

Using riparian vegetation responses in the Mooi River catchment within an ecological water requirement framework

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ABSTRACT

Riparian zones are generally the boundary between aquatic and terrestrial systems which provide several ecosystem services such as an ecological corridor that acts as a migration corridor for animal, birds and even plants. They also provide a natural habitat, useful for riverbank stabilisation and assist with organic matter provisioning, which is used as food for aquatic macro invertebrates. The root systems of riparian vegetation filter sediments and nutrients that discharge of surface slopes and therefore protect and improve the water quality of river systems. Many studies have been conducted on the changes in riparian zones, however, no study has been conducted to determine the ecological status of riparian vegetation in the Mooi River Catchments in South Africa.

This study's aim was to determine how the riparian zone within the Mooi River Catchments has responded in the past 10 years, based on changing land use. The study examined the riparian vegetation cover and established modifications in vegetation composition and the spatial extent of the riparian zone. The study area was within the Mooi River Catchments in the Potchefstroom area where six sites were sampled within the catchment to assess and compare the different responses of the riparian vegetation over time. Different sites were sampled to determine the present ecological status of the riparian vegetation which was compared with the reference condition for the Mooi River Catchments.

The riparian vegetation was assessed in terms of the Vegetation Response Assessment Index (VEGRAI) assessment methodology and a scoring system of generic ecological categories for EcoStatus components. The results showed that the riparian vegetation of this area is moderately to largely modified. This indicated that a loss and a change of the natural environment and biota have occurred but that the basic ecosystem functions were adversely altered and a large loss of natural habitat, biota and basic ecosystem functions have not occurred. It was established that the Mooi River catchment falls within C/D ecological category, i.e. a moderately to largely modified status. Therefore, critical mitigation measures to safeguard the riparian zone and the river system of the Mooi River Catchments should be implemented before it deteriorates further.

Maps were also used to determine the different responses for different species composition within the Mooi River riparian zone over time, using aerial photographs of the study area covering a period between 2009, 2014 and 2019.

Keywords: *Catchment, riparian zone, riparian vegetation transformation, modification, ecosystem functions, floods, reference condition, current ecological status, present condition.*

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LIST OF ABBREVIATIONS

DEA:	Department of Environmental Affairs
DAFF:	Department of Agriculture Forestry and Fisheries
DWAF:	Department of Water Affairs and Forestry
DWS:	Department of Water and Sanitation
EIA:	Environmental Impact Assessment
EIS:	Ecological Importance and Sensitivity
GIS:	Geographic Information System
IUA:	Integrated Unit of Analysis
MC:	Management Class
MCDA:	Multi Criteria Decision Making Approach
NEMA:	National Environmental Management Act
NFA:	National Forestry Act
NWA:	National Water Act
NWRS:	National Water Resource Strategy
PES:	Present Ecological State
RDM:	Resource Directed Measures
REC:	Recommended Ecological Category
RHP:	River Health Programme
NAEHP:	National Aquatic Ecosystem Health Programme
RS:	Remote Sensing
RQO:	Resource Quality Objective
VEGRAI:	Vegetation Response Assessment Index
WRF:	Water Resources Framework

CHAPTER ONE: BACKGROUND OF THE STUDY

1.1 INTRODUCTION

Riparian vegetation has been defined as the physical structure and its associated vegetation of the areas within a watercourse in the National Water Act 36 of 1998 (DWAF, 1998). The National Research Council (2002) defines riparian vegetation as the dense of different plant communities that are existing in the riparian zone. It is an area through which subsurface and surface hydrology connect water resources with the nearby uplands. It includes the terrestrial ecosystems portions that have a substantial effect in terms of exchanging energy and matter with aquatic ecosystems (Sabo *et al.*, 2005).

According to Corenbilt *et al.* (2007), riparian vegetation in rivers physically alters the flow conditions as well as sedimentary processes by protecting banks, colonising deposits and supplying woody debris. Tal *et al.* (2004) indicated that riparian vegetation was used as a supporting structure for the biogeochemical cycles of river systems. The elevated water tables or flooding have an influence on riparian vegetation because the soil can hold water frequently and sufficiently to maintain different riparian vegetation species within the composition and physical structure which is different from the vegetation from the adjacent land areas (Gregory *et al.*, 1991).

According to Garofano-Gomez *et al.* (2017), riparian vegetation forms a mosaic of vegetated patches that can have different physiognomy, structure and composition because of local variability in physical conditions such as flow velocity during floods, elevation above water level, including landform age and land use (grazing and forestry).

Gregory *et al.* (1991) indicate that riparian vegetation are plant communities influenced by the hydrological features such as rivers, streams, lakes or drainage ways, therefore, they may be a few meters wide near streams or more than a kilometre in floodplains. Furthermore, the sentiment was echoed by Trimmel *et al.* (2018) who stated that riparian vegetation has many functions which are considered positive in that it improves the well-being of humans by supplying many ecosystem services such as raw materials, recreation areas (e.g., wood, energy) and water quality improvement.

Riparian vegetation consumes water but it shades the channel which decreases evaporation during low flow (Pivec, 2002). According to Ehrenfeld (2003), even if water consumption depends on vegetation type for example, native vegetation can consume less water than exotic species (Pivec, 2002), which can compete with the needs of the society.

