MAPPING SPATIAL REQUIREMENTS OF ECOLOGICAL PROCESSES TO AID IN THE IMPLEMENTATION OF CORRIDORS

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DECLARATION

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ABSTRACT

The ultimate goal of conservation planning is to ensure persistence of biodiversity. Biodiversity patterns and ecological processes are important aspects in conserving biodiversity. Although most researchers in conservation planning have focused on targeting biodiversity patterns, ecological and evolutionary processes can ensure persistence of biodiversity if incorporated into conservation planning. Ecological processes are the main drivers or sustainers of biodiversity. The aim of this research was to identify and map the spatial components of ecological processes in a portion of the Kavango Zambezi Transfrontier Conservation Area to aid in the implementation of biota movement corridors. Different methods have been used to identify suitable corridors but not much has been done on defining and mapping ecological processes that will ensure that the corridors maintain and generate biodiversity.

A thorough literature survey was done to make a list of ecological processes that are important in maintaining the biodiversity in the area. Spatial components of ecological processes were mapped as surface elements aligned along linear environmental interfaces or gradients. The last part of the research was to suggest suitable movement corridors based on ecological processes.

The results include five spatial components: riverine corridors, areas of high carbon sequestration, edaphic interfaces, upland-lowland interfaces and ecotones. Riverine corridors were mapped using a 1000 m buffer on either side of low lying rivers and 500 m buffer around rivers in the uplands. A map showing the carbon sequestration potential of vegetation in the study area was made using Moderate-Resolution Image Spectroradiometer (MODIS) derived NDVI data and the National Level Carbon Stock dataset done by the Woods Hole Research Center (WHRC) Pantropical. Edaphic interfaces were idenfied using by a 250 m buffer around contrasting soil types. Upland-lowland interfaces identified by a 250 m buffer along upland and lowland habitats. Classification of Landsat 8 was used to identify ecotones in the study area. The results of the spatial components were then compared with the habitat transformation map which shows populated areas.

KEY WORDS

Ecological processes, biodiversity, spatial components, riverine corridors, carbon sequestration, ecotones, edaphic interfaces, upland-lowland interfaces.

OPSOMMING

Die uiteindelike doel van bewaringsbeplanning is om voortbestaan van biodiversiteit te verseker. Biodiversiteitspatrone en ekologiese prosesse is belangrike aspekte in die bewaring van biodiversiteit. Alhoewel die meeste navorsers in bewaringsbeplanning fokus op teiken biodiversiteitspatrone, kan die voortbestaan van ekologiese en evolusionêre prosesse van biodiversiteit verseker word deur insluiting in bewaringsbeplanning. Ekologiese prosesse is die belangrikste drywers, of onderhouers, van biodiversiteit. Die doel van hierdie navorsing was dus om die ruimtelike komponente van ekologiese prosesse in 'n gedeelte van die Kavango Zambezi oorgrensbewaringsgebied te identifiseer en te karteer om te help met implementering van biota bewegingsdeurlope. Verskillende metodes is al gebruik om gepaste deurlope te identifiseer, maar min navorsing is gedoen oor definisie en kartering van ekologiese prosesse om te verseker dat die deurlope biodiversiteit sal onderhou en genereer.

'n Deeglike literatuurstudie is gedoen om 'n lys op te stel van ekologiese prosesse wat belangrik is in die handhawing van biodiversiteit in die gebied. Ruimtelike komponente van ekologiese prosesse is gekarteer as oppervlak elemente gebonde aan lineêre omgewingskoppelvlakke of gradiënte. Die laaste deel van die navorsing was om geskikte bewegingsdeurlope, gebaseer op ekologiese prosesse, voor te stel. Die resultate sluit vyf ruimtelike komponente in: rivierdeurlope, gebiede van hoë koolstofsekwestrasie, edafiese koppelvlakke, hoogland-Laeveld koppelvlakke en grensekotone. Rivierdeurlope is gekarteer met behulp van 'n 1000 meter buffer aan weerskante van laagliggende riviere en 500 meter buffer rondom riviere in die hooglande. ‘n Kaart wat die koolstofsekwestrasiepotensiaal van plantegroei in die studie area toon is gemaak met behulp van Moderate-Resolution Image Spectroradiometer (MODIS) afgeleide NDVI data en ŉ koolstofvoorraaddatastel (National Level Carbon Stock dataset) voorsien deur die Woods Hole Research Center (WHRC). Pantropiese edafiese koppelvlakke is geïdentifiseer met behulp van 'n 250 meter buffer rondom kontrasterende grondtipes. Hoogland-Laeveld koppelvlakke is geïdentifiseer deur 'n 250 meter buffer langs die berg en laagland habitatte. Klassifikasie van Landsat 8 data is gebruik om ekotone in die studie area te identifiseer. Die resultate van die ruimtelike komponente is vergelyk met die habitattransformasiekaart wat bevolkte gebiede toon.

SLEUTELWOORDE

Ekologiese prosesse, biodiversiteit, ruimtelike komponente, rivierdeurlope, koolstofsekwestrasie, grensekotone, edafiese koppelvlakke, hoogland-Laeveld koppelvlakke.

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ACRONYMS AND ABBREVIATIONS

BHUs	Broad Habitat Units
GIS	Geographic information systems
GPS	Global positioning systems
TFCA	Transfrontier conservation area
NDVI	Normalised vegetation index
KAZA	Kavango-Zambezi
MODIS	Moderate-Resolution Imaging Spectroradiometer
VHR	Very high resolution
WWF	World Wildlife Fund

GLOSSARY

Biodiversity feature	A biodiversity component in which measurable conservation targets can be determined (BGIS)
Biodiversity patterns	Described how biodiversity is spatially distributed in an area
Biodiversity processes	Dynamic interactions that happen inside and among ecosystems that are characterised by constant change (Lagabrielle et al. 2009)
Biodiversity surrogates	Species or habitats with defined distributions used as a measure of biodiversity
Broad Habitat Unit (BHU)	Land class that represent the biodiversity pattern of an area
Ecosystem services	These are the benefits that humans get from the ecosystem.
Evolutionary processes	Processes that enable new species to evolve over long periods as a response to conditions that are changing.
Spatial components of biodiversity process	The physical feature of an area associated with certain ecological and evolutionary processes.

CHAPTER 1 ECOLOGICAL PROCESSES IN CONSERVATION PLANNING

For decades conservationists have aimed to conserve biodiversity patterns (Klein et al. 2009). This is the ultimate goal of conservation planning, to make sure that biodiversity persist (Cowling et al. 2003; Klein et al. 2009). Important aspects in conserving biodiversity include biological and environmental patterns as well as ecological processes (Rouget et al. 2005; Klein et al. 2009). Different methods, such as predicting species local probabilities of occurrence as well as identifying areas that are either presumed or known for genetic divergence and then targeting such areas (Cowling et al. 2003; Lagabrielle et al. 2009), have been used in conservation planning to identify areas that are of importance in conserving biodiversity (Rouget et al. 2005; Lombard et al. 2010).

Although most researchers in conservation planning have focused on targeting biodiversity patterns (Lombard et al. 2010), ecological and evolutionary processes can ensure that biodiversity persist over time if incorporated into conservation planning (Cowling et al. 2003; Klein et al. 2009; Nel 2004). Ecological processes are the main drivers or sustainers of biodiversity (Klein et al. 2009; Lagabrielle et al. 2009; Lombard et al. 2010). They operate at different temporal and spatial scales (Nel 2004) and ecologists are now aware of the importance of studying ecological processes at both scales (Dunning, Danielson & Pulliam 1992). Examples of ecological processes include: diversification of plants and animal lineages, migration of biota, natural fire regimes, in land movement of marine sands (Pressey, Cowling & Rouget 2003; Rouget et al. 2003).

It is not common in systematic conservation planning to find studies that include both biodiversity patterns and ecological processes (Klein et al. 2009). Most conservation plans usually focus on aspects of biodiversity patterns rather than on processes (Rouget et al. 2003; Pressey et al. 2007). Pressey, Cowling & Rouget (2003) identified three groups of approaches that can be used to include ecological processes: first by considering only biodiversity patterns, secondly, considering generic designs such as size, shape and connectivity (Rouget et al. 2003), thirdly, considering the design criteria that is specific to a particular process (Pressey, Cowling & Rouget 2003).

Including ecological processes in conservation planning and determining their spatial patterns will ensure that biodiversity persist over time (Rouget et al. 2003). Since ecological processes are essential to biodiversity conservation, it is important to maintain them and make sure that the processes are not disturbed. Conservation planning can however, only capture ecological processes that occur at small scales for example pollination and at mesoscale for example connection of different conservation areas to assist animals to move between the areas (Klein et al. 2009). Processes occurring at a large scale such as plate tectonics are beyond the scope of conservation planning (Klein et al. 2007; Pressey et al. 2007). Identifying spatial components for specific ecological processes will aid in mapping small and mesoscale ecological processes (Nel et al. 2004; Lagabrielle et al. 2009).

A spatial component of an ecological process is an area that is associated with a specific ecological process (Rouget et al. 2004; Rouget et al. 2005; Lagabrielle et al. 2009). This implies that the ecological process does well in that area and a specific biodiversity feature is maintained and persists in that area (Rouget et al. 2003). Different methods have been used to identify spatial components of ecological processes (Lagabrielle et al. 2009). The areas that are said to be suitable for maintaining and generating biodiversity are usually unspoiled or almost in their natural form although they can also include areas of culture or suburban landscapes (Lagabrielle et al. 2009). Spatial components of ecological processes can either be spatially fixed or spatially flexible (Rouget et al. 2003). Components that are associated physical features that are defined clearly are spatially fixed, while spatially flexible components are include those that are associated with ecological processes that can persist in different spatial configurations (Rouget et al. 2003).

Transfrontier Conservation Areas (TFCAs) play an important role in conservation planning. A TFCA is defined as a large piece of land that spans over two or more international boundaries, containing numerous protected areas as well as numerous resource areas that are to be used by communities as well as for conservation (Hanks 2001; Munthali 2007; Smith & De Klerk 2007; Suich, Busch & Barbancho 2005). According to Munthali (2007) the key ecological roles of TFCAs are: protecting international ecosystems by increasing the area available for wildlife and populations therefore reducing the risk of stochastic events extinction. The Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA) is one of the largest transfrontier parks in the world, if not the largest (kavangozambezi.org 2011). Its goal is to manage and sustain the ecosystem, heritage and cultural resources in the area (Peace Parks Foundation 2008).

Biota movement corridors connecting the different parts of the KAZA TFCA can help with ensuring persistence of biodiversity components in the TFCA. For example, animals will be able to find suitable habitats as seasons change, and plant seeds find environmental conditions that are best for germination (Rouget et al. 2005). Corridors are areas of natural habitat that link two or more habitats that are separate, enabling migration or dispersion of plant and animal species over time (Rouget et al. 2005; Garven 2012). There has been a great debate among conservationists on whether corridors are useful in conservation (Simberloff, Cox & Mehlman 1992). Some conservationists claim that connecting separate areas increases movement, which leads to a healthy variation of genetic material, species richness and the abundance of a population (Garven 2012). Caro et al. (2009) noted two uses of corridors: Firstly, corridors can be used to facilitate movement of animals between suitable habitats patches, the corridors in this case are also suitable habitats for the animals. Secondly, wild life corridors can also connect two patches of suitable habitat that pass through a matrix of unsuitable habitat. A challenge in conservation planning is to be able to identify the spatial scales and key landscape elements that are the key maintainers and restore connectivity and ecological processes (Luque, Saura & Fortin 2012).

1.1 RESEARCH PROBLEM

Conservation planning has in the past focused mainly on ecological and biogeographical pattern rather than process (Rouget et al. 2003). Ecological processes such as ecological diversification and migration of biota are the main drivers of biodiversity (Pressey et al. 2003; Rouget et al. 2003; Klein et al. 2009; Lagabrielle et al. 2009; Lombard et al. 2010). Including them into conservation planning and determining their spatial components will ensure the persistence of biodiversity (Rouget et al. 2003). Identifying spatial requirements of ecological processes can aid in including them directly into conservation planning.

One of the objectives of the Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA) is to enable biota movement between the protected areas that make up the TFCA. Connectivity between areas should be able to maintain species migration and gene flow (Rouget et al. 2003).

Different methods have been used to identify suitable corridors but not much has been done on defining and mapping ecological processes that will ensure that the corridors maintain and generate biodiversity in such corridors. The research will identify and map ecological processes that will ensure persistence of biodiversity in the corridors.

1.2 RESEARCH AIM AND OBJECTIVES

Aim

The aim of this research is to identify and map the spatial requirements of ecological processes which are important in the functioning and persistence of biodiversity in a portion of the KAZA TFCA. This identification and mapping will aid in the implementation of corridor areas that are important for sustaining ecological processes.

To achieve the research aim, the following objectives were set:

1. Describe the main biodiversity features in the study area using literature as well as expert knowledge through workshops;

2. Identify key ecological processes that sustain and maintain the main biodiversity features;

3. Identify and map spatial components of the key ecological processes;

4. To outline the best network of corridors that can protect and ensure the persistence of the ecological processes.

1.3 METHODOLOGY

In order to identify and map ecological processes and their relative spatial components the method that will be implemented is adapted from Lagabrielle et al. (2009). Generic design of a protected area is the most common and long standing approach of identifying ecological processes in conservation planning (Rouget et al. 2003). The spatial components of ecological processes have rarely been considered in conservation planning. Studies that have been done have failed to identify spatial dimensions of these processes. It is important to identify the spatial components as this can provide guidelines for prioritising areas for restoration (Rouget et al. 2003).

1.4 RESEARCH DESIGN

Table 1.1 Research Design

1. PROBLEM FORMULATION	Mapping spatial requirements of ecological processes to aid in the implementation of corridors identification Problem formulation → Aim; Objectives → Methodology
2. LITERATURE REVIEW	Literature review → • Conservation planning and its role in biodiversity persistence in TFCAs • Aims and Objectives for the establishment of the KAZA TFCA • Use of corridors • Methods used to identify the corridors • Define ecological processes, how they are useful in biodiversity persistence
3. DATA COLLECTION	GIS Layers of the following: • Rivers and floodplains • vegetation types • Geology types • Altitude data • Landsat 8 • MODIS NDVI
4. DATA PROCESSING AND ANALYSIS	Delineate the spatial component of ecological processes Develop a conceptual scheme that represents the relationships between the patterns, the processes and the threats based on expert knowledge and literature
	The research aim is to produce a map or maps of ecological processes and their suitable spatial components • Recommendation of possible corridors that can connect Chobe and Kafue National parks • Suggestions of how to maintain the ecological processes in the possible corridors. • Further research possibilities with regards to ecological processes.

1.5 REPORT STRUCTURE

The first chapter has given the background to ecological processes in conservation planning. The aim and objectives of the research were outlined as well as the research design.

Chapter 2 discusses the importance of including ecological processes in conservation planning and why mapping the spatial components of ecological processes is an efficient method for long term conservation of plants and animals in protected areas. This chapter is a result of an intense literature study on the topic.

Chapter 3 provides an overview of the methods and data used in this research.

Chapter 4 gives the results of the spatial components of ecological processes and discusses them.

The conclusion of the research is given in chapter 5, with recommendations for park managers and future research also given in this chapter.

CHAPTER 2 IMPORTANCE OF INCLUDING ECOLOGICAL PROCESSES IN CONSERVATION PLANNING

There are various definitions for the term biodiversity. In this review the term biodiversity will refer to the definition given by DeLong (1996:745) “Biodiversity is a state or attribute of a site or area and specifically refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans.” Different variables can be used to measure biodiversity such as genetic diversity, the number of different types of species, assemblages of species, biotic communities, and biotic processes (DeLong 1996). Land use and land cover change, climate change; pollution, fragmentation and infrastructure development are the main drivers of biodiversity change (DeLong 1996). The scale at which biodiversity can be measured ranges from microsites and habitat patches to the entire biosphere (Lopez & Alkemade & Verweij 2010). Moreover, human beings have amplified impacts in a bid to make the earth more comfortable and more suitable for their existence (Zeng, Sui & Wu 2005).

2.1 CONSERVATION PLANNING

The goal of conservation planning is to identify and conserve areas of land and sea that support life and biodiversity (Cowling et al. 2003; Nel et al. 2004; Bennett et al. 2009; Klein et al. 2009). Landscapes that are considered important for conservation have been identified using different methods including predicting the probability that a species will occur in that area, and identifying and targeting areas where it is presumed or known that species’ genetics will go through mutation (Cowling et al. 2003; Rouget et al. 2005; Lagabrielle et al. 2009; Lombard et al. 2010).

During the early days of conservation planning the main priority was to conserve threatened species particularly large mammals (Ricklefs, Naveh & Turner 1984). It is during this early stage when it became clear that the main threat to conservation planning was a lack of suitable habitats. (Ricklefs, Naveh & Turner 1984). Identifying and protecting important biodiversity, species and ecosystems is a common method used in the conservation of nature (Bennett et al. 2009). Systematic conservation planning has been used to achieve this goal by providing a strong basis by which to select suitable areas and achieve set priorities (Nel et al. 2004; Bennett et al. 2009). Systematic conservation planning aims to conserve a sample that represents all species and their suitable habitats that are the structural and compositional elements of biodiversity named biodiversity pattern (Nel et al. 2004; Pressey et al. 2007).

Conservation of biodiversity patterns is very important. However, focusing on just the patterns is not effective enough to ensure the persistence of biodiversity for a long time (Nel et al. 2004; Bennett et al. 2009). In order to conserve biodiversity in the long term, ecological processes that maintain and generate biodiversity patterns also need to be conserved (Nel et al. 2004; Pressey et al. 2007; Bennett et al. 2009; Klein et al. 2009; Lagabrielle et al. 2009; Lombard et al. 2010).

2.2 THE ROLE OF TRANSFRONTIER CONSERVATION AREAS (TFCAS) IN CONSERVATION

A Transfrontier Conservation Areas (TFCAs) is a large piece of land that straddles two or more international boundaries, containing more than one protected area as well as numerous resource areas to be used by communities and for conservation (Hanks 2001; Munthali 2007; Smith & De Klerk 2007). The main aim behind establishing TFCAs is to strengthen relationships between countries while conserving biodiversity (Hanks 2001). According to Munthali (2007) the key ecological roles of TFCAs are: protecting international ecosystems and reducing the risk of stochastic events extinction by increasing the area available for wildlife and populations. The Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA) is centred around the Zambezi-Chobe-Victoria falls areas and covers Namibia, Zambia, Botswana, Angola and Zimbabwe is one of the largest transfrontier parks in the world (kavangozambezi.org 2011). Its goal is to manage and sustain the ecosystem, heritage and cultural resources in the area (Peace Parks Foundation 2008).

2.3 ECOLOGICAL PROCESSES

Biodiversity processes describe how biological and physical characteristics of biodiversity change over time and scale (from molecular to global) (Lagabrielle et al. 2009). They take account of the birth, death and movement of individual organisms, local extinctions and recolonisations of populations, predation, patch dynamics, seasonal migrations, and adjustment of the distributions of species to changing climate, and speciation (Pressey et al. 2007; McGregor et al. 2011; Ricklefs, Naveh & Turner 1984). Therefore, biodiversity processes include both evolutionary and ecological processes (Lagabrielle et al. 2009). Trail (2009) defined ecological processes as “The interactions and connections between living and non-living systems, including movements of energy, nutrients and species” (Trail 2009:4). According to McGregor et al. (2011) ecological processes are not only important to plants and animals but to humans as well because they provide ecosystem services such as cleansing of water and air and pollination.

