BALANCING AGRICULTURAL AND ECOLOGICAL NEEDS: BIODIVERSITY, LAND USE AND ECOSYSTEM SERVICES IN THE KOEDOES RIVER CATCHMENT, LIMPOPO

by

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Environmental Science, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermartizburg campus, South Africa. The research was financially supported by the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation of South Africa.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

WHaddad

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Signed: William A. Haddad (Student) Date

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Signed: Professor Mathieu Rouget (Supervisor) Date

DECLARATION 1: PLAGIARISM

I, *William A. Haddad*, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

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a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

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DECLARATION 2: PUBLICATIONS

Details of contribution to publications that form part of and/or include research presented in this thesis (includes publications in preparation, submitted, in press and published and give details of the contributions of each author to the experimental work and writing of each publication).

Publication 1: Haddad, W.A and Rouget, M. Mapping ecological units for biodiversity and ecosystem services assessment: a vegetation-based approach. **In preparation.**

Publication 2: Haddad, W.A and Rouget, M. Identifying areas of biodiversity and ecosystem service value in the Koedoes River Catchment, Limpopo. **In preparation.**

Publication 3: Haddad, W.A and Rouget, M. The influence of land use on ecological functioning at the farm scale, using invertebrates as indicators. **In preparation.**

The work was done by the first author under the guidance and supervision of the second author.

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ABSTRACT

A major topic in natural science research is land degradation and unwise land use resulting in biodiversity loss and impact negatively on ecosystem functioning. In addition, an increasing human population trend leads to food security concerns. Some commercial farmers are ideally placed on the interface between agricultural and natural systems to investigate these issues. In this thesis we investigate the quaternary catchment-scale biodiversity, land-use patterns and interactions between conservation, restoration and agricultural activities in an agriculturally productive valley. The 40,000ha Koedoes River Catchment in Limpopo Province produces high numbers of tomatoes, avocados and mangoes. Most of this catchment is managed by ZZ2, a farming conglomerate that practice an environmentally sensitive approach to commercial farming. In the first two chapters a fine-scale vegetation map is created for the catchment, accompanied by detailed descriptions of the eleven mapped vegetation units. Over a 1300m altitudinal range, three biomes, 49 red-listed plant species, fifteen protected tree species and more than 500 species of vascular plant are represented in the catchment. In a subsequent chapter, the catchment-wide land-use patterns were mapped and related to vegetation patterns. The most expansive vegetation type appears to be one of the most threatened because large areas have been converted to croplands, while one of the most bio-diverse vegetation units is severely threatened by degradation and invasive plants. Using this information, in addition to stakeholder feedback regarding the relative supply and demand for ecosystem services, a map of high priority biodiversity, ecosystem services and agricultural use areas was created to serve as a strategic management tool for stakeholders and land managers. In the final chapter the fine-scale effects of land use practices on biodiversity and ecosystem functioning are investigated. Using invertebrate community data from three adjacent headwater sub-catchments, invertebrate diversity and downstream biological water quality (measured by SASS5) was related to upstream land use. Ultimately, this thesis serves to illustrate some of the complex interactions and inter-dependencies between conservation and agriculture, and to offer evidence for mutually beneficial synergies between both these important sectors.

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Laastens wil ek my familie bedank, in besonder my ouers en ouma, vir hul onvoorwaardelike ondersteuning en aanmoediging van al my planne.

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- Professor Mathieu Rouget: Guidance in conceptualizing the thesis and constituent chapters and assistance with data analysis and final presentation.
- Professor Braam van Wyk and herbarium personnel: Assistance with plant specimen curation and identification and intellectual guidance.
- ZZ2 laboratories and ZZ2 R&D personnel: Logistical and field work support
- Professor Stefan Foord and students: Assistance with data analysis, SASS surveys and invertebrate specimen curation and identification.
- Professor Erik Holm: Guidance in conceptualizing ideas and outcomes.

ACRONYMS AND ABBREVIATIONS

BD	Biodiversity
ES	Ecosystem Services
KRC	Koedoes River Catchment
MEE	Mass extinction event
CR	Critically endangered
EN	Endangered
VU	Vulnerable
LT	Least threatened
CR PE	Critically endangered, possibly extinct
NT	Near threatened
DD	Data deficient
Lpla	Tzaneen sour bushveld plains
Lslo	Tzaneen sour bushveld slopes
Ldra	Tzaneen sour bushveld drainage lines
Hdsb	Dense slope bushveld
Hbgm	Bushveld/grassland mosaic
Hssm	Steep slope mosaic
Hmmb	Mamabolo mountain bushveld
Mgra	Woodbush granite grassland
Mfor	Northern mistbelt forest
Mwet	Wetlands and streams
Ariv	Koedoes River riverine vegetation
Aroc	Rock faces and surrounding vegetation

CHAPTER 1: INTRODUCTION

1.1. The 'global challenge'

Human activities are having far-reaching effects on global processes. Atmospheric CO^2 concentrations have topped the 400ppm count, a historical landmark concentration with mayor climate change implications (Steffen et al., 2015). Global nitrogen (N) and phosphorus (P) cycles are severely modified and disrupted by human industry and agriculture and global measures have also far exceeded the expected planetary boundaries for these geochemical cycles (Rockström et al., 2009; Steffen et al., 2015). The levels of plastic pollution in the world's oceans are reaching quantities that may have global circulation impacts (Derraik, 2002; Eriksen et al., 2014) while human land use in terrestrial environments are considered to be one of the biggest alterations to the Earth's systems (Vitousek et al., 1997). These consequences of industrial-human activity may lead to sudden and catastrophic changes in the life-supporting biosphere (Scheffer et al., 2001).

The effects of human activity on global systems has escalated to such an extent that the most recent geological epoch, the Anthropocene, is characterised by the effects of human activities on the global environment at geological time scales (Zalasiewicz et al., 2011). Debate exits as to the exact point when human activity started to have global impacts on Earth's systems. The suggested boundary between the previous epoch, the Holocene, and the current Anthropocene range from the initial human domestication of plants and animals some 10 000 years ago, to the Columbian exchange in the 1600's, to the industrial revolution in the late 1700's, up to as recent as the detonation of the first atomic bomb in the 1940's (Smith and Zeder, 2013). Regardless of when it started, we are living in the Anthropocene and all indications are that humans are facing enormous and immediate global environmental challenges during this epoch (Steffen et al., 2007).

With more than 7 billion people on the planet and an ever rising rate of population growth (Roberts, 2011), humans are consuming more and more natural resources. To compound the problem of shear population pressure, improvements in life-style lead to increased rates of consumption which puts further pressure on natural systems (Myers, 1997). Predictions are that the human population will grow by half its current size in the next 50 years and in this time more people are expected to become more affluent, creating a huge demand for natural resources (Tilman et al., 2001). Humanity's vast population size, global reach and increasingly environmentally destructive practices (Vitousek et al., 1997) may be the biggest and most rapid driver of current environmental change.

The extent, value and vulnerability of the vital life support services rendered by natural ecosystems are only in recent years attracting the attention of policy makers and scientists (Daily and Matson, 2008). These services, collectively known as ecosystem services (ES), are defined by Costanza et al. (1997) as "…the benefits human populations derive, directly or indirectly, from ecosystem functions". In their seminal work, Costanza et al. (1997) calculate the value of the world's ecosystem services at US$ $33 x 10^{12}$ – a large amount of capital that is not captured in traditional markets. Further, the cost of our failures to account for it now will likely be borne by future generations.

Ecosystem services are vital to all human societies and diverse examples of such services can be found across a wide range of operative scales. Based on their functional characteristics, ES can be divided into four groups: 1) *Provisioning services* include naturally provided products such as food (e.g. fish, game, wild fruits and vegetables), fresh water, fibre and building materials. 2) *Regulating services* include the global climate (e.g. ocean currents, temperature regulation and rain-bearing winds) and pest and disease suppression. 3) *Cultural services* include spiritual and artistic inspiration, recreation, education and science. 4) Lastly, *supporting services* include soil formation and primary production (Millennium Ecosystem Assessment, 2005). Ecosystem services have such a broad reach, that humanity as we know it will be severely affected if one or more of these services were to fail. It thus seems logical that if we want to keep enjoying life-supporting ecosystem services, we need to sustainably maintain (and probably restore) ecosystem functioning across the globe.

Biodiversity is the variety and variability of all living organisms (IUCN, 1988) and is a concept often associated with functional ecosystems and their ability to render vital ecosystem services (Loreau et al., 2001). This universally unique resource is under immense threat as human activities are driving the sixth mass extinction episode (MEE) in the past 540 million years (Barnosky et al., 2011; Myers, 1996a). The most compelling case for the conservation of biodiversity is arguably the 'insurance hypothesis' (Yachi and Loreau, 1999). It places biodiversity as a buffer, or 'insurance policy', safeguarding ecosystems against environmental fluctuations, such as climate change, and is based on the idea that functionally redundant species in an ecosystem become functional over time. Biodiversity offers a vast pool of resources as each species represents a solution to a unique evolutionary problem. Recent work has focused on attaching economic or monetary values to biodiversity in an attempt to valuate natural resources (Edwards and Abivardi, 1998; Salles, 2011), thus providing a powerful motivation for biodiversity conservation. Despite such efforts, the rate and extent of biodiversity loss continue to accelerate (see Myers (2003) for a comprehensive review on the state of biodiversity conservation). If the state of global biodiversity is used as a proxy for ecosystem health, the picture looks fairly bleak.

Human-driven changes in land cover and land use are associated with biodiversity losses (Myers et al., 2000) and undermine the ability of ecosystems to render life-sustaining services (Foley et al., 2005). Commercial and sustenance agriculture is arguably the most active global drivers of land-use and land-cover change and predictions are that agricultural land use will continue to expand rapidly for another five decades (Tilman et al., 2001; Vitousek et al., 1997). Continuous, high-intensity, commercial agriculture is often a destructive and unsustainable form of land use and its environmental impacts have been well documented (e.g. Mannion, 1995; Skinner et al., 1997; Van Der Werf and Petit, 2002). In addition to physically changing land cover, intensive agriculture has many other severe impacts on natural systems functioning, e.g. soil loss (Montgomery, 2007), eutrophication of water resources (Ulén et al., 2007) and invasive species introductions (Silvertown, 2005).

Food security in the face of climate change, energy crises, failing economies and the growing human population poses a major threat to peaceful societies (Ericksen et al., 2009). In pursuing short term goals, humanity might be trading current increases in food production for long term losses in ecosystem services, many of which are important for sustained agriculture (Foley et al., 2005). On one hand, agricultural production has to increase to keep up with a growing population. On the other hand, increased food production using conventional agricultural approaches result in biodiversity losses and dysfunctional ecosystems. This, in turn, may seriously hamper future generations' agricultural efforts. Such is the *global challenge* faced by humanity.

The importance of balancing natural environments with agricultural land uses is receiving more attention in contemporary scientific literature (e.g. Moonen and Bàrberi, 2008; Robertson and Swinton, 2005; Tscharntke et al., 2012, 2005) and indicates a step in the right direction, but remains less widely recognised and studied. Two alternative propositions to meet the dual challenges of increased food production and biodiversity conservation on a finite amount of land have been proposed. The idea of *land sharing* integrates both objectives in the same landscape, while *land sparing* isolates intensive agriculture from protected natural habitats (Phalan et al., 2011). Both concepts are thus based on the same idea – areas for conservation and areas for production are needed, but the relationship between natural and transformed is expressed at different scales. Is a fine scale mix of small farms and natural areas in the same landscape, or a massive park and continuous farms in separate landscapes better? Opinion remains divided, but if a solution to balancing agricultural and ecological needs can be found, humanity is set to overcome the 'global challenge'.

At the heart of the solution to this 'global challenge' lies the ecological, economic and social unit of the farm. The spatially extensive footprint of the agricultural sector positions it very well to, through very little effort, make massive contributions to landscape and regional scale conservation efforts. The agricultural sector is surely in the best position to take management and mitigation steps that can have the biggest single impact on ensuring a continuous network of functional, bio-diverse and sustainable ecosystems.

1.2. Aims

The main aim of this thesis is to establish a baseline inventory of biodiversity and ecological assets in the agriculturally productive Koedoes River Catchment (KRC) and to assess the impact of agricultural activity on the biodiversity and ecological processes of the KRC. Ultimately, it is hoped that the insights gleaned during the compilation of this thesis (and future work that it initiates) may help steer the regional farming system (and by association the whole KRC) towards a continuous goal of sustainability. Along the way we might contribute towards a solution to the 'global challenge' stated above and possibly present a model system to be applied elsewhere.

1.3. Objectives

The following objectives were set for the study:

- Assess the current state of biodiversity in the KRC using vegetation as a proxy. A rapid vegetation mapping technique was developed to generate a fine scale vegetation map of the KRC.
- Assess the current state of human land use in the KRC using recent aerial photographs.
- Assess the relative contribution of certain habitat types towards ecosystem services (ES) provisioning in the KRC using feedback from stakeholder engagement.
- Assess the effects of various land-use types on biodiversity and down-stream ES provisioning in three sub-catchments at the headwaters of the Koedoes River.

1.4. The Koedoes River Catchment: a case study for balancing ecological and agricultural needs

The Koedoes River Catchment (KRC) in South Africa's Limpopo Province is ideally suited to investigate the interactions between natural and agricultural land uses. This catchment, covering over 40,000 ha, provides a landscape perspective towards understanding the effects, positive and negative, of agricultural land use on biodiversity and its relation to ecosystem services (Figure 1.1). The KRC is home to a massive agricultural conglomerate – ZZ2 is a multi-million rand company that started as a family business on the farm Boekenhoutbult, situated on the banks of the Koedoes River. Through innovative thinking and hard work, ZZ2 has been built up to an agricultural giant and an institution in the Limpopo Province, directly employing more than 7000 people (pers. comm. Org Ehlers). They produced around 19 million cases of tomatoes (translating to between 131 100 and 114 000 tonnes), 2.2 million cases of avocadoes and large quantities of mangoes and onions during the year 2013/2014. Many of these crops are planted in the KRC and its surroundings, where a large herd of commercial cattle is also grazed.

In the mid 1990's, a turbulent time in South African history, ZZ2 was introduced to 'open system' business philosophy. The idea of systems is common in biological sciences (e.g. immune system and ecosystem), but in large corporate entities it is a relatively new approach to view a business as a system (Senge, 1990). ZZ2's 'open system' philosophy led to a paradigm shift which switched ZZ2 management and corporate structures from closed to open systems (van Zyl et al., 2013). It allowed them to develop a long-term view and strategy

Figure 1.1 View of the Koedoes River Catchment looking north. Note the mix of agricultural land use and natural areas.

focused on sustainability – a very well suited approach for agri-businesses, as short term outlooks are often destroyed by unfavourable natural cycles or prices on the free market. Holm and Ehlers (2014) define a system as follows: "A system is an assemblage of components that combine their actions in an orderly fashion towards a common goal" while Senge (1990) adds that a system is autonomous in fulfilling its purpose. But we as humans are part of the autonomous system, so we can manage the system to send it to its goal. Think of a car without a driver – it is not a complete system. But with a driver behind the steering wheel it is autonomous in reaching its destination or goal (analogy adapted from Senge (1990)).

Equipped with their 'open system' approach and following the paradigm shift in goals, from short-term profits to long-term sustainability, ZZ2 developed a new approach to commercial agriculture termed 'Natuurboerdery', or 'nature farming'. The Natuurboerdery approach is seen as an open system, like ecosystems, responding and reacting to changes. One of the architects, Professor Erik Holm, explains it as such: "ZZ2 did not turn to organic production but chose to develop an approach that incorporates organic materials with reduced use of inorganic fertiliser and pesticides. This strategy lends itself to cost-effective, large-scale application, leading to sustainable farming and nutritious produce. The concept lies between organic and industrial farming, but is better than either" (Joubert, 2012). The fact that ZZ2 is in essence a family business – something to pass down to subsequent generations – plays a role in the long-term sustainability driven vision of the company (van Zyl et al., 2013). This lies at the root of ZZ2's sincere concern and care for the environment and the biodiversity among which they farm.

1.5. Thesis outline

This thesis starts with a broad topical and spatial scope and eventually zooms in to more specific analyses at the farm scale. The first three chapters introduce concepts and generate baseline biodiversity (BD) information necessary for more detailed work. The fourth chapter assess the ecosystem service (ES) functioning of the entire catchment, while the fifth chapter zooms in to a smaller spatial scale and tests some assumptions made in the previous chapters. Figure 1.2 illustrates the flow of concepts and information from coarse to fine scale throughout the thesis.

- The introductory chapter briefly introduces some of the global challenges facing humanity, such as ecosystem failure, biodiversity loss, land degradation and food security. The study area where some of these challenges are practically assessed is also introduced here.
- In the second chapter a rapid technique was developed to map the vegetation of the KRC for the purpose of identifying landscape-scale biodiversity patterns and to serve as a predictive model of biodiversity (and other related functions such as ecosystem services) in the region.
- The third chapter presents detailed descriptions of each vegetation type mapped in the KRC.
- The fourth chapter also operates at the landscape scale and aims to produce a map of agricultural, ecosystem service and biodiversity assets for the study catchment. This chapter draws on information presented in the preceding chapters and addresses some of the challenges to sustainable farming and conservation as introduced in the first chapter.
- The fifth chapter zooms in to the farm scale to test the assumptions made in the preceding chapter. It practically assesses the ecological functioning of three small, adjacent sub-catchments using biodiversity and ES delivery as response indicators to different land-use practises.
- Finally, in chapter six we conclude the thesis by summarising our findings and discussing further research questions that may add to the current work.

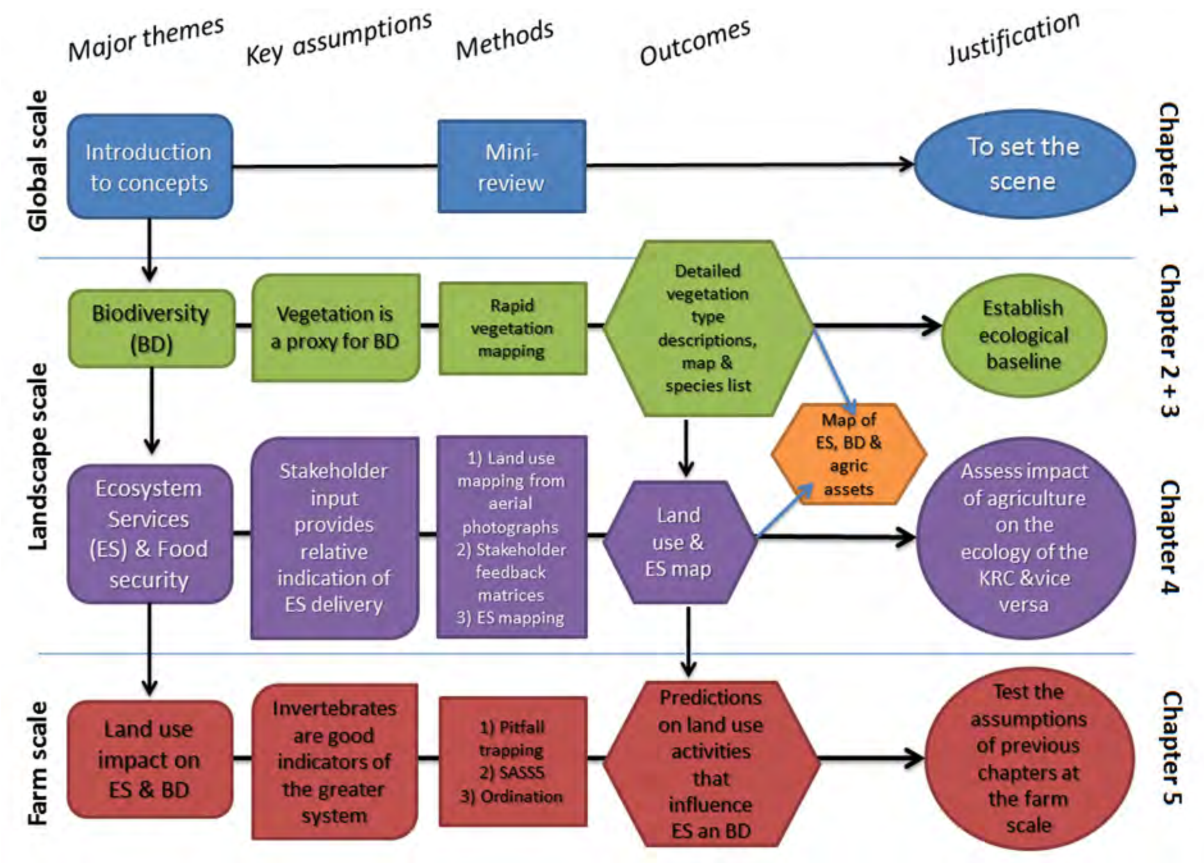


Figure 1.2 Schematic diagram outlining the flow of the thesis.

CHAPTER 2: MAPPING ECOLOGICAL UNITS FOR BIODIVERSITY AND ECOSYSTEM SERVICE ASSESSMENT: A VEGETATION-BASED APPROACH

"Because plants, as primary producers, represent the basal component of most ecosystems, they represented the logical place to begin detailed studies"

Loreau et al. (2001)

2.1. Abstract

Vegetation is considered a good indicator of landscape-scale biodiversity patterns. In this chapter we use a rapid approach to map the vegetation of the agriculturally important Koedoes River Catchment (KRC), Limpopo, South Africa. A hierarchical vegetation classification scheme is developed – consisting of four broad topographic-climatic zones, eleven distinct vegetation types and eighteen vegetation communities. Forty seven red-listed plant taxa are identified. The possible drivers for the observed vegetation patterns are discussed. The vegetation classification structure presented here is used in subsequent chapters to put the degree of habitat transformation in the KRC into context and to provide structure to a catchment-wide ecosystem service supply and demand assessment.

Keywords: *Vegetation mapping, Biodiversity, Koedoes River, Land use, Ecosystem services.*

2.2. Introduction

Biodiversity has become a buzz word in biological and environmental sciences since the publication of Rachel Carson's landmark book *Silent Spring* in 1962. Biotic diversity, or biodiversity (BD) for short, is defined as: "The variety and variability of all living organisms. This includes genetic variability within species and their populations, the variety of species and their life forms, the diversity of the complexes of associated species and of their interactions, and of the ecological processes which they influence or perform" (IUCN, 1988). Today, the rapid loss of biodiversity across all of the earth's biomes is a matter of great global concern (Myers et al., 2000) and experts fear we have entered the next period of great extinction in the history of life on Earth (Barnosky et al., 2011). Myers (1996) identifies the two critical roles that biodiversity plays in maintaining global ecological function. Firstly, it provides ecosystems with their functional properties by being the physical biospheric medium for energy exchange and material flow – in other words, biodiversity can be seen as the reaction surface for many of the global-scale chemical reactions that maintain life on Earth. Secondly, biodiversity upholds ecosystem resilience. Biodiversity losses are often associated with declining ecosystem process integrity and a decline in environmental services supplies (Chapin et al., 2000; Hooper et al., 2005).

Vegetation in itself can be considered a form of biodiversity. It can also be considered a proxy for many other forms of biodiversity such as habitat types, invertebrate and vertebrate animal communities, soil faunal communities etcetera. Grobler et al. (2002) puts it very clearly: "Vegetation is the most physical representation of the environment on which almost all forms of life are ultimately dependent". Mapping the diversity of vegetation in an area would thus be the logical first step towards cataloguing, classifying and ultimately conserving the biodiversity of that area. According to Mucina et al. (2006b), vegetation mapping can be regarded as a modelling and simplification exercise aimed at achieving two goals: 1) a verbal model or worded descriptions of the vegetation units highlighting physiognomy, geographic, environmental and floristic parameters; 2) a graphical spatial model, or a map, indicating the geographical extent and spatial interactions of the vegetation units. Thus, a vegetation map presents a predictive hypothesis about vegetation patterns and dynamics (Mucina et al., 2006b), which in turn predicts greater biodiversity patterns. This represents the focus of the current and following chapters – to develop a verbal and graphical model for the vegetation of a catchment to serve as a predictor of biodiversity patterns, including ecosystem services. The challenge is doing this in a time and cost effective manner at an appropriate resolution.

Identifying and mapping plant communities in the field is riddled with challenges. Although plant communities are defined as "…collections of plant species within a designated geographical unit, which form a relatively uniform patch that is distinguishable from neighbouring patches of different vegetation types" (Pott, 2011), such communities can be very hard to distinguish. The mostly continuous character of vegetation makes it notoriously challenging to classify into distinct groups. The science of classifying and mapping vegetation groups has a contentious history. During the first half of the 20th century, Josias Braun-Blanquet was a leading and dominating figure in the science of vegetation community mapping, or phyto-sociology. His relevé methods are today considered to be burdened by bias, subjectivity, inconsistency, arbitrariness, circular argumentation and large sampling errors (see Podani, (2006) for specific references), which is unprecedented in contemporary natural science. Yet, few fundamentally different alternative approaches exist. Understanding vegetation depends on the objectives pursued, questions posed and the scale of operations and these three factors will determine the methodology used. According to Kenkel et al. (1989) two forms of information are available to vegetation mappers: observational or analytical. Analytical information relies heavily on taxa – which are no longer considered to be universal indicators of ecological function (Mucina, 1997). Observational information takes climatic, edaphic, topographic and factors of biotic interactions into account, but is more difficult to objectively measure and quantify. In this study we use a rapid vegetation mapping technique, based on expert interpretation of structural patterns and species assemblages and drawing mainly on observational information, to map the vegetation of the Koedoes River Catchment, an area of high conservation and economic value.

Conserving biodiversity in production landscapes (areas of high agricultural activity) is not achieved through traditional conservation approaches such as protected areas establishment (Scherr and Mcneely, 2008). Alternative mechanisms, such as mainstreaming biodiversity conservation into other land uses (Pierce et al., 2005), or conservation stewardship programmes (Lobley and Potter, 1998; Von Hase et al., 2010) can secure biodiversity assets and maintain functional natural ecosystems, in partnership with the agricultural and forestry sectors. In recent years the conservation and business successes of initiatives in South Africa, such as the 'Biodiversity and Wine Initiative' launched by the WWF, has put emphasis on the mutually beneficial outcomes when conservation agencies and commercial farmers (who are also major land owners) work together.

South Africa's Koedoes River Catchment (KRC) is an ideal setting for studying the possible synergies between the conservation of ecological resources (such as biodiversity and ecosystem services) and a commercial farming operation. Most of the catchment is managed by ZZ2, a massive farming conglomerate that is committed to sustainability and maintaining a balance with the natural environment (van Zyl et al., 2013). It is important for commercial farmers to be aware of the value of the natural vegetation and its associated biodiversity surrounding their farming ventures. It is hoped that the current study will serve as a baseline for further investigation into synergies between natural systems and commercial farmers. ZZ2 may ultimately become a successful case study not only as an innovative agricultural giant, but also as a champion for biodiversity conservation in an agricultural setting.

The aim of this chapter was to map the vegetation of the KRC for the purpose of identifying landscape scale biodiversity patterns and to serve as a predictive model of biodiversity and ecosystem services in the region. Prior to this work the information available on vegetation patterns and diversity in the area (in the form of various national scale vegetation maps) was not at an appropriate scale or resolution to allow for detailed, fine-scale analysis of ecosystem intactness or ecosystem services. For this reason, we strove to develop and apply a rapid method for classifying, mapping and assessing ecosystem diversity at a quaternary catchment scale. The methodology, a synopsis of results and discussion of its application is covered in this chapter, while chapter three is a descriptive account of the identified vegetation types. In chapter four the resulting vegetation types are applied to an ecosystem services (ES) survey of the catchment.

2.3. Methods

2.3.1. Study site

2.3.1.1. <u>Social context</u>

The Koedoes River Catchment (KRC) is home to a massive agricultural conglomerate. ZZ2 is a multi-billion rand company that started as a family business. Through innovative thinking and hard work, ZZ2 has been built up to an agricultural giant and an institution in the Limpopo Province, directly employing more than 7000 people (pers. comm. Org Ehlers). They produced around 19 million cases of tomatoes (translating to between 131 100 and 114

000 metric tonnes), 2.2 million cases of avocadoes and large quantities of mangoes and onions during the year 2013/2014. Many of these crops are planted in the KRC and its surroundings, where large herds of commercial and stud cattle are also grazed.

In the late 1990's ZZ2 were faced with increasing pesticide and fertilizer costs and a decline in yields. They also became mindful of a growing demand from consumers for food that was produced in an environmentally sensitive manner. This led to the development of a new approach named 'Natuurboerdery', or 'nature farming'. The Natuurboerdery approach is seen as an open system, like ecosystems, responding and reacting to changes. One of the architects of the Natuurboerdery approach, Prof Erik Holm explains it as such: "ZZ2 did not turn to organic production but chose to develop an approach that incorporates organic materials with reduced use of inorganic fertiliser and pesticides. This strategy lends itself to cost-effective, large-scale application, leading to sustainable farming and nutritious produce. The concept lies between organic and industrial farming, but is better than either" (Joubert, 2012).

2.3.1.2. Geographic setting and climate

The Koedoes River Catchment (KRC) is located in South Africa's Limpopo Province, between the major towns of Polokwane and Tzaneen. The catchment drains the northern-most slopes of the Wolkberg range. It is a long narrow catchment of about 50km by 12km at the widest, eventually flowing into the Letaba River (Figure 2.1). The KRC stretches over an altitudinal gradient of more than 1300 meters along its 50km length, with the highest point, Schnellskop at 1903 m.a.s.l., in the south-west and the confluence with the little Brandboontjies (below 600 m.a.s.l.) in the extreme north-east. The southern half of the catchment is a narrow valley with steep slopes topped by mountain plateaus on either side, but with a flat band of alluvial deposits around the river. Further north the valley becomes wider as the flanking mountains are replaced by a number of koppies, of which the most notable is Tswale-kop at 1037 m.a.s.l.

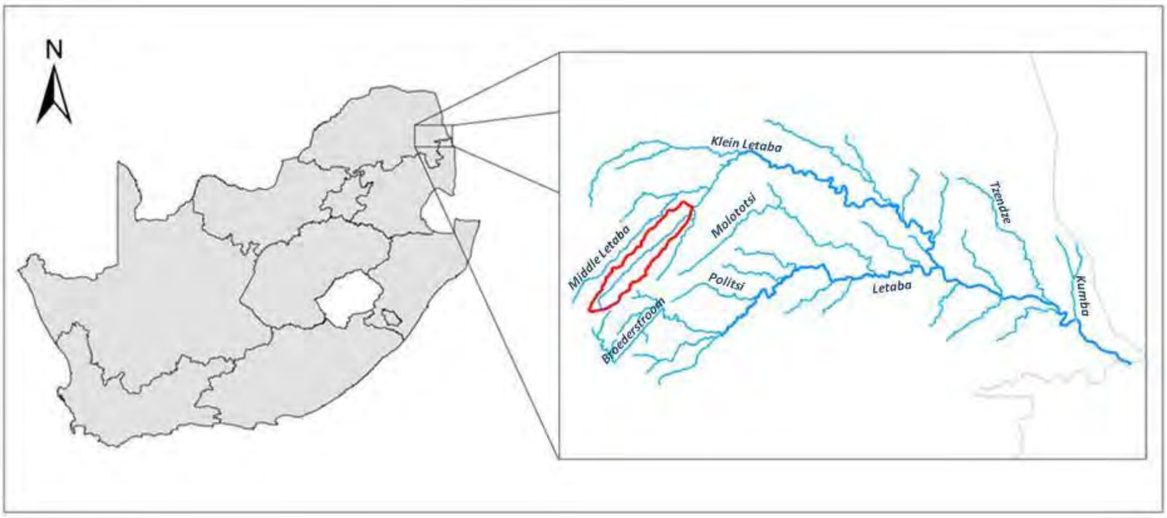


Figure 2.1 The Koedoes River Catchment (red) as part of the Letaba river system (blue) in South Africa's Limpopo Province. Other main tributaries of the Letaba are labelled.

The KRC lies immediately south of the Tropic of Capricorn and for the most part the climate can be considered as xeric-subtropical, but due to topographical differences large parts of the catchment enjoys a cooler and moister climate. We classified the KRC into three zones based on topographical and climatic patterns. These are the Lowveld, Highveld and Montane topo-climatic zones (for detailed discussion of climate per zone, see section 3.3). Winters are generally mild in the Lowveld, but can be very cold at higher altitudes. Summers are warm in the whole catchment, but can be hot in the lower lying areas. Falling within South Africa's summer rainfall region, most of the precipitation occurs between December and February. Much of the early rain falls in the form of scattered thunderstorms, while the rain later in the season is caused primarily by frontal systems. The variability in climate within the KRC, especially regarding precipitation, can be considered a product of the topography. Further, the great range of climatic conditions found across the KRC undoubtedly contributes to the biological diversity seen in the area. The impact of topography on climate and climate on vegetation structures are discussed in section 5.2.1.

2.3.1.3. Geology and soils

The KRC is situated on the north-eastern parts of the Kaapvaal craton – the stable core of an ancient continent (McCarthy and Rubidge, 2005) – and these ancient rocks have not yet been overlain by younger deposits. The Greenstone belts (Pietersburg, Giyani and Murchinson belts) that outcrop in the vicinity of the KRC and the early Archaean granitoid gneisses that are common in the area are some of the oldest preserved material on the surface of the Earth (McCarthy and Rubidge, 2005). According to the South African Council for Geoscience (CGS) 1:250 000 geological maps of the country (2330 Tzaneen & 2329 Pietersburg), seven distinct lithostratigraphic units are represented in the KRC (in *italics*). These units nest into five broader groups (in **bold**) defined in The Geology of South Africa (Johnson et al., 2006). The rock formations and their ages are: **Archaean granitoid gneiss** (3600-3200 Ma) represented by the *Goudplaats gneiss (Zg)* lithostratigraphic unit**; Pietersburg greenstone belt** (3150-2853 Ma) represented by the *Zandrivierspoort (Zpz)* and *Mothiba (Zpm)* units; **Granites** (2800-2650 Ma) represented by the *Turfloop granite (Vt)* and the *Duivelskloof leucogranite (Vlg)* units; ***Diabase dykes*** (3500-1000 Ma); and the considerably more recent ***Quaternary deposits*** (approx. 1.8 Ma).

