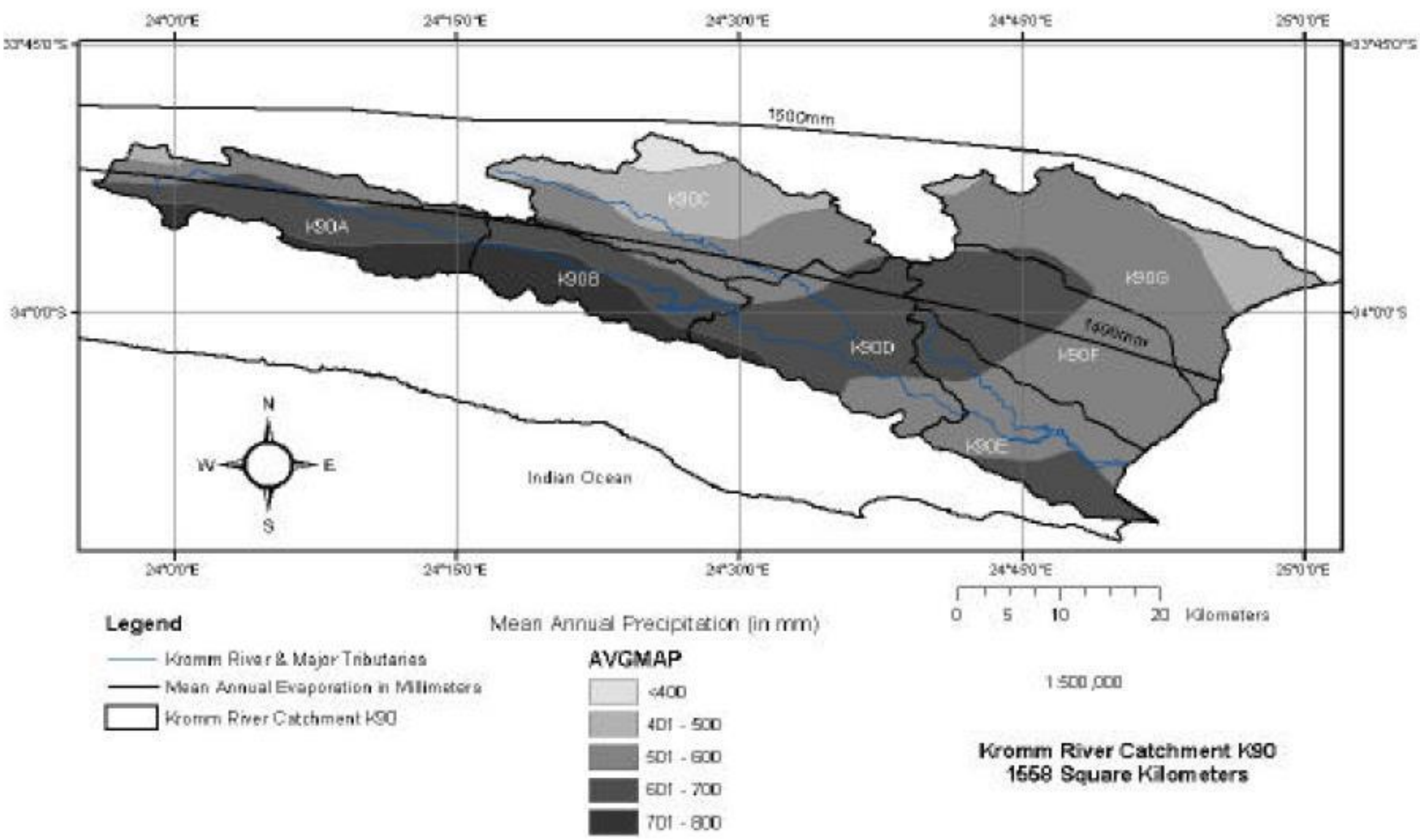

Figure 2.3: The mean annual precipitation in the Kromme river catchment (IWR, 2005).

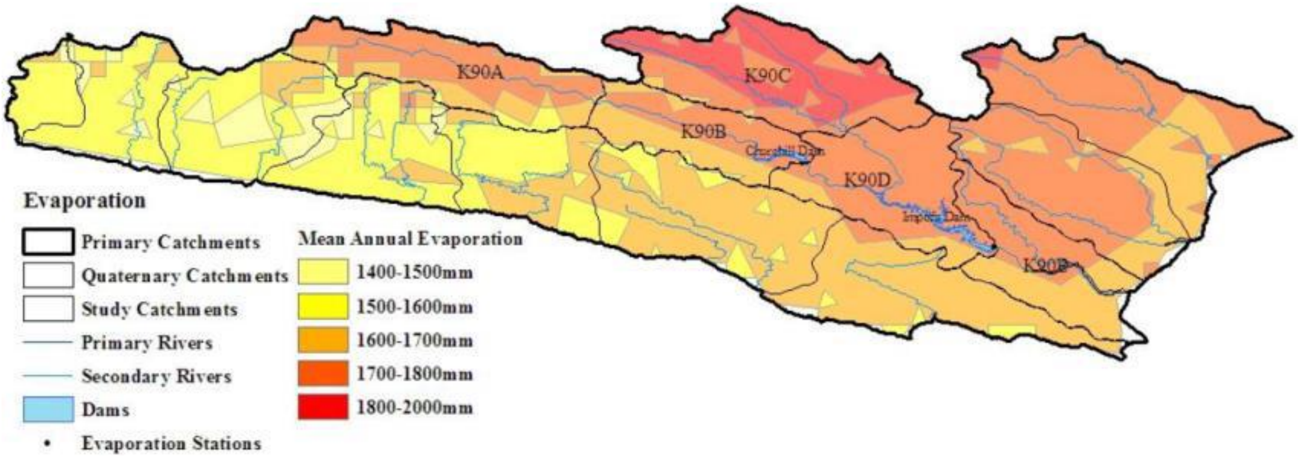

Figure 2.4: The mean annual evaporation in the Kromme river catchment (Middleton and Bailey, 2011a).

2.3 Geology and soil characteristics

The Kromme river catchment has its origin associated with the Pan-African orogenic event. In this tectonic event rifting occurred along the Southern Cape and mudstone and sandstone from the Cape Supergroup (Table Mountain Group) was deposited forming the rift valley basin. This rift started closure, forming Cape Fold Belt, 300 million years ago. In this process the Kromme river valley was formed. The bedrock of the Kromme river valley is formed by subordinate shale horizons and mid-Palaeozoic quartzites. The youngest shale horizons are on the surface in the centre of the valley and towards the mountain ranges the rock horizon increases. The oldest rock horizons are the quartzitic sandstone (Czeglédi, 2013).

In Figure 2.5 two general geological structures are defined in the Kromme river catchment, sandstone and quartzite.

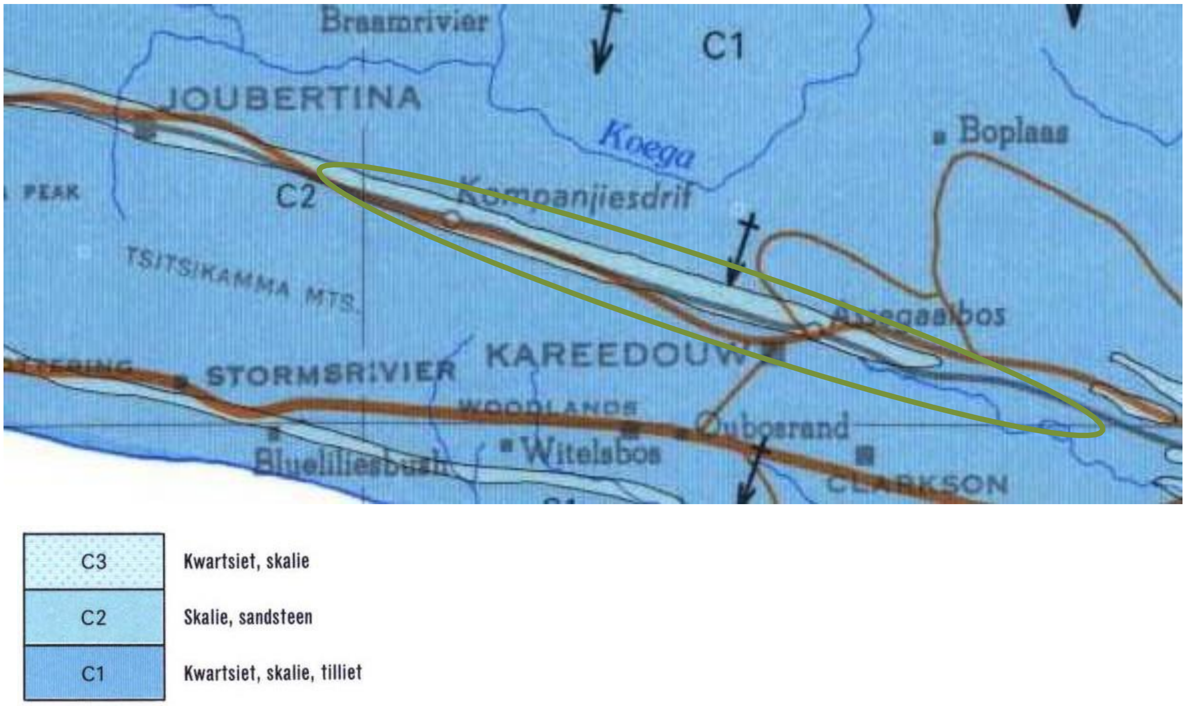

Figure 2.5: Geology of among others the Kromme river catchment is showed. The study area is encircled. The brown lines in the Figure are the roads in the area, the green circle shows the study area (Trigonometrical Survey Office, 1970).

In general the Kromme river catchment consist of a grey sandy soils and table mountain sandstone. Within this general soil type three specific soil types can be found, shown in Figure 2.6. The first one is a rock and rock debris and secondly lithosols and litholic soils on miscellaneous rocks can be found. Thirdly podzolic soils can be found. These soil types and its chemical and physical characteristics are determined by the underlying rock type in the Kromme river catchment. The soil type of the lower slopes are structured dark soils with fine sand, the soil in the mountains are nutrient-poor, acidic lithosol soils (shallow soils on steep slopes). The soils that are permanently or seasonally saturated with water (hydric soils) are found at the valley-bottom. At these places peat is formed. Two types of peat are formed in the area. First, peat having a high organic content and deep profile and second peat having a pale acidic soils (Czeglédi, 2013). This is in the map called not differentiated podzol soil, shown in Figure 2.6.

During sampling all along the river sandy soils are found. Only at the wetland sites the soil was slightly different as it contained more peat, which is related to the plant species growing in this area, but also this soil was sandy. Important is that there is no silt, loam or clay found in the soils all along the Kromme river catchment. This means that the soil samples are comparable and differences in the soils will not be determined by the occurring soil type.

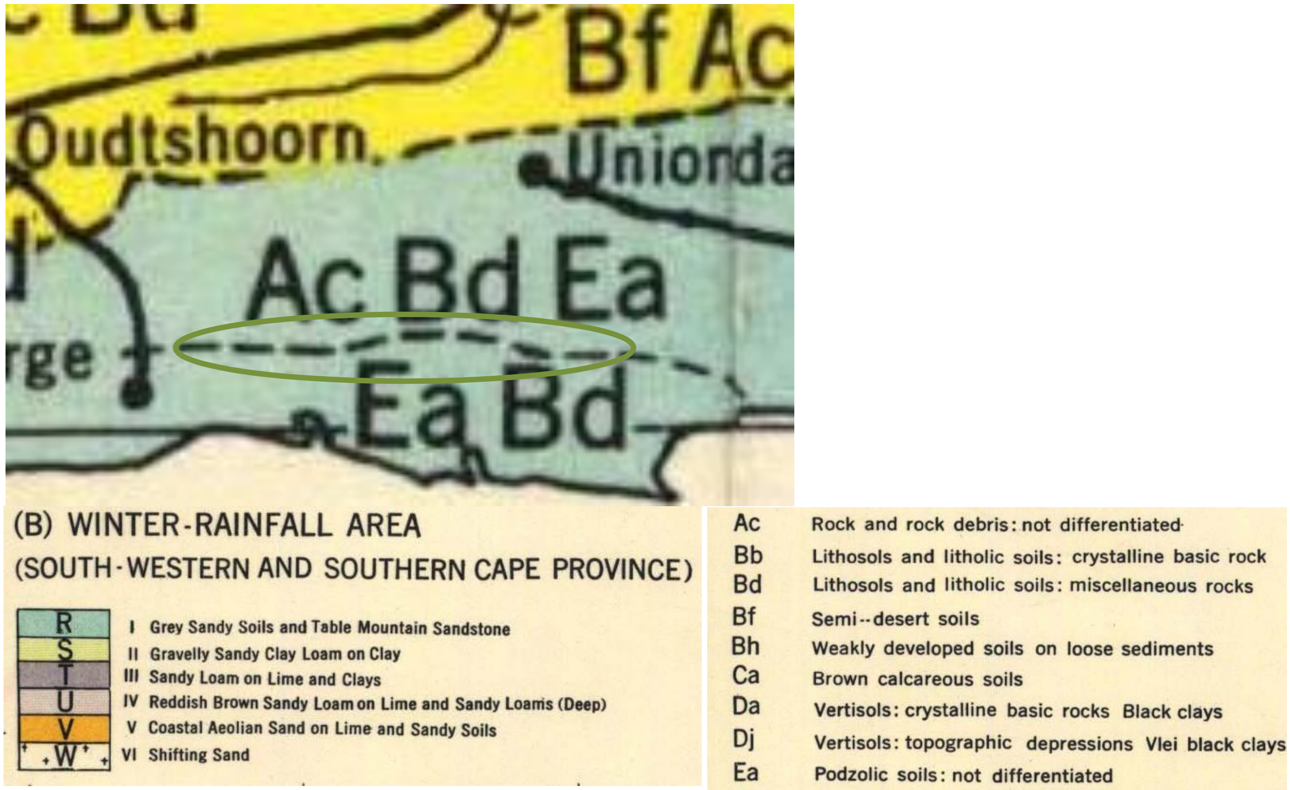

Figure 2.6: Soil type in the study area. The study area is shown with the green circle (Trigonometrical Survey Office, 1965).

Chapter 3
Literature review

This research focuses on the plant species *Acacia mearnsii* and for this a literature review is written to collect information about different aspects related to this invasive species. This is essential to be able to show the importance of this research regarding this invasive species and it helps to compare the results found in this research with what is already found in other studies.

3.1 Phenology and Ecology of *Acacia mearnsii*

Acacia mearnsii has a rapid early stem growth, reaching up to three meters per year and it grows to a height between six and twenty meters. The tree is evergreen, single-stemmed or multi-branched. It has many tiny flowers with a pale yellow colour and the fruits are dark brown pods, finely hairy and usually markedly constricted.

The flowering of the trees starts when the plant is about two years old. The flowers are insect, especially bee, pollinated. The lifespan of *Acacia mearnsii* (Black Wattle) is generally between 15 and 20 years, but in South Africa the tree can become 30 years old and still producing seeds. Furthermore the seeds can stay dormant and viable for more than 50 years (Marchante, 2010; Jansen and Cardon; 2005; Pasiecznik, 2007). Their formation of a large, persistent seed bank combined with water dispersal enables them to disperse very rapidly downstream (Naudé, 2012; Marchante, 2010a; Jansen and Cardon, 2005).

Acacia mearnsii trees have long-lived bipinnate leaves, which may turn brown during drought, but can recover after the first rains. A developed tree is tolerant to drought conditions, but this species is more dependent on water than some other *Acacia* species (Rebelo, 2012; Naudé, 2012; Marchante, 2010a).

Another characteristic of *A. mearnsii* is the ability to obtain resources through mechanism of excessive root production and symbiotic N_2-fixation. This means that it can convert Nitrogen from the atmosphere into NH_4. It fixes the Nitrogen via symbiosis with *Rhizobium*, which is a soil bacteria that forms endosymbiotic association with roots of legumes, in which *Acacia* species belong, and this way the Nitrogen concentration available for the tree increases and it is able to grow in Nitrogen poor soil (Zahran, 1999). Also this tree is able to mineralize Phosphorus by exuding phosphatases. These phosphatases transform Phosphorus to Ortho-Phoshates, which is available for uptake (Naudé, 2012; Hyland et al., 2005).

The species will invade river systems, riparian areas, as well as more mesic regions, urban areas and grassland at an altitude between 2 and 1070 m above sea level (Marchante, 2010; Naudé, 2012; Pasiecznik, 2007).

The riparian areas are subject to frequent disturbances in course of floods (Marchante, 2010). *Acacia mearnsii* prefers disturbed habitats as it is a pioneer species, demanding a lot of sunlight, which means that this tree colonizes an area quickly after disturbances, making sure the tree gets the most sunlight for growth and development (Naudé, 2012).

The climate in which it grows can be a warm temperate climate, but also a moist tropical climate (Marchante, 2010; http://www.florabank.org.au/lucid/key/species%20navigator/media/html/Acacia_mearnsii.htm; Naudé, 2012).

Two pictures of the tree are showed below in Figure 3.1 and the phenological and ecological characteristics of this tree are summarized and compared to the characteristics of an important native species in this research in Table 3.1.

Table 3.1: Comparing phenological and ecological characteristics of the invasive species Acacia mearnsii with the non-invasive species Prionium serratum (http://www.plantzafrica.com/plantnop/prionserr.htm; Rebelo et al., 2012; Sieben, 2012; Munyai, 2013; http://www.fao.org/docrep/005/ac846e/ac846e09.htm).

Acacia mearnsii **(Invasive species)**	***Prionium serratum*** **(Native species)**
Pioneer species, fast growing ability	Slow growing
Growth of three meters per year, between 6 and 20 meters high	Grows up to 2 meters high, grows in dense stands, clonal plants
Large persisting seed bank, can stay dormant for a long time (50 years)	Produces numerous seeds, not as persistent as *Acacia mearnsii* seeds
Sexual reproduction	Clonal and sexual reproduction
Tolerant to drought	Water demanding
N_2-Fixation by the tree, mineralization of P	Ecosystem engineer, creates preferable habitat for itself and its associates, 'leakage' oxygen in the peat layers, the species builds
Demanding light	Not adapted to shade
Occurs in riparian zones, urban areas, water courses and grassland	Occurs in marshland, streams, rivers and riverbanks

Low and intermediate altitude (2 – 1070 m above sea level)	Altitude from 0 to 830 meters above sea level
Moist or temperate climate	Divers climate, with mostly winter rainfall ranging 400 mm to 1200 mm per year

Figure 3.1: Showed is Acacia mearnsii tree, photos made by Sharon van Rossum.

3.2 Ecological impact of *Acacia mearnsii*

The first ecological impact that is discussed is the fast growing ability of *Acacia mearnsii* creating an advantage for the invader in the competition for, especially light. The invasive species overgrow the native species and it outcompetes the native species. The native wetland species, like *Prionium serratum* (Palmiet) cannot survive under dense invasive acacia canopies, as it is not adapted to shade, leaving the understory bare (Morris et al., 2011; Rebelo, 2012). This is shown in the Figure 3.2.

Figure 3.2: Picture of dying or dead Prionium serratum (Palmiet) as understory of Acacia mearnsii invaded area. Photo made by Sharon van Rossum.

Acacia mearnsii also has a large impact on an area during and after disturbances, like flood and fire. The invasive species cannot withstand floods, resulting in trees being ripped out, mainly due to their shallow root system. This causes channel instability and erosion. But the fast growth and large seed bank of the invasive species makes the species return easier than the native species (Rebelo et al, 2012).

A. mearnsii germinates very fast after fire and it has a very large seed bank (Rebelo, 2012). This way it outcompetes native wetland species, like *Prionium serratum*. This native species is adapted to and dependent on fire, but not able to germinate and grow as fast as *Acacia mearnsii* germinates and grows (Rebelo, 2012; van Wilgen, 2009).

Besides the fact that the invader can easily colonize the with fire altered areas the species also creates more likelihood of fire, because the increase of biomass by the plant leads to an increase of fuel loads. Dense stands of the trees also prevent access needed for fire management. These two factors create an increase in fire intensity and damage, like damage to cultivated areas and farmland for cattle (Marchante, 2010[a], Nelson Mandela Metropolitan Municipality, undated).

Fires have a negative impact on the seed bank of the invasive species *Acacia mearnsii*, but especially on the seed bank of the native counterparts. It is most likely that fires create more difficulties in succession and re-assembly of native species, like Palmiet, because their seed bank is likely to be smaller (Fourie, 2012).

During growth and development of the tree the soil is altered in different ways;
Firstly, the N_2 fixating ability of *Acacia mearnsii* results in disadvantages for plants that are adapted to nutrient poor conditions, like *Prionium serratum* (Palmiet). These plants are growing in a peat land that has in general a low availability of nutrients (Bain et al., 2011). Normally only these plants will grow in these circumstances as they are adapted to lower nutrient availability and this way native species had enough time to grow. The Nitrogen fixation by *A. mearnsii* can make it difficult for native plants to develop and the area will become more suitable for other exotic species, due to the change in Nitrogen conditions in the soil (Marchante, 2010a).

At second, *Acacia mearnsii* is able to produce tannin (Jansen and Cardon, 2005). Tannin is an allelopathic substance. *''Allelopathy is a phenomenon involving either direct or indirect and either beneficial or adverse effects of a plant (including microorganisms) on another plant through the release of chemicals in the environment''* (Li et al., 2010).
There are high levels of tannin found in *Acacia mearnsii*. This has an influence on the soil and ecosystem function.
The first ecosystem function that is influenced is the nutrient dynamics of the soil, because tannin has a strong effect on the decomposition rates, which will be limited. It may limit litter decomposition in different ways; by themselves being resistant to decomposition, by sequestering proteins in protein-tannin complexes that are resistant to decomposition, by coating other compounds and protect them from decomposing, by making microbial enzymes more complex or by deactivating microbial enzymes (Kraus, et al., 2003). These characteristics could result in an increase of the concentration of nutrients in the soil. This explains why a lot of tannin producing plants grow on relative infertile soil. The tannin production makes these soils more suitable for living for these specific plants (Kraus, et al., 2003; Adamczyk et al., 2013).
The second and last ecosystem function that is altered is the ability of other plant species to germinate in the presence of *Acacia mearnsii* as tannin is also an allelopathic substance that supresses the germination of seeds and the early growth of plants (Kraus, et al., 2003; Kraus, et al., 2003a).
Tannin has also another effect. Tannin production of *Acacia* species, which is closely associated with plant defence mechanism towards herbivores, has a negative effect on animal production. Animals are responding on tannin by for example a lower food intake and lower protein and dry matter digestibility (Mueller-Harvey, 2006; Hassanpour et al., 2011).

Thirdly, *Acacia mearnsii* makes changes in moisture regimes of the soil. This species evaporates, about 1500 mm per year, and uses a lot of water. The amount the tree evaporates is equal to an evergreen tropical lowland forest. In comparison, the annual evaporation from indigenous grasslands and Fynbos shrub lands is within the range of 600 to 850 mm (Dye and Jarmain, 2004; Maitre et al., 2000).
Not only a lot of water is evaporated, also a lot of water is intercepted and these two factors cause a reduction in stream flow and available water for the growth of other species and for the usage for, among others, farming activities (Marchante, 2010a; Maitre et al., 2000). The decrease of runoff in the Kromme river was 8% in 1990 until 2005 (Middleton and Bailey, 2011a).
As the invasive species is also drought tolerant, the species can survive easily in the dryer situation, while native wetland species are not drought tolerant and cannot survive this dryer situation (Rebelo, 2012).
Soil water availability is besides light, a limiting factor for native species like *Prionium serratum* (Rebelo, 2012) to grow in *Acacia mearnsii* canopies. When *A. mearnsii* is removed, the stream flow is predicted to increase, especially in areas of high evaporative demand and with low drought stress throughout the year (Dye and Jarmain, 2004).

The last ecological impact is the species having an effect on biodiversity in an area. For example the species richness of birds is lower in areas with *A. mearnsii* (Marchante, 2010a). Total plant cover is also lower in areas invaded, because the understory is not covered. The indigenous species are displaced by *A. mearnsii*. Nowadays almost 1900 of the 3435 plant species in the South African Red Data List are threatened (Marchante, 2010a).

These ecological impacts have an impact on the landscapes, but also on the livelihood of people in an area, described in the next subchapter 3.3 ‘Impact of *Acacia mearnsii* on livelihood of people’.

3.3 Impact of *Acacia mearnsii* on livelihood of people

In the research done by Shackleton et al., 2006 about 300 people living in rural areas were interviewed about the alien species, *Acacia mearnsii*. In the interviews they were asked when the tree arrived in the area and what their perceptions of invasion are, if they make use of the tree, if there are other alternatives than this species to use and if the tree is a cultural resource (Shackleton et al., 2006).

77% of the respondents perceived *Acacia mearnsii* to have arrived before they were born. The other 23% said that the tree had arrived later, with the date ranging between 1926 and 1970. All of the respondents were aware that it is an invasive species. 73% of the respondents blamed rapid expansion on the prolific wind dispersal of the seeds, whereas 13% believed that the current eradication of the invasive tree by Working for Water results in a growth rather than a reduction of *Acacia mearnsii*. Another reason suggested for the increase was that the area has fertile soil and high rainfall. Both promote its growth and spread (Shackleton et al., 2006).

Furthermore nearly all households, 96.7% collected Black Wattle for fuel wood and building and fencing poles. Of the users 83% collected the tree for their own supplies and the other 17% purchased those trees (Shackleton et al., 2006). All of the people claimed that they were using Black Wattle because it was located close by and that there are government restrictions to use indigenous species (Shackleton et al., 2006).

The tree is not commonly seen as a cultural resource, rather it was seen as a threat to certain areas and to the livelihood of people. Black Wattle is very dense near the river, preventing access to the river, furthermore the land is taken by the tree, causing problems with farming activities and the tree uses a lot of water from the river, which is lowering the water availability for the people (Shackleton et al., 2006).

Focusing more on the water availability in relation to *Acacia mearnsii* invasion, an opinion-driven research is done in the Kromme river catchment. In this research 26 farmers/landowners were asked about their perceptions of *Acacia mearnsii* on the water yield of an area (Jong, 2012).

54% of the residents indicated *Acacia mearnsii* as an important water yield reducing species and secondly 91% of the residents indicated invasive species having a negative effect on water yield in general and 70% of the respondents link wetland degradation to a decrease in water availability in the catchment. Furthermore some respondents mentioned that wetlands are good for flood attenuation, water quality and biodiversity, while 30% indicated that they do not know whether wetland degradation has a positive of negative effect on water availability as they think the wetland uses a lot of water (Jong, 2012).

The problems with water availability is very dependent on the location of the residence. If a resident in the catchment can use the water from the wetlands directly or if a constant water supply is generated for residents outside the catchment, for example in the Nelson Mandela Bay Municipality, a good functioning wetland most likely to be an advantage for those people. Residents more downstream in the catchment, but not directly at a wetland, could experience a dry river as the water is retained upstream, which makes them more negative about wetlands in the area (Jong, 2012).

Despite the issues regarding the tree, the tree is mostly integrated into the livelihood of the people.