The ways in which ecological processes interact lead to differences in how they maintain and generate biodiversity (McGregor et al. 2011) thus they can be grouped accordingly (Bennett et al. 2009). Some ecological processes occurring in different places and in different habitats are linked by the movement of materials by organisms and by physical processes (Ricklefs, Naveh & Turner 1984). Processes such as such as pollination, seed dispersal and nutrient cycling can determine the spatial distribution and the demographic structure within a population through the interaction between organisms (Bennett et al. 2009). McGregor et al. (2011) made a list of what they believed to be the major themes of ecological processes: climatic processes, land systems productivity, hydrological processes, formation of biophysical habitats, interactions between species, movement of animals and seeds, coastal zone fluxes, natural disturbance regimes and spatially-dependent evolutionary processes. Representing climate and variation in primary productivity associated with topography, geology and soils has been a high priority over the last 30 years (Bennett et al. 2009). The spatial patterns in the composition, richness and local heterogeneity of plant and animal communities can be attributed to the climate and variation in primary productivity (Bennett et al. 2009).

An ecotone is the boundary between two plant communities or two biotic communities (Tueller 1999; Baker, French & Whelan 2002; Kark 2007; Solaimani & Shokrian 2011). Ecotones are usually characterised by diversification of species (Tueller 1999; Rouget et al. 2003), due to divergent selection, and thus an important ecological process. Divergent selection is the increase in differences between populations that can lead to the formation of new species (Schneider 2005). Ecotones can provide landscape supplementation and landscape complementation for species. Dunning, Danielson & Pulliam (1992) define landscape supplementation as the use of supplementary resources in adjacent habitats along ecological boundaries. Due to the availability of substitute resources the species is able to increase. Landscape complementation is the requirement for many species to link together different habitat types to complete their life cycle (Pope, Fahrig & Merriam 2000). The resources found in the different habitat types cannot be substituted as the specie needs both resources for different reasons (Dunning, Danielson & Pulliam 1992). The Grey Crowned-crane (Balearica regulorum) is a good example of a species that needs more than one habitat. The Grey Crowned-crane live in wetlands such as marshes, pans and dams with tall emergent vegetation, riverbanks, open riverine woodland, shallowly flooded and temporary pools (BirdLife International 2014). However, it prefers short to medium height open grasslands adjacent to wetlands for foraging and breeds within or at the edges of wetlands (BirdLife International 2014).

Ecotones have unique environmental and structural characteristics due to the fact that they contain species from at least two communities (Senft 2009). Furthermore, ecotones can influence the flow of materials and energy in the landscape and can be early indicators of ecological reaction to environmental change (Solaimani & Shokrian 2011). Species in ecotones are living near the edge of their tolerances therefore ecotone boundaries might be sensitive to any change in the environment making ecotones indicators of global climate change (Wasson, Woolfolk & Fresquez 2013). The determination and monitoring of ecotones therefore has a vital role in our understanding of biodiversity distribution and the policies that are put in place to enhance it (Kark 2007).

There are many ways in which ecotones can be identified for example, simulation modelling, geographic information systems, statistical tools and remote sensing (Kark 2007). The choice of the methodology used in many studies is largely dependent on the data available. Remote sensing offers strong potential for any analysis of ecotones because of its capability to examine landscapes at a number of spatial scales (Tueller 1999; Kark 2007). An ecotone may appear on the ground as a gradual blending of the two communities across a broad area, or it may manifest itself as a sharp border line (Tueller 1999). In digital satellite data an ecotone may appear as an edge, a boundary of mixed pixels or a zone of continuous variation, depending on the spatial scale of the vegetation communities and their transition zone in relation to the spatial resolution of data (Solaimani & Shokrian 2011).

Several reasons for including ecological processes in conservation planning have been outlined in literature; some examples are discussed below. First, ecosystems change over time and space, whereas most conservation planning methods are based on the distribution and status of species and ecosystems that are considered static (Pressey et al. 2007; Bennett et al. 2009). For example, animal activity varies with seasons, some species migrate and others are inactive during certain seasons (Ricklefs, Naveh & Turner 1984). Second, biodiversity is influenced and sustained by the complex ways in which components of an ecosystem interacts (Bennett et al. 2009). Third, processes may act as selective forces to which particular species are constantly adapting (Bennett et al. 2009) such as cycles of disturbance and recovery in fire dependent ecosystems are important for maintaining ecological processes (Ricklefs, Naveh & Turner 1984). Fourth, if the ecological processes of a certain area are conserved, the knowledge of how they function could be used to in similar areas where there is a need for restoration (Bennett et al. 2009). Lastly a conservation system that incorporates ecological processes in the plan is likely to be more resilient to climate change than one that only considers biodiversity patterns or just one species (Cowling & Heijnis 2001).

The disruption of ecological processes is often human induced by the usage of ecological services (McGregor et al. 2011) through, deforestation, damming of rivers, overharvesting of natural resources (such as fish and timber), introduced invasive species and reduction of connectivity and population sizes through fragmentation (Pressey 2007, Bennett et al. 2009). Potential climate change and fluctuation in regional temperature and rainfall may also pose a threat to ecological processes (Bennett et al. 2009). Agriculture may alter the nutrient and chemical composition of the ecosystem by using fertilisers, pesticides and insecticides (Bennett et al. 2009). The threats often interact with and affect biodiversity in ways that are difficult to understand and more often than not they leave enormous challenges (Bennett et al. 2009). It is difficult to remove wild animals and alien plants once they have been established.

In some cases removal of a threat might be easy but the effects that the threat has done already might not be so easy to reverse (Bennett et al. 2009).

According to Pressey et al. (2007), a series of filters must be applied while planning for ecological processes. Questions such as which ecological processes to plan for, how to plan for the ecological processes and how to choose between ecological processes when conservation resources are insufficient to conserve all identified processes have to be addressed (Pressey et al. 2007). There are ecological processes that might be critical to biodiversity but without any possible measures to ensure their persistence (e.g. plate tectonics). Therefore, a selection of processes that are understood well enough for spatial requirement to be delineated has to be done when (Pressey et al. 2007).

The most popular method used to include ecological processes in conservation considers design criteria such as size, shape and connectivity which can be either generic or process specific (Pressey et al. 2003; Rouget et al. 2003; Lagabrielle et al. 2009). Generic design criteria are those that are preferred in conservation planning but without specific guiding parameters (Pressey et al. 2003). The 'larger is better' concept is a good example for generic design criteria where a larger area is preferred for conservation however; there is no parameter that shows what is meant buy larger (Pressey et al. 2003). Generic design criteria can help maintain biodiversity processes however; it does not consider the requirements of a specific process to survive (Pressey et al. 2003) and it can dismiss small areas as not useful for conservation (Cowling et al. 2003). Alternately, process specific criteria considers whether there is enough information included in the design parameters and then estimate the quantitative requirements for persistence of one process (Pressey et al. 2003). For example, process specific criteria may compare the requirements of a focal species with the spatial criteria of a conservation area (Pressey et al. 2003; Rouget et al. 2003; Lagabrielle et al. 2009).

2.4 BIODIVERSITY SURROGATES

Due to the complexity of biodiversity, most species have not been described (Margules & Pressey 2000). Those that have been described often lack descriptions of their spatial distribution (Grantham et al. 2010). For this reason surrogates are used as measures of biodiversity pattern (Margules & Pressey 2000; Grantham et al. 2010; Lagabrielle et al. 2011). When planning for conservation, clear choices have to be made regarding the features that are to be used as surrogates for biodiversity (Margules & Pressey 2000, Ferrier 2002; Oliver et al. 2004). Examples of surrogates that can be used include: species, species assemblages and habitat types (Margules & Pressey 2000).

Choosing biodiversity surrogates is not an easy task (Margules & Pressey 2000). Two types of surrogates prevail: taxonomic and environmental surrogates (Grantham et al. 2010). The easy and tempting way is to use biological data focusing on a particular group of species (Margules & Pressey 2000; Grantham et al. 2010). It might be common knowledge that the existence of an elephant in an area means that its food plant will also occur in that area. However, just because the elephant requires a lot of space, it doesn't mean that all species that should occur in a particular area are still present and in healthy populations (Margules & Pressey 2000). This assumption is called taxonomic surrogacy (Margules & Pressey 2000; Grantham et al. 2010). Margules & Pressey (2000) found that in South Africa and Britain the efficiency of taxonomic surrogacy has been questionable whereas promising results have been found in Uganda. These differences can be related to the different analytical methods, geographical scales and bio-geographical histories of the areas studied (Margules & Pressey 2000)

Combining physical and biological data is referred to as environmental surrogacy (Grantham et al. 2010). Surrogates based on discrete classes such as ecological classification, habitat or land types and those that analyse continuous data directly in the selection of areas form a subdivision of environmental surrogates (Grantham et al. 2010). Ecological classification, habitat, land types or spatial components (from here forth just referred to as spatial components) have been widely used in conservation planning often with the assumption that they can encapsulate large numbers of the species (Margules & Pressey 2000). Spatial components as surrogates can be derived in many ways depending on the availability of data, spatial scale, data analysis techniques, biogeography and which variables are perceived as important for shaping biological distribution (Grantham et al. 2010).

Spatial components of ecological processes (SCEPs) are the physical features of a region with which particular ecological and evolutionary processes are associated (Pressey et al. 2003; Rouget et al. 2004; Lagabrielle et al. 2009; Lagabrielle et al. 2011). This implies that an ecological process does well in an area and therefore a specific biodiversity feature is maintained (Rouget et al. 2003). Areas known to be suitable for maintaining and generating biodiversity are usually unspoiled or almost in their natural form although they can also include cultural areas or suburban landscapes (Lagabrielle et al. 2009). The spatial components will be divided into two types: spatially fixed (clearly defined physical features) such as riverine corridors and spatially flexible (could be allocated more than one physical features) such as upland-lowland gradients following Rouget et al. (2003) and Lagabrielle et al. (2009).

The foremost advantage of using spatial components as surrogates for ecological processes is that they can incorporate more of the ecological processes that contribute to the maintenance of ecosystem function thereby reflecting factors that are important to the distribution of species (Margules & Pressey 2000). The relevant data are available quickly, widely and consistently at an inexpensive rate (Margules & Pressey 2000; Cowling & Heijnis 2001). Different studies have reported widely varying results on the effectiveness of spatial components as surrogates (Grantham et al. 2010). Oliver et al. (2004) found that lands systems or land classification derived in a similar manner used as environmental surrogates to represent biodiversity in conservation planning are useful. Each land system chosen for the study supported components of biodiversity either not found, or found infrequently, on other land systems (Oliver et al. 2004).

Other methods used to assess the spatial requirements of ecological process besides spatial components include: in situ short-term observations for example the movement of birds in an area and long term surveys of individuals or populations for example bird migration from one habitat to another (Lagabrielle et al. 2009). Margules & Pressey (2000) state that there is no one surrogate that is wrong or right. However, the choice of which surrogate to use will depend on the available data and the techniques available for analysing the data. In most situations planners use a combination of surrogates to compensate for the limitations of surrogates (Margules & Pressey 2000; Grantham et al. 2010)

For mapping biodiversity pattern Broad Habitat Units (BHUs) have shown to be valuable surrogates (Cowling & Heijnis 2001; Rouget et al. 2003; Lagabrielle et al. 2009). BHUs are derived primarily from the intersection of boundaries between the physical themes, namely geology (soil), topography and climate (Cowling & Heijnis 2001). These factors are considered major determinants of most vegetation patterns. A more detailed explanation of the methods used for BHUs derivation will be explained in the methodology chapter.

2.5 CORRIDORS

In the past establishing parks and protected areas was the only way of preserving biodiversity but current initiatives are moving towards increasing connectivity between different protected areas (Hanks 2001; van Aarde, Jackson & Ferreira 2006; Lombard et al 2010). Wildlife and wild land is becoming increasingly fragmented as the human world becomes increasingly connected (Crooks & Sanjayan 2006; Rosas et al. 2011). Habitat fragmentation has consequences on reproduction, gene flow and genetic diversity of species (Lowe et al. 2005; Aguilar et al. 2008). It is expected that reduction in population size restricts the number of local mating partners, increases the probability of inbreeding in self-compatible species, limits pollen availability in outcrossing species or reduces the quantity and/or quality of sires involved in seed production (Rosas et al. 2011). Populations that are isolated will suffer from low levels of gene flow between populations, resulting in low genetic variation (Rosas et al. 2011). These negative effects of fragmentation can be combated or reduced by ensuring connectivity between habitat patches therefore, enabling organism dispersal (Samways, Bazalet & Pryke 2010).

Corridors are defined as continuous strips of land connecting different habitat patches that facilitate animal movement across the patches (Caro, Jones & Davenport 2009; Roever, van Aarde & Leggett 2013). They reduce the effects of habitat loss and fragmentation and may increase genetic mixing (Crooks & Sanjayan, 2006). Historically, long-distance movements were believed to limit local overgrazing (Coughenour 2008), but today long-distance migration among terrestrial vertebrates is one of the world’s most endangered biological phenomena (Bartlam-Brooks et al. 2011). Once conservation areas have been established the next step to achieve long lasting conservation results should be to identify, maintain, and where necessary increase functional connectivity on the landscape (Hanks 2001). The functions of a corridor vary from one species to the other depending on what the species use the corridor for (Samways, Bazalet & Pryke 2010). A useful corridor for one species may be a barrier for another depending on seasons or disturbances occurring. A species can use multiple corridors in one geographical area for different functions (Samways, Bazalet & Pryke 2010).

Large mammals using corridors to move between habitats may also help restore essential ecological processes. For example large herbivores aid in long-distance seed dispersal effectively reducing the isolation of some plant species in small reserves (Couvreur et al. 2004). Certain large herbivores can also transform plant communities (Manier & Hobbs 2006; Pringle et al. 2007) by moving through habitats and feeding on plants. In the case of the African savanna elephants, *Loxodonta Africana*, their movement often has an undesirable impact on the vegetation and knock on affect to other wildlife. This is now a major concern for management of conservation areas (Loarie, van Aarde & Pimm 2009; Roever, van Aarde & Leggett 2013). High concentration of elephants in Southern and East Africa, have the ability to degrade woodlands to shrublands or grasslands (Western & Maitumo 2004; Scholes & Mennell 2008). Their ability to transform vegetation is increased by the fact that they are restricted to small areas and are unable to move between parks (van Aarde et al. 2006; Loarie et al. 2009).

No one corridor will necessarily benefit all ecological integrity, or all natural ecosystem functions (Samways, Bazalet & Pryke 2010). Corridors may also have negative effects, by providing pathways for alien predators or pathogens (Samways, Bazalet & Pryke 2010). Conceptually, it is useful to know to what extent corridors within a transformed matrix can maintain biodiversity and whether they are sustaining the properties of dynamic ecosystems (i.e. durable, robust, stable and resilient; Dawson et al. 2009). Samways, Bazalet & Pryke (2010) give two guiding principles that can be used to decide what a corridor should accomplish. Firstly, visualising the landscape as a large continuous piece of land, the desired place for implementing a corridor in a transformed area would be where the corridor contains the same biodiversity and provides the same functions as a similar area which is untransformed. Secondly, Hess and Fisher (2001) provide a very useful conceptual framework for corridors based on six functions: (1) conduit (2) habitat (3) filter (4) barrier (5) source, and (6) sink (Samways, Bazalet & Pryke 2010). These functions depend on the species or ecotype that is being considered as well as on the spatial and time scale being stipulated and they may not always be true at the same. A focal corridor should be defined in terms of these functions, in relation to the focal species, or community. Generally, the aim of a functioning corridor is to promote the attributes of conduit, habitat and source, and not the other attributes. Improving connectivity for all species in an area, and their interactions under varying weather and climatic conditions, as well as maintaining long term evolutionary advantage, is a challenging task.

2.6 THE USE OF GIS AND REMOTE SENSING TO IDENTIFY AND MAP SPATIAL COMPONENTS OF ECOLOGICAL PROCESSES

Campbell and Wynn (2011) define remote sensing as "the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface." There have been many definitions for remote sensing however, all centres on the use of space borne and airborne sensors to sense and record surface features without being in physical contact with them.

Traditional methods for mapping biodiversity patterns and ecological processes have presented challenges such as cost, time and the intense labour that is needed (Oldeland et al. 2010). Remote sensing provides an easier and faster means of analysing biodiversity and mapping vegetation which is cost effective (Pal & Mathur 2004; Campbell & Wynn 2011). Due to the fact that remote sensing images covers a larger area experts can provide more needed research on biodiversity and provide conservation planning support at a more rapid and accurate rate (Cho et al. 2012).

Different materials on the earth surface have different spectral signatures (Campbell 2007; Campbell & Wynn 2011). Spectral signatures are defined as emission and reflectance properties of various objects on the electromagnetic spectrum (Shaw & Burke 2003; Aggarwal 2004). Leaf pigments on vegetation that is alive such as chlorophyll are absorbed by the visible band of the spectrum, whereas, dry vegetation spectral reflectance is mainly due to minerals such as cellulose and protein (Shaw & Burke 2003). Increasing use of hyper spectral imageries in remote sensing provide researchers with the potential for mapping of vegetation at species level.

The spectral behaviours of various materials have been researched and their spectral reflectance curves archived in spectral databases. Spectral signatures of different vegetation types are associated with distinguishing biochemical and biophysical characteristics (Asner & Martin 2009). Remote sensing and GIS are useful mapping various types of lands (Khan, Gupta & Moharana 2001). To accomplish this, classification of imagery can be done using spectral signatures. The classification and be used for a number of research topics in various fields, such as landcover classification in urban planning, vegetation mapping in conservation. Even though these techniques are useful, a high level of skill and care is needed when interpreting remote sensing images (Cho et al. 2012).

The product most frequently derived from satellite images in ecology, the normalized difference vegetation index (NDVI) is the frequently used satellite imagery product in ecology studies (Oldeland et al. 2010). NDVI is the most common Vegetation Index and has a range of -1 to +1 (Popescu 2007). NDVI is calculated from the visible and near-infrared light reflected by vegetation (Popescu 2007), using the following formula:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Where R is the reflectance in the red band and NIR is the reflectance in the near-infrared band (Popescu 2007; Opoku-Duah et al. 2013). Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light (Pareta & Pareta 2011). If vegetation is healthy it will have high carbon sequestration ability. High NDVI shows healthy vegetation. NDVI correlates directly with vegetation productivity (Pettorelli et al. 2005). NDVI provides information on vegetation phenology and biomass, thus it can be used to assess vegetation quantity and quality (Pettorelli 2013). It could also be used to differentiate between savannah, dense forest and agricultural fields because NDVI and vegetation productivity are related (Pettorelli 2013). Areas that have a high NDVI value, that is a positive value, will be identified as areas of major carbon sequestration. Large areas have high NDVI in wet season, while most of the study area has only medium NDVI in the dry season. The small pockets of habitat that had maintained high NDVI in dry season as well as wet season where mapped as areas of carbon sequestration.

The level of detail that can be seen on a satellite image plays a role on the kind of analysis that can be done on that particular image. Resolution of a satellite image denotes the level of detail in the image (Althausen 2002; Lefsky & Cohen 2003; Campbell & Wynn 2011). Spatial resolution is the smallest size of detail that can be seen in an image (Nagendra 2001; Campbell & Wynn 2011). If an image has a high spatial resolution more detail can be detected from the image, it is therefore important to consider the detail a study is aiming to get out from an image before choosing the spatial resolution (Nagendra 2001; Rocchini 2007).

The current study used remote sensing images to classify vegetation. When classifying vegetation, using an image with a low spatial resolution results in a low accuracy classification (Nagendra 2001). Spectral resolution refers to the ability of a sensor to define fine wavelength intervals (Campbell & Wynn 2011). The finer the spectral resolution, the narrower the wavelength ranges for a particular channel or band. According to Nagendra (2011) datasets with sufficient spectral resolution can effectively identify differences between various plant species. Temporal resolution is the length of time for a satellite to complete one entire orbit cycle (Campbell & Wynn 2011). The ability of a remote sensing system to record sequences of images at close intervals generates fine temporal resolution. When conducting a change detection study high temporal resolution can be beneficial (Nagendra 2001). Using multi-temporal images can increase the classification of vegetation species (Nagendra 2001).

Radiometric resolution is the sensor's ability to discriminate very slight differences in reflected or emitted energy. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in energy. Previous studies have found slight improvements in accuracy when using images with a finer radiometric resolution for instance Legleiter et al. (2002) and Rao et al. (2007) (Nagendra 2001).

