The characteristics of the *Acacia mearnsii* invasion in the Kouga catchment, South Africa

Björn Bolhuis

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Björn Bolhuis

Supervisors:

Michel Riksen and Lammert Kooistra, Wageningen University

Dieter van der Broeck, Living Lands

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Abstract

The invasive *Acacia mearnsii* consumes more water than indigenous vegetation of fynbos landscapes in South Africa, and can be a threat to water yields. This thesis maps the distribution of *A. mearnsii* in the Kouga catchment, South Africa. The characteristics of its spread and the impact of the management programs is investigated. The land cover was classified manually using three datasets – SPOT imagery (2010) and aerial photographs (1990 and 1971/73). The rate of spread was calculated for the period 1971-1990 (without clearing programs) and 1990-2010 (with clearing programs) to investigate the impact of the clearing programs. Furthermore, the potential of the NDVI in IAP research is investigated. A total of 776,6ha invaded with *A. mearnsii* was mapped in the research area in 2010. In particular the areas prone to seed distribution, such as riparian zones and the sides of roads where highly invaded. Fynbos and renoster are the most vulnerable. The impact of the clearing programs is clearly visible, as the rate of spread dropped from 15ha/year to 0,6ha/year. But this is not enough to decrease the total invaded area. Seed banks seem to be the biggest challenge regarding the clearing efficiency. The NDVI has a great potential for research on evapotransipration rates and biomass estimation of invasive alien plants, although it has some disadvantages. Shifting to the “Fell and Remove method” could increase the clearing efficiency. Initiatives like the PES-market and stewardships would be ideal to tackle the problems of IAPs in South Africa, but this still needs time.

Keywords: Acacia mearnsii; invasions; manual classification; IAP management; remote sensing; South Africa

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Acronyms

DWA	Department of Water Affairs
NMBMM	Nelson Mandela Bay Metropolitan Municipality
IAPs	Invasive alien plants
Coega IDZ	Coega Industrial Development Zone
+MSL	Above mean sea level
WfW	Working for Water

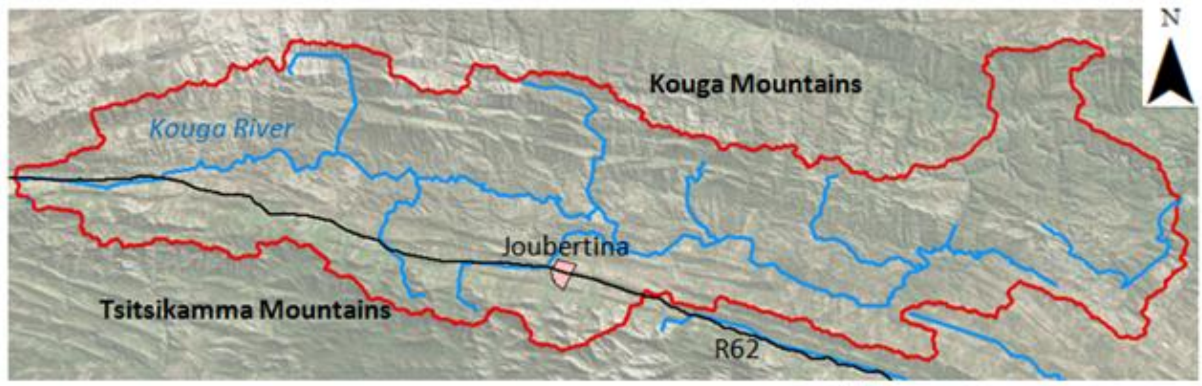
GIB	Gamtoos Irrigation Board
SPOT	Le Système Pour l'Observation de la Terre – A French satellite programme
ETM+	Enhanced Thematic Mapper Plus
NIR	Near-infrared
MIR	Mid-infrared
NDVI	Normalized Difference Vegetation Index
PAR	Photosynthetically active radiation
RMS error	Root mean square error
SLC	Scan Line Corrector
PES	Payment for Ecosystem Services

1. Introduction

1.1 Background

South Africa is an arid country where water availability is critical, with 98,6% of the surface water resources already committed for use (Department of Water Affairs (DWA), 2010). With a growing population which depends on surface water (Statistics South Africa, 2011) and vulnerable water resources, new developments are putting more and more pressure on the already existing water issues. In fact, water scarcity is predicted to be the single greatest constraint to future development (DWA, 2010; Le Maitre *et al*., 2000; WWF - South Africa, 2012) and it has been estimated that South Africa will reach the limits of its usable freshwater resources during the first half of this century (DWA, 1986). The fear is that the country will already face national water shortages as soon as 2025 (WWF - South Africa, 2012).

This Bachelor's study focuses on the catchment area of the Kouga River (figure 1), a typical example of an South African catchment where the water balance is worrying (Veerkamp, 2013). All excess water coming from this area is collected behind the Kouga Dam (Jansen, 2008). The Kouga Dam has a capacity of 128.7 million m^3 and has a significant importance of water provision to downstream users. The Nelson Mandela Bay Metropolitan Municipality (NMBMM), as well as the citrus farmers in the Gamtoos Valley depend on the Kouga Dam for drinking water, domestic purposes and agricultural uses (Veerkamp, 2013). As much as 7,400 hectares of scheduled irrigation lands are irrigated with water coming from the dam and a 97 km long canal provides water directly to the Port Elizabeth water purification works (DWA, 2010) The Kouga River delivers between 73 % and 77 % of the total amount of water that reaches the Kouga Dam (Jansen, 2008).



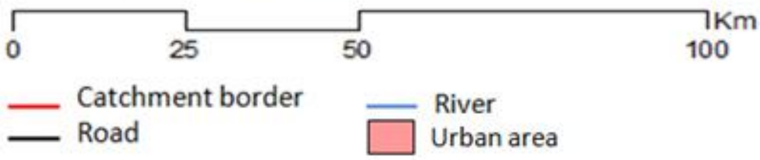


Figure 1: The location of the Kouga River catchment and the position of Joubertina, the R62 and the Kouga- and Tsitsikamma Mountains. The Kouga is located in the Eastern Cape Province of South Africa.

Water abstraction by invasive alien plants (IAPs) is a major threat in South Africa (Dye & Jarmain, 2004). In particular the *Acacia mearnsii* (black wattle) is notorious as it is among the most common alien invaders, and this evergreen tree uses significantly more water than the indigenous vegetation (Le Maitre *et al.*, 2000; Dye *et al.*, 2001). The invasion of *A. mearnsii* can result in differences in transpiration of up to 600 mm per annum (Dye & Jarmain, 2004). It replaces indigenous vegetation, in particular in the riparian zones, reducing the base flow in the rivers and streams in South Africa with on average 6,7 % (Dye & Jarmain, 2004; Le Maitre *et al*., 2000). The tree was introduced in South Africa for commercially reasons in the 19th century (Rouget *et al*., 2002) but it is now a wide-spread problem. Its commercial value combined with its nature as an aggressive invader leads to difficult conflicts of interests (de Wit *et al*., 2001). A biome-scale assessment of the impact of invasive alien plants predicts this problem will grow in the future (Wilgen *et al*., 2008). But the black wattle is not the only threat to the water availability. The agricultural activities in the floodplains are also decreasing the base flow. Furthermore overexploitation of natural resources has degraded the land, leading to increased run-off, higher peak flows, and making it more vulnerable to erosion (Jansen, 2008).

1.2 Problem statement

As the population grows, the region will face increased water demands in the future (Rebelo, 2012). And when the Coega Industrial Development Zone (Coega IDZ) near Port Elizabeth is fully operational, these demands will further increase (Veerkamp, 2013). On the other hand, the amount of water coming from the Kouga catchment is threatened by excessive water use by alien plants as the *A. mearnsii*, land-use changes and land degradation. These factors result in limited water retention possibilities in the catchment, which cause a (too) low base flow (Le Maitre & Colvin, 2008). Over 40 % of South African freshwater systems are in a critical condition (WWF - South Africa, 2012). This will increase the already existing pressure on water resources in the near future. A proper management of the water resources, which includes the removal of invasive alien plants, is therefore crucial.

1.3 Research objective, research questions and significance of study

The research objective of this study was to map the current spread of the *A. mearnsii* in the Kouga catchment, determine how the spread has developed in the past, and assess the management options. As the *A. mearnsii* is seen as the most abundant and the most problematic of all invasive species (Rhodes University; Le Maitre *et al*., 2000), the other invasive plant species were chiefly disregarded in this research. In order not to neglect the impact of other changes in the catchment, a historical overview of the remaining land-uses was also included in this research.

The outcomes of this ecological assessment of the Kouga catchment can be used as input for further research on the influence of IAPs on the water balance. This can provide important information regarding the water quantity that will reach the Kouga Dam. It can also be used to show the impact of the clearing programs which focus on the removal of IAPs, and perhaps even more important: raise awareness for the urge of these clearing programs. In addition this study will provide insights which can be used for the selection and prioritizing of areas where interventions are most needed. Finally it will give a good overview of the (agricultural) developments of the Kouga, and it can provide reliable input to predict possible future scenarios.

For this study I have developed one central research question, which I divided in several more specific sub-questions.

Key research question:

How can the problem of the black wattle (Acacia mearnsii) invasion in the Kouga River catchment be characterised?

Sub-questions:

1. *What is the current distribution of the black wattle?*
2. *How did the land cover of the Kouga catchment develop since 1971?*
3. *Which vegetation types are most vulnerable for black wattle invasions?*
4. *How is the A. mearnsii invasion being managed and is this sufficient?*
5. *Are automated remote sensing methods suitable for studies on invasive alien plants?*

Although the clearing of invasive alien plants will seldom result in the total elimination of shortfalls in water supply, it is known that the invasions of alien plants can lead to significant decreases in water yields (Le Maitre *et al*., 2000; Dye *et al*., 2001; Dye & Jarmain, 2004; Hope *et al*., 2009). Therefore it should be seen as an important part of the water resource management options in order to optimize the water availability (Marais & Wannenburgh, 2008).

1.4 Thesis structure

The structure of this report is as follow. Chapter 2 provides a literature review on the impact of invasive alien plants in South Africa and the currently applied management options. Chapter three describes the methods used to generate and analyse data. The results of this research are presented in chapter 4. This chapter is followed by a critical discussion of the used methods and findings in chapter 5. The conclusions of this research can be found in the last chapter, chapter 6, followed by recommendations for further research and more efficient management options.

2. Invasive alien plants in South Africa: Impacts and management options

This chapter will review the literature on invasive alien plants (IAPs) in South Africa. A lot of alien plants were introduced for their commercial value, but some of them turned out to be able to spread in their new environment without the help of human activity. When they start spreading, replacing indigenous vegetation and altering ecosystems, they become IAPs. This chapter reviews the impact of IAPs on nature and society, and the different available options for management. The focus will be on the *A. mearnsii*, as this is the focus of this study.

2.1 Invasive alien plants in South Africa

Human activity has led to an unprecedented redistribution of other life forms, by dispersing them across previously insurmountable environmental barriers as oceans and mountain ranges. Although only few species survive in these new environments, some become invasive, establishing new ranges, spread, and persist to the detriment of native species (Mack *et al*., 2000). Biological invasions are a major threat to ecosystems all over the world (Rouget *et al*., 2004). Invasive alien plants are known to be able to alter the hydrology, fire regime, nutrient cycling and energy budgets in native ecosystems, which can have important consequences for the survival of native species (Mack *et al*., 2000). South Africa has been invaded my many IAPs, and their ecological and economical impacts are thoroughly studied (Le Maitre *et al*., 2000; Richardson & van Wilgen, 2004; Van Wilgen, 2004; Rouget *et al*., 2004). The fynbos biome is the most invaded biome in South Africa, with over 150 IAP species. Around 30 of them have a "major ecological significance" on natural ecosystems (van Wilgen, 2009).

When it comes to invaded areas, the *A. mearnsii* is among the worst invaders of South Africa with a total area of 2.477.278 hectares. When looking at water use, the *A. mearnsii* is the most important of all (Le Maitre *et al*., 2000). A detailed description of *A. mearnsii* can be found in annex I.

2.1.1 Problems involved with alien plant invasions

The mountainous fynbos catchments of South Africa are very prone to substantial changes in land cover due to invasion by alien tree species. These species tend to be taller in stature than the typical shrub vegetation of the fynbos biome, causing an increase in above-ground biomass (Hope *et al*., 2009). This higher biomass results in increased transpiration rates. Invasions of alien plants in fynbos catchments have therefore been widely associated with stream flow reductions (Le Maitre *et al*., 2000; Dye *et al*., 2001, Hope *et al*., 2009). Case studies have shown reductions in the natural river flows between 6 % and 22 % due to alien plant invasions (Le Maitre *et al*., 2002).

When looking at a national scale, it has been estimated that an area of 10,1 million ha is invaded with alien plants in South Africa and Lesotho, of which 1,7 million ha is 'condensed'. This results in an incremental water use estimated at 3.300 million m^3 per year (Le Maitre *et al*., 2000). The subsequently decrease in surface water runoff is about 7% of the national total, and the potential reduction could be eight times bigger if IAPs reach their full potential (van Wilgen *et al*., 2008).

An additional problem caused by alien invasions in fynbos is that the increased biomass acts as extra fuel, leading to more intense and severe wildfires (Le Maitre *et al*., 2002). This makes them more difficult to control, and it can result in severe erosion, lower soil fertility and a decrease in water retention. The risks of floods increases as well, due to higher peak flows (Le Maitre *et al*., 2002).

The financial consequences of invasive alien species on ecosystem services and biodiversity can be enormous. Estimates vary, but the total costs can be in the order of tens of billions of US$ each year (van Wilgen *et al*., 2008).

2.1.2 Invasive alien plants in the Kouga catchment

The Kouga catchment faces major problems regarding IAPs. According to Mander *et al.* (2010) 212.667 hectares in the Kouga are invaded with alien plants. This is about 75% of the total surface. In total, 54 different IAPs are identified in the Kouga, of which the Black Wattle (*Acacia mearsnii*), Longleaf wattle (*Acacia longifolia*), Hakea, gums (*Eucalyptus spp.*) and pines are among the most important ones (Veerkamp, 2013). The main river channel in particular is highly infested with *A. mearnsii* (Mander *et al*., 2010).

2.2 The management of invasive alien plants

2.2.1 The motivation of clearing programs

It is widely accepted that the removal of black wattle stands leads to improved catchment water yields (Dye *& Jarmain*, 2004; Prinsloo & Scott, 1999). IAP control is expensive, but when compared to alternative water supply schemes such as big dams or other infrastructural schemes, IAP control is a more cost-efficient way to increase the water availability (Le Maitre *et al*., 2000). The negative impact of alien trees on water resources, and the potential increase of water use by IAPs justifies their removal from important water catchments (van Wilgen *et al*., 2008; Dye & Jermain, 2004; Blanchard & Holmes, 2008). Furthermore, the clearing programs will have many other benefits besides enhancing the water supplies. It has the potential to prevent the loss of biodiversity, reduce the fire hazards by removing biomass, prevent erosion, stabilize catchments, and of course create a lot of job-opportunities (Le Maitre *et al*., 2002).

However, it is important to note that alien tree species have additional benefits besides those from commercial plantations. Alien trees are an important source of fuel wood and other products for rural communities, and they can play a role in the development of agro-forestry (Le Maitre *et al.*, 2002). Furthermore it is important to keep in mind that just the clearing of IAPs will not solve the entire water crisis in South Africa. It should be seen as a part of the management of water resources aimed at minimizing the wastage of water (Marais & Wannenburgh, 2008).