- The rural communities are accepting the introduction of the species. Often the introduction is controlled, a farming type of situation, like the plantation of tree species for, for example firewood. Then negative consequences may arise, because the targeted species is spreading rapidly to a broader landscape and this way affecting the livelihoods of non-beneficiaries (Shackleton et al., 2006). These two features, a commercial value on the one hand, and an invasive, damaging ability (e.g. erosion, impact on native species, fires) on the other, give rise to a conflict of interest. Where the benefits accrue to a number of people (people at the plantations), the society bears large external costs (Wit et al., 2001).
- Unintentionally species are introduced and later on they spread in surrounding areas. These populations can make people switch from indigenous species to the invasive species. For example, because the indigenous species become scarce. This may have a positive effect on the people and the indigenous tree as the people can now use this invasive plant and do not have to use the indigenous tree (Shackleton et al., 2006).
- People have to live with invasive species that have no apparent uses. In the early stages of the invasion it is not a big threat to livelihood, but when the density becomes higher the impacts on ecosystem goods and services and their daily activities gets higher as well. When this happens the vulnerability of the people increases and the livelihood of the people will be undermined (Shackleton et al., 2006).

The complexity of the effects of invasive alien species on rural livelihood is shown by these studies. People make use of *Acacia mearnsii*, while others do not. Where some people experience problems with availability of water due to the growth of the tree, others do not. Furthermore some people indicate importance of wetlands, while others do not know whether or not wetlands are beneficial. If an invasive species should be removed or not is not only determined by the effects of the tree for ecology, but also social and economic aspects determine whether or not a species is a threat (Shackleton et al., 2006; Jong, 2012).

The ecological, economic and social problems regarding this invasive species resulted in management strategy and tools and methods to control/eradicate this alien invasive species. This is described in the next subchapter of this literature review.

3.4 Methods to control and/or eradicate *Acacia mearnsii*

The control of *A. mearnsii* can be done at different points in their lifecycle, starting with seedlings. The lifecycle of this species is showed in the figure below (Figure 3.3) (Wilson et al., 2011).

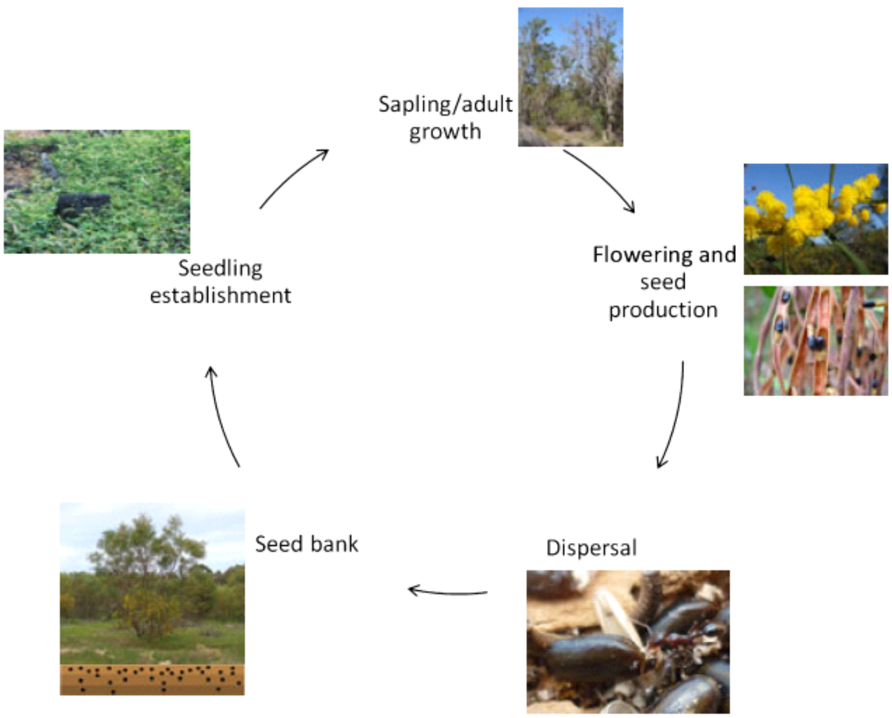

Figure 3.3: A generalized lifecycle of an Acacia. Although there is phenological variation in adult plant size and structure, the general lifecycles are the same (Wilson et al., 2011).

- Seedling: A lot of seedlings do not survive to adult trees, so intervention should target the successful seedlings. This way the waste of resources will be avoided. Hand pulling, grazing, herbicides, ploughing or changing the land management are possible ways to target seedlings (Wilson et al., 2011).
- Pre-mature and mature trees: The amount of pre-mature and adult plants can be reduced by fire or mechanical control. In the mechanical control strategy, harvesting could be interesting, because the plant could be used for firewood. Taken into account should be that many species including *A.*

mearnsii can re-sprout. This means also herbicide treatment of the stumps and additional follow-up to treat regrowth are often necessary (Wilson et al., 2011; Wilgen et al., 2011). A follow-up is treating the newly developing trees in a formerly cleared area (Martens et al., 2003).

- Reduction of seed production: Making use of bio-control agents can limit the spread rates and the build-up of seed banks. Two species that are bio-control agents for *A. mearnsii* are *Melanterius maculatus* (Coleoptera: Curculionidae 1995) and *Dasineura rubiformis* (Diptera: Cecidomyiidae) (Wilson et al., 2011). *Melanterius maculatus* feeds on ripening seed pods and *Dasineura rubiformis* induces the development of galls in the flowers of *Acacia mearnsii*, thereby preventing pod development and reducing the reproductive capacity of the plant (Impson et al., 2008). Another way to reduce the seed bank is by harvesting flowers or hormonally reduce seed set or flowering (Wilson et al., 2011).
- The seed dispersal: Seed predation can be a successful way to reduce numbers of seeds for the seed bank. Also seed dispersal can be reduced, for example by restricting the movement of soil that contains the seeds or by preventing the plants near dispersal routes (e.g. water ways). The seeds that eventually will disperse will be incorporated in the seed bank mostly in the top 10 cm of the soil. Thus effective management contains both clearing the adult trees and removing the seed bank (Wilson et al, 2011).
- The seed bank: Reducing existing seed bank is essential to prevent widespread reinvasion after clearing. Examples to reduce the seed bank are; firstly, earth covering, in which an invaded site is covered with 20 cm of earth, seeds have more difficulties to reach the surface, while germinating. Secondly, soil inversion, which is the removal of the upper 20 cm of the soil and lastly, litter removal before the seeds incorporated in the seed bank (Wilson et al, 2011).

After the control of *Acacia mearnsii* within the lifecycle a rehabilitation step is needed to successfully create a new native habitat. For example the native habitat in the Western Cape until Kwazulu-Natal in South Africa used to be a wetland, and *Prionium serratum* (Palmiet) is a very important native species in these wetlands (Rebelo et al., 2012). Also in the study area of this Master Thesis, the Kromme river catchment, *Prionium serratum* is an important species.

If an area has been invaded heavily, riparian areas left to recolonize by native species via natural processes will experience a re-invasion of non-native plants. This means that *Prionium serratum* (Palmiet) needs to be replanted in the area (http://redlist.sanbi.org/species.php?species=3635-2; Galatowitsch and Richardson, 2005). This native wetland species has a positive influence on the stability of the soil, it decreases erosion, stores more water and this way stops lowering of the water table. Furthermore it increases the water quality and at last as it can store more water it attenuates floods (http://wetlands.sanbi.org/project_details.php?id=79; Jong, 2012). A picture of *Prionium serratum* is shown in Figure 3.4.

Figure 3.4: Picture of Prionium serratum, made by Sharon van Rossum.

3.5 Tools to minimalize the invasion of non-native plant species

Except for reducing the invasive growth by controlling the life cycle and rehabilitating an area, also reducing the risk of invasion is a way to control an invasive species and four different tools are described to minimize the invasion of non-native plant species.

- Education and awareness programs can help targeting the problem of invasive alien species. People should be aware of the problems a non-native species imposes on other people or on the environment. Many invasive plants are becoming more invasive, because there is a lack of awareness (Wilgen et al., 2011).
- In South Africa, a powerful legislative framework is in operation to address invasions. Three categories of invasive species are defined in the legislative framework, shown in Table 3.2 (Wilgen et al., 2011).

Table 3.2: Legislative framework in operation to address invasions in South Africa (Wilgen et al., 2011).

Categories	Value of the species	Actions taken
Category 1	Species that are highly invasive	Species that should be controlled or eradicated
Category 2	Species that have commercial importance	Allowed to grow in specific areas and measures should be taken to prevent spread
Category 3	Species that have ornamental value	Species should remain in the demarcated areas and measured should be taken to prevent spreading

- Trans-boundary cooperation is important in the management of invasive species, because it allows the comparison between different countries and different regions in the way of managing an invasion. This way of dealing with invasions is non-existent in Africa, but it could be recommended to make a unified platform. Current knowledge will be spread and this will be available for all regions and countries. For this a more successful way of controlling invasions can be induced (Wilson et al., 2011).
- Long term funding is important, especially for this species, because it is a species that has a long-lived persistent seed bank. If the funding is too short-term the management efforts will be ineffective (Wilson et al., 2011). An example to collect funds is by making use of payment for ecosystem services, clearing projects can deliver hydrological benefits, water utilities and municipalities can raise funds through water tariffs. This money can be used to contract workers to control invasive alien plants like *Acacia mearnsii* in a catchment (Wilgen et al., 2011).

3.6 Different scenarios resulting from control/eradication methods and tools

The methods and tools to control/eradicate or in general manage the invasive species *Acacia mearnsii* can result in three different scenarios (Wilgen et al., 2011).

The three scenarios are schematically presented in Figure 3.5. The one in Figure 3.5 stands for the maintenance of status quo. In this scenario the management practices are incomplete, not fully coordinated and sustained, or it is partially inefficient. The two in the figure is the preferred scenario, in which the benefits of the tree are optimized and the management practices are fully implemented and the practices effective, which means that the benefits will grow over the invasiveness. And at last the three in the figure is the worst case scenario in which the management strategy is not implemented. In this scenario the invasiveness will be worse and the benefits less (Wilgen et al., 2011).

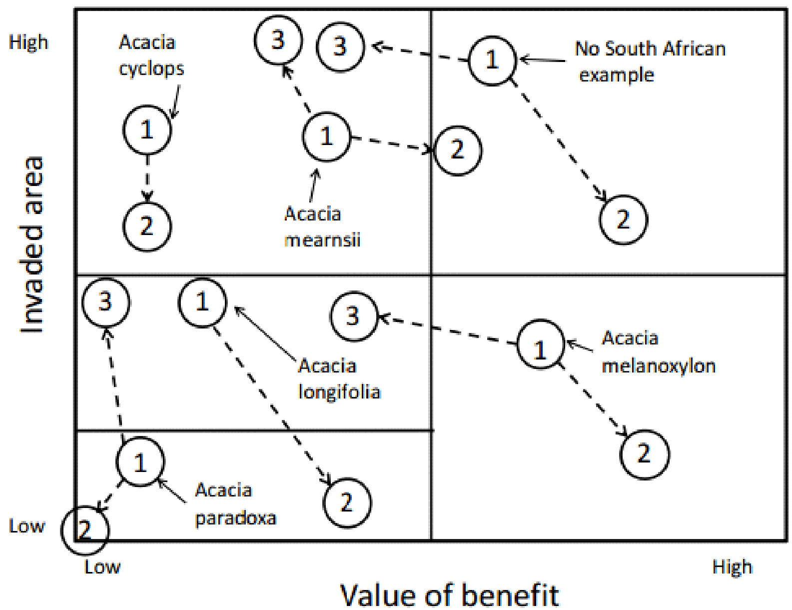

Figure 3.5: Conceptual diagram indicating the possible scenarios of different Acacia species related to the benefits of the tree and the invasiveness of the tree (Wilgen et al., 2011).

3.7 Conclusion

From this literature review one can conclude that *Acacia mearnsii* has major impacts on the environment, but also on the society. The tree has a very large impact on native species in an area, as they cannot compete against *Acacia mearnsii*. This tree is germinating and growing too fast, creating shade, it possibly produces allelopathic substances, it is able to add nutrients to the soil etc. These factors and others cause at least a decline of biodiversity in an area and a decline of the occurrence of native species in favour of the growth of non-native species.

However, it cannot be said that the tree has a negative impact on all aspects the tree influences (ecology, society, economy) as people also benefit from this invasive tree. It was brought into the country for different products and some people are still benefitting from these products. This is to a lesser extent the case in the Kromme river catchment. In this area the ecosystem services, like water retention, this wetland can provide become more and more important, possibly not especially for the people living in the catchment, but mainly for the people not living in the area, as they experience low water availability due to the lower water retention in the area. Nevertheless, one should take into account the possible conflicts of interest and the effects on management purposes. For example it is important to compensate the losses of the people who directly benefitted from the tree, although this is not discussed in the proposed management practices.

Management practices will have a major effect on the landscape and environment as well. For this it is important to choose the right method, as for example herbicides or bio-control species can possibly have a big impact on other plant species as well, when not properly implemented and the right amount used. Bio-control species are non-native species as well and for this the effects of this species on other species or on the landscape is important to know. To make sure bio-control agents do not become invasive themselves it is important to have ecological understanding of natural enemy-host relationship (Pearson and Callaway, 2003). It is important to make sure this is taken into account.

Overall, concluded is that controlling and possibly eradicating *Acacia mearnsii* has a positive effect on an area, although one needs to take into account certain aspects related to the effects on society while controlling or eradicating on the area.

Chapter 4
Empirical field research

4.1 Introduction

In this part of the study, soil properties (physical and chemical) in *Acacia mearnsii* invaded sites were compared with non-invaded wetland sites. Furthermore areal characteristics between the two different sites are compared.

This information will help to get more knowledge on what is important in the change of this former wetland area towards an area overgrown with the invasive species. All of the characteristics of an area are related and without this knowledge the understanding of the effects of this invasive species is limited (Salemi et al., 2012).

4.2 Material and Methods

Two methods are applied in this research:

The first one is called a 'local knowledge study', which is gathering information about *Acacia mearnsii* and its characteristics by talking to people who are living and working in the study area, the Kromme river catchment. In this research questions are asked to 15 people, eight landowners and seven experts. The landowners are living in the Kromme river catchment and the experts are having expertise in the field of work regarding *Acacia mearnsii* and its impact on ecological aspects. The whole conversations can be found in Appendix V.

The following questions were asked to the respondents;

- On what type of soil does *Acacia mearnsii* grow? And what is the difference with the soil where native species grow?
- What do you think of the water availability in the soil? Is it lower where the invasive species grow?
- Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
- Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
- Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?

- Do you think that fire plays a role in the growth of the invasive tree?
- What do you think about the diversity of the plants? Is the diversity lower in invaded areas?

The second method that is used in this research is a 'field research study', which is gathering information about areas invaded by *Acacia mearnsii* and areas not invaded by this tree. This is done by taking soil samples of the upper 20 cm of the soil and analyse them and by doing measurements in the field.

- Five invaded sites (Black Wattle sites), thus five sites along the Kromme river where the invasive *Acacia mearnsii* is growing are analysed. Within these five places three replicates.
- Five not invaded (wetland sites), focusing on the species *Prionium serratum*, thus five sites along the Kromme river where the invasive plant is not or nearly not growing and where the native species are growing are analysed. Within these five places three replicates were sampled.

In Figure 4.1 the sampling sites are shown. This map was made according to the GPS coordinates made in the field.

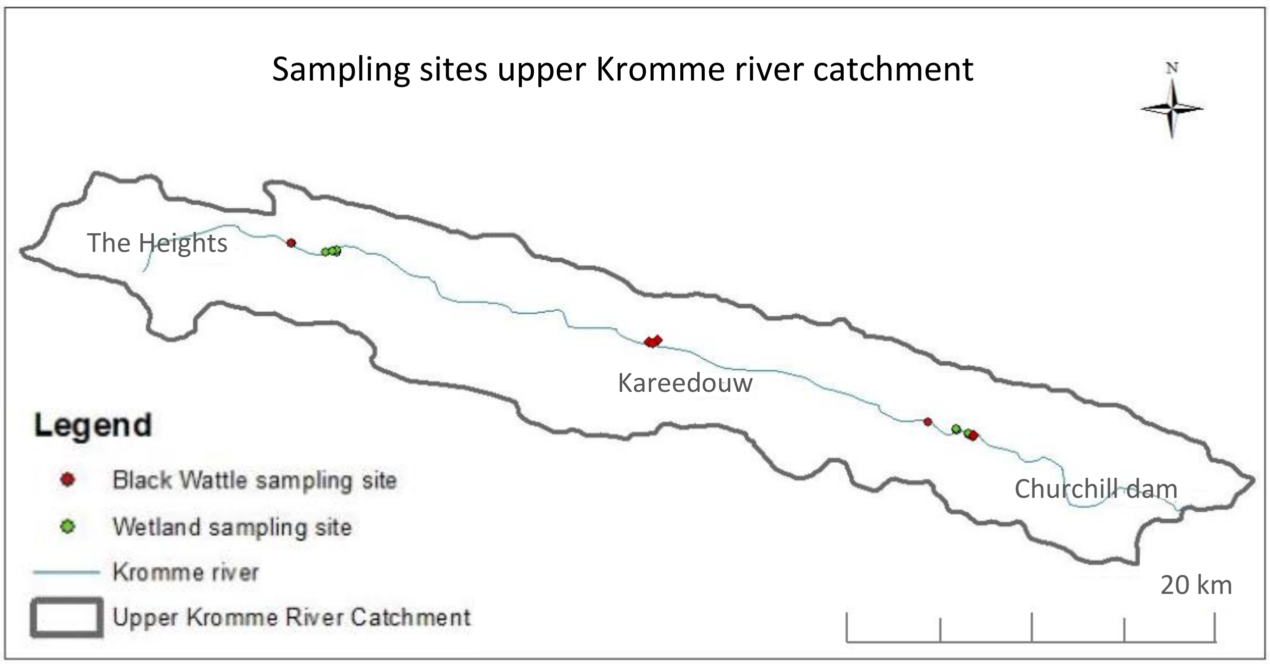

Figure 4.1: A map of the sampling sites in the upper Kromme river catchment is showed. Five sites in the Kromme river catchment with invaders, five sites with native species and all of them three replicates.

At the sites the following characteristics were measured:

- Concentration of nutrients, Nitrate (NO_3), Ammonium (NH_4) and Ortho-Phosphate (PO_4), available in soil were analysed in the lab at Nelson Mandela Metropolitan University (NMMU). The steps taken for the analysis are shown in Table 4.1.

Table 4.1: Preparation and measurement steps of the Nitrate, Ammonium and Ortho-Phosphate analysis.

Steps in preparation for analysis	**Analysis NO_3**	**Analysis NH_4**	**Analysis PO_4**
Preparing solution from the soil samples	5 g soil + 50 ml water Shaken 30 min at 120 rpm	5 g soil + 50 ml water Shaken 30 min at 120 rpm	5 g soil + 50 ml water Shaken 30 min at 120 rpm
Preparing solutions and reagents to add later to the sample		Oxidizing solution: 10 ml of alkaline reagent + 2.5 ml of sodium hypochlorite	Mix reagent: solution of 10 ml Ammonium molybdate + 25 ml of sulphuric acid + 5 ml of potassium antimony tartrate
Preparations of sample before measurement	3ml sample in vial + 2 ml Ammonium chloride + 2 g copper cadmium	2.5 ml sample in vial + 0.1 ml of phenol + 0.1 ml sodium nitroprusside + 0.2 ml oxidizing solution	2.5 ml sample in vial + 0.25 ml mix reagent
	Agitation for 10 minutes	Vials need to be covered, stand in dark for minimum of 1 hour	5 minutes of colour development
	1 ml reduced sample in new vial + 1 ml sulphanilamide + 1 ml of diamine hydrochloride		
	5 minutes colour		

	development		
Measurement in spectrophotometer	Measured at 540 nm	Measured at 640 nm	Measured at 885 nm
Extra notes	Preparation in two steps, Nitrate could not be measured directly. Nitrite is measured to find Nitrate in the sample. The concentration of nitrite is equivalent to the concentration of Nitrate.		
Determining the reliability of the values from spectrophotometer and for calculation of the actual values in µg/g of soil	**Standard solution based on stock solution of 5 mM NO_3**	**Standard solution based on stock solution of 10 mM NH_4**	**Standard solution based on stock solution of 6 mM PO_4**
	0 µM	0 µM	0 µM
	25 µM	5 µM	0.3 µM
	50 µM	10 µM	0.6 µM
	75 µM	15 µM	0.9 µM
	100 µM	20 µM	1.2 µM

For all of the nutrients tested, the values had to be transformed to µg/g soil via the calculation of µM/g soil. For this a regression analysis was done, using the standard solution, the independent values, and the values from the spectrophotometer, the dependent values. After that the following calculations were performed;

$$C_1 = \frac{\left((\alpha + x * \beta) * \frac{50}{1000}\right)}{m}$$ Formula 1

$$C_2 = M * C_1 \text{ hh}$$ Formula 2

C_1 is the nutrient concentration µmoles/gram soil.

α is the intercept calculated in regression analysis.

x is the sample value of that specific nutrient from spectrometer.

β is the slope calculated in regression analysis.

m is the mass of soil in grams for the solution.

50/1000 is the conversion from millilitres to litres, 50 ml are used to dilute the 5 grams of soil.

C_2 is the nutrient concentration (µgram per gram soil).

M is the molecular mass.

- In Table 4.2 the materials and methods regarding the pH and the electric conductivity of the soil is showed.

Table 4.2: Method and material to measure pH and electric conductivity of soil samples.

Soil pH	**Soil electric conductivity (µS/cm)**
Solution ratio 1:1 (e.g. 1 gram of soil and 1 millilitre of distilled water)	Solution ratio 1:10 (e.g. 1 grams of soil and 10 millilitres of distilled water)
Measuring with pH probe from NMMU	Shaken 30 minutes 120 RPM
	Measuring with conductivity probe from NMMU

- Soil type and the texture of the soil were described in the field.

- Water content of the soil was measured by weighing empty cups. Then the cups were filled with soil and weight again. The samples were put in the stove for four hours at 70°C to dry the samples. After the samples cooled down the samples were weight again. Then the percentage of the water content was calculated. In Appendix I a template of the table used is shown.

$$\left(1-\left(\frac{\text{Weight cups before stove}-\text{Weight empty cups}}{\text{Weight cups after stove}-\text{Weight empty cups}}\right)\right)*100\% = \text{Water content } (\%)$$ Formula 3

- Organic matter content of the soil was measured by weighing the cups before and after the samples were combusted at 510 °C for eight hours. The template of a table, shown in Appendix I, was used to calculate the organic matter content. The calculation that was done to find the percentage organic matter was the following;

$$\left(1-\left(\frac{\text{Weight cups after oven}-\text{Weight empty cups}}{\text{Weight cups after stove}-\text{Weight empty cups}}\right)\right)*100\% = \text{Organic matter } (\%)$$ Formula 4

- Riverbed erosion was measured by looking at how deep the river has incised at an area, looking at the floodplain of the river. In former times the whole area was a wetland, with braided rivers and very little surface water, thus there was no incised river. The catchment degraded and became incised and the river as it is now was formed.

- Rainfall data was gathered from Water Research Commission (Middleton and Bailey, 2011a). This was translated to monthly rainfall in mm and calculated to yearly rainfall in the Kromme river catchment. The average rainfall is 700 mm in the area. The formulas that were used for this are;

$$Y = \frac{\text{Percentage of X}}{100} * 700$$ Formula 5

$$Y' = \text{sum of Y}$$ Formula 6

X is the mean annual rainfall.

Y is the monthly rainfall.

Y' is the annual rainfall.

- Plant community structure (species-coverage) using the Braun-Blanquet method (Hennekens, 2009). This method focuses on the abundance of certain species in a plot, which is estimated as percent cover projected on the ground. Per site, five invaded sites and five non-invaded sites, the plants occurring were determined, until species level or genus level. The abundance was coded as displayed in Table 4.3.

Table 4.3: Braun-Blanquet vegetation abundance scale after Hennekens, 2009.

Code	Description	Range of cover	Midpoint of Cover range
R	1-3 individuals	<5%	1%
+	Few individuals	<5%	2%
1	Abundant	<5%	3%
2m	Very abundant	<5%	4%
2a	Irrelevant	5-12.5%	8%
2b	Irrelevant	12.5-25%	18%
3	Irrelevant	25-50%	37.5%
4	Irrelevant	50-75%	67.5%
5	Irrelevant	75-100%	87.5%

4.2.1 Statistical analysis

XLSTAT was used to perform the statistical analysis of the collected data. To analyse the differences between invaded and non-invaded sites for nutrients, NO_3 and PO_4, pH, conductivity water content, and organic matter content, the Mann-Whitney U test was used because of the lack of normality in the distribution of the data (normality tested using the Levene test at P=0.05).

For organic matter outliers were determined and removed, because there tend to be some outliers in the dataset and to make sure the possible occurring outliers were filtered out the Thompson tau test was performed (Cimbala, 2011). The formulas for this calculation are written below (formulas 7 and 8). At first the mean and the standard deviation (σ) of the dataset was calculated. Then delta was calculated, using the following formula;

$$\text{Delta} = \text{abs}(\text{Organic matter content} - \text{Average Organic matter content}) \qquad \text{Formula 7}$$

Delta is the absolute value of the deviation.

Thompson tau (τ) is a value used to determine outliers. In this dataset Thompson τ was 1.86 as there are 15 values per sampling site (Cimbala, 2011).

$$\text{Thompson Tau test} = \tau * \sigma \qquad \text{Formula 8}$$

The outliers are the Delta values higher than the calculated Thompson Tau test. As Delta is the absolute value of the deviation the outliers could be both extreme low and high organic matter.
After performing the calculations one outlier in the Black Wattle sampling sites was determined and removed from the dataset.

For NH_4 concentration, riverbed erosion and plant diversity a Student t test was performed (normality tested using the Levene test at P= 0.05).

The rainfall data from Water Research Commission (WRC) report 2005 was analysed for changes in rainfall trend by making use of R-squared in a linear regression of the rainfall data from 1920 until 2004 in the Kromme river catchment. In the linear regression the dependent value was the annual rainfall and the independent value was the time. The higher the value of R^2 the more reliable the linear regression is.
This data was also tested for outliers. Outliers are the extremes in the dataset and for this can show what happened to the rainfall over the last 85 years. The following formula was used;

$$\text{Delta} = \text{abs}(\text{Annual rainfall} - \text{Average rainfall from } 1920 - 2004) \quad \text{Formula 9}$$

In this dataset Thompson τ was 1.94 as there are 85 values (Cimbala, 2011). Formula 8 determined which values in this dataset are outliers. As Delta is the absolute value of the deviation the outliers could be both extreme low rainfall and extreme high rainfall.

Furthermore the Shannon-Wiener index for diversity was calculated, according to the article written by Nolan and Callahan, 2005. This index is used, because it is the most commonly used index in ecological studies (Spellerberg and Fedor, 2003). This means that the results from this study will directly be comparable with other ecological studies.
The index was calculated to compare the diversity of plants in the two different sites, the Wetland and Black Wattle sites. Also a calculation was done to compare the evenness between the two different sites. The formulas used for this were;

$$Pi = \frac{\text{Individuals of a species (\%)}}{\text{Total number of individuals (\%)}}$$ Formula 10

$$H' = -Sum(Piln[Pi])$$ Formula 11

$$E = H'/\ln(S)$$ Formula 12

In which;

H' is the Shannon-Wiener index, showing the community's diversity at a site. The higher H' the higher the diversity and the evenness.

E is the evenness of a site, which shows how close in number each species are in an environment. The community is most even when the number of species are closer.

S is the species richness found at a site.