According to Lamontagne *et al.* (2005), during floods, riparian vegetation cushions flooding from the channel to the floodplain and this has an opposing effect on flood risks (i.e. reduces water velocity, erosion and damage to human infrastructure) but the water level can also be increased during a given discharge. Lamontagne *et al.* (2005) also indicated that riparian vegetation can decrease flood peaks by storing water upstream as well as produce woody debris that can increase flood impacts. The other potential negative perception as stated by Salemi *et al.* (2012) is related to woodland development that results from land use changes (i.e. abandoning grazing or agriculture).

Sabo *et al.* (2005) indicate that riparian vegetation contains plant communities significantly different from those in upland habitats, so they increase regional richness across the globe. According to Woodborne *et al.* (2003), the riparian habitats often represent the area with high soil water contents, making it an ideal site for plant establishment, growth and fertile soils. It was further identified that growing trees in the riparian zone results in a decrease in riparian functioning because there is an increase in water usage and a loss of natural biodiversity (Woodborne *et al.*, 2003).

According to Sabo *et al.* (2005), the reduction in water inflow generates some sensitivity in riparian vegetation, which is the core driver of its dynamics and variable nature. Ecological water requirement, also referred to as ecological flow requirement, quantifies things such as timing, quality and quantity required to make sure that there is adequate functioning and future persistence of riparian vegetation (DWAF, 1998).

Gregory *et al.* (1991) further described riparian vegetation as vegetation that characterises the boundary between aquatic and upland ecosystems. It is maintained by both perennial and non-perennial streams. Considering all the socio-ecological roles riparian vegetation plays, it is considered more important to study riparian vegetation responses in the Mooi River Catchments within the parameters of an ecological water requirement framework.

1.2 RESEARCH AIM, OBJECTIVES AND HYPOTHESIS

The aim of this study was to determine riparian vegetation responses by assessing the present ecological status (PES) in comparison with the reference condition of the Mooi River Catchment.

1.2.1 The objectives of the study

The specific objectives of this study were:

- To analyse and map trends of riparian vegetation changes for the past 10 years.
- To assess riparian vegetation changes between the PES and the reference conditions
- To quantify and compare the magnitude of changes between the reference conditions and PES using VEGRAI.

1.2.2 Research hypothesis

The hypothesis of this study is summarised as follows:

- The present ecological status (PES) of the riparian vegetation in the Mooi River is largely modified.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter review literature on the trends in riparian vegetation assessment, riparian vegetation changes, the magnitude of riparian vegetation changes and the ecological status of riparian vegetation. This study aimed to determine the present ecological status of riparian vegetation in comparison to the reference conditions and Resource Quality Objectives (RQOs) in the Mooi River Catchment in South Africa. Focus was directed towards studies that studied the ecological status of riparian vegetation and how it can be modified due to various changes. Throughout the study, trends in riparian vegetation and magnitudes of changes are discussed.

2.2 RIPARIAN VEGETATION

Riparian vegetation provides many economic, ecological and aesthetic benefits. It is a key element of riverine ecosystems and provides many benefits, including terrestrial wildlife habitat structure, food resources and stabilising geomorphic properties along banks and floodplains and it provides energy subsidies to aquatic and terrestrial ecosystems (Pusey & Arthington, 2003).

According to Mackenzie *et al.* (2009), riparian vegetation is considered a very complex system with numerous environmental factors driving patterns and processes. The riparian ecosystem has been considered as the major driver of heterogeneity due to its composite gradients such as height above the channel and horizontal distance away from the channel (Mackenzie *et al.*, 2009). It comprises of the areas between the terrestrial landscape and the low- and high-water marks. Riparian vegetation is that portion of the terrestrial landscape from the high-water mark towards the uplands where there is elevated water tables because of flooding which has soils with the ability to hold water (Nilsson, 1992). According to Nilsson and Svedmark (2002), riparian vegetation frequently accommodates various vegetation cover types such as shrubs and trees, which serve as woody debris that provides a conducive natural habitat for both terrestrial and aquatic invertebrates as well as for mammals and birds.

Riparian vegetation can survive in an ever-changing environment; subsequently they have adapted to certain unique reproductive and physiological characteristics (Malanson, 1993). Some of these are growing in saturated or inundated soils and the ability to survive stem breakage, flooding, physical abrasion and sediment deposition (Naima & Bilgy, 1998). In addition, the seed

dispersal of some riparian plants coincides with the seasonal retreat of flood waters. During the environmental monitoring processes, environmental variables such as the availability of water, flooding, soil composition, substrata, nutrients, plant assemblages, water availability, geology and morphology must be taken into consideration in the combination with the environmental gradients and environmental variable (Pusey & Arthington, 2003).

Riparian zones symbolise extremely important natural ecological systems on a global, regional and national scale (Naiman *et al.*, 2005; Kanasashi & Hattori, 2011; Virbickas *et al.*, 2011). These zones bring services such as the purification of contaminants from the seepage flowing from highland areas. It also makes provision for an ecological corridor and habitat for wildlife, for riverbank stabilisation and for control of stream temperature and provides food for aquatic macro-invertebrates in the form of leaf litter (Richardson *et al.*, 2012). In order to manage the riparian zone, effective governance arrangements are imperative in order to rehabilitate degraded riparian zone areas and for sustainable ecological goods and services of these fragile areas.