But as water is acknowledged to be a key constraint to the economic growth, and there already is considerable pressure for the efficient and sustainable use of water resources, such control programmes are economically justified (Le Maitre *et al*., 2002; Marais & Wannenburgh, 2008). A proper management of IAPs is essential if the country’s water resources need to be protected. The key is to identify strategies that will minimize the costs of controlling IAPs, while maximizing the benefits it can give (Le Maitre *et al*., 2000, Le Maitre *et al*., 2002).

2.2.2 Management strategies

Setting priorities

Considerable attention should go to prioritizing, before determining a management strategy (Esler *et al*., 2008). From an ecological and economical perspective, the clearing of scattered invasions (1–5%

cover) is significantly more cost-efficient than the clearing of closed canopy stands (75-100% cover) (Elser *et al*., 2008). The costs of the clearing of dense stands can be as much as 3–25 times higher (Marais & Wannenburgh, 2008). Preventing dense invasions by clearing in an early state is by far the cheapest way for safeguarding the future water resources (Esler *et al*., 2008). On the other hand, looking at generating water yields on short-term, it is generally most efficient to remove the dense alien stands, as they are the largest water consumers (Marais & Wannenburgh, 2008; Esler *et al*., 2008). Hence that this is only in terms of water generated, not in terms of water secured. As IAPs spread, water losses will increase, which makes clearing of light infestations much more viable (Marais & Wannenburgh, 2008).

Another important matter is about the allocation of man labour. As it is the case for most of the major invaders, there is just limited potential left for the *A. mearnsii* to expand his distribution (figure 2). Therefore the management should be focused on controlling the density rather than prevent expansions (Rouget *et al*., 2004). This strongly supports the use of biological control, as this is very effective at maintaining invaders at low densities (Rouget *et al*., 2004). But one of the current aims of the clearing programmes is focused on job creation, by clearing IAPs with the use of manual labour (Koyo, 2013). In fact, the main sources of income for the clearing programmes of Working for Water (WfW) are government and donor poverty-relief funds (Le Maitre *et al*., 2002). WfW programmes employ thousands of previous unemployed South Africans, with a focus on gender and racial equity, youth, disabled and single parents. (Le Maitre *et al*., 2002; United Nations Environment Programme). Switching the focus to the large-scale use of biological control would significantly decrease the need for manual labour (Koyo, 2013).

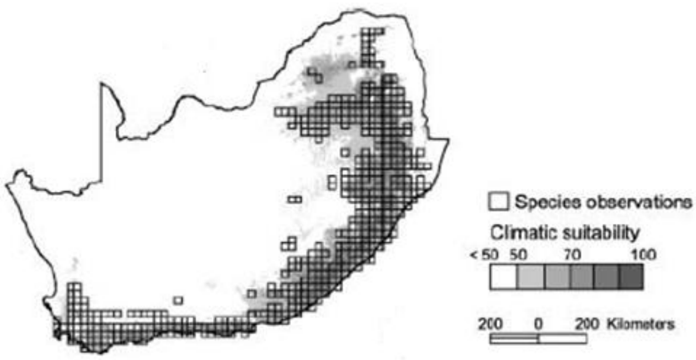


Figure 2: The presence observations and climatic suitability derived from climatic envelope models (Rouget *et al*., 2004)

Important factors of clearing methods

Riparian zones appear to be particular prone to IAPs. This is largely caused by their dynamic hydrology which leads to regular disturbances by floods, and the fact that rivers act as conduits for the dispersal of seeds (Le Maitre *et al*., 2002, Richardson *et al*., 2007). Periodic high water levels make space for new species by removing vegetation and increasing the amount of nutrients and light available. Declining water levels expose unoccupied soil (Richardson *et al*., 2007). Woody IAPs like the *A. mearnsii* can be a big problem in riparian zones (Le Maitre *et al*., 2000; Mander *et al*., 2010).

The recovery of riparian zones after alien invasions proofs to be very challenging (Holmes *et al*., 2005; Richardson *et al*., 2007; Blanchard & Holmes, 2008; Holmes *et al*., 2008; Esler *et al*., 2008). Literature focuses on how the removal should be executed, and when certain restoration management interventions should be applied afterwards (Blanchard & Holmes, 2008; Esler *et al*., 2008).

The best method to deal with IAPs in riparian zones seems to be the Fell & Remove treatment (Blanchard & Holmes, 2008). The removal of biomass seems to promote the growth of re-establishing species and provides a large number of establishment niches. Other investigated methods, the Fell & Burn method and the Fell Only method (which leaves biomass on the fields, leading to higher fire risks) are not recommended as IAPs are specialized in invading areas disturbed by fires (Blanchard & Holmes, 2008). The re-introduction of riparian species is advisable in highly transformed catchments, but the accompanying costs might be a problem for large-scale implementation (Holmes *et al*., 2005). In any case, sufficient alien follow-up control is very important, especially after fires or floods (Holmes *et al*., 2008, Blanchard & Holmes, 2008).

The influence of seed banks

More attention should be paid to the understanding of the role of seed banks in the long-term persistence of Australian Acacia species (Richardson & Kluge, 2008). The success of many plant species as invaders is increased by their capacity to maintain persistent stores of seeds in the soil. The most cost-efficient option is the use of biological control to reduce seed production. Another option would be using fires to reduce the amount of seeds in the litter and top soil (Richardson & Kluge, 2008; van der Merwe, 2013).

Hence that the use of fires is disputable. As fires stimulate seed germination it is an effective way of reducing the amount of seeds in the soil (Richardson & Kluge, 2008). But there are serious problems associated with high fire intensities in Acacia stands and the pressure on effective follow-ups increases (Richardson & Kluge., 2008; Holmes *et al*., 2008; Blanchard & Holmes, 2008). This is currently not always done sufficiently (Rebelo, 2012).

Options for biological control

Two biological control agents for the *A. mearnsii* have already been released in South Africa (McConnacie *et al*., 2012). The first, a seed-feeding weevil (*Melanterius maculates*), has proven to be able to reduce the seed production by half (McConnachie *et al*., 2012). A second one, a gall-forming fly, was established in 2006. On sites where it became established, the pod production had virtually ceased (Impson *et al*., 2011). More options are available, but as the *A. mearnsii* is commercial exploited, the choice of biological control agents is restricted (Denhill *et al*., 1999). Although the *A. mearnsii* is considered as the most important weed in South Africa, and the option of biological control should be seriously considered, there has not been enough attention in this direction (Denhill *et al*., 1999; McConnachie *et al*., 2012).

2.3 Current management in the Kouga

Working for Water (WfW) is by far the largest control programme which is active in the Kouga. The establishment of WfW in 1995 was a milestone in the management of IAPs in South Africa (Rouget *et al*., 2004). This governmental programme aims at the sustainable management of natural resources through the control and management of invasive alien plants while enhancing socio-economic empowerment in South Africa (Marais & Wannenburgh, 2008). A more detailed description of WfW can be found in annex II. This programme successfully merged social, political, economical and environmental considerations, and it is arguably the most ambitious IAP control programme in the world (Rouget *et al*., 2004; Koenig, 2009). Despite its successes on many fronts, many challenges still lie ahead (Rouget *et al*., 2004). One of these is the need to prioritize areas and species, in order to maximize the cost-efficiency (Rouget *et al*., 2004; McConnachie *et al*., 2012).

WfW has been active in the Kouga catchment since its establishment (van der Merwe, 2013). Their current management in the Kouga consists out of cutting down IAPs, combined with the application of chemicals to avoid re-sprouting. This will be repeated during three follow-ups. After this, the landowner himself is responsible for keeping his property free of aliens (Koyo, 2013). The clearing teams work from the top of the catchment down to the bottom to avoid contamination from higher areas (Koyo, 2013). The cleared biomass is left on the fields, and is often burned by the landowners (van der Merwe, 2013). Biological control is no part in the management of WfW in the Kouga catchment (Koyo, 2013).

The Kouga project of WfW covers an area of approximately 242,596 hectares and was initiated primarly to enhance water security for the NMBMM via the Kouga and Loerie Dams. The implementing agent is the Gamtoos Irrigation Board (GIB). Furthermore, the Kouga project is also a big boost for the economy in the region. The people working for WfW represent 2,5 % of the entire employed population of the Kou-Kamma municipality. As much as 59 % of the employees of WfW is female and 20 % of the workers is classified as youth. This excludes those employed in secondary, value added industries created as a result of the programme, including furniture manufacturing, fuel wood, charcoal, and so on. (Veerkamp, 2013; Rebelo, 2012). Exact numbers of the socio-economical environment in the Kouga can be found in annex III.

3. Methodology

3.1 Study area

3.1.1 Location and topography

The Kouga catchment (33°75'00 South, 23°80'00 East) is located in the Eastern Cape Province of South Africa, and covers approximately 282,040 hectares (Powell & Mander, 2009). The catchment falls inside the Kou-kamma municipality, and it is bordered by the Kouga mountains in the north and the Tsitsikamma mountains in the South. The valley in between both mountain ranges is called the Langkloof. This is also where the largest city of the catchment, Joubertina, is located (Veerkamp, 2013). The topography is very rugged and deeply folded. Mountains reach up to 1700 meters, and the area is characterized by steep slopes and deep gorges. The elevation of the valley floor ranges from approximately 300 to 700 meter above mean sea level (+MSL). The lowest point is about 160 meter +MSL (figure 3).

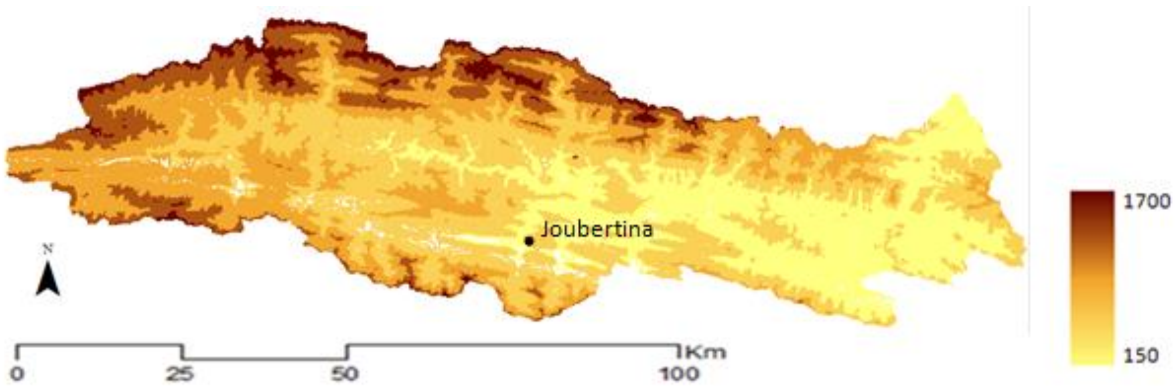


Figure 3: The topography of the Kouga catchment (height in meters)

3.1.2 Climate

The Kouga area is classified as a semi-arid region (Jansen, 2008). The precipitation of the Tsitsikamma mountains is higher than the precipitation in the Kouga Mountains. Generally, the area becomes dryer going from south to north. This orographic rainfall pattern is caused by the mountain ranges parallel to the coastline. The area also tends to be wetter in the west than in the east. The mean annual rainfall in the Kouga catchment is approximately 500 – 550 mm (Mander *et al.*, 2010; Hosking & Du Preez, 2004; Veerkamp, 2013). Although it must be mentioned that it is hard to accurately describe the rainfall because of the high variability between years and differences between different sections of the catchment.

The climate type is Mediterranean, but the great topological differences cause a lot of variation between different part of the catchment (Veerkamp, 2013). In general it can be stated that the mean temperature rises with every mountain ridge, going from south to north, as well as from west to east (Veerkamp, 2013). Climate data of Joubertina, which lays approximately in the middle of the catchment can be found in figure 4.

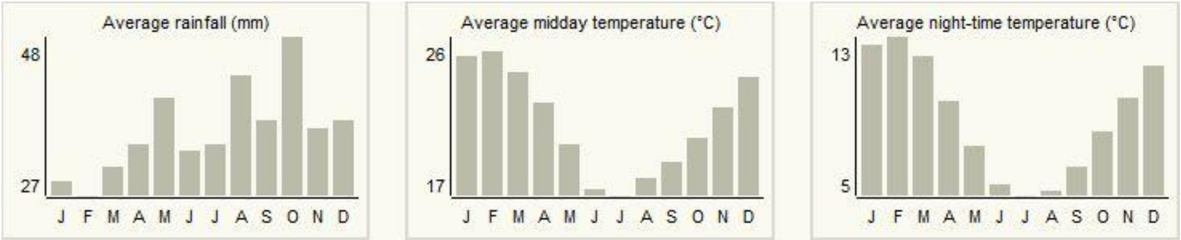


Figure 4: Climate data of Joubertina (Saexplorer, 2000-2011)

3.1.3 Restriction of study area

Because the complete catchment of the Kouga River is simply too large to map and validate in the limited time available for this research, the choice was made to limit the mapping to two sub-catchments: L82A and L82D, marked red in figure 5. These two sub-catchments were selected based on the following characteristics.

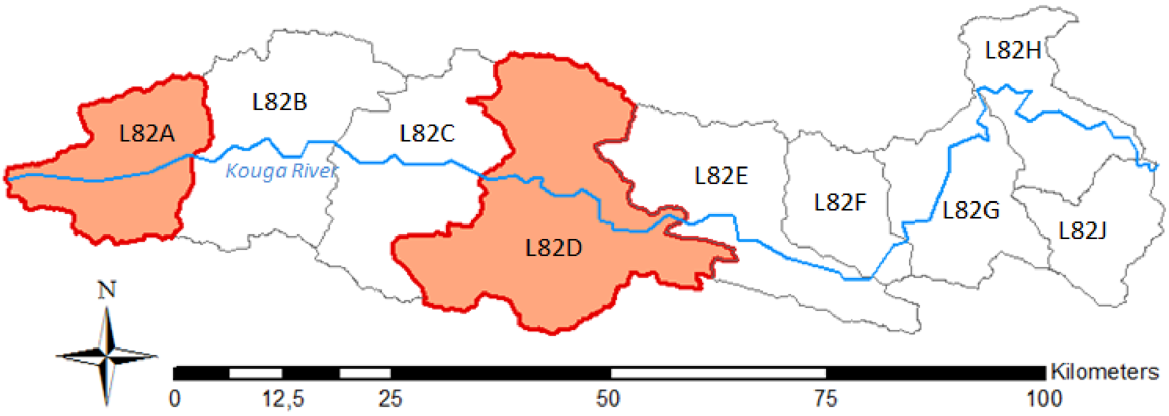


Figure 5: The different sub-catchments of the Kouga catchments. Only L82A and L82D, marked in red, are used in this research.

First of all, and most importantly, both areas have significant problems with the encroachment of *A. mearnsii* (van der Merwe, 2013). Also the clearing programs of WfW have been active in both sub-catchments (Koyo, 2013). This makes it possible to see trends in the distribution of the *A. mearnsii*, as well as the impact that the clearing programs of WfW have on the IAPs. A quick orientation in the sub-catchments proved that they both include all of the land features which were mapped in this research, and they both contain reasonable surfaces of agriculture in the Langkloof and pristine nature in the mountain ranges of the Kouga and the Tsitsikamma. This makes them representative for the whole Kouga catchment. Furthermore these two sub-catchments contain all the major villages. The accompanying infrastructure gives advantages for the validation, as large parts of the Kouga catchment are very remote and impossible to reach by car.