Considering how important soils are for virtually all forms of vegetation, it is unfortunate that no fine scale soil maps are available for the study area. Detailed soil mapping and classification did not fall within the scope of the current study, but will hopefully receive attention in the future. The best available data set containing soil information at a workable scale is that of Schoeman et al. (2002) – a report to the National Department of Agriculture that aimed at classifying the country into eight "land capability classes". The terminology is based on the World Reference Base (WRB) as per IUSS Working Group (2007). The six WRB soil groups identified in the KRC by Schoeman et al. (2002) are: Ferric & Chromic Luvisols, Rhodic Lixisols and Acrisols and Leptic & Eutric Regosols.

South Africa has its own soil classification system (Macvicar and De Villiers, 2006) that was specifically designed for local soil forming factors. Applied at a finer scale, it is more detailed than the WRB system, but little data is available for the catchment as a whole, so only the three most noteworthy soil types found in the KRC are highlighted below:

- The *Hutton* soils which are found occasionally on the plains and slopes of the Koedoes River valley. These are good agricultural soils and are heavily utilised.
- The *Glenrosa* soil forms which are found primarily in the south-western parts of the KRC, on relatively flat mountain plateaus. These soils are moderately to heavily utilised in the KRC.
- Lastly, the *Mispah* soils occur on the steeper slopes of the KRC. These soils are only marginally utilized for silviculture within the KRC.

2.3.2. Vegetation mapping

The approach adopted for the mapping of the KRC vegetation is simple but efficient enough to identify clear vegetation groupings at a catchment scale. A number of 'loosely cruised transects', a term coined by Scheepers (1977), were recorded to explore and catalogue the flora of the catchment. The vegetation was first grouped into three larger zones based on broad topographic and climatic parameters. A number of *a priori* vegetation types were defined based on a combination of topographic factors (e.g. valley, slope or plateau), climate (temperature and rainfall parameters), specialist habitats (such as cliffs or riverine areas), physiognomic structure (e.g. grassland, savanna, forest or combinations), and the presence of characteristic species (such as *Kirkia acuminata, Faurea rochetiana, Pterocarpus angolensis, Colophospermum mopane* or *Cussonia natalensis*). This resulted in a hierarchical scheme into which the vegetation groupings can be organised. The indicator variables for each of the identified vegetation types and larger topographic-climatic zones are discussed in chapter three. Similar approaches have been successfully applied for mapping vegetation in other parts of South Africa such as the Little Karoo (Vlok and Schutte-Vlok, 2010), the Agulhas plain (Euston-Brown, 1999) and the South Cape forests (Von Breitenbach, 1974).

Next, the geographic areas that best correspond to the *a priori* vegetation type descriptions were mapped in ArcGIS 10.1 (ESRI 2013) based on a combination of recent aerial photograph interpretation (2012 geo-rectified images, obtainable from www.NGI.gov.co.za) and numerous field excursions. The distributions of characteristic species were particularly distinct during autumn and spring, when the phenology of different species differed temporally by a few weeks. Land-based photos taken during these seasons were also used to assist in delineating vegetation type boundaries. The vegetation map produced for the KRC can be considered a 'potential natural vegetation' map, as areas currently used for crop lands, gardens or infrastructure are not mapped as such on the vegetation map, but rather as the vegetation type one is likely to find there, excluding human developments.

Most of the vegetation types discussed here extend beyond the borders of the KRC. In certain cases the same names were used as in the national vegetation map (Mucina and Rutherford, 2006) for vegetation entities considered to be essentially the same unit, or subunits of a particular national level unit. This is important for establishing and maintaining links to the greater body of literature that is available on that particular vegetation type outside the KRC. However the descriptions presented here only strictly apply to the parts of these broader units that are mapped within the KRC. For example the Woodbush granite grasslands extend further to the south of the KRC. These areas may no longer be accurately described by the description for the parts mapped and discussed here.

A list of all vascular plant species collected from five quarter degree grids (2329DB & DD, 2330CA, CC & CB) that overlap with the KRC was obtained from the Plants of Southern Africa online checklist (available at http://posa.sanbi.org/searchspp.php, accessed 15/03/2013). From this checklist the species of conservation concern (red-listed species as listed by Raimondo et al. (2009)) were highlighted and discussed with reference to their likely distribution in the KRC. See Appendix 2.1 for the current, yet incomplete, plant species check list of the KRC. Voucher specimens of all collected taxa are housed at the H.G.W.J. Schweickerdt herbarium (PRU), with duplicates in an in-house collection at ZZ2 and at the Larry Leach herbarium at the University of Limpopo.

2.4. Results

The hierarchical vegetation classification structure (Figure 2.2) and vegetation map (Figure 2.3) of the 40 689 hectare Koedoes River Catchment (KRC) is presented here. We identified and described four broad topo-climatic zones based on topographic and climatic parameters. Nesting into these zones, twelve vegetation types were identified and described. All the described units were mapped with the exception of the Montane wetlands (Mwet) vegetation (see section 3.3.3.1 for reasons). A further eighteen distinct plant communities which nest within the vegetation types, but are considered below the functional mapping scale, are also identified and described (in chapter 3) but not mapped.

Table 2.1 summarizes the surface area (in hectares) and percentage area of the KRC covered by each vegetation type. The Lowveld topo-climatic zone is the largest, covering 76% of the KRC. Fifty-nine percent of the catchment is covered by the Tzaneen sour bushveld plains (Lpla) vegetation type, while Tzaneen sour bushveld slopes (Lslo) is the second most common vegetation type at 14.5% of the KRC. Groups like Montane wetlands and streams (Mwet) and exposed rock faces (Aroc) are negligibly small in terms of surface area covered. The Lowveld and Highveld topo-climatic zones fall within the savanna biome, while the Montane zone is characterized by the forest and grassland biomes.

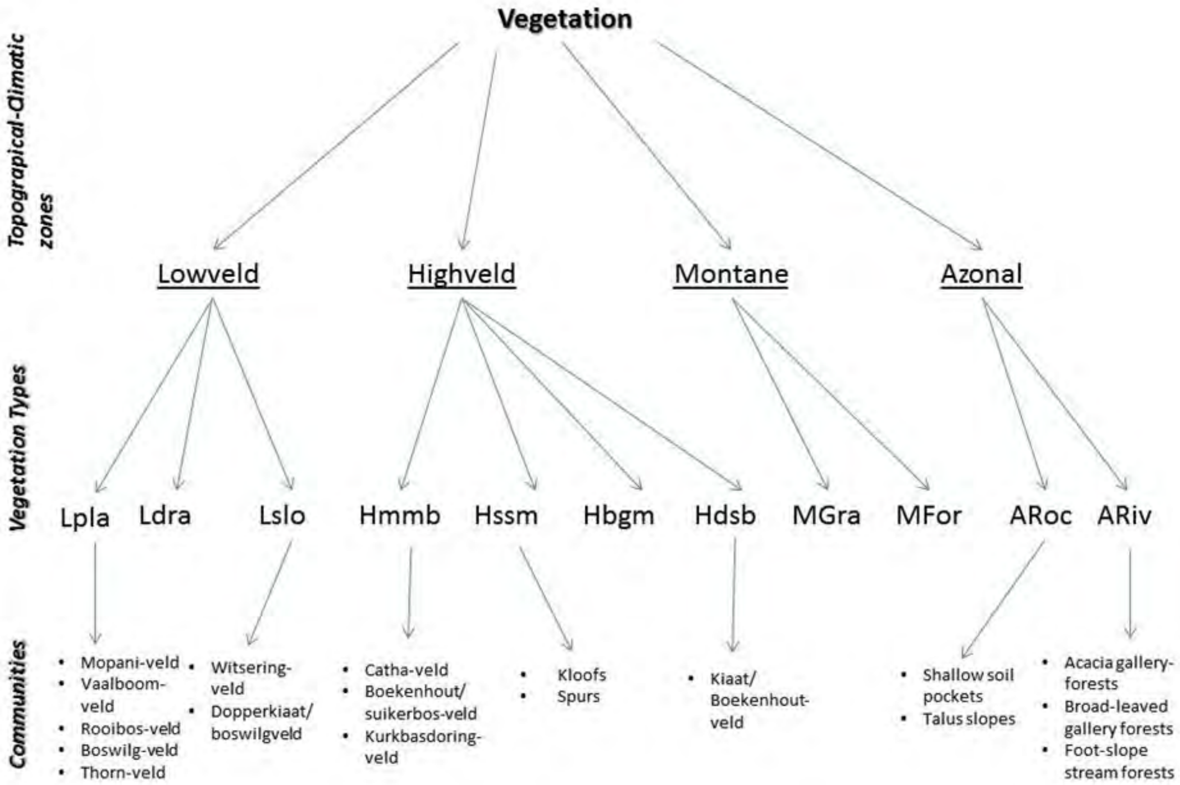


Figure 2.2 Hierarchical classification structure for the vegetation of the Koedoes River Catchment. See Table 2.1 for definitions to the abbreviations.

Forty-nine red-listed plant species are likely to occur in the KRC (see Appendix 2.2). The KRC's smallest topo-climatic zone seems to be the richest in threatened plant species. Thirty-two of these species are likely to occur in the Montane region of the catchment, while eleven and ten species can be expected in the Highveld and Lowveld respectively. Further, fifteen of the 47 indigenous tree species listed as protected by the National forests Act 84 of 1998, have been recorded in the KRC (see Appendix 2.3).

2.5. Discussion

This chapter developed a rapid approach for mapping ecological units based on vegetation patterns. The factors driving the observed diversity patterns are complex, multi-faceted and operate at different temporal and spatial scales. Below we discuss some of the landscape and local scale vegetation patterns and their possible drivers as well as some noteworthy additional observations regarding vegetation patterns and processes.

2.5.1. Vegetation patterns

2.5.1.1. Climate as the driver of vegetation patterns

When considering the spatial and topographical distribution of vegetation types across the catchment, we can make the following deductions regarding the driving forces of biodiversity patterns. With the exception of a few localized phenomena (see Appendix 2.4), factors such as geology, soils, wind, and insolation play a relatively small role in forming and maintaining the vegetation structure of any specific area within the catchment. Regarding the main drivers behind vegetation patterns in the KRC, we reach a similar conclusion to that of Scheepers (1977) after his seminal work on the vegetation of the nearby Westfalia estate. Two associated variables explain the variety in vegetation patterns best: topography and climate. Moist air moves in from the east across the flat plains of the Lowveld. Upon reaching the topographic barrier of the escarpment – in this case Rakgwale ridge – the air moves up into the atmosphere, causing it to cool and the moisture to condense, ultimately precipitating as rain or mist. The eastern side of Rakgwale ridge is much wetter than the west. The KRC thus lies within a rain shadow. The topography effectively dictates what the moisture regime will be. This phenomenon is referred to as the orographic effect and it is this availability of moisture at certain altitudes and eastern slope aspects that influences the vegetation patterns of the KRC most strongly. Figure 2.4 presents a diagrammatic east-west section through the KRC, illustrating the vegetation types in relation to precipitation.

Field observations do not suggest that the underlying geology contributes significantly to current vegetation patterns as may, for example, be witnessed on the Great Dyke in Zimbabwe (Van Wyk and Smith, 2001). It is however likely that some floristic elements may be restricted to the mafic rocks of the Pietersburg greenstone belt and diabase dykes, but the spatial scale and resolution of the current study was not fine enough to discern such patterns.

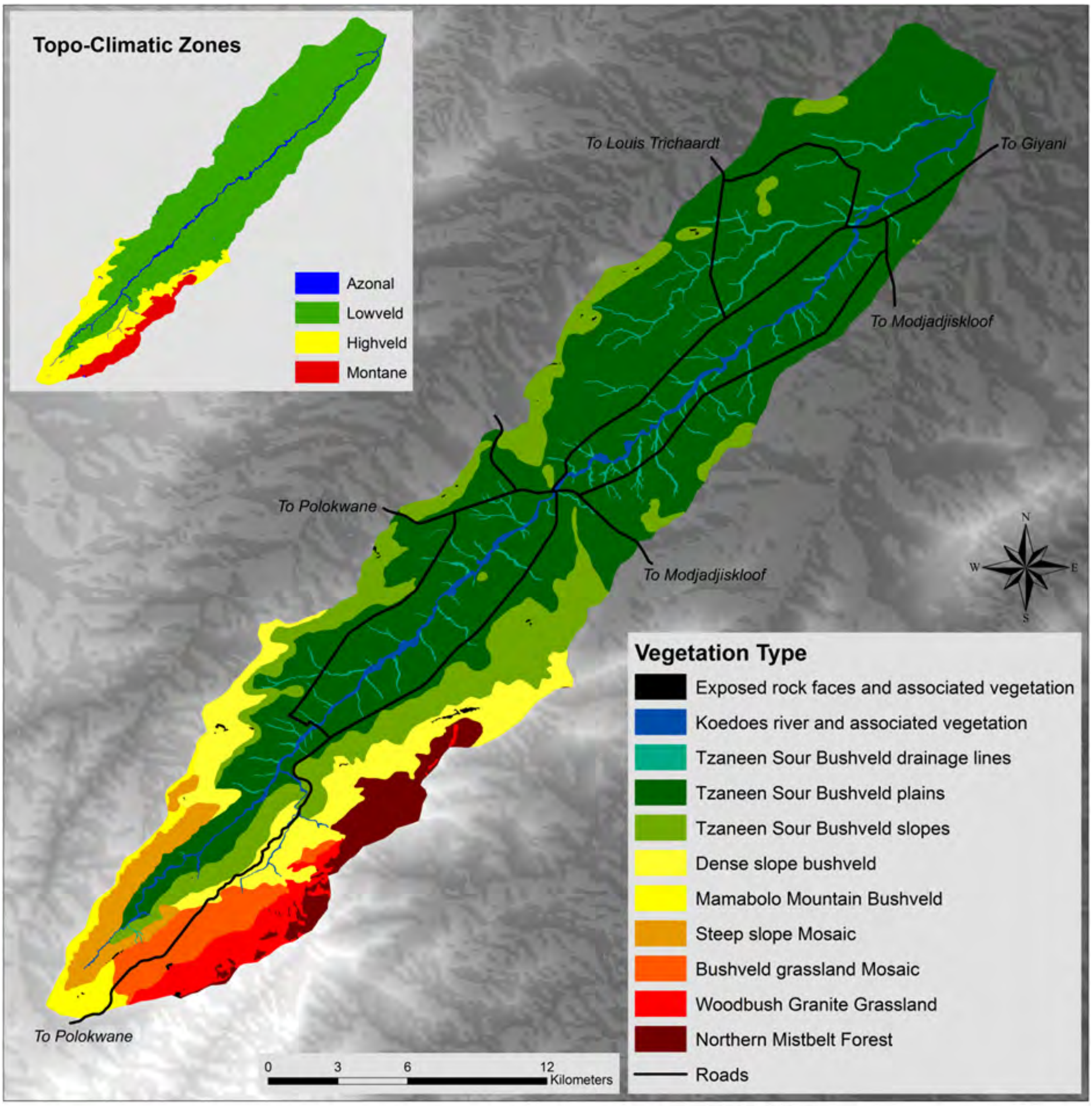


Figure 2.3 Map of the vegetation types of the Koedoes River Catchment with main roads and an insert map of the topographic-climatic zones.

Table 2.1 Extent (in ha) and relative size (%) of Koedoes River Catchment vegetation types.

Topo-Climatic zones	Vegetation types	Hectares	% of KRC
Lowveld		***30944***	***76.05***
	Lpla - Tzaneen sour bushveld plains	24110	59.25
	Lslo - Tzaneen sour bushveld slopes	5912	14.53
	Ldra - Tzaneen sour bushveld drainage lines	922	2.27
Highveld		***6313***	***15.52***
	Hdsb - Dense slope bushveld	3217	7.91
	Hbgm - Bushveld grassland Mosaic	1267	3.11
	Hssm - Steep slope mosaic	1126	2.77
	Hmmb - Mamabolo mountain bushveld	704	1.73
Montane		***2472***	***6.08***
	Mwet - Wetlands and mountain streams	-	-
	Mfor - Northern mistbelt forest	1348	3.31
	Mgra - Woodbush granite grassland	1124	2.76
Azonal		***959***	***2.36***
	Ariv - Koedoes River and associated veg.	899	2.21
	Aroc - Exposed rock faces and associated veg.	60	0.15
TOTAL		**40689ha**	**100%**

2.5.1.2. Vegetation transitions and mosaics

The transition from one vegetation type to another is seldom clear-cut and easily discernable in the field. Most vegetation types grade gradually from one to another over large distances and the transition becomes blurry. We identified two types of vegetation boundaries – sharp and gradual. However, to make the vegetation map (Figure. 2.3) more legible, all boundaries are indicated as clear lines representing the approximated middle of the transitional zone. Figure 2.5 indicates how the different vegetation types of the KRC adjoin one another – whether it is a clear, rapid transition or a diffuse, gradual transition.

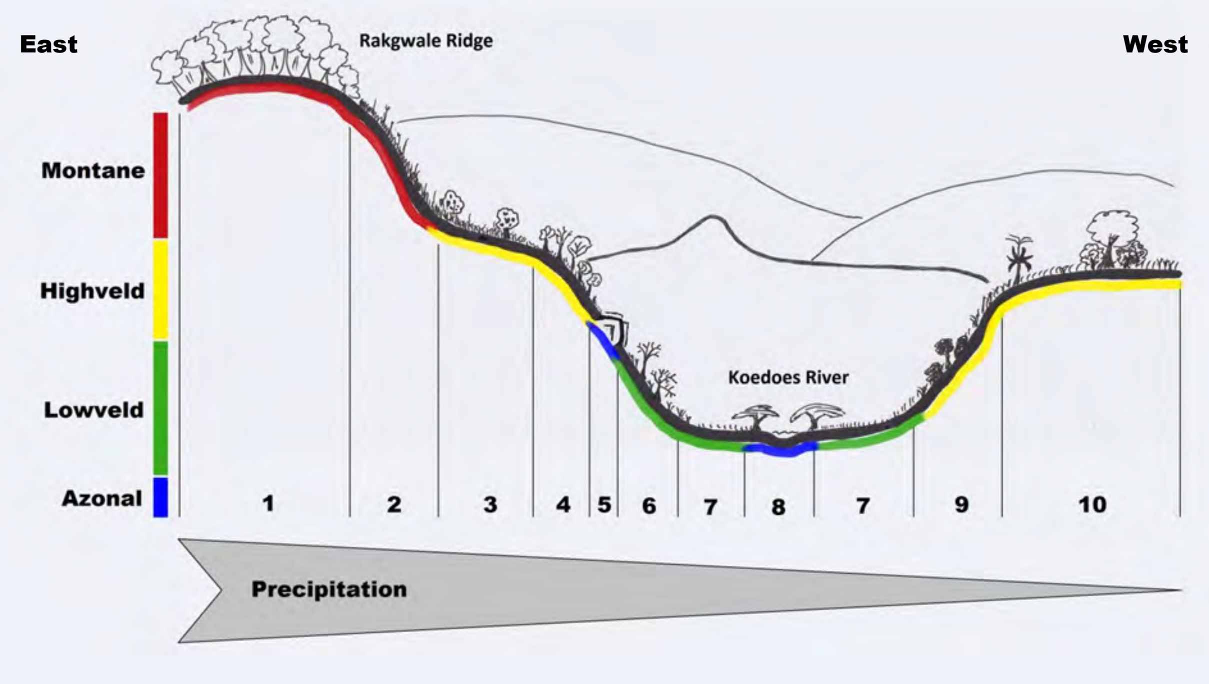


Figure 2.4 A simplified east-west section through the Koedoes River Catchment, showing the relationship between vegetation and precipitation. 1. Northern mistbelt forest (Mfor). 2. Woodbush granite grassland (Mgra). 3. Bushveld grassland mosaic (Hbgm). 4. Dense slope bushveld (Hdsb). 5. Exposed rock faces (Aroc). 6. Tzaneen sour bushveld slopes (Lslo). 7. Tzaneen sour bushveld plains (Lpla). 8. Koedoes River and associated vegetation (Ariv). 9. Steep slope mosaic (Hssm). 10. Mamabolo mountain bushveld (Hmmb).

The vegetation concept of 'mosaic' is introduced here to describe two vegetation types (steep slope mosaic [Hssm] and bushveld/grassland mosaic [Hbgm]). The vegetation of these mosaic units do not have an even physiognomy throughout and large variations in vegetation structure and composition can occur over relatively short geographic distances at the mapping scale used. In some cases mosaics are a way of dealing with scale related mapping issues, e.g. if the mapping was done at a finer scale the mosaic could be split into two units and if the mapping was done at a coarser scale, the mosaic and its two adjacent units might all have been lumped together as a single unit. In this case, however, the mapped mosaics are considered to be ecological units in their own right and not mapping artefacts. These mosaics are distinct eco-tones with unique ecological processes not found in adjacent units. Two other, smaller units (riverine habitats [Ariv] and exposed rock faces [Aroc]) also display an uneven physiognomy, but are not considered mosaics. The great variation in vegetation structure and composition in these units are attributed to the frequent and uneven disturbance regimes in these riverine and cliff-face units.

2.5.1.3. Historical distribution of vegetation types and Red-listed species

The KRC has been subject to varied land-use practices throughout the last century (see Changuion (2007) and Wongtschowski (2003) for the biographies of two individuals that grow up and lived in and around the KRC). It has been shown elsewhere that changes in vegetation structure and composition can be attributed to human land-use and land-management practices. In the case of crop farming it is most clear (e.g. Karlowski (2006)), but grazing regimes may also have lasting effects on vegetation diversity and structure (e.g. Higgins et al. (1999) and Parsons et al. (1997)). The suppression or increase of fire also has a major impact on vegetation structure and composition (discussed in Appendix.2.4). Figure 2.6 shows the same mountain slope at two different times - 1938 and 2008. It is strikingly clear how grasslands have been replaced by more woody communities over the seventy year period. A near complete dataset of historical aerial photos exists for the KRC and a detailed analysis of the historical vegetation patterns is suggested. This may help to identify the drivers of the dramatic changes that seem to have taken place and may shed some light on possible trends and inform future management practices.

A very large number of rare, endangered or protected plant species occur in the relatively small KRC. This means that one is likely to encounter a very high density of species of significance in the remaining natural areas. The ongoing protection and appropriate management of natural areas in the KRC should thus be an area of immediate and intense focus as the major threats to the continued existence of these significant plants seem to be habitat destruction and indiscriminate collection for medicinal and commercial uses.

2.5.1.4. Local scale vegetation patterns

A number of peculiar vegetation patterns on a very local scale occur in parts of the KRC. It is this local heterogeneity of vegetation structure that contributes to, and provides habitat for, the great biodiversity found in the KRC. The most noticeable of these patterns, including bush clumps, bush lines, management lines and localised orographic effects are discussed in Appendix 2.4. The likely causes of these patterns and management considerations are explored.

(I) Clear transition
(O) Unclear transition
(-) No interface

	L - Tzaneen sour bushveld plains	L - Tzaneen sour bushveld slopes	L - Tzaneen sour bushv. drainage	H - Dense slope bushveld	H - Bushveld/grassland mosaic	H - Steep slope mosaic	H - Mamabolo mountain bushveld	M - Mistbelt forest	M - Woodbush granite grassland	A - Riverine	A - Exposed rock faces
L - Tzaneen sour bushveld plains											
L - Tzaneen sour bushv. slopes	O										
L - Tzaneen sour bushv. drainage	I	I									
H - Dense slope bushveld	-	O	-								
H - Bushveld/grassland mosaic	-	-	-	I							
H - Steep slope mosaic	I	O	-	O	I						
H - Mamabolo mountain bushv.	-	O	-	-	O	I					
M - Mistbelt forest	-	-	-	O	-	-	-				
M - Woodbush granite grassland	-	-	-	O	O	-	O	I			
A - Riverine	I	I	O	I	-	-	-	-	-		
A - Exposed rock faces	-	I	-	I	I	I	I	-	I	-	

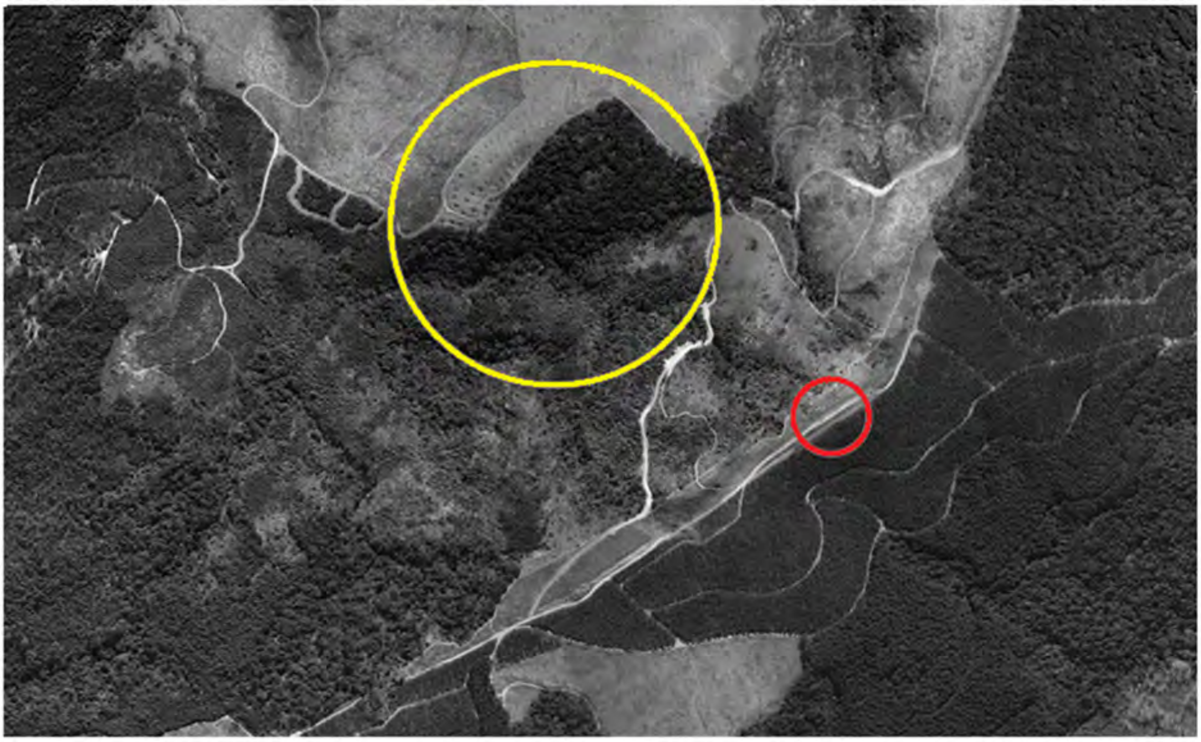
Figure 2.5 The nature of transitions between vegetation types in the Koedoes River Catchment. Transitions are either sharp [I] or gradual [O]. Some vegetation types share no interface [-].

2.5.2. Strengths and limitations of the approach

A number of the vegetation types mapped here can be linked to mapped units from other authors' work. Scheepers (1977) mapped eight vegetation units on the adjacent Westfalia estate. Only four vegetation types are mapped in the KRC area on a national scale by Mucina and Rutherford (2006), with elements from another three of their adjacent vegetation types that are likely to occur in the KRC. Acocks (1953) divided the region into two of his renowned veld types. Table 2.2 is a summary of how the vegetation classification presented here links with the work by above mentioned authors. In creating vegetation maps at a national scale, Mucina and Rutherford (2006) and Acocks (1953) seemed to rely more heavily on edaphic factors to guide their groupings (e.g. sourveld), while Scheepers' (1977) finer-scale map and the current KRC map presented here are informed by climate and topography to a greater extent. This is a scale-related phenomenon, as edaphic variation over a quaternary catchment scale is not enough to explain all observed variation in vegetation structure and composition.

We consider the rapid vegetation mapping technique used here as successful. Mucina et al., (2006b) defines the basic element of the map – the vegetation type – as: “A complex of plant communities ecologically and historically occupying habitat complexes at the landscape scale” and that definition applies to the vegetation map of the KRC produced by this study. Like the useful soil capability classification system of Klingebiel & Montgomery (1961), our approach to the rapid classification of vegetation patterns in the KRC is one of concepts and groupings intuitive to the human mind. We decided not to follow a rigorous methodology of random sampling and statistical analyses to produce a computer-assisted vegetation map of the area for several reasons: 1) such an approach is time-consuming because the area to sample is large with much fine-scale heterogeneity in vegetation patterns which is hard to map; and 2) as this map is primarily intended for use by the local land owners and farmers, an intuitive map is far more attractive and useful to the stakeholders. However, preliminary efforts to validate the map using vegetation plot data suggest that the results of both approaches may be well-correlated.

Although such approach may be criticised as being arbitrary, intuitive and subjective, many landmark vegetation maps were created using a similar ‘intuitive’ approach e.g. Acocks’ Veldtypes of South Africa (1953), Van Wyk & Smith's Regions of Floristic Endemism (2001) and Plants of the Klein Karoo by Vlok & Schutte-Vlok (2010) to name a few. Van Wyk & Smith (2001) describes their method as that of ‘perception and intuitive discernment’. Their (and this) approach harnesses the ability of the human mind and eye to analyse (sometimes unconsciously) large amounts of visual and factual inputs to determine patterns very rapidly and effectively. We are of the opinion that our approach is justified, considering temporal and spatial scale constraints. John Platt (1964) writes in his landmark paper titled ‘Strong inference’ that “you can catch phenomena in a logical box or a mathematical box. The logical box is coarse but strong. The mathematical box is fine-grained but flimsy. The mathematical box is a beautiful way of wrapping up a problem, but it will not hold the phenomena unless they have been caught in a logical box to begin with.” Likewise, the KRC vegetation map can be seen as contained in the strong but coarse logical box. It may



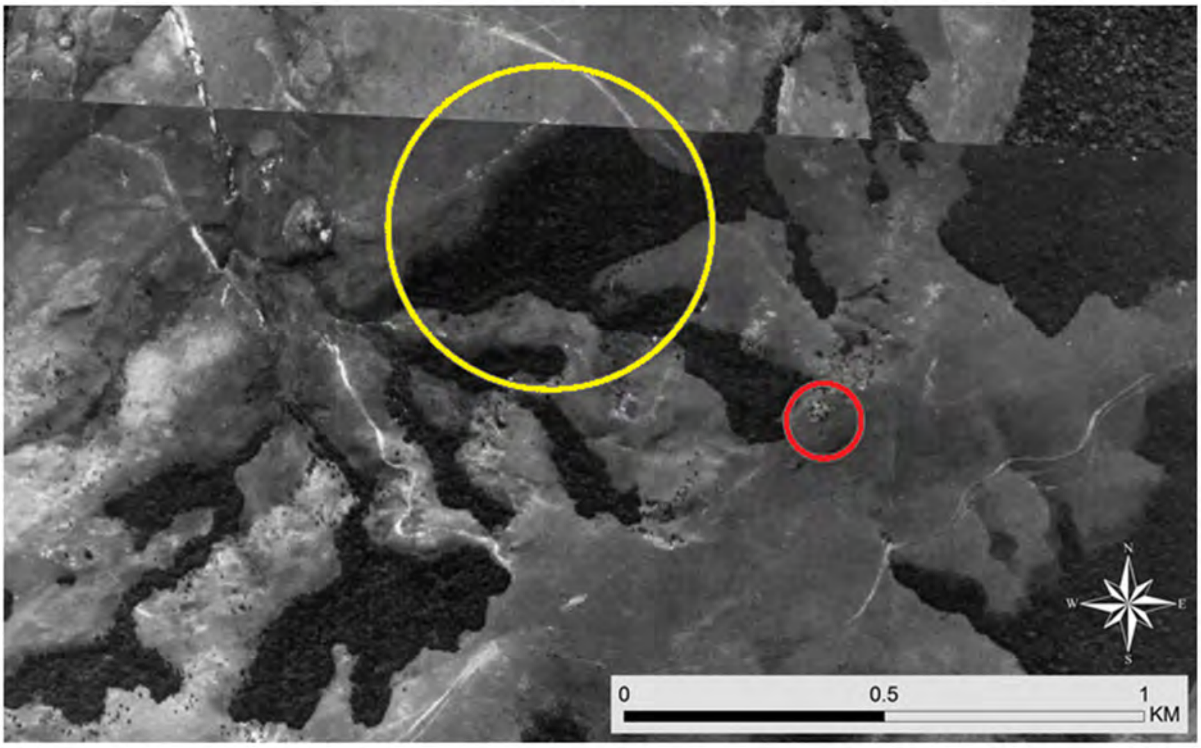


Figure 2.6 Aerial photos of a section of the Koedoes River Catchment, showing the change in vegetation between 1938 (bottom) and 2008 (top). Coloured circles are for reference and orientation purposes.

yet be wrapped in the mathematical box by testing and refining the mapping units and boundaries through statistical analyses.

Table 2.2 The current Koedoes River Catchment vegetation types and their closest comparable units, as mapped by other authors at varying scales.

KRC vegetation type	*Comparable units as defined by other authors* Mucina & Rutherford (2006) vegetation unit	Acocks (1953) veld type	Scheepers (1977) vegetation unit
Tzaneen sour bushveld plains (Lpla)	Tzaneen Sour Bushveld (sVl 8)	Lowveld sour bushveld	Lowveld sour bushveld
Tzaneen sour bushveld slopes (Lslo)	Tzaneen Sour Bushveld (sVl 8)	Lowveld sour bushveld	Lowveld sour bushveld transition zone
Tzaneen sour bushveld drainage lines (Ldra)	-	-	-
Bushveld-grassland mosaic (Hbgm)	Mamabolo Mountain Bushveld (sVcb 24), Woodbush Granite Grassland (Gm 25)	North-eastern mountain sourveld	Lower montane-forest zone; Marginal mistbelt
Steep slope Mosaic (Hssm)	Mamabolo Mountain Bushveld (sVcb 24), Tzaneen Sour Bushveld (sVl 8), Woodbush Granite Grassland (Gm 25)	North-eastern mountain sourveld	Submontane scrub-forest belt
Dense slope bushveld (Hdsb)	Mamabolo Mountain Bushveld (sVcb 24), Tzaneen Sour Bushveld (sVl 8)	North-eastern mountain sourveld	Low scrub-forest zone
Mamabolo mountain bushveld (Hmmb)	Mamabolo Mountain Bushveld (sVcb 24)	North-eastern mountain sourveld	-
Northern mistbelt forest (Mfor)	Northern Mistbelt Forest (Foz 4)	North-eastern mountain sourveld	Upper; Middle; Lower montane-forest zone
Woodbush granite grassland (Mgra)	Woodbush Granite Grassland (Gm 25)	North-eastern mountain sourveld	Upper; Middle; Lower montane-forest zone
Exposed rock faces and associated vegetation (Aroc)	-	-	-
Koedoes River and associated vegetation (Ariv)	Lowveld Riverine Forest (FOa 1), Subtropical Alluvial vegetation (AZa 7)	Lowveld sour bushveld	Lowveld sour bushveld transition zone

2.6. Conclusion

This chapter presents a rapid approach to map and classify vegetation. It was applied in the agriculturally important Koedoes River Catchment (KRC), where twelve vegetation types that nest into four broad zones based on topographic and climatic parameters where identified and mapped. At 59%, Lowveld sour bushveld plains (Lpla) is the most extensive vegetation type in the KRC, followed by Lowveld sour bushveld slopes (Lslo), at 14.5%, and Dense slope bushveld (Hdsb), at 7.9%. All other vegetation types each cover less that 3.5% of the catchment. The KRC is home to more than 450 species of indigenous vascular plants, 32 of which are red-listed by the IUCN (Raimondo et al., 2009). Local scale vegetation patterns contribute to structural, functional and species diversity of vegetation types. The vegetation patterns are best explained by climate and topography and in parts of the KRC, current vegetation patterns differ drastically from those of 80 years ago. Local scale farm management practices – most notably fire suppression – is believed to influences vegetation structure and diversity negatively. The technique we applied worked well as a rapid approach to establish a measure of the diversity of vegetation in the KRC. The vegetation map produced here formed the basis of a catchment-wide biodiversity assessment and ES mapping exercise (chapter 4) and has been used by decision makers to plan new residential and commercial developments in the catchment.