Both anthropogenic and natural disturbances on riparian vegetation can change the natural habitats which can encourage the propagation of alien plants in the riparian zone (Richardson *et al.*, 2007). The riparian systems become vulnerable to invasion by alien plant species and they always increase due to anthropogenic disturbance (Holmes *et al.*, 2005).

The propagation of alien plants disturbs the riparian zones and the indigenous plants because, during rainy times, alien propagules are released into rivers and washed into the river banks. There are also grazing and trampling of riparian zones by livestock. When deforestation leads to soil erosion in the vicinity of the riparian zone and when there are changes in the natural fire regimes, further disturbance of the riparian zones takes place (Richardson *et al.*, 2007; Dark, 2004). According to Dark (2004), physical factors and climatic conditions further determine the success of alien plant invasion in an area. Furthermore, disturbance coupled with alien invasive plant propagules within the riparian zone increases pressure and chances of proliferation of alien vegetation (Meyerson & Mooney, 2007).

Moreover, even though anthropogenic activities play a major role in alien invasion, alien plant propagules may be recruited after a fire has occurred and they can also be dispersed by wind and animals (Holmes *et al.*, 2005). After alien plants established on an area they usually surpass the indigenous vegetation by using much more water, space and light, the reason being that most alien plants grow faster and become woody plants with very tall canopies (Hanula *et al.*, 2009;

Miyawaki & Washitani, 2004). This was confirmed by Drake (2011) with the findings from a study conducted in New Zealand about the degraded riparian zones where the proliferation of alien invasive plants called *Gutierrezia sarothrae* and *Ulex europaeus* has disturbed alluvial riparian zones. Subsequently, a study done in the Western Cape regarding the riparian zone of the Eerste River in South Africa, attributed to the fact that there were agricultural activities that being practiced within the riparian zones that degraded the riparian zones of the Eerste River. This study found that there was degradation of the landscape caused by alien invasions and it was also found that the rate of alien proliferation became higher than in urban areas (Meek *et al.*, 2010). The main contributing factor attributed by the authors was the trend for nutrient inputs from agricultural landscapes along the riparian zone.

According to Du Plessis *et al.* (2008), riparian zones need an adaptive and reliable method of governance that will be able to deal with the changes encountered by the riparian zone system. The necessary governance partnerships and collaborations should bring together all the relevant stakeholders to assist in dealing with the negative impacts in riparian zones (Holmes *et al.*, 2005; Richardson *et al.*, 2012).

2.3 ROLES OF RIPARIAN VEGETATION ON THE ECOSYSTEM

According to Naiman *et al.* (2002), riparian vegetation performs many ecosystem functions, including stabilisation of soil and reduction of erosion. It serves as a basis of organic matter and wood that serve as food and structure for aquatic organisms (Salman, 2007). According to Pusey and Hartington (2003), riparian vegetation may serve as a filter against input from terrestrial areas and it has the capacity to absorb extreme nutrients and toxic compounds from surface and ground water before getting into the streams.

According to Jason *et al.* (2000), flood duration and frequencies of controlled flow regimes frequently cause reduced plant survival and growth. Species richness and the richness of vascular plants have been found to decrease in rivers regulated for hydropower production (Johansson & Nilsson, 2002). Dynasties *et al.* (2004) indicated that this pattern is consistent even between river catchments that have different riparian vegetation.

The riparian zone also acts as an ecological link between terrestrial and aquatic habitats, it is used as corridor for animal movement, it slows down water movement and promotes sediment

deposition which in turn helps in replenishing soil nutrients, creating a unique morphology within river landscapes (Braga, 1999; Nilsson, 1992).

Riparian vegetation may sometimes be impacted by fluvial processes such as flooding and deposition of alluvial soil, which typically supports a distinctive flora that differs in structure and functions from adjacent terrestrial vegetation (Gregory *et al.*, 1991; Naima *et al.*, 1993; Tang & Montgomery, 1995; Naiman & Decamps, 1997). Soil seed banks contribute to vegetation dynamics along lake or reservoir shore-lines and along margins of confined rivers (Keddy & Reznicek, 1986).

There are different types of riparian vegetation which create different vegetation habitats such as reeds and certain herbaceous species which act as pioneer species, creating a suitable environment for the establishment of trees and other plant species (Van Niekerk & Heritage, 1993). After the vigorous riparian plant communities are established, the distribution and interaction of different trees and shrubs are closely interconnected through root completion, shading and littering (Monk & Gabrielson, 1985). However, vegetation litter can change the structure and the composition of plant communities (Monk & Gabrielson, 1985).

2.4 CHANGES IN RIPARIAN VEGETATION

Ecosystem modification, biodiversity loss and environmental change have been affecting the planet as a whole and these issues have been a public concern worldwide. Different debates have been undertaken scientifically and politically on environmental changes both nationally and internationally and these debates started in the 20th century already (Boletta *et al.*, 2006). Land cover change has been identified as one of the important human and natural caused environmental changes in the country (Lambin *et al.*, 2001).