L82A is the most upstream catchment. The total surface is 26.919 hectares. Haarlem is the only big village in L82A. L82D is the largest sub-catchment with a surface of 59.083 hectares. The most important villages are Joubertina and Ravinia.

3.2 Datasets

Since this research investigates the distribution of the *A. mearnsii* at different points in time, several datasets were required for the mapping. The characteristics of these datasets are described below.

SPOT satellite imagery of 2010

Satellite imagery from le Système Pour l'Observation de la Terre (SPOT) of 2010. The data is acquired by the SPOT 5 mission, launched in 2002. The dataset only contains panchromatic imagery (450 – 745 nm) covering an area of 60 km by 60 km, and a spatial resolution of 2,5 to 5 meters. This high resolution makes the data ideal for visual classification. The data was provided by Living Lands.

Aerial photographs of 1990

Digitized black and white photographs, taken from an airplane with a ZEISS RMK A 8,5/23 camera, obtained between the 12th of June 1990 and the 14th of October 1990. The scale of the photography is 1:50.000, and the images cover an area of approximately 12,5 km x 12,5 km. The dataset consist out of a total of 389 photographs, made in 16 different flights. The flight plan can be found in annex IV.. The data was provided by Living Lands.

Aerial photographs of 1971-1973

Digitized black and white images, taken from an airplane with a ZEISS RMK A 15/23 camera, obtained between the 16th of December 1971 and the 26th of February 1973. The scale of the photography is 1:40.000. The surface covered by each photograph is approximately 10 km x 10 km. The data was generated during 21 flights, and consists out of a total of 694 photographs. The flight plan can be found in annex IV. The data was provided by Living Lands.

Landsat TM image 2012

Satellite imagery of the Landsat 7 from the 24th of January 2012. The data is generated by the Enhanced Thematic Mapper Plus (ETM+) which includes 8 spectral bands: 3 visible bands (blue, green and red), and bands in the near-infrared (NIR), mid-infrared (MIR), all with a 30 meter spectral resolution, a thermal infrared channel with a 60 m spatial resolution, and a panchromatic band with a 15 m spatial resolution. The combinations of bands makes it very useful to calculate indices, which can give additional information on for example the vegetation cover. The data was obtained from GLOVIS (LE71720832012241ASN00).

For the analysis of the classification results the following datasets where used:

- ArcGIS data with spatial information about biomes that occur in the Kouga catchment. The data was derived from Euston-Brown (2006) and Vlok *et al*. (2008).
- ArcGIS data with spatial information about biomes that occur in the Kouga catchment. The data was derived from the STEP-project (Lombard, 2003).
- ArcGIS maps with data on the clearing of WfW, including NBALs (clearing polygons). T Wannenburgh, 2012)

3.3 Classification

Besides the distribution of the *A. mearnsii*, six other land-users were mapped as well. The different classes and their description can be found in table 1 .

Table 1: An overview of the different types of land covers and their description, which were mapped in the Kouga catchment. The colours coincide with the lay-out of the maps in chapter 4.

	Land-use	Description
1	*A. mearnsii*	The dominant invasive alien plant in the area
2	Other alien trees	Other woody invasive plants, especially *Pinus sp.* or Eucalyptus
3	Pristine landscape	Mainly fynbos, also thicket, woody riparian vegetation, grasslands and wetlands
4	Orchards	Intensive deciduous fruits, in particular apple and pear, to a lesser extend citrus
5	Other agriculture	Dry land farming; crop fields, pastures used for (extensive) livestock farming
6	Water bodies	Rivers, streams, reservoirs
7	Build-up area	Cities, warehouses, big buildings and other unnatural objects

Since aerial photographs and satellite images are used for the mapping, it is impossible to identify very young or isolated trees. Simply because the spatial resolution is not fine enough. Only a closed canopy of full grown trees, of which at least 80% is black wattle can be recognized as invaded by the *A. mearnsii* (Rebelo, 2012). This will lead to an underestimation of the total distribution. As the *A. mearnsii* is known to exclude other vegetation and form dense forests, the mapping should give a reasonable indication. Other aliens are more problematic. Since species as Eucalyptus and pine trees rarely form a closed canopy they are harder to map, and the results will give a significant underestimation. Nevertheless, they are included in the classification, because they also impact the indigenous vegetation and therefore cannot be ignored.

3.3.1 Classification method

Historical imagery is an important source of information for documenting land use/land change over time. There are a lot of possible methods for mapping the land cover. Traditionally the most used method for the classification of historical imagery is manual (on-screen) classification (Awwad, 2003; Lillesand, Kiefer, & Chipman, 2008). Automated methods like the supervised and unsupervised classification require less labour, and are therefore more cost-efficient. But although their results can be improved by applying filters, the level of accuracy given by these automated classification techniques is too low for many applications of remote sensing. Manual classification of black and white aerial photographs results in the highest accuracy (Rowlinson *et al.*, 1999; Awwad, 2003).

Developments in software and data quality created new possibilities for image classification. LIDAR and object-based classification can improve the accuracy of automated classification methods (Kuilder, 2012). Unfortunately the resources needed to perform these methods were not available for this research. Based on the information above, the choice was made to do the historical mapping in this research with manual (on-screen) classification.

Additionally to this historical mapping, multispectral imagery is used to calculate a vegetation index. Vegetation indexes can give a lot of additional information besides a visual classification (Myeni *et al.* 1995; Srinivas, n.d.). Interesting information regarding IAPs in South Africa are the biomass and evapotranspiration rates, as IAPs can form a threat to the water yields. Multispectral satellite data is nowadays the primary source for estimations of the aboveground biomass (Roy & Raven, 1996; Zheng *et al*., 2004; Dengsheng , 2006) and is already used to assess the problems of IAPs in South Africa (Theron *et al*., 2004). Also large scale evapotransipration mapping is done using multispectral satellite imagery (Wu *et al*., 2006). The Normalized Difference Vegetation Index (NDVI) is the most used vegetation index because of its wide range of purposes and its easy computation. The NDVI is calculated with the measured spectral reflectance acquired in the red and NIR regions (Chang, 2010). Plants (chlorophyll) absorb solar radiation in the photosynthetically active radiation (PAR) (400 – 700 nm) to use as energy source in photosynthesis. This gives them a low reflection in the red spectral region (600-700 nm). The cell structure of leafs has a high reflection in the NIR (700-1000 nm). This combination is unique for plants, and it makes the NDVI suitable for biomass estimations, the mapping of evapotranspiration, as well as predictions of change water yields of catchments (Kustas & Norman, 1996; Dong *et al*., 2003; Courault *et al*, 2003; Hope *et al*., 2009). A NDVI analysis is part of this research to assess the possibilities for the use of automated remote sensing methods in IAP management.

$$NDVI = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

Formula 1: The NDVI calculation. NIR is the spectral reflectance in the near-infrared and RED is the spectral reflectance in the red part of the visible spectrum (Chang, 2010)

3.4 Data analysis methodology

Two different time periods were identified: the period 1971-1990, in which there was no organized IAP management, and the period 1990-2010, in which WfW started with the clearing of alien plants. The first period is used to look at the characteristics of the undisturbed spread of the *A. mearnsii*. The second period is used to show the impact of WfW on the IAPs. The geometric statistics of the land cover classes were computed, and based on the resulting areas of land cover classes in respectively 1971/73, 1990 and 2010, rates of spread were calculated. The rate of spread was expressed both in the increase in area in ha/year, and in a ratio (the distribution of a certain land cover at respectively 2010 or 1990 divided by the distribution of that land cover in respectively 1990 or 1971/73.

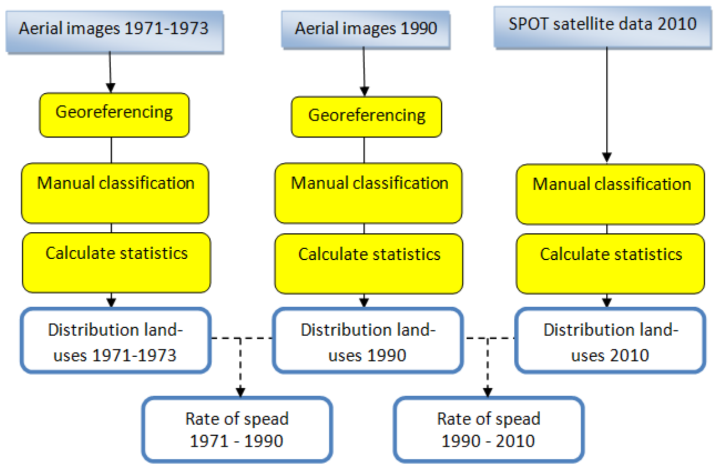


Figure 6: This flowchart gives an overview of the classification process, showing the different components of the classification and how the rate of spread is calculated.

3.4.1 Geo-referencing

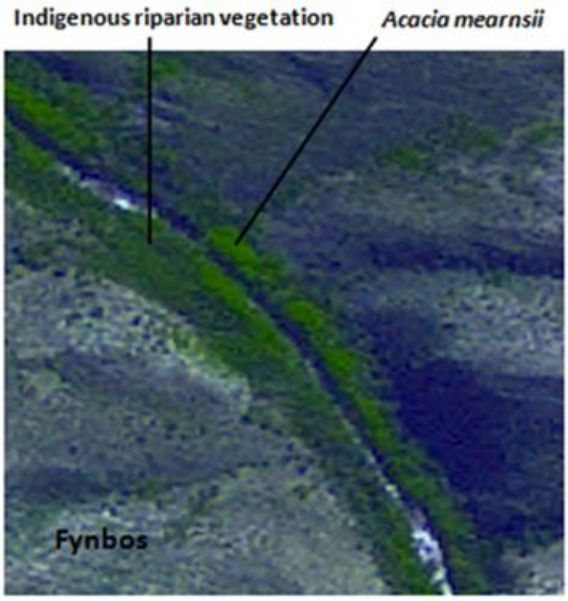
A total of 53 aerial images needed to be geo-referenced to cover the research area for both the 1971/73 and the 1990 datasets. The SPOT-imagery was used as base map. A minimum of 6 ground control points (GCPs) per image was applied, but on average 10 GCPs were used per image (a total of 512 GCPs). The amount of GCPs depended on the proportion of the image falling within the research area. The GCPs where spread evenly over the picture, and only easy identifiable locations like road crossings, buildings where used. Locations with a high elevation where avoided as relief can lead to major spatial distortions on the aerial photographs. The total root mean square (RMS) error was calculated with the formula: $\sqrt{((x_{act} - x_{est})^2 + (y_{act} - y_{est})^2)}$ in which x_{act} and y_{act} are the x and y values of the actual locations and x_{est} and y_{est} are the x and y values of the estimated location (Chang, 2010).

The average total RMS error of all images was under 0,001. This accuracy seems to be within the acceptable range (Verstegen & Ten Haaf, 2011).

3.4.2 Manual classification

For the manual classification, a feature class was created in ArcMap for each of the land uses from table 1. An overlay with these feature classes and the satellite/aerial imagery was made, and with the *create polygons* function in the editor menu of ArcMap polygons were created manually for each land feature. The mapping was performed using a scale of 1:5.000. Afterwards, the surfaces were calculated using the *calculate geometry* function.

Figure 7 shows some typical snapshots of the land covers which where mapped. Every land cover has its own characteristics which make it recognisable. The classification was based on a visual interpretation of these characteristics. When looking at figure 7 it becomes clear that this can give a good indication, but since it is a personal interpretation different people might judge certain situations differently.



Acacia mearnsii stands in a riparian zone in the fynbos biome. The contrast between the A. mearnsii and the fynbos vegetation in the mountains is obvious. A. mearnsii stands can be distinguished from indigenous riparian vegetation thanks to its really dense cover

Acacia mearnsii invasion in the wetlands in a riparian zone in between agricultural fields. The dense cover of trees is easily distinguished from the indigenous wetland species

Orchards, water bodies, pastures and build-up areas are identified relatively easy

Other alien trees like these pines are hard to recognize. Marks are their scattered distribution and shadow patterns

Figure 7: Snapshots of the land covers that were mapped in this thesis, and the characteristics that make them identifiable.

Findings of the classification where analyzed and compared with literature and local knowledge, in order to explain the findings.

3.4.3 The most vulnerable vegetation types

To find out which vegetation types where the most vulnerable to invasions of the *A. mearnsii*, an overlay was made with the feature class indicating the distribution of the *A.* mearnsii in 2010, and datasets with spatial information about the vegetation types and biomes that occur in the Kouga catchment. Subsequently, the geometric statistics where calculated and the attribute table was exported to Excel, where the actual analysis was done. A schematic overview can be found in figure 8. An overlay was made with the classification results of 2010 and datasets with information about biomes and vegetation types. This was used to analyse the total area of *A. mearnsii* per biome/vegetation type.

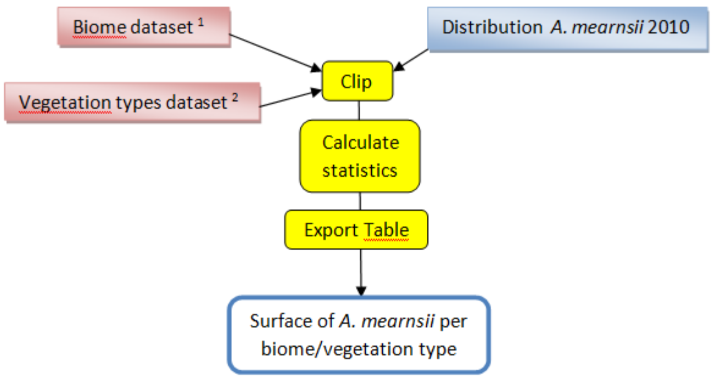


Figure 8: A flowchart illustrating the analysis process of the most vulnerable biomes and vegetation types to *A. mearnsii* invasions. Source: Euston-Brown (2006) and Vlok *et al*. (2008)[1] and (Lombard, 2003)[2]

3.4.4 The efficiency of the clearing of IAPs

A dataset with polygons of cleared areas from 1994 to 2010 was used to analyse the land use developments of the land after WfW carried out the clearing (Wannenburgh, 2012). The assumption was made that all of the *A. mearnsii* mapped using the aerial imagery from 1990, that was located within these cleared areas, was effectively removed. Therefore, all the *A. mearnsii* which occurred within cleared areas according to classification of the SPOT-data (2010), must have grown back after the clearing took place.

Using the historical classification of 1990 and the recent classification from 2010, an analysis was made of the efficiency of the clearing efforts. As seed banks play an important role in the recovery of the vegetation after clearing (Fourie, 2008), and seed banks of the *A. mearnsii* have the potential to have a huge impact on the efficiency of alien management (Richardson & Kluge, 2008), special attention goes to the influence of seed banks. Because the clearing polygons refer to certain regions and not just to the actual cover of IAPs which was cleared, it is not possible to analyse developments of other land-features in more detail.

3.5 Validation

In order to validate the classification results, the research area was ground-truthed with fieldwork. A pilot area, located in the Diepkloof, south of Joubertina, was completely ground-truthed. Other parts of the research area where addressed by identifying land cover next to the road. Unfortunately, large areas, mostly located north of the Kouga River, where inaccessible by car due to the terrain, collapsed bridges or private property. These areas could not be included in the validation.

Furthermore, transects were marked with the use of GPS points. The transects were located in riparian zones with the occurrence of IAPs, and included sites with different densities and age of *A.* mearnsii stands. This is important to be able to distinguish as many invaded areas as possible.