CHAPTER 3: A DESCRIPTIVE ACCOUNT OF THE VEGETATION TYPES OF THE KOEDOES RIVER CATCHMENT, LIMPOPO.

3.1 Introduction

The 40 000 hectare Koedoes River Catchment (KRC) in South Africa’s Limpopo Province is rich in biodiversity. The catchment covers a large altitudinal and rainfall gradient and has a heterogeneous topography ranging from high mountains to rolling plains, koppies and alluvial flood plains. It is of enormous agricultural importance because a major component of South Africa’s gross tomato crop comes from this catchment. Unlike many other catchments subjected to intensive agricultural land use, large parts of this catchment are still covered by natural vegetation. Vegetation in itself can be considered a form of biodiversity. In many cases vegetation maps and accompanying descriptions serve as a departure point when ecologically based research or monitoring is undertaken. Euston-Brown (1999), Scheepers (1977), Vlok & Schutte-Vlok (2010) and Von Breitenbach's (1974) work are examples of regional vegetation maps. The aim of this chapter, in the fashion of the authors mentioned above, is to offer a detailed descriptive account of the vegetation units mapped for the agriculturally important Koedoes River Catchment (KRC). In the previous chapter the rapid method we employed to map the vegetation at a quaternary catchment scale was described and a synopsis of the results provided and discussed. In the chapter following this one, the resulting maps are applied to an ecosystem services (ES) survey of the catchment.

3.2 Methods

Each one of four topographic-climatic zones (see chapter 2) identified for the Koedoes River Catchment (KRC) was described in terms of geology, geomorphology, climate, soils and human land use. Climate data from twelve different Davis weather stations operated by ZZ2 throughout the KRC was used to represent the climate of the three topographical-climatic zones of the catchment (see section 3.3 for further discussion on climate). Information on soils was extracted from the Land Capability dataset of Schoeman et al. (2002) and from personal observations. Information on the geology of the region was gleaned from SA council for Geoscience 1:250 000 geological maps (2328 Pietersburg and 2330 Tzaneen, both of 1985).

The mapped vegetation types and associated plant communities are described in terms of physiognomy, characteristic landscape features, relationships to other vegetation units and distribution. For each vegetation unit, a characteristic and ecologically important indigenous species, invasive plant species, and photographs are presented. For some of the more heterogeneous vegetation types a number of distinct communities are described briefly. In addition, we also offer a brief discussion on the conservation status of each vegetation type. We adopt Huntley's (1989) definition of *conservation status*; "…the extent to which populations, species or communities have been modified by the influence of industrial man, and the degree to which they may be expected to maintain their diversity and ecological processes in the medium term (10 to 100 years)."

The conservation status of vegetation classes at a national scale was adopted from Mucina and Rutherford (2006). At the local scale, the level of intactness of the vegetation types was calculated by overlaying the distribution of each vegetation type with a detailed land use map of the KRC (presented in chapter 4). From the resulting map one can see how much of each vegetation type is still intact, degraded or transformed. All species names are supported by herbarium specimens housed at the H.G.W.J. Schweickerdt herbarium (PRU) – see the species list in Appendix 2.1 for more detail.

3.3 Description of vegetation units

3.3.1 Lowveld

Geologically, most of the Lowveld zone falls on the Goudplaats gneiss, with the tops of most of the koppies being part of the Zandrivierspoort formation. The topography is flat to undulating plains with some rocky koppies dotted around the landscape. Lowveld conditions are typically encountered below 900 m.a.s.l. The northern and central sections of the KRV can be considered Lowveld.

Climatically, the Lowveld zone is characterized by very hot, humid summers and dry, warm winters. In winter frost may occur patchily. The mean monthly minimum temperature for the coldest month is 8.7°C and the mean monthly maximum for the hottest month is 30.2°C (measured at six privately operated Davis weather stations throughout the KRC Lowveld from January 2003 to May 2014). Precipitation occurs primarily in the summer and about 620mm can be expected per year (Figure 3.1). Thunderstorms, often with hail, are common in the summer months. Soils are generally deep, loamy to gravelly with moderate clay content and are well drained. These are good agricultural soils and heavily utilized.

Prior to the settling of the KRC by people from European descent, a number of small African tribes used the land mainly on a nomadic basis (Changuion, 2007). Little is known about their land-use practises in the KRC, but it is generally believed that their activities did not have a major impact on vegetation structure and biodiversity patterns. European settlers started developing and cultivating the Lowveld regions of the KRC in the first decade of the 20th century (Changuion, 2007). After the effective control of malaria in the late 1920's and early 1930's by spraying a pyrethrum compound, the human population and agricultural activities in the Lowveld increased (Hilton-Barber, 2011). Today the Lowveld area is the most developed and economically active part of the KRC.

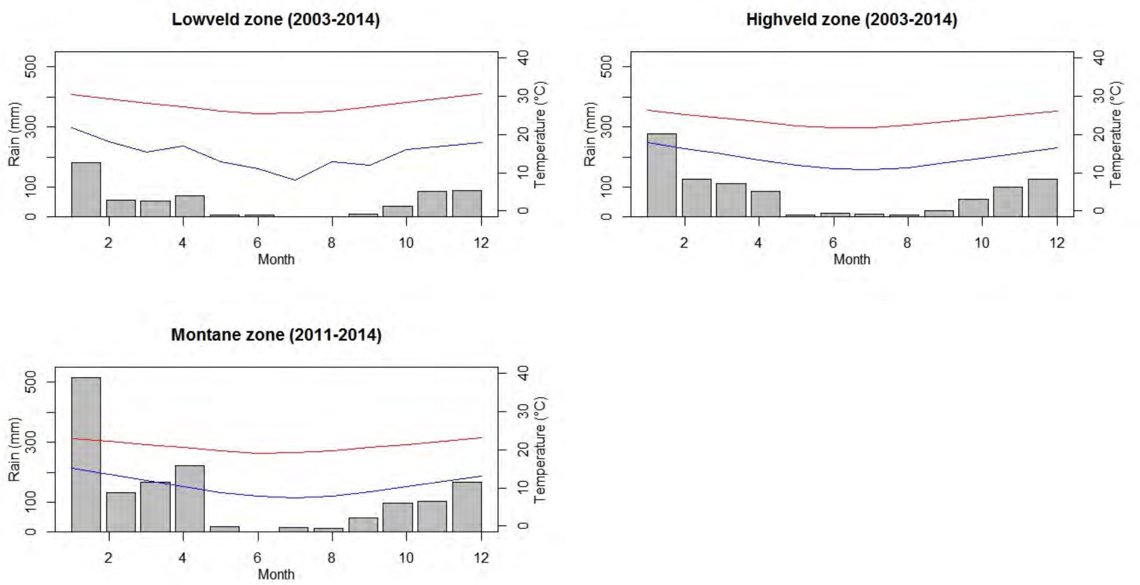


Figure 3.1 Climate diagrams for the three topo-climatic zones of the Koedoes River Catchment. *Rain:* Y-axis on the left, showing average monthly rainfall in mm (The average monthly rainfall for January may be exaggerated by two very heavy rainfall events on 11-12 Jan 2011 and 23-24 Jan 2014) *Temperature:* Y-axis on the right, showing the average daily minimum (blue) and maximum (red) temperatures throughout the year.


Figure 3.2 Tzaneen sour bushveld plains (Lpla) at the end of winter (left) and late summer (right).

3.3.1.1 Tzaneen sour bushveld plains (Lpla)

3.3.1.1.1. *Distribution and landscape features*

The Tzaneen sour bushveld plains occur in the lower lying (580-950 m.a.s.l.) northern and central regions of the catchment, with a narrow band extending far south along the river. The landscape is characterized by the relatively flat (<15° slope) plains of the valley bottom.

3.3.1.1.2. *Physiognomy (vegetation features)*

This vegetation type is a typical savanna or bushveld. Medium to tall sized (mostly deciduous) trees with a well-developed grassy layer below. Tree canopy cover is estimated at 70% in summer. A shrubby component is also present but unevenly distributed. With over grazing and fire suppression the shrub component increases and can completely out-compete the grasses.

3.3.1.1.3. *Relationship to other vegetation maps*

National: Nests with Tzaneen sour bushveld drainage lines (Ldra) and Tzaneen sour bushveld slopes (Lslo) into the Tzaneen Sour Bushveld (SVl 8) of Mucina and Rutherford (2006) and Acocks' (1956) Lowveld Sour Bushveld. A gradual transition exists into Mucina & Rutherford's Granite Lowveld (SVl 3) vegetation type to the north-east (no homologue mapped here). See Table 2.2.

Regional: Corresponds partially with the Lowveld Sour Bushveld unit of Scheepers (1977). See Table 2.2.

3.3.1.1.4. *Relationship to other vegetation units on KRC map*

Transitions to the Azonal riverine vegetation (Ariv) type are always distinct and due to a sharp moisture gradient. Transitions to Tzaneen sour bushveld slopes (Lslo) are usually not clear and may vary locally based on aspect and relief. Transitions to Tzaneen sour bushveld drainage lines (Ldra) are relatively clear and based on a moisture gradient and localized topographic features such as dongas and gulleys. The transition into steep slope mosaic (Hssm) is fairly distinct in most cases (see Hssm description). See figure 2.5.

3.3.1.1.5. *Conservation status and threats*

The Tzaneen sour bushveld plains (Lpla) covers more than half of the Koedoes River Catchment (59.2%) but is also one of the most heavily utilised for agriculture due to its favourable topography, soils and proximity to water. In this catchment, less than 25% of Lpla remain in an almost completely natural state. 27% of the Lpla can be considered degraded due to bush encroachment, alien invasion and fragmentation, while the remainder is completely transformed into agricultural production landscapes. The homologue at national level for Lpla is considered endangered due to a small geographic extent and severe transformation and degradation (Rutherford et al., 2006). Transformation due to crop agriculture and degradation caused by fragmentation, over-grazing, encroachment and invasive plants remain the biggest threat to ecological functioning and biodiversity in this vegetation type.

3.3.1.1.6. *Distinct vegetation communities*

3.3.1.1.6.1. Mopani-veld

A community clearly dominated by dense stands of tree-sized and shrubby forms of *Colophospermum mopane*. Stands appear mono-specific as few other tree species seem to grow among *C. mopane*. The grassy layer is usually not well-developed. It is unlikely to find isolated specimens of *C. mopane* in communities other than mopani-veld. Mopani-veld occurs sporadically in isolated patches, always on very flat ground and is most common in the far northern reaches of the KRC. Patches of Mopani-veld can be seen along Jachtpad, directly north of the airfield and along the Lemondokop road and R81 north of the Lemondokop turnoff. No Mopani-veld has been seen south of the R81/R36.

3.3.1.1.6.2. Vaalboom-veld

This community is dominated by trees of the species *Terminalia sericea*. Stands appear to be nearly mono-specific in terms of the woody component, but a diversity of grasses is usually present. Unlike *C. mopane, T. sericea* may be encountered in communities other than Vaalboom-veld. Vaalboom-veld occurs sporadically in isolated patches, usually on flatter ground with sandy soils. A good example is along the Vreedsaam road driving south, on the eastern side of the road, side just before reaching the Westfalia avocado orchards.

3.3.1.1.6.3. Rooibos-veld

Combretum apiculatum, a shrub to small tree, is well represented in this structurally diverse community. Occasional large trees of various species tower above the smaller *C. apiculatum*. A diversity of grasses and other shrubs are also present, making this a plant community favoured by grazers and browsers alike. Rooibos-veld is common in the KRC and may occur on the flat plains and gentler slopes. Rooibos-veld can be seen in the Cordier conservancy.

3.3.1.1.6.4. Boswilg-veld

Boswilg-veld is characterised by the common occurrence of *Combretum collinum* subsp. *suluense*. This community is less clearly defined in the field than any of the others mentioned here. It is a heterogeneous looking bushveld of small to medium sized trees, usually occurring on gentle slopes. This community can be seen along the Houtbosdorp and Vreedsaam roads.

3.3.1.1.6.5. Thorn-veld

Thorn-veld in this context is a woody community dominated by trees or shrubs with spines, most notably *Acacia karroo, A. rehmanniana* and *Dichrostachys cinerea.* These communities usually have low species richness and are mostly associated with historical disturbance such as ploughing or over-grazing. An example of *A. karroo* dominated thorn-veld can be seen along the Houtbosdorp road, immediately south of the Westfalia Deelkraal entrance, while examples of *D. cinerea* dominated thorn-veld can be seen along Jachtpad and in the Cordier conservancy.

3.3.1.1.7. *Important taxa*

3.3.1.1.7.1. Common or characteristic local species

Some of the most characteristic trees closely associated with the Tzaneen sour bushveld plains (Lpla) vegetation type are *Diospyros mespiliformis, Sclerocarya birrea, Peltophorum africanum, Philenoptera violacea, Bolusanthus spesiosus, Combretum imberbe* and *Acacia nigrescens.*

Figure 3.3 Tzaneen sour bushveld slopes (Lslo) in autumn (left) and summer (right). The distinct autumn colours of *Kirkia acuminata* can be clearly seen on the left.

3.3.1.1.7.2. Invasive plants of most concern

Due to poor past management, many of the remaining fragments of this vegetation type has become encroached by *Dichrostachys cinerea. Lantana camara* is a very common and problematic invader in this vegetation type.

3.3.1.2 Tzaneen sour bushveld slopes (Lslo)

3.3.1.2.1. *Distribution and landscape features*

The Tzaneen sour Slopes vegetation occurs on the koppies and ridges adjacent to the Tzaneen sour bushveld plains (Lpla) in the lower lying (600-1000 m.a.s.l.) northern and central regions of the catchment. The landscape is characterized by rocky slopes (>20°).

3.3.1.2.2. *Physiognomy (vegetation features)*

This unit's physiognomy is similar to that of Tzaneen sour bushveld plains (Lpla) – typical savanna or bushveld. Medium to tall sized (mostly deciduous) trees that are well spaced with a well-developed grassy layer below. A shrubby component is slightly denser and more often conspicuous in the Tzaneen sour bushveld slopes (Lslo) than in the Lpla. With over-grazing and fire suppression the shrub component increases and can completely out-compete the grasses.

3.3.1.2.3. *Relationship to other vegetation maps*

National: Nests with Tzaneen sour bushveld drainage lines (Ldra) and Tzaneen sour bushveld plains (Lpla) into the Tzaneen Sour Bushveld (SVl 8) of Mucina and Rutherford (2006) and forms part of Acocks' (1956) larger unit of Lowveld Sour Bushveld. See Table 2.2.
Regional: Corresponds partially with the Lowveld Sour Bushveld unit of Scheepers (1977). See Table 2.2.

3.3.1.2.4. *Relationship to other vegetation units on KRC map*

Transitions from Tzaneen sour bushveld slopes (Lslo) to the Azonal rock faces (Aroc) vegetation type are always distinct and due to an acute difference in substrate. Transitions to Tzaneen sour bushveld plains (Lpla) are usually not clear and may vary locally based on aspect and relief. The transition into Steep slope mosaic (Hssm) is not very clear and difficult to map due to the very similar physiognomy of both units. The transition to Dense slope bushveld (Hdsb) is fairly sharp and can be clearly observed in autumn, when leaf senescence of the elements from the different units is temporally separated by a few weeks. See figure 2.5.

3.3.1.2.5. *Conservation status and threats*

Tzaneen sour bushveld slopes (Lslo) is the second most common vegetation type in the KRC (14.5%) after the Tzaneen sour bushveld plains (Lpla). Unlike Lpla, the sloped topography and rocky soils of this unit makes it unfavourable for agricultural purposes. Thus it still remains 94% untransformed in the KRC. Sadly, large areas of this unit can be considered degraded due to bush encroachment and alien plant invasions, resulting from a lack of fires and in certain cases heavy grazing pressures. The extent of degradation, encroachment and invasion in this vegetation type is not mapped and quantified here, but should receive attention in future work.

3.3.1.2.6. *Distinct vegetation communities*

3.3.1.2.6.1. Witsering-veld

Characterized and dominated by large specimens (>8m) of *Kirkia acuminata* with a well-developed (although not very diverse) grassy layer dominated by *Panicum maximum*. Large and charismatic specimens of *Euphorbia ingens* are also associated with *Kirkia*-veld. It is open and easy to walk through despite the presence of many lianas and creepers. Found on very rocky or boulder strewn hill sides. *Kirkia*-veld can be seen on most of the rocky koppies of the Lowveld region.

3.3.1.2.6.2. Dopperkiaat/boswilg-veld

Characterized and dominated by small to medium sized (4-8m) specimens of *Pterocarpus rotundifolia* and *Combretum collinum* subsp. *suluense*. The sparse to well-developed grass layer is dominated by *Panicum maximum.* It is relatively easy to walk through Dopperkiaat/boswilg-veld, but one can generally not see much further than 20m through the vegetation in the summer. Found on deeper soiled and less rocky slopes than the Witsering-veld. A particularly nice example of this vegetation type can be seen on the slopes of the basin between Kranskop and the Boschrand hill (with cellphone tower).

3.3.1.2.7. *Important taxa*

3.3.1.2.7.1. Common or characteristic local species

Some of the most characteristic trees associated with the Lowveld bushveld slopes (Lslo) vegetation are *Kirkia acuminata, Euphorbia ingens* and *Pterocarpus rotundifolia.* In early spring individuals of *Dombeya rotundifolia* and *Steganotaenia araliacea* can be seen flowering on the slopes.

3.3.1.2.7.2. Invasive plants of most concern

Many of the smaller and fragmented pieces of this vegetation type are invaded by *Lantana camara* and *Chromolaena odorata.* Lianas such as *Macfaydena unguis-cati* are also prolific in areas.

<u>3.3.1.3 Tzaneen sour bushveld drainage lines (Ldra)</u>

3.3.1.3.1. *Distribution and landscape features*

The Tzaneen sour bushveld drainage lines (Ldra) vegetation type is associated with dongas and gulleys that drain the Tzaneen sour bushveld slopes (Lslo) and Tzaneen sour bushveld plains (Lpla) vegetation units. These drainage lines may harbour ephemeral streams after rainfall events.

3.3.1.3.2. *Physiognomy (vegetation features)*

The Tzaneen sour bushveld drainage lines (Ldra) is a very dense bushveld with a prominent shrub component. Trees are medium to large and may keep their foliage for a few weeks longer than those growing in the surrounding plains. The grassy component is less distinct and the dongas and gulleys that harbour the Ldra may provide some measure of protection against fire – explaining the greater density of woody elements.

Figure 3.4 A typical Tzaneen sour bushveld drainage line (Ldra) at the end of winter, pictured here as a line of evergreen trees in the matrix of deciduous Tzaneen sour bushveld plains (Lpla) vegetation.

3.3.1.3.3. *Relationship to other vegetation maps*

National: This vegetation unit is too small to have been recognised on any national level vegetation map. See Table 2.2.

Regional: Scheepers (1977) does not map any vegetation types that can be viewed as a homologue to the Tzaneen sour bushveld drainage lines (Ldra), but he does discuss several plant communities associated with drainage lines in his text. See Table 2.2.

3.3.1.3.4. *Relationship to other vegetation units on the KRC map*

Transitions to Tzaneen sour bushveld slopes (Lslo) and Tzaneen sour bushveld plains (Lpla) are relatively clear and based on a moisture gradient and localized topographic features such as dongas and gulleys. The transition into Riverine vegetation (Ariv) is much more gradual. The major difference being that the Ariv vegetation has access to shallow subsurface water for most of the year, while this may not be the case for Tzaneen sour bushveld drainage lines (Ldra). See figure 2.5.

3.3.1.3.5. *Conservation status and threats*

Due to the scattered distribution and small individual unit-sizes of this vegetation type, exact estimates of its conservation status could not be made at the scale of current mapping efforts. The Tzaneen sour bushveld drainage lines (Ldra) do not seem to be highly transformed, since most of the croplands are laid out to avoid drainage lines and it is in fact these drainage lines that form a network of corridors (colloquially called greenbelts) that inter-connect patches of natural vegetation. This unit faces threats from problematic invasive plants such as *Lantana camara* and *Chromolaena odorata.* It is also at risk of encroachment by woody elements and may be subject to species losses due to a lack of cyclical fires.

3.3.1.3.6. *Distinct vegetation communities*

No distinct communities within the Tzaneen sour bushveld drainage lines (Ldra) vegetation unit were recognised during the current work. It does not, however, mean that no such communities exist. Further phytosociological work would be required to identify and describe such communities.

3.3.1.3.7. *Important taxa*

3.3.1.3.7.1. Common or characteristic local species

Spirostachys africana and *Philenoptera violacea* is often seen in the Tzaneen sour bushveld drainage lines (Ldra), but other water loving trees such as *Syzygium cordatum, Combretum erythrophyllum* and *Ficus sur* may also be seen here.

3.3.1.3.7.2. Invasive plants of most concern

Some of the drainage lines are particularly badly invaded by *Lantana camara.* Other problem plants include *Ricinus communis* var. *communis* and *Chromolaena odorata.*

3.3.2 Highveld

Topographically the Highveld is characterised by rolling mountains, steep slopes and mountain plateaus. The Highveld topographic-climatic zone can be found in the southern and south-western parts of the KRC and Highveld elements are typically found between 800 and 1200 m.a.s.l. Three of the major geological groupings found in the KRC - the Pietersburg greenstone belt, Granites and Diabase dykes - can be seen in the Highveld areas. Soils are generally of the Glenrosa and Mispah forms, but steep slopes and a lack of surface water has prevented large scale agricultural use.

Figure 3.5 Bushveld/grassland mosaic (Hbgm) at mid-summer. Note the open nature of the vegetation, especially on the far slope below the pine plantation on the left. The small trees in the fore-ground are *Protea caffra*.

The Highveld zone is noticeably cooler that the Lowveld and drier than the Montane zone, primarily due to the steep moisture gradient from east to west across the KRC. The mean monthly minimum temperature for the coldest month is 6.8°C and the mean monthly maximum for the hottest month is 26.4°C (measured at four weather stations throughout the KRC and adjacent Highveld from January 2003 to May 2014). Precipitation occurs in the summer (Figure 3.1). Thunderstorms, often with hail, are common in the summer months. Rainfall varies markedly from east to west. It ranges from about 1480mm p.a. measured in the east to less than 540mm p.a. on the western Highveld. Historically and currently, there are very little human activities in the Higveld zone of the KRC. This is most likely due to the inaccessibility of many of the steep slopes and a lack of surface water.

3.3.2.1 Bushveld/grassland mosaic (Hbgm)

3.3.2.1.1. *Distribution and landscape features*

The Bushveld/grassland mosaic (Hbgm) vegetation occurs on the steep moisture gradient between the Highveld and Montane zones. It is essentially the interface between the

Mamabolo mountain bushveld (Hmmb) and Woodbush granite grassland (Mgra) units and elements of both vegetation classes are present. This unit is found on the flat to gently sloping mountain plateaus in the south-east of the catchment.

3.3.2.1.2. *Physiognomy (vegetation features)*

The physiognomy of the Bushveld/grassland mosaic (Hbgm) is very similar to that of the Mamabolo mountain bushveld (Hmmb) – an open savanna system with the trees small to medium sized (<6m) and usually spaced far apart. The grassy component is very prominent. It is separated from the Hmmb unit because there is good reason to believe that the Hbgm was in fact grasslands less than a century ago, before modern human activities altered the vegetation features on many different levels (see section 2.5.1.3 and Appendix 2.4).

3.3.2.1.3. *Relationship to other vegetation maps*

National: This unit has no homologues on the national scale vegetation maps. It is principally a unit that forms the transition between Mucina and Rutherford's (2006) Mamabolo Mountain Bushveld (SVcb 24) and Woodbush Granite Grassland (Gm 25) units. The mentioned units are also recognised in the KRC vegetation map, but at the much finer scale of this landscape level map it was possible to recognise the very complex transitional zone between these two units as a separate vegetation unit, something that is not feasible at a national scale. See Table 2.2.

Regional: This unit fits into Scheepers' (1977) Marginal mistbelt and Lower montane-forest zones. See Table 2.2.

3.3.2.1.4. *Relationship to other vegetation units on KRC map*

As mentioned above, the relationship of Bushveld/grassland mosaic (Hbgm) with Woodbush granite grassland (Mgra) and Mamabolo mountain bushveld (Hmmb) is complex. Hbgm is in essence one big transitional zone between Mgra and Hmmb. The boundaries of these three units indicated on the map are to a large extent speculative as the characteristics of the natural vegetation are obscured by transformation and invasive species in this part of the catchment. The transition to Steep slope mosaic (Hssm) and Dense slope bushveld (Hdsb) is clear and based on slope and a distinct change in physiognomy respectively. See figure 2.5.

3.3.2.1.5. *Conservation status and threats*

Large parts of this vegetation type have been invaded by alien species after attempts at farming a variety of crops failed. Only 38.4% is still in a relatively unaltered state.

Conserving this remaining portion should be a priority because this vegetation type – being the transition between Woodbush granite grassland (Mgra) and Mamabolo mountain bushveld (Hmmb) – is very rich in species. Threats to this vegetation type include further agri- and silvicultural development, fragmentation, bush encroachment and invasive species.

3.3.2.1.6. *Distinct vegetation communities*

As discussed above, the Bushveld/grassland mosaic (Hbgm) is essentially a transitional vegetation unit, consisting of various elements of Woodbush granite grassland (Mgra) and Mamabolo mountain bushveld (Hmmb). No distinct vegetation communities were identified for this unit, but some communities described for Hmmb may be found here, e.g. kurkbasdoring-veld.

3.3.2.1.7. *Important taxa*

3.3.2.1.7.1. Common or characteristic local species

Dombeya rotundifolia, Faurea rochetiana, Volkameria glabra, Acacia davyi, Carrisa edulis, Lippia javanica and *Clematis brachiata.*

3.3.2.1.7.2. Invasive plants of most concern

The most problematic invasives in this area are plants that were previously cultivated here for economic reasons. These include *Acacia melanoxylon, A. mearnsii, A. decurrens, Eucalyptus grandis* and *Psidium guajava. Pteridium aquilinum, Solanum mauritianum* and *Senna didymobotrya* are also expected to become more numerous if not controlled.

3.3.2.2 Mamabolo mountain bushveld (Hmmb)

3.3.2.2.1. *Distribution and landscape features*

Mamabolo mountain bushveld (Hmmb) occurs in the extreme southern and south-western parts of the KRC (usually between 1200-1600 m.a.s.l.). The landscape is characterized by relatively flat plateaus and gently rolling hills.

3.3.2.2.2. *Physiognomy (vegetation features)*

Figure 3.6 A typical Mamabolo mountain bushveld (Hmmb) landscape at the end of winter.

Mamabolo mountain bushveld (Hmmb) is a very open savanna system with the trees small to medium sized (<6m) and usually spaced far apart. The grassy component is very prominent and there are many succulents present, especially on rocky outcrops. An interesting phenomenon in this vegetation type is the formation of bush clumps. These are small patches of dense woody growth usually dominated by one or two big trees in the surrounding landscape of grass and sparse woody elements. The physiognomic structure and balance between woody and grassy elements are maintained primarily by fire.

3.3.2.2.3. *Relationship to other vegetation maps*

National: The KRC Mamabolo mountain bushveld (Hmmb) corresponds directly to that of Mucina and Rutherford's (2006) SVcb 24 and thus the same name is used. The current map however maps the unit’s boundaries at a finer and more accurate scale. Further, the Mamabolo mountain bushveld (Hmmb) will fall within Acocks’ (1953) broader North-eastern mountain sourveld veldtype. See Table 2.2.

Regional: The Hmmb does not align with any of Scheepers' (1977) mapped units. See Table 2.2.

3.3.2.2.4. *Relations to other vegetation units on KRC map*

The Mamabolo mountain bushveld (Hmmb) is the only Highveld vegetation typed mapped in the KRC that can be considered a truly Highveld vegetation. The other three Highveld types are all essentially transitional or eco-tonal units. Transition from Hmmb to Steep slope mosaic

(Hssm) is distinct in most cases and is generally delimited by the scarp edge. The change from Hmmb to Lowveld bushveld slopes (Lslo) is fuzzier and is due to elevation linked changes in climate. Transition from Hmmb to Woodbush granite grassland (Mgra) and Bushveld/grassland mosaic (Hbgm) is difficult to determine at present due to the highly transformed state of the current vegetation. It is believed to have been very gradual along the east-west moisture gradient. In fact, the whole Hbgm unit can be seen as the transition between Hmmb and Mgra. See figure 2.5.

3.3.2.2.5. *Conservation status and threats*

On a national scale, Mamabolo mountain bushveld (Hmmb) is regarded as least threatened by Mucina and Rutherford (2006). In the KRC we find that 98% of Hmmb can still be considered as natural. The rugged terrain and scarcity of surface water has limited human activities in this vegetation type, contributing to its state of intactness. Bush encroachment caused by over-grazing and inappropriate fire regimes is the biggest threat currently faced by the Hmmb.

3.3.2.2.6. *Distinct vegetation communities*

3.3.2.2.6.1. *Catha*-veld

Closed woodland dominated by *Catha edulis*. This community almost resembles a young eucalypt plantation because of the high density of *Catha edulis*, which bears an uncanny resemblance to *Eucalyptus* species. *Catha*-veld occurs scattered in small patches and may also be encountered in the Steep slope mosaic (Hssm) and Dense slope bushveld (Hdsb) vegetation types.

3.3.2.2.6.2. Boekenhout/suikerbos-veld

An open woodland community characterized by large specimens of *Faurea rochetiana* and *Protea caffra.* A rich grassy layer is present and this community is maintained by fire.

3.3.2.2.6.3. Kurkbasdoring-veld

Relatively closed woodland dominated by *Acacia davyi*. These shrubs to medium sized trees are the most dominant woody element in a dense layer of grasses including large grasses such as *Diheteropogon amplectans*. It seems that kurkdasdoring-veld is on the increase and this community may be considered a form of bush encroachment. *Acacia davyi* may be to the Highveld what *Dichrostachys cinerea* is to the Lowveld.

3.3.2.2.7. *Important taxa*

3.3.2.2.7.1. Common or characteristic local species

Englerophytum magalismontanum, Dombeya rotundifolia, Faurea rochetiana, Aloe marlothii subsp. *marlothii, Volkameria glabra, Afrocanthium mundianum, Heteropogon contortus* and *Digitaria eriantha*.

3.3.2.2.7.2. Invasive plants of most concern

There does not seem to be a big problem with invasive plants in this unit. *Lantana camara*, *Acacia melanoxylon, A. mearnsii, A. decurrens, Eucalyptus grandis* and *Pteridium aquilinum* are present in low numbers but may become problematic with poor management.

3.3.2.3 Dense slope bushveld (Hdsb)

3.3.2.3.1. *Distribution and landscape features*

Dense slope bushveld (Hdsb) vegetation occurs mainly on the north-west facing slopes of the large mountains in the south-east of the KRC. The landscape is characterised by continuous steep to very steep slopes. The vegetation has a relatively closed canopy of deciduous and evergreen trees.

3.3.2.3.2. *Physiognomy (vegetation features)*

The Dense slope bushveld (Hdsb) is a very dense savanna dominated by medium sized trees that form a nearly closed canopy (>75% closed). A shrubby layer is present but not always very distinct. The grassy component is present and locally well developed in patches free of trees.

3.3.2.3.3. *Relationship to other vegetation maps*

National: This unit has no homologues on the national scale vegetation maps. It is principally a unit that forms the transition between Mucina & Rutherford’s (2006) Northern Mistbelt Forest (Foz 4), Mamabolo Mountain Bushveld (SVcb 24) and Tzaneen Sour bushveld (SVl 8) units. The mentioned units are also recognised in the KRC vegetation map, but at the much finer scale of the current work it was possible to recognise the very complex transitional zone between these two units as a separate vegetation unit, something that is not feasible at a national scale. See Table 2.2.

Regional: This unit fits into Scheepers’ (1977) Low scrub-forest zone of his Submontane scrub-forest belt. See Table 2.2.

3.3.2.3.4. *Relationship to other vegetation units on KRC map*

The Dense slope bushveld (Hdsb) can be considered a transitional zone between the Northern mistbelt forest (Mfor) in the mist-belt higher on the mountain and the Tzaneen sour bushveld slopes (Lslo) of the warm, dry valley bottom. Boundaries between Hdsb, Mfor and Lslo are thus not distinct and difficult to delineate with certainty. The transitions into Bushveld/grassland mosaic (Hbgm) and Woodbush granite grassland (Mgra) are clearer and relatively easy to delineate based on physiognomic traits. See figure 2.5.

3.3.2.3.5. *Conservation status and threats*

More than 98% of the Dense slope bushveld (Hdsb) is still undisturbed and untransformed in the KRC. This is due to the steep topography associated with the unit. The Hdsb is, however, at risk of bush encroachment and invasion by problem plants, most notably *Chromolaena odorata*.