Characteristics of the plant's life history can have a significant impact on the trajectory of riparian primary succession (Walker *et al.*, 1986). Initial colonisation of bare sediment in riparian environments is achieved by means of combined wind and water dispersal, even though animal dispersal may bring a more diverse set of propagates to a site in the long run (Kalliola *et al.*, 1991, Galatowitsch *et al.*, 1999).

River dynamics such as flow regime, hydrology, geology and topography determine the plants assembly patterns of succession and their distribution in a riparian ecosystem (Puhakka &

Kalliola, 1995; Schnitzler, 1997). Many river ecosystems are now lost and populations of species connected to these environments are therefore highly fragmented (Nilsson *et al.*, 2005).

There are different ways of creating a rich biodiversity in riparian vegetation through natural and manmade disturbances, i.e. floods and fire. Disturbances may create patchiness in the river landscape which may promote the dispersal of propagules and distributes nutrient-rich sediments that may attract an establishment of different types of riparian ecosystems (Foxcroft *et al.*, 2008). It is important to broadly understand all possible cycles, biotic and abiotic factors and gradients at all different categories to ensure proper management of river ecosystems (Hupp & Rinaldi, 2007).

Disturbances are one of the main key elements in creating a loss of biodiversity in riparian vegetation and it creates patchiness in the landscape and increases the alien invasive (Turner & Dale, 1998). According to Bendix and Hupp (2000), natural disturbances such as a flood, destroy the established riparian vegetation completely and may alter vegetation that is found within the stream boundaries, resulting a negative impact on the stream (Bischoff & Wolter, 2001).

Both natural and human disturbances should be considered because the combination of these natural disturbances together with anthropogenic activities may result in different effects within the ecosystem (Turner & Dale, 1998), for example, the construction of structures within the water course such as weirs and dams can cause major changes to the biophysical components of a river ecosystem (Katz *et al.*, 2005). After construction of newly structures within the river course, the characteristics of the modified channel may change the hydrology and morphology of the river and these manmade constructed structures within the river system can cause major and permanent disturbances and disruptive consequences such as a loss of natural biodiversity (Katz *et al.*, 2005).

According to O'Connor (2010), the riparian forest of the Mapungubwe National Park in South Africa has been transformed from forest to woodlands within 15 years due to several environmental factors and abstraction of water from the river for mining operational purposes. It has further been mentioned that the abstraction of water from the river influences the height of the water table which in turn can influence the structure, composition and function of riparian vegetation (O'Connor, 2010).

Riparian vegetation can be categorised according to the species tolerance level to floods and droughts (Naiman *et al.*, 2002). Hopp (2000) indicated that changes in water flows are capable of causing major changes in riparian vegetation. According to Jansson *et al.* (2000), it was discovered that certain vegetation stretches in the riparian zones, except for the amphibious vegetation, are expected to decrease in species richness with anticipated climate change. According to Naiman *et al.* (2002), free flowing rivers showed greater capability to buffer against changes in land-use as well as changes in climatic condition through dynamic interactions within the river ecosystem and flow adjustments.

It is evident that disturbance events to the river ecosystems and flow adjustments can significantly alter the composition and cover of the riparian vegetation (Naiman *et al.*, 2002). However, it is important to note that plant species vary in their susceptibility to flood disturbance and therefore, the varying severity disturbances within the riparian zones serve to influence the spatial pattern of river catchment and changes in reference conditions (Postel & Richter, 2003).

Although there might be other factors that are contributing towards the changes of the riparian vegetation structure and composition, except anthropogenic activities, it is difficult to focus on all the interactions and factors associated with the riparian ecosystem changes (Nilsson & Svedmark, 2002). Ward (1998) indicated that, due to continuous disturbances within the biophysical template of the riparian corridors, the riparian ecosystem can adapt to changes in sediment depositions, water availability and changes in soil nutrients which are sometimes accelerated by large infrequent floods (Kalliola *et al.*, 1991; Ward, 1998).

2.5 EFFECTS OF ANTHROPOGENIC AND NATURAL ACTIVITIES ON RIPARIAN VEGETATION

Other scholars have indicated that urbanisation is one of the drastic and dynamic global human alterations of ecosystems (Grimm *et al.*, 2001; Pickett *et al.*, 2001). It has been found to have some drastic effects on the ecology of the riparian area because it changes the hydrological conditions that could lead to hydrological drought by lowering of the water table which in turn lowers soil, vegetation and pollutants functions. Grimm *et al.* (2004) mentioned riparian zones are sources rather than sinks for nitrate in urban watersheds and are regarded as some foci for human nature interactions. They can serve as catalysts for ecological and socio-economic revitalisation in urban ecosystems.

In a study conducted on the Sabie River in the Kruger National Park (Mpumalanga region in South Africa), it was concluded that the hydrological characteristics and the flow regime of this river catchment have been changed because of anthropogenic activities such as agricultural activities, human activities and other man-made structures constructed within the Sabie Riverine environment (Naiman *et al.*, 1998; Naiman & Bilby, 1998). It was further found that the Sabie Riverine modifications also contributed towards the unpredictable flood pulses (Naiman & Bilby, 1998).