4. Results

4.1 The extent of the spread of the A. mearnsii in 2010

An area of 776,6 hectares invaded with the *A. mearnsi* was mapped in the sub-catchments L82A and L82D of the Kouga catchments (table 2). This alien tree typically occurs in floodplains and riparian zones (figure 9), where it is able to block out and replace the indigenous vegetation, and it can form dense woods. The black wattle is also a common sight at the side of the roads and next to agricultural lands (figure 10). What these spots have in common is that they usually have favourable physical conditions such as a high water availability (thanks to a stream or irrigation) and sufficient soil depth. Furthermore, these spots are prone to seed distribution, what happens through water, wind and animal/human activity.

Figure 9: A top view of a riparian zone, invaded by the *A. mearnsii* (Photo: Veerkamp, 2013)

The other IAP species are mainly Eucalyptus, which is mostly found around farms and next to roads, and *Pinus sp.* which can be abundant on slopes or in between agricultural fields. However, these trees rarely form a closed canopy cover. Therefore they are much harder to recognize and map with the use of aerial photographs or satellite imagery, making the 193,7 hectares most-likely an underestimation. This is confirmed by field observations, not all sites where these aliens were found could be identified using satellite images.

People seem to be aware of the IAP problem, but lack incentives to take action themselves. WfW is the only party who performs large-scale clearing. WfW is well known in the area and the communication with the land owners is clear.

Figure 10: The *A. mearnsii* occurs typically in riparian zones and next to roads. Wattles can form dense forests which block out all other vegetation

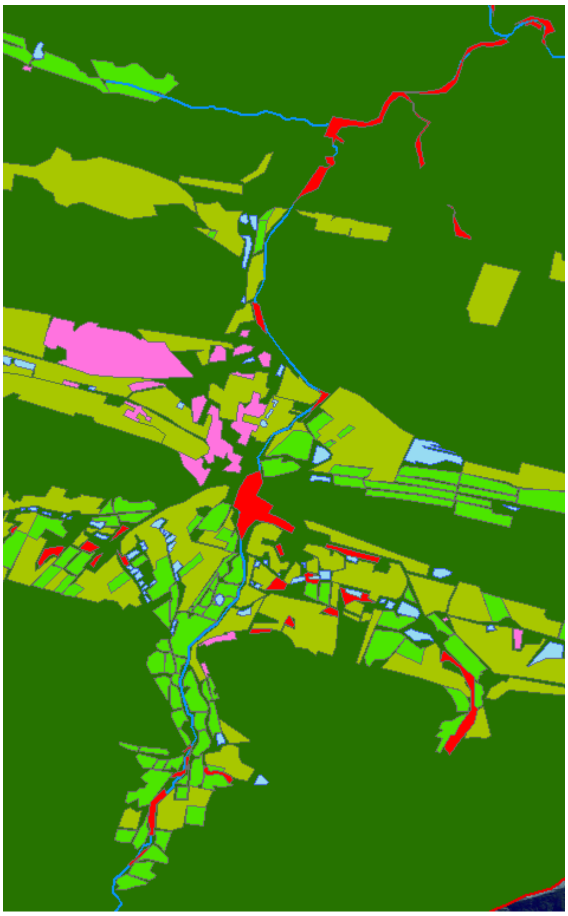
Table 2: The total area of the mapped land-uses in hectares, 2010.

Land-use	*A. mearnsii*	Other IAPs	Orchards	Other agriculture	Water bodies	Build-up area
Area (ha)	776,6	193,7	1901,9	7388,8	232,2	445,3

4.1.1 Distribution of the remaining land uses (2010)

The intensive deciduous fruit farming occurs almost exclusively on the richer soils of the Langkloof. These are predominantly apple and pear orchards, and to a lesser extent plums and citruses. The orchards have (drip)irrigation systems. Other class “other agriculture” consists out of small scale crop farming and extensive livestock farming. The crop farming includes maize, wheat, potatoes, millet and cabbage, and fallow fields, and can be found on plains both within as outside the Langkloof. Although there are some farmers with irrigation systems, the majority of this is dry land farming. The livestock consists out of cows, sheep and goats, and is not limited to the valleys in and around the Langkloof but also occurs in the hills.

The majority of the water reservoirs are used for irrigation purposes and are located in between or just upstream of the orchards. Some are accessible for cattle as water holes or are used for domestic purposes. There are 3 villages of reasonable size in the research area, of which Joubertina is the largest. Together they constitute almost the entire build-up area. Joubertina and Ravinia are located in sub-catchment L82D, and Haarlem is located in sub-catchment L82A. Figure 11 gives a typical image of the land cover in the study area.



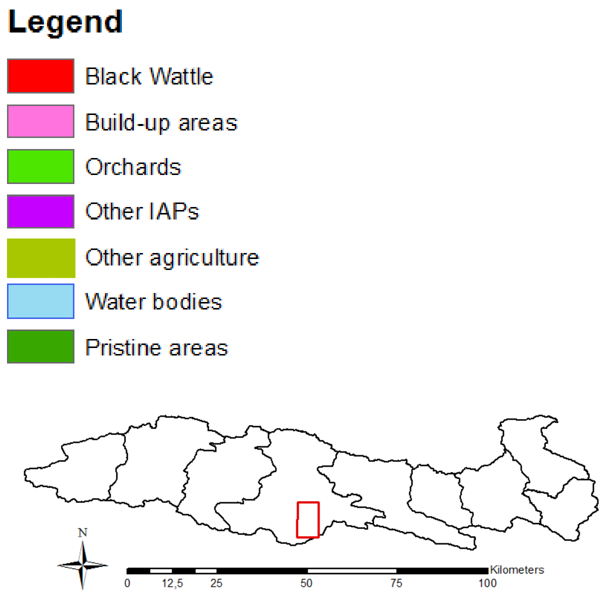


Figure 11: A snapshot of the area Twee Riviere, just east of Joubertina. The distribution of the *A. mearnsii* in riparian zones, orchards near water sources, agriculture on the remaining flat areas and pristine natural vegetation north and south of the Langkloof is very typical and represents the whole catchment.

4.2 Developments in land use since 1971

An overview of all land cover changes in the period of 1971 to 2010 can be found in figure 12 . Based on these mapping results, the rate of spread was calculated both for the period 1971 to 1990 as for the period 1990 to 2010 (table 3). The outcomes are analysed in the chapters below.

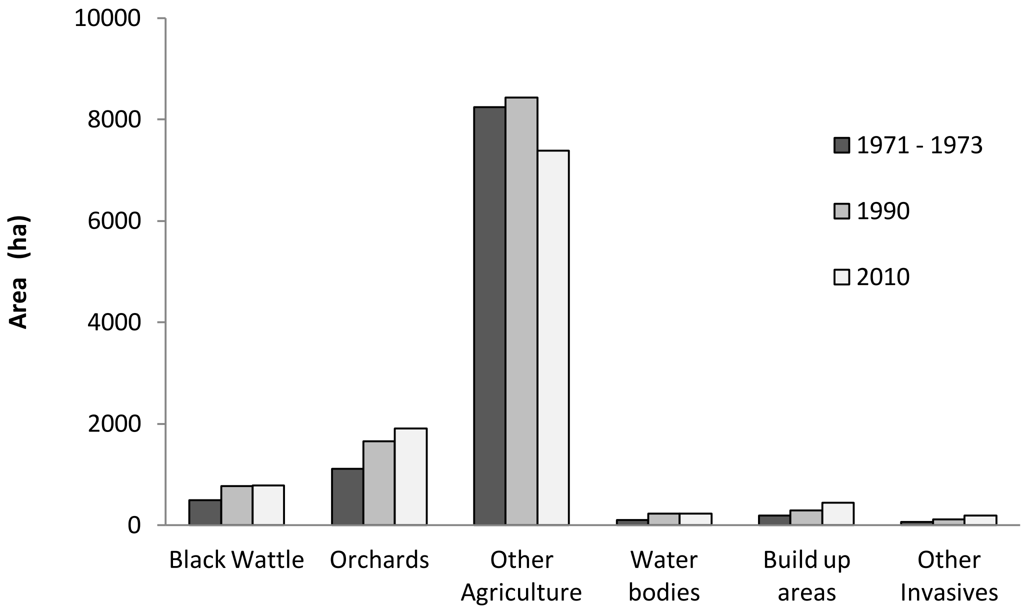


Figure 12: An overview of the land cover change in L82A and L82D in the period 1971 to 2010.

Table 3: A comparison of the rates of spread of the period 1971-1990 and 1990-2010.

	1971/73	**1990**	**2010**	**Rate of spread 1971 - 1990**		**Rate of spread 1990 – 2010**	
	Area in ha	Area in ha	Area in ha	ha/year	Relative growth	ha/year	Relative growth
A. mearnsii	487,3	764,6	776,6	15,40	1,57	0,60	1,02
Orchards	1105,0	1647,7	1901,9	30,15	1,49	12,71	1,15
Other agriculture	8245,3	8431,9	7388,8	10,36	1,02	-52,15	0,88
Water bodies	101,7	224,1	232,2	6,80	2,20	0,40	1,04
Build-up areas	183,3	290,7	445,3	5,97	1,59	7,73	1,53
Other IAPs	64,1	109,1	193,7	2,49	1,70	4,23	1.78
Pristine landscape	75814,4	74533,0	75062,6	-71,19	0,98	26,48	1,01

4.2.1 The *A. mearnsii* and other IAPs

The results show an obvious difference in the rate of spread between both periods. In the period between 1971 and 1990 there were no clearing programs for *A. mearnsii*. This changed when the WfW project began in the Kouga in 1994 (van der Merwe, 2013). The impact of WfW programme is clearly visible in the period between 1990 and 2010, as the diffusion almost came to an end. It shows that WfW is capable of at least controlling the spread (figure 12). There does not seem to be a significant difference since the start of WfW when it comes to the other IAPs. Hence I only mapped a small part of the 54 IAPs that occur in the Kouga catchment. Figure 13 illustrates the proces of an *A. mearnsii* invasion in a riparian zone.

However, the ultimate goal is to remove all aliens from the Kouga catchment. As the amount of area covered with black wattle did not decrease since 1990, it proofs to be a large challenge.

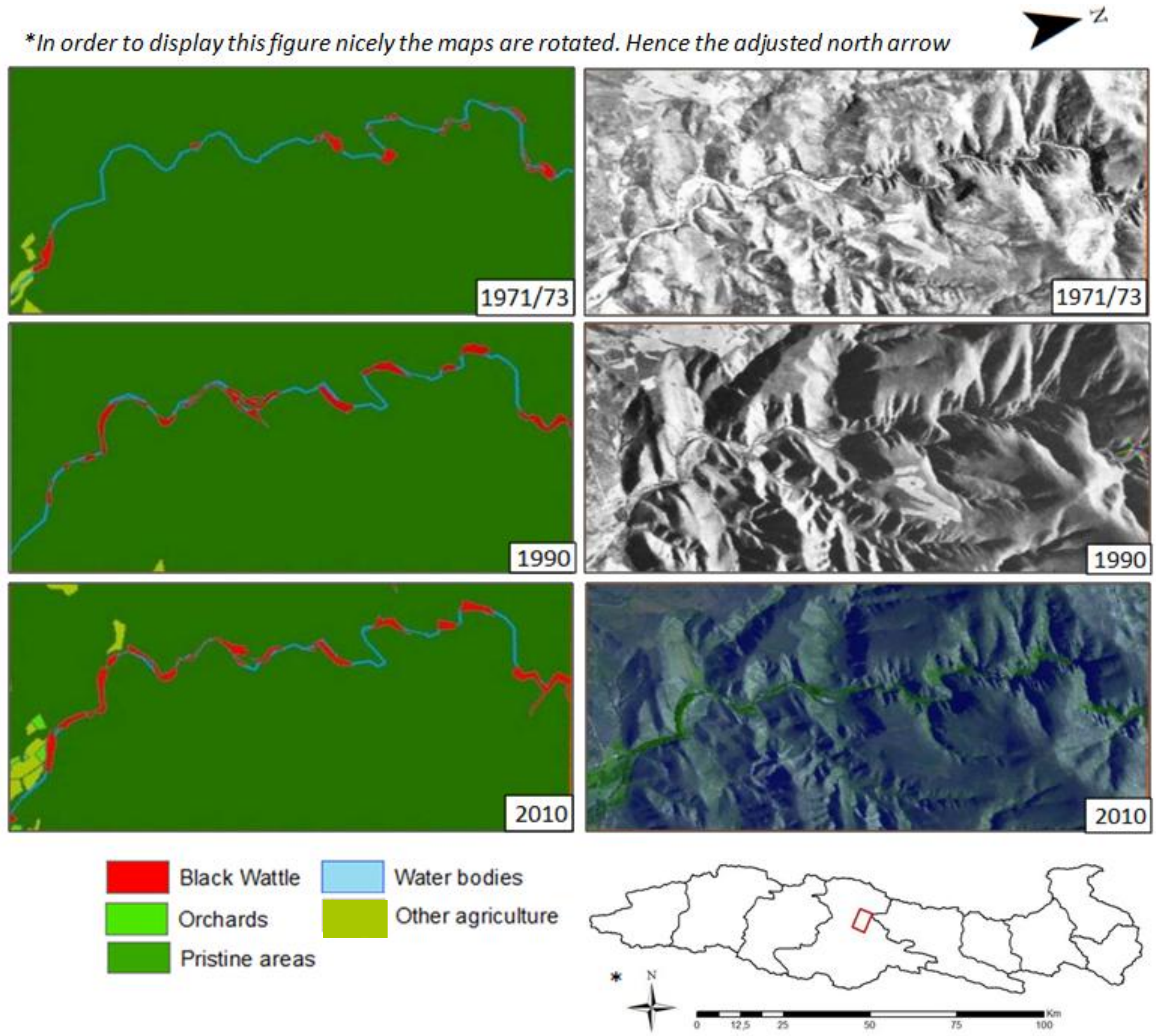


Figure 13: Snapshots capturing the invasion of the *A. mearnsii* from 1971 to 2010 in the riparian zone of a side stream of the Kouga River.

4.2.2 Agricultural developments

From the moment farmers began with deciduous fruit farming in the Langkloof in the early nineteen hundreds it has been the main economic activity in the Kouga catchment. In the period from 1971 to 2010 the fruit farming became more intensive and expanded rapidly. As fruit farming is limited to the more fertile soils found in the bottom of the valley, most of the original vegetation in the valley is already replaced by agriculture. And when new areas come available, for example through the clearing of the *A. mearnsii*, this is often turned into orchards as well. This is clearly illustrated in figure 14. One could question how much water is saved in this way, but orchards do use a little bit less than *A. mearnsii* (Taylor & Gush, 2009). Dams are constructed for irrigation purposes and water security. As can be seen in table 3 the amount of water bodies increased rapidly between 1971 and 1990, to enable the agricultural developments. Since the new water act of 1992 it is prohibited by law to build new dams in the Kouga catchment without permission (Veerkamp, 2013). This corresponds with the findings in table 3 as the rate of spread clearly dropped after 1990. The total capacity of all dams in the Langkloof was estimated to be 26 Million m^3 in 1992 (DWAF, 2004, Veerkamp, 2013).

The category “other agriculture” in the Kouga comprises extensive livestock farming and small scale crop farming. This research shows a remarkable drop after 1990. Some of the land is converted to orchards, but this is not enough to explain this development. The drop could have several causes. Some farmers might be abandoning this branch of agriculture, as intensive fruit farming generates way more income. It is also a possibility that the pastures and the non-irrigated fields are not always as clearly recognisable on the SPOT satellite imagery as on the aerial photographs. These options are further clarified in the chapter ‘Discussion’.