CHAPTER 3 RESEARCH METHODS

There many ways in which mapping spatial components of ecological processes can be achieved. This chapter provides an overview of the data used, the methodology used to delineate spatial components and outlining suitable movement corridors.

3.1 STUDY AREA

The study area is a portion of the Kavango-Zambezi Transfrontier conservation area (KAZA TFCA), which includes the Kafue National Park, Simalaha Community Conservancy (both in Zambia) and Chobe National Park in Botswana (Figure 3.1). Of these three Kafue National Park is the largest, covering an area of approximately 155 699 km^2.

3.1.1 Location

The KAZA TFCA includes areas of five neighbouring southern African countries; namely Angola, Botswana, Namibia, Zambia and Zimbabwe (KAZA secretariat 2012; Van der Lande & Viljoen 2013). It spans an area of approximately 446 287 km^2 The area includes more than 36 national parks, game reserves, forest reserves, game or wildlife management areas and intervening conservation and tourism concessions set aside for consumptive and non-consumptive uses of natural resources (Van der Lande & Viljoen 2013). The formation of landscapes in an area can be influenced by factors such as geology, slope, soil, rainfall, hydrology and vegetation (Peace Parks Foundation 2008). Understanding how these factors are connected enables effective and sustainable decision making.

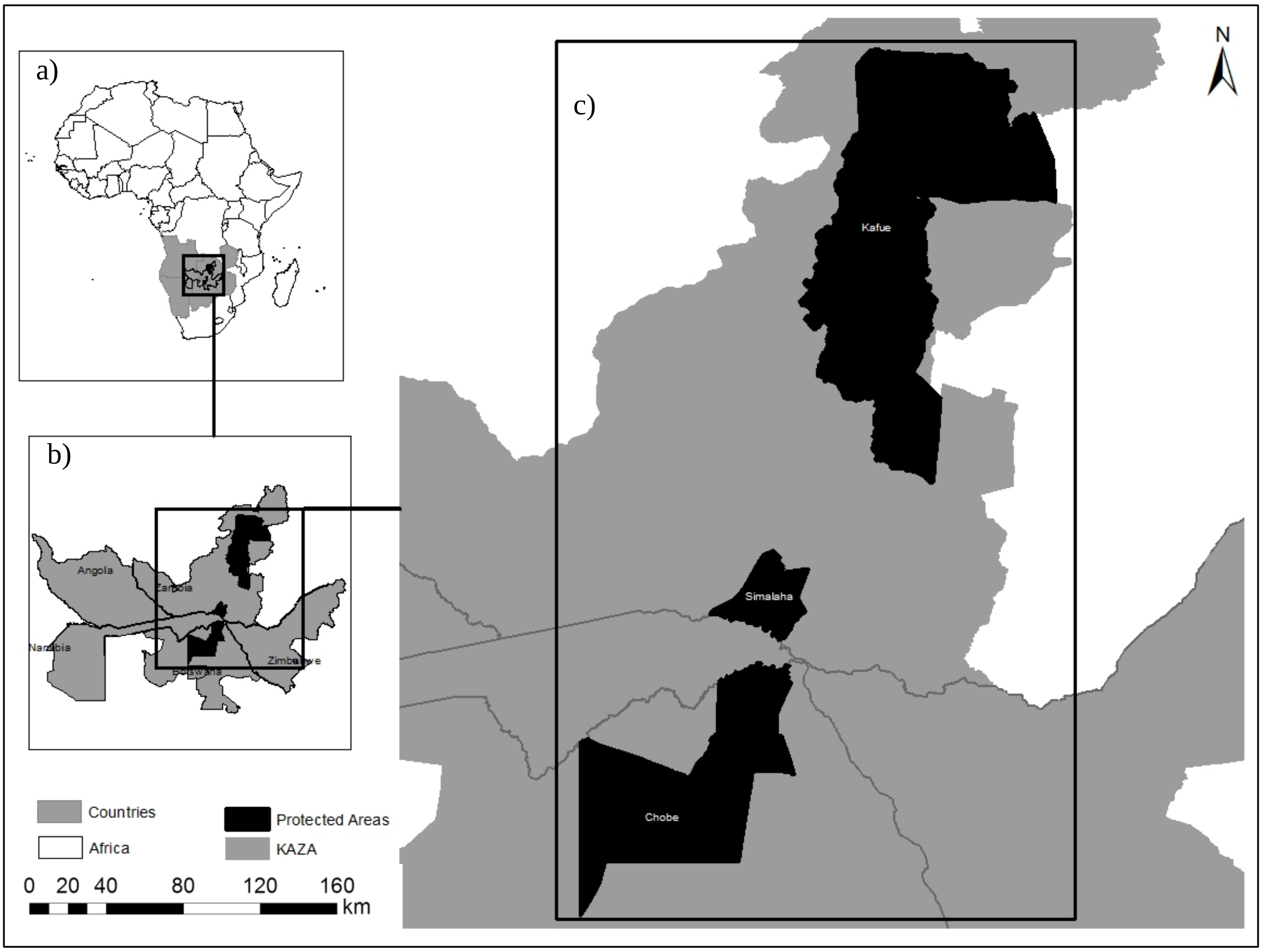

Figure 3.1 a) Location of KAZA on the African continent. b) The extent of the KAZA showing the location of Kafue National Park, Simalaha Community Conservancy, and Chobe National Park. c) The extent of the study area

3.1.2 Geology

Most vegetation relies on soil to provide the medium from which water and nutrients can be obtained. The properties of soils determine the diversity and species composition of the vegetative cover (Peace Parks Foundation 2008). Soil also influences the nutrient load within rivers based on the amount of dissolved chemicals and solids. Since most of the study area drains through Kalahari Sand, composed largely of quartz grains, the nutrient load in the rivers is low and the water clear (Peace Parks Foundation 2008). The predominant soil types within the study area as described by Peace Parks Foundation (2008) are: podzols, leptosols, luvisols, and planosols.

3.1.3 Topography and Slope

The altitudinal variation within the study area ranges from approximately 493 to 1432 m. The area is relatively flat with most of it not exceeding nine degrees in slope. The flat landscape resulted in the area having a lot of open plains and floodplains which has unique vegetation adapted to the prevailing conditions (Peace Parks Foundation 2008).

3.1.4 Climate

KAZA region has a tropical savannah climate (Von Gerhardt-Weber 2011). Rainfall occurs mainly between November and May with averages between 600 mm to 1 000 mm varying depending on location (Von Gerhardt-Weber 2011). According to the Peace Parks Foundation (2008) variation in altitude also affects the amount of rainfall, with the higher areas receiving more rainfall than the lower lying areas. The dry season runs from May to November, during which fire is a serious concern with September to October being particularly dry and peak burns are recorded in the same period (Mendelsohn & Roberts 1998).

3.1.5 The main biodiversity features

The biodiversity features in the study area had to be identified before the spatial components of ecological processes were delineated. The four main structural vegetation types that are recognised in KAZA TFCA are grassland, wetlands, dry forest and diverse woodland (Van der Lande & Viljoen 2013). Figure 3.2 below shows the vegetation species that are found in the study area. The plant life has at least 3 000 species, about 100 of which are endemic to the area (Kavangozambezi.org 2011).

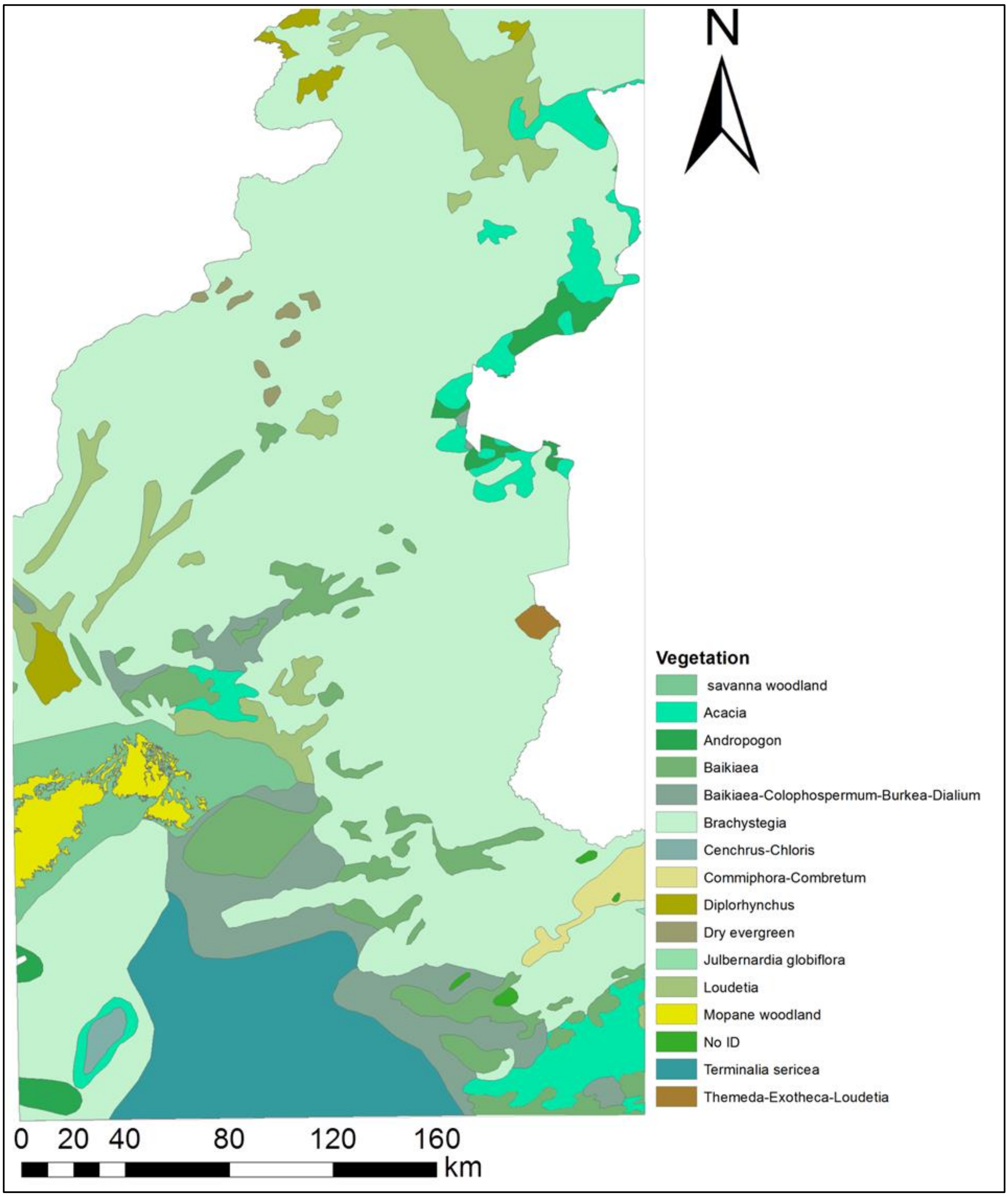

Figure 3.2 Vegetation types that occur within the study area clipped from Rutherford et al. 2005.

The terrestrial ecoregions of the world layer was used to identify the ecoregions in the study area (Figure 3.3). Thereafter, literature was used to identify the endemic species in the KAZA Transfrontier Park. The description of each ecoregion of the study area is given below with the species found in the ecoregions.

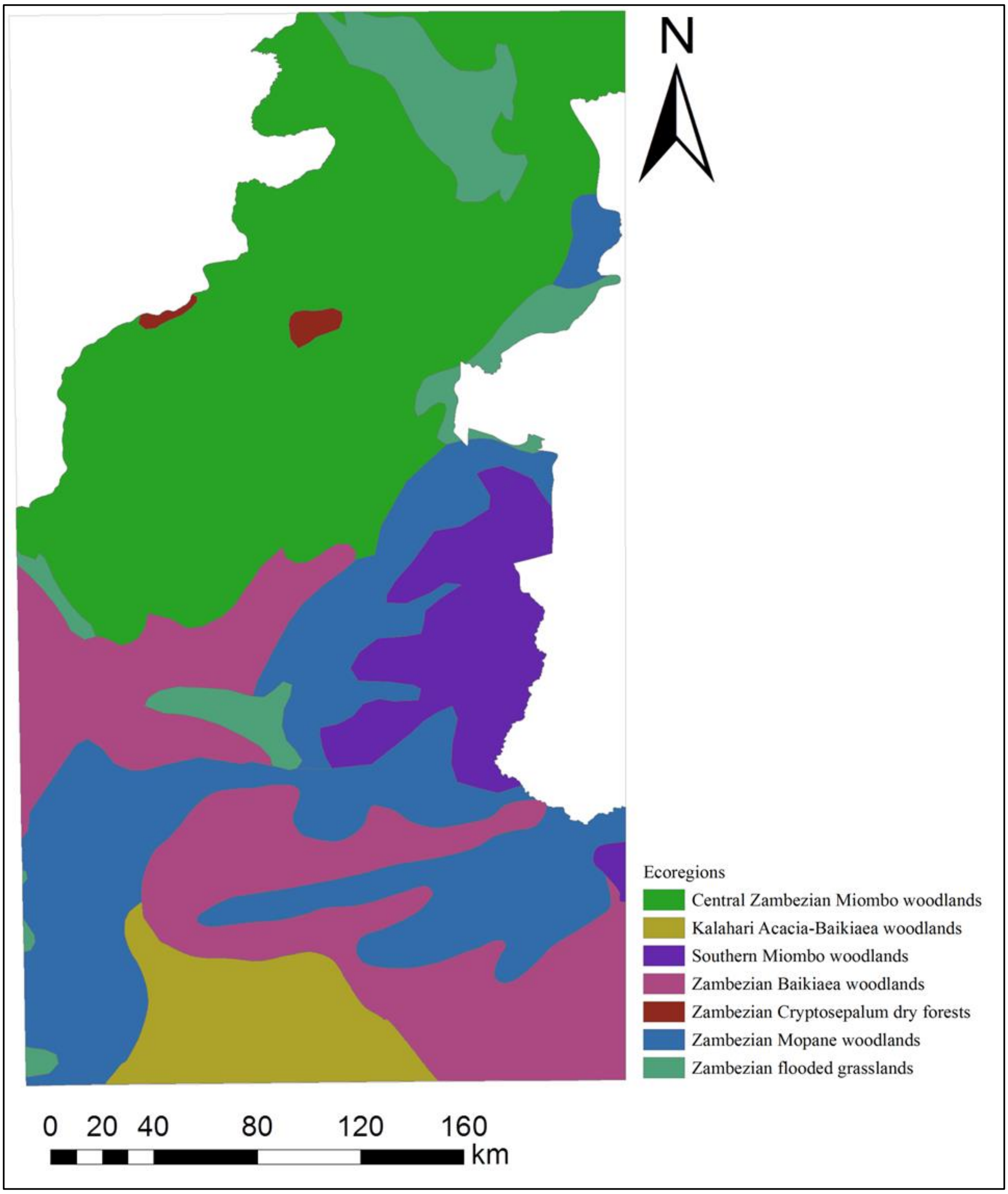

Figure 3.3 Ecoregions in the study area (Clipped from the terrestrial ecoregions of the world shapefile)

3.1.5.1 Miombo woodland

Miombo woodland is one of the most prevalent ecoregions in Africa and has a greater degree of floral richness than most woodland (Olsen et al. 2001). It is divided into central and southern miombo woodlands. The main difference between the two ecoregions is that the central miombo woodland is dominated by *Isoberlinia angolensis*, *Julbernadia paniculata* and *Brachystegia spp.* whereas southern miombo woodland does not have *Isoberlinia angolensis* present in it (Malambo & Syampungani 2008). The presence of a lot of wetlands throughout this ecoregion makes the harsh dry seasons, long droughts and nutrient deficient soils tolerable for plants and animals (Hogan 2013). The miombo ecoregions do not support large animals in high densities, although due to the size of the ecoregion it is still important for such species. The low large-mammal density is attributed primarily to the harsh dry season, long droughts and the poor soils which generally support only vegetation of low nutritional value (Hogan 2013).

3.1.5.2 Kalahari Acacia-Baikiaea woodlands

This ecoregion is characterised by semi-arid climate, with droughts occurring on a seven-year cycle (Spriggs 2013). Rainfall is highest in the summer months, from October through March mostly due to thunderstorms. Little or no rain falls during the winter months (May through August). The annual rainfall ranges from about 300 mm in the southwest to 600 mm in the north, with high annual variance (Spriggs 2013). Temperatures are typical of a continental climate, with high diurnal and seasonal ranges. In June and July, temperatures can drop below freezing, but in the summer months temperatures may exceed 40°C (Spriggs 2013).

3.1.5.3 Zambezian Baikiaea woodlands

This woodland is dominated by Zambezian teak or mukusi (*Baikiaea plurijuga*). In the Sesheke district which forms part of Simalaha, the ecoregion forms dwarf forests of Zambezian teak that range from 1 to 1.5 m in height (Hogan 2013). This ecoregion is mostly found in hot, semi-arid climate and on nutrient poor soils with mean annual rainfall of less than 600 mm. Therefore the region is not suitable for farming (Hogan 2013). More than 160 mammal species occur in the ecoregion. These include several large predator species, different ungulate species, elephant (*Loxodonta africana*), black rhinoceros (*Diceros bicornis*), white rhinoceros (*Ceratotherium simum*) (both are now rare in the ecoregion), hippopotamus (*Hippopotamus amphibius*) and honey badger (*Mellivora capensis*) (Hogan 2013).

3.1.5.4 Zambezian Crytosepalum dry forests

The Zambezian cryptosepalum dry forests are mainly found in Zambia, with this distinctive evergreen forest being confined to an area around the Kabompo River. Dominated by the native tree *Cryptosepalum exfoliatum pseudotaxus* which is locally known as mukwe (Fund & Hogan 2014. The ecoregion has a tropical savanna climate with mean annual temperatures between 20° and 22° C and mean annual precipitation ranges from 800 mm to 1200 mm. There is one near endemic species in the ecoregion, the Rosevear's Striped Grass Mouse (*Lemniscomys roseveari)* (Fund & Hogan 2014). The large mammal fauna includes a variety of predators and ungulates (Fund & Hogan 2014).

3.1.5.5 Zambezian Mopane woodlands

Characterized by the Mopane tree and found in the Kalahari sands where the Zambezian Baikiaea woodlands also occur. This ecoregion falls largely within the tropical summer rainfall zone, with precipitation largely confined to the period of November to April (White 1983). Some of the largest and most significant wildlife populations in Africa, particularly those of the vulnerable elephant and critically endangered wild dog are found in this region.

3.1.5.6 Zambezian flooded grasslands

This ecoregion experiences most of its rainfall in the hot summer months with the cooler season marked by harsh droughts that can last up to seven months (Goldberg 2013). Unlike the surrounding woodlands, the wetlands and floodplains of this ecoregion provide habitats to sizeable faunal populations because food and water are abundant throughout most of the year (Hogan 2013). Large herds of mammals move seasonally through the floodplain in response to the fluctuating water levels. The Kafue lechwe (*Kobus leche*) and Tsessebe (*Damaliscus lunatus*) prefer the residing water therefore, they follow residing water in the dry season and they move to higher grounds in the wet season when the water rises. Furthermore, the wetland and floodplain provides important habitat to a range of wetland birds (Hogan 2013). In general, there are rather few endemic species in this ecoregion, but there are high levels of species richness.

3.1.6 Endemic species in the KAZA transfrontier conservation area

According to Cumming (2008) 15 endemic or near endemic plant species are found in the KAZA TFCA. They comprise one species of sedge (*Cyperaceae)*, four grass species, one lily, and nine dicotyledonous species, of which five are small trees or shrubs, three are herbs and one is a succulent. There is one endemic or near endemic mammal species in the KAZA TFCA, namely, Woosnam's desert mouse (*Zolotomys woosnami*) of which its distribution is centred in Babwata NP in the Caprivi (Cumming 2008). One of the last remaining populations of wild dogs on the continent that are capable of living and breeding are found in Kafue National Park in Zambia (http://www.kavangozambezi.org).