Pi is proportion of individuals of each species belonging to the ith species of the total number of individuals.

Ln is natural logarithm.

The whole dataset and calculations of this research are shown in Appendix I and all statistical tests are shown in Appendix IV.

4.3 Results

4.3.1 Area characteristics according to landowners and experts

The respondents were living and working in the Kromme river catchment or working on the invasive species, *Acacia mearnsii* and its effect on Fynbos vegetation. The information from the landowners is reliable as the same questions were asked and similar answers were given by the respondents. The expertise of the experts is reliable as well, as they were asked the same questions and also their answers were similar. Furthermore the experts were working in mostly riparian areas as well, which make the answers useful in especially the Kromme river catchment. The answers to the questions are presented in the table below (Table 4.4).

Table 4.4: Shown is the general impression given by the landowners and experts, if there was an effect estimated by the experts and/or landowners and if the answers are reliable.

Questions	**Landowners**	**Experts**	**Estimated effect on the Kromme river catchment**	**Reliability**
On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?	The tree has a N_2 fixating mechanism, resulting in a nutrient rich soil Soil organisms related to *Acacia mearnsii* growth in the soil Tannin production by the invasive species has an effect on the soil.	High nutrients in soil; N_2 fixation and P mineralization by *Acacia mearnsii*, Nitrogen compounds stored in nodules, are released when the tree dies. Tannin production and soil organisms related to *Acacia mearnsii* has an influence on the soil.	Higher nutrients in invaded sites, competition with native species Tannin and soil organism negative effect on native species.	Nutrient change (Nitrogen): Eight respondents Nutrient change (Phosphorus): one respondent Tannin: Five respondents Soil organism: Five respondents Often mentioned together.
What do you think of the	Experience of dryer soils in the area. High	Black wattle is initially growing in wet soils,	Severe drought in the Kromme river	Initial growth of *Acacia mearnsii* on

water availability in the soil? Is it lower where the invasive species grow?	water use of *Acacia mearnsii*. Initial growth on wet soils, but invasive tree can grow on dry soils.	but the soil becomes dryer when the tree is situated in an area	catchment, especially downstream, due to Black Wattle growth. Affecting wetland species as these species are intolerant for dry soils.	wet soils: Four respondents Lower water content and water table, due to invasive species: All (15) respondents
Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?	High water use by the tree. Effect is severe in downstream areas, as the river is more incised and the water table dropped.	*Acacia mearnsii* high water using tree. Invasive tree causes a severe hydrological change.	High water usage of Black Wattle, causes lower water availability, which is a problem for the native wetland species.	High water usage Black Wattle: 15 respondents
Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?	Black Wattle has a shallow root system, which is easily ripped out during floods. Invasive trees cause a clogging bridges, resulting in water taking another route, causing also erosion outside riverbed. Also in wetlands water takes another course, due to Palmiet growth	Incision of rivers due to Black Wattle growth as native species are replaced by Black Wattle. Wetlands plants, which anchor the soil are replaced by these invasive species with a root system that does not anchor the soil well.	Black Wattle causes severe erosion in a river system, also in Kromme river catchment. Incision of the river downstream is severe due to this tree and wetlands are degrading. Taking another course in wetlands is natural as it is a braided system	Erosion problems: 12 respondents Importance of root system: Four respondents Clogging bridges, resulting in water taking another course: One respondent In wetland, water taking another course: One respondent
Do floods have more effect on	Possibly more frequent floods,	No steady flow since the wetland is	Possibly more impact of floods due to	Impact of floods due to black wattle is

the area at places where invasive species are growing than at places where native species are growing?	possibly more problems with floods, e.g. erosion. Sediment is carried downstream and deposited downstream. This has an effect on the ability for landowners to use their land downstream	degrading, thus after a big rainfall the water is flushed down and not retained by the wetland.	Black Wattle. Straightened river, water is less retained by wetland species and more sediment is brought down, which also means there is more erosion.	high: Four respondents There were difficulties to answer this question as not all of the respondents had to deal with floods. It is dependent on the working area and the place of residence.
Do you think that fire plays a role in the growth of the invasive tree?	Fast return of Black Wattle after fire, immediate germination. The invasive tree has a more fire resistant seed bank than native species.	Smoke is a trigger for Black Wattle to germinate. Fire plays a severe role in the colonization of an area by Black Wattle. Smoke is the main trigger for the tree to germinate.	Black Wattle is germinating faster after fire than Fynbos species, such as Palmiet. This way it outcompetes the native species and colonizes an area.	Role of fire on growth of invasive tree is severe: Ten respondents Smoke as a trigger: One respondent
What do you think about the diversity of the plants? Is the diversity lower in invaded areas?	Palmiet and Black Wattle do not grow together. There is a lower diversity in invaded sites. Reasons are tannin and soil organism	Lower diversity in invaded sites, reasons light, water availability, fast recolonizing capacity of Black Wattle and tannin (allelopathic substance)	In invaded sites the plant diversity is lower than in non-invaded sites. Major reason given are; water availability and changes in the soil by tannin or soil organism	Lower diversity: 14 respondents Shadow: Two persons Water availability: Four respondents Changes in soil (tannin, soil organism): Seven respondents

4.3.2 Area characteristics from field measurements

4.3.2.1 Soil sample analysis

There was no significant difference found for soil NO_3 (Mann-Whitney U test: p=0.34), Figure 4.2a, and NH_4 concentrations (Students t-test: p=0.31) (Figure 4.2b).

Soil PO_4 content was significantly different (Mann-Whitney U test: p=0.000) between wetland sites and Black Wattle sites (Figure 4.2c), with lower PO_4 contents in wetlands.

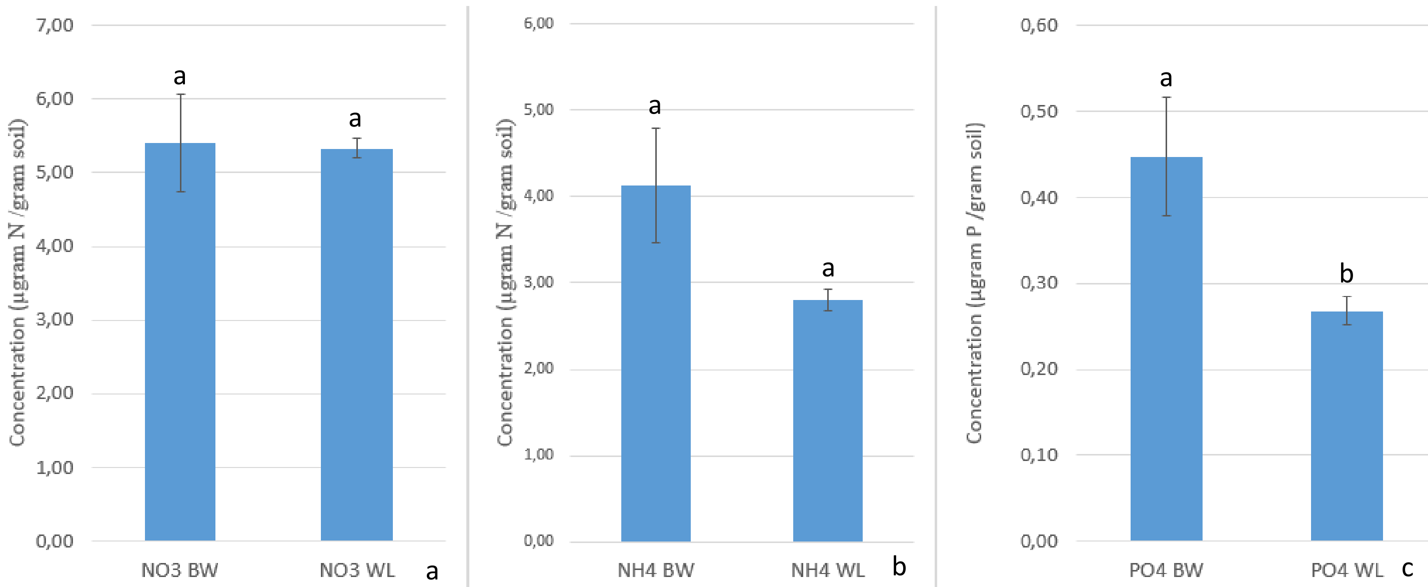

Figure 4.2: a) Nitrate concentrations in the soil of a wetland site (WL) and of a Black Wattle site (BW) is showed. In Figure 4.2b Ammonium concentrations are showed. Ortho-Phosphate concentrations are shown In Figure 4.2c. For this analysis 15 wetland samples are taken and 15 Black Wattle samples. Means with different letters are significantly different. Also the standard error is shown.

Furthermore there was no significant difference (Mann-Whitney U test: p=0.27) found in soil pH between wetland and Black Wattle sites (Figure 4.3).

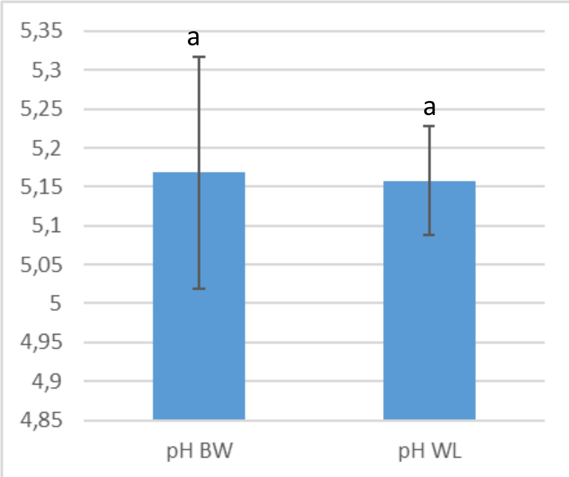

Figure 4.3: The pH of the soil at Black Wattle sites (BW) and wetland sites (WL) are compared. For this analysis 15 wetland samples are taken and 15 Black Wattle samples. Means with different letters are significantly different. Also the standard error is shown.

Also no significant difference is found in the electric conductivity (p= 0.28), Figure 4.4. The conductivity of the soil in wetland sites is not significantly different than the conductivity of the soil at Black Wattle sites after performing a Mann-Whitney U test.

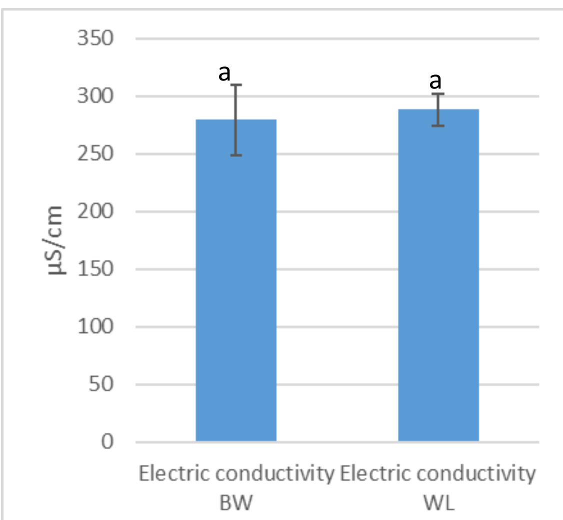

Figure 4.4: The electric conductivity (µS/cm) in Black Wattle sites (BW) and wetland sites (WL) is shown. The statistics showed that there is a significant difference between the conductivity in the both sampling sites. For this analysis 15 wetland samples are taken and 15 Black Wattle samples. Means with different letters are significantly different. Also the standard error is shown.

The water content showed a significant difference (Mann-Whitney U test: p=0.01), Figure 4.5a. The water content of the soil in Black Wattle sites is lower than at wetland sites. The organic matter content did not differ significantly (Mann-Whitney U test: p=0.10), although it tends to be highly significant, shown in Figure 4.5b.

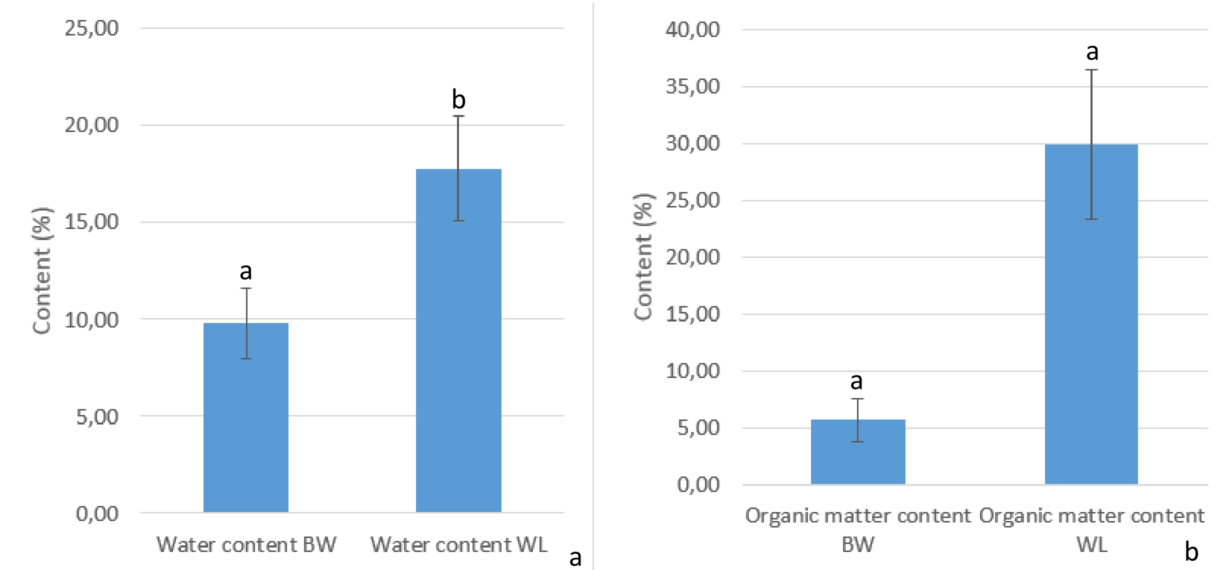

Figure 4.5: a) The water content of the samples at a Black Wattle site (BW) is compared to the water content and t at a wetland site (WL), 15 Black Wattle samples and 15 Wetland samples were compared. In Figure 4.5b the organic matter content is compared between Black Wattle sites and Wetland sites. For this analysis 15 wetland samples are taken and 14 Black Wattle samples, one outlier was found. Means with different letters are significantly different. Also the standard error is shown.

In Figure 4.6 two pictures of soils in invaded areas and in non-invaded areas are taken. The colour of the soil shows a possible difference in organic matter between invaded sites and non-invaded wetland sites. This contributes to the result of the organic matter content tending to be highly significant. In Figure 4.6a the soil in invaded area is shown and in Figure 4.6b soil in non-invaded area is shown.

Figure 4.6: a) Soil at a Black Wattle sampling site and b) soil at a wetland sampling site.

4.3.2.2 Analysis of erosion of the riverbed

Furthermore the depth of incision of the river, or riverbed erosion, is measured. No statistical difference in incision of the river is found between Wetland sites and Black Wattle sites (Students t-test: p=0.07). Showed in Figure 4.7

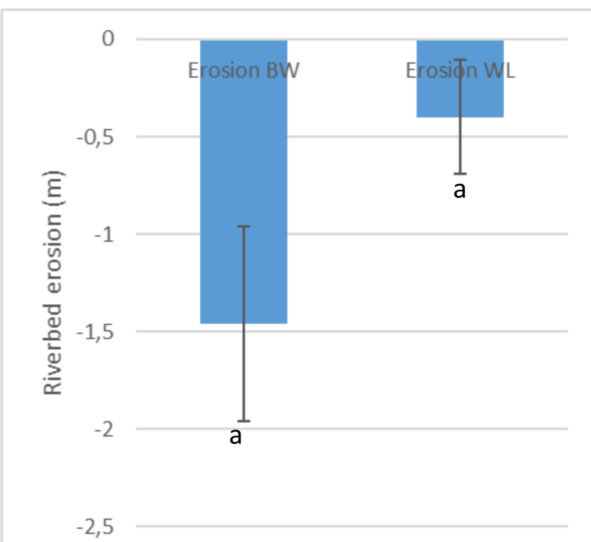

Figure 4.7: The riverbed erosion in meters is shown, BW stands for Black Wattle sample site and WL stands for wetland sample site. For this analysis 15 wetland samples are taken and 15 Black Wattle samples. Means with different letters are significantly different. Also the standard error is shown.

In Figure 4.8 two pictures of the Kromme river catchment are showed.

In Figure 4.8a the photo is taken in the upstream direction and in Figure 4.8b the photo is taken in the downstream direction. The gabion, which is an artificial structure to slow down the water flow and to retain the water, is shown with the blue arrow.

The wetland upstream of the gabion, pointed at with the red arrow in Figure 4.8a, shows no incision of the river, while the river is clearly incised downstream of the gabion, pointed at with the red arrow in Figure 4.8b.

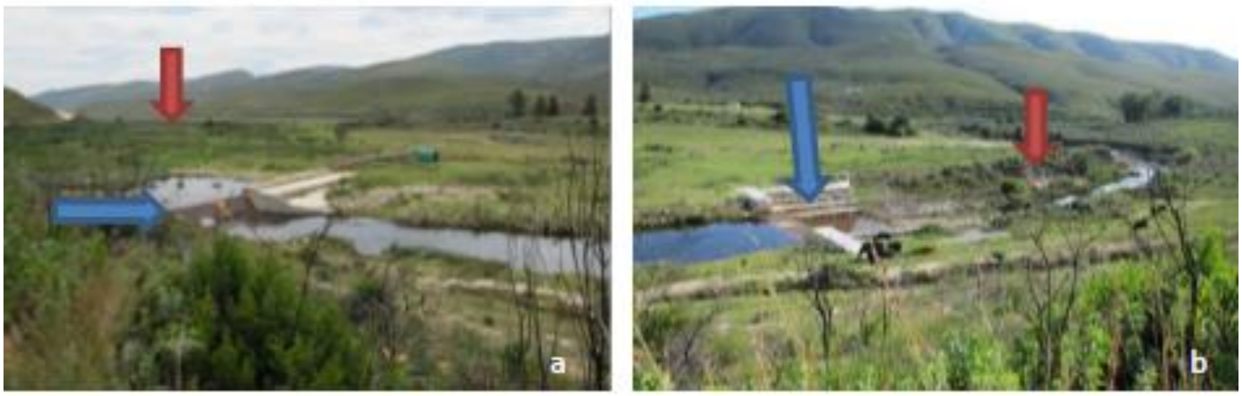

Figure 4.8: Gabion placed to protect the wetland upstream. On Figure 4.8a the gabion is shown downstream to upstream. Here the protected wetland is shown, protected by the gabion. On 4.8b the gabion is shown upstream to downstream and a lot of erosion is visible. The photos are taken by Alanna Rebelo, 2012.

4.3.2.3 Analysis of rainfall data in the Kromme

Taken a look at the rainfall in the Kromme river catchment there is a downward trend in rainfall (R^2=0.0219), although this trend is not significant. Also extreme rainfall or in statistical terms outliers are determined (arrows in Figure 4.9). All of the extremes are in the second half of the 20th century.

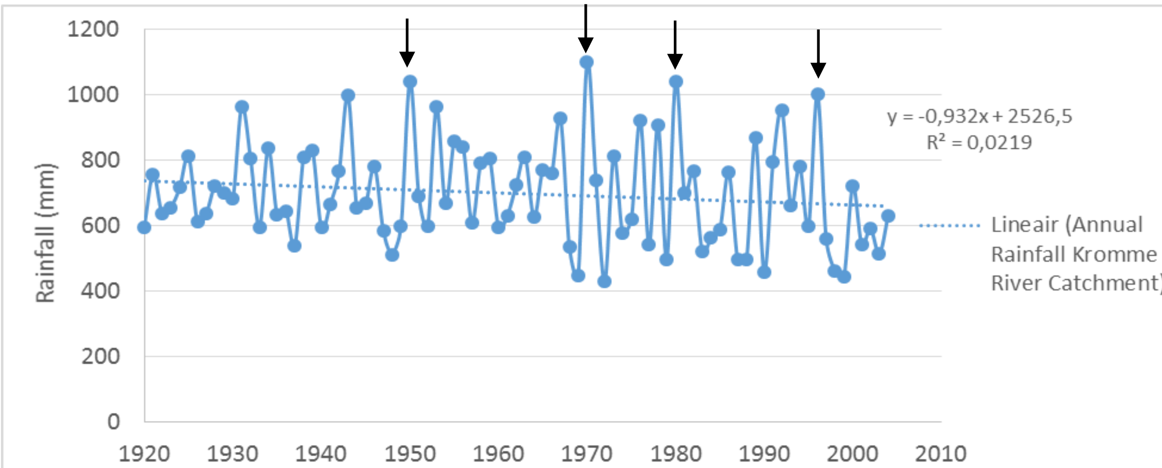

Figure 4.9: Rainfall data in de upper Kromme river catchment from 1920 to 2004 (Middleton and Bailey, 2011a). The arrows show the extreme rainfall events in this dataset.

4.3.2.4 Analysis of plant community structure

During sampling the plant community structure of the sample sites is determined. In Table 4.5 the different plant species are described. In Appendix II the species per sampling site are shown. The sampling sites are named according to the names of the different private lands, shown in Appendix III.

Table 4.5: Determined species, their average coverage in percentage and the standard error of the average coverage, in the Kromme river catchment. At every sampling site, five Black Wattle sites and five Wetland sites, the species are determined.

Family name, Species name, Common name (author of species)	**Average coverage of all sampling sites (%)**	**Standard error of the average coverage**
Fabaceae, *Acacia* mearnsii, Black Wattle (De Wild. 1925)	29.3	12.09
Myrtaceae, *Eucalyptus globulus*, Blue gum (Labill. 1800)	18.0	0
Poaceae, *Arundo donax*, Giant cane (L. 1758)	1.7	0.7
Cyperaceae, *Cyperus rotundus*, Coco grass (L. 1753)	1.0	0
Poaceae, *Pennisetum clandestinum*, Kikuyu grass (Hochst. ex Chiov. 1903)	44.5	16.0
Juncaceae, *Juncus* spp., Rushes (L. 1753)	17.7	12.9

Asteraceae, *Helichrysum odoratissimum*, Imphepho, (C. F. Ecklon. 1828)	18.3	12.7
Cyperaceae, *Eleocharis limosa*, Spikerush (Schrad. Schult. 1824)	13.0	5
Cyperaceae, *Cyperus involucratus*, Umbrella sedge (Rottb. 1772)	67.5	0
Thurniaceae, *Prionium serratum*, Palmiet ((L.f.) Drège ex E.Mey. 1843)	61.6	16.5
Rosaceae, *Cliffortia strobilifera*, Bog ricebush (L. 1753)	10.6	3.3
Poaceae, *Eragrostis spp.*	9.7	4.4
Asteraceae, *Conyza scabrida*, Paddabossiev (D.C. 1827)	18.3	8.5
Asteraceae, *Helichrysum anomalum*, Everlasting (Less. 1832)	8.0	0
Cyperaceae, *Isolepis prolifera*, Vleigras (Rottb. R.Br. 1810)	3.0	0
Poaceae, *Eragrostis curvula*, Weeping lovegrass (Schrad. 1841)	3.0	0
Poaceae, *Eragrostis* chloromelas, Blue lovegrass (Steud. 1854)	3.0	0
Anacardiaceae, *Searsia lucida*, Waxy-leaved rush (L. 1753)	3.0	0
Mackinlayaceae, *Centella asiatica*, Centella (L. 1763)	3.0	0
Rosaceae, *Rubus rigidus*, Wild bramble (S.m. 1919)	3.0	0
Campanulaceae, *Lobelia* spp., Lobelias (L. 1753)	2.0	0
Rosaceae, *Cliffortia linearifolia*, River ricebush (E. & Z. 1862)	1.5	0.5
Menyanthaceae, *Nymphoides* spp., Floating hearts (Ség. 1754)	1.0	0
Poaceae, *Pennisetum macrourum*, Beddinggrass (Trin., 1860)	1.0	0
Asteraceae, *Helichrysum spp.*, Everlasting (Mill. 1754)	1.0	0

Fabaceae, *Psoralea axillaris*, Tumble-weed (L.f. 1781)	1.0	0
Amaranthaceae, *Salsola kali*, Prickly Russian thistle (L., 1753)	1.0	0
	Species growing in Black Wattle sites	
	Species growing in Wetland sites	
	Species growing in both	

In Figure 4.10 the amount of plant species in wetland and Black Wattle sampling sites is shown. At sites where the *Acacia mearnsii* is growing the amount of plant species is less. This is statistically proven by the Students t-test, p=0.002.

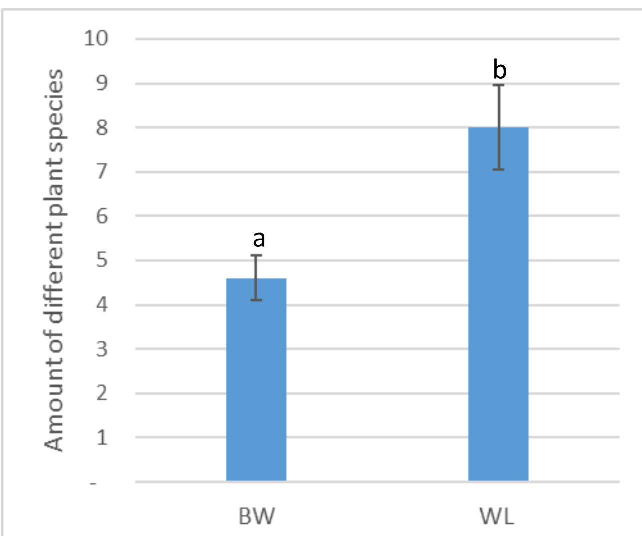

Figure 4.10: Shown is the mean amount of plant species in an area. BW stands for Black Wattle sample site and WL stands for wetland sample site. For this analysis the plant species are determined, one plot at every sampling site. Means with different letters are significantly different. Also the standard error is shown.

Shannon-Wiener diversity index is performed to find differences in diversity between invaded areas and non-invaded areas, shown in Table 4.6.

Table 4.6: Shown is the abundance of the different species in the whole upper Kromme river catchment and the Shannon-Wiener index of Diversity. BW stands for Black Wattle sampling site and WL for wetland sampling site. S is the species richness in Black Wattle sites and Wetland sites, H' is the Shannon-Wiener index and E is the evenness of the different sites.

Species name	Frequency of occurrence	Total abundance (%)	Average abundance (%)	Type of analysis	Value
Acacia mearnsii	8	234	29.3	S BW	8.00
Prionium serratum	5	308	61.6	S WL	23.00
Pennisetum clandestinum	5	222.5	44.5	H' BW	1.35
Helichrysum odoratissimum	5	91.5	18.3	H' WL	2.08
Juncus spp.	5	88.5	17.7	E BW	0.65
Cliffortia strobilifera	5	53	10.6	E WL	0.66
Cyperus involucratus	2	135	67.5		
Eleocharis limosa	2	26	13.0		
Eragrostis spp.	3	29	9.7		
Conyza scabrida	3	56.5	18.3		
Arundo donax	3	5	1.7		
Cliffortia linearifolia	2	3	1.5		
Psoralea axillaris	2	2	1.0		
Eucalyptus globulus	1	18	18.0		
Cyperus rotundus	1	1	1.0		
Salsola kali	1	1	1.0		
Lobelia spp.	1	2	2.0		
Nymphoides spp.	1	1	1.0		
Isolepsis prolifera	1	3	3.0		
Eragrostis curvula	1	3	3.0		
Eragrostis chloromelas	1	3	3.0		
Pennisetum macraurum	1	1	1.0		
Helichrysum spp.	1	1	1.0		

Helichrysum anomalum	1	8	8.0
Searsia lucida	1	3	3.0
Centella asiatica	1	3	3.0
Rubus rigidus	1	3	3.0

As shown in Table 4.6 *Acacia mearnsii*, *Pennisetum clandestinum* and *Prionium serratum* are abundant in the Kromme river catchment. *Eucalyptus globulus* is only found at one site but is relative abundant at that site compared to the other species found at only one site. *Cyperus involucratus* is a very abundant species in two wetland sites.