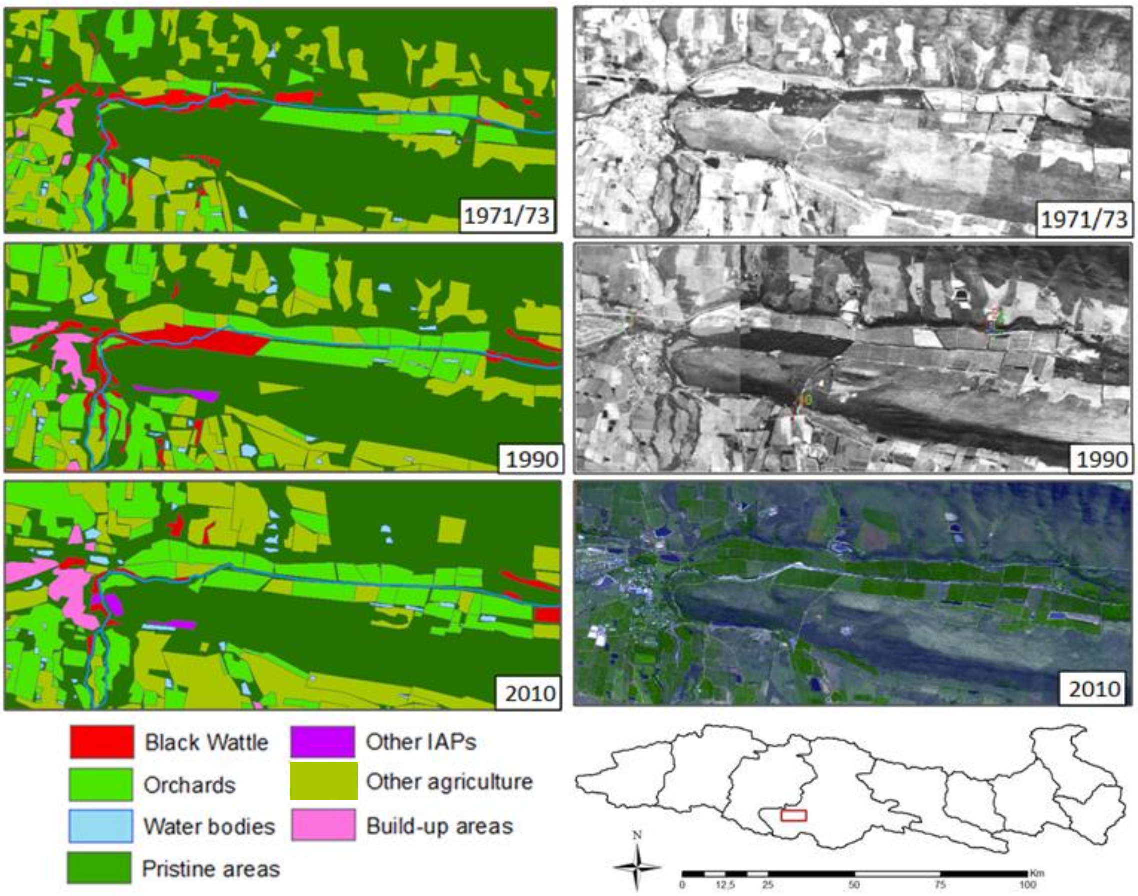


Figure 14: Snapshots showing the development of agriculture in the period 1971 – 2010, west of Joubertina. Areas cleared form the A. mearnsii, as well as dry land agriculture are replaced by orchards.

4.2.3 The urban sprawl

Since 1971 there has been a steady increase in urban areas. The two major cities in the research area, Joubertina and Haarlem, both show considerable expansion. Furthermore, a new village, Ravinia, appeared east of Joubertina. Especially after the ending of the apartheid in 1994, the amount of inhabitants increased significantly due to a redistribution of land rights. The infrastructural developments around Joubertina and Ravinia are illustrated in figure 15. All the larger settlements are located in the Langkloof where all the economic activity finds place. Other parts of the Kouga like the Tsitsikamma or the Kouga mountains, hardly show any signs of infrastructural development.

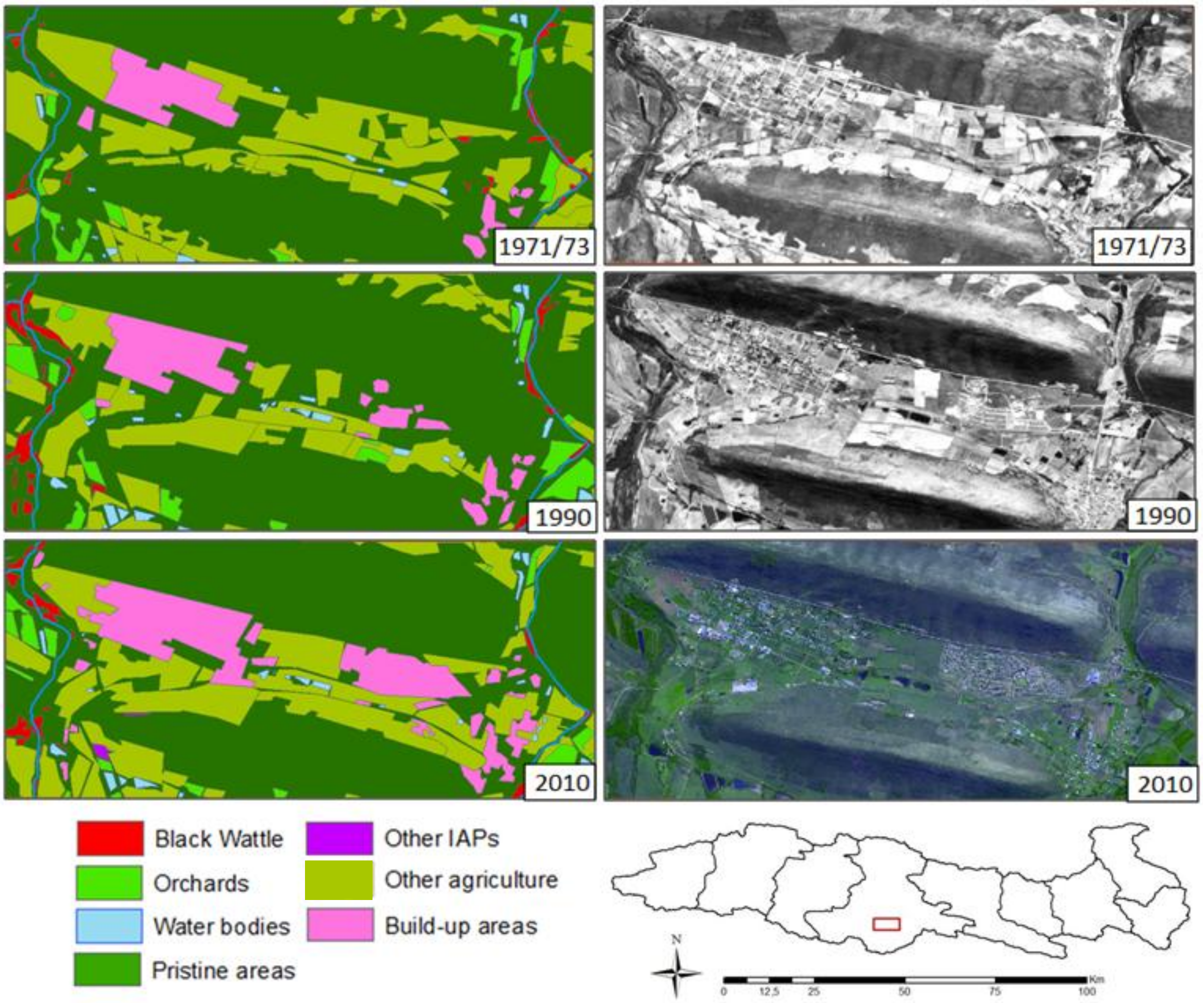


Figure 15: Snapshots capturing the expansion of Joubertina and the appearance of Ravinia, in the period 1971 - 2010

4.3 The most vulnerable vegetation types for invasions of the *A. mearnsii*

The *A. mearnsii* is known to be capable of invading in a wide range of habitats. Table 4 shows which biomes were the most sensitive to invasions by the black wattle in the Kouga.

Table 4: The vulnerability of the different biomes in the Kouga that are invaded by the *A. mearnsii*. The percentages show what proportion of the total surface area of *A. mearnsii* invasion occurs in each biome. (based on data from Esuton-Brown (2006) and Vlok *et al*. (2008))

Biomes	%
Fynbos	42,91
Renoster mosaic[1]	19,53
Renoster	15,15
Thicket	10,52
Forest	7,21
Fynbos mosaic[1]	2,70
Thicket mosaic[1]	1,99

Fynbos is by far the most vulnerable biome when it comes to invasions of the *A. mearnsii*. Over 80% of the black wattle invasion occurs in the fynbos biome or the very comparable renoster biomes. This can be explained by the fact that these shrub-like vegetation types have a hard time competing for light with this fast growing tree. Furthermore fynbos only occurs on poor soils. The black wattle fixes nitrogen, which enriches the soils. This impedes the original fynbos species. Dense thicket is more difficult to penetrate for the *A. mearnsii*. This is also the case for indigenous forests.

Fires also play an important role. The seed germination of the black wattle is stimulated by fire. In the fynbos and renoster biomes fires occur regularly, but dense forests and thicket are less prone to fires. Looking more specific at vegetation types (table 5) a similar pattern is found. Fynbos en renosterveld are by far the most vulnerable, while only a small percentage of the black wattle invades in the thicket.

Table 5: The vulnerability to invasion of the *A. mearnsii* for specific vegetation types. The percentages show what proportion of the *A. mearnsii* invasion occurs in each vegetation type (based on data derived from Lombard, 2003) .

Vegetation types	%
Langkloof fynbos and renosterveld mosaic[1]	44,94
Kouga mountain fynbos complex	34,61
Baviaans spekboom thicket	10,27
Kouga fynbos thicket	6,40
Tsitsikamma mountain fynbos complex	3,78

[1] *The term 'mosaic' means it is a transitional zone between two different biomes. The name prior to 'mosaic' indicates which biome has the upper hand.*

4.4 The results of the current management

The current clearing method in the Kouga is called “Fell Only”. The alien trees are cut down, and the biomass is left on the field (Koyo, 2013). Pesticides are applied to avoid re-sprouting of the stems, and three standard follow-ups are carried out to clear germinated seeds. After this, the landowner is responsible to keep it free of IAPs (Koyo, 2013). As water distributes the seeds, WfW is currently clearing in the top of the catchment, working down in eastern direction. But this has not always been the tactic (Koyo, 2013).

When IAPs are cleared on farmlands, the remaining biomass is often burned by the farmer (van der Merwe, 2013). As fire stimulates seed germination of the *A. mearnsii*, it is absolutely essential that follow-ups are carried out sufficient and in time. If this happens it can be a useful method to reduce the amount of seeds in the soil. But if not, the *A. mearnsii* will probably invade again.

4.4.1 Effectiveness

In 1990 there was 141,6 ha of black wattle cover in areas which were cleared in the period 1994 to 2010. Assuming that indeed everything was cleared, any *A. mearnsii* found in these areas in 2010 must have grown there (or sprouted again) afterwards. The mapping results of 2010 show 150,3 ha of black wattle in the cleared areas. This is an increase of 6,2 % of the original cover.

After the initial clearing chemicals are applied to avoid that trunks sprout again. However, according to the maps there was 22,0 ha of *A. mearnsii* on exactly the same spots as it was in 1990. So about 16% of the black wattle that was cleared since 1990 grew back after the clearing took place. This can happen when the follow-ups are executed insufficient or too late, or if the same area invades again.

The fact that 84% of the *A.* mearnsii invasion grew on areas which were “clean” of aliens in advance, indicates the problems of seed banks that develop in *A. mearnsii* stands. The seeds remain well for a long time and germinate when the circumstances are favourable. The current clearing methods do not take these seed banks into account, so they can keep acting as a source for seed distribution to downstream areas. Some seeds could also germinate within the seed bank itself, what could help explain the 22 ha on the same spot as in 1990. This shows that seed banks can be a threat to the efficiency of the WfW program.

4.5 The use if the NDVI in research on invasive alien plants

The previous findings are generated with the use of visual classification. As this is very labour intensive, the use of automated alternatives become more attractive. In figure 14 a comparison is made between the visual classification results and a map showing the NDVI.

Higher NDVI values show a higher relative biomass. As dense forests of alien trees like the *A. mearsnsii* have a higher biomass than the indigenous fynbos and thicket vegetation, they should be recognisable when using the NDVI. Figure 16 confirms this. The high NDVI values match the areas identified as *A. mearnsii* very well. Productive agricultural fields also have high NDVI values but are usually recognisable by their shape. *A. mearnsii* is evergreen, but as this is not a rarity in the study area this does not give extra possibilities for the use of vegetation indices.

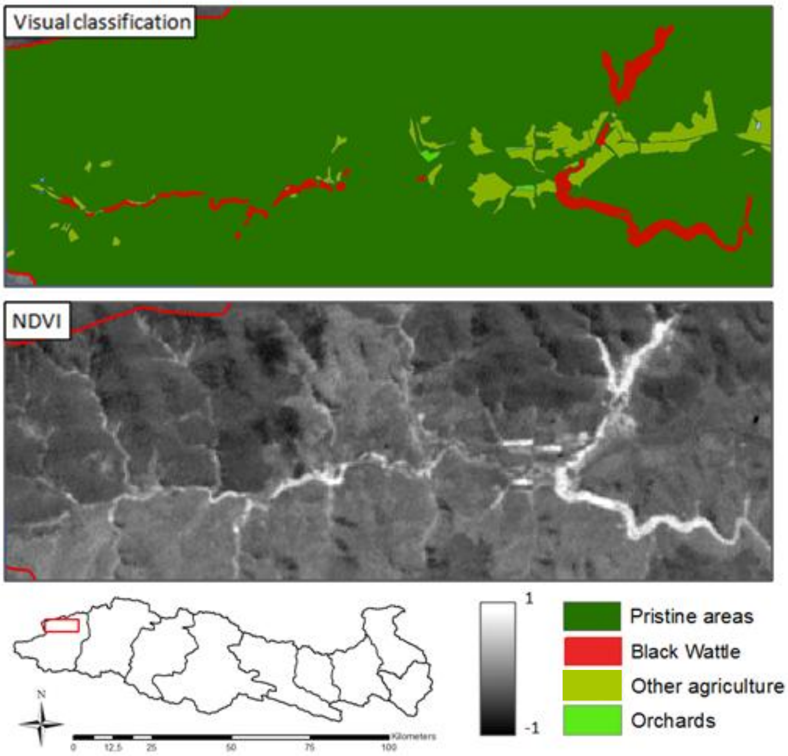


Figure 16: Snapshots of a valley north of Haarlem, comparing the visual classification results with the NDVI. Black wattle gives higher NDVI values than indigenous vegetation due to a higher biomass.

Figure 17 shows the NDVI for an area which contains the other land features that were mapped. Water bodies are very easily recognised by their low NDVI values. Because agri-cultural fields are more productive than natural areas, they can also be recognised. The difference between orchards and other agriculture is challenging. Although orchards have more biomass, they have a less dense cover than crop fields, which results in similar NDVI values. The build-up areas are also not very obvious. The pattern of gardens, roofs and streets gives a speckled effect.