Eighteen butterfly species were identified in the area and only two are near endemic, namely the Modest Bar, (*Cigaritis modestus modestus*) and the Fiery Acraea (*Acraea acrita ambigua*). There is also one endemic species Norman's Copper (*Erikssonia alaponoxa*) which is known only from miombo woodland (www.kavangozambezi.org/conservation). The one endemic fish present is the killifish (*Nothobranchius sp.)* that are found in pans in the East Caprivi (Timberlake & Childes, 2004). The only KAZA endemic bird species is the black cheeked lovebird (*Agapornis nigrigenis*) (www.kavangozambezi.org/conservation).

The biodiversity features discussed above were identified from literature due to the limited species specific information available. The species were not specific to the study area but were general to the KAZA Transfrontier conservation area. There is lack of available species occurrence data. In order for systematic conservation planning to be more effective plans have to be made to conserve ecological processes that are specific to the area.

3.1.7 Motivation for selecting site

Traditionally, conservation planning was only done by conservation and ecology experts (Peace Parks Foundation 2008). This approach leads to communities, traditional authorities, tourism investors and operators as well as other stakeholders resenting and resisting conservation plans because they might distrust the experts (Peace Parks Foundation 2008). TFCAs aim to remedy this situation by enabling both conservationist and the local people to manage the park together with the aim of making it beneficial to both conservation and the economy (Spierenburg, Steenkamp & Wels 2008). Community conservancies are a way of bringing local people and conservationists to work together. These are geographically defined areas which are recognized by the law, formed by communities that have united to manage and benefit from wildlife and other natural resources (Weaver & Petersen 2008).

The study area of this research contains a number of Community Conservancies. However, for this study only the Simalaha Community Conservancy will be taken into account. This conservancy is made up by the Sisheke and Chudu Chiefdoms (Van der Lande & Viljoen 2013). It is situated south of Zambia, near the Namibian border. The aim of establishing the Simalaha Community Conservancy is to re-establish wildlife populations and their migration routes (Van der Lande & Viljoen 2013). It will also serve as a link between Chobe National Park in Botswana and Kafue National Park in Zambia, this link will allow relocation of wildlife to secure environments making it a good case study for ecological processes aiding movement of biota.

3.2 DATA COLLECTION

Different data types were used for the purposes of this study (Table 3.1). All data in this study were projected to Universal Transverse Mercator (UTM) Zone 35S. Due to the fact that the collected data were for the whole of KAZA or Africa the different layers were clipped to the study area.

Table 3.1 summarises the different data that were used in the study. Landsat 8 images that are already corrected for geometric distortions were ordered from the United States Geological

Survey (USGS) earth explorer. Landsat 8 images have a spatial resolution of 30 meters and have nine spectral bands. Band 1 (ultra-blue) is useful for coastal and aerosol studies and band 9 is useful for cirrus cloud detection (USGS 2013). This study used spectral bands one to seven of the Landsat images. Different Landsat scenes were inspected before the cloud free scenes that cover the entire study area were selected.

Terrestrial Ecoregions of the World (TEOW) is a biogeographic regionalization of the Earth's terrestrial biodiversity (Olsen et al. 2001). Biogeographic regions also called ecoregions are defined as relatively large units of land or water that are characterised by a distinct assemblage of natural communities sharing a large majority of species, dynamics, and environmental conditions (Olsen et al. 2001). The ecoregions layers were downloaded from the World Wildlife Fund (WWF) website.

Table 3.1 Summary of the data used in the study

Used to map:	Data	Source
Identify biodiversity features	Terrestrial ecoregions	http://worldwildlife.org/publications/terrestrial-ecoregions-of-the-world
Habitat transformation	Infrastructure Roads Populated areas Tourism	Peace parks foundation
Ecotones	Landsat 8	http://earthexplorer.usgs.gov
Edaphic interfaces	Soil types Vegetation types	The SOTER database for Southern Africa (SOTERSAF) SAFARI 2000 NBI Vegetation Map of the Savannas of Southern Africa
Upland and lowland gradients	Digital elevation model	http://earthexplorer.usgs.gov
Riverine corridors	Rivers	Peace parks foundation
Areas of high carbon sequestration	MODIS derived NDVI Pantropical national level carbon stock	http://modis.gsfc.nasa.gov/data Woods Hole Research center

The MODIS on board the Terra satellite was launched in December 1999. MODIS instrument provides improved monitoring for land, ocean, and atmosphere research (Justice et al. 1998). MODIS combines characteristics of the Advanced Very High Resolution Radiometer (AVHRR) and the Landsat Thematic Mapper (Justice et al. 1998). The MODIS product used in this study is the vegetation Indices 16 Day level three with a 250 m resolution. Global MODIS vegetation indices are designed to provide consistent spatial and temporal comparisons of vegetation conditions. Blue, red, and near-infrared reflectances, centered at 469-nanometers, 645-nanometers, and 858-nanometers, respectively, are used to determine the MODIS daily vegetation indices. The MODIS Normalized Difference Vegetation Index (NDVI) complements NOAA's Advanced Very High Resolution Radiometer (AVHRR) NDVI products and provides continuity for time series historical applications (USGS 2013).

3.3 DATA ANALYSIS

3.3.1 Describe the main biodiversity features

A biodiversity feature is defined as an element of biodiversity for which it is possible to set a quantitative conservation target (Bragg & Parramon-Gurney 2013), for example a vegetation type, a species or the spatial component of an ecological process (Pressey et al. 2003). For this study the ecoregions and spatial components of ecological processes will be described as the biodiversity features.

Biodiversity is not spread evenly across the Earth but follows complex patterns called ecoregions determined by climate, geology and the evolutionary history of the planet (wwf.panda.org). The World Wildlife Fund (WWF) defines an ecoregion as a "large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (wwf.panda.org). The terrestrial ecoregions shape files from WWF was clipped to the study area using ArcGIS.

3.3.2 Habitat transformation

Rouget et al. (2003) categorised transformation into three criteria of habitat: extant, restorable, and lost. Areas currently free of urbanisation or agriculture (including forestry), were categorised as extant. These areas according to Rouget et al. (2003) are to be considered were classified as potentially restorable, to supplement the extant areas. Although biodiversity pattern have been permanently transformed in these areas, processes could possibly still operate or be restored (Rouget et al. 2003). Urban areas and roads are considered to be lost for conservation purposes.

Linear buffers were used around roads and circular buffers around tourist attractions and populated places. These areas were buffered according to the visual and audible impacts that they have on the landscape. Fahrig & Rytwinski (2009) observed a concern among conservationists and environmental planners that roads and traffic may be reducing or even eliminating wildlife populations. For instance, with respect to wildlife and roadside plants, roads can contribute to loss and fragmentation of habitat; injury and death of wildlife especially when they are attempting to cross roads; and pollution of air, water, and soil; and finally, they can disturb audio communication especially in areas affected by traffic noise (Parris & Schneider 2008 and Wilkie et al. 2000).

The buffer widths in metres (**Error! Not a valid bookmark self-reference.**) are based on how far the impacts of a development extend, this is determined by how far it can be seen or heard. For example camps are usually smaller than lodges therefore have less impact on the environment. It is thus important that the impacts of transformation should not be accounted for in the immediate space of infrastructure but also in a buffer around it.

Table 3.2 Buffer values used to define the transformed areas

Type	Buffer Values (M)
Populated Places	
Village (Rural)	1000
Rural settlement	1000
Tourism	
Camps	500
Lodge	1000
Tourism Activity	2000
Airstrip	1500
Gate	500
Viewpoint	750
Infrastructure	
Boat launch	2000
Tower	1000
Roads	1000
unknown	250

3.3.3 Identifying key ecological processes

There are many published methods for identifying ecological or biodiversity processes. However these usually focus on large charismatic species and neglect other ecological processes. From the review of literature conducted (Chapter 2), a list of ecological processes and their spatial components was made (

Table 3.3).

This list is the bases of the mapped spatial components done in the study. The assumption is that ecological processes that generated and maintained biodiversity in the past will continue to do so in future.

Table 3.3 spatial components of ecological processes identified from literature as important to the study area.

Spatial component	**Ecological process**
Major carbon sequestration areas	Carbon sequestration
	Nutrient cycling
Ecotones	Diversification of plant and animal species
Edaphic interfaces	Ecological diversification of plant lineages
Upland-Lowland interfaces	Ecological diversification
	migration and exchange between upland and lowland
Riverine corridors	Migration and exchange between rivers and land
	Pollination
Habitat connectivity	Migration and exchange of biota
	Predator-prey relationships
Biogeographical nodes	Ecological speciation
	Ecological refugia

3.3.4 Identify and map spatial components of the key ecological processes

Spatial components of ecological processes were mapped as surface elements along linear environmental interfaces or gradients following the studies done by Lagabrielle et al. (2009) and Rouget et al. (2003). Biodiversity pattern, vegetation types, soil maps and the distribution of rivers, wetlands and other water features were used to derive the different spatial components of biodiversity processes. The spatial components were divided into two types: spatially fixed (clearly defined physical features) and spatially flexible (with several options for spatial allocation) following Rouget et al. (2003). Some of the spatial components that were found to be important to the study area will be discussed below with methods of how they will be delineated.

3.3.4.1 Ecotones

An ecotone is the boundary between two plant communities or two biotic communities (Tueller 1999; Baker, French & Whelan 2002; Kark 2007; Solaimani & Shokrian 2011). There are many ways in which ecotones can be identified for example, simulation modelling, geographic information systems, statistical tools and remote sensing (Kark 2007). The choice of the methodology used in many studies is largely dependent on the data available.

This study developed and implemented a novel approach to identifying and mapping vegetation ecotones. The approach maximises the use of spectral properties of different vegetation types and identifies ecotones as unique combinations of the vegetation types. Identifying ecotones in the study area was done by doing a spectral classification of Landsat 8.imagery. Spectral classification involves categorising pixels that are within satellite data into land cover classes (Campbell and Wynne 2011). Although, spectral classification is a common method when classifying land cover, it has not been previously used in published literature for the identification of ecotones. Prior to the spectral classification preparing the satellite data is was necessary.

Pre-processing

The operations that are done prior to the main analysis of remote sensing imagery are referred to as pre-processing (Campbell and Wynne 2011). The two typical pre-processing operations are atmospheric pre-processing which is done to adjust digital values for effects of a hazy atmosphere and geometric pre-processing which brings an image into registration with another image or with real world co-ordinates (Kardoulas, Bird & Lawan 1996; Campbell and Wynne 2011). Landsat 8 images used for this study were already geometrically corrected when downloaded therefore, only atmospheric correction had to be done. This was an important step because atmospheric effects can lead to the images being interpreted incorrectly if it is not taken into account (Campbell & Wynne 2011). The atmospheric correction of Landsat 8 data in this study was done using PCI Geomatica’s ATCOR 2. According to Richter (2004) ATCOR is a method used for the atmospheric and topographic correction of remotely sensed optical imagery. There are different versions of ATCOR

(2/3/4), in this study ATCOR 2 was used because it is suitable for atmospheric correction of an image consisting of mostly flat terrain.

Classification

The purpose of image classification in this study was to categorise the pixels in the Landsat 8 images into different vegetation types and therefore to be able to identify the transitions between vegetation types (ecotones). Multiple classification techniques were used in order to separate the different types of vegetation more accurately. First the ISODATA unsupervised classification was done, second, a maximum likelihood on the natural vegetation, followed by a ruleset classification. The first step prior the classification was to develop a definition of the classes had to be done (Table 3.4).

ISODATA (Iterative self-organizing data) classification technique was used to separate water and bare spectral signatures from the vegetation. This was done to simplify the ecotones identification process. The pre-processed Landsat 8 images were classified into eight classes. Following the classification, each of the eight classes was reclassified into water, soil and natural vegetation. Water was given a value of one, soil a value of two and the natural vegetation were classified as nodata. Ecotones that the study intended to map were between different natural vegetation types, the ISODATA classification was used as a pre-step to the classification which would determine the ecotones.

Table 3.4 Definition of classes used when classifying Landsat 8 images

Code	Class	Land-uses and land-covers included in class
1	Savanna woodlands	Acacia, Baikiae, Brachsytegia
2	Colosphospermum	Colosphospermum mopane
3	Dry evergreen	Dry evergreen
4	Andropogon	Andropogon grass
5	Chloris	Cenchrus chloris grass
6	Loudetia	Loudetia grass

The next step was a maximum likehood classification using the training sites from signatures of the classes defined in Table 3.5. Training sites were selected using spectral signatures of the different classes in the study area had to first be manually defined in the form of areas of interest (AOIs) using the Region Grow tool in ERDAS IMAGINE software. A line graph showing the vegetation types and their mean spectral signatures is presented in appendix A. Google Earth was viewed along with the Landsat image in ERDAS using a function that enables the user to connect to Google Earth which compares an area on an image to the real location on google earth. This function was to geo-locate observations simultaneously on both images to ensure good representations (AOIs) of each vegetation type were defined. A total of 251 training sites were collected, 125 of them were combined according to spectral similarity then used for the maximum likelihood classification. The remaining 126 saved for the accuracy assessment.

A reclassification of the maximum likelihood results was done to separate the grasslands from the woodlands. The model maker toolbox in ERDAS was used to make a decision tree classification of the different vegetation types. A decision tree describes the conditions under which a set of low level constituent information gets abstracted into a set of high level informational classes (Patil et al. 2012). For each vegetation type, decision threshold were defined after analysis of their spectral signatures (Table 3.5).

Table 3.5 Decision tree rules used for classification

Code	Land cover	Classification rule (B=Band)
1	Savanna woodlands	B6 (SWIR1) 1750-2421
2	Colosphospermum	B4 (RED) 869-1297
3	Dry evergreen	B3 (GREEN) 207-330
4	Andropogon	B5 (NIR) 500-1600
5	Chloris	B7 (SWIR2) 2800-3200
6	Loudetia	B5 (NIR) 1800-2180

Different bands were used for the threshold, based on where between the eight bands the vegetation type is most separable from the others. It was not possible to separate different vegetation types using bands one and two therefore, these two bands were not used for the decision rulesets. Each vegetation has a reflectance value (spectral signature). Savannah woodlands for example had a different spectral signature from the rest of the vegetation types in band six with their spectral reflectance ranging from 1750 to 2421.

Ecotones were mapped as the unclassified pixels falling between vegetation types. These pixels were then exported into a shapefile in order to make a map of ecotones. This ecotone polygon layer will be used instead of a 'static' buffer of adjacent vegetation types used in previous studies (Rouget et al. 2003) as ecotones vary in width and shape over landscapes.

Accuracy assessment

AOIs that were not used for the classification were used as reference data in the accuracy assessment. A confusion matrix was produced with a producer's accuracy, user's accuracy, overall accuracy and kappa (k) statistic.

3.3.4.2 Edaphic Interfaces

Edaphic interfaces represent specific juxtapositions of soil types which drive ecological plant diversification (Pressey et al. 2003; Rouget et al. 2003). For example, in the fynbos edaphic interfaces are specifically combinations of acidic and alkaline parent materials (Pressey et al. 2003; Rouget et al. 2003). Edaphic interfaces can either be soft or hard interfaces (Driver et al. 2003). Soft edaphic interfaces are made of vegetation types that have similar geology or soil type and they are important for plant species migration (Driver et al. 2003). Hard edaphic interfaces contain vegetation types that have different geology or soil type and they are important for species diversification (Driver et al. 2003).

To identify edaphic interfaces a soil map compiled by the Soil Survey Section Research Branch, ministry of Agriculture in Zambia was used. The soil data was digitized from exploratory Soil Map of Zambia at a scale of 1:100 000. The vegetation layer used was provided by the National Botanical Institute (NBI). Pressey et al. (2003) considered any untransformed section of interface larger than 50 ha as suitable for maintaining species diversification. Soft edaphic interfaces were identified using ArcMap's spatial analysis clip tool. The different soil types where separated into new layers, then used to clip the vegetation layer in order to identify the vegetation types that occur in each type of soil. The soil type with ten or more vegetation types that occur in it was identified as a soft edaphic interface because it would cater for easy vegetation species movement. This soil type was then buffered by 250 m around it.

3.3.4.3 Upland-lowland interfaces and gradients

Upland and lowland gradients are complimentary to upland and lowland interfaces. Rouget et al. (2003) defined upland–lowland interfaces as short gradients for diversification and range adjustment in response to climate change. These interfaces are associated with plant and animal ecological diversification (Rouget et al. 2003; Pence 2008). Upland–lowland gradients are important for ecological processes such as seasonal movements of animals, local-scale adjustment of species distributions to climate change and ecological assemblages of plant and animal lineages. According to Rouget et al. (2003) gradients connect distant land classes and cross larger parts of adjacent land classes than upland–lowland interfaces. However, habitat transformation constrains the role of gradients, especially in the lowlands (Rouget et al. 2003; Pence 2008).

Vegetation in the study area was divided into upland and lowland in order to have an upland-lowland surface that could be used to identify both the upland-lowland interfaces and gradients. A DEM of the study area was used for the separation. Upland vegetation were defined as vegetation occurring at an altitude of 1000 m and higher and lowlands all vegetation at an altitude below 1000 m.

Upland-lowland interfaces were identified by digitizing the boundary between the uplands and lowland vegetation to get an interface between the two. The boundary was then buffered by 500 m on either side of the interfaces following Rouget et al. (2003).

To identify uplands and lowland gradients, source and destination points had to be identified. The methodology by Lagabrielle et al. (2009) was followed, where the three highest points where identified as the source points and the destination points distributed along the coastline at regular intervals (Lagabrielle et al. 2009). For this study a DEM of the study area was used to identify the three highest points (Figure 3.4). First the DEM was converted into a points shape file using the ArcMap spatial analysis. Then the three highest points where identified and exported to a new shape file. Destination points in the study area were identified as the areas along floodplains and river deltas. For their delineation, a layer that shows water features was used to select all floodplains and river deltas in the study area and then the selection exported to a new shape file.