The evenness of Black Wattle sites is similar to the evenness of wetland sites (respectively E=0.65 and E=0.66). Looking at the diversity of the two sites, the diversity of Wetland sites is higher than the diversity in Black Wattle sites (respectively H'=2.08 and H'=1.35). All of the calculations of the Shannon-Wiener index can be found in the Appendix I.

A calculation is done to find where the most non-native species are occurring, in invaded sites or not invaded sites (Table 4.7).

Table 4.7: Unique and joint occurrences of selected species at Black Wattle, wetland and both sites and which species are native and which are non-native.

All different species at all sampling points	**Site type**	**Native or Non-native species**
Acacia mearnsii	Black Wattle	Non-native
Arundo donax	Black Wattle	Non-native
Salsola kali	Black Wattle	Non-native
Eucalyptus globulus	Black Wattle	Non-native
Cyperus rotundus	Black Wattle	Native
Pennisetum clandestinum	Both	Non-native
Helichrysum odoratissimum	Both	Native
Eleocharis limosa	Both	Native
Conyza scabrida	Wetland	Non-native
Centella asiatica	Wetland	Non-native

Cliffortia strobilifera	Wetland	Native
Prionium serratum	Wetland	Native
Eragrostis curvula	Wetland	Native
Cyperus involucratus	Wetland	Native
Eragrostis chloromelas	Wetland	Native
Pennisetum macraurum	Wetland	Native
Rubus rigidus	Wetland	Native
Helichrysum anomalum	Wetland	Native
Psoralea axilaris	Wetland	Native
Cliffortia linearifolia	Wetland	Native
Searsia lucida	Wetland	Native
Isolepsis prolifera	Wetland	Native
% of Native species in Wetland sites	82	
% of Native species in Black Wattle sites	38	

Besides the diversity also the species composition differs. At places where Black Wattle was growing, 38% of the species were native, while at places where Black Wattle was absent 82 % of the species were native (Table 4.7).

Chapter 5
Management suggestions

5.1 Introduction

The management of invasive species, *Acacia mearnsii,* and the rehabilitation of wetlands in among others the upper Kromme river catchment is done by Working for Water and Working for Wetland programs, but according to Rebelo, 2012, *''Recent research has shown that the Working for Water program is sometimes inefficient, as follow-up invasive alien plant clearing treatment is often not done timeously''* and a study should be done to make the management program more efficient (http://www.dwaf.gov.za/wfw/, Rebelo, 2012). For example; in seven years after clearing and no implemented follow-up in the Kouga River Catchment, it was covered with *Acacia mearnsii* again, according to the study done by Díaz González, 2012. This is also seen in the upper Kromme river catchment where one year after clearing and no follow-up implemented Black Wattle was returning (Zwinkels, Pers. Comm., 2014).

A detailed focus on the current management strategy, the knowledge and awareness of local people is needed to make some suggestions to the current control and/or eradication strategy of *Acacia mearnsii* in the Kromme river catchment.

5.1.1 Methods

The method, to answer the research questions, used for this part of the thesis is to ask questions about how the current management strategies are implemented and about what people indicate that could be important as suggestions to the current clearing strategy for a more efficient approach to for example replant native species. Also the management strategy for clearing *Acacia mearnsii* written by the Working for Water program is gathered. Both are able to give a very good idea about the whole management strategy to clear *Acacia mearnsii*.

Nine persons were asked the following questions about the management practises in the area. The entire conversations can be found in Appendix V.

- What are the steps in the current strategy to clear the Black Wattle?

- To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?
- Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?
- Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?
- What suggestions would you want to give to create this ´new´ landscape?

5.2 Results and Recommendations

5.2.1 Current management strategy

The current strategy of the Working for Water (WfW) program to eradicate and/or control invasive species contains of a few general steps in the basis of the program. A support strategy deals with the problem of invasive species. It has four main focus points; a national jobs development program, an education and communication program, a legislative framework and a focus point on biological control (McQueen, 2001). These focus points of the program ensures that citizens take collective responsibility for the problem of spreading invasive species.
Another aspect of this program is to make sure the landowners take their responsibility by implementing a legislative framework. All of this is to eventually implement the control and management strategy of invasive species in this case *Acacia mearnsii* (McQueen, 2001).

5.2.1.1 Working for Water Advisory Committees/Forums

In order to ensure optimal community participation in a Black Wattle clearing program (parts of the so called support strategy), WfW works with a community representative structure to guide project-level operations. Among others, the representatives will serve the project in an advisory capacity, hence facilitating sufficient consensus among all relevant stakeholders. For this, Advisory Committees or Forums ensure optimal community participation in clearing projects, for example by setting up an agreement for clearing of private land. Also the community interests are addressed, equity, transparency and fairness in terms of access to employment and work distribution has to be ensured. Advisory Committees also mediates in situations of conflicts related to WfW projects and it ensures collaboration between local and regional community structures and processes (Reference for advisory forums, 2009).
An Advisory Committee should be representative for the whole area of the project, for example the Kromme river catchment. At this local level the stakeholders that should be participate in the Committee are; representatives from the project management, local government representatives (Koukamma municipality in the Kromme river catchment), locally based non-governmental organisation, community based organisation, local landowners association, private landowners, religious institutions, the local Nature Conservation representative, locally based South Africa National Parks Board Representative, implementation agent, representatives of other relevant community identified local stakeholders (Terms of Reference for Advisory Forums, 2009).

5.2.1.2 Agreements for clearing on private land

This community participation and collective responsibility is important for clearing of invasive trees on private lands. For clearing on these lands specific rules are applied.

- The landowner should have right to fell trees or remove trees or wood from their land. Then on receipt of application the Working for Water program will decide if it is going to assist on clearing the land. If the Working for Water program approves, a representative of the program will prepare a plan for clearing of the area. This plan is among others based upon the density and age of the invader. The representative will also determine the costs of the clearing work and the dates upon which any contributions by the land users are to be made. The Working for Water representative will conduct an inspection of the land with the land-use to determine the general condition of the land with regard to fencing, litter, erosion, quality of roads etc., because these aspect may affect the clearing work (Working for Water program, 2006).
- The clearing work should be done within six months of the land user being notified that the Working for Water program is prepared to assist in clearing. If this is not done, the contract between WfW and the landowner will be deemed to void (Working for Water program, 2006).
- When the clearing starts the WfW program is responsible for all negotiations and dealings with the independent contractors and workers and the landowner must take all reasonable precautions to prevent injury to persons doing clearing on that specific land, other than the injuries associated with carrying out the clearing work. The clearing work may require burning activity and for this the landowner must supervise and take responsibility for this and it also is responsible for any damage as a result of such burning (Working for Water program, 2006).
- Once a part of the area is cleared the representative of WfW program will set a date for inspection and the landowner can determine the adequacy of the clearing. If, after inspection, the parties agree that the clearing is incomplete and that further work is required, the representative will get into contact with the contractor to make a plan for this and the landowner will refund to the Working for Water program the costs incurred by the program in providing assistance to the landowner (Working for Water program, 2006).
- When the clearing work had been completed another joint inspection will be planned and when all parties agree upon the land being clear, the landowner will be issued with a Directive by the National Department of Agriculture in terms of Conservation of Agricultural Resources Act. In this the terms of further maintenance by the landowner will be set out. The dates in which the further work has to

be done will be determined by the representative of the WfW program. This will make sure the land stays clear and the recurrence of the Black Wattle will be limited (Working for Water program, 2006).

5.2.1.3 Working for Water and Working for Wetland methodology

The former communicative aspects are key for the successful clearing practices, as it is important that the local people as well as the people from Working for Water know the rules of the clearing practises, especially in the Kromme river catchment as a lot of this area is privately owned land.

The clearing practice itself includes physical, chemical and biological control methods (Venter, 2005). The method that is used is dependent on the age and the density of the stands.

- Clearing of seedlings; these plants can be removed by hand pulling. This is very labour intensive and this is used only in small areas or where herbicides are not desirable. Burning seedlings is also possible but it is ecologically unacceptable to burn in such a frequent matter (Martens et al., 2003).
- Clearing of pre-mature trees in dense stands; these trees are removed by felling or burning, but if stumps are left, they must be treated with herbicides, as the tree is able to re-sprout (Martens et al., 2003).
- Clearing of pre-mature trees in low density stands; the same approach is used as when the pre-mature trees stand in dense stands (Martens et al., 2003).
- Clearing of mature trees; clearing is done by felling, using herbicides or bio-control agents (*Melanterius maculatus* and *Dasineura rubiformis*). These agents predate on the seeds and this is an important long term control strategy (Martens et al., 2003; Wilson et al., 2011). Another technique used is ring barking. Ring barking involves removal of 10 cm wide strip near the base of the trunk. In this technique herbicides are used, for the same reason that herbicides are used for felling trees. Normally, ring barking prevents the flow of water and nutrients up and down the trunk, but the ability to re-sprout makes this technique without herbicides unsuccessful (Martens et al., 2003). And at last also burning is a management strategy, but fire stimulates the seed bank to germinate and a follow-up is necessary (Martens et al., 2003).

In Table 5.1 details about the different methods are shown and the herbicides used to control this plant are shown in Appendix VI (http://www.dwaf.gov.za/wfw/default.aspx, Martens et al., 2003). According to the Working for Water program the strategy to control the Black Wattle is comparable to the theory of controlling the Black Wattle at different points in the lifecycle, described in the introduction of this report.

Table 5.1: Showed are methods to clear Acacia mearnsii, dependent on their age and the density of the stands (Martens et al., 2003).

METHOD		**Felling & Burning**	**Bulldozing/ Mulchmaster (Mechanical)**	**Herbicide**	**Frilling**	**Bark stripping/ Ringbarking**	**Biological control**
AGE	Mature medium to dense stands	Fire stimulates seed bank thus follow up is imperative. Intense fires may cause damage to soil, revegetation may be necessary.	Where cultivation or establishment of pastures is to occur. Slash can be burnt or placed strategically to prevent erosion.	After felling stumps smaller than 20cm. Treated immediately, dye is advisable.	Series of continuos cuts into cambium, Timbrel applied, tree left standing.	As an alternative to herbicide or fungus bark of cut stumps peeled to the ground. Ringbarking involves removing 10cm wide strip near base of trunk, herbicide applied.	*Melanterius acaciae* attacks the seeds of Blackwood. Long term control. Fungus can be applied as a stump treatment on Black Wattle instead of herbicide.
	Scattered mature	All the methods of eradication described above are applicable.	All the methods of eradication described above are applicable.	All the methods of eradication described above are applicable.	All the methods of eradication described above are applicable.	Good options for this category.	All the methods of eradication described above are applicable.
AGE	**Medium & dense stands of saplings**	Trees can be felled and later burned, stumps must be treated with herbicide.	Advisable where infestation is dense. Slash to be burnt.	Treated by spraying / painting herbicide onto lower 40cm of the stem.			Fungus can be applied to Black Wattle stumps instead of herbicide.
	Scattered & single young trees			Stem treatment as above, or stump treatment with herbicide.			Fungus can be applied as described above.
	Seedlings	If there is enough dry material fire can be used. Frequent burning is however ecologically unacceptable.	Hand pulling is possible in soft soil. It is very labour intensive and used only for sparse infestations or a small area or where herbicide is not desirable.	Foliar spray effective on Black Wattle, knapsacks used with a flat fan nozzle. Mamba/water mixture recommended. Can also be used on Blackwood seedlings, spraying should be done in winter or early spring. 0.5% Garlon/water mixture recommended.			

After successful clearing of an area, rehabilitation work should be done. Working for Wetland is rehabilitating/restoring (parts) of the Kromme river catchment. The rehabilitation plan for the Kromme river catchment started in 2000 and was important to prevent further destruction of peat basins through mainly head cut erosion.

The program was implemented to improve the hydrological functions of the wetland, to decrease the sediment yield from erosion and this way to reduce the sedimentation rates within the storage dams. The main goal was to ensure a sustained supply of water to the two dams (Churchill and Impofu dam).
Also species diversity and habitat diversity protection was part of the plan and this is done by rising the water table, thereby ensuring a sustained water supply to the peat basins.
Furthermore flood retention and poverty relieve by developing skills in contractors and workers was part of the plan (Kotze and Ellery, 2009).
The rehabilitation/restoration work was and is done by building gabions at places where native wetland species are growing. This structure retains the water in a specific area, which is what a good functioning wetland does. Thus, it prevents water from flushing downstream taking a lot of soil and it prevents head cut erosion, as it decreases the energy of the water (Buckle, Pers. Comm., 2014). In Figure 4.8 the effects of the gabion on the area is showed.
Building those gabions is a strategy from the Working for Wetland program to make sure the wetland and its ecosystem services can return and can be able to grow and develop (Zwinkels, Pers. Comm., 2014; Rebelo et al., 2012).

5.2.2 Management strategy according to local people

The local people living and working in the Kromme river catchment all have experience with the clearing of *Acacia mearnsii* by the Working for Water program. This means that all of the respondents have seen and experienced what happened in the Kromme river catchment regarding clearing *Acacia mearnsii* and what the results of those clearing practises are. All of the respondents were asked the same questions and similar answers were given, presented in the table below (Table 5.2).

Table 5.2: Shown are the answers to the questions asked by the local people and also some additional information regarding the questions is given.

Questions	**Local community**	**Additional information**
What are the steps in the current strategy to clear the Black Wattle?	Initial clearing consists of felling, but the trees are left in the field. The felling is done according to aerial photographs, according to one respondent. Other methods are using herbicides, ring-	Clearing on private lands, for this an agreement had to be written and signed. The clearing should be done from the highest part of the area to the lowest

	barking and bio-control agents.	part of the area.
To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?	Follow-up is lacking, which means the tree is growing back. The trees are growing fast, up to three meters in two years (Figure 5.1). Also the trees that are left in the field after clearing are now causing problems as the tree trunks are flowing downstream, causing clogging of bridges and causing more erosion (Figure 5.2). Furthermore, some areas are not covered with the aerial photographs, which means *Acacia mearnsii* is not cleared in those areas.	If clearing successfully is implemented, native species can return. Palmiet is able to return after successfully clearing an area and after recovering the hydrology. No follow-up or follow-up not properly implemented resulted in a concern of a waste of money and time and even more degradation of the area regarding the clearing practises of the tree, among the respondents.
Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?	Consequently removing the species, by preferably ring-barking as an initial clearing strategy and using bio-control agents for long term clearing. Also seedlings should be removed by hand-pulling. In private land goats can be used to keep an area clear. These animals also eat the roots, which is very successful in clearing. After clearing, in case of felling, the tree should be turned into compost, construction wood or fire wood.	Eradication of this tree is about dedication, time and making sure no new seeds are produced or spread. In general cattle have problems with the uptake of nutrients from the tree, due to their tannin production. Tannin is also a plant defence mechanism towards herbivory.
Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´	Disturbances of soil, by for example fire causes *Acacia mearnsii* to (re) colonize an area. The soil contains the seed bank of the tree, so clearing the soil from the seed bank is important in clearing Black Wattle.	Tannin is mentioned by the locals as being an allelopathic substance, creating problems for other species to germinate. Local people indicate that the soil stays bare for a long time after clearing.

(Black Wattle free) landscape?	Tolerance to soil organisms and tannin production by *Acacia mearnsii* is important factor in difficulties for native species to return, like Palmiet. To really restore the Kromme river catchment to its natural state the water content of the soil should be recovered.	The organism in the soil, so called nematodes or eelworms, cause possibly problems for the uptake of nutrients for plants and the plants do not survive in these soils, for example honeybush is one of the species suffering. The hydrology can be recovered by for example placing gabions, which stops head cut erosion and prevents water from flushing downstream very fast, *Prionium serratum* (Palmiet) will grow back by itself as the returned water cleans the soil from the tannin and the soil organism, as claimed by the respondents.

Figure 5.1: Tree growth in two years after initial clearing, photo made by Sharon van Rossum.

Figure 5.2: Cleared area, with tree trunks from upstream area deposited in this area and with trees left in the field, photo made by Sharon van Rossum. In the circle the deposited and left tree trunks are showed.

Comparing Table 5.2 with the current management strategy by Working for Water and Working for Wetland program, a difference in clearing strategy is encountered and there could be a possible communication problem between the two parties.

Differences are found in the management strategy regarding replanting species, taking a look at soil characteristics, as the tree has possibly an effect on the soil (tannin, soil organism) and taking a look at the possible products of the invasive tree. These three aspects are more taken into account by the local community than by the Working for Water program.

To close the gap between the Working for Water program and the knowledge of the local people about the program suggestions, partly based upon suggestions from the local people, to the current management strategy are given.

5.2.3 Suggestions to the current strategy

At first, the communication between the governmental structures and the landowners should be improved to overcome the differences in knowledge between local landowners and the people from Working for Water program. Advisory committees are a central component of Sustainable Development Programs and community participation. These advisory committees are a very good way to communicate the actions taken by governmental organization to the local people. If this is properly done it could increase a sense of responsibility and consciousness regarding land use and alien clearing. The advisory committees formed by WfW can allow for an accurate understanding of community needs, resources, social structure, values and early citizen involvement, in order to build collaborative partnerships and facilitate broad community participation (Appalraju, 2006).

Secondly, replanting is very important, and should be done more consequently. Locals suggested to replant plants like Kikuyu grass (*Pennisetum clandestinum)*, to make the river more resistant to floods and erosion. Kikuyu grass is a species that grows fast and is able to grow on soils where Black Wattle used to grow and it anchors the soil really well. However, one needs to take into account that Kikuyu grass is also an alien species in South Africa and it could become invasive as well as this happened in the Agulhas Plain in South Africa (Gaertner et al., 2011).
Another plant that is able to anchor soil is Palmiet, but this species needs a high water content in the soil and is possibly having difficulties growing in the altered soil. To make this species return the hydrology should be changed. After that, the wetland species possibly returns by itself (Buckle, Pers. Comm., 2014). In the Working for Wetland program, rehabilitation of the area is started, but this could have major effect on the landowners' practices. For example this plant is not suitable for cattle to feed on. But to restore or rehabilitate the Kromme river catchment and its important ecosystem services, e.g. water storage, water purification and flood attenuation, the landowners need to change their land use practises if restoration/rehabilitation is further implemented. This possibly creates a big conflict of interest that needs to be solved, before one starts to take action in how the area should function.

Thirdly, an important aspect to look at more in the future is a way to take into account the soil properties especially the water content of the soil. The landowners indicated that water content cause the difficulty in the regrowth of native species, due to competition. The water content is for a large part determining the growth of Palmiet in an area, as it grows in very moist soil. Also mentioned was the possible allelopathic substance, tannin, which could create difficulties for the growth of native species.

At last, the local people have also good ideas about making use of the alien tree. They mention a way to use the N_2 fixing tree as a type of compost to fertilize the poor soil. *Acacia mearnsii* stores some Nitrogen from the N_2 fixation in its biomass, which makes the tree a good fertilizer of soils for farming activities in the Kromme river catchment (Forrester et al., 2007).

Another idea that came up is to use the wood from the cleared sections for fire wood. Furthermore making charcoal out of it is also an opportunity for using the tree. This charcoal can for example be used for filtering water. Also, Black Wattle wood is very hard wood and this can be useful in construction, but also in decorating.

These five cases show the possible functions the alien tree can fulfil. Furthermore the tree is removed after clearing and this is good to prevent damage to the catchment by the loose trees.

Feedback about the usage of the tree is given by an expert related to Working for Water program. Making use of the tree not a given opportunity, which does not mean that these people do not want to make a product out of the tree, but as there is a lot involved and it may cost a lot of money it is very difficult. Explained was that in forestry the most expensive operation is logging, which is similar to the alien clearing itself and most of the products will be used downstream thus also a lot of transport costs have to be added (Kawa, Pers. Comm., 2014). Taken into account should be that there are landowners willing to do something, even though it will cost money. Stated was; *''the money that will be earned by producing this compost may be less than the costs to fell the trees, but it will create job opportunities and this is also a way of earning''*. Also people were already able to get compost from the tree, as there are connections with people for the production of these products. Furthermore, if the Kromme river catchment is going to be restored the people need to change their land use practises as it is impossible to continue farming in the restored areas. Using this tree to create jobs in another direction than farming activities could help to change the land use of the people, shown with the statement above.

Overall, clearing the area from *Acacia mearnsii* is a long term process and consequently removing and trying to make a market out of the removed trees is the best way to clear the area, according to the local people. And related to restoration or rehabilitation of the area, workshops and meetings are very important to make clear what every party in the area wants to achieve, so it will be a joined solution to the problem of this alien species.

Chapter 6
Discussion and Conclusion

6.1 Shortcomings during this research

During my research some shortcomings were encountered, which partly determined the results that were presented in this study. At first, regarding the empirical field study, I also wanted to take groundwater and surface water samples, besides soil samples, to see if there are differences between invaded sites and non-invaded sites. Unfortunately I did not have the right equipment to take groundwater samples. I was limited in the equipment I could borrow from the Nelson Mandela Metropolitan University in Port Elizabeth, as I am not a student there and for this both parties were not insured, for example in case I broke a measurement device. Furthermore, I only found surface water in the invaded areas and not in the non-invaded, wetland sites. Thus instead of taking groundwater and surface water samples I took more soil samples than originally planned to make the dataset more reliable. Unfortunately I could not just go in the field and take samples everywhere I wanted, because most of the area in the Kromme river catchment is privately owned. It was key to make sure to first speak to the landowner and then see if the landowner allows the student or researcher to take samples.

The soil samples were taken in the driest period of the year, which could have an influence on the results I found, for example in the water content of the soil, which is most probably different in a wetter period of the year. Other methodological issues encountered are the fact that the samples had to be stored for some time before they could be analysed. This could have influenced the results as in the time between sampling and analysing chemical or biological reactions could have taken place. I tried to overcome that by making sure the samples were cooled as soon as possible to minimize the reactions that could take place.

Also, regarding the results, one should take into account that *Acacia mearnsii* is able to grow on dry soil, but also on wet soil. This means that it could be that the soil was already dryer at the first infestation of this tree, although the tree prefers riparian wet soils for germination and development to a mature tree. Yet, the ability to grow in wider water niche could have an effect on the results of the water content of the soil. For this I carefully chose the sampling sites in the area that used to be the Palmiet river, which is now degraded and incised, but from which I was sure it ones was comparable with the still existing wetlands in the Kromme river catchment.

Furthermore, I was dependent on speaking to people in the area and some problems were encountered. For example, I could not get hold of some people I wanted to speak to and for this it was not possible to set a meeting as I had only limited amount of time to go to the study area. Another problem was that some of the people did not want to speak to me. To overcome these problems I arranged some meetings with a person who knows the local people in the area and who was trusted by the local people. Via this person I was able to get hold of and speak more people than I would have been able to without this person.

At last, logistical problems were encountered. I was living more or less two hours from the study area and from the university where I analysed the samples and there were only two cars available for the students and the staff members. To overcome that a good planning was very important. The students had to arrange a way to go together and to make a time planning that everybody could do his or her research in the area, which was not always time efficient.

6.2 Criticizing opinion-driven research

A critical note should be given about the opinion-driven research in which landowners and experts are asked about their perception on Black Wattle in the Kromme river catchment.
At first should be noted that possibly some of the experts are related and could answer the questions from the same research. This means that the experts are not entirely independent. This also applies for the landowners questioned. Some of the landowners know each other and the perception and opinion on this subject could be influenced by others. Furthermore the answers given by the landowners are based upon what they see and notice, while the answers given by the experts is based upon their scientific knowledge, but possibly not specifically on the area of interest. These factors can have an effect on the results of this part of the research.

6.3 Discussion and conclusion drawn from the results

In this research soil characteristics are compared and this is related to possible management suggestions. The discussion and conclusion of the results is written below.

There are no significant effects of Black Wattle on major chemical soil characteristics in this study. Although, in the paper of Jacobs et al., 2013 a difference is found in the amount of available Nitrogen (Nitrate and Ammonium) in the soil. It was significant greater in invaded sites than in non-invaded (Fynbos) sites (Jacobs et al., 2013). But if one takes a look at the research done by Gaertner et al., 2011 no difference is found in the available Nitrogen (Gaertner et al., 2011). These two examples show the difficulty in answering whether or not the amount of available Nitrogen is different in Fynbos sites versus *Acacia* invaded sites. A few possible reasons are given.

The ability of *Acacia mearnsii* to fixate Nitrogen does not increase Ammonium and Nitrate in the soil directly, as it could be that the Nitrogen stays in the nodules of the tree as long as the tree lives (Waal, Pers. Comm., 2014). When the tree dies the Nitrogen is released from the nodules, which increases the amount of Nitrogen in the soil (Waal, Pers. Comm., 2014). Also, the soil type can make a difference in the results. As it was not clear what exactly the soil type was in the research done by Gaertner et al., 2011 and Jacobs et al., 2013 this could explain why the results are not the same. The soil type determines for example the amount of nutrients that is washed down. In a sandy soil nutrients are washed down much easier than in clayish soil types (Nguyen and Marschner, 2013).

A significant difference is found in the Ortho-Phosphate concentrations. In the Black Wattle sites the concentration was higher than in wetland sites.

The difference in PO_4 can be explained by the ability of *Acacia mearnsii* to mineralize Phosphorus to Ortho-Phosphates, which is available for plants to take up (Naudé, 2012; Hyland et al., 2005). A second reason can be given by the ability of Black Wattle to extract P from deeper down and it then concentrates in the surface layer through leaf litter (Waal, Pers. Comm., 2014). The research done by Waal, 2009, the litter cover is higher in Black Wattle sites than in Fynbos sites (Waal, 2009).

The (possible) difference in nutrient richness (N and P) is important to take into account in management strategies as species that are slow growing and adapted to nutrient poor conditions, for example *Prionium serratum* (Palmiet) is in disadvantage over pioneer species (Bain et al., 2011; Marchante, 2010). These pioneer species can grow much faster in these less nutrient poor conditions and compete with native species like *Prionium serratum*, which is a species likely to lose this competition. This is important to know in management practices, because restoring or rehabilitating an area is not efficient when the tree has chances to germinate in these areas chosen to restore.

Although it is not found significant, the organic matter content tends to be highly significant and much lower in invaded sites with *Acacia mearnsii*. The dataset of the wetland samples was very variable and this could be the reason no significance is found. More samples are needed to determine the most probably occurring outliers in the dataset. No outliers were determined in the wetland samples, because the standard deviation was very high and for this the Thompson tau test as well, which means that the delta calculated did not exceed the Thompson tau value.
Despite this non-significant finding, an explanation is given to explain why the organic matter tends to be lower in invaded areas. *Acacia mearnsii* has a large effect on the degradation of the wetlands and on the peat in the wetland as the tree uses a lot of water (Grundling and Grobler, 2005). The degradation of peat is related to a lower organic matter content of the soil (USDA, 2011).