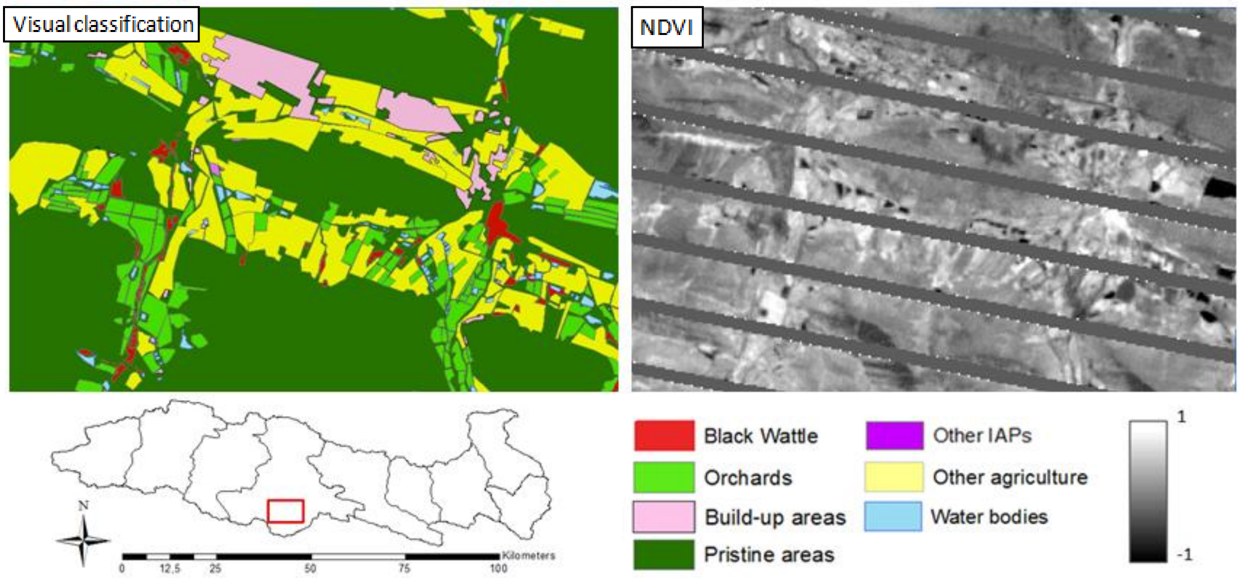


Figure 17: Snapshots showing the land uses around Joubertina, and the NDVI map of the same area. The diagonal grey lines in the NDVI map are caused by the Scan Line Corrector (SLC) error of the Landsat 7.

5. Discussion

The Kouga catchment is a very diverse and unique catchment. But its problems with the invasions of alien plants and its worrying water balance reflect the situation in many catchments all over the country. Therefore, the results of this thesis could be used as an example to illustrate the general issues regarding alien plant invasions and their management in South Africa. This chapter will compare the results with other research and discuss the study's contribution to IAP management. However, one should be aware that the choices and assumptions made during this research led to uncertainties and possible errors. In order to take the uncertainties and weak points into account, the methodology and the analysis of the results will also be reviewed in this chapter.

5.1 The study's insights in (national) IAP management

5.1.1 Kouga in comparison with research in other catchments

This study shows the extent of the invasion of the *A. mearnsii*, as well as its characteristics. In particular the riparian zones of the fynbos biome seem to be vulnerable. This corresponds to findings in literature (Le Maitre *et al*., 2002; Richardson *et al*., 2007; Hope *et al*., 2009; Mander *et al*., 2010). Furthermore it shows that the clearing programs of WfW have a huge impact on the rate of spread of the *A. mearnsii*, but that the recovery of invaded land still is very challenging. This confirms the statements made in literature regarding the management of riparian zones in South Africa (Holmes *et al*., 2005; Blanchard & Holmes, 2008). The calculated rates of spread suggest that the current management does not have enough impact to create an environment free of IAPs in the Kouga catchment. This reflects the situation in other South African catchments (Rouget *et al*., 2004). WfW has booked a lot of progress, but they will have to become more efficient in order to control the IAPs.

These similarities with other studies show that, in the field of IAPs, the Kouga catchment can be considered as a common case in South Africa. The findings of this research can therefore be seen as trends which can give information about situations outside the study area.

5.1.2 The study's contribution to IAP management

This research illustrate the urge of proper IAP management, and can therefore be used to raise awareness about alien clearing, both within as outside the catchment. Additionally, the results can be used to show the impact that the clearing programs have, and to select and prioritize areas where interventions are most needed. The outcomes of this ecological assessment of the Kouga catchment can also be used as input for research on the impact of IAPs on the water balance of the Kouga. The mapping and monitoring of the distribution of IAPs is required to be able to estimate the quantity of water that will reach the Kouga Dam. A part of the results of this study was used as input in the research of van der Hoeven, 2013, on the water use of the black wattle in comparison with indigenous vegetation. Van der Hoeven estimated the water yields for several future scenarios covering different *A. mearnsii* densities in the Kouga. The monitoring of IAPs is essential in order to predict future scenarios, and develop management tactics.

5.2 Discussion on data suitability

The relatively high spatial resolution of the SPOT-data makes it very suitable for classification purposes. The disadvantage of this dataset is that it is panchromatic imagery. This means it is hard to compensate for shadow effects. Some deep gorges were therefore hard to classify. When it was impossible to identify the land cover, pristine landscape was assumed. This will give some minor errors in the classification results.

The black and white aerial photographs have even more severe shadow effects. Furthermore, the imagery includes spatial distortions along the edges, and on sites with major differences in relief. Even though the pictures overlap each other, geo-referencing can only partly compensate this. This causes errors when comparing classification results of different years, such as the clearing efficiency.

The multispectral Landsat imagery gives a lot of additional information on top of the panchromatic SPOT-data. The disadvantage is the relatively low spatial resolution. A pixel size of 30 x 30 meters is enough to identify most riparian zones, but will miss a lot of details. Information about individual plant species can only be obtained through methods like the NDVI, Leaf Area Index or other vegetation indices. Another disadvantage of the Landsat is the gaps in the data due to the Scan Line Corrector (SLC) failure. This can be redressed with the use of several overlapping images, but that was not possible for this research. The consequences of the SLC failure are clearly visible in figure 17.

5.3 Discussion on the methodology

The choices and assumption made in this research have several consequences for the results. Some of them are important to keep in mind when looking at this case study. They are discussed below.

5.3.1 Consequences of the mapping technique

The manual classification of land cover with the use of black and white imagery is, according to literature, the most accurate of method for historical land cover mapping (Awwad, 2003) Nevertheless, it is a personal interpretation, and some land features will be judged differently by different persons. It is important to keep as consistent as possible in order to make your results logical and reproducible.

5.3.2 Errors involved with the geo-referencing of aerial images

The topography of the research area is very rugged. This, in combination with the angle created by the camera, creates spatial distortions. In particular along the edges of photographs. Even though the images overlap, a minimum amount of GCPs was applied, and the calculated RMS-error was very small, geo-referencing is not sufficient to compensate for all of the distortions. As the pictures cover respectively 1.000.000 m^2 (1971/73 data) or 1.562.500 m^2 (1990 data), it is possible to miss the original data with several dozens of meters while still having a minimal RMS-error. This will not have significant consequences for the mapped surfaces, but it will cause errors when overlaying classification results from different time periods.

5.3.3 Limitations of the land cover classes

Acacia mearnsii: Only a canopy of which at least 80% of full-grown *A. mearnsii* can be mapped (Rebelo, 2012). Individual and young trees cannot be identified as well. This will lead to an underestimation, but as the *A. mearnsii* is known to exclude other vegetation and form closed canopies, this will be relatively small.

Other invasive alien plants: As only a cover of full-grown trees can be recognized, it is impossible to include all alien species in the research area. Furthermore, many species do rarely form closed canopies. This leads to a major underestimation in the classification results.

Orchards: New planted orchards with very small trees cannot be identified. Furthermore, the deciduous fruit trees are not easy recognized on images taken in winter, as they lose their leaves. Because of these reasons, some orchards might have been wrongly classified in the category 'Other agriculture'.

Other agriculture: Not all grazing areas are distinguishable from natural vegetation. Only fenced pastures or degraded land can be identified.

Water bodies: The total surface of water bodies depends on the water level. As the pictures are snapshots of a certain moment, different water levels can cause a difference in surface. The Kouga catchment does not have a wet and a dry season, but there still can be a difference between seasons or years.

Build-up areas: Small secluded (farm)houses are not included in this class.

Pristine landscape: This class includes all the land without signs of human interference or IAPs. It basically is the remaining surface after the mapping of the classes above is finished. This does not necessarily means that it is untouched indigenous vegetation.

5.3.4 Validation

The possibilities for validation where quit limited. This is arguably the weakest part of this research. First of all, only the classification results from 2010 could be validated. This is not possible for the data from 1990 and 1971/73. Furthermore there is a time gap of three years between the data used for the most recent classification (2010) and the actual validation (2013). This is not enough for major changes in land cover, but slight differences due to fires or agricultural developments could have occurred. And perhaps the biggest problem, a big part of the area was inaccessible by car. This means that large areas could not be included in the validation.

In order to compensate this, the results of the classification were discussed with several local people. Especially Sam van der Merwe, an agricultural expert of the department of Agriculture and Rural Development, proved to be very useful. He gave his opinion about the possibilities of the main findings, and he shared his experiences in all the years he worked in the Kouga. This triangulation of local knowledge and research findings improved the analysis of the mapping results. Considering that the most accurate mapping methods where used, the results should be acceptable.

5.4 Discussion on the results

Some of the results of this research contain significant uncertainties due to choices made in the analysis. These are discussed below.

5.4.1 The difference between satellite imagery and aerial photographs

It is possible that certain land covers are easier identified in respectively satellite imagery or aerial photographs. Since there are no black and white aerial photographs of recent years, nor satellite data of the time before WfW started the clearing, it was not possible to avoid the use of both. If for example pastures are harder to differentiate from natural vegetation on satellite imagery than on aerial photographs, that could partly explain the drop in agricultural surface after 1990. As the amount of fieldwork was limited, it was not possible to investigate this possibility.

Furthermore, some of the classes are more clearly recognisable in certain seasons. The impact of this could not really be examined. The aerial photographs are taken over a long period of time, and the date on which the SPOT-data is acquired is unknown. But it is clear that the SPOT-data shows a certain stage of the growing season, which is in general the most suitable for the classification of vegetation and agriculture. And as the *A. mearnsii* is an ever green tree (and this is also the case for a lot of indigenous species), it should be recognisable on all datasets.

5.4.2 The calculation of the rate of spread

The period of 1990-2010 is used to show the impact of WfW. However, the clearing began only in 1994. This means that the *A. mearnsii* could spread undisturbed for the first four years in this period. The calculated rate of spread will therefore be slightly higher than the actual rate of spread since the clearing began.

5.4.3 The analysis of the clearing efficiency

The mapping results of both 1990 and 2010 were used in an overlay for the analysis of the clearing efficiency. As already mentioned above, the geo-referencing of aerial photographs was not sufficient to correct all spatial distortions. Most of the cleared areas are located on relatively plane areas in the Langkloof where spatial distortions are minimal. Nevertheless, this will result in some errors. The calculated percentages should therefore be seen as an indication rather than exact numbers.

6. Conclusion and recommendations

This chapter first presents the final conclusions of this research, followed by recommendations for further research and IAP management in the Kouga catchment.

6.1 Conclusion

6.1.1 The distribution of the *A. mearnsii* in 2010

A total of 776,6 hectares invaded with the *A. mearnsii* was mapped in the sub-catchments L82A and L82D of the Kouga catchment for the year 2010. It typically occurs in floodplains and riparian zones, as these spots are prone to seed distribution, they are often disturbed by water fluctuations and they have favourable physical conditions. Other sites where the *A. mearnsii* is abundant is at the side of roads and along the borders of agricultural lands. These spots are prone to seed distribution as well, and usually have enough water availability and soil-depth.

6.1.2 The developments in land cover since 1971

The historical analysis of the land cover showed that the spread of the *A. mearnsii* virtually ceased after the start of the WfW program. The rate of spread of over 15 ha/year in the period before the clearing efforts was turned into a rate of spread of only 0,6 ha/year after WfW became active in the Kouga. This proofs that the management has a big impact, but it also shows that the current management has to be improved in order to purify the Kouga catchment from IAPs. The total surface invaded by the *A. mearnsii* has not decreased since 1990.

Other important developments were increased surfaces of intensive fruit farming, build-up areas and other alien plants. The surface of water bodies showed a rapid increase in the period 1971-1990, but this stopped since the new water act in 1992. The total area of non-irrigated agriculture shows a remarkable drop since 1990.

6.1.3 The most vulnerable vegetation types for A. mearnsii invasions

The low shrub-like vegetation of the fynbos and renosterveld biomes are by far the most vulnerable vegetation types, over 80% of the invasion occurred within these regions. This is caused by the fact that these species struggles to compete for light with the taller *A. mearnsii*. The regular field fires that occur in the fynbos and renosterveld biomes stimulate further spread of the *A. mearnsii*. Dense forests and thicket are less vulnerable to alien invasions as they are more resistant to fires and are better equipped to compete with alien trees.

6.1.4 The clearing efforts

Currently the “Fell only” method is applied in the Kouga, followed by three follow-ups. When this is completed, the landowner himself is responsible for keeping his land free of IAPs. In terms of effectiveness, there is still a lot of room for improvement. In fact, there were more hectares invaded within the cleared areas in 2010 than there was in 1990 before the clearing programs began. This is partly because the trunks can re-sprouts. This is possible when follow-ups are not executed sufficiently. But the biggest challenge is arguably caused by seed banks in the soil, which remain intact after the clearing takes place. These banks can germinate, and act as a source for seed distribution.

6.1.5 The potential of the NDVI in research on invasive alien plants

The automated remote sensing technique NDVI seems to have a high potential in monitoring the alien trees in the fynbos biome. The alien trees are easily distinguishable from indigenous vegetation due to their higher biomass. Identifying individual species is not possible, but it can give information about the biomass and evapotranspiration rates. And as it can decrease the amount of labour and time needed for the manual classification, it looks ideal for big-scale monitoring. The application of the NDVI in IAP monitoring outside the fynbos biome can in some situations be more complicated.

6.1.6 General conclusion

To conclude, the invasion of the *A. mearnsii* still is a serious problem, even after 15 years of clearing. It replaces the vulnerable fynbos and renosterveld species, and as it occurs abundantly in riparian zones it can have serious impacts on the water availability downstream. WfW has a big impact on the rate of spread, but not enough to decrease the total area invaded by aliens. This suggests that the management should be improved. Attention should go to the impact of seed banks, the fire regime, and the possibility of biological control.

6.2 Recommendations

6.2.1 Recommendations for further research

A lot is already known about the water use of IAPs such as the *A. mearnsii*. However, a better understanding of the role of seed banks and field fires could possibly improve the clearing efficiency. The financial benefits that can be made by safeguarding the water availability through the clearing of aliens is also very important. Developments like the PES-market and stewardships could be suitable for giving farmers more incentives to take care of the IAP problem. If the clearing of aliens could be made profitable for land owners, that could make a big difference in the battle against IAPs. These options require further attention. Lastly, other approaches to control the IAPs should not be ignored, further research on biological control agents could benefit the cost-efficiency of the clearing programs.