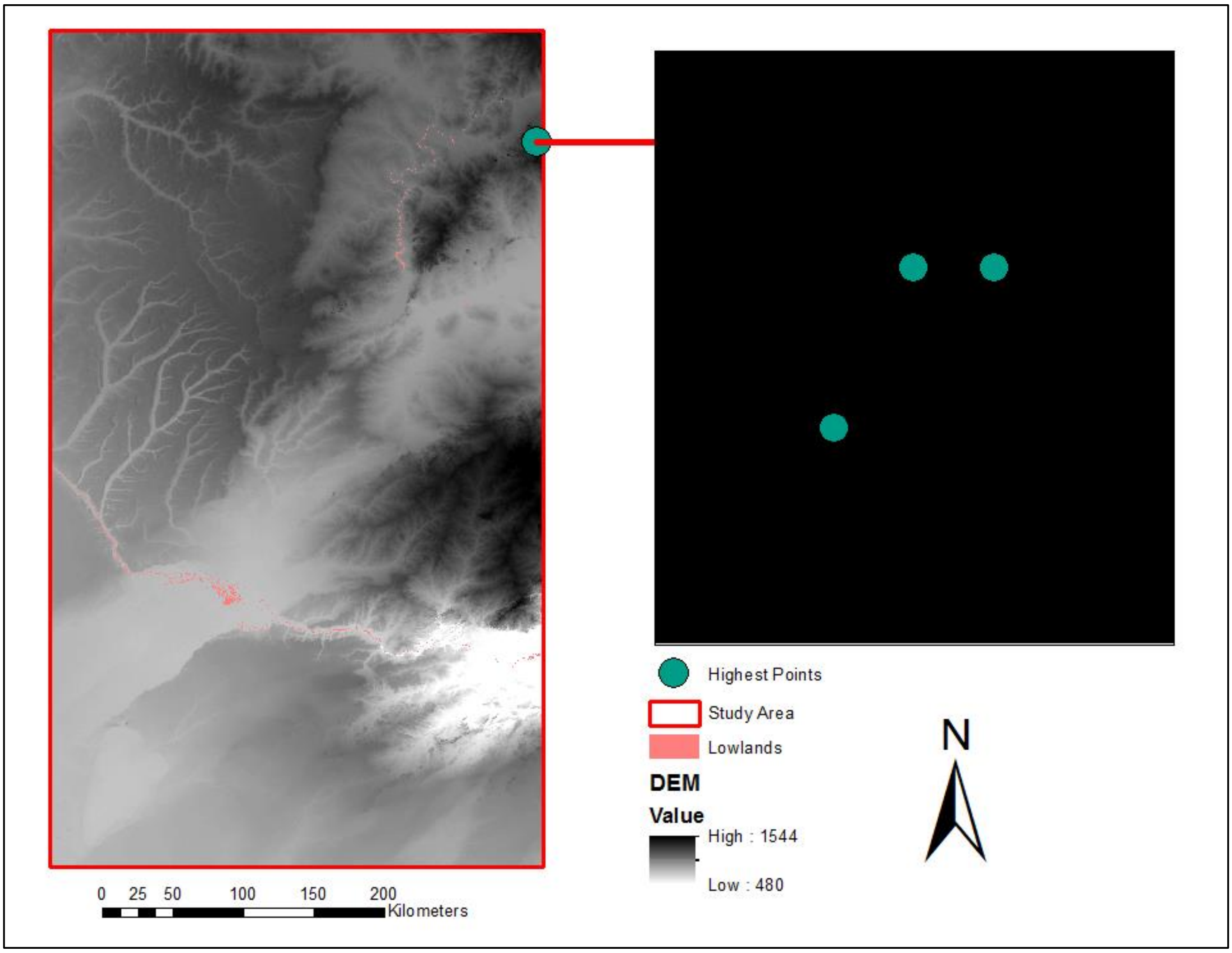

Figure 3.4 Highest points and lowlands in the study area

The least cost paths were calculated to link the source points to the destination points. Figure 3.4 shows the source and destination points. Least-cost path analysis seeks the shortest route (in terms of distance and cost) to link nominated start and end points (Rouget et al. 2003). The least cost paths were calculated across a cost matrix coded with costs associated with transformation status and protection status. This means that it was (arbitrarily) 100 times more 'expensive' to cross a completely transformed cell than to cross a completely untransformed cell. Following Rouget et al. (2003) a 1000 m wide buffer around the paths will act as suitable upland-lowland gradients corridors for animal and plant migration. For each gradient identified, the percentage of transformation was calculated. We categorised gradients unaffected by agriculture or high density alien plants as extant and the others restorable (the scale of restoration being indicated by the degree of transformation).

3.3.4.4 Riverine corridors

By linking different valleys and mountains riverine corridors serve as channels for the movement of plants and animals (Driver et al. 2003; Lagabrielle et al. 2009). Exchanges between lowlands and uplands such as top down nutrient flows and bird movement are supported by riverine corridors (Lagabrielle et al. 2009). Riverine corridors act as refuge for species that contain moderate amount of moisture during major climatic events for example fire and drought (Driver et al. 2003; Rouget et al. 2003). They are also important as a source of water for human use. Vegetation on riverbanks needs to be maintained in order for rivers themselves to remain healthy, thus the focus is not just on rivers alone, but on riverine corridors (http://bgis.sanbi.org/skep).

In the study area three indicators were identified to help decide on the buffer space, the hippopotamus (*Hippopotamus amphibious*), studies done by Lagabrielle et al. (2009) in Reunion Island and Rouget et al. (2003) in the Cape Floristic region, the altitude of the river was considered as well. Rouget et al. (2003) buffered riverine systems by 250 m because they considered it acceptable for species dispersal and Lagabrielle et al. (2009) used buffers of 50, 100, 150 and 200 m wide along perennial rivers 50 m wide buffer along non-perennial rivers

This study wanted to test the applicability of these buffer widths from the literature as they were used in rather different ecosystems (Cape Floristic Region in South Africa) to the savannah-woodland of this study area. So this study looked at the space utilisation of the hippopotamus because of it being tied to riverine habitats in this ecosystem. The hippopotamus spends the day in water and it leaves at night for feeding as it does not eat aquatic vegetation (McCarthy et al. 1998; Kanga et al. 2013). The hippopotamus impact the life cycles within their habitats greatly because they keep water channels and land well grazed (http://www.krugerpark.co.za/africa-hippopotamus.html). Aquatic microorganisms and fish get nourished from the hippopotamus' nutrient rich dung. Open water is not essential and the animal can survive in muddy wallows but it must have access to permanent water to which it can return in the dry season. The hippopotamus requires a permanent supply of water which is large enough to allow the territorial males to spread out and adequate grazing area that is close to their resting place (http://www.krugerpark.co.za/africa-hippopotamus.html). Hippopotamus rarely walk more than 2 to 3 km from water for feeding (McCarthy et al. 1998) although sometimes they can walk as far as 8 km inland to graze on short grass (http://www.krugerpark.co.za/africa-hippopotamus.html). In the Mara River (Kenya), hippos were found to travel parallel to the river for grazing and they moved 2.2 km from the river (Kanga et al. 2013).

Rivers in lower altitudes will flow more slowly and thus the river channel broadens and the vegetation zone is wide. It is for this reason that a 1000 m buffers on either side of the rivers on the lower lying areas was decided upon. This buffer also gives enough space for mammals like the Hippo to move to and from the river. In the upper areas of the rivers a buffer of 500 m was decided on because river channels are narrower and there is a lower chance of mammals to reside there.

3.3.4.5 Areas of high carbon sequestration

Carbon sequestration is an important ecological process as it ensures that nutrients are cycled in the atmosphere as well as in the soil, and it enriches organic soil matter (Rouget et al. 2004). Storing carbon dioxide in plant tissue or in organic matter found in the soil reduces the levels of CO_2 in the atmosphere (Rouget et al. 2004). This has led to carbon sequestration receiving a lot of interest as it is now viewed as a way of mitigating the impacts of global change (Rouget et al. 2004).

Vegetation types were classified into three categories according to their ability to sequester carbon, following an approach suggested by Rouget et al (2004): low to none (e.g. desert), medium (e.g. grassland), high (e.g. thicket). The vegetation types with high carbon sequestration ability were identified as major carbon sequestration areas. Table 3.6 below shows the classification used for this study, to classify vegetation as according to their carbon sequestration potential.

Table 3.6 Vegetation carbon sequester potential

Carbon sequestration potential	NDVI range	Example from literature	Probable equivalents in this study
low to none	0-0.1	Desert and bare soils	Sand banks
Medium	0.2-0.5	Grassland	Andropogon
High	>0.5	Thicket	Dry evergreen forests

Moderate-Resolution Image Spectroradiometer (MODIS) derived NDVI data was used to identify vegetation's ability to sequester carbon depending on the vegetation's volume, structure and health. In addition to the use of NDVI, the Woods Hole Research Center (WHRC) Pantropical National Level Carbon Stock Dataset was used (Baccini et al. 2014; WHRC 2014). A national level aboveground dataset for tropical countries was generated using a combination of co-located field measurements, LiDAR observations and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery. This dataset together with the MODIS NDVI were compared in order to make a better informed choice about the areas of high carbon sequestration in the study area.

3.3.5 Network of corridors

To outline the best possible corridor for the persistence of ecological processes a least cost path analysis was done on all the outlined spatial components. A cost matrix coded with costs associated with transformation status and protection status was used for the least cost paths.

Populated areas, areas with infrastructure and roads were weighted to be the most expensive. Paths that went through protected areas, along riverine corridors or through any of the defined spatial components were the least expensive.

CHAPTER 4 RESULTS AND DISCUSSION

The aim of this research was to identify and map the spatial requirements of ecological processes which are important in the functioning and persistence of biodiversity in a portion of the KAZA TFCA. This was done to delineate corridor areas that link the Chobe National Park and Kafue National Park through the Simalaha Community Conservancy. The corridors had to be able to sustain ecological processes in the area. Different spatial components were chosen based on the knowledge of the ecological processes in the area. These are riverine corridors, ecotones, areas of high carbon sequestration and edaphic interfaces. The methods of delineation were discussed in chapter 3. In the current chapter the results found will be discussed.

4.1 HABITAT TRANSFORMATION

The total transformed area is 12 387 km2 which cover a total of 8% of the whole study area. Studies done in the Cape Floristic Region (Rouget et al. 2003; Pressey et al. 2003) included agriculture and invasive species to the transformation map. This study excluded agriculture because it is possible to restore ecological processes in such areas. Due to the limited data available, it was not possible to include the invasive species in the transformation map. Habitat transformation can also be mapped more accurately using remote sensing over a fine temporal resolution. This would give the amount of change that has a happened over the years. The current study however, was interested in finding out which areas are transformed, not the land cover change of the area. Future research can embark on a study that focuses on the land cover change in the area and how it has affected ecological processes.

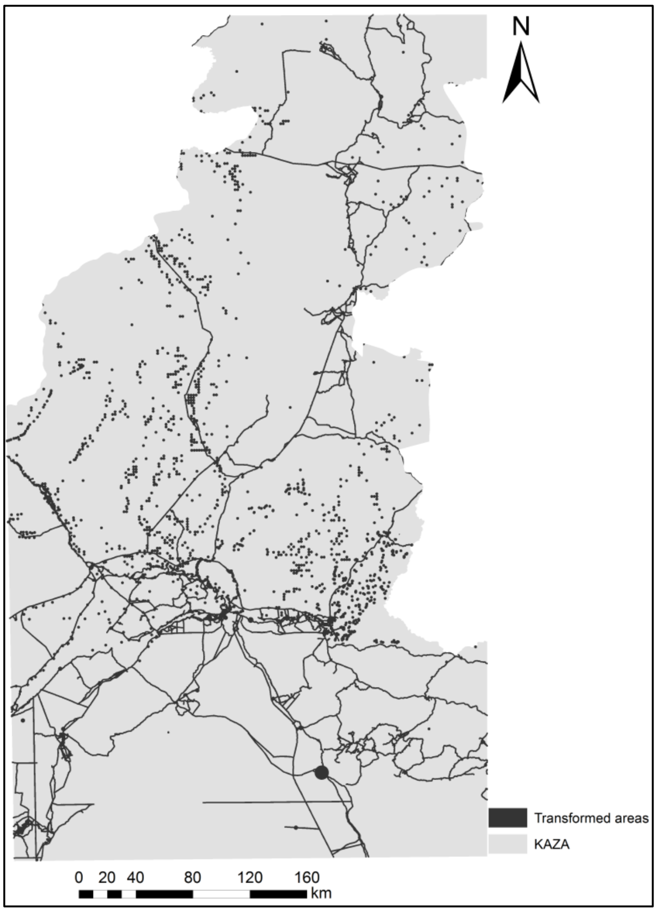

Figure 4.1 Map showing areas transformed beyond restorability, i.e. built-up areas and roads

4.2 IDENTIFY AND MAP SPATIAL COMPONENTS OF THE KEY BIODIVERSITY PROCESSES

4.3.1 Ecotones

The study mapped ecotones by using the spectral properties of vegetation. ISODATA and maximum likelihood classification algorithms were done on Landsat 8 images of the study area. This section will discuss the outcome of the different classification methods leading to the delineation of the ecotones. The first classification was the ISODATA unsupervised technique, used to separate water and bare spectral signatures from vegetation. The mosaic image of the ISODATA classification results is depicted by Figure 4.2.

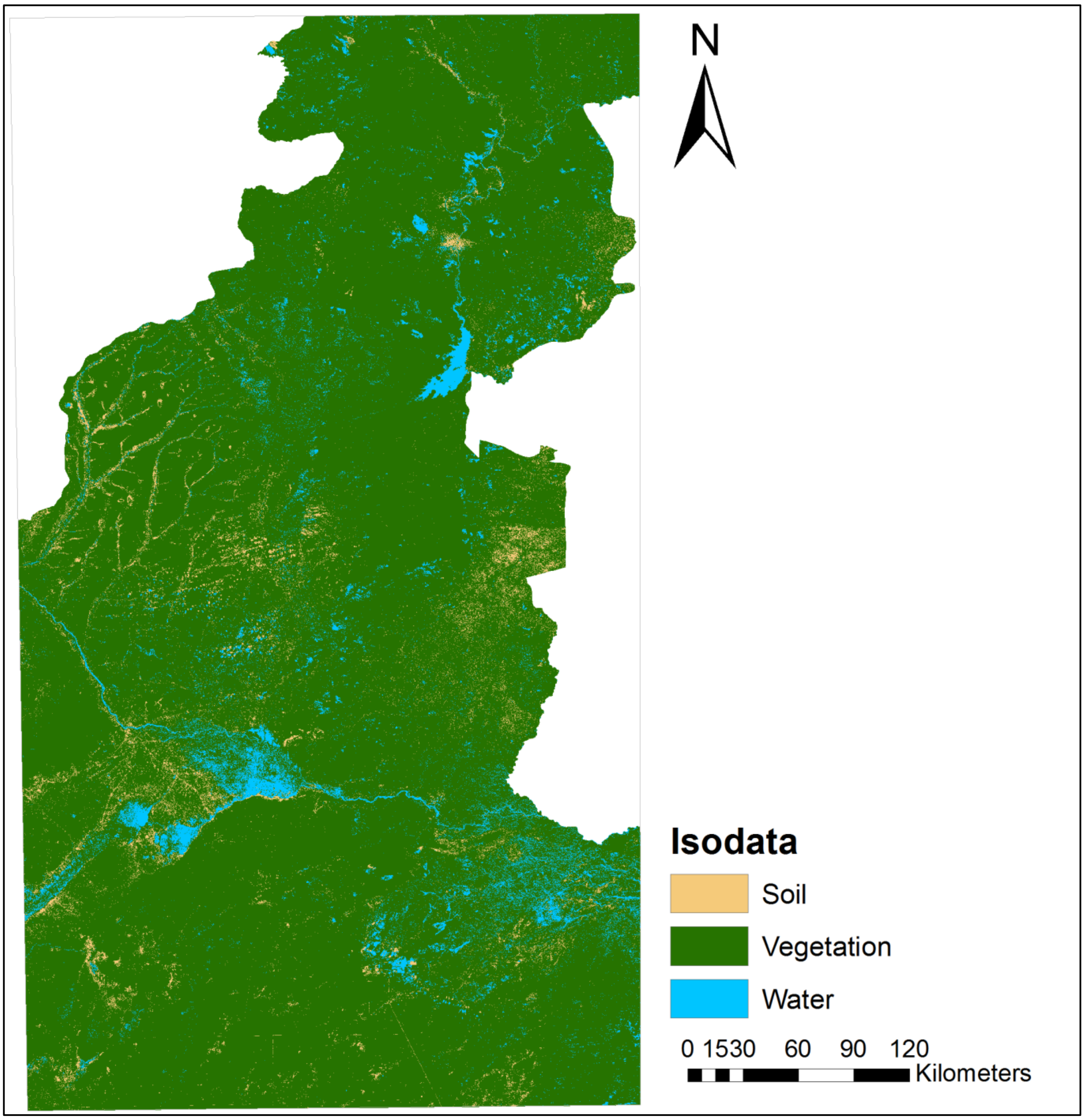

Figure 4.2 Results from ISODATA unsupervised technique, separating soil and water from vegetation

The ISODATA classification resulted in an image which contained 36 classes, not shown in the map. The results were reclassified in order to make an image that contains only three classes namely water, bare soil and vegetation (Figure 4.2). The purpose of this was so that a mask image could be created. A mask image was created by extracting the water and soil pixels from the ISODATA results. The water and soil mask was then used to mask out water and bare pixels from the atmospherically corrected Landsat 8 images.

A maximum likelihood classification was done from the Landsat 8 images that contained no water and bare soil pixels, the results of which are presented in Figure 4.3. The classification was done to classify the two grass and four tree species found in the study area.

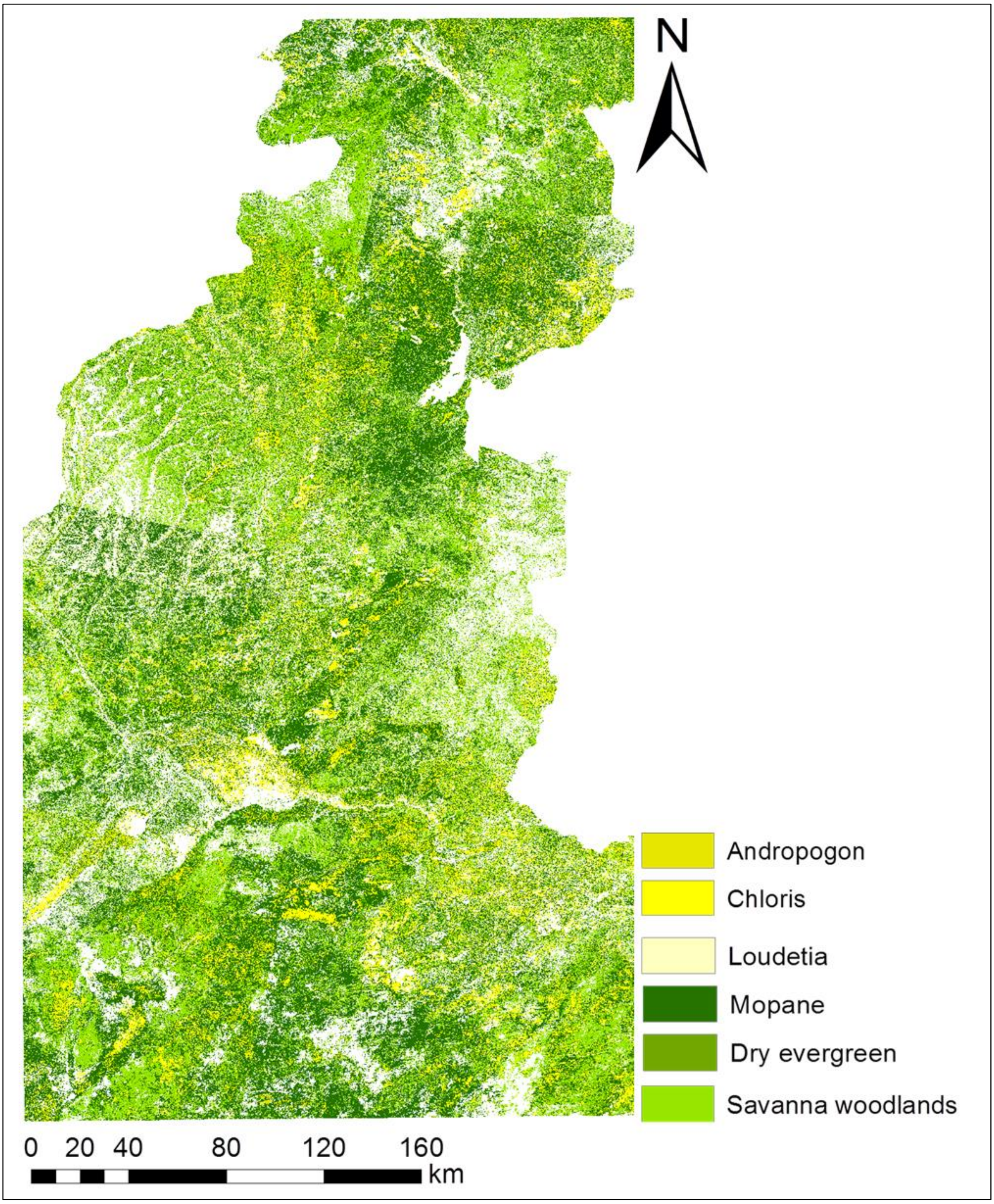

Figure 4.3 Six classes from the maximum likelihood classification showing three grass species and three woodlands vegetation.

The maximum likelihood results were reclassified to produce separate layers of grasslands and woodlands. Thereafter, a decision tree classification was the final step. The results of the decision tree classification are shown in Figure 4.4 below.