Mentioned by the respondents was a lower amount of water available in the soil in invaded areas. The tree uses a lot of water, causing the soil to dry out. This perception of those persons was empirically analysed and statistically proven: the soil water content at Black Wattle sites was significantly lower than the soil water content in the wetlands.
An explanation for the lower water content of the soil is the evaporation rate of this species. The total annual evaporation in invaded sites could exceed 1500 mm, while the total annual evaporation in areas with native Fynbos species is in between 600 and 850 mm (IWR, 2005; Dye and Jarmain, 2004). Also the amount of rainfall intercepted by this invasive tree is much higher than the interception of rainfall by native species in the area, which also has an influence on the soil water content (Maitre, et al., 1999).
Furthermore, riverbed erosion results in the water table to drop. According to the respondents in this research riverbed erosion is a very important problem related to *Acacia mearnsii* growth and clearing activities, but it is not found significant. However, riverbed erosion tends to be lower in non-invaded areas than in invaded areas.
Also related to riverbed erosion and the lower water content is the rainfall. Rainfall from 1920 until 2004 was examined for extremes. The extremes are found in the last 50 years of the 20th century, in 1950, 1970, 1980 and 1996. Major floods occurred in the area in the years 1950, 1981 and 1996, most probably related to the amount of rainfall in the same or the previous year (Rebelo et al., 2012a). By then the

wetlands were already (partly) degraded and the effect of the rainfall was severe. The wetlands could not store the amount of water that it was able to store and it could not attenuate floods, causing riverbed erosion to rapidly accelerate, among others due to the shallow root system of *Acacia mearnsii* (Rebelo et al., 2012a). These floods are also related to even more spreading of *Acacia mearnsii*, causing even more problems with among other soil water availability and riverbed erosion in the Kromme river catchment (Nsor, 2007).

The problems with riverbed erosion and water content related to *Acacia mearnsii* growth are very important in management practises and rehabilitating or restoring the area.

At first, after clearing, tree trunks are left in the field, which also creates possible problems with riverbed erosion and possible problems with clogging. For this a management approach could be to remove the trees and possibly to make a product out of the trees. For this to be successful, it should be found out if there is a market for these products and what the costs and benefits are going to be. Communication between the different parties is for this very important to solve this issue.

Secondly, the bare soil left after clearing should be directly stabilized and protected from erosion, by replanting species, like Kikuyu grass. In the perspective of ecosystem services and nature conservation, rehabilitation and restoration, Kikuyu grass is not desirable, but it is a fast way to stabilize the soil in this area and for this important.

And as the Kromme river catchment used to be a wetland, restoration is in terms of nature conservation and in terms of the provision of ecosystem services very important (Rebelo, 2012). A possible way to restore this area to its natural state is to change the hydrology and giving *Prionium serratum* the chance to colonize the area again. A gabion structure can help in increasing the amount of water in the area in favour of the native wetland species. Also the increase of the water amount possibly can remove tannin and soil organisms, formed by or related to *Acacia mearnsii*. Tannin is water soluble and can for this leach out of the soil, also soil organisms may probably wash out as well (Pansera et al., 2004). This makes the native species able to return. As a result of the change in hydrology the peat layer and the related high organic matter content will be formed by the returned *Prionium serratum*.

Eventually restoring the wetland has major effects on what happens in the Kromme river catchment with for example extreme rainfall. On the one hand the wetland attenuates floods, slowing down the water, causing less erosion and on the other hand, more water is stored in the area, instead of intercepted or evaporated by the tree.

Mentioned by local people is that disturbances are a very important trigger for the invasive species to germinate. Fire is such a disturbance and the smoke extract by the fire is a trigger for *Acacia mearnsii* to germinate (Richardson and Kluge, 2008; Waal, Pers. Comm., 2014). Besides, fire being a trigger for germination, the seed bank of this species can survive fires better than native species in an area. Also in the paper written by Richardson and Kluge (2008), *Acacia mearnsii* is mentioned to be a species that is fire adapted and the tree is able to re-sprout from the roots after fire (Richardson and Kluge, 2008). These two mechanisms are very important for the survival of the tree (Waal, Pers. Comm., 2014).

To restore the area or to make sure the Kromme river catchment does not degrade even more, disturbances should be minimized or controlled disturbances (controlled non-natural fires) should take place. As there are still natural fires the disturbances cannot be minimized to zero or entirely controlled, but by minimization of unexpected disturbances the soil can stabilize and more controlled clearing can be done. Seedlings could directly be removed when a controlled non-natural fire takes place, as one knows exactly where the fire is and direct clearing action after fire can be implemented. This way the seed bank of the tree will be reduced (Wilson et al., 2011). Yet, it is not known if this method is feasible in this specific area.

The last result from the empirical study is the species diversity. A significant higher diversity is found in Wetland sites and also according to the Shannon-Wiener index for diversity a higher diversity is found in wetlands. The value of Shannon-Wiener diversity index is usually found to fall between 1.5 and 3.5, with exceptional values above 4.5 (Kent and Coker, 1992). The invaded sites show diversity of H'=1.35, while the non-invaded sites show a diversity of H'=2.08. The diversity is determined by the evenness E and the abundance of the species. Both site groups are comparable plant communities in terms of evenness E (E=0.65 and E=0.66). This evenness also shows that there are some dominant species found in the sites, otherwise the evenness would be 1.

At first *Acacia mearnsii* and *Prionium serratum* are, as one can expect, abundant species in invaded sites and in non-invaded sites respectively. There is also a species that is abundant in both areas, namely *Pennisetum clandestinum* (Kikuyu grass). Explanations for the abundance are that this species can grow on a large range of soil types, although it cannot grow in nutrient poor, especially Nitrogen poor conditions (Marais, 2001). The Nitrogen concentration (Ammonium and Nitrate) measured during analysis were not high or low according to the paper written by Horneck et al., 2011. Furthermore Kikuyu grass tends to be able to grow in very dense stands of other plant species. And at last landowners use Kikuyu grass to prevent erosion and to feed the cattle and for this the species is abundant in the whole Kromme river catchment.

Besides the higher species diversity in wetland sites also the percentage of native species is higher, 82% versus 38% in Black Wattle sites. These native species are growing together with *Prionium serratum*, which is an ecosystem engineer and it changes its environment in favour of itself and associates. It is creating a stable soil and builds up peat land (Sieben, 2012). Palmiet also possibly plays a role in creating an increase of oxygen in the peat which would otherwise be anoxic and not suitable for other plant species to grow, but due to the 'leakage' of oxygen it is more suitable (Sieben, 2012). In this wetland some South African red list species are growing, for example; *Searsia lucida*, *Cliffortia strobilifera* and *Conyza scabrida* (http://redlist.sanbi.org/species.php?species=5522-84; http://redlist.sanbi.org/species.php?species=3455-195; http://redlist. sanbi.org /species.php? Species=3129-25).
In Black Wattle areas, a lot of species are non-native and fast growing species, such as *Eucalyptus globulus*. This is necessary for the competition for, for example light and density of stands.

Knowledge on the plant species in an area says something about the development of an area and what the impact is of management practices. For example *Pennisetum clandestinum* (Kikuyu grass) is able to grow on the by *Acacia mearnsii* altered soil (lower water content, possible change in nutrient amount etc.), while *Prionium serratum* is not able to grow in the soil, where *Acacia mearnsii* grows, unless the hydrology is changed (Buckle, Pers. Comm., 2014).
Salsola kali and *Cyperus involucratus* are two species that grow in disturbed areas (Langeland and Craddock Burks, 2008; Wall and Moore, 1999). The first plant species was growing in a newly invaded area in the Kromme river catchment. *Acacia mearnsii* started to colonize that area after 2011. The change in the area is shown in Appendix VII. The second plant species (*Cyperus involucratus*) was most likely growing in a disturbed wetland area, as this wetland was situated in the middle of an invaded area with *Acacia mearnsii*. It is very likely that this tree has an effect on this specific wetland, which makes it a disturbed area suitable for plant species, such as *Cyperus involucratus,* to grow.

Thus, knowing which plants are growing in an area, show for example whether or not an area is disturbed and in favour of getting invaded by *Acacia mearnsii*. This can help to prevent invasion of new areas. Also plant species can show when an area is starting to recover. When the hydrology of an area is recovered and *Prionium serratum* and its associates are returning the area is improving and returning to its natural state.

Overall, it is very important to take into account the ability of the tree to dry out the soil, as it uses a lot of water, intercepts a lot of water and related to that it evaporates a lot of water. This is a very important focus point in possible rehabilitation or restoration of the Kromme river catchment. Furthermore, it is key to know that the tree germinates direct after disturbances of the area, especially after fire.

Also, taking direct action in terms of rehabilitating or restoring an area after clearing is important to prevent major erosion issues for example. The soil is very unstable after removal of alien vegetation and stabilizing measures, like replanting species or constructing gabions as a restoration measure, are key to prevent such problems.

A clearing program should work upstream to downstream of the Kromme river catchment, otherwise the seeds from upstream areas can still disperse downstream.

Furthermore, it is also important to know which plant species are growing in what area. This can show whether or not restoration is successful or whether or not an area is degrading even further.

Another key point is to take a look at the possibility to use the tree. This is not done at the moment, but the local people have a lot of ideas and possible implementation plans for this.

All of these issues should be communicated properly and for this the advisory committee is very important and should be the connecting factor in the process of clearing the area.

In the next chapter, chapter 7, some recommendations for future research in this area of interest are described. This research is important to see whether or not there is an important factor in the growth of the tree, which can be used and possibly be the key to successfully remove the tree in a more efficient way.

Chapter 7
Recommendations for future research

For future research in this field of interest the microbiology and the biology in the soils where *Acacia mearnsii* is growing and where wetland species *Prionium serratum* is growing should be studied. The differences in soil organisms can possibly determine in a more specific way the inhibiting factor of native species to grow after the removal of the Black Wattle, besides the dryness of the soil which could also be an important factor of the lack of regrowth. Black Wattle is possibly tolerant for the infections of a soil organism, which creates problems for the uptake of nutrients for other plants. This can be possibly tested by analysing soil samples for these types of organisms and furthermore also one can take a look at the growth rate of species on soil with and without these organisms. A difference in growth rate could explain the importance of these organisms. This way also plant species can be compared. If there is no difference in growth rate in the two types of soil for *Acacia mearnsii* and there is a difference in growth rate in the two types of soil for *Prionium serratum* then these organisms could be a reason for this.

Furthermore, recommended would be to perform a study on tannin production of *Acacia mearnsii* as it is possibly an allelopathic substance, which could have a negative effect on germination of other plants then *Acacia mearnsii* (Kraus et al., 2003). The pH of the soil is related to the tannin concentration (Kraus et al., 2003a). As both soils in this research, soils from invaded areas and from non-invaded areas, had a low pH, which was expected for wetland sites, but not for Black Wattle sites, it could be related to the tannin production by the tree. It is not certain, because there are more factors related to pH and for this more research is important.

For the research on tannin availability and production it is important to measure tannin separately. Tannin is part of dissolved Folin Phenol Active Substances (FPAS). Also lignins are part of this group of substances (Kalesh et al., 2000). If specifically tannin is not measured, but the FPAS, a possibility is to find both lignin and tannin in the samples, wetland samples and Black Wattle samples. In this case it is not clear if there is a difference in the samples for the tannin amount. This can only become clear when tannins are measured separately and this is a rather complex process (Kalesh et al., 2000).

It could also be interesting to take a look at the mineralizing capacity of *Acacia mearnsii*. This could explain the availability of Ortho-Phosphate in the soil, which is found to be higher at the places where the Black Wattle is growing. The reason for this recommendation is that the difference in Ortho-Phosphate could not be explained by the pH of the soil as the pH was acidic in both types of soil.

Another important factor in the growth of this invasive species and the impact on the area is erosion of the riverbed. In this research erosion is measured at one time at different points in the area, as it is clear that in former times the river was a braided river at no real stream was flowing. At the moment the river is straightened into one stream and this shows already an erosion process. But it is important to know the changes of the river, to see what the influence of among others the tree has on the area over a longer time span. Thus erosion should be measured over a period of time.

At last, a possible management approach is making use of non-natural fires to control the growth of *Acacia mearnsii*. At this stage it is not known if this approach is feasible in this area. For this it could be interesting and useful to take a look at this possible management approach to see whether or not it could be implemented in the future. This approach could help to decline the seed bank of *Acacia mearnsii* as seedlings could directly be removed after they are triggered to germinate after the controlled non-natural fire.

References

Adamczyk, B., Kitunen, V., Smolander, A. (2013) *Response of soil C and N transformations to condensed tannins and different organic N-condensed tannin complexes*, Finnish Forest research institute, Vantaa research unit, Finland, Applied Soil Ecology, Vol. 64, February 2013, pp. 163-170

Alshaal, T., Domokos-Szabolcsy, É., Márton, L., Czakó, M., Kátal, J., Balogh, P., Elhawat, N., El-Ramady, H., Geröes, A., Fári, M. (2013) *Restoring soil ecosystems and biomass production of Arundo donax L. under microbial communities-depleted soil*, Department of Plant biotechnology, Department of agricultural chemistry and soil sciences, Department of Economic analysis and statistics, University of Debrecen, Hungary, Department of biological sciences, University of South California, USA, Department of Biological and environmental sciences, Al-Azhar University, Egypt, BioEnergy Research, March 2014, Vol. 7, Issue 1, pp. 268-278

Appalraju, T. (2006) *Working for water programme Advisory Committees*, Social development Unit, South Africa

Ashwath, N., Dart, P. J., Edwards, D. G., Khanna, P. K. (1995) *Tolerance of Australian tropical and subtropical acacias to acid soil*, CSIRO Forestry Brisbane, Australia, Department of Agriculture, University of Queensland, Brisbane, Australia, CSIRO Forestry Canberra, Australia, Plants and Soil, April 1995, Vol. 171, Issue 1, pp. 83-87

Bain, C.G., Bonn, A., Stoneman, R., Chapman, S., Coupar, A., Evans, M., Gearey, B., Howat, M., Joosten, H., Keenleyside, C., Labadz, J., Lindsay, R., Littlewood, N., Lunt, P., Miller, C.J., Moxey, A., Orr, H., Reed, M., Smith, P., Swales, V., Thompson, D.B.A., Thompson, P.S., Van de Noort, R., Wilson, J.D., Worrall, F. (2011) *Commission of inquiry on peatlands*, IUCN UK peatland program

Cimbala, J. M., (2011) *Outliers*, Pennsylvania State University

Czeglédi, N. (2013) *Integrated assessment of human impacts on wetland services in the Upper Kromme River Catchment, South Africa, Illustrated by a case study of Hudsonvale wetland*, Master thesis Wageningen University, the Netherlands

Deacon, J. (undated) *The microbial world: The Nitrogen cycle and Nitrogen fixation*, Institute of Cell and Molecular Biology, The University of Edinburgh, http://archive.bio.ed.ac.uk/jdeacon/microbes/Nitrogen.htm

Díaz González, J. D. (2012) *Technical report of the restoration of a section of the Witteklip River as part of the pilot project for rehabilitation of the Kouga River*, PRESENCE, Living Lands, South Africa

Doerge, T. (undated) *Fitting soil electrical conductivity measurements into the precision farming toolbox*, agronomy science department

Dybzinski, R., Fargione, J. E., Zak, D. R., Fornara, D., Tilman, D. (2008) *Soil fertility increase with plant species diversity in a long-term biodiversity experiment*, Department of Ecology, Evolution and Behavior, University of Minnesota, Midwest Resource Office, The nature conservancy, Minneapolis, School of Natural Resources and Environment, Department of Ecology and Evolutionary Biology, University of Michigan, Institute of Environmental and Natural sciences, Lancaster University, Ecosystem Ecology – original paper

Dye, P., Jarmain, C. (2004) *Water use by Black Wattle (Acacia mearnsii): implications for the link between removal of invading trees and catchment streamflow response*, Working for water, South Africa, Journal of Science

Ehrenfeld J.G. (2003) *Effects of exotic plant invasions on soil nutrient cycling processes*, Ecosystems 6, 503-523.

Esler, K.J., Holmes, P.M., Richardson, D.M., Witkowski, E.T.F. (2008) *Riparian vegetation management in landscapes invaded by alien plants: Insights from South Africa,* South African Journal of Botany 74, 397-400.

Fatunbi, A. O., Dube, S., Yakubu, M. T., Tshabalala, T. (2009) *Allelopathic potential of Acacia mearnsii De Wild*, Agricultural and Rural development, Research Institute, Department of Livestock and Pasture science, Department of Botany, University of Fort Hare, South Africa, World applied sciences journal, Vol. 12, 2009, pp. 1488-1493

Forrester, D. I., Schortemeyer, M., Stock. W. D., Bauhus, J., Khanna, P. K., Cowie. A. L. (2007) *Assessing Nitrogen fixation in mixed- and single-species plantations of Eucalyptus globulus and Acacia mearnsii*, School of Resources, Environment and Society, The Australian National University, Australia, Cooperative Research Centre for Greenhouse Accounting, Australia, School of Forest and Ecosystem Science, Australia, Ecosystem dynamics group, Research School of Biological Sciences, Australia, Centre for Ecosystem Management, School of Natural Sciences, Australia, NSW Department of Primary Industries, Australia, Institute for Silviculture, University of Freiburg, Germany, Tree physiology, Vol. 27, pp. 1319-1328

Fourie, S. (2012) *The restoration of an alien-invaded riparian zone in grassy Fynbos, South Africa*, Department of Environmental science, Rhodes University, Grahamstown, South Africa

Gaertner, M., Richardson, D. M., Privett, S. D. J. (2011) *Effects of Alien plants on ecosystem structure and functioning and implications for restoration: Insights from three degraded sites in South*

Africa Fynbos, Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Flower valley conservation trust, Gansbaai, South Africa, Environmental Management, 2011, vol. 48, pp. 57-69

Galatowitsch, S., Richardson, D. M. (2005*) Riparian scrub recovery after clearing of invasive alien trees in headwater streams of the Western Cape, South Africa*, Department of Horticultural science, University of Minnesota, USA, Botany Department, University of Cape Town, South Africa, Biological Conservation, April 2005, Vol. 122, Issue 4, pp. 509-521

Grisso, R., Wysor, W.G., Holshouser, D., Thomason, W. (2009) *Precision Farming Tool: Soil electrical conductivity*, Virginia Tech, Virginia State University, Virginia Cooperative Extension, publication 442-508

Grundling, P. L., Grobler, R. (2005) *Peatlands and Mires in South Africa*, Biologiezentrum Linz, Austria, Landesmuseum Neue Serie, 35, 2005, pp. 379-396

Hassanpour, S., Maheri-Sis, N., Eshrathkhah, B., Mehmandar, F. B. (2011) *Plant and secondary metabolites (tannins): A review*, Department of Animal Science, Department of Veterinary Medicine, Azad University Iran, Department of Agriculture, Payame Noor University, Iran

Hennekens, S. (2009) *Protocol 'vegetatieopname'*, Alterra Wageningen

Higgins, S. I., Richardson, D. M., Cowling, R. M., Trinder-Smith, T. H. (1999) *Predicting the landscape scale distribution of alien plants and their threat to plant diversity*, Institute for Plant Conservation, Department of Botany, University of Cape Town, Bolus Herbarium, Department of Botany, University of Cape Town, South Africa, Conservation biology, 1999, vol. 15 no. 2 pp. 303-313

Hocking, P. J. (1984) *Responses of Cyperus involucratus rottb. to Nitrogen and Phosphorus with reference to wastewater reclamation*. CSIRO Centre for irrigation research, Australia, Water research, Vol. 19, Issue 11, 1985, Pages 1379–1386

Horneck, D. A., Sullivan, D. M., Owen, J. S., Hart, J. M (2011) *Soil test interpretation guide*, Oregon Sate University

Hydrological services and Groundwater Information (2013), *Active stations used for groundwater level* monitoring, cited on 31-01-2014 http://www.dwaf.gov.za/Groundwater/images/National%20Groundwater%20Level%20Mon toring%20Network_Aug2013.pdf

Hyland, C., Ketterings, Q., Dewing, D., Stockin, K., Czymnek, K., Albrecht, G., Geohring, L. (2005) *Phosphorus basics – The Phosphorus cycle*, Department of Crop and Soil sciences, College of Agriculture and Life Sciences, Cornell University Cooperative Extension.

Impson, F., *The acacia seed weevils (Melanetrius species)*, cited on 28-01-2014 http://www.dwaf.gov.za/wfw/Control/BioDossiers/07.Acacia%20Seed%20weevil.pdf Grahamstown, South Africa

Impson F. A. C., Kleinjan, C. A., Hoffman, J. H., Post, J. A. (2008) *Dasineura rubiformis (Diptera: Cecidomyiidae), a new biological control agent for Acacia mearnsii in South Africa*, South African journal of science, 2008, vol. 104 pp. 247-249

Jansen, P. C. M., Cardon, D. (2005) *Acacia mearnsii De Wild*, PROTA, Wageningen, Netherlands, cited on 03-02-2014 http://database.prota.org/PROTAhtml/Acacia%20mearnsii_En.htm

Jacobs, S., Naude, M., Slabbert, E., Kambaj, O., Fourie, M., Esler, K., Jacobs, K., Mantlana, B., Rozanov, A., Cowan, D. (2013) *Identifying relationships between soil processes and biodiversity to improve restoration of riparian ecotones invaded by exotic Acacias*, Department of Conservation Ecology and Entomology, Faculty of AgriSciences, Stellenbosch University, Department of Microbiology, Faculty of Science, Stellenbosch University, Centre for Invasion Biology, Stellenbosch University, Global Change Research Group, South African National Biodiversity Institute, Kirstenbosch Research Centre, Department of Soil Science, Faculty of AgriSciences, Stellenbosch University, Department of Biotechnology, University of the Western Cape, Department of Environmental Affairs, Department of Genetics, University of Pretoria, WRC report No. 1927/1/13

Jong, T., de (2012) *Fragmentation as a collective interest*, A *case study about irrigating |farmers| water scarcity| and collective action in the Upper Kromme river catchment| South Africa*, Irrigation and Water engineering Group, Master thesis, Wageningen University

Kalesh, N. S., Sujatha, C. H., Nair, S. M. (2000) *Dissolved Folin phenol active substances (tannin and lignin) in the seawater along the West Coast of India*, Department of chemical oceanography, school of marine science, Cochin University of Science and Technology, India, Journal of Oceanography Vol. 57, pp. 29-36

Kent, M., Coker, P. (1992) *Vegetation description and analysis. A practical approach*. John Wiley and Sons Ltd, West Sussex- England. 162 p

Kerkhoff. (2010) *Measuring biodiversity of ecological communities*, Ecology Lab, Biology

Kotze, D., Ellery, W. (2009) *An evaluation of the rehabilitation outcomes at six wetland sites in South Africa, Part 4 The wetland rehabilitation project in the Kromme river Wetlands, Eastern Cape*, Wetland Management series, P.109-170

Koutika, L. S., Epron, D., Bouillet, J. P., Mareschal, L. (2014) *Changes in N and C concentrations, soil acidity and P availability in tropical mixed acacia and eucalypt plantations on a nutrient-poor sandy soil*, Plant and Soil, 2014, vol. 379, issue 1-2, pp. 205-216

Kraus, T. E. C., Dahlgren, R. A., Zasoki, R. J. (2003) *Tannins in nutrient dynamics of forest ecosystems a review*, University of California USA, Plant and Soil, Vol. 256, pp. 41-66

Kraus, T. E. C., Zasoki, R. J., Dahlgren, R. A. (2003a) *Fertility and pH effects on polyphenol and condensed tannin concentrations in foliage and roots*, Land Air and Water Resources, University of California, Soil, May 2004, Vol. 262, Issue 1-2, pp 95-109

Krebs, C.J. (2014) *Ecological methodology, 3rd edition*, Chapter 13: Species Diversity Measures, University of California, Harper & Row

Langeland, K. A., Craddock Burks, K. (2008) *Cyperus Involucratus Rottb.*, Identification and Biology of Non-native plants in Florida's natural areas, second edition, University of Florida, p27

Li, Z., Wang, Q., Ruan, X., Pan, C., Jiang, D. (2010) *Phenolics and plant allelopathy*, College of Life Sciences, Zhejiang University, Ningbo Institute of Technology, Zhejiang University, College of Forest, Xinjiang Agricultural University, Molecules, 2010, pp 8933-8952

Mäder P., Flieβbach, A., Dubois, D., Gunst, L., Fried, P., Niggll, U. (2002) *Soil fertility and biodiversity in organic farming*, Science, 2002, vol. 296, pp 1694-1697

Maitre, Le, D. C., Scott, D. F., Colvin, C. (1999) *A review of information on interactions between vegetation and groundwater*, CSIR Division of Water, Environment and Forestry Technology, Stellenbosch, South Africa

Maitre, Le, D. C., Versfeld, D. B., Chapman, R.A. (2000) *The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment*, CSIR Division of Water, Environment and Forestry Technology, Stellenbosch, South Africa

Marais, J. P. (2001) *Factors affecting the nutritive value of Kikuyu grass (Pennisetum clandestinum) a review*, KwaZulu-Natal Department of Agriculture and Environmental Affairs, South Africa

Marchante, A. H., (2010) *Ecology of Acacia mearnsii,* In IUCN/SSC Invasive Species Specialist Group (ISSG), Cited on 10-03-2014, http://www.issg.org/database/species/ecology.asp?si=51&fr=1&sts=tss&lang=EN

Marchante, A. H., (2010[a]) *General impact of Acacia mearnsii*, In IUCN/SSC Invasive Species Specialist Group (ISSG), cited on 10-03-2014

http://www.issg.org/database/species/impact_info.asp?si=51&fr=1&sts=&lang=EN

Martens, C., Waller, L., Delahunt, K. (2003) *Alien plant control, an operational guideline for land managers*, Ecoguard, Working for Water Program, Department: Water Affairs, South Africa

McQueen, C., Noemdoe, S., Jezile, N. (2001) *Working for Water Programme*, Land use and Water Resources Research

Middleton, B. J., Bailey, A. K. (2011) *Water resources of South Africa, 2005 study (WR2005), Executive summary*, Water research commission, South Africa Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-Being: Policy responses, findings of the responses working group*, Millennium Ecosystem Assessment Series, Appendix D: Glossary, pp. 599-605

Middleton, B. J., Bailey A. K. (2011a), *Water Resources of South Africa 2005*, WRC Report No.:K5/1491

Morris, T. L., Esler, K. J., Barger, N. N., Jacobs, S. M., Cramer, M. D. (2011) *Ecophysiological traits associated with the competitive ability of invasive Australian acacias*, Department of Ecology and Evolutionary Biology, University of Colorado, USA, Department of Botany, University of Cape Town, South Africa, Department of Conservation Ecology and Entomology, Stellenbosch University, South Africa, Centre for Invasion Biology, Stellenbosch University, South Africa, School of Plant Biology, the University of Western Australia, Australia, A Journal of Conservation of Biogeography, Diversity and Distributions, September 2011, Vol. 17, Issue 5, pp. 898-910

Moyo, H. P. M., Fatunbi, A. (2010) *Utilitarian perspective of the invasion of some South African biomes by Acacia mearnsii*, Global Journal of Environmental Research, Vol. 4 (1) pp. 6-17

Mueller-Harvey, I. (2006) *Review Unravelling the conundrum of tannins in animal nutrition and health*, NSRU Chemistry and Biochemistry Laboratory, Agriculture Department, Reading University, UK, Journal of the Science of food and agriculture, October 2006, Vol. 86, Issue 13, pp. 2010 2013