6.2.2 Recommendations to improve the IAP management

The aim of the clearing programs of WfW is currently making more water available through the clearing of aliens, while creating chances for job opportunities and education at the same time. One could argue that as water scarcity is the biggest constraint for economical growth of the country, the focus should be on efficiency and cost-effectiveness, rather than employing and educating a few thousands of people. This might involve less labour intensive tactics as biological control. On the other hand, focussing on rural development, education and other social services is very admirable in a region as the Kouga where approximately 35% of the potential economically active people is employed.

A situation where it is profitable for landowners to manage their land more sustainable, which also includes the clearing of IAPs, would be a perfect solution. For example the market of Payment for Ecosystem Services (PES) would be ideal. Unfortunately, it will still need time and development before this market becomes established, and can function well and independently.

The current ambition of WfW in the Kouga is to increase the amount and size of their teams, to increase their impact on the IAPs (Koyo, 2013). Considering the impact they already had (almost stop the *A. mearnsii* from spreading), this could be sufficient on the long term. But they should still try to improve their current efficiency. Removing the biomass from the field, instead of leaving it to burn, could attribute to the recovery of original vegetation. It would be convenient when this biomass could be used in an useful way. Currently, the possibility of using the biomass as a bio-fuel is investigated (Palmer, 2013). Other options could be nursing and planting indigenous plants to support vegetation recovery, or adapting the follow-up schemes to local fire events. This study shows that when the efficiency of the clearing could be improved, WfW can be a very successful program, both in IAP management as in rural development. This will not solve all water shortages in South Africa, but it can definitely contribute to a more sustainable management of the countries natural resources.

Bibliography

Affairs, D. O. (2004). Fish to Tsitsikamma Water Management Area: Tsitsikamma to Coega Internal Strategic Perspective. South Africa: Directorate National Water Resource Planning.

Awwad, W. A. (2003). *Land Cover Mapping: a comparison between manual digitizing and automated classification of black and white historical aerial photography.* Florida: University of Florida.

Blanchard, R., & Holmes, p. (2008). Riparian vegetation recovery after invasive alien tree clearance in the Fynbos Biome. *South African Journal of Botany 74* , 421-431.

Boonzaier, E., Malherbe, C., Berens, P., & Smith, A. (2000). *The Cape Herders - A History of the Khoikhoi of Southern Africa.* Cape Town: David Philip Publishers.

Boshoff, A. (2005). *The Baviaanskloof Mega-Reserve.* Port Elizabeth: Terrestrial Ecology Research Unit (TERU).

Brown, C., Boucher, C., Pienaar, E., & Pemberton, C. (2004). *Project Report: Effects of alien invasives on the Breede River.* Mowbray: Department of Water Affiars and Forestry.

Centre, W. A. (sd). *AgroForestryTree Database*. Opgeroepen op March 5, 2013, van World Agroforestry Centre: http://www.worldagroforestrycentre.org/sea/products/afdbases/af/SpeciesInfo.asp?SpID=70

Chang, K.-T. (2010). *Introduction to Geographic Information Systems.* New York: McGraw-Hill.

Courault, D., Seguin, B., & Olioso, A. (2003). Review to estimate Evapotranspiration from remote sensing data: some examples from the simplified relationship to the use of mesoscale atmospheric models., (pp. 1-17).

Cowling, R. (1992). *The Ecology of Fynbos - Nutrients, Fire and Diversity.* Cape Town: Oxford University Press.

Crous, C., Jacobs, S., & Esler, K. (2012). Drought-tolerance of an invasive alien tree, Acacia mearnsii and two native competitors in fynbos riparian ecotones. *Biol Invasions 14* , 619-631.

de Wit, M., Crookes, D., & van Wilgen, B. (2001). Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. *Biological Invasions 3* , 167-178.

Dengsheng, L. (2006). The potential and challange of remote sensing-based biomass estimation. *International Journal of Remote Sensing Vol. 27, No. 7* , 1297-1328.

Denhill, G., Donnelly, D., Stewart, K., & Impson, F. (1999). Insect agents used for the biological control of Australian Acacia species and Paraserianthes lophanta (Willd.) Nielsen (Fabaceae) in South Afirca. *African Entomology Memoir No. 1* , 45-54.

Department of Water Affairs. (1986). *Management of the Water Resources of the Republic of South Africa.* Pretoria, South Africa.

Department of Water Affairs. (2010). *The Kouga Working for Water Management Unit Clearing Plan.*

Dong, J., Kaufmann, R., Myneni, R., Tucker, C., Kauppi, P., Liski, J., et al. (2003). Remote sensing estimates of boreal and temperate forest woody biomass: carbon pools, sources, and sinks. *Remote Sensing of Environment 84* , 393-410.

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. *South African Journal of Science 100* , 40-44.

Dye, P., Moses, G., Vilakazi, P., Ndlela, R., & Royappen, M. (2001). Comparative water use of wattle thickets and indigenous plant communities at riparian sites in the Western Cape and KwaZulu-Natal. *Water S.A. Vol. 27 No. 4* , 529-538.

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

Euston-Brown, D. (2006). *Baviaanskloof Mega-reserve project: Vegetation Mapping Contract: Report on methodology, vegetation classification and short description of habitat units.* Scarborough.

Explorer, S. (2011). *Climate data Joubertina*. Opgeroepen op March 3, 2013, van SA Explorer: http://www.saexplorer.co.za/south-africa/climate/joubertina_climate.asp

Fourie, S. (2008). Composition of the soil bank in alien-invaded grassy fynbos: Potential for recovery after clearing. *South African Journal of Botany 74* , 445-453.

Henderson, L. (2001). *Alien Weeds and Invasive Plants.* Pretoria: Mac Image.

Holmes, P., Esler, K., & Richardson, D. W. (2008). Guidelines for improved management of riparian zones incaded by alien plants in South Africa. *South African Journal for Botany 74* , 538-552.

Holmes, P., Richardson, D., Esler, K., Witkowski, E., & Fourie, S. (2005). A decision-making framework for restoring riparian zones degraded by invasive alien plants in South Africa. *South African Journal of Science 101* , 553-565.

Hope, A., Burvall, A., Germishuyse, T., & Newby, T. (2009). River flow response to changes in vegetation cover in a South African fynbos catchment. *Water S.A. Vol. 35 No. 1* , 55-60.

Hosking, S., & du Preez, M. (2004). A cost-benefit analysis of the Working for Water Programme on selected sites in South Africa. *Water S.A. Vol. 30 No. 2* , 143-152.

Impson, F., Kleinjan, C., Hoffman, J., Post, J., & Wood, A. (2011). Biological control of Acacia species and Paraserianthes lophanta (Willd.) Nielsen (mimosaceae) in South Africa. *Afr. Entomol. 19* , 186-207.

Jansen, H. (2008). *Water for Food and Ecosystems in the Baviaanskloof Mega Reserve.* Wageningen: Alterra.

Koenig, R. (2009). Unleashing an army to repair alien-ravaged ecosystems. *Science 325* , 562-563.

Koyo, V. (2013). (B. Bolhuis, Interviewer)

Kuilder, E. (2012). *Mapping River Floodplain Vegetation Structure with a consistent mapping scale by aerial images and LiDAR data in object-based random forest.* Wageningen: Wageningen University.

Kustas, W., & Norman, J. (1996). Use of remote sensing for evapotranspiration monitoring over land surfaces. *Hydrological sciences 41* , 495-516.

Le Maitre, D. C., & Colvin, C. A. (2008). Assessment of the contribution of groundwater discharges to rivers using monthly flow statistics and flow seasonality. *Water S.A. Vol. 34 No. 5* , 549-564.

Le Maitre, D., van Wilgen, B., Gelderblom, C., Bailey, C., Chapman, R., & Nel, J. (2002). Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. *Elsevier - Forest Ecology and Management 160 (2002)* , 143 - 159.

Le Maitre, D., Versfeld, D., & Chapman, R. (2000). The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment. *Water S.A. Vol. 26 No, 3* , 397-408.

Lillesand, T., Kiefer, R., & Chipman, J. (2008). *Remote Sensing and Image Interpretation.* USA: Wiley.

Lombard, A. (2003). *GIS coverages and spatial analysis for the subtropical thicket ecosystem planning (STEP) project.* Port Elizabeth: Terrestrial Ecology Research Unit, University of Port Elizabeth.

Mack, R., Chair, Simberloff, D., Lonsdale, W., Evans, H., Clout, M., et al. (2000). Biotic Invasions: Causes, Epidemiology, Global Consequences and Control. *Issues in Ecology* , 1-21.

Mander, M., Blignaut, J., van Niekerk, M., Cowling, R., Horan, M., Knoesen, D., et al. (2010). *Baviaanskloof - Tsitsikamma Payment for Ecosystem Services: A Feasibility Assessment. Synthesis Report.*

Marais, C., & Wannenburgh, A. (2008). Restoration of water resources (natural capital) through the clearing of invasive alien plants from riparian areas in South Africa - Costs and water benefits. *South African Journal of Botany* .

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

Montgomery, C. (2001). Understanding acidic soil. *Farmer's weekly* .

Myneni, R., Hali, F., Sellers, P., & Marshak, A. (1995). The Interpretation of Spectral Vegetation Indexes. *IEEE Tranactions on Geoscience and Remote Sensing Vol. 33 No.2* , 481-486.

Palmer, Z. (2013, June 12). The potential of using clelared IAPs as biofuel. (B. Bolhuis, Interviewer)

Powell, M., & Mander, M. (2009). *Baviaans - Tsitsikamma Payment For Ecosystem Services: Water Services Suppliers Report.*

Prinsloo, F., & Scott, D. (1999). Streamflow responses to the clearing of alien invasive trees from riparian zones at three sites in the Western Cape Province. *The Southern African Forestry Journal* , 1-7.

Rebelo, A. J. (2012). *An Ecological and Hydrological Evaluation of the Effects of Restoration on Ecosystem Services in the Kromme River System, South Africa.* Stellenbosch: Stellenbosch University.

Rhodes University. *Gamtoos System Report.*

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

Richardson, D., & van Wilgen, B. (2004). Invasive alien plants in South Africa: how well do we understand their impacts? *South African Journal of Science* , 45-52.

Richardson, D., Holmes, P., Esler, K., Galatowitsch, S., Stromberg, J., Kirkman, S., et al. (2007). Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Diversity and Distribution 13* , 126-139.

Rouget, M., Richardson, D. M., Nel, J. L., & van Wilgen, B. W. (2002). Commercially important trees as invasive aliens - towards spatially explicit risk assessment at a national scale. *Biological Invasions 4* , 397-412.

Rouget, M., Richardson, D., Nel, J., Le Maitre, D., Egoh, B., & Mgidi, T. (2004). Mapping the potential ranges of major plant invaders in South Africa, Lesotho and Swaziland using climate suitablilty. *Diversity and Distribution 10* , 475-484.

Roux, D., & Paulus, E. (1961). *Condensed Tannins - Polymeric Leuco-Fisetinidin Tannins from the Heartwood of Acacia Mearnsii.* Grahamstown, South Africa: Leather Industries Research Institute, Rhodes University.

Rowlinson, L. C., Summerton, M., & Ahmed, F. (1999). Comparison of remote sensing data sources and techniques for identifying and classifying alien invasive vegetation in riparian zones . *Water S.A. Vol. 25 No. 4* , 497-500.

Roy, P., & Ravan, S. (1996). Biomass estimation using satellite remote sensing data - An investigation on possible approaches for natural forest. *J. Biosci Vol. 21 No. 4* , 535-561.

Srinivas, P., Das, B., Saibaba, J., & Krishnan, R. *Application of Distance Based Vegetation index For Agricultural Crops Discrimination.* Secunderabad, India: ADRIN (Department of Space).

Statistics South Africa. (2011). *Mid-year population estimates 2011.*

Taylor, N., & Gush, M. (2009). *The Water Use of Fruit Trees and Orchard Crops in South Africa - KA Knowledge Review.* Pretoria: University of Pretoria.

Theron, J., van Laar, A., & Kunneke, A. B. (2004). A preliminary assessment of utilizable biomass in invading Acacia stands on the Cape coastal plains. *South African Journal of Science 100* , 123-125.

United Nations Environment Programme. *Working for Water: A South African Sustainability Case.*

Van der Hoeven, S. (2013). *The change in water availability as a result of invasion by Acacia mearnsii in the Kouga valley, South Africa.* Wageningen: Wageningen UR.

van der Merwe, S. (2013). (B. Bolhuis, Interviewer)

van Huyssteen, A. (2008). *Die Story van Langkloof.* Paardeneiland: Mega Digital.

van Wilgen, B. (2004). Scientific challanges in the field of invasive alien plant management. *South African Journal of Science* , 19-21.

van Wilgen, B. (2009). The evolution of fire and invasive alien plant management practices in fynbos. *South African Journal of Science 105* , 335-342.

van Wilgen, B. W., Cowling, R. M., & Burgers, C. J. (1996). Valiation of Ecosystem Services: case Fynbos. *BioScience Vol. 46 No. 3* , 184-189.

van Wilgen, B., Reyers, B., Le Maitre, D., Richardson, D., & Schonegevel, L. (2008). A biome-scale assessment of the impact of invasive plants on ecosystem services in South Africa. *Journal of Environmental Management 89* , 336-349.

Veerkamp, C. (2013). *Agriculture and biodiversity conservation in a water-stressed catchment - An inventory and integrated assessment of the relation between land management and ecosystem services in the Kouga catchment, South Africa.* Wageningen: Wageningen University and Research Centre.

Veerkamp, C. (2013). *The Kouga Catchment - Discover The Diversity.* Living Lands.

Verstegen, J., & ten Haaf, W. (2011). *Introduction Geo-Information Science.* Wageningen: Wageningen University.

Vlok, J., & Euston-Brown, D. (2008). *A vegetation map for the Garden Route Initative. Unpublished 1:50 000 maps and report supported by CAPE FSP task team.*

Wannenburgh, A. (2012, December 10). *Working for Water NBALs.* Opgeroepen op June 15, 2013, van http://www.arcgis.com/: http://www.arcgis.com/home/item.html?id=227cf316bed84a17be1bdea0d97044eb

Water, W. f. (2010). *the Working for Water Webpage*. Opgeroepen op March 16, 2013, van Department of Water Affairs Webpage: http://www.dwaf.gov.za/wfw/

Wu, W., Hall, C., Scatena, F., & Quackenbush, L. (2006). Spatial modelling of evapotranspiration in the Luquillo experimental forest of Puerto Rico using remotely-sensed data. *Journal of Hydrology 328* , 733-752.

WWF - South Africa. (2012). *Water Balance Programme.*

Zheng, D., Rademacher, J., Chen, J., Crow, T., Bresee, M., Le Moine, J., et al. (2004). Estimating aboveground biomass using Landsat 7 ETM+ data across a managed landscape in northern Wisconsin, USA. *Remote Sensing of Environment 93* , 402-411.

Annexes

Annex I: Description of the *Acacia mearnsii*

The Australian Blackwattle (*Acacia Mearnsii*) is a tree in the family of the *Fabaceae*, subfamily *Mimosoideae.* It is an evergreen, medium sized leguminous tree, native to south-eastern Australia. The black wattle is named after his brownish-black bark. Trees in their natural habitat have a rounded crown, but they are erect and slender when growing in dense vegetation. The leaves are dark green, binately compound and 8 - 15 cm long. They have 8 - 21 pairs of 2 - 5 cm long leaflets (pinnea). Each leaflet has 20 – 80 sub-leaflets.