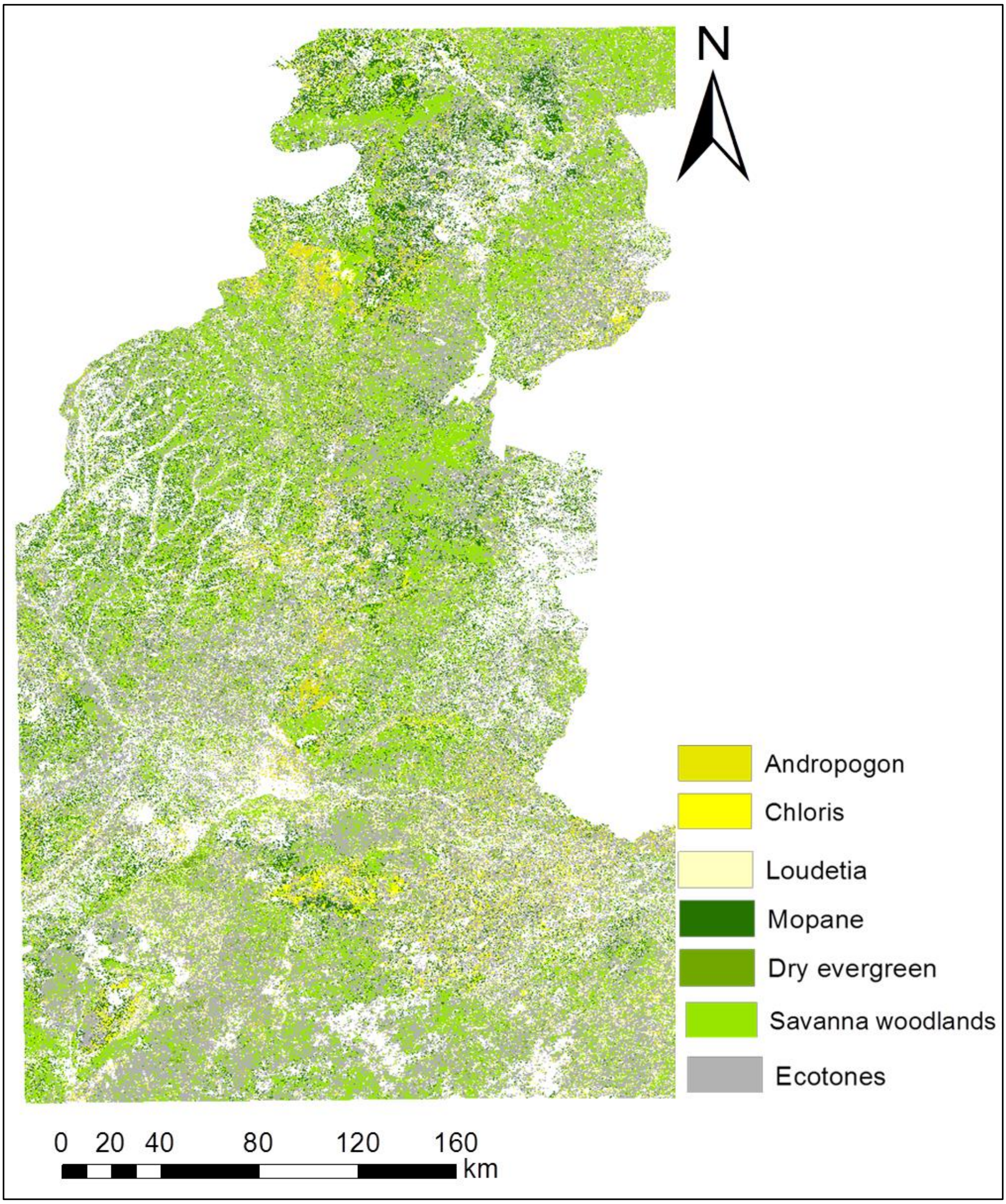

Figure 4.4 Results of the decision tree classification computed by rule-sets defined from the vegetation spectral signatures.

The pixels between vegetation types (unclassified pixels) were identified as the ecotones. These pixels were exported into a shapefile (Figure 4.5) for further analysis.

Figure 4.5 Ecotones mapped as pixels between vegetation types

Ecotones in the study area make up a total of 878 km^2 which is 0.6% of the whole study area. Comparing the NBI vegetation layer to the final classification which is the decision tree shows that Mopane covered 2604 km^2 in the NBI vegetation. Chloris covered 415 km^2 in the NBI vegetation layer but the signal picked up from the satellite image classifies 770 km^2 as Chloris. This is 335 km^2 more than the NBI vegetation layer. It was mentioned above in the literature review that remote sensing technology has an advantage over field surveys when it comes to ecological research. This is due to the fact that remote sensing satellites can be able to capture vegetation spectral signatures in hard to reach areas. This might be the cause of more Chloris being picked up from the satellite image than from the vegetation layer. Field verification can play an important role in making this verification. Savannah woodlands covers 15 758 km^2, this is the largest vegetation class, covering 10 % of the whole study area.

Mapping transitional zones between vegetation types using a rule-based/decision tree classification is a new method in identifying spatial components of ecological processes. The methods used have to be refined. The use of very high resolution (VHR) satellite images can improve the classification results, as VHR satellite image have a high level of detail.

Accuracy assessment of the maximum likelihood classification

Statistical accuracy assessments were performed after the completion of the maximum likelihood classifications. The error matrix showing the accuracy of the maximum likelihood classification is presented in Table 4.1. The full confusion matrix is given in appendix B. The overall accuracy of the classification is a low 31% and the KAPPA index is 0.10.

Table 4.1 Confusion matrix showing accuracy of maximum likelihood classification

Classes	**% Error of Omission**	**% Error of Commission**	**Producer`s Accuracy %**	**User / Consumer`s Accuracy %**
Savanna woodlands	65.62	24.13	34.37	75.86
Colosphospermum	0	83.67347	100	16.32
Dry evergreen	100	100	0	0
Andropogon	100	100	0	0
Chloris	90.47	85.71	9.52	14.28
Loudetia	66.67	90.90909	33.33	9.09
KAPPA Index = 0.10				
Overall accuracy = 31%				

The Kappa index is a measure of how well the classification agrees with the reference data (Congalton & Green 2009). A value between 0.01-0.20 means that there is a slight agreement between the reference data and the classification results. The low overall accuracy in the maximum likehood is dependent on the fact that, separating between vegetation species using Landsat 8 data is almost impossible. Satellite data with a finer resolution is needed for this task.

4.3.2 Edaphic interfaces

Plant diversification can be driven by habitat specialisation (Driver et al. 2003). Both soft and hard edaphic interfaces were identified. Figure 4.6 below shows the soil types in the study area and Table 4.2shows the vegetation types linked to the soils.

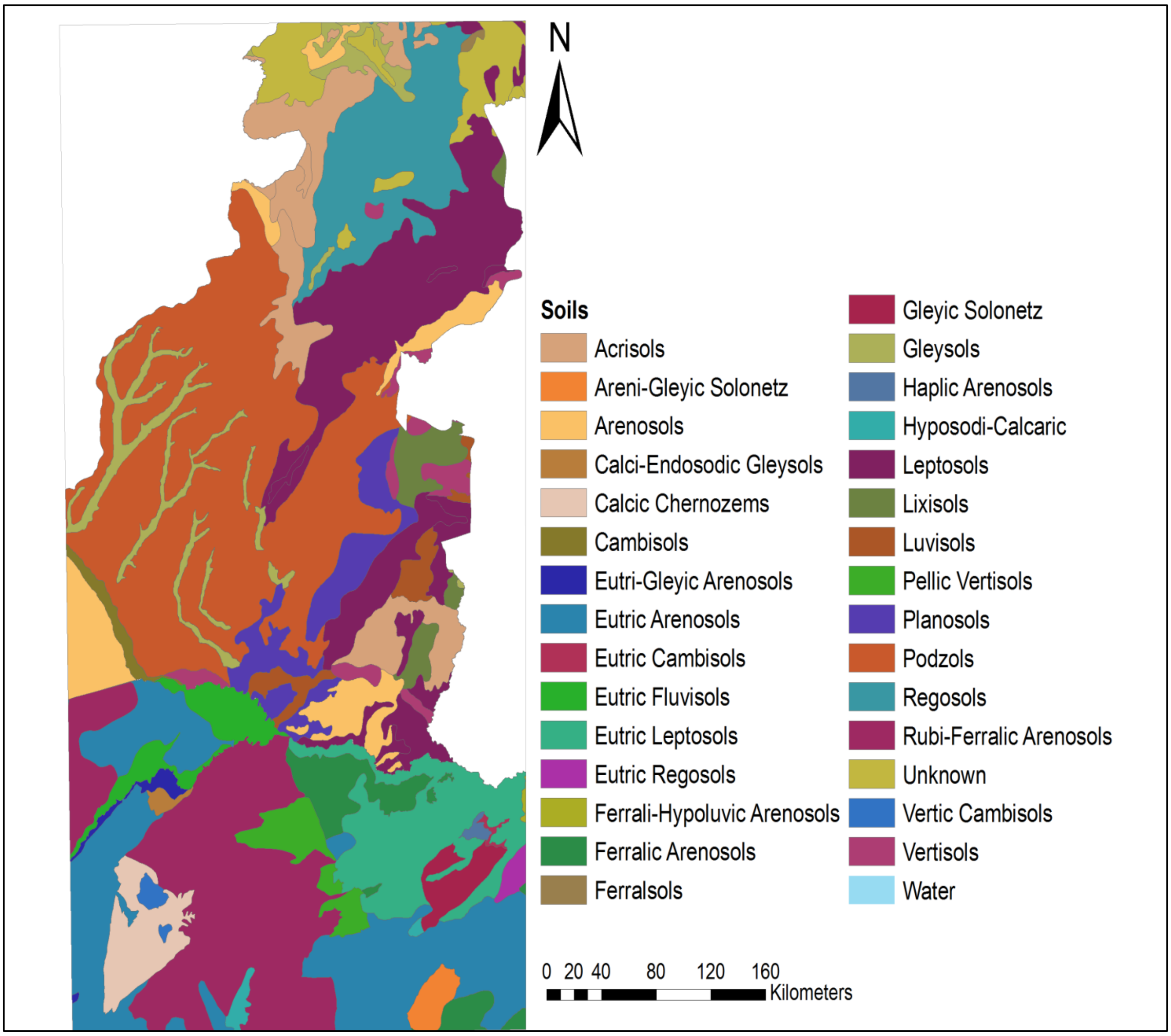

Figure 4.6 Soil types in the study area

Table 4.2 Vegetation found in every soil type

	Cambie Arenosols	**Chrornic Luvisols**	**Eutric Fluvisols**	**Eutric Gleysols**	**Humic Podzols**	**Lithosols Chromic Cambisols Vertis**	**Lithosols Luvisols Arenosols**	**Luvic Arenosols**	**Acacia spp.**	**Pellic Vertisols**	**Vertic Cambisols**	**Vertisols**	**Xanthic Ferralsols**
	Acacia leuderitzii-Acacia giraffae-Lonchocar	*Acacia spp.*	*Acacia spp.*	*Andropogon*	*Brachystegia spiciformis (on Kalahari Sand)*	*Baikiaea*	*Brachystegia boehmii Brachystegia allenii*	*Acacia leuderitzii-Acacia giraffae-Lonchocar*	*Andropogon*	*Acacia*	Colophospermum	Baikiaea	Brachystegia floribunda-Julbernardia globifl
	Andropogon, Baikiaea, Acacia	*Andropogon*	*Baikiaea*	*Brachystegia floribunda-Julbernardia globifl*	*Diplorhynchus*	*Baikiaea-Colophospermum-Burkea-Dialium*	*Brachystegia spiciformis-Julbernardia globif*	*Baikiaea*	*Brachystegia boehmii Brachystegia allenii*	*Andropogon*		Baikiaea-Colophospermum-Burkea-Dialium	Brachystegia floribunda-Julbernardia panicul
	Baikiaea-Colophospermum-Burkea-Dialium	*Brachystegia boehmii Brachystegia allenii*	*Baikiaea-Colophospermum-Burkea-Dialium*	*Brachystegia floribunda-Julbernardia panicul*	*Dry evergreen*	*Brachystegia boehmii Brachystegia allenii*	*Colophospermum*	*Brachystegia spiciformis (on Kalahari Sand)*	*Brachystegia floribunda-Julbernardia globifl*	*Baikiaea-Colophospermum-Burkea-Dialium*		Colophospermum	Brachystegia spiciformis (on Kalahari Sand)
	Brachystegia boehmii Brachystegia allenii	*Brachystegia floribunda-Julbernardia panicul*	*Brachystegia spiciformis (on Kalahari Sand)*	*Diplorhynchus*	*Dry Semi-Deciduous (Baikiaea)*	*Brachystegia spiciformis (on Kalahari Sand)*		*Colophospermum*	*Brachystegia floribunda-Julbernardia panicul*	*Brachystegia floribunda-Julbernardia panicul*			Diplorhynchus
	Brachystegia floribunda-Julbernardia globifl	*Brachystegia spiciformis-Julbernardia globif*	*Cenchrus-Chloris*	*Dry evergreen*	Loudetia	*Colophospermum*		*Julbernardia globiflora*	*Brachystegia spiciformis-Julbernardia globif*	*Brachystegia spiciformis-Julbernardia globif*			Dry evergreen
	Brachystegia floribunda-Julbernardia panicul	*Colophospermum*	*Colophospermum*	*Loudetia*	*Humic Podzols*	*Commiphora-Combretum*			*Brachystegia spiciformis (on Kalahari Sand)*	*Brachystegia spiciformis (on Kalahari Sand)*			Loudetia
Vegetation	*Brachystegia spiciformis-Julbernardia globif*	*Commiphora-Combretum*	*Cymbopogon-Panicum repens-Andropogon eucomus*	*Pterocarpus angolensis-Pericopsis-Acacia*	*Brachystegia spiciformis (on Kalahari Sand)*	*Julbernardia globiflora*			*Colophospermum*	*Colophospermum*			
	Brachystegia spiciformis (on Kalahari Sand)	*Julbernardia globiflora*	*Dry Semi-Deciduous (Baikiaea)*		*Diplorhynchus*	*No ID*			*Diplorhynchus*	*Dry evergreen*			
	Colophospermum, Diplorhynchus, Dry evergreen	*Pterocarpus angolensis-Pericopsis-Acacia*	*Loudetia*		*Dry evergreen*				*Julbernardia globiflora*	*Dry Semi-Deciduous (Baikiaea)*			
	Cymbopogon-Panicum repens-Andropogon eucomus		Mopane woodland		*Dry Semi-Deciduous (Baikiaea)*				*Loudetia*	*Julbernardia globiflora*			
	Dry Semi-Deciduous, Loudetia		*North Forest savanna and woodland*		*Loudetia*				*Pterocarpus angolensis-Pericopsis-Acacia*	*Loudetia*			
	Mopane woodland,North Forest savanna woodland		*Terminalia sericea*						*Themeda-Exotheca-Loudetia (submontane)*	*Pterocarpus angolensis-Pericopsis-Acacia*			
	Terminalia sericea												

According to Driver et al. (2004) soft edaphic interfaces are those made of vegetation with similar geology or soil types. Looking at Table 4.1, the cenchrus-chloris is limited to one soil type which is the Eutric fluvisols. The mopane woodlands and north forest savannah woodlands are each limited to the cambie arenosols and eutric fluvisols. The rest of the vegetation types occur in four or more soil types.

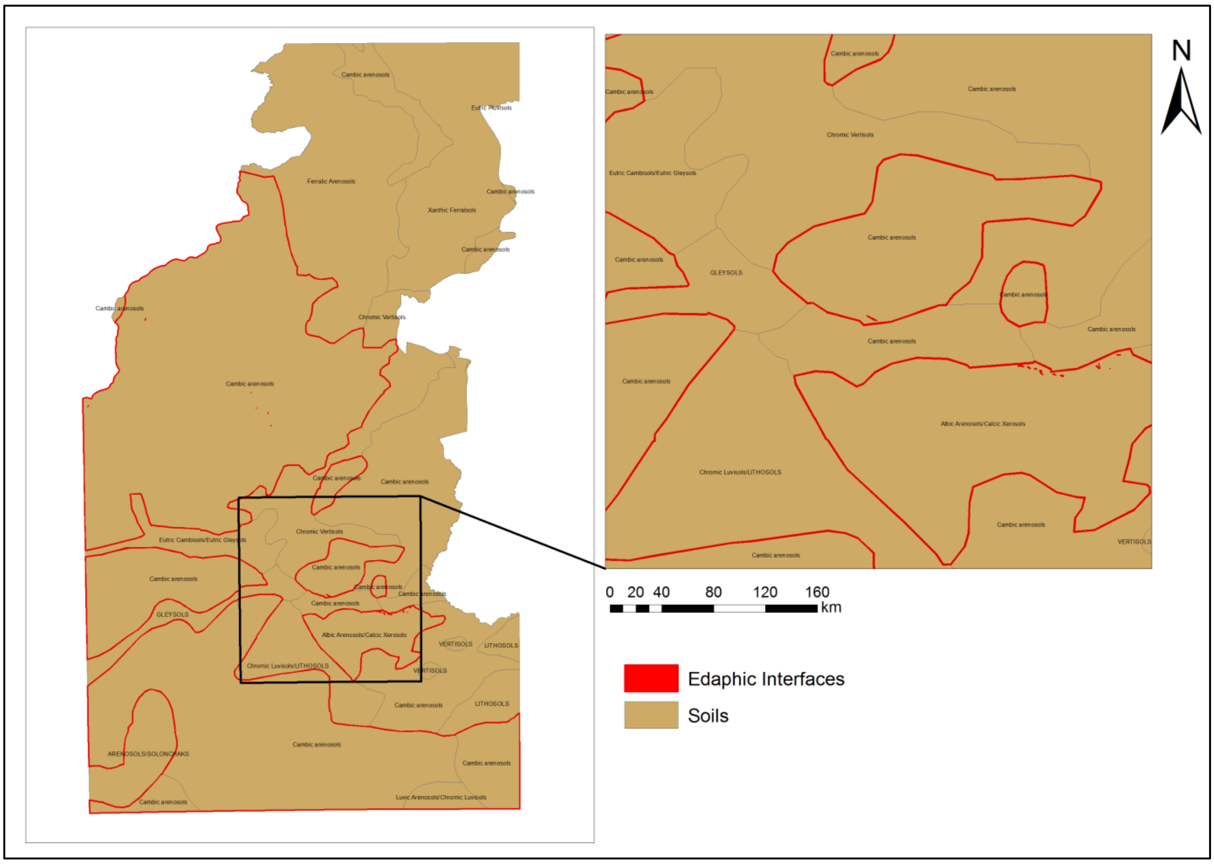

Figure 4.7 Soft edaphic interfaces

Vegetation types that occur on cambie arenosols and eutric fluvisols were buffered by 250 m on either side to delineate soft edaphic interfaces. The results of the edaphic interfaces are shown in Figure 4.7. The total area of the interfaces 875 km^2 with 263 km^2 transformed and irreversible. Over 80% of the edaphic interfaces are either suitable for ecological processes or can be restored if there is a need. Agricultural fields have to be taken into account as well as invasive species to delineate how much restoration has to be done.

Hard edaphic interfaces are made of vegetation types with different underlying material or soil types (Driver et al. 2004). The ecoregions layer was used to identify the hard edaphic interfaces. Similar to that of soft edaphic interfaces, the ecoregions were separated into different layers. The new layers were then used to clip soil types in order to identify on which type of substrate the ecoregions occur in. The soil types were then grouped into soil groups (see Table 4.3 below). The ecoregions with five or more soil groups where classified as hard edaphic interfaces. This is based on the assumption that the more substrate a vegetation type has the greater the potential for species diversification.