3.3.2.3.6. *Distinct vegetation communities*

3.3.2.3.6.1. Kiaat/Boekenhout-veld

Characterized by *Pterocarpus angolensis* (usually large and spreading trees) and *Faurea rochetiana* (medium sized trees). The well-developed grassy layer, characterised by taller grasses such as *Themeda triandra* and *Cymbopogon nardus* is also noteworthy. This community can be considered a transitional community between the Lowveld bushveld slopes (Lslo), Dense slope bushveld (Hdsb), Mamabolo mountain bushveld (Hmmb) and Steep slope mosaic (Hssm) vegetation types, as some form of it is present in all four vegetation types. Here it is grouped under the Hdsb vegetation type, because it is associated most closely with

Figure 3.7 Dense slope bushveld (Hdsb) seen from above the canopy (left) and from within (right). *Combretum collinum* and the blue-greyish *Mundulea sericea* can be seen on the right of the picture on the right.

this vegetation type.

3.3.2.3.7. *Important taxa*

3.3.2.3.7.1. Common or characteristic local species

Dense slope bushveld (Hdsb) is rich in tree species. Some of the most commonly encountered are ***Cussonia natalensis, Catha edulis, Olea europaea*** subsp. ***africana*** and ***Maytenus undata***. Some of the most charismatic species found here include ***Pterocarpus angolensis*** and ***Calodendrum capense.***

3.3.2.3.7.2. Invasive plants of most concern

Lantana camara, Psidium guajava and ***Chromolaena odorata*** are prolific on some slopes. The biggest concern is that these invasives seem to be growing in areas which are relatively disturbance free.

3.3.2.4 Steep slope bushveld/forest mosaic (Hssm)

3.3.2.4.1. *Distribution and landscape features*

The Steep slope mosaic (Hssm) can be found in the extreme south western corner of the KRC, where it links the Lowveld and Highveld units along the very steep slopes between the river valley and the mountain plateaus.

3.3.2.4.2. *Physiognomy (vegetation features)*

The topographic setting of this unit allows for great habitat heterogeneity, which is reflected in the physiognomy. Here one can find semi-deciduous forests in the kloofs, through dense woodlands to an open grassy, sparsely wooded savanna on the hill spurs.

3.3.2.4.3. *Relationship to other vegetation maps*

National: Like some other vegetation units described here, this unit has no homologues on the national scale vegetation maps. It is a unit that forms the transition between Mucina & Rutherford's (2006) Mamabolo Mountain Bushveld (SVcb 24) and Tzaneen Sour Bushveld (SVl 8) units, with some elements of the Northern Mistbelt Forests (FOz 4) present. These units are also recognised to some extent in the KRC vegetation map, but at the much finer scale of current work it was possible to recognise this complex transitional zone between these two units as a separate vegetation unit, something that is not feasible at a national scale.

Figure 3.8 Steep Slope bushveld/forest mosaic (Hssm) at the end of winter. Note the open bushveld on the steep mountain spurs (centre) and the closed forest communities in the valleys (lower right).

This unit can also be considered as transitional between Acocks' (1953) North-eastern mountain sourveld and Lowveld Sour Bushveld units. See Table 2.2.

Regional: Although there is no clear homologue for this unit in Scheepers' (1977) work, it may correspond to some elements of his 'Submontane scrub-forest belt'. See Table 2.2.

3.3.2.4.4. *Relationship to other vegetation units on KRC map*

The Steep slope mosaic (Hssm) is, in essence, a transitional unit between the Lowveld units of Tzaneen sour bushveld slopes (Lslo) and Tzaneen sour bushveld plains (Lpla) and the Highveld units of Mamabolo mountain bushveld (Hmmb) and Bushveld/grassland mosaic (Hbgm). Transitions to Lpla and Hmmb is distinct and based on topography while the transitions to Hbgm and Lslo is less clear and occurs across a wider geographic zone. See figure 2.5.

3.3.2.4.5. *Conservation status and threats*

Due to the steep nature and inaccessibility of the terrain, this vegetation unit is still 99% in a natural condition in the KRC. The only immediate threat the Steep slope mosaic (Hssm) seems to face is an apparent increase in woody cover, probably due to a lack of occasional veld-fires.

3.3.2.4.6. *Distinct vegetation communities*

3.3.2.4.6.1. Kloofs

The kloofs and sheltered areas along the slopes are home to densely wooded communities. A variety of tree species may be found here, with no one species clearly dominating. Elements of the northern mistbelt forest (Mfor) are encountered here, such as *Brachyleana tranvaalensis, Diospyros whyteana, Gymnosporia harveyana* and *Carissa bispinosa*.

3.3.2.4.6.2. Spurs

The spurs and exposed slopes are home to an open woodland community with a well-developed grassy layer and scattered small trees. Elements from Woodbush granite grassland (Mgra) (e.g. *Loudetia simplex, Merwilla natalenesis*) as well as Mamabolo mountain bushveld (Hmmb) (e.g. *Afrocanthium mundianum* and *Aloe marlothii* subsp. *marlothii*) are found here.

3.3.2.4.7. *Important taxa*

3.3.2.4.7.1. Common or characteristic local species

Clutia pulchella, Catha edulis, Pavetta schmanniana, Themeda triandra and *Maytenus undata*.

3.3.2.4.7.2. Invasive plants of most concern

No invasive plants of any concern have been encountered in the steep slope mosaic (Hssm).

3.3.3 Montane

The Montane zone consists of the northern most mountains of the Wolkberg-range, which forms part of the eastern Great-Escarpment. The landscape is characterized by steep mountain slopes and small valleys – each harbouring a small stream of fresh water. It is this Montane zone that is the highest water yield area for the Koedoes River Catchment. Montane vegetation is usually not found below 1100 m.a.s.l., this topographic-climatic zone is thus confined to the high mountains in the south east of the catchment. Precipitation is typically high in the summer, with a large proportion from mist. The average yearly precipitation measured at two stations between January 2011 and April 2014 was 2180mm per annum.

Summers are relatively cool compared to the Lowveld. The mean monthly minimum temperature for the coldest month is 4.9°C and the mean monthly maximum for the hottest month is 22.7°C (Figure 3.1).

Geologically, most of the KRC Montane areas are under-lied by Turfloop granites and some more recent diabase dykes are present too. The good quality Hutton soils that occur in parts of the Montane area are utilized agriculturally, mainly for the growing of avocados, while the shallower Mispah soils are marginally utilized for silviculture.

European settlers have been practicing agriculture and logging in the Montane areas since the mid to late 1800's. Typical of the era, people streamed to the area during a gold rush (Changuion, 1987). But what kept them here was the subsequent "wood-rush". The first loggers started exploiting the large Woodbush forest around 1880 and a thriving services industry developed around the logging activities (Wongtschowski, 2003). Many pioneer farmers settled on the grassy plateaus, above the malarial conditions that haunted the Lowveld in those years, and experimented with a variety of crops ranging from granadillas to potatoes to cut flowers to small scale silviculture (Wongtschowski, 2003). Unfortunately these early enterprises were not very viable and many farmers went bankrupt, leaving a legacy of severe environmental degradation and invader infestation in the Montane region.

3.3.3.1 Wetlands and streams (Mwet)

The Montane wetland and stream bank vegetation unit (Mwet) is considered too small to indicate on the KRC vegetation map. It is, however, considered to be a very unique and important unit and was therefore recognised at the same rank as the mapped vegetation units. The wetlands (Mwet) unit includes wetlands, sponge areas and stream banks with permanently moist soils and is nestled within the Northern mistbelt forest (Mfor) and Woodbush granite grassland (Mgra) units. This corresponds in part to the 'Hydrosere' communities described by Scheepers (1977) for his 'Montane-forest belt'. *Breonadia salicina* and *Syzygium cordatum* are the trees most likely to be encountered along a mountain stream, while *Kniphofia crassifolia*, which is now considered extinct, is associated with such Montane wetland areas.

Figure 3.9 A Montane wetland (Mwet) in mid-summer. This particular wetland has been cleared from *Eucalyptus grandis* and *Populus* X *alba* invasion. Coppicing shoots of both species can still be seen in the background.

3.3.3.2 Northern mistbelt forest (Mfor)

3.3.3.2.1. *Distribution and landscape features*

The Northern mistbelt forest (Mfor) occurs on the high mountains in the south-eastern corner of the catchment, between 1100 to 1900 m.a.s.l. Forests are usually associated with steep slopes and valleys which serve as fire refugia.

3.3.3.2.2. *Physiognomy (vegetation features)*

Northern mistbelt forests (Mfor) are characterized by a high (>10m) closed canopy of semi-deciduous and evergreen trees with a well-developed and floristically distinct understory shrub layer with no grassy or ground cover component.

3.3.3.2.3. *Relationship to other vegetation maps*

National: Our Northern mistbelt forest (Mfor) corresponds directly to that of Mucina and Rutherford (2006) (FOz 4) and thus the same name is used. The current map however maps the unit's boundaries at a finer and more accurate scale. This forest type corresponds with Acocks' (1953) broader North-eastern mountain sourveld forest types. See Table 2.2.

Regional: Corresponds with the upper, middle and lower montane-forest zones of Scheepers (1977). See Table 2.2.

3.3.3.2.4. *Relationship to other vegetation units on KRC map*

The Afromontane forest types of Africa are well known for the sharp boundaries between forests and the surrounding vegetation matrices i.e. Fynbos in South Africa's Cape region and grasslands throughout the rest of the continent (White, 1978). These boundaries are maintained by regular fire in the surrounding vegetation and no fire in the forests. In this case there is a sharp boundary between Northern mistbelt forest (Mfor) and all surrounding vegetation types, with the exclusion of the Dense slope bushveld (Hdsb) in some cases. The driver of the change from Mfor to the Hdsb vegetation type in this case is not attributed to fire but rather the steep moisture gradient on the north western slopes. See Appendix 2.4.

3.3.3.2.5. *Conservation status and threats.*

The small part of the catchment (3.4%) covered by Northern mistbelt forest (Mfor) forms part of the very large Woodbush forest in the next valley. This is the third largest patch of Afromontane forest in the country (Berliner, 2009). The Mfor is still 92% intact in the catchment, but the historical distribution of the forests might have been larger as the forests were heavily exploited around the turn of the 19^{th} century (Hutchins, 1903). To this day the accessible parts of the forest near the settlement of Houtbosdorp are devoid of large specimens of the high value timber trees (e.g. *Podocarpus* and *Curtisia* sp.). Mucina and Rutherford (2006) list the Northern Mistbelt Forests as least threatened due to the large areas of forest that enjoys a formal conservation status. The forests are also known to be expanding (e.g. Luger & Moll (1993), Lawes et al. (2004) and Haddad et al. (2012)) due to widespread

Figure 3.10 Northern mistbelt forests (Mfor) from inside the canopy (left) and outside the canopy (right).

fire suppression practices along the escarpment. The national biodiversity assessment (Driver et al., 2012), however, states that 5% of forests in SA are critically endangered while about 40% is endangered and another 30% is vulnerable. The fragmentary nature of this vegetation type results in a very heterogeneous conservation and threats picture. In the case of the Koedoes River Catchment and surroundings, the Mfor can be considered as least threatened. The forests may face some immediate threats from invasive species and disturbance by forestry activities.

3.3.3.2.6. *Distinct vegetation communities*

No distinct communities within the Northern mistbelt forest (Mfor) vegetation unit were recognised during the current work. It is however, extremely likely that a number of communities will be recognisable within the forests following further phytosociological work. See Lötter et al. (2014) and Von Breitenbach (1990) for examples of phytososiological work on Afromontane forest communities.

3.3.3.2.7. *Important taxa*

3.3.3.2.7.1. Common or characteristic local species

Canopy species: ***Brachyleana tranvaalensis, Cussonia spicata, Combretum kraussii, Rothmannia capensis***. Understory trees: ***Ochna arborea*** var. ***oconnorii, Oxyanthus speciosus, Carissa bispinosa*** subsp. ***zambesiensis***. Non woody species: ***Clivia caulescens, Asparagus falcatus***.

3.3.3.2.7.2. Invasive plants of most concern

Most invasives in this area seem to be plants that were previously cultivated here for economic reasons. These include ***Acacia melanoxylon, A. mearnsii, A. decurrens, Eucalyptus grandis, Hakea salicifolia*** and ***Pinus elliottii. Caesalpinia decapetala*** is a major problem in the Magoebaskloof area, but fortunately seems to be less prolific in the KRC at present. ***Solanum mauritianum*** and ***Setaria megaphylla*** are other invaders associated with forestry and found in the area.

3.3.3.3 Woodbush granite grassland (Mgra)

3.3.3.3.1. *Distribution and landscape features*

The Woodbush granite grassland (Mgra) occurs in the same climatic zones as Northern mistbelt forest (Mfor) (high mountains in the south eastern corner of the catchment, between

1100 to 1900 m.a.s.l.). These grasslands occur on the open plateaus and spurs of the mountains where it is exposed to its most important abiotic formative agent – fire.

3.3.3.3.2. *Physiognomy (vegetation features)*

Low to medium high (10-150cm) grassy layer rich in non-grassy forbs with a slight increase in low woody growth on some slopes and fire suppressed areas. Some fire-resistant trees are present at low density in the grasslands.

3.3.3.3.3. *Relationship to other vegetation maps*

National: Woodbush granite grassland (Mgra) corresponds directly to that of Mucina and Rutherford (2006) (Gm 25) and thus the same name is used. The current map, however, defines the unit's boundaries at a finer and more accurate scale. These grasslands correspond with Acocks' (1953) broader North-eastern mountain sourveld grassland types. See Table 2.2.
Regional: Corresponds with the upper, middle and lower montane-forest zones of Scheepers (1977). See Table 2.2.

3.3.3.3.4. *Relationship to other vegetation units on KRC map*

These grasslands share a very sharp boundary with the Northern mistbelt forest (Mfor) and have few common floristic elements. Towards the south-west the Woodbush granite grassland

Figure 3.11 The only sizable patches of Woodbush granite grasslands (Mgra) that remain within the Koedoes River Catchment are along forestry firebreaks as pictured here. Above the firebreak is a plantation of *Pinus patula* and below an invasive stand of several different wattle species. The small trees within the firebreak are *Protea caffra*.

(Mgra) merges gradually into the Mamabolo mountain bushveld (Hmmb), mainly due to the moisture gradient and dissipating orographic effect of the high mountains to the east. Due to the indistinct border between these two vegetation types over a large geographical range, much of this transition has been mapped as a separate mosaic unit (Hbgm). Transition into the Dense slope bushveld (Hdsb) towards the north is relatively sharp, but not as distinct as that of the Mfor. This is probably due to the steep slopes on which these transitions occur. In many places this transition is becoming fuzzier due to a lack of regular fires in the grasslands. See figure 2.5.

3.3.3.3.5. *Conservation status and threats*

This is one of the most threatened vegetation types in the KRC. Mucina et al. (2006a) lists their Woodbush Granite Grassland vegetation (Gm 25) as critically endangered due to the facts that it has a very small distribution nationally and of this small area where it can be found, 90% has been transformed, primarily for silviculture. Woodbush granite grassland (Mgra) make up only 2.7% of the KRC and this small area is 85.5% transformed and degraded. Only 14.5% remains natural within the KRC. Invasive alien plants and lack of regular fires are the biggest threats faced by the remaining remnants of Mgra. A very noticeable effect of reduced fire frequency is the increase of *Helichrysum kraussii* in areas that do not experience fire regularly enough (see Appendix 2.4).

3.3.3.3.6. *Distinct vegetation communities*

No distinct communities within the Woodbush granite grassland (Mgra) vegetation unit were recognised during the current work. It is likely that a number of communities will be recognisable following further phytosociological work in the grasslands.

3.3.3.3.7. *Important taxa*

3.3.3.3.7.1. Common or characteristic local species

Grasses: *Loudetia simplex, Eragrostis curvula, Themedia triandra*. Trees and shrubs: *Acacia davyi, Protea caffra* subsp. *caffra.* Forbs and non-grassy herbs: *Merwilla natalensis, Gnidia caffra, Schizocarpus nervosus*, *Pelargonium luridum, Smilax kraussiana, Callilepis salcifolia.*

3.3.3.3.7.2. Invasive plants of most concern

Trees that escaped from forestry are the biggest threats to Woodbush granite grassland (Mgra) - *Acacia melanoxylon, A. mearnsii, A. decurrens, Eucalyptus grandis, Hakea salicifolia, Pinus elliottii.* Other invasives associated with forestry such as *Solanum mauritianum* and

Setaria megaphylla pose some threat. The mono-specific stand forming cosmopolitan fern, *Pteridium aquilinum,* seems to be expanding vigorously at the expense of more diverse grassland communities. Small populations of the notorious *Lilium formosanum* and *Cortadaria selloana* have recently been noticed in this area.

3.3.4 Azonal

Azonal vegetation types are those that do not strictly correlate with the broad topographic-climatic zones delineated for the catchment. These groups are defined by other abiotic factors such as soil or water.

3.3.4.1 Riverine vegetation (Ariv)

3.3.4.1.1. *Distribution and landscape features*

Riverine vegetation (Ariv) is closely associated with the Koedoes River and its major tributaries and is to a great extent the product of geomorphological processes associated with rivers. Riverine vegetation (Ariv) is restricted to a band of about 20m from the river or dams, but in most cases this band is much narrower.

3.3.4.1.2. *Physiognomy (vegetation features)*

The structure of the Riverine vegetation (Ariv) can vary from tall gallery forests with a well-structured tree layer and thick shrub undergrowth to reed beds and grassy floodplains. The unifying factors are the year-round presence of shallow subsurface water and intermittent disturbances caused by flooding.

3.3.4.1.3. *Relationship to other vegetation maps*

National: The gallery forest component of Riverine vegetation (Ariv) corresponds to the Lowveld Riverine Forest (FOa 1) of Mucina and Rutherford (2006) and the reed beds, grassy floodplains and more open shrubby vegetation aligns with their Subtropical Alluvial Vegetation (AZa 7) unit. See Table 2.2.
Regional: Scheepers (1977) does not map any vegetation types that can be viewed as a homologue to the Ariv, but he does discuss a riparian forest plant community under his 'Lowveld Sour Bushveld transition zone' unit. See Table 2.2.

3.3.4.1.4. *Relationship to other vegetation units on KRC map*

Transitions from the Azonal riverine vegetation (Ariv) to any adjacent unit (except Ldra) are always distinct due to a sharp moisture gradient. The boundary between Ariv and Tzaneen sour bushveld drainage lines (Ldra) vegetation is fuzzier. Ariv plants have access to shallow subsurface water for most of the year, while Ldra vegetation's does not. See figure 2.5.

3.3.4.1.5. *Conservation status and threats*

The riverine vegetation in the KRC is still 72.4% intact, the rest being lost to dams, which also favour the establishment of riverine vegetation. This figure might thus be considered an under estimate. Construction of roads, pipelines, pump stations and fences influence this vegetation type negatively, but the Riverine vegetation's (Ariv) biggest threat comes from highly invasive plants associated with waterways. Many of these plants are near impossible to eradicate once established.

3.3.4.1.6. *Distinct vegetation communities*

3.3.4.1.6.1. *Acacia* gallery forests

Tall (>8m), closed canopy forest dominated by *Acacia polyacantha*. These forests are found

Figure 3.12 Riverine vegetation (Ariv) along the Koedoes River. The big trees are *Acacia polyacantha*.

in a band no wider than 100m from the river bed, on deep alluvial soils.

3.3.4.1.6.2. Broad-leaved gallery forests

These tall, closed canopy forests are found in the same setting as the above mentioned *Acacia* dominated gallery forests, but are dominated by broadleaved species including *Ekebergia capensis* and *Ficus sur*. What drives the establishment of either a broad-leaved or *Acacia* dominated gallery forest in a particular environment is not clear.

3.3.4.1.6.3. Foot-slope stream forests

These tall, closed canopy forests are found along fast flowing streams at the foot-slopes of the mountains. There is not a thick layer of deposited soil along these streams; rather, the trees seem to be growing directly from cracks in bedrock (most notably *Syzygium cordatum* and *Breonadia salicina).*

3.3.4.1.7. *Important taxa*

3.3.4.1.7.1. Common or characteristic local species

Acacia polyacantha, Ekebergia capensis, Ficus sur, Breonadia salicina, Combretum erythrophyllum, Syzygium cordatum and *Phragmites australis.*

3.3.4.1.7.2. Invasive plants of most concern

The frequent disturbance regime, heavy human and animal traffic and availability of water make riverine environments exceptionally vulnerable to invasion by problem plants. *Lantana camara, Ricinus communis, Melia azedarach, Tecoma stans, Macfadyena unguis-cati, Eucalyptus grandis, Populus* X *canescens, Nicotiana glauca* and *Sesbania punicea* are all present along the Koedoes River. No major infestations were noticed, but the riverine environment should be closely monitored to prevent the spread and proliferation of invasives.

3.3.4.2 Rock faces and surroundings (Aroc)

3.3.4.2.1. *Distribution and landscape features*

The rock faces and surroundings (Aroc) vegetation unit is both the smallest and most widespread vegetation unit in the KRC. It occurs only on, and directly adjacent to, exposed rock faces. But such rock faces can be found from Schnellskop at the very top of the valley, down to the rocky koppies flanking the Koedoes River near its confluence with the Brandboontjies.

3.3.4.2.2. *Physiognomy (vegetation features)*

The physiognomy of the Rock faces (Aroc) unit ranges from small herbs and grasses growing in shallow pockets of soil to dense shrubs and even small trees growing on the talus slopes directly below the exposed cliffs. Abiotic factors influencing this vegetation type are the very shallow soils or absence of soil, enhanced runoff from exposed rock faces, presence of a talus slope below cliffs and the protection from fire offered by un-vegetated rocks and boulders.

3.3.4.2.3. *Relationship to other vegetation maps*

National: This vegetation unit is too small and insignificant to have been recognised on any national level vegetation map. See Table 2.2.

Regional: Scheepers (1977) did not map any vegetation types that can be viewed as a homologue to the Rock face (Aroc) type, but he does discuss several plant communities associated with exposed and semi exposed rocks and areas of extremely shallow soils under the name of 'lithoseres'. See Table 2.2.

3.3.4.2.4. *Relationship to other vegetation units on KRC map*

Transitions from Rock faces (Aroc) to any other vegetation type are always distinct due to an acute difference in substrate. Floristically, however, each individual Aroc occurrence probably has more in common with its adjacent vegetation unit than other members of the Aroc unit in other parts of the KRC. See figure 2.5.

3.3.4.2.5. *Conservation status and threats*

The rock faces and surroundings (Aroc) vegetation type is still completely undisturbed in the KRC. Invasive plants such as wattles and Eucalypts may pose a threat to Aroc flora in the moister southern regions of the KRC.

Figure 3.13 Rock face vegetation (Aroc) at the end of winter (left) and mid-summer (right). Note the presence of evergreen trees along a narrow band below the cliffs (left). In the picture on the right two 'resurrection plants' typical of this environment, *Myrothamnus flabellifolia* (middle of big rock surface) and *Xerophyta villosa* (upright stems along edge of rock face) can be seen.

3.3.4.2.6. *Distinct vegetation communities*

3.3.4.2.6.1. Communities on shallow soil pockets

These communities grow in very shallow pockets of soil that accumulate in depressions and cracks on exposed rock faces. These communities are characterised by two species of 'resurrection plant' viz. *Myrothamnus flabellifolia* and *Xerophyta villosa.*

3.3.4.2.6.2. Communities on talus slopes

This community of small trees and shrubs is associated with the rock debris accumulated directly below a cliff face or rocky outcrop. These piles of loose rock and boulders offer protection from fire and herbivory. In early summer the pink-flowering canopies of *Calodendrum capense* can clearly be seen on some talus slopes.

3.3.4.2.7. *Important taxa*

Floristically this unit is very heterogeneous, occurring across big climatic gradients between north and south. It is considered as one group for the sake of convenience and there are probably very few shared species between the most southerly and most northerly occurrences of this unit within the KRC. The 'resurrection plants' *Myrothamnus flabellifolia* and *Xerophyta villosa* are two of the most characteristic species of this vegetation type. No problematic invasives have been spotted in this vegetation unit.

3.4. Conclusion

A hierarchical model that predicts vegetation structure, composition and physiognomy is presented for the Koedoes River Catchment (KRC) in chapter two. In the current chapter detailed descriptive accounts of the four topo-climatic zones, twelve vegetation types and eighteen vegetation communities that make up the hierarchical model is set out. These vegetation type descriptions are a first for this region at this fine scale. Future work may refine the boundaries between vegetation types and expand the lists of characteristic species and species-combinations for greater mapping accuracy and resolution. These mapped and described vegetation types are used in the following chapter to inform the mapping of ecosystem services and biodiversity assets in the KRC. The vegetation map (presented in chapter 2) and the detailed descriptions offered here may further serve as a starting point for long-term ecological monitoring in the agriculturally important KRC.

CHAPTER 4: IDENTIFYING AREAS OF AGRICULTURAL, ECOSYSTEM SERVICE AND BIODIVERSITY VALUE IN THE KOEDOES RIVER CATCHMENT, LIMPOPO

"In the long term, the economy and the environment are the same thing. If it is unenvironmental, it is uneconomical. That is the rule of nature."

Mollie Beattie

4.1. Abstract

Ecosystem services are the benefits humans obtain from natural ecosystems. The agricultural sector relies on numerous ecosystem services to support and sustain continuous crop production in a landscape. Farming operations do not generally consider ecosystem services in their planning. Here we use a rapid matrix-based approach informed by stakeholder feedback to map ecosystem services in the agriculturally important Koedoes River Catchment (KRC), Limpopo. A series of maps showing areas of agricultural, ecosystem services and biodiversity importance for the KRC is presented to inform future planning efforts. This approach can be replicated in other similar settings.

Keywords: *Biodiversity, Koedoes River, Land use, Ecosystem services, Agriculture.*

4.2. Introduction

Ecosystem services (ES) is a relatively new concept used to document the benefits people derive from natural ecosystems and landscapes. The concept of ES became widespread in scientific literature in the 1990's even though it has been around since at least the 1970's (De Groot et al., 2010). Broadly defined as "…the benefits people obtain from ecosystems…" (Millennium Ecosystem Assessment, 2005), ES can be divided into four main groups, *provisioning* (e.g. products such as food, water and fibre), *regulating* (e.g. climate, pest and disease regulation), *cultural* (e.g. spiritual and artistic inspiration, recreation, education and science) and *supporting* (e.g. soil formation and primary production) (Millennium Ecosystem Assessment, 2005).

In a landmark paper, Costanza et al. (1997) value global ES at $33 trillion, but argue that the value of ES are in fact, infinite – globally, economies will cease to exist without the ecological life support systems and services offered by the natural environment. Broad ecosystem services frameworks such as Costanza et al. (1997) and others (e.g. Daily 1997; Millennium Ecosystem Assessment 2005) have been successful at emphasising the globally significant role of these services and humanity's dependence thereon. Developments in mapping and valuating ecosystem services are also being made on local to regional scales (e.g. Egoh et al. 2008; Raymond et al. 2009; Sandhu et al. 2010) and a number of examples exist where ecosystem service values have been incorporated into societal decisions (e.g. Goldstein et al. 2012 and Raymond et al. 2009). But the valuation of ES is challenging and not yet an exact and calculating science, seldom producing robust figures (Spangenberg and Settele, 2010). This does not mean that ES have little value and should not be considered in planning and management activities. Costanza et al. (1997) argues that because ES can be seen as infinitely valuable, it should always be considered when making policy and strategy decisions in order to ensure the sustainability of humans in the biosphere.

The intrinsic value of ecosystems and the services they supply are not always well recognised at the farm management level. Agriculture has expanded and intensified (and continues to do so) over the past decades in response to the growing human population (Vitousek et al., 1997). An unintended consequence of this expansion is the alterations of ecosystems' ability to supply ES (Matson et al., 1997) . Modern agriculture is feeding us, but at the same time it is eroding away at the natural infrastructure and systems (soil, water, air, biodiversity, etc.) that sustain all life on Earth (Pretty et al., 2000; Tegtmeier and Duffy, 2004). Sandhu and co-authors (2010) put the challenge faced by farmers, ecologists and policy-makers as such: “The key challenge is to meet the food demands of a growing population by maintaining and enhancing the productivity of agricultural systems without further damaging (and ideally, enhancing) their ES provision”. Because the ability of natural systems to provide ES seems to be negatively affected by intensive agricultural practises (Foley et al., 2005), we need to understand the biological processes and the environmental consequences of agricultural intensification in order to manage these agricultural and natural systems in such a way that they can continue to satisfy the most basic of human needs.

South Africa’s Koedoes River Catchment (KRC) is an ideal setting for studying the possible synergies between the conservation of ecological resources (such as biodiversity and ES) and a commercial farming operation. Firstly, the KRC and its adjacent catchments to the south and south-east were mapped as ecosystem service hotspot by Egoh et al. (2008) – falling within the top 5% of the country’s quaternary catchments with regards to ES delivery. The KRC also falls within a very bio-diverse part of the country. Biodiversity has been linked to ES outputs (Haines-Young and Potschin, 2010) and biodiversity can even be considered as a collective term for a number of separate ES (e.g. scientific value, genetic potential, ornamental species). Secondly, most of the catchment is managed by ZZ2, a massive farming conglomerate which is becoming increasingly ecologically aware. ZZ2’s long term corporate vision and ‘open system’ strategic management approach (see chapter 1) should make the use of the ecosystem services concept to inform long term planning and management very appealing to them.

Farmers, as major land owners, typically only use a fraction of their land for crop production or other economic activities. The remaining natural areas are usually considered of little significance to the economic activities on the farm. Here we develop a rapid assessment of the importance of natural areas as ES providers and as areas of biodiversity significance. This can serve as a tool to assist farm managers in identifying and prioritising natural areas of importance, as well as in planning and maintaining the right mix of land uses. The mix of intact, disturbed and transformed vegetation types and their relative conditions is what characterises an area’s ecological functioning and ability to deliver ecosystem services and goods (Folke et al., 2004). Thus, the more a landscape is transformed (without being mindful of ES), the less capable it becomes in providing a complete bundle of services (De Groot et al., 2010).

Because maps are powerful tools that allow for the visualization of complex phenomena (Burkhard et al., 2012), we aim to produce a map of ecosystem service, biodiversity and agricultural assets in the KRC as the outcome of this chapter. Such a map may ultimately help to inform management decisions and future land use changes. In order to achieve this, we first mapped the land use patterns of the KRC, subsequently comparing it to previously mapped vegetation and biodiversity patterns (chapter 2 and 3). We structured shareholder feedback into the easy-to-apply matrix method of Burkhard et al. (2012) to establish a relative valuation of ES for the KRC. Information on land use, biodiversity and ES patterns was grouped to produce a map of areas of high economic, ES and biodiversity value within the KRC for use by the main stakeholder, ZZ2, as a powerful strategic management tool.

4.3. Methods

4.3.1. Study site

The Koedoes River Catchment (KRC) is home to a massive agricultural conglomerate. ZZ2 is a multi-million rand company, directly employing more than 6000 people (pers. comm. Org Ehlers) in Limpopo Province. They produced around 19 million cases of tomatoes, 2.2 million cases of avocadoes and large quantities of mangoes and onions during the year 2013/2014. Many of these crops are planted in the KRC and its surroundings, where ZZ2 is the majority land owner/manager.

The KRC is located in South Africa’s Limpopo Province, between the major towns of Polokwane and Tzaneen. It stretches over an altitudinal gradient of more than 1300 meters along its 50km length. The KRC lies immediately south of the Tropic of Capricorn and for the most part the climate can be considered as xeric-subtropical, but due to topographical differences, large parts of the catchment enjoys a cooler and moister climate. It lies within South Africa’s summer rainfall region, with most of the precipitation expected between December and February. A great variability in climate is evident within the KRC, especially regarding precipitation, and can be considered a product of the topography. In terms of biodiversity, the KRC is home to a vast complement of plant species. Three biomes (forest, grassland and savanna) are represented here (see chapters two and three). The great range of climatic conditions found across the KRC undoubtedly contributes to the biological diversity seen in the area.

Ancient rocks and well-formed soils characterise the KRC. Greenstone belts (Pietersburg, Giyani and Murchinson belts) that outcrop in the vicinity of the KRC and the early Archaean granitoid gneisses that are common in the area are some of the oldest preserved material on the surface of the Earth (McCarthy and Rubidge, 2005). These rocks have weathered to form soils with varying characteristics in different parts of the catchment. The three most noteworthy soil types in the KRC, based on the South African soil classification system (Macvicar and De Villiers, 2006), are: 1) The ***Hutton*** soils which are found occasionally on the plains and slopes of the Koedoes River valley. These are good agricultural soils and are heavily utilized. 2) The *Glenrosa* soil forms which are found primarily in the south-western parts of the KRC, on relatively flat mountain plateaus. These soils are moderately to heavily utilised in the KRC. 3) Lastly, the *Mispah* soils occur on the steeper slopes of the KRC. These soils are only marginally utilized for silviculture within the KRC.

4.3.2. Land use mapping

A current, fine scale land-use map for the KRC was created to use in conjunction with the potential vegetation map (chapter 2) for assessing habitat loss of vegetation units within the KRC. The current land use for the KRC was identified and mapped by manually digitising polygons in ArcGIS 10.1 based on the interpretation of geo-rectified aerial photographs (1:10 000) from 2012 and 2008 obtained from National Geospatial Information(www.ngi.gov.za). The land use was classified according to a hierarchical classification structure working from five broad land-use classes down to 26 land-use types (outlined in Appendix 4.1, Table A4.1). The mapping took place over a period of five months including numerous site visits to confirm the land use types of areas not clear from the aerial images. Some of the land use categories have limitations that need to be kept in mind when interpreting the data – these are outlined below.

Tomatoes - the tomato production cycle is only about 25 weeks long, preceded and followed by a fallow period. The current trend at ZZ2 is for the fallow periods to become shorter - being as long as 10 years in the 1990's but as short as four for current plantings (pers. comm. S. Malherbe). Thus, only a small percentage of the areas mapped as tomato production zones are presently planted with tomatoes. The remainder is currently fallow and will be utilised during the following seasons, or was used for growing tomatoes in the recent past.

Forestry – it was not possible to determine whether all areas mapped as forestry are still actively managed plantations or have been abandoned. It is thus possible that this category over estimates the amount of forestry in the KRC. The areas that are no longer managed should then rather be classed with the a) 'Invaded or encroached by woody elements' or b) 'Abandoned cultivated land' classes.