The cream-coloured flowers grow in clusters along the axis, usually 20 – 30 together. In South Africa, the *A. mearnsii* flowers in July/August. The pods grow up to 10 cm and contains between 3 and 12 seeds. The pod is dark brown when ripe and can be straight or twisted. The tree produces many seeds, which are potentially dispersed by birds, rodents, domestic animals or by contaminated soil or water. Fires stimulate the germination. The tree can also sprout profusely from root suckers, in particular when the roots are damaged (Henderson, 2001).


A full-grown tree in a open field and a close-up of the leafs of the *A. mearnsii*

The uses of the *A. mearnsii*

The bark of the black wattle contains vegetable extracts which can be used for tanning leather (Roux 1961) This commercial value is the reason why it was introduced to South Africa. Furthermore it is a fast-growing, nitrogen fixing tree, which makes it useful for the remediation of degraded sites. The black wattle is valuable fuel wood and can also be used for construction material. Additionally the pulp can be used as a fibre. The leafs have a high protein content (about 15%) which makes it suitable to serve as fodder for cattle. The extra floral nectarines (containing about 20 % pollen protein and 40 % sugar) combined with its late flowering makes the tree also quit suitable for bee forage (World Agroforestry Centre, 2013).

Environmental impacts of invasions

The occurrence of the black wattle in areas like the Kouga catchment is not desirable for a number of reasons. First of all it is known to displace the vegetation in the area that it invades, which can range from grasslands to dense forests (Wilgen *et al*. 2008). There are several mechanisms that give it a competitive advantages over other plants. First of all it can reach a maximum height of 6 – 25 meters, while the indigenous vegetation of the fynbos biome typically consists out of low shrubs. Their crowns block out the sun, which is detrimental for smaller plants (Brown *et al.*, 2004; van Wilgen *et al*, 2008). Additionally, the higher water use, in combination with its shallow rooting system results in a decrease in water availability for other plants. Logically, this also effects the water quantities which are available for downstream areas. (Dye, 2004, Allen Hope, 2009). Furthermore black wattle trees can lead to allelopathy and acidification of the soil (Montgomery, 2001).

The *A. mearnsii* is a pioneer species specialized in colonizing previously disrupted or damaged ecosystems. Since fires are common – even necessary – in the fynbos biome (Cowling, 1992; van Wilgen *et al.*, 1996) the wattle can be potentially very dangerous for this region. Another disadvantage is that the loss of undergrowth increases the erosion risks on slopes.

Legislation

In terms of the amendments to the regulations under the Conservation of Agricultural Resources Act, 1983 (Act No. 43 of 1983), landowners are legally responsible for the control of invasive alien plants on their properties. The black wattle is a declared invader, and is classified as a category 2 plant. This means, as it is a commercially used plant, it may be grown in demarcated areas providing that there is a permit and that steps are taken to prevent their spread (Henderson, 2001).

A. mearnsii is arguably one of South Africa's most aggressive IAPs. It is a tall woody tree, a competitive invader with extremely rapid growth rates, high seed production and drought tolerance (Crous *et al*. 2012).

Annex II: A description of the Working for Water programme

Working for Water is a governmental programme which was established on a national scale in 1995. The goal of the programme is to clear invasive plants while providing social services and rural employment (United Nations Environment Programme, n.d.). As clearing invasive alien plants is very labour intensive, it is a good opportunity to create jobs and educate people. Combined with the water resources which can be saved by removing the IAPs, this program has the potential of giving solutions to some of the biggest environmental and socio-economical issues that South Africa faces (DWA, 2010; Veerkamp, 2013). It is arguably the largest conservation project in Africa (van Wilgen, 2009) and the most ambitious invasive alien plant control programme (Koenig, 2009).

Currently there are 300 projects across all nine South African provinces (Rebelo, 2012), and since WfW started, over two million hectares of IAPs have been cleared throughout the country (Rebelo, 2012; United Nations Environment Programme, n.d.). Due to the broad goals of the Working for Water Programme, the program has a tendency to be a pioneer in addressing social issues in South Africa. Training for workers includes not only technical skills such as herbicide application, but also small business development and health education. (United Nations Environment Programme, n.d.) The program is globally recognized as one of the most outstanding environmental conservation initiatives (Veerkamp, 2013). To date, the programme has created thousands of jobs, with a strong emphasis on gender equality, and provided substantial ancillary benefits through skill training, workshops addressing health and HIV awareness, sexual education and helping ex-offenders to reintegrate in society (Department of Water Affairs, 2010).

The clearing of IAPs includes follow ups after the species is initially removed, and consists out of:

- Mechanical methods: felling, removing or burning alien plants.
- Chemical methods: using (environmental safe) herbicides.
- Biological control: using species-specific insects and diseases from the alien plant's country of origin. To date 76 biological control agents have been released in South Africa against 40 plant species. For the black wattle the biological control agent *Melanterius maculates* is used. Hence that this is only on small scale, and is not applied in the Kouga catchment (Working for Water, 2010).

Annex III: the human history and socio-economic environment

The human occupation in the Kouga goes back as far as the Middle Stone Age, 25.000 years ago, when the area was habited by the hunter-gatherers 'San' (Boshoff, 2005). About 2.000 years ago the Khoekhoen (also known as Khoi-Khoi) came to the Cape region. They where nomads, and they are believed to be the first (cattle) farmers in the Kouga (Boonzaier *et al.*, 2000). The first ship of the Dutch East Indian Company reached the Cape of Good Hope in 1652, but it was only in the year 1760 that the first Europeans settled in the Langkloof area and started farming. (Huyssteen, 2008). At this time the farming practices consisted only out of keeping livestock and growing wheat. But it was in the beginning of the 20th century when the real value of the Langkloof was discovered: cultivating apples. (Huyssteen, 2008). Today the fruit industry in the Langkloof belongs to the top fruit producing areas of South Africa, exporting to the whole world (Veerkamp, 2013).

The high agricultural potential can also be seen in the employment data of the region, over 50 % is working in the agricultural sector. Of the potentially economically active people in Kou-Kamma, 35 % is currently employed. This is substantially higher than the National (22,9 %) and the Provincial (12,6 %) numbers. However, the level of high education in the region is lower than the national average (Department of Water Affairs, 2010).

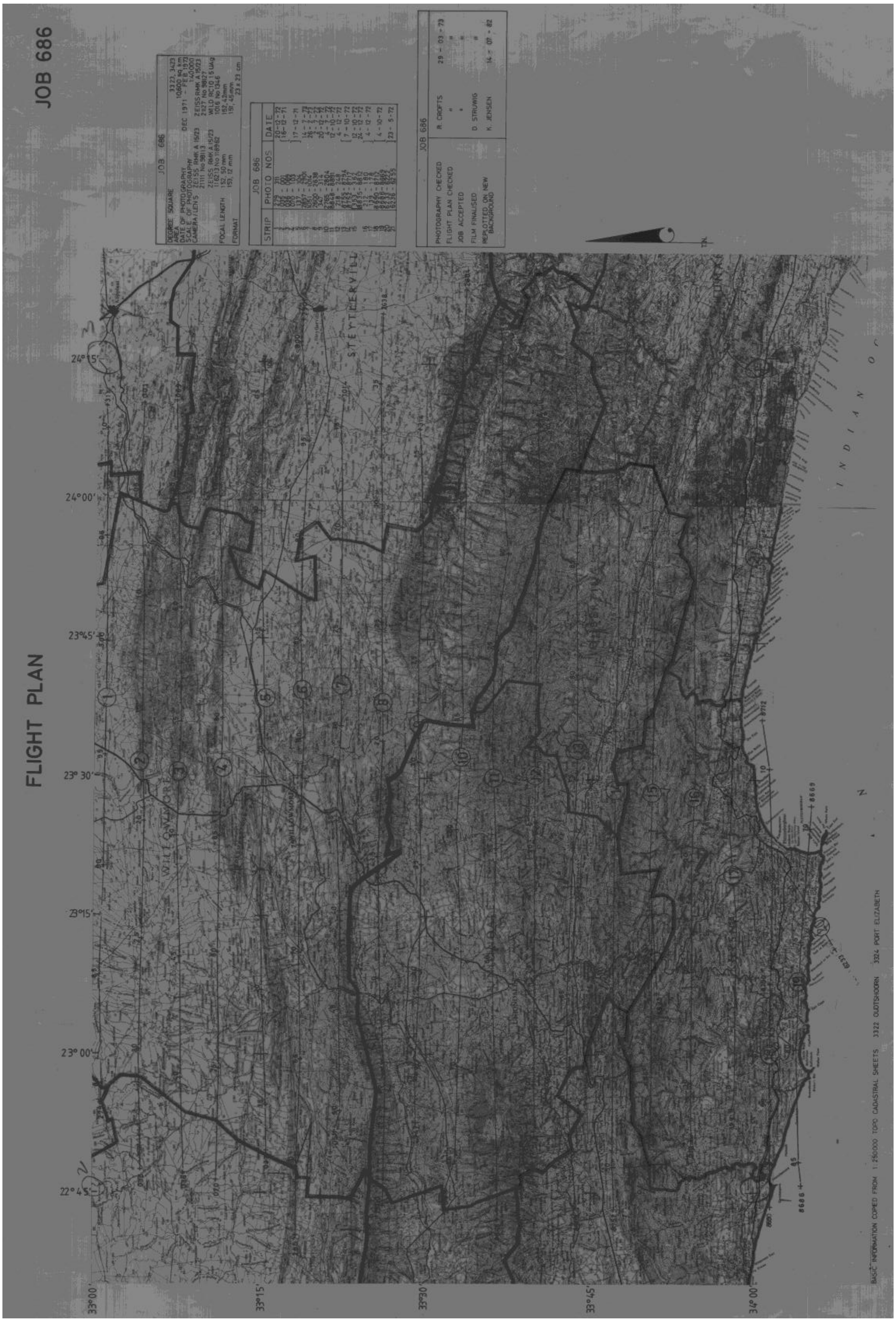
The distribution of labour in the different industries present in the Kouga (DWA, 2010)

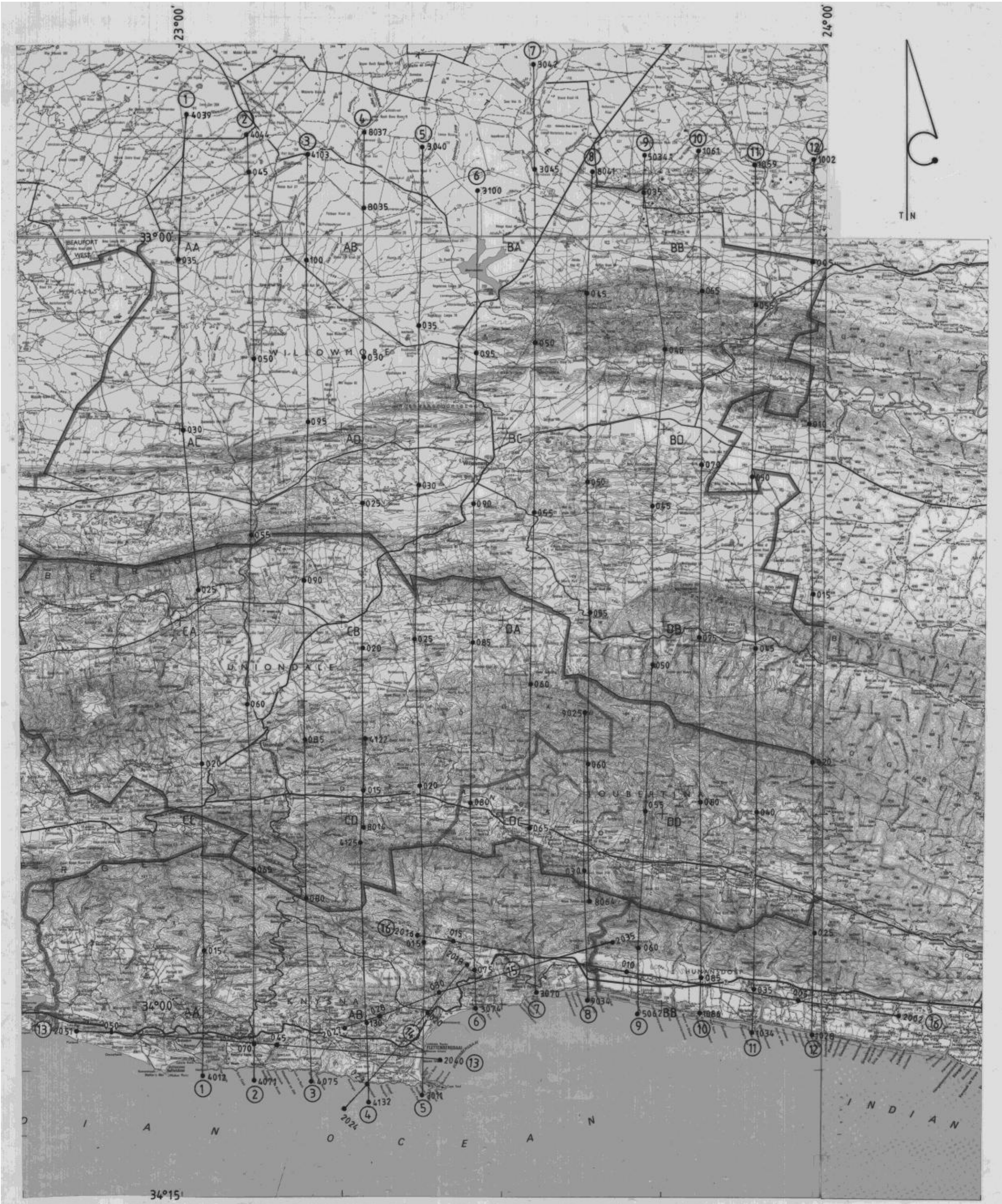
Industry	Number	Percentage
Agriculture	6383	52.32 %
Wholesale and retail trade	1797	14.73 %
Community; social and personal services	963	7.89 %
Manufacturing	703	5.76 %
Private Households	664	5.44 %
Other	1691	13.86 %
	12201	**100.00 %**

The statistics of education levels in the Kouga in comparison with the provincial and national statistics (DWA, 2010)

Education	Number	Percentage	%	%
Kou-kamma			Eastern Cape	National
No schooling	2124	10.15 %	23 %	18 %
Some primary	6289	30.05 %	20 %	16 %
Complete primary	2727	13.03 %	7 %	6 %
Some secondary	6333	30.26 %	30 %	31 %
Std 10 / Grade 12	2553	12.20 %	14 %	20 %
Higher	905	4.32 %	6 %	8 %
Total	**20931**	**100.00 %**	**100 %**	**100 %**

Annex IV: The flight plans of the aerial photographs of 1971/73 and 1990





BASIC INFORMATION COPIED FROM 1 : 250 000 TOPOSHEET 3322 OUDTSHOORN

SCALE OF PHOTOGRAPHY	1/50,000
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LENS	132019
PRINCIPAL DISTANCE	85,54mm
JOB FINALISED	91-01-05

JOB 943		
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3	4103 - 4075	"
4	8037 - 8014	90-10-09
4	4122 - 4132	90-09-24
5	3040 - 3011	90-09-22
6	3100 - 3074	"
7	3042 - 3070	"
8	8041 - 8064	90-10-09
8	9025 - 9034	90-10-14
9	5034 - 5062	90-09-25
10	1061 - 1086	90-06-12
11	1059 - 1034	"
12	1002 - 1028	"
13	2051 - 2040	90-07-01
14	2018 - 2024	"
15	2027 - 2035	"
16	2016 - 2002	"