However, the removal of the riparian vegetation through flooding creates the opportunity for plant species to colonise and re-colonise. Plant species that are intolerant to moderate floods may not be able to re-colonise (Dixon, 2003). Although floods cause environmental damage, it also has advantages in that some riparian vegetation may be displaced to riverbanks after floods, but they re-colonise back in the channel floor when the conditions are favourable and they mostly do not fully establish on river banks until the environmental conditions become suitable for their survival and establishment (Henry & Amoros, 1996, Johnson, 2000).

Subsequently, it was further identified that sedimentation from the streams and rivers is rich in nutrients, is moist and has a high concentration of plant propagules, which create favourable conditions for seedling formations. It was further identified that the woody debris piles were good in protecting the newly formed seedlings against natural disasters such as droughts abrasion, erosion and herbivore (Naiman & Decamps, 1997; Naiman *et al.*, 2005). Crawley (1995) indicated that the success of established seedlings is mainly influenced by these types of surrounding landscapes and its micro habitats because they are high in nutrients, are moist and they provide protection which promotes seedling formation and growth (Petit & Naiman, 2006).

Naiman *et al.* (1998) further indicated that the majority of riparian vegetation species are dependent on certain environmental conditions, such as flow patterns, for the success of seedlings' establishment (Naiman & Bilby, 1998). However, environmental changes such as flooding can cause certain riparian species to disperse their seeds very early or very late for the seedling process to establish successfully and this creates a gap for another species to fully establish (Stromberg *et al.*, 1991; Naiman & Bilby, 1998).

Naiman *et al.* (1998) concluded that the regional climate also determines the type of vegetation in a riparian zone, the hydrological, geomorphological and regional pool of species and the disturbance regime (Shaw & Cooper, 2003). In most parts of the world, riparian vegetation can

be classified based on the dominant woody plants and possibly also based on its structure, e.g. woodland, shrub land or forest vegetation.

Shaw and Cooper (2003) further found that the disturbance regime is unfavourable for woody species, e.g. in areas that are too waterlogged, areas that have high latitudes and altitudes or are too cold, or that burn too frequently to permit shrub and tree persistence. The degree of seasonal drought as well as hydrology are important factors for determining whether woodland or shrub land vegetation develop in riparian zones in arid areas.

Alterations in the physical ecosystem process have major changes in plant species composition, therefore, the causes of the changes can be difficult to be determined which could lead to 'ascribed blame'. Ecosystem function can be changed by certain plant species that alter the composition and structure of the vegetation and those that replace indigenous vegetation over substantial areas (termed 'transformers'; see Richardson *et al.*, 2000). For example, the increased biomass of dense stands of invasive *Acacia mearnsii* or *Eucalyptus* species in riparian zones results in increased water use by the vegetation (Dye & Jarman, 2004). This in turn alters the hydrology of the catchment, causing stream reductions of up to 100% in wooded catchments in South Africa's grassland biome (Van Lill *et al.*, 1989).

Mackenzie *et al.* (1999) defined a riparian ecosystem as a complex system with different environmental factors driving patterns and processes, i.e. a horizontal distance away from the channel and height above sea level are considered as two of the major drivers of heterogeneity within the riparian ecosystem. Due to riparian vegetation complexity, it is crucial to carefully understand all possible gradients, cycles and biotic and abiotic factors at all classified levels to ensure that there is proper management of the river ecosystem (Hupp & Rinaldi, 2007).

The significant roles of riparian vegetation within an ecosystem are well documented, however, the riparian zone delineation and classification remain challenges (Nilsson, 1992; Hancock *et al.*, 1996; Van Coller *et al.*, 1997; Braga, 1999; Soman, 2007).

In concurring with other research findings, Dollar *et al.* (2007) and Stallins (2006) reported that plant distribution within the riparian landscape is influenced by a selection of bio-geomorphic factors at numerous categorised scales because there is a strong link between riparian vegetation and fluvial landscapes and its processes (Hupp & Osterkamp, 1985; Van Coller, 1997). The

patchy distribution of the geomorphic units can create patchiness within the distribution of riparian vegetation (Osterkamp & Hupp, 1985).

However, the distribution of riparian vegetation is closely linked to the height as well as the sloping distance from the active channel and flooding frequency (Parsons *et al.*, 2007). Therefore, there is a strong link between fluvial landscapes, riparian vegetation as well as associated processes (Hupp & Osterkamp, 1985; Van Coller, 1997). A riparian ecosystem is further characterised and distinguished by the unique combination of hydrology, geomorphology, geology, topography, channel type and vegetation and the anthropogenic factors around the riverine environment (Sharitz & Mitsch 1993; Hupp, 2000; Hupp & Rinaldi, 2007).

It is evident from the literature reviewed that river catchments have been modified and the scale of the hydrological modifications and invasive alien plants is among the most influential agents of degradation or changes in the ecosystem structure and functioning (Hupp, 2000). A review of the alien invasion and restoration impacts in South African river catchments in the context of riparian ecosystems revealed that, in highly transformed river catchments, interventions, for example along short river lengths may fail if important constraints at the catchment scale are not addressed (Parsons *et al.*, 2007). Such constraints include altered flow regimes and land-uses in the catchment, which lead to excessive soil erosion (Hupp, 2000).