Natural areas – certain areas classified as natural may in fact be well-recovered or restored areas that were cultivated in the past. They may also currently be subjected to invasion or encroachment that was not identified in the field or from aerial photo identification. The natural areas are thus likely to be slightly over estimated.

Invaded or encroached by woody elements – the increase of naturally occurring species to form a thick, impenetrable or encroached area is notoriously difficult to describe and quantify. This is because these plants (*Dichrostachys cinerea* in the case of the Lowveld areas and *Acacia davyi* and *Helichrysum kraussii* in the Montane areas) represent a naturally occurring element, but there are no clear density thresholds to separate encroached areas from natural ones. Only the densest and most notable areas of encroachment were indicated on the map. These are the areas that were identified by the land managers and are considered of little economic value in its current state. Some highly invasive alien species (e.g. *Lantana camara* and *Chromoleana odorata*) may also be establishing dense populations deep into natural and undisturbed areas. Many of these areas remain unmapped. Significant areas of the 'natural areas' category may thus be marginally invaded or partially encroached.

Abandoned cultivated land – only areas that could clearly be distinguished as former croplands and separated from fallow lands (by the increased woody cover and consultation with farmers) were indicated. Some older areas of previous cultivation have recovered so well that they are no longer distinguishable from natural veld. These areas were grouped under the natural categories.

Unmapped area – The land use of the extreme northern section of the catchment (1276ha) could not be mapped. Although it is very likely that this area is mostly natural and very patchily cultivated, we could not ascertain the current land use to the same level of confidence as the rest of the catchment. It was therefore left unmapped. This area amounts to 3.14% of the total catchment and was excluded from all further calculations.

4.3.3. Vegetation type intactness

Using ArcGIS 10.1, the potential vegetation (chapter 2) and land-use maps for the KRC were overlaid and combined into a landscape unit map to produce the most accurate and detailed functional representation of the KRC. Based on the land-use map, individual landscape units were classed as either 'transformed', 'natural' or 'degraded/disturbed' (see Appendix 4.1, Table A4.1). Areas classified as 'transformed' are those that have been completely transformed from their former state, e.g. the clearing of bush for the creation of orchards. 'Natural' areas are those that are considered to still be in a state similar to what it would have been like before the arrival and settlement of industrialized man in the area. 'Degraded/disturbed' areas are somewhere in-between transformed and natural – not as drastically altered as transformed areas, yet not as pristine as natural areas – typically overgrazed or encroached areas.

The intactness (defined by the percentage of remaining natural areas) of KRC vegetation types was compared to their national scale analogues using data from the 'National list of threatened terrestrial ecosystems for South Africa (2011)' retrieved from http://bgis.sanbi.org/ecosystems/project.asp#3 (accessed 2015.03.17), also available as a notice in the government gazette (DEA, 2011). The thresholds-approach followed by Driver et al., (2012) to determine the national ecosystem threat status was replicated here at a finer scale. Similar approaches have been used internationally to identify threatened ecosystems (Keith et al., 2013; Rodríguez et al., 2011). Vegetation type intactness is determined by comparing the proportion of each vegetation unit that is still in a natural and undisturbed condition to a series of thresholds (Figure 4.1).

- The first threshold is called the biodiversity target. Vegetation types that have less of their original extent than this threshold still intact are likely to have lost much of its natural structure and functioning and associated species may have been lost.

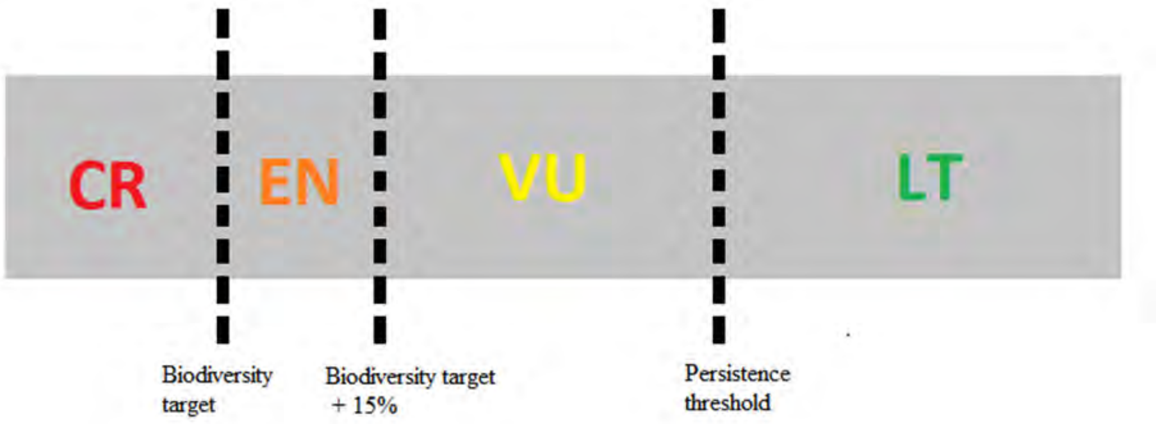


Figure 4.1 Thresholds for determining conservation status of vegetation types based on Driver et al. (2012).

Vegetation types that fall below this threshold are considered Critically Endangered (CR).

- The second threshold is set at the biodiversity target + 15%. It indicates vegetation units that are considered to be Endangered (EN). This threshold serves to identify areas that are close to becoming CR.
- The third threshold is called the persistence threshold and delimits the cut-off for Vulnerable (VU) vegetation types. This is set at 75% and indicates vegetation types that are likely to have lost some of their structure and functioning. These units are at risk if they face further deterioration.
- Units that are represented at higher percentages than the persistence threshold are considered to be of Least concern (LT).

Conservation status ratings for KRC vegetation is worked out using the conservation targets from the government gazette (DEA, 2011) for comparable vegetation units. For units with no national analogue, a conservation target of 26% (average of conservation targets for other KRC vegetation units) was used.

4.3.4. Relative valuation of ecosystem services

A workshop was convened with well-informed and influential decision makers from ZZ2 in order to explain the ecosystem services concept and collect feedback. Individuals influencing policy and strategy within ZZ2's structures were specifically targeted as their opinions regarding ES are most likely to influence long-term management of the KRC. Special care was taken to ensure all respondents had a uniform understanding of concepts.

We used the ‘expert approach’ – a form of ES valuation based on feedback from experienced and informed individuals (De Groot et al., 2010) to determine of the relative importance of ES supply and demand in the KRC. During the workshop the following steps were followed:

- From the ES listed by De Groot et al. (2010), twelve ecosystem services of particular relevance to the study area were identified and their definitions refined to be more locally applicable (listed in Table 4.1). Further work focused only on these selected ES.
- In order to formalise the feedback, a rapid, qualitative matrix technique based on Burkhard et al. (2012) was employed. The matrix lists the specific ES along the x-axis and landscape units (as identified above, see section 4.3.3) along the y-axis (see Appendix 4.2 for an example of the matrix).
- Using the matrix, the relevant capacity (expressed as a six-point scale – see Appendix 4.2) for each landscape unit to supply each one of the twelve ES was rated by the individual respondents on the panel (n=11) based on their experience.
- Ultimately the total scores from all respondents for each ES and each landscape unit could be summed to determine both which ES are in the greatest relative supply and which landscape unit has the highest relative ES supply. All matrices representing the views of individuals were averaged into a single matrix which best represents the collective view of ZZ2’s executive regarding ES.
- In addition, the panel was asked to “rank the twelve ES in order of which service you perceive to be the most important to the continued sustainable growth of agriculture in the KRC”. The rankings of all respondents were averaged and used as a measure of the relative order of ecosystem services demanded in the KRC.
- The total ES supply estimates calculated from each respondent’s feedback was converted to a ranking and the rankings averaged in the same way as mentioned above for the demand ranking. This produced a relative order of ES supplied in the KRC. Relative ES supply and demand can now be compared.

4.3.5. Identifying priority management areas

A map of priority management areas was developed by identifying areas of high agricultural, ecosystem services and biodiversity value. Based on profitability per hectare, all fruit tree orchards and net houses were marked as high value agriculture. These areas will remain under agricultural land use for at least another 10-15 years due to the expected lifetime of the crop tree. Open land tomatoes and fallow lands were mapped as moderate agricultural value. Potential agricultural value of undeveloped land was not considered here.

Table 4.1 Definitions for twelve ecosystem services mapped in the Koedoes River Catchment.

Ecosystem service	Description
Aesthetical value	How the particular landscape influences your state of mind. How do I feel living or working in this landscape?
Ecotourism	The potential value of landscapes for ecotourism developments like hunting, bird watching and botanical expeditions.
Grazing	The grazing potential of a particular landscape.
Harvestable products	The potential of this particular landscape to produce wild harvestable products such as medicinal or usable plants, wood and material for compost, fish and insects as a source of dietary protein, etcetera. (Not including agricultural produce)
Nutrient cycling	To what extent do populations of wild animals in a particular landscape assist in the breaking down of wastes – eg. dung beetles, animals feeding on waste tomatoes, decomposition of other organic wastes
Pest control	How landscape units act as reservoirs of predators on agricultural pests.
Pollution control	To what extent does a landscape prevent or mitigate chemical and solid waste from entering river systems and the environment at large.
Protection/buffer value	How important is this landscape as a buffer or protection zone against people, theft, poaching, and other external influences.
Soil regeneration	How the different landscapes affect soil fertility in the cultivated areas and in future cultivated areas.
Value to ZZ2 brand	How important is a particular landscape setting to establish and grow ZZ2's reputation as a trusted brand?
Water availability	The effect different lanscapes have on the volume of water available in the catchment.
Water quality	The effect different landscapes have on the quality of water in the catchment e.g. sediment control.

We used three criteria to determine which areas are to be mapped as important for ES provisioning. Firstly, the landscape units that scored medium, high or very high relevant capacity (on the averaged Burkhard-matrix – see section 4.3.4 and Appendix 4.2) to supply all ES were mapped. These areas are called areas of 'broad ES' importance. Secondly, the landscape units that scored medium, high or very high relevant capacity to supply the three ES most in demand (see section 4.3.4) were mapped as being of significant value. These areas are called areas of 'targeted ES' importance. Thirdly, to show the relative contribution of larger landscape units, we multiplied the percentage area covered by each unit with its total relative capacity score. The three units that scored highest were mapped as important for ES provisioning due to their large geographical extent or footprint. These areas are called areas of 'footprint ES' importance.

In terms of biodiversity, the vegetation types with a conservation status of critically endangered (CR), endangered (EN) or vulnerable (VU) and those that are considered near-pristine (more than 95% undisturbed) are marked as high value. The two vegetation types with a higher proportion of red-listed species – Woodbush granite grassland (Mgra) and Northern mist-belt forest (Mfor) – were also mapped as important areas of biodiversity (see chapter 2 for details on red-listed species and their distribution in the KRC). The resulting map thus shows areas of agricultural, ecosystem services and biodiversity importance.

4.4. Results

4.4.1. Land use

As a whole, 47.5% of the vegetation of the KRC is still intact in a predominantly natural and undisturbed state, while 30% has been actively transformed (Figure 4.2) – mainly due to agricultural activities. The remainder has been disturbed or altered to some extent by human activities, but not completely transformed. Developed and transformed land is mostly confined to the flat areas such as the valley bottom and mountain plateaus (Appendix 4.1, Figure A4.1). The natural areas are mostly confined to mountain slopes. Human activities in the landscape also seem to be spatially linked to road infrastructure. Figure 4.2a show the habitat transformation and degradation of the major topographic-climatic zones (chapter 2). At below 40% natural, the Lowveld has the least amount of natural vegetation left. This is the area of most intensive development and harbours the longest sections of road infrastructure in the KRC. The Montane zone is not very transformed, but almost 40% is degraded due to the abundance of invasive plants. Making up just below 2.5% of the total catchment, the ecologically and economically important Azonal areas seem to be in a good state (74.1% natural). The mostly steep and inaccessible Highveld areas are still more than 80% intact.

4.4.2. Vegetation type intactness

The relative proportions of each vegetation type in the KRC that is still in a natural state or altered due to transformation or degradation is indicated in Figure 4.2b. At more than 98% natural, exposed rock faces (Aroc), steep slope mosaic (Hssm) and Mamabolo mountain bushveld (Hmmb) are the most pristine vegetation types of the KRC. However, less than 15% of the original extent of Woodbush granite grassland (Mgra) and less than 25% of Tzaneen sour bushveld plains (Lpla) still persist in the KRC.

Zooming out to a national level, Table 4.2 summarizes the state of vegetation associated with the KRC at a local and national scale. The KRC makes up 9.5% of the possible national extent of the Tzaneen sour bushveld (SVl 8) vegetation unit as defined by Rutherford et al. (2006) and the existing natural SVl 8 vegetation in the KRC represents 7.1% of what is still remaining of this vegetation type nationally. The status of most of the vegetation types in the KRC reflect the status of their national-scale analogues, with the notable exception of the riverine vegetation (Ariv), which is of least concern nationally, but considered to be vulnerable locally. Our calculations indicate that a total of 0.4% of the KRC is critically endangered (CR), 16.7% endangered (EN) and 1.6% is vulnerable (VU).

4.4.3. Ecosystem services

Provisioning and regulating ES regarding water are considered the most in demand, followed closely by a cultural ES – value to ZZ2 brand (Figure 4.3). Ecotourism and wild harvestable products were regarded as the ES least in demand. Three cultural ES (aesthetical value, value to the ZZ2 brand and ecotourism) seem to be available in the greatest supply.

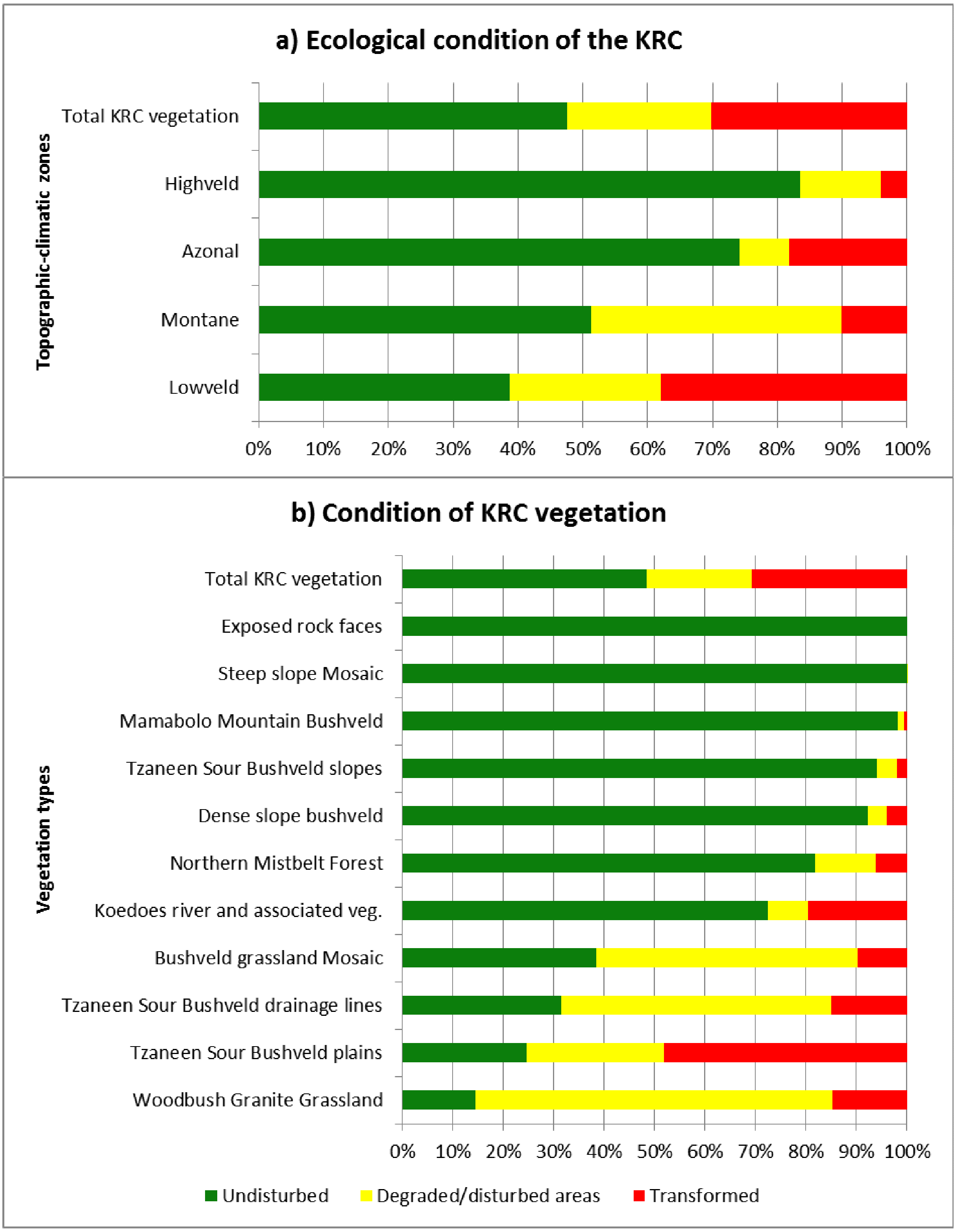


Figure 4.2 a) Ecological condition of the Koedoes River Catchment per topo-climatic zone and b) vegetation type. Relative proportion of each unit that is still in a natural state, degraded/ disturbed or lost due to transformation is shown.

When we consider the ES rating per landscape unit, we see that the natural units tend to supply more ES than degraded or transformed areas (Figure 4.4). The river itself and associated vegetation, dams and intact bushveld and forest has the highest capacity to supply ES. Two degraded landscape units (invaded and encroached by woody elements) have the lowest capacity to provide ES.

Table 4.2 Conservation status of vegetation types associated with the Koedoes River Catchment at national and local scales. (LT = least threatened, VU = vulnerable, EN = endangered, CE = critically endangered)

National^					Koedoes River catchment				
Vegetation type	Total (ha)	% Remaining in tact	BD Target %	Ecosystem status	Vegetation Type	Total (ha)	% Remaining in tact	BD Target %	Ecosystem status
Mamabolo mountain bushveld	68295	94.0	24	LT	Mamabolo mountain bushveld	704	98.1	24	LT
Tzaneen Sour bushveld	342613	59.0	19	EN	Tzaneen sour bushveld plains	22837	24.7	19	EN
					T. s. bushveld drainage lines	922	31.4	19	EN
					T. s. bushveld slopes	5912	94.1	19	LT
					Dense slope bushveld	3216	92.2	19	LT
Northern mistbelt forest	61338	84.0	30	LT	Northern mistbelt forest	1348	81.9	30	LT
Woodbush granite grassland	33986	26.0	27	CE	Woodbush granite grassland	1124	14.5	27	CE
Subtropical alluvial vegetation	66346	84.0	31	LT	Koedoes River and associated vegetation	898	72.4	31	VU
No analogue at national level					Exposed rock faces vegetation	60	100.0	26*	LT
					Steep slope mosaic	1126	100.0	26*	LT
					Bushveld / grassland mosaic	1268	38.4	26*	EN

*Average of five other targets

^Data from National list of threatened ecosystems (DEA, 2011)

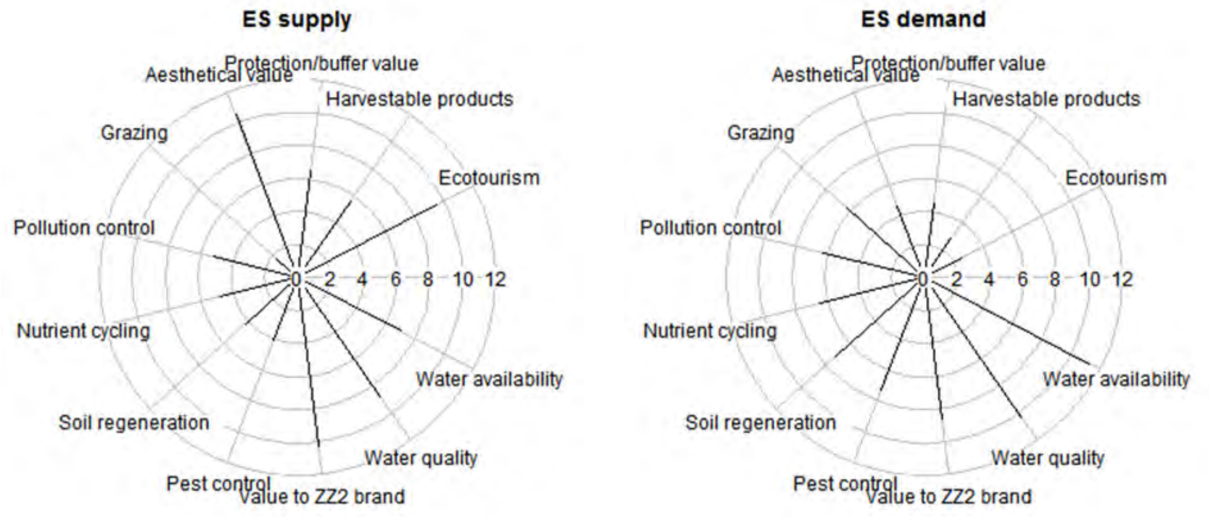


Figure 4.3 Average ecosystem services (ES) supply and demand ranking in the Koedoes River Catchment calculated from stakeholder feedback.

4.4.4. Priority management areas

The areas of greatest biodiversity conservation value, ecosystem service value and current agricultural value are presented as a map (Figure 4.5). This map can be used as a strategic tool to guide future development, restoration and conservation activities.

The following landscape units were mapped as important due to their high relative capacity to provide all twelve considered ES: Dams and reservoirs; Tzaneen sour bushveld; Northern mistbelt forest; Koedoes River and associated vegetation. In addition Woodbush granite grassland; Dense slope bushveld; Mamabolo mountain bushveld; and Cultivated land (fruit trees) were also mapped as being of importance specifically for having a high capacity to render the three ES most in demand (water quality and availability and value to the ZZ2 brand). Finally, the corridors and green belts and fallow tomato lands were added as important for ES provision because of their large footprint and ES supply.

Remaining undisturbed patches of the following vegetation types were marked as biodiversity assets due to their conservation status: Vulnerable types, Koedoes River and associated vegetation (Ariv); Endangered types, Tzaneen sour bushveld drainage lines (Ldra), Tzaneen sour bushveld plains (Lpla) and Bushveld/grassland mosaic (Hbgm); Critically

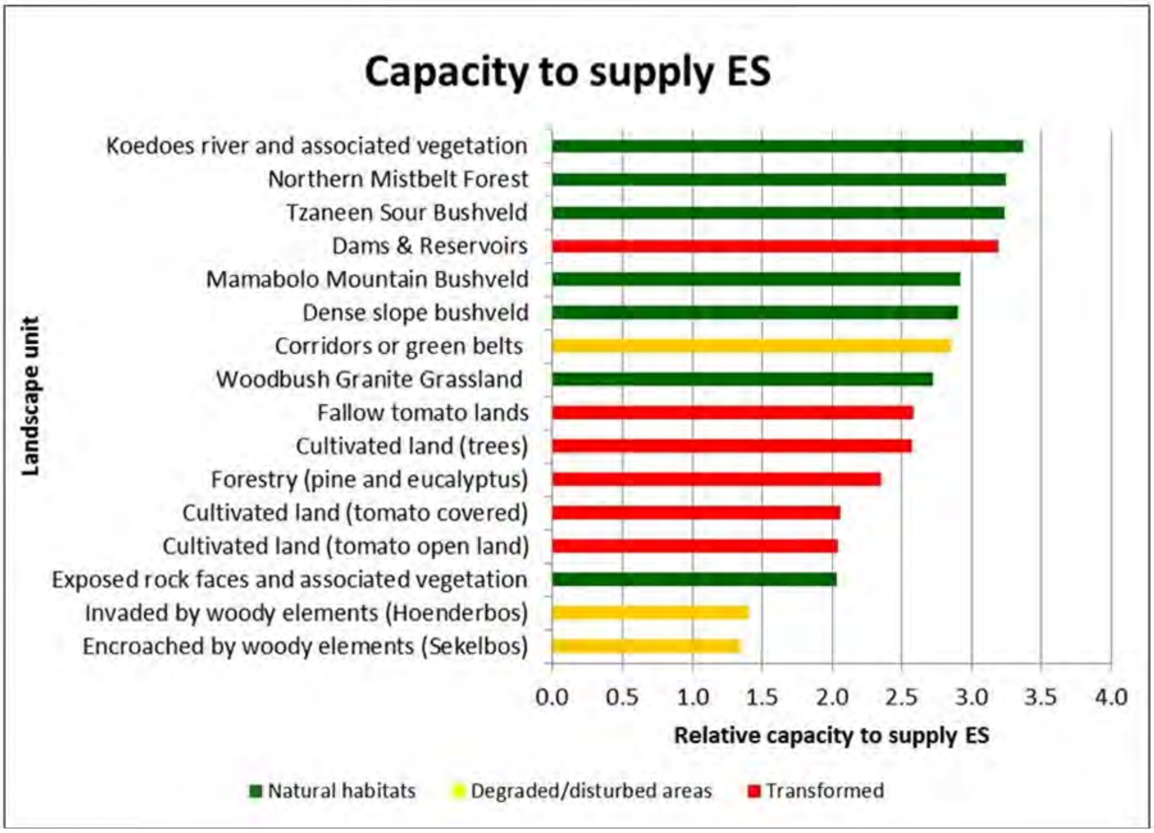


Figure 4.4 Relative ES supply capacity per landscape unit. See appendix 4.2 for relative ES capacity scale.

endangered types, Woodbush granite grassland (Mgra). Further, the Steep slope mosaic (Hssm), Exposed rock faces (Aroc) and Mamabolo mountain bushveld (Hmmb) vegetation units were mapped as biodiversity assets because these are still more than 95% intact in the KRC. The two vegetation types with a higher proportion of red-listed species – Woodbush granite grassland (Mgra) and Northern mistbelt forest (Mfor) – were also mapped as important areas of biodiversity (see chapter 2 for details on red-listed species and their distribution in the KRC)

4.5. Discussion

4.5.1. Interpretation of results

Regarding the relative supply and demand of ES in the KRC, there appears to be a greater demand for certain services in the KRC than the catchment is able to supply (based on the views of the respondents). Not surprisingly, the availability and quality of water are the two most sought after and valued ES in the KRC. This is because virtually all economic activity in the catchment relies heavily on the use of good quality water. Water is also the limiting factor that will restrict any further agricultural expansion with water intensive crops such as tomatoes. The relative supply for both water related ES were less than demand. Through sound ecosystem management the supply and quality of water in the KRC may be improved. We believe that the relatively low supply versus high demand for water is one of the factors driving farm managers to seek an ecologically sound and holistic management strategy for the KRC.

The value of an ecologically intact and functional environment is regarded as very valuable by ZZ2, the largest economic role player in the KRC. They are constantly trying to build their image as an environmentally responsible entity and farming in a well preserved and natural setting is believed to contribute greatly to that goal. It is thus no surprise than that 'Value to the ZZ2 brand' is the ES third most in demand. A private nature reserve and common use of images of local natural landscapes in marketing material has already contributed to the value perception of such an ES, so 'Value to the ZZ2 brand' is considered to be available in a near equally great supply.

Due to the long history of tomato farming in the Lowveld areas (Changuion, 2007), soil regeneration is another ES in relative high demand. This is an ES that operates at much longer time scales than the other, with natural areas having a relatively low capacity to supply in immediate needs. However, the large scale composting of agricultural soil is having more immediate effects on the recovery of depleted soils.

The move away from chemical pest control agents and synthetic fertilizers is creating a greater demand for nutrient cycling and pest control related ES from farmers. Natural, ecosystem-driven alternatives to these services in the KRC agricultural setting have not been greatly explored. For this reason we interpret the low relative supply scores of pest control and nutrient cycling ES not as a lack of supply, but as a lack of the realisation of what may be available. Grazing is another ES that is in relative high demand in the KRC. There is sufficient grazing available within the KRC for the current herd size. The very low relative supply rating for grazing is rather a reflection of a demand for more accessible, centrally located and logistically manageable grazing areas.

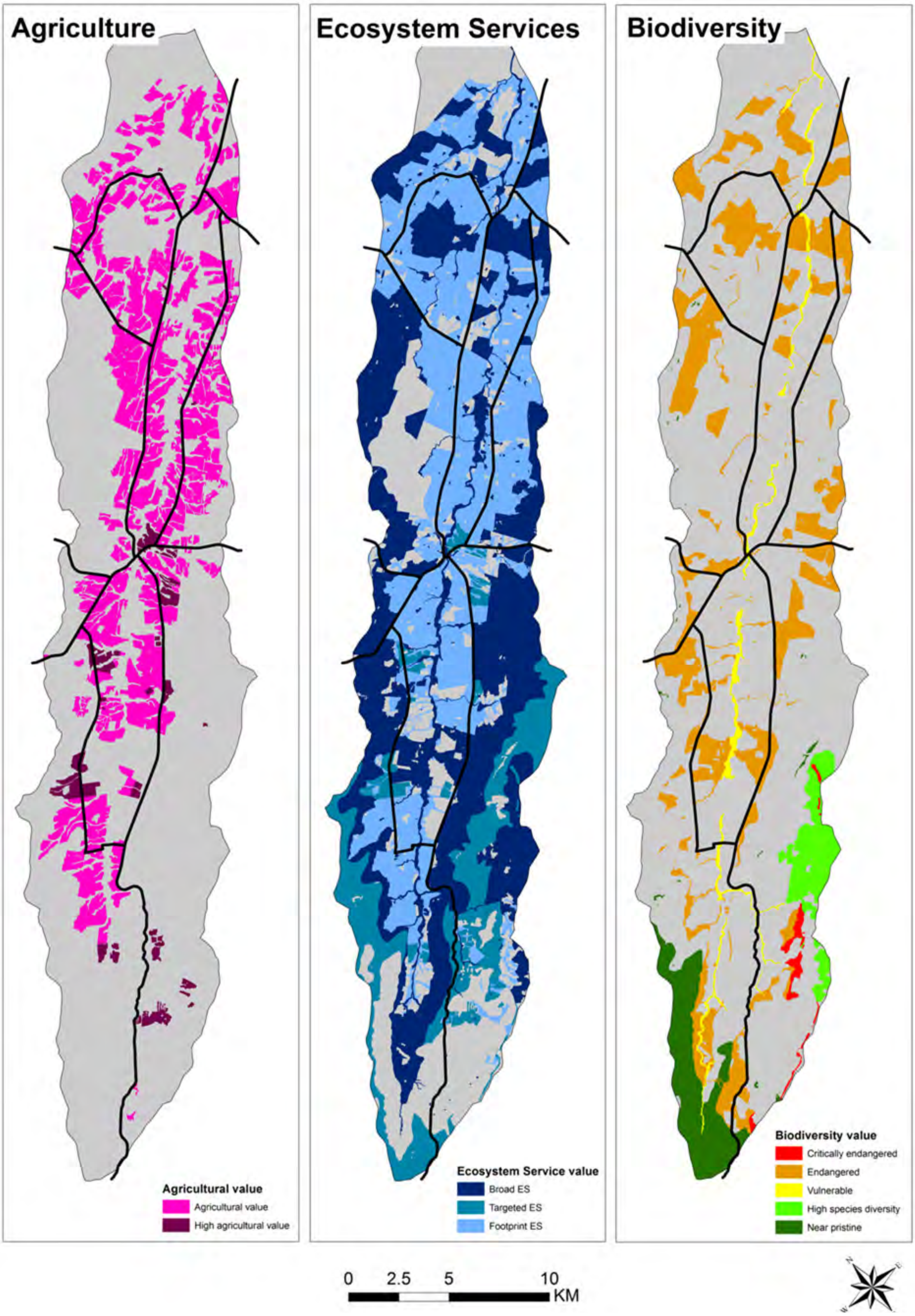


Figure 4.5 Priority areas of agricultural value, ecosystem services and biodiversity for the Koedoes River Catchment.

The low demand for ecotourism, wild harvestable products, protection/buffer value and aesthetical values can be explained by its un-relatedness to the core business of agriculture in the KRC. These four (with the exception of 'Value to the ZZ2 brand') are the only ES that are considered to be available in greater supply in the KRC than demand. All other surveyed ES are directly related to agricultural activities and are considered to be in greater demand than the catchment can supply currently. Notable too, is the low significance of services like pollination to the farmers. This may be because the crops grown here are not dependant on natural pollinators. To what extent the respondents' vested interests in agriculture may have influenced these ratings is not explored here. It may be of great value to attempt more objective and quantitative valuations of one or more of these ES to evaluate the accuracy of the rapid, qualitative technique employed here.

The maps presented in Figure 4.5 are considered good representations of areas of direct economic value (agriculture panel), direct conservation value (biodiversity panel) and indirect conservation and agricultural value (ES panel). This ES map not only shows the areas that are currently important to the effective functioning of ecosystems to provide benefits to humans, but it also shows where an effort can be made to restore areas to a state more capable of delivering ecological benefits to the KRC community. All grey areas (Figure 4.5) are currently not considered of significant biodiversity or ES value. But through interventions – such as the invasive tree clearing already taking place in the upper reaches of the catchment – the potential of an area to contribute to healthy ecological functioning in the catchment can be drastically improved.

Fischer et al. (2006) listed ten principles to enhance ecosystem functioning and resilience and maintain biodiversity in farming and forestry settings. It is our opinion that the KRC is still in a relatively very good ecological state, considering the intensive agricultural land use, because most of these ten principles are applied by land managers in the KRC, whether purposefully or coincidentally. Of Fischer et al.'s (2006) ten principles, the following are applied in the KRC: 1) Large patches of structurally complex vegetation is present. 2) Structural complexity throughout the landscape is maintained. 3) Buffers around sensitive areas are present in most cases. 4) Corridors are present. 5) Landscape heterogeneity across environmental gradients is captured. 6) Functional diversity is maintained in most places. 7) Invasive and aggressive species are being controlled in most cases. A principle that is not currently applied, but is likely to have a noticeable influence on ecosystem functioning and biodiversity in the KRC, is the application of appropriate disturbance regimes (most notably fire).

4.5.2. Advantages and limitations of the approach

The stakeholder feedback we received was (and can only be) subjective. Individuals vary in their opinions and the individuality of the respondents is reflected in the data – the range of scores for subjective ES such as aesthetical value is greater than that of a more measurable ES such as water availability. For this reason individuals at a policy and strategy forming level within ZZ2's structures were specifically targeted. This means that their opinions regarding ES has likely had an influence on the long-term management of the KRC and will continue to do so into the near and medium term future.