Table 4.3 Ecoregions with their specific soil types

Ecoregion	Soil type	Soil group
Central Zambezian miombo	Orthic Ferralsols	Ferralsols
	Xanthic Ferralsols	
	Eutric Gleysols	Gleysols
	Eutric Gleysols	
	Chrornic Luvisols	Luvisols
	Humic Podzols	Podzols
	Cambie ArenosoIs	Arenosols
	Pellic Vertisols	Vertisols
Kalahari Acacia Baikiaea	Eutric Fluvisols	Fluvisols
	Cambie ArenosoIs	ArenosoIs
	Cambie ArenosoIs	
Southern miombo	Orthic Ferralsols	Ferralsols
	Lithosols-Chromic CambisoIs-Vertisols	Lithosols/CambisoIs/Vertisols
	Lithosols-Luvisols-Arenosols	Lithosols-Luvisols-Arenosols
	Chrornic Luvisols	Chrornic Luvisols
	Chrornic Luvisols	
	Cambie ArenosoIs	ArenosoIs
	Luvic Arenosols	
	Pellic Vertisols	Vertisols
Zambezian Baikiaea	Lithosols-Chromic CambisoIs-Vertisols	Lithosols-Chromic CambisoIs-Vertisols
	Eutric Fluvisols	Fluvisols
	Eutric Fluvisols	
	Cambie ArenosoIs	ArenosoIs
	Cambie ArenosoIs	
	Cambie ArenosoIs	
	Cambie ArenosoIs	
	Luvic Arenosols	
	Vertisols	Vertisols
	Pellic Vertisols	
	Pellic Vertisols	
Zambezian Cryptosepalum	Xanthic Ferralsols	Ferralsols
	Eutric Gleysols	Gleysols
	Humic Podzols	Podzols
	Cambie ArenosoIs	ArenosoIs
	Cambie ArenosoIs	
Zambezian flooded	Orthic Ferralsols	Ferralsols
	Orthic Ferralsols	
	Xanthic Ferralsols	
	Eutric Gleysols	Gleysols
	Eutric Fluvisols	Fluvisols
	Eutric Fluvisols	
	Eutric Fluvisols	
	Chrornic Luvisols	Luvisols
	Humic Podzols	Podzols
	Cambie ArenosoIs	ArenosoIs
	Cambie ArenosoIs	
	Pellic Vertisols	Vertisols
	Pellic Vertisols	
Zambezian Mopane woodlands	Vertic Cambisols	Cambisols
	Orthic Ferralsols	Ferralsols
	Orthic Ferralsols	
	Lithosols-Chromic CambisoIs-Vertisols	Lithosols-CambisoIs-Vertisols
	Lithosols-Luvisols-Arenosols	Lithosols-Luvisols-Arenosols
	Eutric Fluvisols	Fluvisols
	Eutric Fluvisols	
	Eutric Fluvisols	
	Chrornic Luvisols	Luvisols
	Chrornic Luvisols	
	Chrornic Luvisols	
	Cambie ArenosoIs	ArenosoIs
	Cambie ArenosoIs	
	Cambie ArenosoIs	
	Luvic Arenosols	
	Vertisols	Vertisols
	Pellic Vertisols	

4.3.3 Upland-lowland interfaces

Upland-lowland interfaces are located between high and low lying areas. They are associated with ecological diversification of plants and animal lineages (Pressey et al. 2003; Rouget et al. 2003). Figure 4.8 shows the interfaces identified in the study area. Habitats that are above 1000 m were delineated as the uplands and those that are below 1000 m as the lowlands. The boundaries between the uplands and lowlands digitised as the interfaces. Upland-lowland interfaces in the study area cover an area of 2166.22 km^2. The upland-lowland interfaces make biotic exchange between upland and lowlands possible.

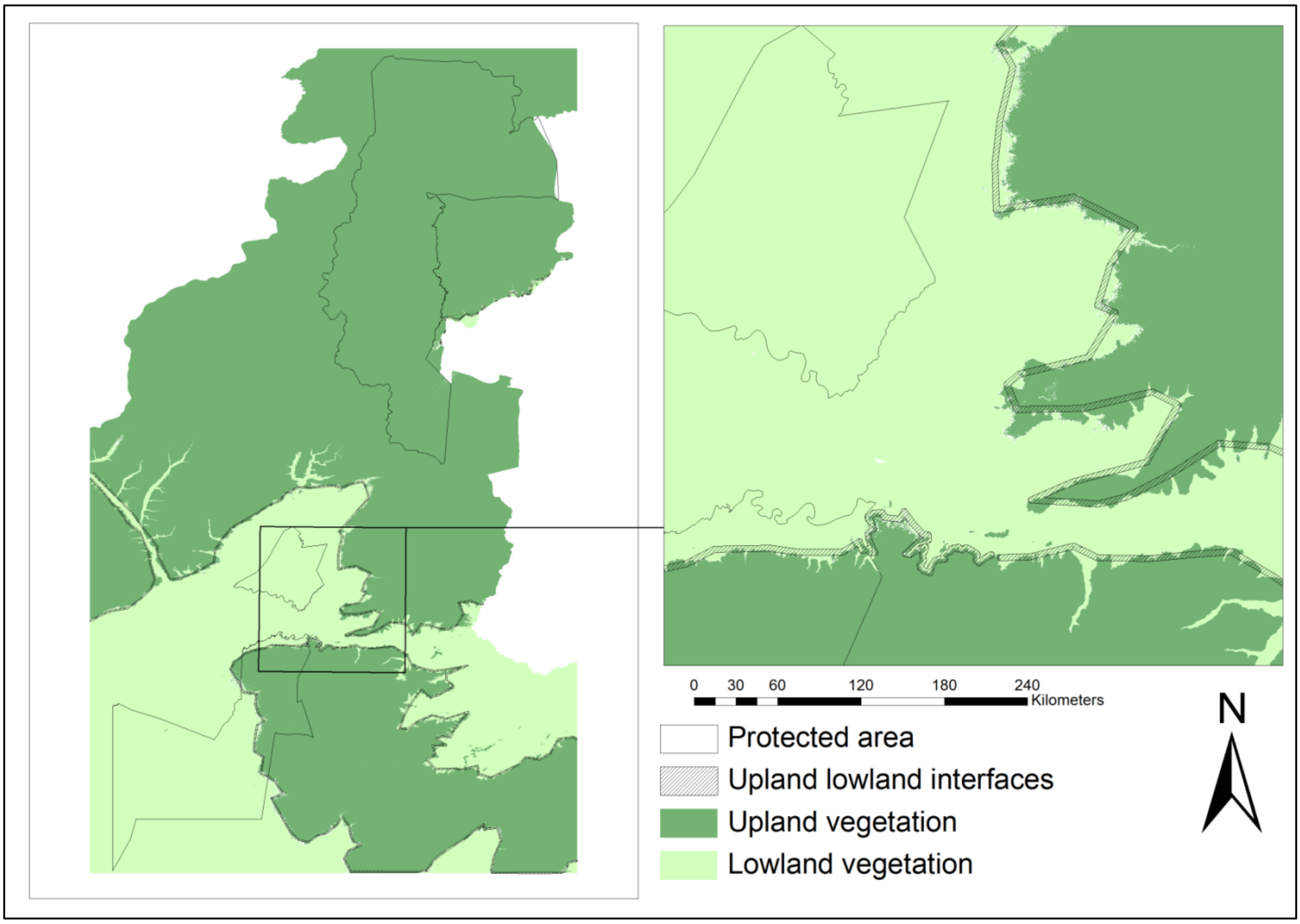

Figure 4.8 Upland and lowland interfaces between high and low lying vegetation

4.3.4 Riverine corridors

The study area has 574 rivers measuring 11747.69 km in totality, of which only 35 with a total length of 900.18 km are non-perennial, such that the majority of the study area's rivers are perennial with flowing water throughout the year. The few non-perennial rivers that do occur in the study area fall mostly in the Botswana area, i.e. southern part of the study area. The fact that the majority of the study area has perennial rivers is probably due to the large flat floodplain. The north-eastern part of the study area lies at high altitude and serves as a source of water catchment feeding the rivers.

The altitudinal range in the study area varies between 1525 m and 480 m with the south of the study area on low altitude. Majority of the upland rivers occur north of the Zambezi River and they are a total of 8764.79 km in length which is 74.61% of all rivers in study area. The lowland rivers have a length of 2982.90 km which comprises 25.39% of all rivers in study area.

Unsurprisingly perennial rivers are lined by many homesteads but the steep/high altitude perennial rivers of the north-eastern part of the study area (inside Kafue National Park and the east of KNP) do not have any homesteads. Riverine corridors were delineated by making 1000 m buffer zones on rivers in the lowlands and 500 m on those in the uplands. Figure 4.9a shows both the 500 m and 1000 m buffers for the full study area extent, and Figure 4.9b shows the Simalaha Community conservancy.

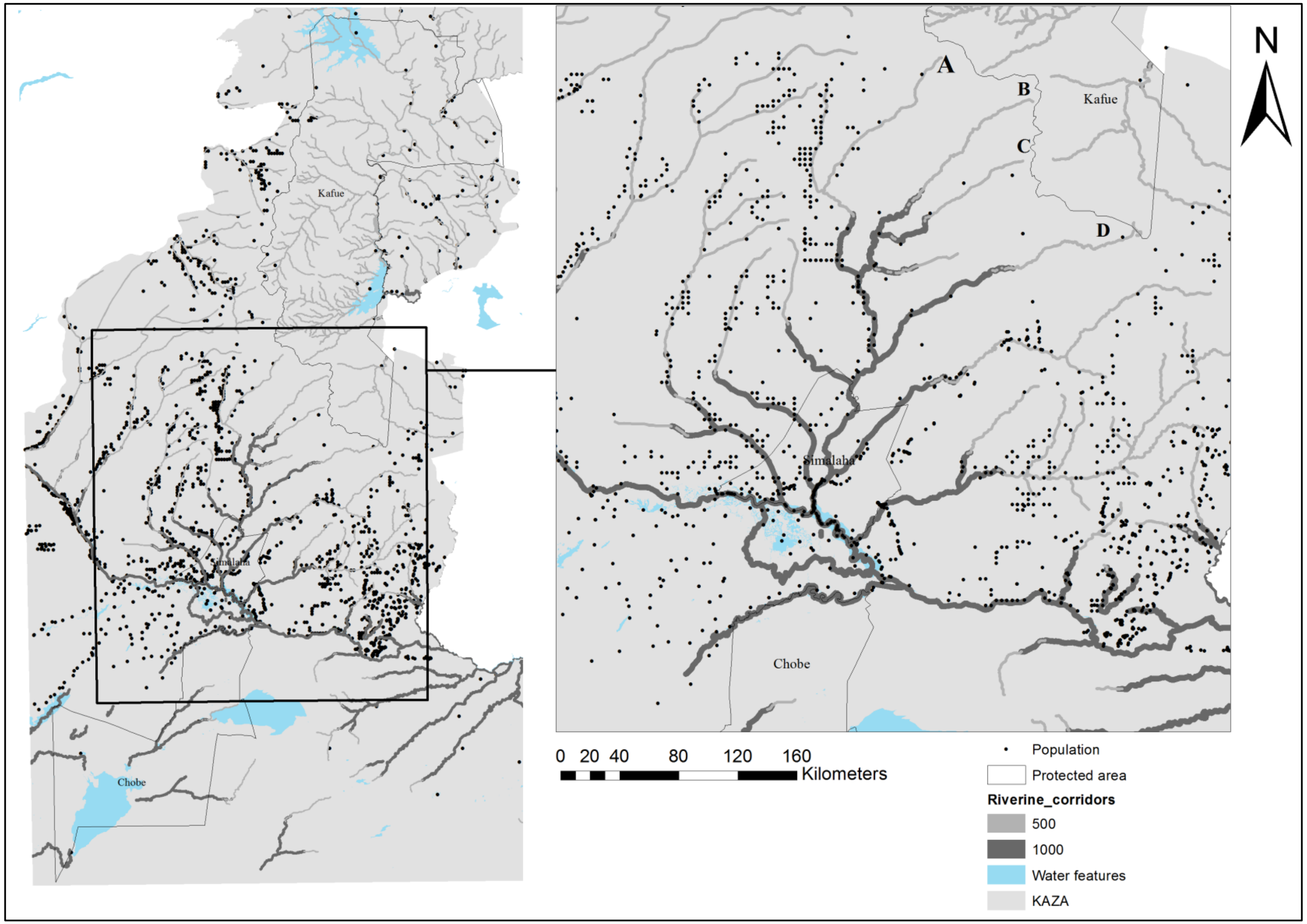

Figure 4.9 a Riverine corridors (study area extent), Figure 4.9b zoomed to show connection between Kafue and Chobe.

Looking at Figure 4.9b (zoomed in riverine corridors) there are different river corridors that connect Chobe with Kafue national parks through the Simalaha community conservancy (labelled A, B, C and D). To determine the best suitable river corridor the corridor distances were measured, Table 4 below shows the distance of each corridor.

Table 4.4 River corridor distances between Chobe and Kafue

Corridor	Distance (kilometres)
A	225.20
B	226.09
C	137.14
D	259.96

Corridor C has the shortest connecting distance at 137.14 followed by corridor A with 225.19 km. However, due to the number of populated areas along corridor C, the best suitable riverine corridor is corridor A. The loss of habitat through land-use practices has been recognised as the major threat to biodiversity (Wilcove et al. 1998).

Due to the fact that they link different valleys, riverine corridors are important for plant and animal species movement (Driver et al. 2003; Rouget et al. 2003; Kark 2007). It is important not just to keep the rivers themselves healthy but the vegetation around them as well (Driver et al. 2003). There are four riverine corridors that connect Kafue and Chobe through Simalaha. Most parts of the riverine corridors have agricultural activities, in these areas normal functioning of the corridors to maintain ecological processes can be restored. Those parts that are extant can be stepping stones of ecological processes in the riverine corridors however their migration role is compromised (Rouget et al. 2003).

4.3.5 Areas of high carbon sequestration

In order to identify areas of high carbon sequestration, MODIS NDVI product and WHRC aboveground carbon biomass data were used. The aim was to identify areas that have constant high NDVI values during both the wet and dry season. The NDVI maps were compared with the aboveground carbon biomass to produce maps of areas that have the ability to sequester high carbon in the study area. The MODIS NDVI images for the wet and dry seasons were acquired.

Figure 4.3 below shows the NDVI for the wet season which is between the months October and April. The NDVI image was classified into three classes (Low, Medium and High). Low shows NDVI values less than 0. Negative NDVI values show an area that has water. In the study area the lowest NDVI value is the Itechi Techi Dam located north of Nkala village and east of the Kafue National Park.

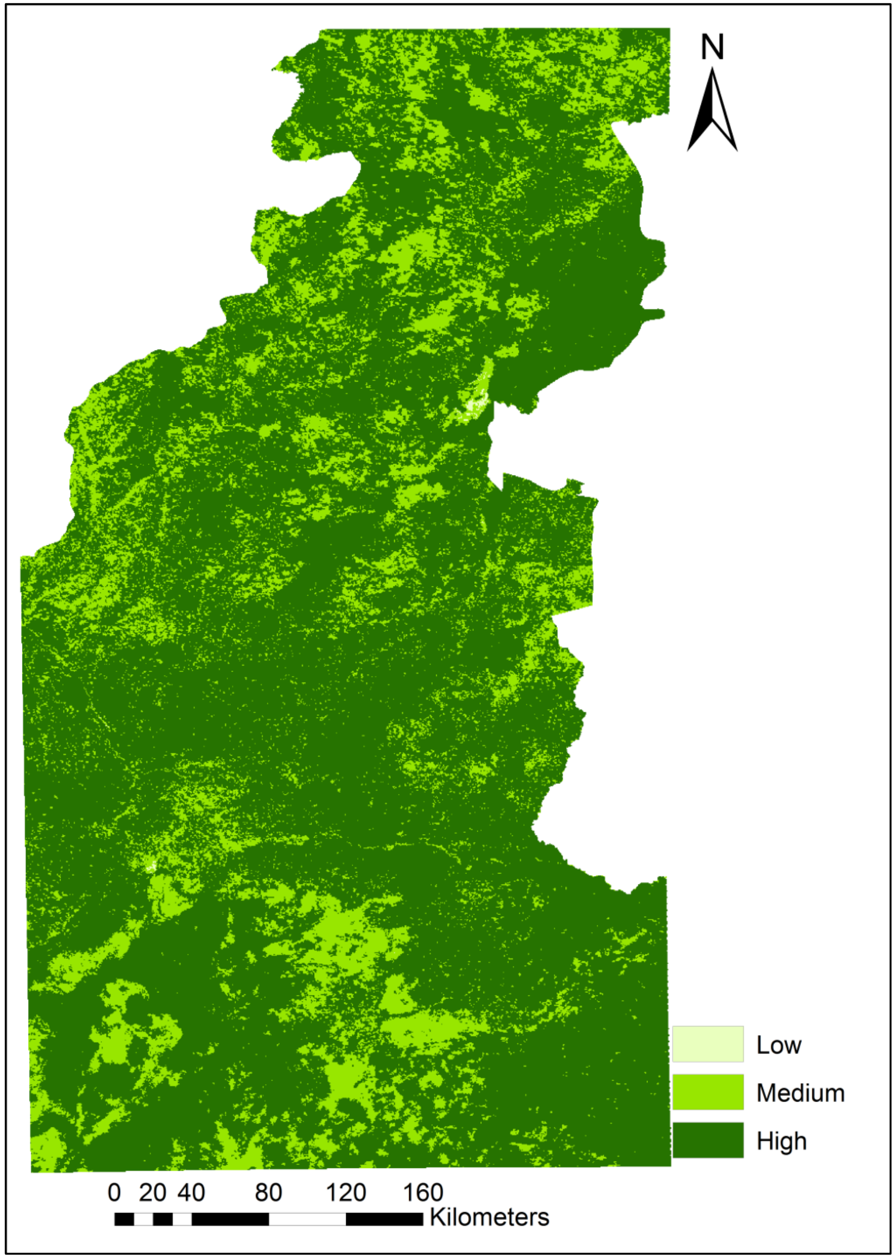

Figure 4.10 NDVI for the wet season.

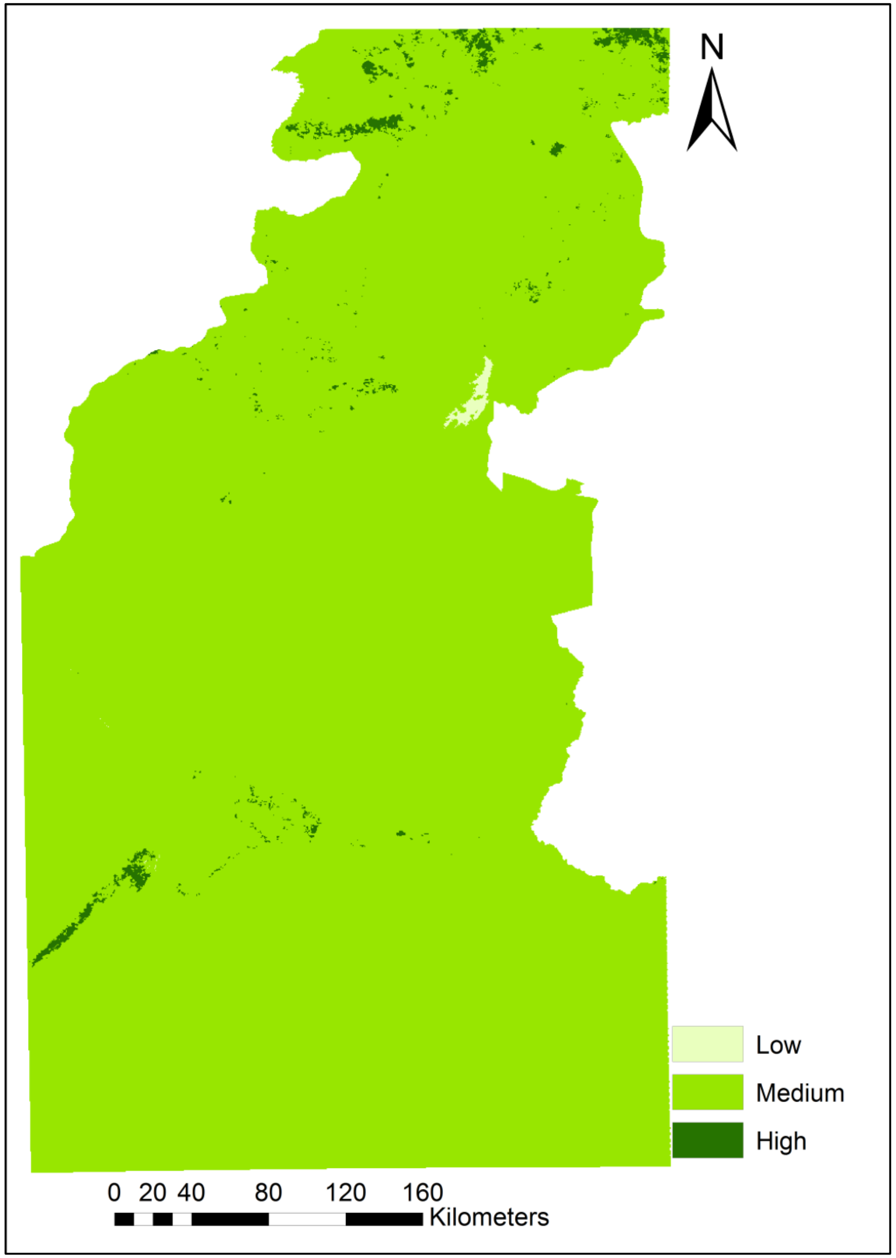

Figure 4.11 NDVI for the dry season

The dry season NDVI (Figure 4.10) looks different from the wet season NDVI (Figure 4.10). In the dry season the NDVI values are mostly medium throughout the study area. A large area with high values can be found in the north west of Kafue National park. There is also a patch of high values west of Chobe National Park. Areas which have high NDVI values during both the wet and dry seasons were identified as the areas with high carbon sequestration potential. To identify these areas a cross tabulation of the two images was done.