Eriksson (2008) indicated that the ability to manage riparian vegetation changes in river catchments will depend on the geographic location of the river and cooperation from surrounding land-users in relation to water-use and cultivation methods, as well as negotiations relating to water release from impoundments to meet the ecological reserve (i.e. environmental flow). According to Hupp and Rinaldi (2007), most river catchments are invaded by alien invasive species to a greater or lesser extent, therefore, they respond differently due to the magnitudes of invasion.

CHAPTER THREE: STUDY AREA: MOOI RIVER CATCHMENT

3.1 INTRODUCTION

This chapter provides the description of Mooi River Catchment as well as its biophysical components.

3.2 DESCRIPTION OF MOOI RIVER CATCHMENT

The Mooi River Catchment is situated in the western Gauteng and North-West provinces. The Mooi River Catchment is over 4500 km² in extent and is relatively flat with elevations varying from 1520 m in the north to about 1300 m near the Vaal River confluence. A rocky ridge (known as Gatsrand) runs through most of the mining area in the lower Wonderfontein Spruit, which renders the area in general to be rocky on the ridges, slopes and flat areas (Van der Walt *et al.*, 2002).

It consists of three major catchments, namely the Wonderfontein Spruit which is located on the North-Eastern reach, the Mooi River Proper which is in the Northern reach and the Loop Spruit which is in the eastern reach of the Mooi River Catchment. There are also four major dams around the Mooi River Catchment, namely the Klerkskraal Dam, the Boskop Dam, the Klipdrift Dam and the Potchefstroom Dam, as indicated in Figure 3.1 (Van der Walt *et al.*, 2002).

The predominant land-use activities in the northern sub-catchment are crop farming, grazing, mining, farming, recreation and development such as roads and bridge constructions (Van der Walt *et al.*, 2002). The soils and climate of the Mooi River Catchment are suitable for a moderate range of agricultural products and the principal land uses are dry land maize and sunflower cultivation as well as cattle ranching.

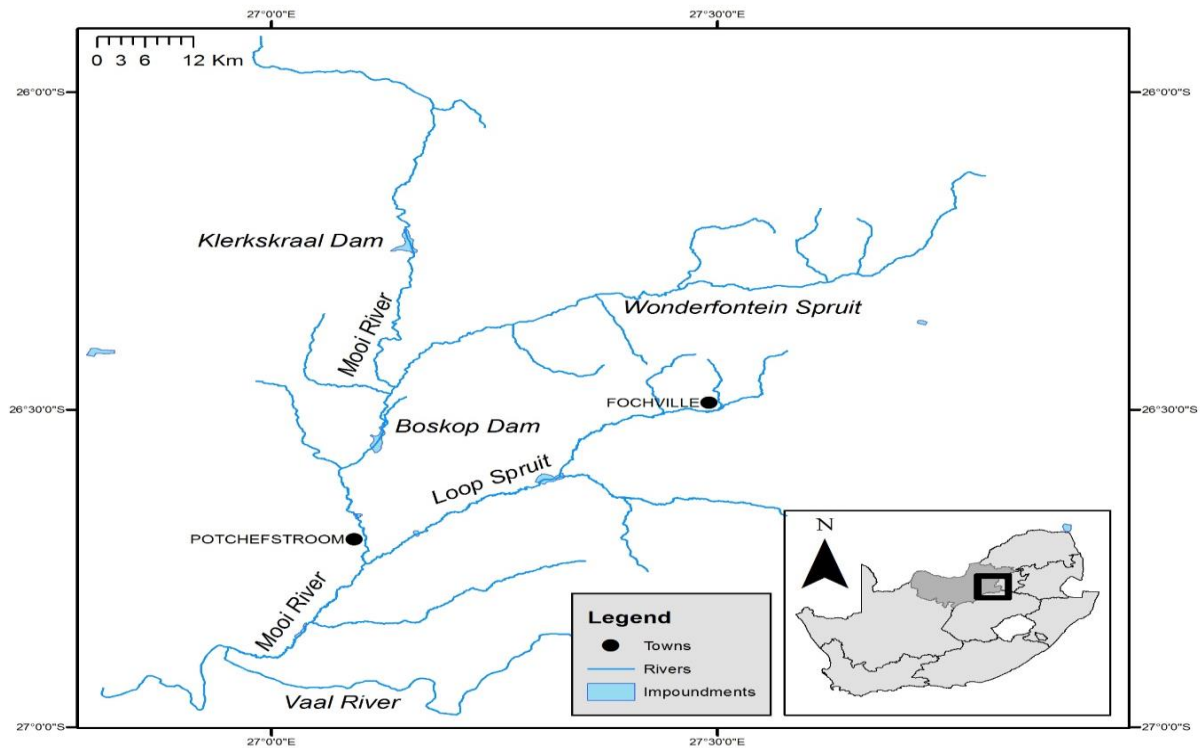


Figure 3- 1: Map representing the study area of the Mooi River Catchments of the Vaal River Water Management Area (WMA 3) (McDonald, 2014).