In our mapping effort, relative ES values were linked to particular landscape units (e.g. avocado orchards or Northern mistbelt forests), but the actual ES values may vary within each landscape unit (e.g. small forest patches vs. larger patches or avocado orchards in different parts of the landscape). The representation of ES within the KRC is thus scale dependant. The landscape scale is, however, considered to be the ideal scale for understanding interactions between agriculture, biodiversity and ES (Tscharntke et al., 2005). The delivery of ES may also be case specific, for example: generally the building of dams facilitate the settling of suspended solids, which has a positive influence on water quality (Bilotta and Brazier, 2008). But in some cases in the KRC, dams have caused the salinization of water due to soluble salts in the underlying geology, resulting in a negative impact on water quality. Thus, any spatial variability regarding ES rendering within landscape units are not captured here.

Possible links between different ES were not investigated. For example ecotourism potential and aesthetical value could be related. The relationship between water availability and quality is also a complex one. We thus admit that a degree of 'double counting' may be present in our ES map.

The approach and techniques used to qualitatively valuate ES, using a rapid matrix technique and stakeholder feedback, seem to have produced positive results. This project represents the first efforts to quantify and map ES at a fine scale in this particular setting – the KRC. Exploratory qualitative measures of ES, such as the ones presented here, are regarded as good first order attempts at presenting an overview and raising awareness of ES (Burkhard et al., 2012). It is definitely "better than simply ignoring ecosystem services altogether, as is generally done in decision making" (Daily, 1997). It is hoped that this work will lay the foundation for a more detailed survey of the value of ES and biodiversity to a socially and economically important agricultural enterprise such as ZZ2 in the future.

Through conversation with key stakeholders, ES assessments can contribute to a paradigm shift enabling commercial agricultural business to recognise the value of natural environments. The systems thinking philosophy already in practise at ZZ2 sets a very receptive scene for the social learning processes associated with changing mind sets and perceptions (Cundill et al., 2011) towards ultimately achieving greater sustainability and finding an integrated solution to the 'global challenge' introduced in chapter one.

4.6. Conclusion

We effectively used a direct, observational approach to map the land use of the KRC and found that just less than half of the catchment is still in a natural state, mainly along the slopes and mountainous areas. Despite some limitations, our technique of stakeholder ES rating based on the Burkhard et al. (2012) matrix proved effective at generating qualitative data of ecosystem service supply and demand in the KRC. Water related regulating and provisioning services seem to be the most in demand within the KRC, while the natural setting provides ample aesthetical and brand value to ZZ2. The relative valuation of ES could be effectively mapped in combination with areas of threatened vegetation and valuable agricultural land. The resulting map can be seen as a very concise summary of this thesis. Ultimately, the real value of this work lies in the conversations it started and the paradigm shifts in agricultural and conservation circles it may unlock.

CHAPTER 5: INVESTIGATING THE INFLUENCE OF LAND USE ON BIODIVERSITY AND ECOSYSTEM SERVICES AT THE FARM SCALE.

5.1. Abstract

The influence of land use on biodiversity and ecosystem services is investigated in three adjacent sub-catchments, each subjected to a different combination of land uses. Invertebrate community composition in thirty $100m^2$ plots are used as an indication of biodiversity, while down-stream biological water quality is used as an indication of ecosystem services. The findings suggest that biodiversity responds to very fine-scale land-use patterns, while land use may influence down-stream ecosystem service quality. The finding from experiments like this one may help inform land-use decisions at the farm scale that will promote biodiversity and ecosystem services within an agricultural setting.

Keywords: *Invertebrates, Biodiversity, Land use, Ecosystem services, SASS5, Ecological monitoring.*

5.2. Introduction

Functional ecosystems are vitally important to sustain human civilizations in the 21st century (Costanza et al., 1997; Steffen et al., 2015). The benefits humanity derive from functioning natural ecosystems are known as ecosystem services (ES). These services range from global (e.g. oceanic circulation, geochemical cycles) to local (e.g. harvestable products, recreation, pollution control) scales (Millennium Ecosystem Assessment, 2005). Current indications suggest that the natural base responsible for the provisioning of ecosystem services is being eroded at an alarming rate (Millennium Ecosystem Assessment, 2005). For this reason, ES as a non-renewable resource is a topic of much interest in contemporary environmental sciences.

Biodiversity is the variety and variability of all living organisms (IUCN, 1988) and is a concept often associated with functional ecosystems (Loreau et al., 2001). The irreplaceable nature of ecosystem services (ES) is often used as the prime argument for the case of biodiversity conservation. But does healthy biodiversity really facilitate high ES provision? Myers (1996b) states that "[ecosystem services] do not stem necessarily and exclusively from biodiversity", but goes on to say that biodiversity often plays a key role. That key role may lie in contributing to ecosystem resilience (Yachi and Loreau, 1999). Resilience is the ability of an ecosystem to withstand and recover from shocks, disturbance and disruptive changes. The high levels of species redundancy associated with bio-diverse systems are thought to contribute to ecosystem resilience (Chapin et al., 2000; Hooper et al., 2005). Thus, if an ecosystem's biodiversity declines, its resilience and associated ES are also expected to decline.

Land use and land cover change are considered to be the major anthropogenic drivers of biodiversity loss, ecosystem degradation and subsequent loss of ES (Metzger et al., 2006). As a major land user, the agricultural sector carries much responsibility for this degradation of ecosystems (Foley et al., 2005). Not only do the actual land cover changes resulting from large-scale agriculture negatively affect biodiversity, ecosystem functioning and ES, but also the ubiquitous invasive alien plants associated with the physical soil disturbances of agricultural practises (Gordon, 1998; Vilà et al., 2011). In some cases, farmers have recognised that by managing their land-use practices in a different way, they can reduce impacts on ecosystems. Wenning and Apitz (2012) list a number of frameworks developed in Europe specifically aimed at the management of ecosystem service assets in the agricultural sector. Through well-informed management techniques farmers may well be able to both maintain and enhance the functioning of ecosystems on their farms, while still sustainably producing commercial crops (Tscharntke et al., 2005).

In this chapter we investigate how land-use may affect biodiversity and ecosystem services in a working agricultural landscape at the farm scale. In the previous chapters of this thesis we have explored the biodiversity, land-use patterns and relevant ecosystem services of the economically important Koedoes River Catchment (KRC), Limpopo, South Africa. Now we zoom in on three small sub-catchments at the headwaters of the KRC. These sub-catchments fall along a continuum of land use, ranging from mostly invaded by alien trees through mostly cleared from invasives to natural forest, grassland and savanna. We use two invertebrate based measures to get a relative indication of both biodiversity and ES provisioning in the sub-catchments subjected to a spectrum of land uses.

The use of invertebrates as indicators of the state of a particular system is a well-established method in modern conservation biology (Carignan and Villard, 2002; Folgarait, 1998; McGeoch, 1998). We use invertebrate community structure (taxa richness and abundance) as an indicator of biodiversity. Changes in community structure respond to different drivers (e.g. land use, topographic position or soil properties) and are used here in an attempt to identify the land-use associated factors that influence biodiversity. The production of clean, fresh water is a critically important ES rendered by natural systems. Benthic macroinvertebrates form the basis of the technique used to monitor an ES – biological water quality – for each catchment. The South African Scoring System version 5 (SASS5) is a rapid bioassessment method for determining the biological condition of river systems (Dickens and Graham, 2002) and was used to determine the relative biological quality of water in the stream flowing from each catchment.

Using these invertebrate-based indicators, we test the following hypotheses:

- 1) Invertebrates will respond strongly to land use change and therefore strong differences in invertebrate community composition across three sub-catchments, ranging from most disturbed to most natural, will be apparent.
- 2) Biological water quality of a stream flowing from a catchment in a more natural state will be relatively better than those flowing from a cleared or invaded catchment.

In other words, the more natural sub-catchment (as informed by land use) will be more ecologically functional – due to a greater intactness of natural systems – than the cleared or currently invaded sub-catchments. The alternative hypotheses will be that invertebrate taxa composition responds more strongly to vegetation structure and local setting (plot characteristics) rather than to large-scale catchment condition; therefore plots might cluster according to grassy vs. woody plots (irrespective of degree of invasion of the catchment it forms part of).

5.3. Methods

5.3.1. Study site

The study area is located on the north-western slopes of the Wolkberg range in Limpopo Province, South Africa. The landscape is characterized by steep mountain slopes and small valleys – each harbouring a stream of fresh water. The area of study encompasses three sub-catchments of about 220ha each, which are important primary catchment areas for the downstream Koedoes River. The Koedoes is of great economic importance, being the primary water source for the production of large quantities of tomatoes, avocados, mangoes and onions. Precipitation is typically high in the summer, with the average yearly precipitation (measured at two privately operated Davis weather stations between January 2011 and April 2014) at 1500mm per annum. The climate is sub-tropical montane with a mean monthly minimum temperature for the coldest month of 4.9°C and the mean monthly maximum for the hottest month of 22.7°C.

Typical of these climatic conditions in South Africa, a combination of evergreen Afromontane forests and species-rich sour grasslands can be found growing on the slopes. More specifically Northern-mistbelt forest and Woodbush granite grasslands, while a number of bushveld communities are also established at lower altitudes (see chapter two and three for in-depth information on the vegetation). Geologically the area is made up of ancient formations of Archean granitoid gneiss and granite, with occasional diabase dykes (Johnson et al., 2006). Well developed and exceptionally erosion resistant ***Hutton*** soils are utilized in the area for avocado orchards while shallower ***Mispah*** soils are marginally utilized for silviculture (soil classifications according to Macvicar & De Villiers, (2006)).

The study site and adjacent areas have been subjected to intensive human land use impacts since the 1870's (King, 1941). Indigenous timber harvesting in the adjacent Woodbush forest was a big industry by the end of the 19th century (Hutchins, 1903) and the nearby town of Houtbosdorp (today an uninhabited ghost-town) was home to about 40 families at the time (Wongtschowski, 2003). They made their living by felling and processing timber, as well as small scale and subsistence farming with a variety of crops on the grassy slopes (Wongtschowski, 2003). It was during this period that many of the invasive plant species that is a major problem today were introduced. The first European settlers in the Woodbush area were five British army deserters of the Sekhukune campaign of 1879. One of them, Jock Schnell, reportedly planted the first black wattle trees (*Acacia mearnsii*) in the area (Wongtschowski, 2003). Currently, the study area is of mixed land use, including pine plantations, avocado orchards and natural grasslands and forests. The relatively long history of utilisation has left a legacy of environmental degradation, most clearly expressed in the extent of invasive alien plant stands.

5.3.2. Study design

We test the effect of different land use combinations in three adjacent sub-catchments on the following ecological components: 1) Biodiversity represented by invertebrate community composition and 2) Ecosystem services represented by in-stream biological water quality. The insect communities were sampled at a plot scale ($100m^2$), with ten plots randomly placed per catchment, while the measure of ES functioning, as determined by SASS5 biological monitoring protocol, is taken at the sub-catchment scale immediately down-stream of each catchment.

The three study sub-catchments fall along a continuum of different land use combinations. Table 5.1 shows the hectares and percentages of each sub-catchment covered by one of four land use types (land-use classes and values are adapted from the land use map presented in chapter four of this thesis).

- The invaded catchment is 63.4% invaded by unchecked stands of invasive *Acacia melanoxylon, A. mearnsii, A. decurrens, Eucalyptus grandis, Hakea salicifolia* and *Pinus elliottii* trees. Only 22.6% of this catchment remains as small and fragmented natural areas.

- The cleared catchment was also severely invaded in the recent past, but an intensive clearing program now leaves this sub-catchment with 46.1% recently cleared of invasives (now secondary grassland) and 11.8% still invaded. More than a quarter of this sub-catchment is still in a natural state.
- More than 60% of the natural catchment is still in a natural state. Pine plantations cover nearly a quarter of this sub-catchment, and these plantations are considered as functionally very similar to a stand of un-managed invasive trees.

5.3.3. Sampling procedures

During the autumn of 2014 (24 – 29 April) ground dwelling invertebrates were sampled using 60mm diameter un-baited pitfall traps. A sampling plot consisted of six individual traps, arranged along the sides of a 10x10m square – one on each corner, with a fifth and sixth trap along each of the two down slope sides of the square (Figure 5.1). The traps were left out for five days and five nights. The contents of the six traps per plot were lumped to form one representative sample per plot. The collected invertebrates were identified to different taxonomic levels. The ants were sorted to morpho-species level through comparison with reference collections at the department of Zoology, University of Venda (Munyai and Foord, 2015) and spiders were identified to family level using keys by Dippenaar-Schoeman and Jocque (1997). Coleopterans were identified to family level using keys in Scholtz and Holm (2008). All other taxa were identified to order level.

In addition to the traps, 100ml of soil from each trap-hole was collected and mixed together to form a representative sample for each plot. The soil samples were analysed in the laboratory for moisture content, active carbon (AC) and potentially mineralizable nitrogen (PMN) following the methodology of Gugino et al. (2009). Cover estimates for vegetation structural classes were made for each 10x10m plot (see Appendix 5.1 for cover-class scale) and abiotic variables (aspect, slope, lithology and altitude) were recorded.

The biological condition of the water immediately down-stream of each sub-catchment was measured in the autumn of 2014 (5 May) and summer of 2015 (9 January) using the SASS5 rapid bio-assessment method as described by Dickens and Graham (2002). The surveys provide a measure for two physical variables (pH and levels of dissolved oxygen) in the water and three benthic macroinvertebrate based indices (a SASS score, 'number of taxa' score and an ASPT score). The 'number of taxa' score is simply obtained by summing the number of individual invertebrate families (as stipulated on the official SASS score sheet) present. The SASS score is calculated by summing a quality score for each specific taxon. Quality scores are based on each taxon's sensitivity to disturbances in the water system, so the more sensitive taxa (less likely to occur in disturbed systems) have higher quality scores and thus add more weight to the SASS score relative to less sensitive taxa. The ASPT (average score per taxon) is calculated by dividing the SASS score by the number of taxa.

Table 5.1 The distribution of land use types – in percentage (%) – in three adjacent

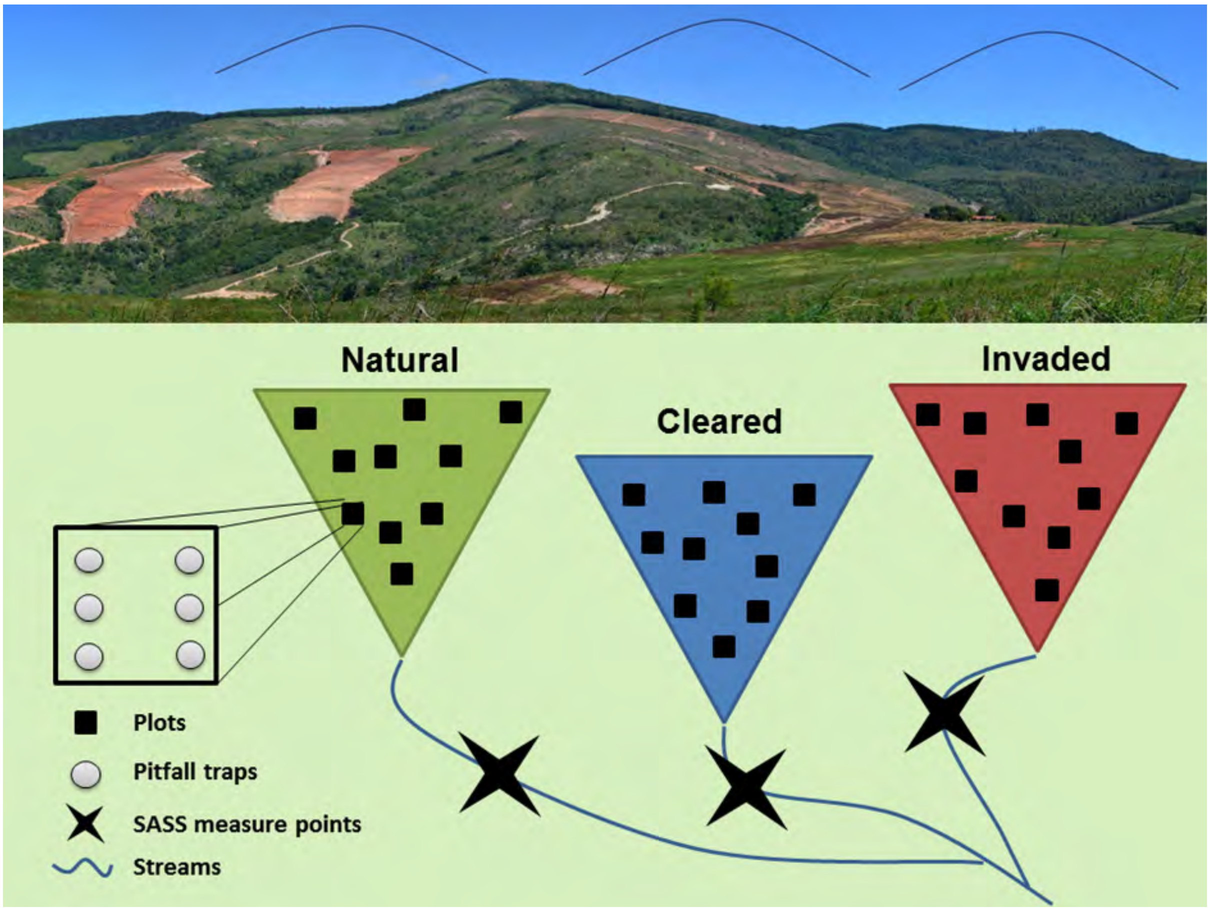


Figure 5.1 Schematic diagram of the experimental design. These three adjacent sub-catchments exhibit a range of land use types, ranging from mostly invasive trees, through mostly secondary grassland resulting from alien vegetation clearing to mostly natural. Within each catchment the vegetation cover in ten 100m^2 plots were surveyed and six pitfall traps were deployed per plot in the arrangement shown. Immediately down-stream of each catchment the biological water quality was assessed by means of the SASS5 protocol.

headwater sub-catchments of the Koedoes River (figures current May 2014).

	Catchment		
Land use	**Invaded %**	**Cleared %**	**Natural %**
Natural woody	6.96	8.44	34.80
Natural grassland/savanna	15.68	25.92	29.03
Secondary grassland	13.34	46.10	2.74
Exotic woody	63.43	11.81	26.39
Avocado orchards	0.59	7.73	7.03
Total hectares	**228.01**	**232.09**	**201.07**

5.3.4. Statistical analysis

Using the vegan package in R 3.0.1 (R Core Team, 2013), we used non-metric multidimensional scaling (NMDS) ordinations to ascertain how plots group based on invertebrate community structure. Because the two ordination axes explain the greatest variation in plot communities, these coordinates were used in further analyses as a summary of the invertebrate community patterns. Next, we attempt to ascertain which explanatory variable accounts for the most variation in the two ordination axes. For this purpose we use generalised linear models (GLMs), as these tests are robust and well suited to analysing relationships between a response variable (an ordination axis in this case) and several explanatory variables simultaneously. The model was run including all seventeen explanatory variables. Over several iterations, the least significant variables were removed until the most significant model was obtained.

5.4. Results

5.4.1. Invertebrate biodiversity

The invertebrate sampling yielded organisms from three Phyla (Mollusca, Annelida and Arthropoda) and seven taxonomic classes (Gastropoda, Oligochaeta, Chilopoda, Diplopoda, Malacostraca, Arachnida and Insecta). Of these classes, all were represented by a single Order, except the Insecta represented in fourteen Orders. Of these Orders, the Coleoptera were identified to ten Families, Hymenoptera: Formicidae was identified to 46 morpho-species and the spiders were identified to nineteen Families (see Appendix 5.2 for a list of taxa). In total 5058 individuals were sampled. See Table 5.2 for a summary of taxa richness, abundance and Shannon diversity-index values averaged per catchment and per land use. Grassy vegetation seems to house a higher abundance of invertebrates than woody vegetation. Exotic woody vegetation in particular seems to be very taxa poor.

The ordination diagram for 30 invertebrate community plots is shown in Figure 5.2., first coloured according to sub-catchment and then according to land use. When considering the ordination diagrams, it seems as if the invertebrate communities do not cluster together according to sub-catchment as hypothesised. However, where the plots are coloured according to land use, some grouping of colour is apparent – most notably the two grassier groups (red and blue) in the top-right corner (Figure 5.2).

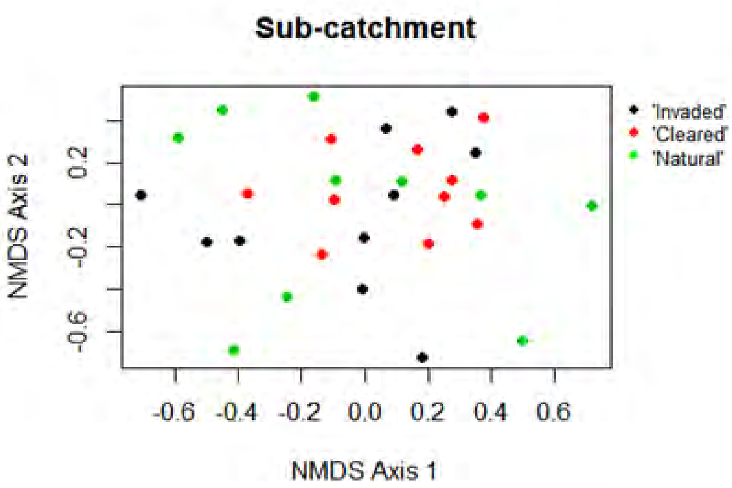
Table 5.2 Abundance, taxa richness and Shannon diversity index scores from thirty plots surveyed across three sub-catchments. Here the data is first averaged according to catchments and then according to plot-scale land use.

	Abundance (SE)		**Richness (SE)**		**Shannon index (SE)**	
Average per catchment (n)						
Invaded (10)	194.60	(50.79)	8.50	(0.86)	0.70	(0.08)
Cleared (10)	226.30	(48.44)	10.10	(0.59)	0.72	(0.05)
Natural (10)	84.90	(22.31)	8.00	(0.84)	0.62	(0.08)
Average per land use (n)						
Natural woody (6)	94.00	(32.21)	10.33	(1.05)	0.82	(0.11)
Natural grass/savanna (9)	209.56	(42.68)	8.44	(0.67)	0.67	(0.06)
Secondary grassland (7)	221.29	(66.27)	9.57	(1.17)	0.57	(0.06)
Exotic woody (8)	132.38	(55.60)	7.63	(0.75)	0.69	(0.08)

The best fitting GLM (AIC=9.8) for explaining the variation on the first ordination axis included only one significant variable, large tree (>5m) cover (P-value = 0-0.001), which is negatively correlated to the axis. The best fitting GLM (AIC=11.5) for the second axis includes both PMN content of the soil (positively correlated, P-value = 0.01-0.05) and percentage bare ground (negatively correlated, P-value = 0.001-0.01). Thus, the most variation in the first ordination axis can be explained by large tree cover. The plots with the most big trees are towards the left of the diagram, while those with no big trees are towards the right. The second ordination axis can be explained by bare ground cover of plots and PMN content of the soil. The plots with the highest percentage bare ground and lowest PMN are towards the bottom and those with the least amount of bare ground and highest PMN towards the top of the ordination diagram.

5.4.2. Down-stream ecosystem services

Table 5.3 present values for five measures of biological water quality (pH, dissolved oxygen, SASS, ASPT and 'number of taxa'-scores) during two seasons (autumn and summer). These were recorded in the mountain streams flowing from the three study catchments, immediately below the catchment. An extra stream flowing from a fourth small catchment covered entirely by natural forest was included as a control during the summer sampling. We consider the results of the different streams to be comparable because all biotopes were present and sampled in all streams and sampling effort was consistent across streams. Care was taken to



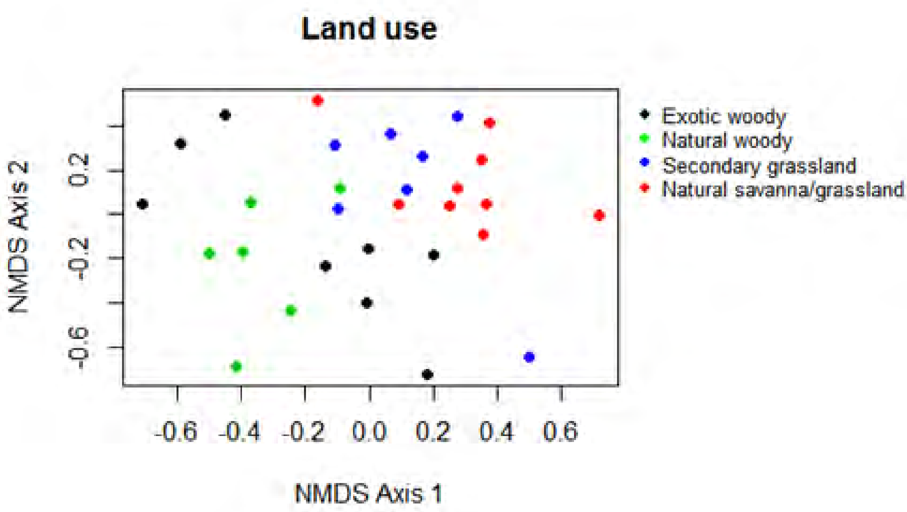


Figure 5.2 Ordination diagrams for invertebrate diversity and abundance in thirty plots.

adhere strictly to the sampling procedures outlined by Dickens and Graham (2002).

The water in all streams evaluated can be considered of very good biological quality. The relative differences between the indicators measured per stream show that the dominant land use in the sub-catchments may be correlated to the ability of the sub-catchments to provide water of good biological quality. Simple comparison of the SASS and ASPT-scores for each catchment (Table 5.3) show that the more natural catchment scored higher over two seasons than the invaded and cleared catchments for all measures except one in a season. The completely natural control catchment (measured only in summer 2015) scored markedly higher on all measures than the three catchments subjected to some degree of transformative land-use.

Table 5.3 Down-stream biological water condition values for four sub-catchments along the headwaters of the Koedoes River measured for two seasons.

Catchment	Invaded		Cleared		Natural		Natural control	
	Autumn	Summer	Autumn	Summer	Autumn	Summer	Autumn	Summer
SASS	136	77	91	97	145	109	na	171
No. of Taxa	23	14	16	16	21	16	na	23
ASPT	5.9	5.5	5.7	5.9	6.9	6.8	na	7.4
pH	6.2	9.9	6.6	9.2	6.6	9.4	na	10.2
Dissolved O (mg/L)	8.5	8.4	8.4	8.6	9.2	9.3	na	9.4

5.5. Discussion

5.5.1. Invertebrate biodiversity

It appears as if a fair amount of collinearity among covariates exists between the explanatory variables used here. This is not ideal, as it may influence the significance of the GLM models (Zuur et al., 2010). For example, the AC and PMN content of soils is very closely correlated to vegetation cover in this data set. The fact that PMN is significant in explaining the variation of the second ordination axis may thus indicate its close correlation to a variable like bare ground, rather than the actual role soil PMN plays in predicting the invertebrate community that forms at that particular plot.

The most important drivers of invertebrate diversity and abundance seem to be the structure of the vegetation – whether it is wooded or bare. Land use can be considered as an umbrella category encompassing all vegetation cover categories as the land-use classes used here are based on broad vegetation structural properties. We can thus say that the land-use class of a plot is a relatively good predictor of the plot's invertebrate community. The patterns evident in Table 5.2 support this notion.

Based on these analyses we reject our first hypothesis – invertebrate communities do not seem to respond to sub-catchment scale drivers, but rather to plot scale vegetation structures (most notably large tree cover). The implications of this finding are discussed below in section 5.5.4.

5.5.2. Down-stream ecosystem services

The following observations are noteworthy:

- The SASS and 'number of taxa'- score for the invaded catchment dropped markedly between the two sampling seasons, while the ASPT-score was less affected. This dramatic change may be attributed to a fire that engulfed large parts of the invasive tree stands, an invasive tree clearing project that resulted in the clearing of more than 15ha of invasive trees and the grading and preparation of land for new avocado orchards in the catchment since the first sampling effort.
- A slight drop in the SASS and 'number of taxa' scores across seasons for the natural catchment is also apparent. This may be attributed to the preparation of new avocado orchards in the lower part of the catchment during this period. It is not indicated in Table 5.4, but the turbidity of the water in this catchment was also much higher in summer than autumn and can be attributed to the recent earth works mentioned.
- The cleared catchment stayed relatively constant across seasons for all three indices. This can be explained by the absence of any large scale earth works in this catchment between survey dates.
- The water pH seems to show some seasonal trends, as the pH for all three catchment is consistently about three points higher in summer than autumn.
- As mentioned by Dickens and Graham (2002), the ASPT score is less variable across different streams and seasons and is thus the most robust measure of relative

biological water condition. The ASPT scores stayed relatively constant across seasons for each catchment, despite fluctuations in the other measures. The two more natural streams have markedly higher ASPT scores across seasons.

- It appears that the higher scoring catchments have slightly more acidic and oxygen rich waters than the lower scoring catchments. Whether it is the land use practices that cause a change in dissolved oxygen and pH, in turn leading to lower SASS and ASPT scores or whether the lower scores influence the dissolved oxygen and pH remains an open question.

Based on ASPT-scores, it appears as if our second hypothesis may be true, but the current SASS5 data is too limited in spatial and temporal distribution to support this statement statistically. We suggest more observations over time and at a number of localities along each stream. Perhaps other measures of stream health, such as the 'index of habitat intactness' (Kleynhans et al., 2008) should be incorporated. Such data may form the backbone of a very informative long-term monitoring program on the effect of land use on downstream water quality. Particularly noteworthy results would be to see how the establishment and maturation of long-term tree crops such as avocados influence downstream water quality over time. Stream flow measurements were attempted in some of the streams (data not included here) and continued data on flow regimes may also be very useful in determining the impact of land use on downstream water quality and availability. Although our attempts to link land use and management to down-stream water quality in the KRC may still be inconclusive, strong evidence exists that management practises do influence ES provision (e.g. Galatowitsch and Richardson, 2005; Van Oudenhoven et al., 2012).

5.5.3. Strengths and limitations of the approach

Alterations to several components of the study design may improve the quality and applicability of results. The most significant caveat is that biodiversity and ES were measured at different scales. Biodiversity (at plot scale) can thus not clearly be related to ES (at sub-catchment scale). Biodiversity plots can be lumped per catchment in order to make it relatable to ES measures, but considering the findings that invertebrate communities respond to plot level factors (see section 5.4.1) we decided not to attempt that with a sample size of only ten plots per catchment.

Further, a number of factors that may obscure trends are not controlled for in this study. Invertebrate sampling is from a single season only and seasonal variability is thus not taken into account. Preliminary results from a second sampling session in the spring of 2014 does, however, suggest that the results obtained will be similar during other times of the year. Further, the broad spectrum of indicator taxa used here may not reveal specific trends as clearly as a more focused indicator group, such as ants (Folgarait, 1998) or rodents (Avenant, 2000) for example, would. But in this instance we assess broad ecological integrity and the use of the broadest feasible spectrum of indicators thus seem justifiable. However, sorting taxa into functional guilds (e.g. primary consumers, detritus feeders or predators) may be the most successful in revealing actual trends associated with ecological functioning within this study design. In addition, a fair amount of collinearity among the covariates likely exists between the explanatory variables used here. This may cause models to appear insignificant, until one of the covariates are removed (Zuur et al., 2010). The use of more complicated statistical procedures or the use of unrelated explanatory variables may solve this problem.

Two additional factors that may serve to clarify results warrant mentioning. Firstly, the invertebrate sampling method employed (un-baited pitfall trapping) was quick and easy, but it does not provide equal representation of invertebrate diversity across vegetation and habitat types. For example, in indigenous forests a large component of the invertebrate biodiversity lives in the canopy and is extremely unlikely to be caught in a pitfall trap. In grasslands however, the majority of the invertebrate biota will stand a good chance to be trapped. This means that the data does not capture the full spectrum of invertebrate diversity across the habitat types investigated. Secondly, no plots were located in any orchards, constituting a major gap in this study's understanding of land use effects on biodiversity and ecosystem services in an agricultural setting.

5.5.4. Land use and ecosystem service provisioning implications

Amis et al. (2007) found that natural vegetation cover was the most significant predictor of riparian and in-stream ecological integrity – "In the absence of other data on the state of a river, assessing the natural vegetation cover alone can provide a fairly reasonable prediction of integrity". Similarly, from the results presented here, it appears as if invertebrate diversity and abundance patterns respond more strongly to fine scale vegetation factors at the $100m^2$ plot level, than to larger scale sub-catchment level factors. The structure of vegetation seems to be particularly important to invertebrate communities. This may have significant implications for biodiversity conservation and ecosystem services provision, as it means that management practices at the finest scale has an impact on biodiversity.

At a global scale fresh water resource-use do not seem to warrant as much attention as other planetary boundaries such as biogeochemical flows and climate change (Rockström et al., 2009; Steffen et al., 2015). From the South African perspective, however, fresh water resources are very important (Driver et al., 2012; Le Maitre et al., 2002) and if we zoom in to the quaternary catchment scale – to the KRC – we find that a healthy water system is considered the most important and valuable natural asset (see chapter 4). The results from this chapter suggests that land use management to the finest scale of 10x10m plots can have an influence on biodiversity and ecosystem processes which in turn seems to affect downstream ecosystem service delivery.

5.6. Conclusion

In this chapter we attempted to find a correlation between the patterns of land use for three adjacent sub-catchments (±200ha) and possible responses in the biodiversity (expressed as ground dwelling invertebrate communities) and ecosystem services provisioning (expressed in down-stream biological water quality) of the catchments. It was hypothesised that the invertebrate communities will respond to sub-catchment scale land use patterns. This hypothesis was rejected in favour of the alternative – fine scale plot characteristics (particularly vegetation structure) is a more significant driver of invertebrate community composition. The second hypotheses, that sub-catchment scale land use patterns will influence down-stream ES delivery (represented by biological water quality in this case), could not be conclusively tested. Early indications partially support this hypothesis. The results of this chapter imply that land use and management to the finest scale of $100m^2$ plots may have a significant influence on biodiversity and ecosystem functioning. This may have significant implications on downstream ecosystem services provisioning. The functioning and integrity of ecological systems should thus be considered and applied at the finest farm management scale The findings of this and related future work can be used to inform restoration and agricultural development efforts to optimize ES delivery in the headwaters of important quaternary catchments.