Munyai, R. (2013) *A systematic study of the South African genus Prionium (Thurniaceae)*, Master thesis, University of Cape Town, department of botany

Naudé, M. (2012) *Fynbos riparian biogeochemistry and invasive Australian acacias*, Conservationecology, Master thesis, Stellenbosch University

Nelson Mandela Metropolitan Municipality (undated) *Save the wetlands in the Kromme river from extinction*, Natural Bridge Communication, Working for Wetland Programme, Eastern Cape, South Africa

Nguyen, T., Marschner, P. (2013) *Addition of a fine-textured soil to compost to reduce nutrient leaching in a sandy soil*, School of Agriculture, Food and Wine, University of Adelaide, Australia, Soil Land Care and Environmental Research, 2013, vol. 51, Issue 3, pp 232-239

Nolan, K. A., Callahan, J. E. (2005) *Beachcomber biology: The Shannon-Weiner Species Diversity Index*, Association for Biology Laboratory Education, 2005, vol. 27, pp. 224-228

Nsor, C. A. (2007) *Plant community distribution and diversity, and threats to vegetation of the Kromme River peat basins, Eastern Cape Province, South Africa*, Rhodes University

Nsor, C. A., Gambiza, J. (2013) *Land use changes and their impacts on the vegetation Kromme river Peat Basin, South Africa*, Mesuna Sualihu, Deliman, Oil Company, Accra North, Ghana, Department of Environmental Science, Rhodes University, Grahamstown, South Africa, Journal of Environmental Engineering research

Pansera, M. R., Iob, G. A., Atti-Santos, A. C., Rossata, M., Atti-Serafini, L., Cassel, E. (2004) *Extraction of tannin by Acacia mearnsii with super critical fluids*, Instituto de Biotecnologia, Departamento de Física e Química, Departamento de Ciências Exatas e da Natureza, Universidade de Caxias do Sul, Rua Francisco Getúlio Vargas, Faculdade de Química e Faculdade de Engenharia; Pontifícia Universidade Católica do Rio Grande do Sul; Av. Ipiranga, Brazil, Brazil, Brazilian Archives of Biology and Technology, vol. 47, pp. 995-998

Pasiecznik, N. (2007) *Datasheet, Acacia mearnsii*, visited 01-07-2014 http://www.cabi.org/isc/datasheet/2326

Pearson, D. E., Callaway, R. M. (2003) *Indirect effects of host-specific biological control agent*, Division of biological sciences, University of Montana, Missoula, Trends in ecology and evolution, 2003, vol. 18 no. 9, pp. 456-461

Rebelo, A. J. (2012) *An ecological and hydrological evaluation of the effects of restoration on ecosystem services in the Kromme river system, South Africa*, Master thesis, Faculty of Agriscience, Stellenbosch University

Rebelo A. J., Maitre, Le, D., Esler, K. J., Cowling, R. M. (2012) *Are we destroying our insurance policy? The effects of alien invasion and subsequent restoration on wetlands; A case study of the Kromme River system, South Africa*, Department of Conservation Ecology and Entomology, Stellenbosch, South Africa, Council for scientific and industrial research (CSIR), Stellenbosch, South Africa, Centre for invasion biology (CIB), Stellenbosch, South Africa, Restoration research group, department of botany, Nelson Mandela Metropolitan University, South Africa, Landscape ecology for sustainable environment and culture, 2013 pp 335-364

Rebelo A. J., Le Maitre, D., Esler, K. J., Cowling, R. M., Horan, M. J. C., Thomoton-Dibb, S. L. C. (2012a) *Hydrological responses to land-cover change in a high energy South Africa catchment: Making a case for wetland restoration*, Department of Conservation Ecology and Entomology, Stellenbosch University, Council for Scientific and Industrial Research (CSIR), Stellenbosch, Centre for Invasion Biology (C.I.B), Stellenbosch, Restoration Research Group, Department of Botany, Nelson Mandela Metropolitan University, Port Elizabeth, Department of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, South Africa

Rebelo A. J., Jarmain, C., Le Maitre, D. L., Esler, K. J., Cowling, R. M. (2012b) *Does Palmiet (Prionium serratum) use water conservatively?* Department of Conversation Ecology and Entomology, Stellenbosch University, Council for Scientific and Industrial Research, Stellenbosch, Centre for Invasion Biology, Stellenbosch, Restoration Research Group, Department of Botany, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa

Richardson, D. M., and Wilgen, B. W. (2004) *Invasive alien plants in South Africa: How well do we understand the ecological impacts?* Working for water, South Africa Journal of Science, Vol. 100 pp. 45-52

Richardson, D. M., Kluge, R. L. (2008) *Seed banks of invasive Australian Acacia species in South Africa: Role in invasiveness and options for management*, Centre for invasion biology, Department of Botany and Zoology, Stellenbosch University, ARC-plant protection research institute, South Africa, Perspectives in Plant Ecology, Evolution and Systematics, 2008, vol. 10, pp. 161-177

Sakai, A. K., Allendorf, F. W., Holt, J. S., Lodge, D. M., Molofsky, J., With, K. A., Baughman, S., Cabin, R. J., Cohen, J.E., Ellstrand, N. C., McCauley, D. E., O'Neil, P., Parker, I. M., Thompson, J. N., Weller, S. G. (2002) *The population biology of invasive species*, Department of Ecology and Evolutionary Biology, University of California-Irvine, Division of Biological Sciences, University of Montana, Missoula, Department of Botany and Plant Sciences, University of California Riverside, Department of Biological Sciences, University of Notre Dame, Department of Botany, University of Vermont, Division of Biology, Kansas State University, Department of Biological Sciences, Plattsburgh State University of New York, Laboratory of Populations, Rockefeller University and Columbia University, Department of Biological Sciences, Vanderbilt

University, Nashville, Department of Biological Sciences, University of New Orleans, Department of Ecology and Evolutionary Biology, University of California-Santa Cruz, Annual review of ecology, evolution and systematics, 2001, vol. 32, pp. 205-332

Salemi, L. F., Groppo, J. D., Trevisan, R., de Moraes, J. M., de Paul Lima, W., Martinelli, L. A. (2012) *Riparian vegetation and water yield: A synthesis*, Centro de Energia Nuclear na Agricultura, University of Sao Paolo, Brazil, Escola de Engenharia de Piracicaba, Sao Paulo, Brazil, Escola Superior de Agricultura Luiz de Queiroz, University of Sao Paulo, Brazil, Journal of hydrology, August 2012, Vol.s 454-455, pp. 195-202

Shackleton, C. M., McGarry, D., Fourie, S., Gambiza, J., Shackleton, S. E., Fabricius, C. (2006) *Assessing the effects of invasive alien species on rural livelihoods: Case examples and a framework from South Africa*, Department of Environmental Science, Rhodes University, Grahamstown, South Africa, Human ecology, February 2007, Vol. 35, Issue 1, pp. 113-127

Sieben, E. J.J. (2012) *Plant functional composition and ecosystem properties: the case of peatlands in South Africa*, Department of plant sciences, University of the Free State, South Africa, Springer Science and Business, Plant Ecology, May 2012, Vol. 213, Issue 5, pp. 809-820

Spellerberg, I. F., Fedor, P. J. (2003) *A tribute to Claude Shannon (1916-2001) and a plea for more rigorous use of species richness, species diversity and the ´Shannon-Wiener' Index*, Isaac Centre for Nature conservation, Lincoln University, New Zealand, Department of Ecosozology, Faculty of Natural Sciences, Comenius University, Slovakia, Global Ecology and Biogeography, 2003, vol. 12, pp. 177-179

Terms of Reference for Advisory Forums (2009), Department of Environmental affairs, Eastern Cape, South Africa

Trigonomterical Survey Office (1970) cited at 26-06-2014 http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/africa/images/maps/download/afr_z2003_2toge.jpg

Trigonomterical Survey Office (1965) cited at 26-06-2014 http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/africa/images/maps/download/afr_za1000_toso.jpg

USDA (2011) *Soil quality indicators, Soil electrical conductivity*, Natural Resources Conservations Service

Venter, J. H. (2005) *Invasive species and Working for Water programme in South Africa*, National Department of Agriculture, Pretoria, South Africa

Waal, van der, B. W. (2009) *The influence of Acacia mearnsii invasion on soil properties in the Kouga mountains, Eastern Cape, South Africa*, Master thesis, Rhodes University, Grahamstown, South Africa

Waal, van der, B. W., Rowntree, K. M., Radloff, S. E. (2012) *The effect of Acacia mearnsii invasion and clearing on soil loss in the Kouga mountains, Eastern Cape, South Africa*, Department of geography, Rhodes University, Grahamstown, Department of Statistics, Rhodes University, Land degradation and development, 2012, Vol. 23, pp. 577-585

Wagner, R. G., Hagan, J. M. (2000) *Forestry and the riparian zone*, Wells Conference Center, University of Main Orono, Maine

Wall, D. H., Moore, J. C. (1999) *Interactions underground: Soil biodiversity, mutualism and ecosystem processes*, Oxford Journals, Bioscience, Vol. 49, Issue 2, pp. 109-117

Wallace, H. R. (1987) *A perception of tolerance*, Department of Plant Pathology, Waite Agricultural research Institute, University of Adelaide, South Australia, Nematologica, Vol. 33, Issue 4, pp. 419-432

Walters, D., Koopman, V. (undated) *The impacts of agriculture on wetlands-a brief discussion*, Mondy Wetlands Project, South Africa

Wardle, D. A., Bardgett, R. D., Klironoms, J. N., Setälä, H., Putten, van der, W. H., Wall, D. H. (2004) *Ecological linkages between aboveground and belowground biota*, Soils the final frontier, Science, 2004, vol. 304, pp 1629-1633

Weis, J. S., Edwards, J., Enger, E. D., Gall. G. A., Jarra, H. J., Lauritsen, D. D., Pixley, E. Y., Poulson, T. L., Samuels, E., Shafer, C. L., Temple, P. J., Weis, P., Young, J. E. (2002) *Biology, Environment and Conservation in South Africa,* Bioscience, 2002, vol. 52, no. 9, pp 781-789

Wilgen, van B. W. (2009) *The evolution of fire and invasive alien plant management practices in Fynbos*, Centre of Invasion Biology, Stellenbosch, South Africa, South African Journal of Science, 1999, vol. 105

Wilgen, van B. W., Richardson, D. M., Maitre, le D. C., Marais, C., Magadlela, D. (2001) *The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa*, CSIR division of Water, Environment and Forestry Technology, Stellenbosch, Institute for Plant Conservations, Department of Botany, University of Cape Town, Working for Water program, South Africa, Environment, Development and sustainability, 2001, vol. 3, Issue 2, pp. 145-168

Wilgen, van, B. W., Dyer, C., Hoffmann, J. H., Ivey, P., Le Maitre, D. C., Moorel, J. L., Richardson, D. M., Rouget, M., Wannenburgh, A., Wilson, J. R. U. (2011) *National-scale strategic approaches for managing introduced plants: Insights from Australian acacias in South Africa*, Centre for Invasion Biology, CSIR Natural Resources and the Environment, Institute for Commercial Forestry Research, Department of Zoology, University of Cape Town, South African National Biodiversity Institute, Australian Centre of Excellence for Risk Analysis, University of Melbourne, Australian Research Centre for Urban Ecology, Royal Botanic Gardens, Melbourne, School of Botany, University of Melbourne, Centre for Invasion Biology, Department of Botany & Zoology, Stellenbosch University, Department of Plant Science, University of Pretoria, National Working for Water Programme, Department of Water Affairs, South Africa, Biodiversity research

Williams, D. G., Baruch, Z. (2000) *African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology*, School of Renewable Natural Resources, University of Arizona, Departmento de Estudios Ambientales, Universidad Simón Bolivar Aptdo, Biological invasions, 2000, Vol. 2, pp. 123-140

Wilson, J. R. U., Gairifo, C., Gibson, M. R., Arianoutsou, M., Bakar, B. B., Baret, S., Celesti-Grapow, L., DiTomaso, J. M., Dufour-Dror, J., Kueffer, C., Kull, C. A., Hoffmann, J. H., Impson, F. A. C., Loope, L. I., Marchante, E., Marchante, H., Moore, J. I., Murphy, D. J., Tassin, J., Witt, A., Zenni, R. D., Richardson, D. M., (2011) *Risk assessment, eradication and biological control: global efforts to limit Australian acacia invasions*, A journal of Conservation Biogeography, Diversity and Distribution, 2011, Vol. 17, Issue 5, pp. 1030-1046

Wit, de M. P., Crookes, D. J., Wilgen, van B.W. (2001) *Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion*, CSIR division of Water, Environment and Forestry Technology, Pretoria and Stellenbosch, South Africa, Biological Invasions, 2001, Vol. 3, Issue 2, pp. 167-178

Working for Water program (2006) *Application for clearing assistance*, Working for Water program, Department of Water Affairs and Forestry, National Department Agriculture and Department of Environment Affairs and Tourism, South Africa

Yelenik, S. G., Stock, W. D., Richardson, D. M. (2004) *Ecosystems level impacts of invasive Acacia saligna in the South African Fynbos*, Institute for Plant Conservation, University of Cape Town, Department of Evolution, Ecology, and Marine Biology, University of California, Centre for Ecosystem Management, South Africa, Restoration ecology, 2004, Vol. 12, No. 1, pp 44-51

Zahran, H. H. (1999) *Rhizobium-legume symbiosis and Nitrogen fixation under severe conditions and in an arid climate*, Microbiology and Molecular Biology Reviews, 1999, vol. 63 (4), pp. 968-989

Websites

http://academic.sun.ac.za/cib/team/academic/gthompson.asp, cited on 23-06-2014

http://www.dwaf.gov.za/wfw/, cited on 14-05-2014

http://www.dwaf.gov.za/wfw/default.aspx, cited on 28-01-2014

http://www.fao.org/docrep/005/ac846e/ac846e09.htm, cited on 09-07-2014

http://www.florabank.org.au/lucid/key/species%20navigator/media/html/Acacia_mearnsii.htm, cited on 15-05-2014

http://www.plantzafrica.com/plantnop/prionserr.htm, cited on 01-07-2014

http://redlist.sanbi.org/species.php?species=3635-2, cited on 17-02-2014

http://redlist.sanbi.org/species.php?species=5522-84, cited on 15-04-2014

http://redlist.sanbi.org/species.php?species=3455-195, cited on 15-04-2014

http://redlist.sanbi.org/species.php?species=3129-25, cited on 15-04-2014

http://wetlands.sanbi.org/project_details.php?id=79, cited on 04-02-2014

Personal Communication

Buckle, J. (Pers. Comm., June, 2014) Working for Wetland, South Africa

Kawa, M. (Pers. Comm., May, 2014) Department of Environmental affairs, East London, South Africa

Waal, van der, B. W. (Pers. Comm., June, 2014) Rhodes University, Grahamstown, South Africa

Zwinkels, M. (Pers. Comm., February, 2014) Living Lands, Kouga Dam, South Africa

Appendix

Appendix I

Table A I 1: Data of the upper Kromme river catchment, which is used in this report.

Sample type	GPS		Altitude	Soiltype	Weight of samples (g)	Nutrients			
	Latitude	*Longitude*				*Nitrate spectrometer*	*Concentrations Nitrate microM*	µmoles N per gram soil	µg N per gram soil
BW	-33.57617	24.2225	174	Humid sand, near the water, but the sand contains very small particles, smaller than a micron.	5.35	0.2338	50.82608696	0.473526102	6.629365425
BW	-33.57608	24.22252	175	Dry sand, very sandy, but the sand contains very small particles, smaller than a micron.	5.15	0.2896	62.95652174	0.585061399	8.19085958
BW	-33.57615	24.22242	176	Dry sand, very sandy, but the sand contains very small particles, smaller than a micron.	5.23	0.2163	47.02173913	0.438546394	6.139649517
BW	-33.58246	24.24305	164	Humid lose sand with some stones	5.39	0.1871	40.67391304	0.380180253	5.322523543
BW	-33.58248	24.24302	166	Lose sand	5.36	0.1973	42.89130435	0.400568426	5.607957959
BW	-33.58251	24.24307	167	Very dry sand	5.04	0.217	47.17391304	0.439945582	6.159238153
BW	-33.52235	24.01456	381	A lot of deposit sand, 'beach sand'. Soil was a bit humid below that	4.96	0.1669	36.2826087	0.339803676	4.757251466
BW	-33.52242	24.01446	382	Very dry sand, part of it deposit	5.19	0.2424	52.69565217	0.49071613	6.870025815
BW	-33.52238	24.01445	382	Very dry sand, part of it deposit	5.06	0.1976	42.95652174	0.401168078	5.616353089
BW	-33.58122	24.24078	166	Lose, a bit humid sand with some stones (large stones), near the water	5.07	0.1807	39.2826087	0.367387674	5.14342744
BW	-33.58142	24.24089	169	Lose sand	5.02	0.2002	43.52173913	0.406365063	5.689110881
BW	-33.5814	24.24088	169	Dry lose sand	5.33	0.3738	81.26086957	0.753363764	10.54709269

BW	-33.55495	24.14323	227	Sandy, not stones, not big roots. Lose sands	5.1	0.0985	21.41304348	0.057878781	0.810302938
BW			227	More roots, but still sandy, with some small stones, like those ones on the beach	4.99	0.0683	14.84782609	0.025896861	0.362556056
BW			227	Some roots as well, but still very sandy	5.16	0.2566	55.7826087	0.22530731	3.154302345
WL	-33.58135	24.24092	170	Humid sandy	5.03	0.1812	39.39130435	0.368387094	5.157419323
WL	-33.57927	24.23573	171	Dryer sandy, some roots	5.21	0.1988	43.2173913	0.403566686	5.649933608
WL	-33.57929	24.23576	171	Dry sandy, some roots	5.06	0.1824	39.65217391	0.370785703	5.190999842
WL	-33.57903	24.23543	173	Humid sandy, with a lot of roots	5.31	0.1902	41.34782609	0.386376658	5.409273219
WL			178	Dryer sandy, a lot of roots	5.2	0.2048	44.52173913	0.415559729	5.817836205
WL			178	Dryer sandy, a lot of roots	5.24	0.2091	45.45652174	0.424154743	5.9381664
WL	-33.52671	24.03085	350	Humid, almost wet sandy, with a lot of roots	5.32	0.1676	36.43478261	0.341202864	4.776840102
WL	-33.52677	24.03069	350	Humid, almost wet sandy, with a lot of roots	5.32	0.191	41.52173913	0.387975731	5.431660232
WL	-33.52671	24.03078	350	Humid, almost wet sandy, with a lot of roots	5	0.1734	37.69565217	0.352796139	4.939145946
WL	-33.52676	24.03583	346	Humid, sandy, with a lot of roots	5.03	0.2335	50.76086957	0.47292645	6.620970295
WL	-33.52679	24.03587	346	Humid, sandy, with a lot of roots	5	0.1836	39.91304348	0.373184312	5.224580362
WL	-33.52675	24.03586	346	Humid, sandy, with a lot of roots	5.06	0.1684	36.60869565	0.342801937	4.799227115
WL	-33.52639	24.03362	355	Humid sandy, with a lot of roots	5.13	0.17	36.95652174	0.346000082	4.844001141
WL	-33.52639	24.0337	355	Humid, almost wet sandy, with a lot of roots	5.16	0.1776	38.60869565	0.361191269	5.056677764
WL	-33.52639	24.03374	355	Humid, almost wet sandy, with a lot of roots	5.04	0.1813	39.41304348	0.368586979	5.160217699

Ammonium spectrometer	*Concentrations Ammonium microM*	**µmoles N per gram soil**	**µg N per gram soil**	*Phosphorus spectrometer*	*Concentrations Phosphorus microM*	**µmoles P per gram soil**	**µg P per gram soil**
0.2236	11.89361702	0.1083321	1.516648872	0.0324	1.246153846	0.0111827	0.3463733
0.6199	32.97340426	0.3042966	4.260152313	0.0484	1.861538462	0.016879	0.5228099
0.4321	22.98404255	0.2114323	2.960051515	0.0191	0.734615385	0.0064477	0.1997104
0.1476	7.85106383	0.0707512	0.990516494	0.0296	1.138461538	0.0101859	0.3154969
0.4404	23.42553191	0.2155365	3.017510709	0.0349	1.342307692	0.0120728	0.3739415
0.4835	25.71808511	0.2368488	3.31588315	0.0417	1.603846154	0.0144937	0.448927
0.1936	10.29787234	0.0934975	1.308965039	0.0175	0.673076923	0.005878	0.1820667
0.3069	16.32446809	0.1495227	2.09331765	0.0211	0.811538462	0.0071597	0.221765
0.2891	15.37765957	0.1407209	1.970091909	0.0254	0.976923077	0.0086906	0.2691823
1.1277	59.98404255	0.5553962	7.775547335	0.0476	1.830769231	0.0165942	0.513988
2.1807	115.9946809	1.0760893	15.06524989	0.0291	1.119230769	0.0100079	0.3099832
2.3402	124.4787234	1.1549597	16.16943561	0.0299	1.15	0.0102927	0.3188051

0.1138	6.322222222	0.0321401	0.449961027	0.0723	2.93902439	0.0237232	0.7348022
0.0931	5.172222222	0.0215504	0.301705404	0.0766	3.113821138	0.0253474	0.7851108
0.1543	8.572222222	0.052859	0.740026375	0.1094	4.447154472	0.0377368	1.16886
0.1238	6.585106383	0.0589824	0.825753986	0.0183	0.703846154	0.0061629	0.1908885
0.1362	7.244680851	0.065114	0.911596637	0.0165	0.634615385	0.005522	0.1710394
0.1445	7.686170213	0.0692183	0.969055831	0.0183	0.703846154	0.0061629	0.1908885
0.1887	10.03723404	0.0910745	1.275043346	0.0189	0.726923077	0.0063765	0.1975049
0.1922	10.22340426	0.0928052	1.299273126	0.0198	0.761538462	0.0066969	0.2074295
0.1216	6.468085106	0.0578946	0.810523838	0.0239	0.919230769	0.0081566	0.2526414
0.447	23.77659574	0.2188001	3.063201152	0.0194	0.746153846	0.0065545	0.2030186
0.2568	13.65957447	0.124749	1.746485648	0.0154	0.592307692	0.0051304	0.1589094
0.3503	18.63297872	0.1709834	2.393766929	0.017	0.653846154	0.0057	0.1765531
0.7089	37.70744681	0.3483058	4.876281019	0.0208	0.8	0.0070529	0.2184568
0.5056	26.89361702	0.2477769	3.468876907	0.019	0.730769231	0.0064121	0.1986076
0.3181	16.92021277	0.1550609	2.170852948	0.0391	1.503846154	0.013568	0.4202561
0.8091	43.03723404	0.3978532	5.569945023	0.016	0.615384615	0.005344	0.1655258
0.9036	48.06382979	0.4445821	6.224149099	0.0158	0.607692308	0.0052728	0.1633203
0.9342	49.69148936	0.4597133	6.435986609	0.0197	0.757692308	0.0066613	0.2063267

Determine area characteristics in the upper Kromme river catchment to compare indigenous and invasive species

pH	Conductivity of the soil	Weight of cup (g)	before stove (g)	After stove (g)	After oven (g)	Water content	Organic content	Plant diversity	Erosion (m)	Comments
	µSiemens/cm									
4.75	242	13.264	44.868	40.155	37.689	14.912669	9.170354394	4	-1.5	This was an area, in which also another tree species was very dominant. Not as dominant as Black Wattle, but it needs to be taken into account. Eucalyptus tree. The soil had very small particles, smaller then a micron.
4.78	321	10.637	33.006	32.133	31.456	3.9027225	3.149423148			
5.23	283	16.625	43.182	42.555	41.679	2.3609594	3.378326263			
6.4	343	11.354	34.701	31.108	30.512	15.389558	3.017110459	5	-2	This area is cleared by the landowner before. The Black Wattle is growing back at this spot. The plant can be three meters high after clearing two years ago.
4.94	328	11.315	24.264	23.888	23.23	2.9036991	5.233436729			
5.11	332	11.418	28.148	27.599	26.968	3.2815302	3.899635375			
4.85	321	12.904	44.259	39.191	35.751	16.163291	13.08631643	6	-0.5	Looks like a newly invaded site. There were species that grow in disturbed areas and this area is right in between a big wetland. Right now it is still open, not as dense as other places, but it starts to be overtaken by Black Wattle. This could also cause problems in the wetland itself, the seeds can spread rather easily in the wetland and there are already trees there.
4.99	329	13.254	34.51	33.807	33.367	3.3073015	2.140806695			
4.88	324	13.444	32.028	31.61	29.412	2.2492467	12.09952659			
4.32	412	11.263	27.61	24.447	20.464	19.349116		3	-3	Invaded a long time ago, at this spot it was not cleared shortly before the samples were taken. The trees were large and there was a lot of erosion, about three to four meters.
5.01	361	11.441	24.744	23.857	22.857	6.6676689	8.054123711			
4.82	393	13.234	29.506	28.448	27.179	6.5019666	8.341001709			

5.3	85	16.44	51.16	43.51	42.27	22.03341	4.580716661	5	-0.3	At this spot the BW was cleared. At this moment there are few BW growing here. This area is rather properly cleared. Still it will take about 50 years before it is totally cleared, including the seedbank, according to the landowner.
6.2	49.2	16.61	49.22	43.83	43.64	16.528672	0.698016165			
5.94	66.9	66.19	106.38	101.71	100.72	11.619806	2.787162162			
5.29	216	66.211	113.506	106.331	102.833	15.170737	8.71884347	6	-0.5	This is a bit of a altered palmiet wetland. It was a spot where the river is flowing, but still a wetland was formed as well. It could be that this spot is degrading into another type of area. If the soils looks more like the soil in Black wattle it could be degraded, which is the case. There was a bit of erosion, about half a meter.
4.85	323	18.473	42.909	42.064	41.568	3.4580128	2.102496715			
4.5	366	18.309	45.61	44.239	43.857	5.0217941	1.473197069			
5	315	15.113	34.676	33.695	33.513	5.0145683	0.979442471	8	-1.5	Most dry palmiet wetland of the Upper Kromme River Catchment. It was also very close to a dense Black Wattle area. Could be a site that is degrading.
5.04	318	15.539	32.84	31.91	31.541	5.3754118	2.253985706			
5.24	325	14.753	40.099	39.524	39.212	2.2686025	1.259537362			
5.2	315	18.609	47.141	38.963	26.142	28.662554	62.99007566	6	0	This was an area with a very dense root structure, not special for this wetland type, but there was also cattle walking there, it was an entrance to the water.
5.01	268	18.751	44.68	37.445	24.825	27.90312	67.50829143			
4.95	233	15.456	39.904	34.321	21.689	22.836224	66.9599788			
5.41	365	18.46	29.543	26.867	24.34	24.145087	30.05828476	11	0	This was also a wetland with very dense root structure and the soil was very peat like. Also here cattle was walking around.
5.5	308	18.18	37.535	33.227	27.882	22.257815	35.52203097			
5.22	284	18.085	38.192	33.367	28.354	23.996618	32.803298			
5.3	276	18.609	43.842	36.712	28	28.256648	48.12462023	9	0	Cattle was grazing in this area and it was very diverse in plant diversity, just as the other wetland, where samples were taken. Furthermore all the wetlands were very difficult to access and to walk through.
5.45	227	18.335	38.772	33.183	26.833	27.347458	42.76670259			
5.41	187	15.089	37.297	31.784	24.262	24.824388	45.05540581			

Table A I 2: Calculation of Shannon-Wiener index of diversity (Krebs, 2014).