The Mooi River Catchment falls within the Vaal River Water Management Area in secondary catchment C2 and tertiary catchment C23. In the North-West Province (Winde & Stoch, 2010), the Mooi River has its tributaries that run through the district of Westonaria, Tlokwe, Fochville, Oberholzer and Carletonville forming part of the Vaal Catchment (Figure 3.1) (McDonald, 2014).

There are several dolomitic eyes that recharge both the Mooi River and its tributaries through the precipitation process along the area that ends up as ground water recharge (Winde & Van der Walt, 2004). The Mooi River is fed by both the Bovenste Oog and surface water from the Wonderfontein Spruit (WFS). However, the Mooi River is further supplemented by other eyes in the Boskop-Turffontein compartment and Gerhard Minnebron Eye through underground dolomitic compartments (Annandale & Nealer, 2011).

According to DWA (2016), the Mooi River is one of the rivers presently categorised as the water course that falls under a class III water resource, meaning it is significantly affected by anthropogenic activities such as water abstraction due to recreational and mining activities, development and pollution due to the wastewater treatment plants, but nonetheless, it is still

ecologically sustainable. The Mooi River is in an ecologically category of C/D, which indicates that the water resource is moderately to largely modified (DWA, 2016).

3.3 BIOPHYSICAL COMPONENTS OF THE MOOI RIVER CATCHMENT

3.3.1 Climate

The Mooi River receives an annual rainfall of approximately 680 mm. The mean annual rainfall range in the catchment (DWA, 1998) is from about 750 mm on the north-eastern boundary to about 520 mm near Boskop Dam. However, the average evaporation potential in the catchment is 1 650 mm (Van der Walt *et al.*, 2002). The mean temperatures range from > 32 °C in the summer to -1 °C in the winter months. Frost is also a common occurrence in the winter season (Cilliers & Bredenkamp, 2000).

The study area has a typical South African Highveld climate (DWA, 1998), as the summers are warm to hot and winters mild to warm with frosty nights. Rainfall occurs predominantly during the summer months in the form of thunderstorms (convection rain) with associated lightning and hail.

3.3.2 Topography

DWA (1998) explains that the originally gently undulating topography of the upper parts of the Wonderfontein Spruit has been modified by mine dumps. The topography in the lower Mooi River Catchment results in a moderate river slope. The average slope of the Mooi River between Boskop Dam and Potchefstroom is 2.5 mm and between Potchefstroom and the Vaal River the slope is 900 mm, which explains the extensive wetland areas downstream of Potchefstroom (DWA, 1998).

3.3.3 Geology and soil

The geological condition in the area is dominated by dolomite and there are major gold mining operations across the upper reaches of the catchment (DWA, 2009; Barnard *et al.*, 2013; DWS, 2014). The Mooi River has a geology which has an assemblage of dolomitic aquifers in the upper and middle catchments. This geology is the main source of water supply into the Mooi River.

The soil in the area is categorised as moderate to deep sandy loam soils on undulating plains because of the predominant geological strata and the climate. The study area has an average

soil depth of 650 mm and the sandy loam soils are considered to be ideal for irrigation purposes because they possess a good balance between the ability to drain water and water holding capacity. The water holding capacity is high, estimated to range between 104 mm per m and 117 mm per m (Schoeman & Van der Walt, 2002).

3.3.4 Vegetation

According to Bezuidenhout and Bredenkamp (1990), the broad vegetation type of the entire dolomitic region can be described as an *Eragrostis curvula* - *Elionurus muticus* grassland. Predominant grasses are *Eragrostis curvula*, *Nionurus muticus*, *Themeda triandra*, *Digitaria eriantha*, *Aristida congesta*, *Cymbopogon plurinodis*, *Rhynchelytrum repens* and *Cynodon dactylon*. The herbaceous layer of most of the plant communities is also well developed. Although the tree stratum consisting of *Acacia* (*Vachellia*) *karroo* woodlands or trees such as *Searsia* (*Rhus*) *pyroides*, *Acacia* (*Senegalia*) *caffra*, *Celtis africana*, *Diospyros lycioides* and *Ziziphus mucronata* in various communities is often absent, a shrubby layer is often present, consisting of prominent species such as *Searsia pyroides*, *Grewia flava* and the occasional *Asparagus africanus* (Bezuidenhout & Bredenkamp, 1990).

However, the natural vegetation is threatened by overgrazing and maize cultivation (Bezuidenhout & Bredenkamp, 1990). The presence and high constancy of pioneer grasses such as *Aristida congesta*, *Cynodon dactylon* and *Rhynchelytrum repens* emphasise the generally degraded condition of the vegetation (Bezuidenhout & Bredenkamp, 1990). Exotic tree species (such as *Eucalyptus* and *Acacia mearnsii*) also occur in clusters often associated with mine dumps (DWAF, 1998).

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 INTRODUCTION

The fundamental principle of this study was to understand the environmental changes to the riparian zone along the Mooi River stretch over an extended period to improve the governance of the river system. Both primary and secondary data collection methods such as field surveys, the VEGRAI survey, Geographical Information Systems (GIS) and/or Remote Sensing (RS) mapping tools were used to analyse the changes in the riparian vegetation of the Mooi River Catchment. Six different sites were sampled to determine the riparian zone responses along the Mooi River catchment (Figure 4-1 and Table 4-1).