CHAPTER 6: CONCLUSION

6.1. Introduction

This thesis sets out to contribute towards finding a solution to the 'global challenge' – the contemporary trade-off faced by humanity between maintaining our consumptive life styles and ensuring global environmental integrity for future generations. As practical starting point we aimed to establish a baseline inventory of biodiversity and ecological assets in the agriculturally productive Koedoes River Catchment (KRC) and to assess the impact of agricultural activity on the biodiversity and ecological processes of the KRC. The main objectives for the study are to: 1) assess the current state of biodiversity in the KRC using vegetation as a proxy. For this purpose, a rapid vegetation mapping technique was developed to generate a fine scale vegetation map of the KRC. 2) Assess the current state of human land use in the KRC by creating a recent land use map using aerial photographs. 3) Assess the relative contribution of certain habitat types towards ecosystem services (ES) provisioning in the KRC using feedback from stakeholder engagement. 4) Lastly, to assess the effects of various land-use types on biodiversity and down-stream ES provisioning in three sub-catchments at the headwaters of the Koedoes River.

6.2. Major findings

6.2.1. Biodiversity

From a botanical perspective, the KRC is a very bio-diverse catchment. On the national scale only four vegetation types are identified for the catchment (Mucina and Rutherford, 2006). We present a map and detailed descriptions of eleven distinct vegetation types identified for the KRC, grouped into three distinct topographical-climatic zones. In order to achieve this, we developed and successfully applied a rapid vegetation mapping technique. A list of 49 red-listed plant species likely to occur in the KRC is provided along with a list of 454 plant species encountered in the KRC to date (this list is expected to grow considerably with continued collecting).

The KRC is still in a relatively good environmental condition. Just less than half of the catchment can still be considered in a natural state, while about a third has been transformed by human land use. The remainder is subject to some form of degradation, such as over grazing or alien plant invasion. The different topo-climatic zones and vegetation types are affected to varying degrees by human land use. The Lowveld and Montane zones are most transformed by agricultural activities and within these zones the Woodbush granite grassland and Tzaneen sour bushveld plains vegetation types are under the most pressure. For the most part the Highveld zone and its associated vegetation types are under very little pressure. The riverine vegetation is in a fair state.

6.2.2. Ecosystem services

Functioning and reliable ecosystem services are vital to agriculture (Tscharntke et al., 2005). Knowing the state and position in the landscape of ecosystems that provide vital ecosystem services is the first step towards sustainable ES management. Building on the methodology of Burkhard et al. (2012), we used a specifically created fine-scale land-use map, the vegetation map and information from stakeholder feedback to identify areas of ES importance. Water related ES were the most in demand, while supporting ES such as 'aesthetical value' is in the most abundant supply. Combining information from the vegetation, land use and ES maps, we can see the relative importance of different areas of the catchment. The Montane and Highveld areas are important for both biodiversity and water related ES, while the Lowveld is mainly of agricultural importance. Small patches and corridors of natural vegetation in a matrix of agricultural land use are of considerable ES value.

6.2.3. Farm scale application of concepts

At the farm scale, biodiversity seems to respond to very fine-scale drivers. This suggests that biodiversity should be considered at the very finest of scales when planning agricultural developments. Further inconclusive evidence points to negative effects of land-use practices on down-stream biological water quality.

6.3. Management implications and further research

This work has served to create a baseline of biological information for the agriculturally important KRC. Interventions such as extended alien clearing and a move from open-land cultivation to net houses are bound to have effects on the state of natural systems in the KRC. To keep track of these impacts, a set of long-term monitoring programs are suggested in order to continuously monitor the state of biodiversity and the responses of certain key ecosystem services to management interventions in the KRC over time. Such monitoring programs may include fixed-point repeat photography, biological monitoring of water resources using simple techniques such as miniSASS and tracking changes in vegetation using repeat monitoring plots. Some further work that may be of value to the holistic management of the KRC are outlined below:

- An early detection and rapid response monitoring program for new invasive plants is suggested, along with a management plan for invasive species already established in the KRC.
- More fine-scale investigations into the interactions between natural areas and agriculture will also be helpful towards planning a sustainable, ecologically functional and bio-diverse agricultural landscape (e.g. determining fragment sizes of natural vegetation for optimal biodiversity conservation, determining the connectivity of natural areas, effects of smaller orchards in a matrix of natural vegetation opposed to large, unbroken orchards).
- A Headwater management and restoration plan for the Koedoes River.
- A survey of landscape connectivity to guide and prioritise restoration efforts in order to connect as many natural areas as possible.
- Connections to larger initiatives outside the KRC (such as the UNESCO Kruger to Canyons Biosphere Reserve) should be kept in mind.
- The possibility of carbon farming in combination with ecological restoration should also be considered.
- Vegetation type-specific management plans aimed at optimum biodiversity conservation incorporating appropriate disturbance regimes (such as fire) can be drawn up using the classification schemes presented here.

A striking feature about ZZ2 and the KRC community is their openness to new ideas and their willingness to change old ways for the sake of sustainability. The paradigm shifts that took place in this community (and are still in the process of taking place) enabled them to adopt a new, more environmentally friendly and ultimately more sustainable approach to commercial farming. This approach may be a step in the direction towards finding a solution to the ‘global challenge’. If that is the case, we should keep track of the social processes busy taking place among the people of the KRC, so that it can be replicated in another setting.

6.4. Concluding remarks

To conclude, the KRC has an exciting and positive story to tell in a world dominated by environmental ‘doom and gloom’ (see the introductory chapter of this thesis). Here we find a landscape where large untouched pieces of natural vegetation, rich in biodiversity, can co-exist with state-of-the-art modern agriculture. Each justified in its right to exist – the crops to feed people and create prosperity and the natural areas to maintain vital ecosystem services.

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APPENDICES

Appendix 2.1 A working list of plant species collected in the Koedoes River Catchment between October 2013 and March 2015.

Family name	Species name	Voucher specimen number
ACANTHACEAE	*Crabbea hirsuta*	WAH: 368a 473 430
ACANTHACEAE	*Rhinacanthus xerophilus*	WAH: 533
ACANTHACEAE	*Barleria kaloxytona* cf	WAH: 313a 360
ACANTHACEAE	*Barleria* sp. 1	WAH: 527
ACANTHACEAE	*Barleria* sp. 2	WAH: 266
ACANTHACEAE	*Barleria* sp. 3	WAH: 313b 456
ACANTHACEAE	*Barleria* sp. 4	WAH: 323
ACANTHACEAE	*Crossandra greenstockii* cf	WAH: 833
ACANTHACEAE	*Thunbergia* sp. 1	WAH: 392
ACANTHACEAE	*Thunbergia* sp. 2	WAH: 429
ACANTHACEAE	*Thunbergia* sp. 3	WAH: 541
ACANTHACEAE	*Thunbergia* sp. 4	WAH: 557
ACANTHACEAE	*Thunbergia* sp. 5	WAH: 644
ACANTHACEAE	*Thunbergia* sp. 6	WAH: 346
AGAPANTHACEAE	*Agapanthus inapertus*	WAH: 1004
AMARANTHACEAE	*Achyranthes aspera* cf. var. *sicula*	WAH: 394 422 445
AMARANTHACEAE	*Kyphocarpa angustifolia*	WAH: 265 343 538
AMARANTHACEAE	*Pupalia lappacea*	WAH: 310 452 467
AMARYLLIDACEAE	*Crinum buphanoides* cf.	WAH: 993
ANACARDIACEAE	*Lannea discolor*	WAH: 911
ANACARDIACEAE	*Lannea edulis*	WAH: 649 943
ANACARDIACEAE	*Ozoroa sphaerocarpa*	WAH: 499
ANACARDIACEAE	*Sclerocarya birrea*	WAH: 203a 838 843
ANACARDIACEAE	*Searsia chirindensis*	WAH: 901
ANACARDIACEAE	*Searsia leptodictya*	WAH: 263 549
ANACARDIACEAE	*Searsia transvaalensis*	WAH: 647
ANACARDIACEAE	*Searsia magalismontana* cf	WAH: 930
ANACARDIACEAE	*Searsia* sp. 1	WAH: 611
ANACARDIACEAE	*Searsia* sp. 2	WAH: 526
ANACARDIACEAE	*Searsia* sp. 3	WAH: 607
ANACARDIACEAE	*Searsia* sp. 4	WAH: 924
APIACEAE	*Heteromorpha arborescens*	WAH: 667
APIACEAE	*Steganotaenia araliacea*	WAH: 334 574 829
APOCYNACEAE	*Carissa bispinosa*	WAH: 905
APOCYNACEAE	*Carissa bispinosa* subsp. *zambesiensis*	WAH: 740
APOCYNACEAE	*Carissa edulis*	WAH: 244 250 857
APOCYNACEAE	*Stomatostemma monteiroae*	WAH: 912
AQUIFOLIACEAE	*Ilex mitis*	WAH: 757
ARALIACEAE	*Cussonia natalensis*	WAH: 576
ARALIACEAE	*Cussonia spicata*	WAH: 879
ASCLEPIADACEAE	*Gomphocarpus fruticosus*	WAH: 492
ASCLEPIADACEAE	*Gomphocarpus physocarpus*	WAH: 985
ASCLEPIADACEAE	*Sarcostemma viminale*	WAH: 609 661
ASCLEPIADACEAE	*Secamone parvifolia*	WAH: 963
ASPARAGACEAE	*Asparagus asparagoides*	WAH: 707 1002
ASPARAGACEAE	*Asparagus falcatus*	WAH: 713 744a
ASPARAGACEAE	*Asparagus* sp. 1	WAH: 317
ASPARAGACEAE	*Asparagus* sp. 2	WAH: 402
ASPARAGACEAE	*Asparagus* sp. 3	WAH: 593 595
ASPARAGACEAE	*Asparagus* sp. 4	WAH: 702
ASPHODELACEAE	*Aloe arborescens*	WAH: 971

ASPHODELACEAE	*Aloe zebrina*	WAH: 399
ASTERACEAE	*Acanthospermum australe*	WAH: 682
ASTERACEAE	*Ageratina altissima*	WAH: 798 810
ASTERACEAE	*Athrixia phylicoides*	WAH: 503 606 790
ASTERACEAE	*Bidens biternata*	WAH: 349 367a
ASTERACEAE	*Bothriocline laxa*	WAH: 594
ASTERACEAE	*Brachylaena tranvaalensis*	WAH: 826
ASTERACEAE	*Callilepis salcifolia*	WAH: 226
ASTERACEAE	*Chromolaena odorata*	WAH: 780
ASTERACEAE	*Crassocephalum* X *picridifolium*	WAH: 718
ASTERACEAE	*Flaveria bidentis*	WAH: 865
ASTERACEAE	*Gerbera jamesonii*	WAH: 978
ASTERACEAE	*Gymnanthemum coloratum*	WAH: 586 792
ASTERACEAE	*Helichrysum kraussii*	WAH: 805b 655
ASTERACEAE	*Lopholaena coriifolia*	WAH: 808
ASTERACEAE	*Macledium zeyheri* subsp. *Zeyheri*	WAH: 507
ASTERACEAE	*Psiadia punctulata*	WAH: 489 630 909
ASTERACEAE	*Senecio babertonicus*	WAH: 979
ASTERACEAE	*Senecio pleistocephalus*	WAH: 449
ASTERACEAE	*Senecio venosus*	WAH: 484 592
ASTERACEAE	*Tarchonathus parvicapitulatus*	WAH: 666
ASTERACEAE	*Vernonia adoensis*	WAH: 579
ASTERACEAE	*Vernonia aurantiaca*	WAH: 566 726
ASTERACEAE	*Vernonia wollastonii*	WAH: 815
ASTERACEAE	*Berkheya* sp. 1	WAH: 517
ASTERACEAE	*Felicia muricata* cf	WAH: 598
ASTERACEAE	*Geigeria burkei* cf	WAH: 605
ASTERACEAE	*Senecio* sp. 1	WAH: 714
ASTERACEAE	*Senecio* sp. 2	WAH: 804b
BALANITACEAE	*Balanites maughamii*	WAH: 712
BALANITACEAE	*Balanites pedicellaris*	WAH: 962
BALSAMINACEAE	*Impatients sylvicola*	WAH: 903
BIGNONIACEAE	*Macfadyena unguis-cati*	WAH: 873
BIGNONIACEAE	*Tecoma stans*	WAH: 872
BIGNONIACEAE	*Markhamia* sp. 1	WAH: 791
BORAGINACEAE	*Ehretia amoena*	WAH: 260 1009
BORAGINACEAE	*Ehretia rigida* subsp. *nervifolia*	WAH: 200
BORAGINACEAE	*Ehretia* sp. 1	WAH: 992
BUDDLEJACEAE	*Buddleja saligna*	WAH: 249
BUDDLEJACEAE	*Buddleja salviifolia*	WAH: 731 800
BUDDLEJACEAE	*Nuxia congesta*	WAH: 668 738
BURSERACEAE	*Commiphora africana*	WAH: 989
BURSERACEAE	*Commiphora mollis*	WAH: 299 333 551
CACTACEAE	*Opuntia* sp. 1	WAH: 553
CAESALPINIACEAE	*Bauhinia galpinii*	WAH: 258
CAESALPINIACEAE	*Caesalpiniaceae decapetala*	WAH: 781
CAESALPINIACEAE	*Cassia abbreviata*	WAH: 847
CAESALPINIACEAE	*Cassia fistula* cf.	WAH: 958
CAESALPINIACEAE	*Dalbergia armata*	WAH: 881
CAESALPINIACEAE	*Delonix regia*	WAH: 957
CAESALPINIACEAE	*Peltophorum africanum*	WAH: 956
CAESALPINIACEAE	*Piliostigma thonningii*	WAH: 1008
CAESALPINIACEAE	*Pterocarpus angolensis*	WAH: 925
CAESALPINIACEAE	*Pterocarpus rotundifolia*	WAH: 917
CAESALPINIACEAE	*Schotia brachypetala*	WAH: 885
CAESALPINIACEAE	*Senna italica* subsp. *arachoides*	WAH: 851
CAESALPINIACEAE	*Senna didymobotrya*	WAH: 908
CAESALPINIACEAE	*Senna petersiana*	WAH: 259 298
CAMPANULACEAE	*Wahlenbergia* sp. 1	WAH: 587 241 286
CAPPARACEAE	*Capparis tomentosa*	WAH: 208

CAPPARACEAE	*Maerua angolensis*	WAH: 883 884
CAPPARACEAE	*Maerua juncea* subsp. *crustata*	WAH: 869
CELASTRACEAE	*Catha edulis*	WAH: 212
CELASTRACEAE	*Elaeodendron transvaalense*	WAH: 896 888 994
CELASTRACEAE	*Gymnosporia buxifolia*	WAH: 878
CELASTRACEAE	*Gymnosporia harveyana*	WAH: 762 907
CELASTRACEAE	*Gymnosporia tenuispina*	WAH: 570
CELASTRACEAE	*Maytenus undata*	WAH: 629 671 672 754 853
CELASTRACEAE	*Mystroxylon aethiopicum* subsp. *schlechteri*	WAH: 789
CELTIDACEAE	*Celtis africana*	WAH: 858
CELTIDACEAE	*Chaetacme aristata*	WAH: 852
CELTIDACEAE	*Trema orientalis*	WAH: 571
CHENOPODIACEAE	*Chenopodium album*	WAH: 1014
CHENOPODIACEAE	*Chenopodium ambrosioides*	WAH: 1015
CHRYSOBALANACEAE	*Parinari curatellifolia*	WAH: 583
CLUSIACEAE	*Hypericum revolutum*	WAH: 722
COLCHICACEAE	*Androcymbium melanthioides* var. *subulatum*	WAH: 1000
COLCHICACEAE	*Gloriosa superba*	WAH: 245
COMBRETACEAE	*Combretum apiculatum*	WAH: 205
COMBRETACEAE	*Combretum collinum*	WAH: 827
COMBRETACEAE	*Combretum collinum* subsp. *suluense*	WAH: 257
COMBRETACEAE	*Combretum erythrophyllum*	WAH: 856
COMBRETACEAE	*Combretum hereroense*	WAH: 406 846
COMBRETACEAE	*Combretum imberbe*	WAH: 890
COMBRETACEAE	*Combretum kraussii*	WAH: 737 954
COMBRETACEAE	*Combretum molle*	WAH: 938
COMBRETACEAE	*Combretum zeyheri*	WAH: 918
COMBRETACEAE	*Combretum* sp. 1	WAH: 405 501 617
COMMELINACEAE	*Commelina africana* cf.	WAH: 970
CONVOLVULACEAE	*Evolvulus alsinoides*	WAH: 342 367b
CONVOLVULACEAE	*Ipomoea albivenia*	WAH: 254
CONVOLVULACEAE	*Ipomoea* sp. 1	WAH: 280
CONVOLVULACEAE	*Ipomoea* sp. 2	WAH: 420
CONVOLVULACEAE	*Ipomoea* sp. 3	WAH: 448
CONVOLVULACEAE	*Ipomoea* sp. 4	WAH: 359 544
CONVOLVULACEAE	*Ipomoea* sp. 5	WAH: 296 425 465 491
CRASSULACEAE	*Kalanchoe* sp. 1	WAH: 328 373
CRASSULACEAE	*Kalanchoe* sp. 2	WAH: 408 458
CURCUBITACEAE	*Coccinia variifolia* cf.	WAH: 997
CURCURBITACEAE	*Cucumis myriocarpus* subsp. *myriocarpus*	WAH: 462 475
CURCURBITACEAE	*Momordica balsamina*	WAH: 256
CURCURBITACEAE	*Cucumis anguria* cf	WAH: 395
CURCURBITACEAE	*Curcurbit* sp. 1	WAH: 311
CURTISIACEAE	*Curtisia dentata*	WAH: 720
CYATHEACEAE	*Cyathea dregei*	WAH: 897
CYPERACEAE	*Cyperus obtusiflorus*	WAH: 981
CYPERACEAE	*Cyperus sexangularis*	WAH: 863 864
CYPERACEAE	*Cyperaceae* sp. 1	WAH: 961
DIOSCOREACEAE	*Dioscorea sylvatica*	WAH: 914
DIPSACACEAE	*Scabiosa columbaria*	WAH: 927
DRACAENACEAE	*Sansevieria hyacinthoides*	WAH: 535
EBENACEAE	*Diospyros lycioides* subsp. cf. *nitens*	WAH: 627
EBENACEAE	*Diospyros lycioides* subsp. cf. *sericea*	WAH: 862
EBENACEAE	*Diospyros mespiliformis*	WAH: 201 304 563
EBENACEAE	*Diospyros whyteana*	WAH: 590 663
EBENACEAE	*Euclea crispa* subsp. *crispa*	WAH: 614a 614b
EBENACEAE	*Euclea divinorum*	WAH: 454
EBENACEAE	*Euclea crispa* cf	WAH: 222
EUPHORBIACEAE	*Acalypha indica* var. *indica*	WAH: 536
EUPHORBIACEAE	*Clutia pulchella*	WAH: 664

EUPHORBIACEAE	*Euphorbia heterophylla*	WAH: 350
EUPHORBIACEAE	*Euphorbia ingens*	WAH: 531
EUPHORBIACEAE	*Euphorbia tirucalli*	WAH: 850
EUPHORBIACEAE	*Flueggea virosa* subsp. *virosa*	WAH: 272 573 355 329
EUPHORBIACEAE	*Jatropha latifolia*	WAH: 264 485
EUPHORBIACEAE	*Ricinus communis* var. *communis*	WAH: 867
EUPHORBIACEAE	*Spirostachys africana*	WAH: 889
EUPHORBIACEAE	*Clutia* sp. 1	WAH: 641
EUPHORBIACEAE	*Tragia okanyua* cf	WAH: 294 396
FABACEAE	*Cordyla africana*	WAH: 848
FABACEAE	*Dalbergia melanoxylon*	WAH: 302
FABACEAE	*Philenoptera violacea*	WAH: 861
FLACOURTIACEAE	*Flacourtia indica*	WAH: 321
FLACOURTIACEAE	*Scolopia zeyheri*	WAH: 834
FLACOURTIACEAE	*Trimeria grandifolia* subsp. *grandifolia*	WAH: 736b 750 996
GERANIACEAE	*Pelargonium luridum*	WAH: 240
GESNERIACEAE	*Streptocarpus cyaneus*	WAH: 973
HETEROPYXIDACEAE	*Heteropyxis natalensis*	WAH: 377 591
HYACINTHACEAE	*Schizocarphus nervosus*	WAH: 236
HYACINTHACEAE	*Scilla natalensis*	WAH: 238
HYPOXIDACEAE	*Hypoxis argentea*	WAH: 966
HYPOXIDACEAE	*Hypoxis filiformis*	WAH: 234
HYPOXIDACEAE	*Hypoxis rigidula*	WAH: 946
HYPOXIDACEAE	*Hypoxis* sp. 1	WAH: 631
ICACINACEAE	*Apodytes dimidiata*	WAH: 785
ICACINACEAE	*Apodytes dimidiata* subsp. *dimidiata*	WAH: 665
IRIDACEAE	*Aristea tortulosa* cf	WAH: 223
IRIDACEAE	*Gladiolus* sp. 1	WAH: 660
IRIDACEAE	*Gladiolus* sp. 2	WAH: 984
IRIDACEAE	*Morea* sp. 1	WAH: 581
KIRKIACEAE	*Kirkia acuminata*	WAH: 209
LAMIACEAE	*Clerodendrum ternatum*	WAH: 301 391
LAMIACEAE	*Clerodendrum ternatum* var. *ternatum*	WAH: 986
LAMIACEAE	*Leonotis intermedia*	WAH: 393 418
LAMIACEAE	*Ocimum americanum* var. *americanum*	WAH: 987
LAMIACEAE	*Ocimum obovatum* ssp. *obovatum*	WAH: 923
LAMIACEAE	*Rotheca myricoides*	WAH: 977
LAMIACEAE	*Tinnea rhodesiana*	WAH: 308 356a
LAMIACEAE	*Volkameria glabra*	WAH: 247 251
LAMIACEAE	*Hemizegia* sp. 1	WAH: 968
LAMIACEAE	*Leonotis* sp. 1	WAH: 276
LAMIACEAE	*Plectranthus* sp. 1	WAH: 322
LAMIACEAE	*Plectranthus* sp. 2	WAH: 934
LAMIACEAE	*Rotheca* sp. 2	WAH: 816
LAMIACEAE	*Rotheca* sp. 3	WAH: 231
LILIACEAE	*Ledebouria ovatifolia*	WAH: 967
LILIACEAE	*Lilium formosanum*	WAH: 1013
LOBELIACEAE	*Cyphia transvaalensis*	WAH: 1003
LOBELIACEAE	*Lobelia flaccida* subsp. *flaccida*	WAH: 983
LORANTHACEAE	*Tapinanthus* sp. 1	WAH: 203b
MAESACEAE	*Maesa lanceolata*	WAH: 747
MALPIGHIACEAE	*Sphedamnocarpus pruriens* subsp. *pruriens*	WAH: 331
MALVACEAE	*Abutilon angulatum*	WAH: 552
MALVACEAE	*Gossypium herbaceum* var. *africanum*	WAH: 711
MALVACEAE	*Hibiscus cannabinus*	WAH: 400 463
MALVACEAE	*Hibiscus praeteritus*	WAH: 202 347
MALVACEAE	*Melhania acuminata* var. *acuminata*	WAH: 278
MALVACEAE	*Pavonia columella*	WAH: 719
MALVACEAE	*Abutilon* sp. 1	WAH: 268
MELIACEA	*Melia azedarach*	WAH: 870

MELIACEAE	*Ekebergia capensis*	WAH: 213 975
MIMOSACEAE	*Acacia davyi*	WAH: 216 880
MIMOSACEAE	*Acacia decurrens*	WAH: 696 793
MIMOSACEAE	*Acacia exuvialis*	WAH: 916
MIMOSACEAE	*Acacia gerrardii*	WAH: 926
MIMOSACEAE	*Acacia karroo*	WAH: 882
MIMOSACEAE	*Acacia mearnsii*	WAH: 695 794
MIMOSACEAE	*Acacia polyacantha*	WAH: 207
MIMOSACEAE	*Acacia rehmanniana*	WAH: 1007
MIMOSACEAE	*Albizia harveyi*	WAH: 839
MIMOSACEAE	*Albizia versicolor*	WAH: 1006
MIMOSACEAE	*Dichrostachys cinerea* subsp. *africana*	WAH: 623
MIMOSACEAE	*Senegalia caffra*	WAH: 624
MIMOSACEAE	*Vachellia tortilis*	WAH: 469
MIMOSACEAE	*Elephantorrhiza* sp. 1	WAH: 293
MONIMIACEAE	*Xymalos monospora*	WAH: 745
MORACEAE	*Ficus burkei*	WAH: 876
MORACEAE	*Ficus glumosa*	WAH: 936
MORACEAE	*Ficus ingens*	WAH: 805a 859
MORACEAE	*Ficus stuhlmannii*	WAH: 204
MORACEAE	*Ficus sur*	WAH: 860
MORACEAE	*Ficus* sp. 1	WAH: 582
MYROTHAMNACEAE	*Myrothamnus flabellifolia*	WAH: 932
MYRSINACEAE	*Myrsine africana*	WAH: 801
MYRSINACEAE	*Rapanea malanophloeos*	WAH: 752
MYRTACEAE	*Syzygium cordatum*	WAH: 812
MYRTACEAE	*Syzygium gerrardii*	WAH: 742
OCHNACEAE	*Ochna arborea* var. *oconnorii*	WAH: 764
OCHNACEAE	*Ochna confusa*	WAH: 947
OCHNACEAE	*Ochna natalitia*	WAH: 354 375
OLACACEAE	*Ximenia caffra* var. *natalensis*	WAH: 854
OLEACEAE	*Jasminum fluminense*	WAH: 725
OLEACEAE	*Jasminum multipartitum*	WAH: 841
OLEACEAE	*Jasminum streptopus* var. *transvaalensis*	WAH: 982
OLEACEAE	*Olea europaea* subsp. *africana*	WAH: 220 612
OLEACEAE	*Schrebera alata*	WAH: 659b
OLEACEAE	*Jasminum fluminense* cf	WAH: 324
OLEACEAE	*Jasminum* sp. 1	WAH: 705
OXALIDACEAE	*Oxalis* sp. 1	WAH: 230
OXALIDACEAE	*Oxalis* sp. 2	WAH: 435
OXALIDACEAE	*Oxalis* sp. 3	WAH: 632
PAPAVERACEAE	*Argemone ochroleuca*	WAH: 828
PAPILIONACEAE	*Bolusanthus speciosus*	WAH: 868
PAPILIONACEAE	*Calpurnia aurea* subsp. *aurea*	WAH: 902
PAPILIONACEAE	*Chamaecrista absus*	WAH: 427
PAPILIONACEAE	*Chamaecrista mimosoides* cf.	WAH: 528 928
PAPILIONACEAE	*Crotalaria pallida* var. *pallida*	WAH: 580
PAPILIONACEAE	*Desmodium repandum*	WAH: 959
PAPILIONACEAE	*Eriosema psoraleoides*	WAH: 585 964
PAPILIONACEAE	*Ormocarpum trichocarpum*	WAH: 332
PAPILIONACEAE	*Psoralea pinnata* var. *latifolia*	WAH: 802b
PAPILIONACEAE	*Sesbania bispinosa*	WAH: 1017
PAPILIONACEAE	*Tephrosia cordata*	WAH: 1001
PAPILIONACEAE	*Chamaecrista* sp. 1	WAH: 344a 366 472
PAPILIONACEAE	*Chamaecrista* sp. 2	WAH: 650
PAPILIONACEAE	*Crotalaria* sp. 1	WAH: 898
PAPILIONACEAE	*Rhynchosia nitens* cf	WAH: 676 952
PAPILIONACEAE	*Rhynchosia* sp. 1	WAH: 273 558
PAPILIONACEAE	*Rhynchosia* sp. 2	WAH: 274
PAPILIONACEAE	*Rhynchosia* sp. 3	WAH: 279

PAPILIONACEAE	*Rhynchosia* sp. 4	WAH: 306
PAPILIONACEAE	*Rhynchosia* sp. 5	WAH: 345
PAPILIONACEAE	*Rhynchosia* sp. 6	WAH: 390
PAPILIONACEAE	*Rhynchosia* sp. 7	WAH: 398
PAPILIONACEAE	*Rhynchosia* sp. 8	WAH: 437
PAPILIONACEAE	*Rhynchosia* sp. 9	WAH: 512
PAPILIONACEAE	*Rhynchosia* sp. 10	WAH: 515
PAPILIONACEAE	*Rhynchosia* sp. 11	WAH: 539
PAPILIONACEAE	*Rhynchosia* sp. 12	WAH: 555
PAPILIONACEAE	*Tephrosia rhodesica* cf	WAH: 351
PAPILIONACEAE	*Tephrosia* sp. 1	WAH: 466
PAPILIONACEAE	*Tephrosia* sp. 2	WAH: 376
PAPILIONACEAE	*Tephrosia* sp. 3	WAH: 370 428
PAPILIONACEAE	*Tephrosia* sp. 4	WAH: 496
PAPILIONACEAE	*Tephrosia* sp. 5	WAH: 281
PERIPLOCACEAE	*Ectadiopsis oblongifolia*	WAH: 646 656
PERIPLOCACEAE	*Cryptolepis* sp. 1	WAH: 327 537
PERIPLOCACEAE	*Cryptolepis* sp. 2	WAH: 875
PHYLLANTHACEAE	*Antidesma venosum*	WAH: 577
PHYLLANTHACEAE	*Bridelia micrantha*	WAH: 877
PHYLLANTHACEAE	*Bridelia mollis*	WAH: 303a
PHYLLANTHACEAE	*Phyllanthus reticulatis*	WAH: 219
PHYLLANTHACEAE	*Phyllanthus* sp. 1	WAH: 290 341 642
PHYLLANTHACEAE	*Phyllanthus* sp. 2	WAH: 474
PHYLLANTHACEAE	*Phyllanthus* sp. 3	WAH: 554
PINACEAE	*Pinus elliottii*	WAH: 651
PLUMBAGINACEAE	*Plumbago zeylanica*	WAH: 319 950
POACEAE	*Andropogon eucomus*	WAH: 715
POACEAE	*Bothriochloa radicans*	WAH: 414
POACEAE	*Brachiaria deflexa*	WAH: 424 441
POACEAE	*Brachiaria serrata*	WAH: 382 479
POACEAE	*Dactyloctenium giganteum*	WAH: 255
POACEAE	*Digitaria milanjiana*	WAH: 380
POACEAE	*Diheteropogon amplectens*	WAH: 521
POACEAE	*Eleusine coracana*	WAH: 679
POACEAE	*Enneapogon cenchroides*	WAH: 440
POACEAE	*Enteropogon macrostachyus*	WAH: 547
POACEAE	*Eragrostis curvula*	WAH: 830
POACEAE	*Eragrostis rigidior*	WAH: 388
POACEAE	*Fingerhuthia africana*	WAH: 409a
POACEAE	*Heteropogon contortus*	WAH: 387 407 773
POACEAE	*Hyparrhenia cymbaria*	WAH: 685
POACEAE	*Hyparrhenia filipendula*	WAH: 621a
POACEAE	*Ischaemum fasciculatum*	WAH: 690
POACEAE	*Leersia hexandra*	WAH: 436
POACEAE	*Loudetia simplex*	WAH: 509
POACEAE	*Melinis repens*	WAH: 384
POACEAE	*Oplismenus hirtellus*	WAH: 998a
POACEAE	*Pogonarthria squarrosa*	WAH: 776
POACEAE	*Schizachyrium sanguineum*	WAH: 518 635
POACEAE	*Setaria pumila*	WAH: 477
POACEAE	*Sporobolus africanus*	WAH: 698
POACEAE	*Themeda triandra*	WAH: 774
POACEAE	*Trachypogon spicatus*	WAH: 529 657a
POACEAE	*Trichoneura grandiglumis*	WAH: 379 777
POACEAE	*Urochloa oligotricha*	WAH: 546
POACEAE	*Andropogon* sp. 1	WAH: 383 483
POACEAE	*Andropogon* sp. 2	WAH: 657b 634
POACEAE	*Aristida* sp. 1	WAH: 409b 482 530 620
POACEAE	*Aristida stipitata* cf	WAH: 381