Table 4.5 Cross tabulation of wet and dry seasons NDVI

PERCENT

		DRY			
	NDVI	Low	Medium	High	Sum
WET	Low	0.78	8.43	31.36	40.57
	Medium	1.33	9.70	45.64	56.67
	High	0.04	0.36	2.36	2.76
	total rows	2.15	18.49	79.36	100.00

Table 4.5 shows the results of the cross tabulation. Just over 2 % of the area has a high NDVI throughout the wet and dry season. 76.99% of the area with a high NDVI in the wet season dries out and has a low NDVI in the dry season. 20% of the area has a medium NDVI during dry and wet seasons. The results of the NDVI were compared with the WHRC above ground carbon biomass. The WHRC researchers produced national level maps showing the amount and spatial distribution of aboveground carbon. Figure 4.12 below shows above ground carbon biomass for the study area. The overall carbon biomass in the study area seem to range from medium to low.

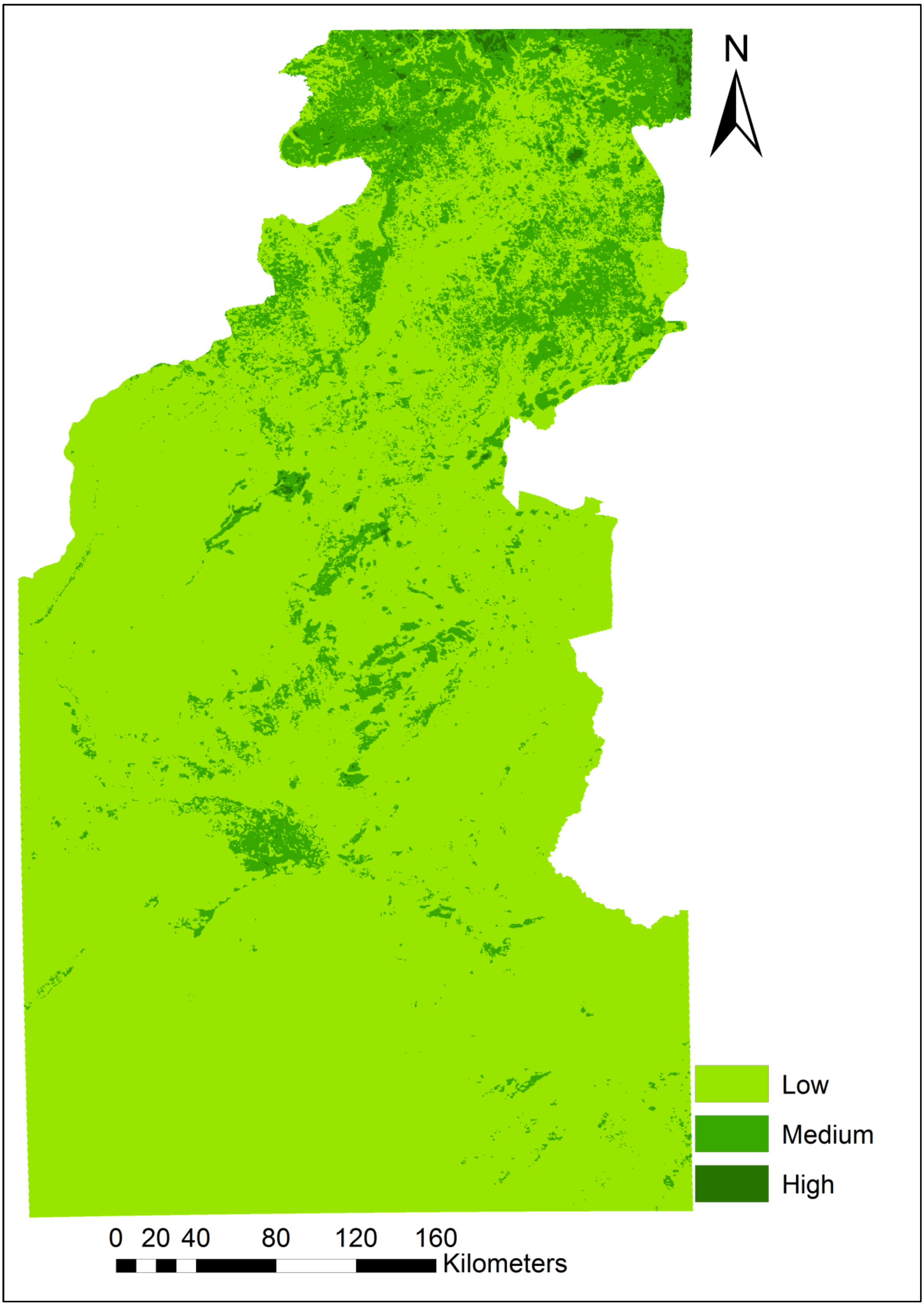

Figure 4.12 Areas with high, medium and low carbon sequestration potential based on the above ground carbon biomass.

For the areas of high carbon sequestration regions that have high NDVI during both the dry and wet season were compared with the high above ground carbon biomass of the study area. The areas that have both high NDVI (in both seasons) and high carbon biomass where considered the areas of high carbon sequestration ability (Figure 4.13). Jantz, Goetz and Laporte (2014) developed a pan-tropical map of corridors that connect adjacent protected areas while passing through areas of high vegetation carbon stock. Following Jantz, Goetz and Laporte (2014), carbon corridors were developed for the study area connecting areas of high carbon sequestration through protected areas (see Figure 4.13 below). Corridors followed relatively straight courses between the protected areas.

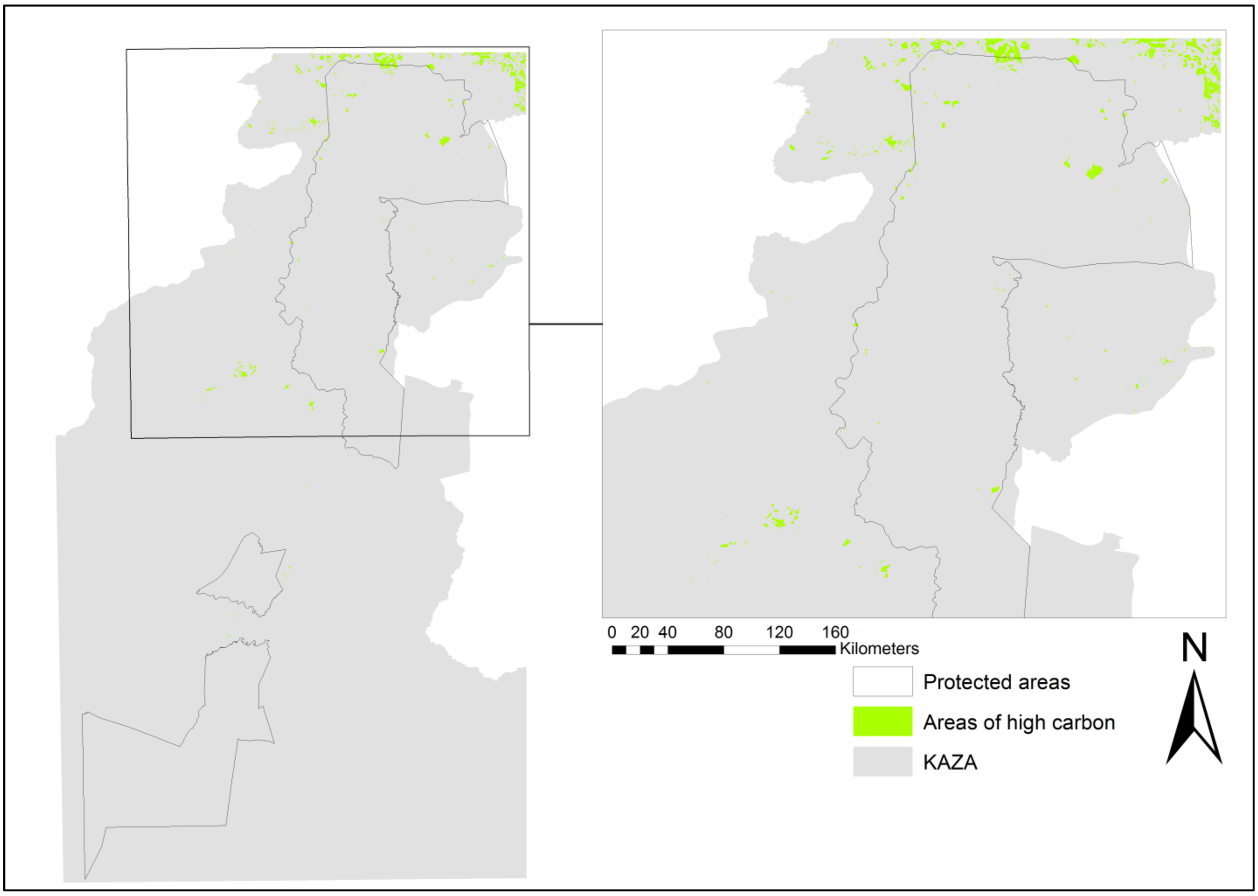

Figure 4.13 Areas of high carbon sequestration potential based on high NDVI and high carbon biomass during both the wet and dry seasons.

This spatial component covers an area of 695 km^2 which is only 0.44% of the study area. 98% of areas of high carbon sequestration are not affected by irreversible transformation. In those areas ecological processes are able to persist over a long time if not disturbed by transformation.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

In this chapter, the evaluation and conclusions of the research findings are made. The conclusions made here follow the structure of the thesis objectives. Consequently, the first section revisits and provides an evaluation of each research objective. Thereafter, the conclusions of the study are drawn, while the last section offers recommendations and suggestions for further research.

5.1 REVISIT OBJECTIVES IN CONTEXT OF THE RESULTS

5.1.1 Describe the main biodiversity features in the study area using literature as well as expert knowledge through workshops

The first objective of the research was to describe the main biodiversity features in the study area using literature. This objective was established because it is important to know the biodiversity patterns in an area before trying to map the ecological processes in an area. The biodiversity feature give an indication of what is driving the pattern of biodiversity in the area, thereafter easier delineation of ecological processes. Literature was used to understand the biodiversity features in the area that is the ecoregions, vegetation and animal species that occur. There are endemic and near endemic species in the areas as well as species that are threatened. It is therefore important for this to be able to persist in the area. This further supports the need for ecological processes to be accounted for in conservation planning.

5.1.2 Identify key ecological processes that sustain and maintain the main biodiversity features

With the biodiversity features identified, the second objective was to identify key ecological processes that sustain and maintain the main biodiversity pattern. This was done by reading literature on biodiversity and ecological processes. The assumption that the ecological processes that drove biodiversity pattern in the past will continue to drive biodiversity in future played a major role in the delineation of the ecological processes in the study area.

5.1.3 Identify and map spatial components of the key ecological processes

The last objective which is also the main aim of the study was to map spatial components of the ecological processes. Five spatial components were mapped using GIS and remote sensing. The methods followed those done the Cape Floristic region however, the study introduced a new way of mapping ecotones as spatial components of ecological processes. In some of the spatial components the delineation of suitable corridors that connect Kafue and Chobe national parks through Simalaha community conservancy were suggested.

5.2 LIMITATIONS OF THE STUDY

The research was the first in the Kavango-Zambezi Transfrontier area to map spatial components of ecological processes. There is still a lot to be done in order to understand the ecological processes in the area. The main limitation to the study is that there was no field work done, this was due to time and finances. Consultations with ecological and biodiversity expects needed to be consulted in order to adjust the spatial components mapped. The second limitation is that there are no available data on species occurrence in the study area. If these were easily accessible identifying ecological processes would have not been highly dependent on literature.

5.3 RECOMMENDATIONS

Ecotones have been proven to have a high biological diversity over different spatial scales (Kark 2007). However, there are studies that found conflicting results. There ecotones identified in the study were not assessed of whether they have a high biological diversity, it is therefore recommended that future research look at these and study the diversity difference between the ecotones and other vegetation types. It is also recommended that a study on evolutionary processes in the study area be done. The future study will assess the biological processes in the past and how they have aided in the speciation processes of the area. Speciation is the processes by which species form and according to Kark (2007) this process has had a great success in ecotonal boundaries in other areas.

It is also recommended that future research should map the vegetation types in the area using remote sensing and these should be field verified. The spatial components of ecological processes that the current research was able to delineate should be used considered when designing biota movement corridors in the KAZA Transfrontier Park.

5.4 CONCLUSION

Based on the assumption that processes driving biodiversity in the study area will remain the same in future. This research mapped spatial components of ecological processes to aid in the development of corridors in the KAZA Transfrontier Park. The research does not in any way assume that all ecological processes in the study area were represented as there is no set of spatial components that is able to represent all ecological processes that are important to biodiversity. The aim of this research was to identify and map the spatial components of ecological processes in a portion of the Kavango Zambezi Transfrontier Conservation Area to aid in implementing corridor biota movement corridors. The methods that have been used to identify biota movement in the past did not take into consideration the ecological processes that will ensure that the corridors maintain and generate biodiversity.

A thorough literature survey was done to make a list of ecological processes that are important in maintaining the biodiversity in the area. Spatial components of ecological processes were mapped as surface elements aligned along linear environmental interfaces or gradients. The resulting spatial components are riverine corridors, areas of high carbon sequestration, edaphic interfaces, upland and lowland interfaces and ecotones. This study followed methods used in the Cape floristic region, South Africa and tried to apply them in KAZA however, some of the methodology was changed to get the best results for the study area.

The ecological processes mapped do not in any way form a comprehensive list, there are more that could be added with further analysis of the biodiversity in the area. Although a small portion of the KAZA was studied, the idea is that the results of the current study will be applicable to the whole conservation area and beyond. The spatially fixed (edaphic interfaces, upland-lowland interfaces and riverine corridors) as well as the spatially flexible (areas of carbon sequestration and ecotones) can play an important role in selecting conservation priorities.

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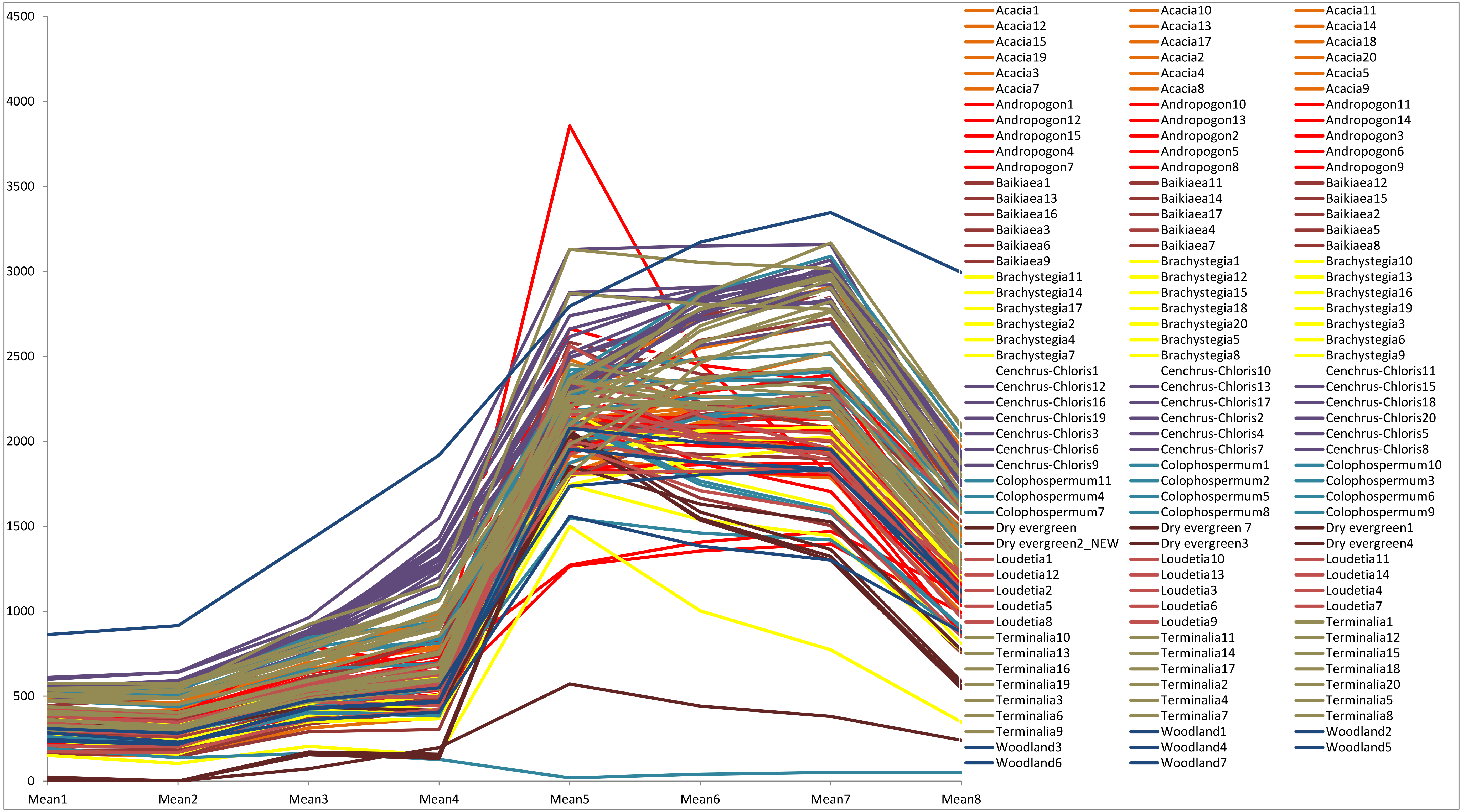
APPENDICES

Appendix A: Mean spectral signatures

Appendix B Detailed confusion matrix

Appendix A Mean spectral signatures



Appendix B Detailed confusion matrix for maximum likelihood classification

Observed values

	Image to evaluate / classification										
	Savanna woodlands	Mopane woodlands	Dry evergreen	Andropogon	Chloris	Loudetia	Total	% Error of Omission	% Error of Commission	Producer`s Accuracy %	User / Consumer`s Accuracy %
Savanna woodlands	22	25	1	1	10	5	64	65.6	24.1	34.4	75.9
Mopane woodlands		8					8	0.0	83.7	100.0	16.3
Dry evergreen	3	2					5	100.0	100.0	0.0	0.0
Andropogon		1			2	2	5	100.0	100.0	0.0	0.0
Chloris	3	12		1	2	3	21	90.5	85.7	9.5	14.3
Loudetia	1	1				1	3	66.7	90.9	33.3	9.1
Total	29	49	1	2	14	11	106			46.23	

Sum diagonals (observed) = i.e. sum of correctly classified pixels =

33

Observed correct = correctly classified pixels / grand total = sum of diagonals / grand total

0.311321