Species name	Occurrence	Total percentage	Average	Pi	Pi kwadraat	Piln(Pi)	Measure	Value
Acacia mearnsii	8	234	29.3	0.3409	0.1162	-0.3669	S BW	8.0000
Prionium serratum	5	308	61.6	0.2942	0.0865	-0.3599	S WL	23.0000
Pennisetum clandestinum	5	222.5	44.5	0.2125	0.0452	-0.3291	H BW	1.3504
Helichrysum odoratissimum	5	91.5	18.3	0.0874	0.0076	-0.2130	H WL	2.0799
Juncus spp.	5	88.5	21.9	0.0845	0.0071	-0.2088	E BW	0.6494
Cliffortia strobilifera	5	53	10.6	0.0506	0.0026	-0.1510	E WL	0.6633
Cyperus involucratus	2	135	67.5	0.1289	0.0166	-0.2641		
Eleocharis limosa	2	26	13.0	0.0248	0.0006	-0.0918		
Eragrostis spp.	3	29	9.7	0.0277	0.0008	-0.0993		
Conyza scabrida	3	56.5	18.3	0.0540	0.0029	-0.1575		
Arundo donax	3	5	1.7	0.0073	0.0001	-0.0358		
Cliffortia linearifolia	2	3	1.5	0.0029	0.0000	-0.0168		
Psoralea axillaris	2	2	1.0	0.0019	0.0000	-0.0120		
Eucalyptus globulus	1	18	18.0	0.0262	0.0007	-0.0955		
Cyperus rotundus	1	1	1.0	0.0015	0.0000	-0.0095		
Salsola kali.	1	1	1.0	0.0010	0.0000	-0.0066		
Lobelia spp.	1	2	2.0	0.0019	0.0000	-0.0120		
Nymphoides spp.	1	1	1.0	0.0010	0.0000	-0.0066		
Isolepis prolifera	1	3	3.0	0.0029	0.0000	-0.0168		
Eragrostis curvula	1	3	3.0	0.0029	0.0000	-0.0168		
Eragrostis chloromelas	1	3	3.0	0.0029	0.0000	-0.0168		
Pennisetum macrourum	1	1	1.0	0.0010	0.0000	-0.0066		
Helichrysum spp.	1	1	1.0	0.0010	0.0000	-0.0066		
Helichrysum anomalum	1	8	8.0	0.0076	0.0001	-0.0372		
Searsia lucida	1	3	3.0	0.0029	0.0000	-0.0168		
Centella asiatica	1	3	3.0	0.0029	0.0000	-0.0168		
Rubus rigidus	1	3	3.0	0.0029	0.0000	-0.0168		
		Total BW	686.5					
		Total WL	1047					
	BW species							
	WL species							
	Both							

Table A I 3: Template of a table to measure water content in the soil.

Code of sample	Weight of empty cups (g)	Weight of cups before drying in the stove (70 °C) (g)	Weight of cups after drying in the stove (70 °C) (g)	Water content (%)
1				
2				

Table A I 4: Template to measure organic matter content of the soil.

Code of sample	Weight of cups afterdrying in the stove (70 ºC) (g)	Weight of cups after incineration at 510 °C (g)	Organic matter content (%)
1			
2			

Table A I 5: Raw data and the p-value of the statistical tests.

pH BW	pH WL	nitrate BW	nitrate WL	water content BW	water content WL	organic content BW	organic content WL	ammonium BW	ammonium WL	phoshate BW	phosphate WL	conductivity BW	conductivity WL	Erosion (m) BW	Erosion (m) WL	Diversity of plants BW	Diversity of plants WL
4.75	5.29	6.629365	5.157419	14.91267	15.17074	9.170354	8.718843	1.516649	0.825754	0.346373	0.190889	242	216	-1.5	0	4.00	6.00
4.78	4.85	8.19086	5.649934	3.902723	3.458013	3.149423	2.102497	4.260152	0.911597	0.52281	0.171039	321	323	-2	0	5.00	8.00
5.23	4.5	6.13965	5.191	2.360959	5.021794	3.378326	1.473197	2.960052	0.969056	0.19971	0.190889	283	366	-0.5	0	6.00	6.00
6.4	5	5.322524	5.409273	15.38956	5.014568	3.01711	0.979442	0.990516	1.275043	0.315497	0.197505	343	315	-3	-0.5	3.00	11.00
4.94	5.04	5.607958	5.817836	2.903699	5.375412	5.233437	2.253986	3.017511	1.299273	0.373942	0.207429	328	318	-0.3	-1.5	5.00	9.00
5.11	5.24	6.159238	5.938166	3.28153	2.268603	3.899635	1.259537	3.315883	0.810524	0.448927	0.252641	332	325				
4.85	5.2	4.757251	4.77684	16.16329	28.66255	13.08632	62.99008	1.308965	3.063201	0.182067	0.203019	321	315	p-value (c	0.265	p-value (c	0.243
4.99	5.01	6.870026	5.43166	3.307301	27.90312	2.140807	67.50829	2.093318	1.746486	0.221765	0.158909	329	268	p-value (T	0.066	p-value (T	0.002
4.88	4.95	5.616353	4.939146	2.249247	22.83622	12.09953	66.95998	1.970092	2.393767	0.269182	0.176553	324	233				
4.32	5.41	5.143427	6.62097	19.34912	24.14509		30.05828	7.775547	4.876281	0.513988	0.218457	412	365				
5.01	5.5	5.689111	5.22458	2.232579	22.25781	8.054124	35.52203	15.06525	3.468877	0.309983	0.198608	361	308				
4.82	5.22	10.54709	4.799227	6.501967	23.99662	8.341002	32.8033	16.16944	2.170853	0.318805	0.420256	393	284				
5.3	5.3	0.810303	4.844001	22.03341	28.25665	4.580717	48.12462	0.449961	5.569945	0.734802	0.165526	85	276				
6.2	5.45	0.362556	5.056678	16.52867	27.34746	0.698016	42.7667	0.301705	6.224149	0.785111	0.16332	49.2	227				
5.94	5.41	3.154302	5.160218	11.61981	24.82439	2.787162	45.05541	0.740026	6.435987	1.16886	0.206327	66.9	187				
p-value (one-	0.043	p-value (c	0.010	p-value (c	0.026	p-value (c	< 0,0001	p-value (c	0.053	p-value (c	0.002	p-value (c	0.027				
p-value (Two	0.951	p-value (T	0.922	p-value (T	0.012	p-value (T	0.001	p-value (T	0.344	p-value (T	0.001	p-value (T	0.785				
p-value (Two	0.271	p-value (T	0.340	p-value (T	0.011	p-value (T	0.097			p-value (T	0.000	p-value (T	0.281				
First test is Levene test																	
Second test is Students t-test				Green	Not significant Leven test												
Third Mann-Whitney U test				Red	Significant Levene test												

Table A I 6: Rainfall data and calculations for outliers, Thomson tau was 1.94 in this calculation (Cimbala, 2011).

year	Annual rainfall	delta	year	Annual rainfall	delta	year	Annual rainfall	delta
1920	595.42	102.4718	1948	511.63	186.2618	1976	922.18	224.2882
1921	756.14	58.24824	1949	596.61	101.2818	1977	540.54	157.3518
1922	638.12	59.77176	1950	1041.6	343.7082	1978	907.06	209.1682
1923	655.48	42.41176	1951	690.62	7.271765	1979	497.63	200.2618
1924	715.68	17.78824	1952	598.57	99.32176	1980	1040.9	343.0082
1925	812.28	114.3882	1953	962.15	264.2582	1981	699.37	1.478235
1926	612.78	85.11176	1954	667.31	30.58176	1982	766.29	68.39824
1927	637.84	60.05176	1955	857.71	159.8182	1983	520.1	177.7918
1928	720.58	22.68824	1956	841.54	143.6482	1984	561.96	135.9318
1929	699.72	1.828235	1957	609.56	88.33176	1985	588	109.8918
1930	681.59	16.30176	1958	792.47	94.57824	1986	761.95	64.05824
1931	962.99	265.0982	1959	805.35	107.4582	1987	496.3	201.5918
1932	805.56	107.6682	1960	593.46	104.4318	1988	496.09	201.8018
1933	593.95	103.9418	1961	630.21	67.68176	1989	866.53	168.6382
1934	836.22	138.3282	1962	723.38	25.48824	1990	456.68	241.2118
1935	631.54	66.35176	1963	810.04	112.1482	1991	794.01	96.11824
1936	644.14	53.75176	1964	625.31	72.58176	1992	952.07	254.1782
1937	539.28	158.6118	1965	769.79	71.89824	1993	661.43	36.46176
1938	809.9	112.0082	1966	760.76	62.86824	1994	782.18	84.28824
1939	828.31	130.4182	1967	926.52	228.6282	1995	597.94	99.95176
1940	592.83	105.0618	1968	534.03	163.8618	1996	1000.51	302.6182
1941	664.79	33.10176	1969	448.28	249.6118	1997	558.32	139.5718
1942	765.24	67.34824	1970	1099.35	401.4582	1998	460.11	237.7818
1943	997.71	299.8182	1971	737.45	39.55824	1999	441.7	256.1918
1944	653.87	44.02176	1972	430.36	267.5318	2000	719.67	21.77824
1945	666.68	31.21176	1973	811.65	113.7582	2001	542.78	155.1118
1946	779.31	81.41824	1974	578.34	119.5518	2002	590.38	107.5118
1947	582.47	115.4218	1975	620.06	77.83176	2003	513.24	184.6518
						2004	630.35	67.54176
Average rainfall	697.8917647							
Standard deviation	155.5967817							
Thompson Tau test value	301.8577565							

Table A I 7: Organic matter content and calculations for outliers, Thomson tau was 1.86 in this calculation (Cimbala, 2011).

Organic matter content	**Delta**		**Organic matter content**	**Delta**
9.170354394	1.847233		8.71884347	21.18623593
3.149423148	4.173698		2.102496715	27.80258269
3.378326263	3.944795		1.473197069	28.43188233
3.017110459	4.306011		0.979442471	28.92563693
5.233436729	2.089684		2.253985706	27.6510937
3.899635375	3.423486		1.259537362	28.64554204
13.08631643	5.763195		62.99007566	33.08499626
2.140806695	5.182315		67.50829143	37.60321203
12.09952659	4.776405		66.9599788	37.05489939
30.21086165	22.88774		30.05828476	0.15320536
8.054123711	0.731003		35.52203097	5.616951567
8.341001709	1.01788		32.803298	2.898218595
4.580716661	2.742405		48.12462023	18.21954083
0.698016165	6.625105		42.76670259	12.86162318
2.787162162	4.535959		45.05540581	15.15032641
Average	7.323121		Average	29.9050794
Standard deviation	7.325659		Standard deviation	25.49596251
Thompson Tau test	13.60563		Thompson Tau test	47.36894875
Green	Black Wattle sites			
Black	Wetland sites			
Red	Outlier			

Appendix II

Table A II 1: Plant species at different sampling sites and their Braun Blanquet code. BW stands for Black Wattle and WL stands for Wetland, furthermore, the name of the land and the GPS locations are given in DD°MM'SS.s.

Sampling site	Species name	Code
Essenbos 1 BW	*Acacia mearnsii*	5
S 33°58’12.2	*Juncus* spp.	R
E 24°24’07.8	*Arundo donax*	R
Willowvale BW	*Acacia mearnsii*	4
S 33°57’61.7	*Eucalyptus globulus*	2b
E 24°22’25.2	*Pennisetum clandestinum*	4
	Helichrysum odoratissimum	2b
Essenbos 2 BW	*Acacia mearnsii*	3
S 33°58’24.4	*Arundo donax*	1
E24°24’30.8	*Pennisetum clandestinum*	+
	Juncus spp.	R
	Cyperus rotundus	1
Krugersland BW	*Acacia mearnsii*	3
S 33°52’23.3	*Arundo donax*	R
E 24°02’45.6	*Pennisetum clandestinum*	4
	Eleocharis limosa	2b
	Cliffortia strobilifera	2a
	Salsola kali	R
Schaapsdrift BW	*Eleocharis limosa*	2a
S 33°55’49.5	*Acacia mearnsii*	R
E 24°14’32.3	*Lobelia spp.*	+
	Nymphoides spp.	R
	Isolepis prolifera	1
Waterfal right site of the river WL	*Acacia mearnsii*	R
S 33°58’13.5	*Prionium serratum*	2a
E 24°23’57.3	*Cliffortia strobilifera*	R
	Eragrostis curvula	1
	Cyperus involucratus	4
	Eragrostis chloromelas	1
	Pennisetum macrourum	R
Waterfal left site of the river WL	*Prionium serratum*	5
S 33°57’90.3	*Helichrysum odoratissimum*	R
E 24°23’54.3	*Cliffortia strobilifera*	2b
	Helichrysum spp.	R
	Cyperus involucratus	4
	Eragrostis spp.	1
	Pennisetum clandestinum	2b
	Conyza scabrida	R
Klein Langkloof WL	*Prionium serratum*	5
S 33°52’67.1	*Helichrysum odoratissimum*	+
E 24°03’08.5	*Helichrysum anomalum*	2a
	Psoralea axillaris	R

	Cliffortia strobilifera	2b
	Juncus spp.	R
Walletjies 1 WL	*Prionium serratum*	5
S 33°52’63.9	*Helichrysum odoratissimum*	1
E 24°03’36.2	*Cliffortia linearifolia*	+
	Juncus spp.	2b
	Cliffortia strobilifera	2a
	Eragrostis spp.	2b
	Searsia lucida	1
	Conyza scabrida	2b
	Acacia mearnsii	R
Walletjies 2 WL	*Prionium serratum*	3
S 33°52’67.9	*Cliffortia linearifolia*	R
E 24°03’58.7	*Juncus spp.*	4
	Centella asiatica	1
	Pennisetum clandestinum	4
	Eragrostis spp.	2a
	Rubus rigidus	1
	Conyza scabrida	3
	Acacia mearnsii	R
	Helichrysum odoratissimum	4
	Psoralea axilaris	R

Appendix III

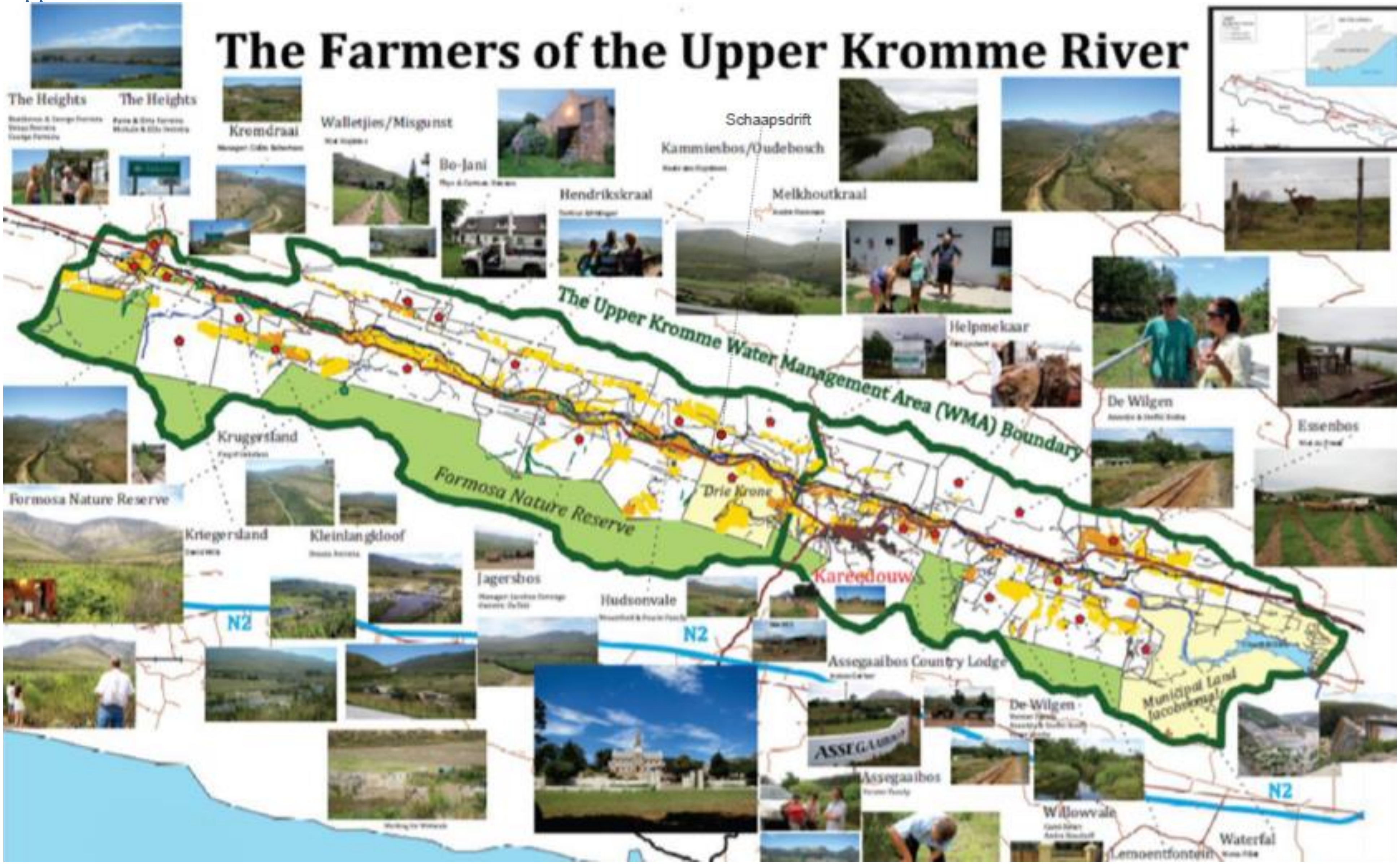

Figure A III 1: Map of the Kromme river catchment and the names of the lands of the landowners in the area (Rebelo, 2012).

Appendix IV

Mann-Whitney U test to compare Nitrate in Black Wattle sites and Nitrate in Wetland sites.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Nitrate BW	15	0	15	0.481	5.039	2.628	1.118
Nitrate WL	15	0	15	2.259	3.148	2.528	0.242

Mann-Whitney test / Two-tailed test:

U	136.000
Expected value	112.500
Variance (U)	581.250
p-value (Two-tailed)	0.340
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The difference of location between the samples is equal to 0.

Ha: The difference of location between the samples is different from 0.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 34.01%.

Mann-Whitney U test to compare Ortho-Phosphate in Black Wattle sites and Ortho-Phosphate in Wetland sites.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ortho-Phosphate BW	15	0	15	0.064	0.422	0.158	0.101
Ortho-Phosphate WL	15	0	15	0.056	0.143	0.073	0.021

Mann-Whitney test / Two-tailed test:

U	201.000
Expected value	112.500
Variance (U)	581.121
p-value (Two-tailed)	0.000
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The difference of location between the samples is equal to 0.

Ha: The difference of location between the samples is different from 0.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.03%.

Mann-Whitney U test to compare pH in Black Wattle sites and pH in Wetland sites.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
pH BW	15	0	15	4.320	6.400	5.168	0.577
pH WL	15	0	15	4.500	5.500	5.158	0.269

Mann-Whitney test / Two-tailed test:

U	85.500
Expected value	112.500
Variance (U)	580.733
p-value (Two-tailed)	0.271
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The difference of location between the samples is equal to 0.

Ha: The difference of location between the samples is different from 0.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 27.15%.

Mann-Whitney U test to compare Conductivity in Black Wattle sites and Conductivity in Wetland sites.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Conductivity BW	15	0	15	49.200	412.000	279.340	116.980
Conductivity WL	15	0	15	187.000	366.000	288.400	53.488

Mann-Whitney test / Two-tailed test:

U	139.000
Expected value	112.500
Variance (U)	580.991
p-value (Two-tailed)	0.281
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The difference of location between the samples is equal to 0.

Ha: The difference of location between the samples is different from 0.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 28.07%.

Mann-Whitney U test to compare Water content in Black Wattle sites and Water content in Wetland sites.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Water content BW	15	0	15	2.233	22.033	9.516	7.239
Water content WL	15	0	15	2.269	28.663	17.769	10.450

Mann-Whitney test / Two-tailed test:

U	51.000
Expected value	112.500
Variance (U)	581.250
p-value (Two-tailed)	0.011
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: The difference of location between the samples is equal to 0.
Ha: The difference of location between the samples is different from 0.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 1.14%.

Mann-Whitney U test to compare Organic content in Black Wattle sites and Organic content in Wetland sites. Outlier removed

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Organic content BW	14	0	14	0.698	13.086	5.688	3.823
Organic content WL	15	0	9	0.979	67.508	29.910	25.496

Mann-Whitney test / Two-tailed test:

U	67.000
Expected value	
Variance (U)	
p-value (Two-tailed)	0.0972
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The difference of location between the samples is equal to 0.

Ha: The difference of location between the samples is different from 0.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 9.72%.

Students t-test to compare Ammonium in Black Wattle sites and Ammonium in Wetland sites.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ammonium BW	15	0	15	0.093	2.241	0.585	0.689
Ammonium WL	15	0	15	0.116	0.895	0.392	0.283

z-test for two independent samples / Two-tailed test:

95% confidence interval on the difference between the means:
] -0.184 ; 0.570 [

Difference	0.193
z (Observed value)	1.004
|z| (Critical value)	1.960
p-value (Two-tailed)	0.316
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 31.56%.

Students t-test to compare Erosion in Black Wattle sites and Erosion in Wetland sites.

Variable	Observations	Obs.	Obs.	Minimum	Maximum	Mean	Std.

		with missing data	without missing data				deviation
Erosion (m) BW	5	0	5	-3.000	-0.300	-1.460	1.110
Erosion (m) WL	5	0	5	-1.500	0.000	-0.400	0.652

z-test for two independent samples / Two-tailed test:

95% confidence interval on the difference between the means:
] -2.189 ; 0.069 [

Difference	-1.060
z (Observed value)	-1.841
|z| (Critical value)	1.960
p-value (Two-tailed)	0.066
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 6.57%.

Students t-test to compare Diversity of plants in Black Wattle sites and diversity of plants in Wetland sites.

Variable	Observations	Obs.	Obs.	Minimum	Maximum	Mean	Std.

		with missing data	without missing data				deviation
Diversity of plants BW	5	0	5	3.000	6.000	4.600	1.140
Diversity of plants WL	5	0	5	6.000	11.000	8.000	2.121

z-test for two independent samples / Two-tailed test:

95% confidence interval on the difference between the means:
] -5.511 ; -1.289 [

Difference	-3.400
z (Observed value)	-3.157
|z| (Critical value)	1.960
p-value (Two-tailed)	0.002
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 0.16%.

Appendix V

The 15 conversations about area characteristics of invaded sites and non-invaded sites are written below and the eight conversations about the management strategy is described.

1 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
Black Wattle grows on wet and dry soil, it grows when it has the chance to grow and it will take over the place. Then it will dry out the soil and Palmiet cannot grow anymore.
Black Wattle is an N-fixating plant and it can create nutrient richness in the soil and it can regrow fast after removal. It does not matter if one leaves the tree after clearing or burns them, the nutrients will get into the soil.

What do you think of the water availability in the soil? Is it lower where the invasive species
The groundwater table is lower in the landowner's opinion. The tree initially grows on wetter soils, the water use of the tree is high and he also thinks that climate change has an effect on the water availability.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
Possibly Black Wattle has a role in the water availability and floods, but also climate change could be a reason for this. Stated was ''*in the last years we have had more extreme weather*''. More extreme rainfall and more extreme droughts. Black Wattle could be related to that, especially drought.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
There is a lot of erosion after removal of Black Wattle, the sand is loose and there are no roots to keep the soil together. Kikuyu grass is planted to make sure the soil will stay more stable. This is done after removal of the tree. This grass can easily grow on the soil of the Black Wattle. It looks like that it can stand the effects the tree has on the soil.
Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?

There have been more floods last years, but it is not clear whether the plant has a role in it or if it is climate change, as said before.

Do you think that fire plays a role in the growth of the invasive tree?
Fire can be used to remove the plant, but it is important to plant another plant, because it can grow fast easily.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
Palmiet is a slow growing plant and cannot compete against Black Wattle. A possible reason for this could be the shading or lower water availability when the tree is growing. Palmiet and Black Wattle do not grow together. Black Wattle is basically the only plant growing in an invaded area.

2 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
The soil in which Black Wattle grows contains probably some kind of micro-organism.

What do you think of the water availability in the soil? Is it lower where the invasive species
Probably the water availability in the soil is less, where Black Wattle is growing.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
When the plant is burned there is less water taken up by this plant and the amount of water available is higher after burning. The plant takes up a lot of water and this causes less water in the area. Fynbos takes up less water than Black Wattle.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
Black Wattle will be easily removed when there is a lot of water flowing, because they are easily ripped out. Erosion is a big problem with Black Wattle growth.
Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?

After fire the amount of water available is higher, because the plant does not take up that much water. More water is flowing downstream, than when Fynbos is growing in the area.

Do you think that fire plays a role in the growth of the invasive tree?
Black Wattle burns entirely and then it will grow back, because of the seed bank. But more important is the relation with erosion. The roots of Fynbos are not burned when fire takes place, so the soil stays stable and that is not the case with Black Wattle. Fynbos is a species that needs to be burned every 20 years, but too much burning is bad and will degrade the area.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
Black Wattle is growing alone and no other plants grow there. Fynbos and Black Wattle do not grow together.

3 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
At places where Black Wattle grows every other species dies. Thus it has an influence on the soil, but what it is exactly is not clear, it could be the tannin production by the tree.

What do you think of the water availability in the soil? Is it lower where the invasive species
The water supply and the springs contain more water after clearing. The water supply was decreased by Black Wattle.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
The water quantity is decreased by the Black Wattle and least the springs were less, but that is a combination of groundwater and surface water. Black Wattle uses a lot of water.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
Erosion is a big problem with floods and when Black Wattle is growing. In the flood of 2006 the water was finding a way outside of the riverbed, because the plant was blocking the natural flow and then

the soil was washed away. It was bare, due to the growth of the tree. In 2012 the erosion was much less after removal of the tree and replanting grass. The water stayed more in the river and flowed wider and more gradually on the grass. Meant was that it did not create another course. The grass kept the soil and the more gradual flow also created less problems. Thus the Black Wattle has a lot of influence on erosion. Another important aspect was the way the tree can clog bridges. When the trees are cleared or ripped out by the water they will flow down and they can clog the bridge and this can cause the bridge to break.

Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?
There have been a lot of floods lately, 2006, 2007 and 2012. When Black Wattle is growing more damage is caused during a flood.

Do you think that fire plays a role in the growth of the invasive tree?
After fire the Black Wattle regrows fast and it actually speeds up the process of growth.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
At places where Black Wattle is growing, native species die.

4 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
Black Wattle takes up a lot of nutrients from the soil, but puts N back in the soil via N-fixation. There is possibly also a nematode in the soil, which does not have an effect on Black Wattle but that creates problems for the uptake of nutrients for other plants.

What do you think of the water availability in the soil? Is it lower where the invasive species
The plant takes up a lot of water and it dries out the soil, but it can stand a low amount of water and a high amount of water, but initial growth is on moist soils. There is less water available at Black Wattle overgrown areas.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?