POACEAE	*Chloris* sp. 1	WAH: 442
POACEAE	*Cymbopogon* sp. 1	WAH: 519 686
POACEAE	*Digitaria* sp. 1	WAH: 386 446 621b 687 688
POACEAE	*Eragrostis rigidior* cf	WAH: 534
POACEAE	*Eragrostis* sp. 1	WAH: 522
POACEAE	*Loudetia flavida* cf	WAH: 385 481
POACEAE	*Loudetia simplex* cf	WAH: 633
POACEAE	*Phragmitis australis* cf	WAH: 433
POACEAE	*Setaria megaphylla* cf	WAH: 694
POACEAE	*Setaria* sp. 1	WAH: 480 689
POACEAE	*Triraphis* sp. 1	WAH: 524
POACEAE	*Urochloa mosambicensis* cf	WAH: 545
PODOCARPACEAE	*Podocarpus latifolius*	WAH: 749
POLYGALACEAE	*Polygala virgata*	WAH: 221
POLYGALACEAE	*Polygala producta* cf	WAH: 224
POLYGONACEAE	*Persicaria* sp. 1	WAH: 960
PORTULACACEAE	*Portulacaria afra*	WAH: 849
PROTEACEA	*Hakea salicifolia*	WAH: 831
PROTEACEA	*Protea caffra*	WAH: 955
PROTEACEAE	*Faurea rochetiana*	WAH: 588
PROTEACEAE	*Faurea saligna*	WAH: 500
PROTEACEAE	*Protea caffra* subsp. *caffra*	WAH: 639
RANUNCULACEAE	*Clematis brachiata*	WAH: 584
RHAMNACEAE	*Berchemia zeyheri*	WAH: 210 565 837
RHAMNACEAE	*Rhamnus prinoides*	WAH: 735
RHAMNACEAE	*Ziziphus mucronata*	WAH: 991 572
RHAMNACEAE	*Berchemia discolor* cf	WAH: 297
ROSACEAE	*Leucosidea sericeae*	WAH: 796
ROSACEAE	*Rubus* sp. 1	WAH: 432 723
RUBIACEAE	*Afrocanthium mundianum*	WAH: 669
RUBIACEAE	*Anthospermum welwitschii*	WAH: 637
RUBIACEAE	*Breonadia salicina*	WAH: 578
RUBIACEAE	*Canthium armatum*	WAH: 990
RUBIACEAE	*Canthium ciliatum*	WAH: 357 568
RUBIACEAE	*Canthium inerme*	WAH: 615 708
RUBIACEAE	*Cephalanthus natalensis*	WAH: 736a
RUBIACEAE	*Coddia rudis*	WAH: 305 457 625 892 893
RUBIACEAE	*Coptosperma supra-axillare*	WAH: 613
RUBIACEAE	*Fadogia homblei*	WAH: 652 974
RUBIACEAE	*Gardenia ternifolia*	WAH: 948
RUBIACEAE	*Keetia gueinzii*	WAH: 953 744b
RUBIACEAE	*Othiophora calycophylla*	WAH: 237
RUBIACEAE	*Oxyanthus speciosus*	WAH: 751
RUBIACEAE	*Pavetta gardenifolia* var. *subtomentosa*	WAH: 616
RUBIACEAE	*Pavetta schumanniana*	WAH: 378 670
RUBIACEAE	*Pavetta trichardtensis*	WAH: 662
RUBIACEAE	*Pentanisia prunelloides*	WAH: 525
RUBIACEAE	*Rothmannia capensis*	WAH: 768
RUBIACEAE	*Sericanthe andongensis* subsp. *legatii*	WAH: 673 784
RUBIACEAE	*Tricalysia capensis*	WAH: 739 758
RUBIACEAE	*Tricalysia lanceolata*	WAH: 835
RUBIACEAE	*Anthospermum* sp. 1	WAH: 510
RUBIACEAE	*Galium* sp. 1	WAH: 374 415 542
RUBIACEAE	*Pavetta* sp. 1	WAH: 972
RUBIACEAE	*Pentanisia* sp. 1	WAH: 1005
RUBIACEAE	*Rotheca* sp. 1	WAH: 513 922
RUTACEAE	*Calodendrum capense*	WAH: 217
RUTACEAE	*Cassimiroa edulis*	WAH: 818
RUTACEAE	*Zanthoxylem capense*	WAH: 951
RUTACEAE	*Zanthoxylum davyi*	WAH: 767

RUTACEAE	*Zanthoxylum* sp. 1	WAH: 604
SANTALACEAE	*Osyris lanceolata*	WAH: 788 944
SAPINDACEAE	*Dodonaea viscosa* var. *angustifolia*	WAH: 874
SAPINDACEAE	*Pappea capensis*	WAH: 564 840
SAPOTACEAE	*Englerophytum magalismontanum*	WAH: 939
SAPOTACEAE	*Mimusops zeyheri*	WAH: 211
SCROPHULARIACEAE	*Nemesia* sp. 1	WAH: 248
SINOPTERIDACEAE	*Cheilanthes quadripinnata*	WAH: 270 307 416 486
SINOPTERIDACEAE	*Cheilanthes viridis*	WAH: 699
SINOPTERIDACEAE	*Cheilanthes viridis* var. *glauca*	WAH: 288 338 488 602 636 653b
SINOPTERIDACEAE	*Cheilanthes viridis* var. *viridis*	WAH: 701
SINOPTERIDACEAE	*Pellaea calomelanos* var. *calomelanos*	WAH: 287 653a
SMILACEAE	*Smilax kraussiana*	WAH: 806b
SOLANACEAE	*Nicotiana glauca*	WAH: 891
SOLANACEAE	*Solanum anguivi*	WAH: 999
SOLANACEAE	*Solanum mauritianum*	WAH: 729
SOLANACEAE	*Solanum seaforthianum*	WAH: 218
SOLANACEAE	*Solanum delagoense* cf	WAH: 434
SPARRMANNIACEAE	*Grewia flavescens*	WAH: 253
SPARRMANNIACEAE	*Grewia monticola*	WAH: 252
SPARRMANNIACEAE	*Grewia occidentalis*	WAH: 243
STERCULIACEAE	*Dombeya pulchra*	WAH: 995
STERCULIACEAE	*Dombeya rotundifolia*	WAH: 618 804a
STERCULIACEAE	*Sterculia rogersii*	WAH: 910
STERCULIACEAE	*Waltheria indica*	WAH: 363
STERCULIACEAE	*Melhania* sp. 1	WAH: 988
STRYCHNACEAE	*Strychnos* sp. 1	WAH: 976
THYMELACEAE	*Gnidia caffra*	WAH: 229
THYMELAEACEAE	*Gnidia kraussiana*	WAH: 648
THYMELAEACEAE	*Gnidia rubescens*	WAH: 550
THYMELAEACEAE	*Peddiea africana*	WAH: 760 761 806a
THYMELAEACEAE	*Gnidia* sp. 1	WAH: 921
TILIACEAE	*Corchorus confusus*	WAH: 369 543
TILIACEAE	*Triumfetta welwitschii*	WAH: 640 929
URTICACEAE	*Pouzolzia mixta*	WAH: 842
VELLOZIACEAE	*Xerophyta villosa*	WAH: 969
VERBENACEAE	*Lantana camara*	WAH: 871
VERBENACEAE	*Lantana rugosa*	WAH: 348 368b 478
VERBENACEAE	*Lippia javanica*	WAH: 282 453
VERBENACEAE	*Priva meyeri* var. *meyeri*	WAH: 450
VITACEAE	*Cissus cornifolia*	WAH: 303b 325
VITACEAE	*Rhoicissus tomentosa*	WAH: 803b
VITACEAE	*Cyphostemma* sp. 1	WAH: 913

<u>Appendix 2.2</u> **Red-listed plant species likely to occur in the KRC**

Red-listed species (Raimondo et al., 2009) for the KRC as determined from the Plants of Southern Africa database (http://posa.sanbi.org/searchspp.php). The following IUCN categories were searched for: Critically endangered (CR), Critically endangered: Possibly extinct (CR PE), Endangered (EN), Vulnerable (VU), Near threatened (NT), Data deficient (DD) (see http://www.iucnredlist.org/technical-documents/categories-and-criteria/2001-categories-criteria#definitions for definitions and criteria). Some categories from the national assessment (Raimondo et al., 2009) were also included: Rare= taxa do not classify for an IUCN threat classification, but has small ranges and specific habitat requirements. Declining= taxa do not classify for an IUCN threat classification, but population sizes are continuing to decline due to threatening processes. Threatened= taxa that are likely to be threatened, but have not been fully assessed yet

Family	Species	Status	KRC Veg. type	Plant habit	Reason for conservation status
ASPHODELACEAE	*Kniphofia crassifolia*	CR PE	Mgra, Mwet	Monocotyledonous herb	Habitat destruction
ANTHERICACEAE	*Chlorophytum radula*	CR	Mgra	Monocotyledonous herb	Habitat destruction
ORCHIDACEAE	*Oberonia disticha*	CR	Mfor	Epiphyte	?
ZINGIBERACEAE	*Siphonochilus aethiopicus*	CR	Higveld and Lowveld	Perrenial geophyte	Collection for medicinal use
FABACEAE	*Argyrolobium muddii*	EN	Mgra	Dwarf shrub	Habitat destruction
ASTERACEAE	*Inezia speciosa*	EN	Mgra	Perrenial herb	Habitat destruction
APOCYNACEAE	*Mondia whitei*	EN	Mfor	Climber	Habitat destruction, Medicinal use collection
SCROPHULARIACEAE	*Nemesia zimbabwensis*	EN	Mfor	Perrenial herb	Habitat destruction
LAURACEAE	*Ocotea bullata*	EN	Mfor	Tree	Habitat destruction, Medicinal use collection
CANELLACEAE	*Warburgia salutaris*	EN	Mfor, Highveld	Tree	Collection for medicinal use
ASPHODELACEAE	*Aloe chortolirioides var. chortolirioides*	VU	Mgra	Succulent dwarf shrub	Habitat destruction
APOCYNACEAE	*Brachystelma minor*	VU	Mgra	Perrenial geophyte	Habitat destruction
POACEAE	*Festuca dracomontana*	VU	Mgra	Grass	Habitat destruction
LAURACEAE	*Ocotea kenyensis*	VU	Mfor	Tree	Habitat destruction, Medicinal use collection
ROSACEAE	*Prunus africana*	VU	Mfor	Tree	Collection for medicinal use
SANTALACEAE	*Thesium gracilentum*	VU	Highveld	Herb	Habitat destruction
APIACEAE	*Alepidea attenuata*	NT	Mwet	Herb	Habitat destruction
AMARYLLIDACEAE	*Clivia caulescens*	NT	Mfor	Perrenial herb	Collection for medicinal and horticultural use
CORNACEAE	*Curtisia dentata*	NT	Mfor	Tree	Medicinal and timber use

ORCHIDACEAE	*Disa extinctoria*	NT	Mwet	Herb	Habitat destruction
CELASTRACEAE	*Elaeodendron transvaalense*	NT	Ldra, Lpla	Tree	Collection for medicinal use
AIZOACEAE	*Lithops lesliei subsp. lesliei*	NT	Lslo, Lpla	Succulent	Collection for medicinal use
HYACINTHACEAE	*Merwilla plumbea*	NT	Mgra, Highveld	Geophyte	Collection for medicinal use
PASSIFLORACEAE	*Adenia gummifera var. gummifera*	Declining	Mfor, Highveld	Climber	Collection for medicinal use
CYATHEACEAE	*Alsophila capensis*	Declining	Mfor	Fern	Collection for horticultural use
ORCHIDACEAE	*Ansellia africana*	Declining	Lowveld	Epiphyte	Medicinal and horticultural use
ASTERACEAE	*Callilepis leptophylla*	Declining	Mgra, Highveld	Herb	Collection for medicinal use
RHIZOPHORACEAE	*Cassipourea malosana*	Declining	Mfor	Tree	Collection for medicinal use
AMARYLLIDACEAE	*Crinum macowanii*	Declining	Lowveld, Highveld	Geophyte	Collection for medicinal use
LAURACEAE	*Cryptocarya transvaalensis*	Declining	Mfor	Tree	Collection for medicinal use
HYACINTHACEAE	*Drimia altissima*	Declining	Lowveld	Geophyte	Collection for medicinal use
CELASTRACEAE	*Elaeodendron croceum*	Declining	Mfor, Highveld	Tree	Collection for medicinal use
GUNNERACEAE	*Gunnera perpensa*	Declining	Mwet, Ariv	Freshwater herb	Collection for medicinal use
HYPOXIDACEAE	*Hypoxis hemerocallidea*	Declining	Lowveld, Highveld	Geophyte	Collection for medicinal use
AQUIFOLIACEAE	*Ilex mitis var. mitis*	Declining	Mfor, Highveld	Tree	Collection for medicinal use
MYRSINACEAE	*Rapanea melanophloeos*	Declining	Mfor, Highveld	Tree	Collection for medicinal use
ASPHODELACEAE	*Aloe thompsoniae*	Rare	Mgra		Habitat specialist
APOCYNACEAE	*Brachystelma villosum*	Rare	Mgra	Geophyte	Habitat specialist
IRIDACEAE	*Hesperantha brevicaulis*	Rare	Mgra	Monocotyledonous herb	Habitat specialist
ACANTHACEAE	*Blepharis acuminata*	Threatened	Lowveld		Habitat destruction
OROBANCHACEAE	*Buchnera remotiflora*	DD	Mgra	Herb	-
LAMIACEAE	*Plectranthus esculentus*	DD	Lowveld	Succulent herb	-
EUPHORBIACEAE	*Acalypha caperonioides*	DD		Dwarf shrub	-
APIACEAE	*Alepidea peduncularis*	DD		Herb	-
APIACEAE	*Alepidea reticulata*	DD		Herb	-
DIOSCOREACEAE	*Dioscorea undatiloba*	DD		Geophytic climber	-
HYACINTHACEAE	*Drimia elata*	DD		Geophyte	-
ERICACEAE	*Erica leucopelta var. luxurians*	DD		Dwarf shrub	-
CAMPANULACEAE	*Wahlenbergia brachiata*	DD		Herb	-

Appendix 2.3 **Protected trees as listed in the National forests Act 84 of 1998 that occur in the Koedoes River Catchment.**

Family	Species
Anacardiaceae	*Sclerocarya birrea*
Balanitaceae	*Balanites maughamii*
Bombaceae	*Adansonia digitata*
Celasteraceae	*Catha edulis*
Celasteraceae	*Eleadendron transvaalense*
Combretaceae	*Combretum imberbe*
Curtisiaceae	*Curtisia dentata*
Fabaceae	*Philenoptera violacea*
Fabaceae	*Pterocarpus angolensis*
Lauraceae	*Ocotea bullata*
Pittosporaceae	*Pittosporum viridiflorum*
Podocarpaceae	*Podocarpus falcatus*
Podocarpaceae	*Podocarpus latifolius*
Rosaceae	*Prunus africana*
Rubiaceae	*Breonadia salicina*

Appendix 2.4 Discussion on local-scale vegetation patterns.

A number of peculiar vegetation patterns on a very local scale occur in parts of the KRC. It is this local heterogeneity of vegetation structure that contributes to, and provides habitat for, the great biodiversity found in the KRC. The most noticeable of these patterns are discussed here and the likely causes of these patterns and management considerations are explored.

I. Bush clumps and bush lines

Bush clumps are common in savannah systems and typically small (<30m diameter) roughly-circular shaped patches of dense woody growth in a mostly grassy matrix. Examples of well-established bush clumps can be seen in the south-western corner of the KRC in the Hmmb vegetation (Figure A2.3a). These clumps are usually dominated by one to five large trees, under the canopy of which numerous smaller trees and shrubs have established. In a natural system where fire plays a major regulating and restricting role for woody plants, the founder tree(s) typically establish and grow large in association with the protection offered by a termite mound, large boulder or abandoned man-made structures. Once large, the founder tree(s) offers perches for birds and other small animals that deposit seed under the tree when defecating. The assumption is thus that there is a higher concentration of seeds under the founder tree(s), relative to the open grassy surroundings. Many of these seeds germinate and establish in the more protected environment below the founder tree(s). This next generation of woody plants offer increased protection from fire to the founder tree(s) and start acting as “nurseries” themselves by offering perch space for birds and protected conditions form fire, large herbivores and excessive UV for seedling establishment. Bush clumps thus seem to enter into a self-reinforcing loop.

Monitoring bush clumps expansion or contraction rates over a long time period and determining establishment rates of new clumps may be of academic and economic interest. This presents an alternative process of bush-encroachment leading to the loss of grasslands and in the reduction of the utility of the land for certain uses. Further, bush clumps are of considerable biodiversity interest, as many of the species in a bush clump are unlikely to be encountered in the open vegetation outside. In the KRC, the bush clumps may also serve as refugia for Northern mistbelt forest species outside of the forest, as several forest canopy and understory species were witnessed growing inside bush clumps in the adjacent savannas. The beta diversity between bush clumps appears to be very high (although, to the author’s knowledge, this has not yet been tested), as the species composition presumably depends largely on the stochastically deposited seeds at the site.

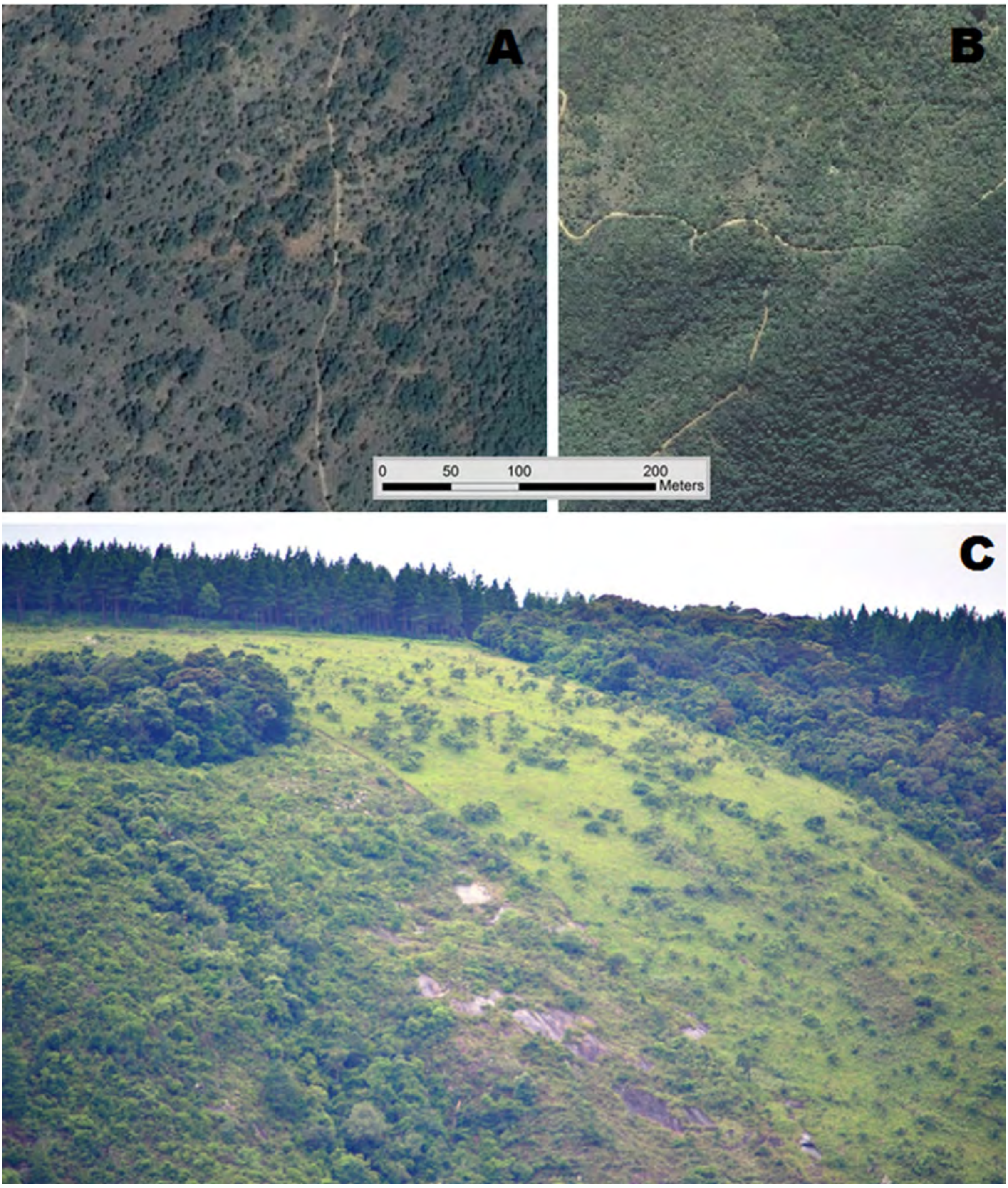

Figure A2.3: a) Bush clumps and bush lines as seen in the southern parts of the KRC. b) Montane forest (Mfor) grows on the eastern aspect of this hill, where moisture is deposited via the orographic effect. The dense slope bushveld (Hdsb) on the much drier western slope falls in a rain shadow. c) Differences in vegetation structure on either side of a fire management line. An increased density of *Helichrysum kraussii* is clearly visible on the left hand side.

Bush lines are, similar to bush clumps, patches of dense woody vegetation in a matrix of more open, grassy vegetation. Bush lines are typically no wider than ten meters but can be up to hundreds of meters long. The trees in bush lines do not seem to reach the size and density of those in bush clumps. Good examples of bush lines can also be seen in the south-western corner of the KRC in the Hmmb vegetation (Figure A2.3a). These are always associated with linear features of outcropping bedrock. Presumably these rocks offer some shelter from fire for seedlings, allowing them to establish and escape the fire trap. Bush lines are typically populated by fire-resistant woody species associated with the surrounding savannas or grasslands. Bush lines seem to be less dense than clumps, possibly due to the shallow soils. Investigation of diversity patterns along bush lines may be of great academic interest.

II. Localized orographic effects

As mentioned earlier, a steep moisture gradient exists in the upper reaches of the KRC. This gradient is as a result of the orographic effect and is clearly expressed on a very local scale in the vegetation on some of the mountain spurs in the south-eastern parts of the catchment.

Figure A2.3b effectively pictures the transition from one vegetation type to the next at a very local scale, a phenomenon that is often only visible at a landscape scale. In these cases, however, the steep topography and resulting sharp moisture gradient caused by the orographic effect makes it visible at such a local scale. Aspect and associated heat, insolation and evaporative water loss may also play a role in some cases, but the topographically induced climate gradient is considered to be the major driver.

III. Management lines

Human activities on the local scale also have an impact on vegetation structure and diversity in areas otherwise considered to be fully natural. A particularly applicable example in the KRC is the suppression of wild fires. Fire is an integral part of the ecology for most South African vegetation types (Bond et al., 2003), especially savannas (Roques et al. (2001) and Van Langeveld et al. (2003)). In the KRC, all vegetation types, except Mfor and the azonal units, rely to a lesser or greater extent on fire to maintain its structure and diversity.

The KRC is situated adjacent to a major forestry area and the lighting of any fires is illegal during the dry season according to the national fire act (Act no. 101 of 1998). Fires are subsequently prevented and suppressed at all cost. Only certain strategic strips of land are burned annually as fire breaks. This has been the practise for as much as the last eight decades in parts of the KRC and it has become clearly expressed in the vegetation. Figure A2.3c shows the Woodbush granite grassland (Mgra) vegetation along an annually burned fire break. The vegetation to the left, which has not burned for at least 15 years, is beginning to appear scrubby due to a notable increase in *Helichrysum kraussii.* Altering the frequency and intensity of fires over a long term can have severe impacts on vegetation structure and diversity. In the case of Figure A2.3c, the yearly burned firebreak is becoming impoverished, because many species do not have the time to fully recover from a fire every year. In contrast, species that rely on fire to flower or reproduce are becoming moribund and eventually locally extinct in the parts that has not burned for more than a decade.

Adverse effects resulting from the practise of fire suppression can also be seen in other parts of the KRC. In the three Tzaneen sour bushveld vegetation units, bush encroachment by woody elements (especially *Dichrostachys cinerea*) is associated to an extent with lack of fire. In the Dense slope bushveld (Hdsb) unit, the lack of fire has allowed for the establishment and spread of an extremely problematic invasive plant, *Chromolaena odorata.* Lastly, the suppression of fire leads to the build-up of a large stock of dry biomass – creating an even bigger fire risk. In the event that such an area with a high dry biomass fuel load does ignite, the fire will be so hot that it kills most plants – leaving the soil open to colonization by a host of weeds and invasive plants. The practise of fire suppression is understandable and necessary from an asset protection point of view, but an effort should be made to devise and implement a management strategy that both minimises risk to plantations and infrastructure in the fire season and ensures the maintenance of vegetation structure and species diversity.

Appendix 4.1 **Land-use patterns in the Koedoes River Catchment (current May 2014).**

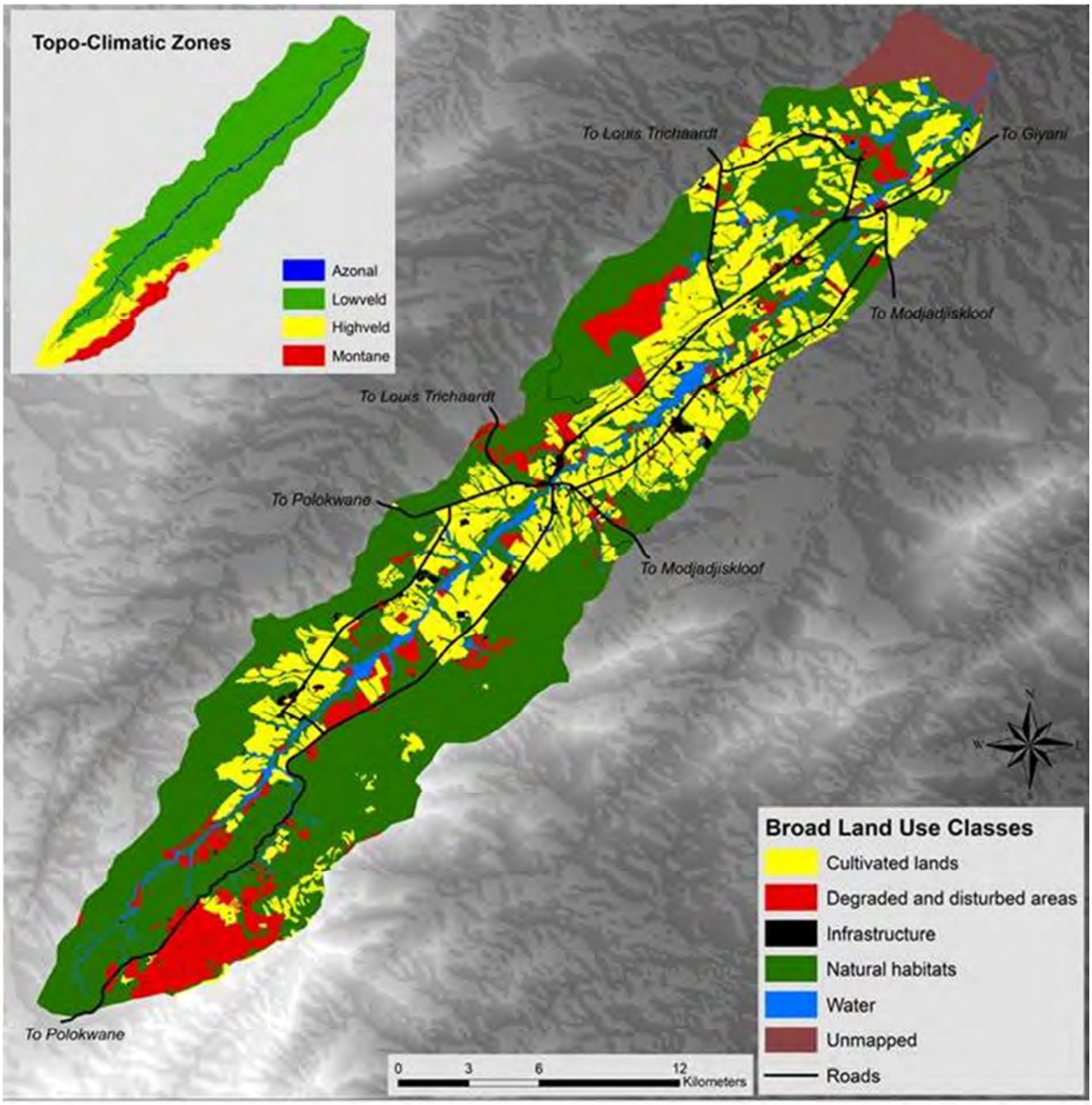

Figure A4.1 Broad land use map of the Koedoes River Catchment.

Table A4.1 Land use (LU) classes in the KRC, with total hectares and percentage cover.

LU class	Broad LU	Land use	Disturbance regime[a]	Hectares*	% of KRC
1	*Cultivated lands*			*10459*	*26.54*
1a		Tomato fields	Transformed	8357	21.20
1b		Avocado orchards	Transformed	633	1.61
1c		Forestry plantation	Transformed	264	0.67
1d		Other crops	Transformed	1034	2.62
1e		Mango orchards	Transformed	172	0.44
2	*Infrastructure*			*862*	*2.19*
2a		Net house or green house	Transformed	37	0.09
2b		Residences and gardens	Transformed	187	0.47
2c		Offices, workshops, pack houses and gardens	Transformed	106	0.27
2d		Tar roads and reserves	Transformed	170	0.43
2e		Major dirt roads and reserves	Transformed	209	0.53
2f		Railroads and reserves	Transformed	41	0.10
2g		Other	Transformed	112	0.28
3	*Water*			*1537*	*3.90*
3a		Reservoirs	Transformed	10	0.02
3b		Dams/weirs and other standing water	Transformed	592	1.50
3c		Koedoes River and associated vegetation	Natural	574	1.46
3d		Tributaries and drainage lines with associated vegetation	Natural	362	0.92
4	*Natural habitats*			*22175*	*56.27^*
4a		Mountain plateau	Natural	396	1.01
4c		Valley bottom	Natural	5826	14.78
4d		Mountain / koppie slopes	Natural	11520	29.23
4e		Small patch or corridor	Degraded/disturbed[#]	4311	10.94
4g		Exposed rock faces	Natural	61	0.16
4h		Firebreak	Degraded/disturbed[#]	61	0.16
5	*Degraded and disturbed areas*			*4378*	*11.11*
5a		Abandoned cultivated lands	Degraded/disturbed	1496	3.79
5d		Invaded or encroached by woody elements	Degraded/disturbed	2411	6.12
5e		Bare ground, quarries, eroded areas, places of recent disturbance	Degraded/disturbed	404	1.02
5f		Uncertain	Degraded/disturbed	68	0.17
		TOTAL		39412*	

*This total surface area excludes the 1276ha that were not mapped for land use.

^This is the total percentage for areas classified as natural habitats, not to be confused with the figure for undisturbed vegetation which ranges between 47.5 – 58.6% depending on interpretation – see section 4.3.2.

[#]See section 4.3.2 for a discussion on why these units were considered as degraded/disturbed and not natural.

[a]The disturbance regime field does not align fully with the nesting broad and finer land use classes. See section 4.3.2 for a discussion.

Appendix 4.2 **Burkhard-matrix averaging the scores of all respondents (n=11).**

Landscape unit*	Aesthetical value	Grazing	Protection/Buffer	Ecotourism	Value to ZZ2 brand	Pest control	Nutrient cycle	Pollution control	Soil regenration	Water quality	Water availibilty	Harvestable products	**Averaged Total**
Natural													
Koedoes river and associated vegetation	4.4	2.3	2.2	4.5	4.2	3.4	3.0	3.4	2.6	4.2	4.1	2.3	3.4
Exposed rock faces and associated vegetation	4.6	0.7	2.2	4.7	4.1	0.7	1.2	0.6	0.7	1.5	2.4	0.9	2.0
Mamabolo Mountain Bushveld	3.8	3.5	3.6	3.9	2.5	2.3	2.6	1.8	1.5	4.1	3.3	2.1	2.9
Dense slope bushveld	3.5	1.8	3.9	4.2	2.5	2.3	2.3	2.4	1.9	4.3	3.3	2.3	2.9
Tzaneen Sour Bushveld	3.6	3.7	3.4	3.8	3.8	3.5	3.6	3.4	2.2	2.9	2.4	2.5	3.2
Northern Mistbelt Forest	4.5	0.7	4.1	4.5	3.5	2.9	3.0	2.2	2.8	4.5	4.5	1.8	3.2
Woodbush Granite Grassland	2.8	1.7	2.9	3.5	3.2	2.3	2.2	1.9	2.7	4.1	3.8	1.5	2.7
Degraded													
Invaded by woody elements (Hoenderbos)	0.5	0.5	1.7	0.3	0.5	1.5	1.6	2.1	2.1	2.0	1.2	2.9	1.4
Encroached by woody elements (Sekelbos)	0.5	0.6	2.0	0.3	0.2	1.5	1.7	1.5	2.5	1.5	0.9	2.9	1.3
Corridors or green belts	3.7	1.9	1.7	2.5	4.0	4.2	3.7	3.9	2.6	3.0	1.9	1.2	2.9
Transformed													
Fallow tomato lands	2.3	4.6	1.0	0.9	3.3	1.8	3.4	3.5	4.0	2.3	2.2	1.8	2.6
Dams & Reservoirs	4.8	0.0	2.5	4.8	4.1	2.8	2.7	3.7	0.9	3.8	4.7	3.5	3.2
Cultivated land (trees)	4.5	0.3	1.7	3.3	4.6	2.0	2.2	2.2	3.0	2.6	1.9	2.6	2.6
Cultivated land (tomato open land)	4.2	0.3	1.5	2.5	4.8	1.3	1.2	1.1	1.9	1.3	1.3	3.3	2.0
Cultivated land (tomato covered)	3.5	0.0	2.4	2.0	4.3	1.4	0.9	1.9	1.8	1.8	1.8	3.0	2.1
Forestry (pine and eucalyptus)	2.8	0.8	3.2	2.9	2.9	1.8	2.0	2.2	2.3	2.7	1.5	3.1	2.3
Averaged Total	3.4	1.5	2.5	3.0	3.3	2.2	2.3	2.4	2.2	2.9	2.6	2.4	

Capacity to supply ES	
0	No relevant capacity
1	Low relevant capacity
2	Relevant capacity
3	Medium relevant capacity
4	High relevant capacity
5	Very high relevant capacity

*In an effort to simplify an original matrix containing all vegetation and land use types, some landscape units considered to be very similar in terms of ES delivery were combined in this matrix. Hssm and Hbgm were grouped with Hmmb. Lslo and Lpla were grouped as Tzaneen sour bushveld. Ldra was considered under Corridors and green belts. Fire breaks were considered part of Mgra. All orchards (high, mid and low altitude avocados and mangoes were grouped as cultivated land (fruit trees).

Appendix 5.1 **Cover class scale for vegetation cover estimates.**

Cover class	% Surface cover
0	0-1%
1	1-5%
2	5-25%
3	25-50%
4	50-75%
5	75-95%
6	95-100%

Appendix 5.2 **Invertebrate taxa collected and identified during pitfall-trapping.**

Phyllum	Class	Order	Family	(Morpho)species
Mollusca	Gastropoda	1	1	-
Annelida	Oligochaeta	1	1	-
Arthropoda	Chilopoda	1	1	-
Arthropoda	Diplopoda	1	1	-
Arthropoda	Malacostraca	Amphipoda	1	-
Arthropoda	Malacostraca	Isopoda	1	-
Arthropoda	Arachnida	Araneae	19	-
Arthropoda	Insecta	Collembola	1	-
Arthropoda	Insecta	Orthoptera	-	-
Arthropoda	Insecta	Diptera	-	-
Arthropoda	Insecta	Hymenoptera	Formicidae	46
Arthropoda	Insecta	Hymenoptera: non-Formicidae	-	-
Arthropoda	Insecta	Lepidotptera	-	-
Arthropoda	Insecta	Thysanura	1	-
Arthropoda	Insecta	Thysanoptera	-	-
Arthropoda	Insecta	Blatodea	-	-
Arthropoda	Insecta	Archeognatha	1	-
Arthropoda	Insecta	Isoptera	-	-
Arthropoda	Insecta	Psocoptera	-	-
Arthropoda	Insecta	Dermaptera	-	-
Arthropoda	Insecta	Hemiptera	-	-
Arthropoda	Insecta	Coleoptera	10	-

(- indicates that the taxon has not been sorted to that particular taxonomic level)