Especially the water quantity is influenced by the Black Wattle, as the tree uses a lot of water. Stated was; *''I saw Black Wattle during drought and the leaves were dried out and after the first rain the leaves were green again''*.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
Black Wattle has a shallow root system and a lot of erosion happens at places where the plant is growing. The plant is easily ripped out due to this shallow root system.

Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?
The plant has been growing in the area for a long time, at least 60 years and it is not clear if there is a difference, but the effect is bigger in the area invaded.

Do you think that fire plays a role in the growth of the invasive tree?
The tree is very suitable to burn, but grows back very easy and fast. After removal (felling) the plant can be used for fuel wood for example.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
The nutrient uptake for other plants is more difficult when Black Wattle is growing in an area, causing species to die in that area. Probably the amount of species is lower in Black Wattle areas.

5 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
There are no other plants growing after removal of Black Wattle. Other plants need to be planted, otherwise there is not plant to grow back except for Black Wattle. It has influence on the soil. The plant creates tannin, which can have an influence on the soil and other plants. It has at least an influence in whether or not it is eaten. Tannin is toxic to cattle and for this the plant cannot be eaten.

What do you think of the water availability in the soil? Is it lower where the invasive species
The water use of Black Wattle is very high, this has influence on the groundwater.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
The Black Wattle uses a lot of water and this has an influence on the quantity. The quality is not influenced by the plant. Also was said that Palmiet stores a lot of water, at least more than other indigenous species.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
After removal erosion was a big problem in the flood of 2012. The plant will hold the soil a bit better then when nothing is growing. But also Palmiet created a new channel in the wetland. This has influence on the river as well.

Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?
There has been a big flood in 2012 created a lot of problems, especially because of the removal of the plant and no regrowth of other plant species. The tree has an important role in the effect of floods.

Do you think that fire plays a role in the growth of the invasive tree?
The fire of 2009/2010 created an almost sterile soil and the only seeds that survived where the Black Wattle seeds. 80 % of the Black Wattle seeds were burned.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
As the tree produces a substance, other plants have difficulties recolonizing an area after clearing. Thus there is low diversity in those areas. Also when the tree is growing in an area, the substance has influence on the growth of other species.

6 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
Black Wattle is tolerant for the infections of a nematode. That is a problem to other plant species, because it creates a problem for other plants to take up nutrient. The density of the stands also is very important in a problem for other species to grow.

What do you think of the water availability in the soil? Is it lower where the invasive species

The plant starts to grow at moist soils, but it can grow on dryer soil as well. It takes up a lot of water and dries out the soil.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?

There is no change of water quantity mentioned, only that the plant takes up a lot of water. What is mentioned was the water quality, which is not influenced by the plant. The quality was good, but is influenced by the waste of human kind and not by the plant.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?

This landowner did not see a lot of erosion happening in his land, because it is not really close to the river and for this erosion is not a very big problem.

Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?

There have been floods, but for this landowner there has not been a big problem with floods, related to Black Wattle growth.

Do you think that fire plays a role in the growth of the invasive tree?

The plant is a good plant for firewood, it burns really fast. It is better to burn it then to clear it and leave it on the ground, because then seedlings have protection and will grow even faster than when the soil is bare.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?

Other species are troubled to grow in invaded areas, due to the nematode and also the density of the stands as said before. There are lower amount of plant species in invaded areas.

7 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?

The Black Wattle is tolerant for a nematode, but this nematode has no influence on kikuyu grass, but it does have influence on the nutrient uptake for other species. Kikuyu grass is a good grass for cattle to graze on and it keeps the Black Wattle from returning. The N-fixation by the tree has a positive effect on the growth of kikuyu grass.

What do you think of the water availability in the soil? Is it lower where the invasive species

The groundwater table is low, thus water availability is low, because a lot of erosion occurred and the river was digged out very deep and the groundwater table decreased probably.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?

The former also made the surface water level decrease. The amount of water is low in summer time. Then the tree uses the most water.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?

The tree has a shallow root system and the water can dig underneath the roots and create a problem of ripping out the trees. This is not with kikuyu grass or Palmiet. Palmiet is a species that traps too much sand and the land is getting higher and higher.

Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?

Especially the sand that is brought down by a flood is a problem, because it gets trapped by the Palmiet and that is causing problems for farming activities.

Do you think that fire plays a role in the growth of the invasive tree?

In 2005 a big fire occurred and among others, Black Wattle was burned and the landowner also burns this tree, because then it can reclaim land, if the landowner immediately plants grass. Otherwise it will grow back.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?

Other plants cannot grow in invaded areas, as they are not tolerant to a nematode, but Kikuyu grass can. There are two species that can grow in these areas with nematodes in it, as is seen. That is not much.

8 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?

The tree is dependent on water at the initial growth, the difference with native species is that it can grow in lower water conditions as well. It also lives with some kind of an eelworm and other species, like honeybush, cannot live with it and it also possibly lives with some kind of a micro-organism. What these species do exactly is not clear. Another thing that is mentioned is the ability for the plant to form allelopathic substances. And this influences the soil, resulting in other trees to have difficulties in growing at this spot.

What do you think of the water availability in the soil? Is it lower where the invasive species

In this upstream part of the Kromme river, the water is not really a problem. The water table is not mentioned as a problem in that area, although the tree causes problems with water amount more downstream.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?

The water quantity is changing, but more downstream it is more severe than upstream. That is where people clear the tree for the water availability, although the water movement is not much.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?

Erosion is a big problem and for this the tree is removed at this land. This is together with preserving indigenous species the main reason for removing the tree. Erosion is very severe in the Kromme river and also more downstream it is a big problem.

Do floods have more effect on the area at places where invasive species are growing than at places where native species are growing?

Currently and already some time the water movement is not much and until five years ago Black Wattle was growing all over and it is cleared now. It is not yet clear what it did to the amount of water. At this part of the area floods are not a big issue, because it has a higher altitude. It is only the lack of water sometimes.

Do you think that fire plays a role in the growth of the invasive tree?
Black Wattle burns very fast and is often used for fuel wood and it germinates very fast.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
The amount of different plants is less in invaded areas, due to soil characteristics as said before.

9 Area characteristics *Acacia mearnsii* versus Wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
Black Wattle changes the soil, it produces some kind of chemical substance, like an oily substance (tannin). Also a high nutrient amount in the soil is expected.

What do you think of the water availability in the soil? Is it lower where the invasive species
The soil is dry and water availability is not much.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
The tree uses a lot of water and the water availbility is lower because of that.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
This tree causes a big problem with erosion. Erosion happens a lot where the invasive species is growing.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
Lower diversity is expected, due to these soil characteristics and water availability.

10 Area characteristics *Acacia mearnsii* versus wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?

Black Wattle is able to fixate N, but it does not immediately alter the soil, as it can stay in the nodules of the roots of the tree. Furthermore the tree is able to mineralize Phosphorus and this also changes the soil nutrients.

What do you think of the water availability in the soil? Is it lower where the invasive species

An incised river, caused by erosion, due to among others alien growth, causes the water table to drop and the water availability in the soil is lower.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?

Incised rivers are related to growth of Black Wattle, thus the lower water availability in the soil is related to Black Wattle. And the tree evaporates a lot of water

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?

Black Wattle causes a lot of erosion, thus erosion happens most at Black Wattle areas.

Do you think that fire plays a role in the growth of the invasive tree?

The invasive plant is able to germinate fast after fire. This is the way to make sure the tree survives. Furthermore the seeds of the trees are often in the top layer of the soil, so they can easily and fast germinate.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?

As the tree is able to germinate fast it colonizes the area and it makes sure the tree gets its spot and other species cannot grow there anymore, causing less amount of plants. The wetlands have much greater diversity than Black Wattle invaded areas.

11 Area characteristics *Acacia mearnsii* versus wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?

The plant fixates a lot of Nitrogen, but in a riparian area, this is may be not found back, because of leaching into the water. Furthermore there is much more shadow in these areas, this causes problems for native species.

What do you think of the water availability in the soil? Is it lower where the invasive species
There is less water in the soil under Black Wattle invaded areas.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
Black Wattle uses a lot of water and for this the moisture of the soil is less.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
The moisture of the soil is less, the sand is dryer. Easier to erode. Black Wattle could have an impact on erosion in the area.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
Native species have more difficulty in growing in invaded areas. And as Black Wattle takes a lot of water from the soil and creates shadow, native species will not grow anymore.

12 Area characteristics *Acacia mearnsii* versus wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
Black Wattle adds nutrients in the soil, but also uses them. It could be that there are no change in soil for that, although there could be a change in the soil, due to tannin production.

What do you think of the water availability in the soil? Is it lower where the invasive species
Lower water amount in Black Wattle sites.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
Black Wattle uses a lot of water, more than native species, and for this it could be lower.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
There is a lower diversity of species, could be related to water availability.

13 Area characteristics *Acacia mearnsii* versus wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
Nutrients could be higher in the soil, as the tree is able to add nutrients to the soil, furthermore in riparian areas these nutrients could be flowing in the water. So it is possible that the higher nutrients are not found.

What do you think of the water availability in the soil? Is it lower where the invasive species
There is a lower water content in areas invaded with Black Wattle.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?
Erosion and changes in geomorphology is very important in this, as erosion causes the water table of the river to drop and also the soil water level.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?
Erosion is a big problem with this tree. Erosion happens more in invaded areas that in non invaded areas.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?
The change in soil is problematic for other plants. Clearing is very difficult due to that. And other species cannot grow very good.

14 Area characteristics *Acacia mearnsii* versus wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?
Black Wattle degrades the area and nutrient cycle could be disrupted. For this there could be differences in nutrients in the soil. Nitrogen enrichment is possible but also due to this disrupted nutrient cycle, lower nutrient content is also possible. Not directly related to soil, but very important is competition with other species. This is probably light and water related. As Black Wattle grows quick and can easily outcompete other species.

What do you think of the water availability in the soil? Is it lower where the invasive species

The water amount in invaded areas is reduced as the tree uses much more water than the native species. For their water use they prefer to grow in moist soil, but they can easily survive in dryer soils.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?

Water amount is lower as the tree uses a lot of water, this also effects as said before the plant community structure.

Do you think that fire plays a role in the growth of the invasive tree?

More seeds survive in marginal conditions. After fire the soil could be barer, as the organic matter and humus layer is burned. But Black Wattle seeds can survive and germinate.

15 Area characteristics *Acacia mearnsii* versus wetlands

On what type of soil does Acacia mearnsii grow? And what is the difference with the soil where native species grow?

Black Wattle changes a lot in the hydrology of an area and furthermore it produces tannin and some kind of nematode. All these factor make the soil change in favour of Black Wattle. Causes competition to other species, which the other species lose.

What do you think of the water availability in the soil? Is it lower where the invasive species

Water table drops at invaded sites. The hydrology changes with the growth of this tree.

Why do you think it is lower or not lower? What is the role of the invasive species Black Wattle?

The role of Black Wattle is their water use. The water use is a lot and much more than native species, causes dry out of the soil.

Where does erosion happen most? Places where the invasive species grows, places where no invasive species grow?

Normally there is a steady flow in the area, but when erosion happens the flow is less steady and the tree has a big role in the erosion processes. And a lot of erosion is transported downstream as the soil is much dryer and looser and for this it is taken much easier.

What do you think about the diversity of the plants? Is the diversity lower in invaded areas?

Among others Palmiet is a species that loses competition with Black Wattle. The wetland starts to disappear and so do the other species, growing in that wetland.

1 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?

First felling happens then there should be a follow-up happening, but that is not happening or too late.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?

The initial felling is successful, but the follow-up is not done. The Working for Water does not follow-up or the landowners do not follow-up and the tree is growing back. It is not growing back heavily, but the seeds might flow downstream and create a bigger problem there.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?

The tree should be used after removal, there should be a market for, for example fuel wood, fertilizer or for construction. *''The WfW people should chop the wood into small pieces and sell it as fire wood''.* Also replanting is very important.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?

The soil stays bare for a long time after removal. Thus replanting is needed to make sure the Black Wattle does not grow back. The soil characteristics are important in the management.

What suggestions would you want to give to create this ´new´ landscape?

The spreading of seeds is a problem and the tree does re-sprout. Thus the follow-up is important to make sure the seeds do not spread again. Removing them when they are small decreases the seed bank and that is the most important thing.

2 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?

There is contract between a landowner and Working for Water and this should be signed. Then the clearing can begin. The initial clearing was good, but the follow-up lacked a bit. But after a while the

land is clear and the regrowth is much less. The landowner has to follow-up after the Working for Water people did their job. Often this is not done, because the follow-up earlier in the process is not properly done.
Another aspect is the usage of aerial photographs for clearing. This way they tend to 'forget' some parts of the area and at those places the tree is still growing.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?
Follow-ups are a problem with this program. Actually it is not clear what the program of Working for Water is, but at this landowner's land the follow-up is done very year in March/April. This makes it difficult to work together and to clear an area properly. Another aspect is that the trees are left to rot at the site and that is not good.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?
The trees that are left to rot could be used for, for example compost. Maybe the costs are higher than the profit, but one will create work and about 1000 people can be employed. So jobs are created. The statement was *''the money that will be earned by producing this compost may be less than the costs to fell the trees, but it will create job opportunities and this is also a way of earning''*.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?
If the trees are left it creates problems in the streams. For example it can be clogging bridges and it can create bigger floods in an area. It is also important to replant species after removal. And because it takes up a lot of water the water properties in the area change.

What suggestions would you want to give to create this ´new´ landscape?
Making sure the follow-up happens every year, the plant cannot grow big and cannot create seeds yet. And it does not use a lot of water and that created a better water supply in this area.

3 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?
Working for water fells the tree and leaves it in the area.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?
What Working for Water should do is to use the tree. Thus they should fell it and then chop it and to make compost out of it. Then the tree is used and not left.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?
The tree should be used, as written before, then there is more market in this field of work and one will earn some money from it.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?
Because the plant is tolerant for the infection of a nematode, the soil is often not really suitable to regrow plant naturally and plants should be replanted.

What suggestions would you want to give to create this ´new´ landscape?
The plants takes up and evaporates a lot of water, thus it should be cleared before that happens. The plants should stay small, to make sure the water is not too much used.

4 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?
The Black Wattle was just removed and no other plants were planted. This created problems with the flood of 2012. In that year a lot of damage was done, because nothing was left after clearing of the plant.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?

The Black Wattle was growing back after removal and after the fire of 2009/2010. Then the soil was almost sterile by then and what should be done is to reintroduce some micro-organisms. These organisms can help plants to regrow.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?
The main thing according to this landowner is patience. It is important to just keep on removing it. It will take time, but if it is kept on removing than the seed bank will decrease. Furthermore using the tree by for example, making charcoal out of it is also an opportunity for using the tree. This charcoal can for example be used for filtering water. This should be activated charcoal. Black Wattle wood is very hard wood and this can be useful in construction, but also in decorating.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?
It is probably just a matter of time before it is removed entirely and then probably some micro-organisms should be introduced and grass species should be replanted, because the soil is not suitable for regrowth naturally. Another important aspect of the tree is the tannin production, which has at least a big influence on the management of the tree, because using cattle is due to tannin difficult.
The farmer explained; ‘‘*tannin is a substance that cannot be absorbed by animals. This means that the animal does not get nutrients to survive even though their stomachs are full if it only eats the tree. The animal will eventually die*’’.

What suggestions would you want to give to create this ´new´ landscape?
It is important to make sure the seed bank becomes smaller and it just takes time to do that. It is important to keep on removing it.

5 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?
The tree is just cleared and left at the spot. Then it regrows easily.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?

It should be done more properly, for example by replant kikuyu grass. Then the tree does not grow back. And the tree can be used, as there is compost made from it by a son of mine.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?

It is very important to replant plants after clearing an area. Kikuyu grass is a very good plant to replant, because it has a dense root system and the stand is dense. The tree cannot grow in between and it stays away. Also the tree can be used for, for example compost. Now nothing is done with the tree.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?

Replanting plants like kikuyu grass could be a good way to in the first place make the river more resistant to floods and erosion. Kikuyu grass is a species that grows really fast and anchors the soil really well. This way Black Wattle trees have more difficulty to grow in the area again, because of the density of the root system of the kikuyu grass and the density of the stand itself. Although planting the grass species, the seeds are still in the soil and when the grass is somehow removed, then the tree will grow back fast. Another plant that is able to anchor soil is Palmiet, but this species also traps a lot of soil and the cattle will feed less on this plant.

What suggestions would you want to give to create this ´new´ landscape?

Goats can eat the small trees and make sure they do not get big. The goats will also eat the roots, but they have to have something else to eat as well, because the production of tannin creates problems in the absorption of nutrients and if it does not eat something else the tree will have an effect on cattle.

6 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?

The Black Wattle is removed for example by felling and making use of herbicides and sometimes also bio-control in the whole area, including private lands. It is a practical strategy in which also the landowners are informed and in which they also have tasks in clearing. Furthermore the approach is to work from upstream to downstream areas. This is to prevent seeds from spreading.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?
The regrowth of the tree is less where the plant is removed, thus it is a rather successful strategy, but it is important to keep on working upstream to downstream.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?
As said before the most important thing is to prevent seeds from spreading and for this consequent removal (upstream to downstream, do not let the tree develop to seed producing trees etc.) is most important.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?
The seed bank is very big and the seeds can spread via the water easily and for this the seed bank in the soil should be decreased. Thus the soil should become seed free to get rid of the tree. The landscape changes when Black Wattle is growing, but the landscape is changing even more when the plant is removed and no further measures are taken, like replanting other species. Especially erosion is even a greater problem after removal. It looks like that the riparian zone erodes and this way it deepens the riverbed. The soil in terms of erosion is definitely an important aspect in managing.

What suggestions would you want to give to create this ´new´ landscape?
The practical strategy of removal should be done regularly with follow-ups. Then the trees do not grow to seed producing trees and the seed bank will decrease.

7 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?
An integrated approach is used to clear the Black Wattle. The species is controlled by felling and by the application of herbicides and this happens less dense to heavily dense patches and top-down, thus upstream to downstream. Taking into account the density is done, because heavily dense areas

cannot become denser and clearing top down is important for the spreading of seeds. Also areas are selected for biological control. Furthermore follow-ups are part of the plan and replanting vegetation is also part of the follow-up. Replanting species is very expensive, but also very important.
The work is done on public land and private land. The landowners also have tasks to control the alien species. For this a program to incentivise the landowners is implemented and they have to make sure the density level of Black Wattle is decreased by 5 %.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?
If the replanting is done the clearing is very successful, as said it is very important but when it is done the Black Wattle does not return easily.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?
The seed bank needs to be lowered and for this fire must be avoided, because it stimulates germination. Also the clearing methods can only be applied if there is a way to make sure the germinating plants are also taken out in early stages, before they produce seeds. Follow-ups are as said very important and not only due to the fast germination and the big seed bank also because the plant is able to re-sprout.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?
It is important to not disturb the soil by for example fires, because that initiates germination. And if this happens someone needs to be ready to start and remove the seedlings again, before they develop into seed producing seeds.

What suggestions would you want to give to create this ´new´ landscape?
To win the battle against the Black Wattle the tree should be removed in an early stage of development. Then the tree is not producing seeds and it cannot spread fast. That is the main reason why they should be removed in an early stage.

8 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?

Clearing should be properly done to remove the tree, thus first initial clearing and then follow-up. Clear the area again, before the tree produces seeds.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?

Biggest problem is follow-up, this is not properly done at the moment and for this the regrowth is a problem. But where it is properly done, Palmiet can even return.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?

Well, keep on clearing, when there is competition between native species and non-native alien species than the native species will lose and you can start all over again. Replanting should be done, but only when the area is fully cleared, including seed bank. Ring barking is a very good way of clearing an area efficiently.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?

To make sure the native species, like Palmiet, returns the hydrology needs to change. Water is the most important aspect, soil will be possibly cleaned by the water.

What suggestions would you want to give to create this ´new´ landscape?

Gabion structures can be a good initiative to restore an area as gabions hold the water on one side and create sediment deposit in that site and Palmiet will regrow in such a wet area.

9 Management of Black Wattle

What are the steps in the current strategy to clear the Black Wattle?

The tree is mechanically controlled (felling) and chemically controlled (herbicides). Furthermore there are plots selected to do bio-controlling.

To which extent is the control and eradication strategy of the Black Wattle successfully implemented and are the follow-ups properly done?

Total eradication cannot be achieved by only doing this. What is now done is controlling, not eradication. The seed bank makes it difficult to eradicate the plant. For this bio-controllers (*Melanterius maculatus)* are introduced. The bio-control agents reduce the rate of spread, but does not damage the existing seed bank. *Dasineura rubiformis* is also introduced and this bio-control against but it is not clear yet what it does exactly in the long term. What is known is that it attacks the fruits.

Is there an aspect in the strategy that could be improved? And what do you think should be added to the strategy to make it (more) successful?

Bio-control agents could be a very important aspect to the control better or to start eradicating the plant.

Could the soil and water properties be an important aspect of clearing the tree and creating a ´new´ (Black Wattle free) landscape?

One needs to take into account what the possible use of herbicides does to the soil and what the plant itself does to the soil, as this tree produces allelopathic substances.

What suggestions would you want to give to create this ´new´ landscape?

Wetlands should be brought back as they are among the most productive ecosystems in the world.

It is important to take a look at the allelopathic substances the tree can produce.

Appendix VI

Table A VI 1: Current treatment of the A. mearnsii (Black Wattle) (http://www.dwaf.gov.za/wfw/default.aspx).

TREATMENT DETAIL				APPLICATION DETAIL				PLANNING DETAIL		
Species	**Size class**	**Treatment**	**Herbicide**	**Dosage**	**a.i. Litres**	**Mix Litres**	**% Mix a.i.**	**Density**	**Estimated Product Litres / Ha (or kg)**	**if Mix vol. Litres / Ha**
	Seedlings	Hand pull	None							
	Seedlings and up to 1 m tall	Foliar spray	**clopyralid / triclopyr (-amine salt) 90 / 270 g/L SL** *Confront 360 SL (L7314)*	30ml / 10 Litres water and 0.5% Wetter & Dye	**0,03**	**10**	0,3	Closed / Dense	**0,90**	300
			fluroxypyr 200 g/L EC *Starane 200 EC (L4918), Tomahawk 200 EC (L6652), Voloxypyr 200 EC (7776)*	12.5ml / 10 Litres water and 0.5% Wetter & Dye	**0,0125**	**10**	0,125	Closed / Dense	**0,38**	300
			glyphosate (isopropylamine) 240 g/L SL *Tumbleweed 240 SL (L4781)*	112.5ml / 10 Litres water and 0.1% Dye	**0,1125**	**10**	1,125	Closed / Dense	**3,38**	300
			glyphosate (isopropylamine) 360 g/L SL *Glyph 360 SL (L4767), Mamba 360 SL (L4817), Roundup 360 SL (L407), Springbok 360 SL (L6719)*	150ml / 10 Litres water and 0.1% Dye	**0,15**	**10**	1,5	Closed / Dense	**4,50**	300
			glyphosate (isopropylamine) 450 g/L SL *RoundUp Turbo 450 SL (L7166)*	120ml / 10 Litres water and 0.1% Dye	**0,12**	**10**	1,2	Closed / Dense	**3,60**	300
			glyphosate (isopropylamine) 480 g/L SL *Mamba Max 480 SL (L7714)*	110ml / 10 Litres water and 0.1% Dye	**0,11**	**10**	1,1	Closed / Dense	**3,30**	300
			glyphosate (sodium) 500 g/kg WG *Kilo 500 WSG (L7431)*	100gr / 10 Litres water and 0.1% Dye	**0,1**	**10**	1	Closed / Dense	**3,00**	300
			triclopyr (butoxy ethyl ester) 240 g/L EC *Ranger 240 EC adjuvant incl. (L6179)*	50ml / 10 Litres water and 0.1% Dye	**0,05**	**10**	0,5	Closed / Dense	**1,50**	300
			triclopyr (butoxy ethyl ester) 480 g/L EC *Garlon 4 EC (L3249) & 480 EC (L4916), Triclon EC (L6661), Viroaxe EC (L6663)*	25ml / 10 Litres water and 0.5% Wetter & Dye	**0,025**	**10**	0,25	Closed / Dense	**0,75**	300

Wattle, Black (Acacia mearnsii)	Up to 2m tall & Coppice	Spot spray	**clopyralid / triclopyr (-amine salt) 90 / 270 g/L SL** *Confront 360 SL (L7314)*	50ml / 10 Litres water and 0.5% Wetter & Dye	**0,05**	**10**	0,5	Closed / Dense	**1,50**	300
			fluroxypyr / picloram 80 / 80 g/L ME *Plenum 160 ME (L7702)*	75ml / 10 Litres water and 0.5% Wetter & Dye	**0,075**	**10**	0,75	Closed / Dense	**2,25**	300
			glyphosate (isopropylamine) 240 g/L SL *Tumbleweed 240 SL (L4781)*	150ml / 10 Litres water and 0.1% Dye	**0,15**	**10**	1,5	Closed / Dense	**4,50**	300
			glyphosate (potassium) 500 g/L SL *Touchdown Forte Hitech 500 SL adjuvant incl.(L7305)*	100ml / 10 Litres water and 0.1% Dye	**0,1**	**10**	1	Closed / Dense	**3,00**	300
			triclopyr (butoxy ethyl ester) 240 g/L EC *Ranger 240 EC adjuvant incl. (L6179)*	150ml / 10 Litres water and 0.1% Dye	**0,15**	**10**	1,5	Closed / Dense	**4,50**	300
			triclopyr (butoxy ethyl ester) 480 g/L EC *Garlon 4 EC (L3249) & 480 EC (L4916), Triclon EC (L6661), Viroaxe EC (L6663)*	75ml / 10 Litres water and 0.1% Wetter & Dye	**0,075**	**10**	0,75	Closed / Dense	**2,25**	300
	Mature	Bark strip	None	Strip into the ground						
		Fell stump	**fluroxypyr / picloram 80 / 80 g/L ME** *Plenum 160 ME (L7702)*	200ml / 10 Litres water and 0.5% Wetter & Dye	**0,2**	**10**	2	Closed / Dense	**4,00**	200
			imazapyr 100 g/L SL C *hopp 100 SL (L3444), Hatchet 100 SL (L7409)*	1000ml / 10 Litres Water and 0.1% Dye	**1**	**10**	10	Closed / Dense	**20,00**	200
			picloram (potassium salt) 240 g/L SL *Access 240 SL (L4920), Browser 240 SL (L7357)*	150ml / 10 Litres Water and 0.5% Wetter & Dye	**0,15**	**10**	1,5	Closed / Dense	**3,00**	200
			triclopyr (-amine salt) 360 g/L SL *Lumberjack 360 SL (L7295), Timbrel 360 SL (L4917)*	300ml / 10 Litres Water and 0.5% Wetter & Dye	**0,3**	**10**	3	Closed / Dense	**6,00**	200
		Frill	**picloram (potassium salt) 240 g/L SL** *Access 240 SL (L4920), Browser 240 SL (L7357)*	600ml / 10 Litres Water and 2% Wetter & Dye	**0,6**	**10**	6	Closed / Dense	**12,00**	200

Appendix VII

Figure A VII 1: Aerial photograph of the area of 2011. In this area is currently Salsola kali found. In 2011 Black Wattle was less growing in that specific area.

Figure A VII 1: Aerial photograph of the area of 2013. In this area is currently Salsola kali found. In 2013 Black Wattle was growing heavily in that specific area.