This study adopted a mixed method approach. According to Creswell (2008), mixed methods research is both a method and methodology for conducting research that involves collecting, analysing and integrating quantitative and qualitative research in a single study or a longitudinal program of inquiry. The purpose of this form of research is that both qualitative and quantitative research, in combination, provide a better understanding of a research problem or issue than either research approach alone. The mixed method research involved the use of surveys (reconnaissance survey) and satellite images (maps) to show the scale of land use changes over time.

Table 4-1: A summary of the six sampling sites depicting site's number, name, coordinates and date of sampling.

Site Surveyed	Site Name	GPS Coordinates	Description	Date Visited
1.	Kromdraai	<i>S 26° 88' 27"</i> <i>E 26° 96' 45"</i>	Kromdraai, adjacent the road and the bridge.	10/10/2018
2.	South Bridge	<i>S 26° 74' 80"</i> <i>E 27° 10' 50"</i>	South Bridge, eastern side of the Wastewater treatment works	10/10/2018
3.	North Bridge	<i>S 26° 68' 58"</i> <i>E 27° 09' 79"</i>	North Bridge	10/10/2018
4.	Downstream of Boskop Dam	<i>S 26° 58' 80"</i> <i>E 27° 08' 98"</i>	Downstream of Boskop Dam	11/10/2018
5.	Muiskraal Farm	<i>S 26° 50' 03"</i> <i>E 27° 12' 60"</i>	Upstream of the confluence Wonderfontein, downstream of Klerkskraal Dam	11/10/2018
6.	Rysmierbult	<i>S 26° 45' 61"</i> <i>E 27° 11' 12"</i>	Downstream of Wonderfontein spruit, upstream of Boskop Dam	11/10/2018

4.2 DATA COLLECTION

4.2.1 Field survey

Primary data collection in the form of a field survey was undertaken to assess trends and changes on woody and non-woody vegetation components. The different sites within the Mooi River catchment were visited in October 2018 to determine riparian vegetation composition. A site transect were completed at each site to acquire composition in the marginal, lower and upper zones of the riparian zone. Photographs were taken as a reference for future assessments (Appendix B).

Different sites were sampled in the study area to identify possible changes in vegetation richness, composition and structure for the past 10 years (Table 4-1). Two consecutive days were dedicated for the survey to be undertaken. A site transect within the riparian zone of the Mooi River Catchment sites was undertaken at all six sites sampled in order to assess the different types of plants species within the riparian zone as well as different land uses along the river. The vegetation cover was visually identified and photographs were taken to further identify the different plants species (if not possible in the field survey). The six sites that were assessed within the Mooi River catchment were Muiskraal, Rysmierbult, Downstream of Boskop Dam, North Bridge, South Bridge and Kromdraai (Figure 4-1). However, since similar sampling techniques were used before and because belt transects are time consuming and labour intensive, plants were visually identified and photos were taken. It must be noted that no belt transects were measured during the survey.

The field survey was used to identify and visualise the riparian zone of the Mooi River Catchment. This included the observation of land use and land cover changes of the area and effects associated with the land use and land cover changes. It was important to do the field observation as not all effects of land use are visible on maps; thus, ground trothing was necessary. However, different species were identified during the field survey and through photographs taken. Different species types such as woody, non-woody, indigenous and exotic vegetation were identified. Extrapolated data showing a buffer of 10 meters was estimated on maps since no buffer zonation was undertaken during the plants survey. The extrapolation was completed at each site from the river to the riparian zone and this enabled the classification of riparian vegetation which was classified in proximity of 10 meters from the river. The buffer was motivated by Hawes *et al.*

(2005), who indicated that the minimum width of a riparian buffer was about 33 feet, which is equivalent to 10.0584 meters. However, according to the Water Research Commission (WRC) report for river buffer guideline the estimated riparian zone width is based on the maximum of 1:100 flood line or relevant alluvial vegetation types included in the Vegetation map of South Africa (Mucina & Rutherford, 2006). Aerial photography can also be used to more accurately map riparian areas at a desktop level, where applicable.

4.2.1.1 Data analysis

Data collected during the field survey in the Mooi River catchment was analysed using Microsoft Excel to create graphs of the species composition at each site. The analysis included determining the percentage of species distribution for all six sampled areas during the field survey along the riparian zone as well as determining the percentage of species distribution for each specific area along the riparian zone. Each VEGRAI metric such as woody and non-woody vegetation, exotic and indigenous species and the species lifeform classifications such as trees, shrubs, herbs and grass were visually presented to identify changes.

4.2.2 Secondary data collection

The methodology that was incorporated in the study involved mapping and remote sensing image classification techniques using multi temporal Landsat images covering the study area. These images were used to produce land use and land cover maps using the maximum likelihood classification (supervised classification) in Arc Map 10.2. which was obtained from Google Earth Pro software on 15 November 2019. Post classification comparison was used to produce a spatio-temporal change map, where all classified images were overlaid on each other. Thus, spatial extent and rate of urban growth changes were analysed and quantified (Navalgund *et al.*, 2007).

The secondary data was collected through a desktop study wherein different Geographic Information System (GIS) models were visited to determine if there were changes on the riparian vegetation of the Mooi River as compared to the reference conditions of the catchment. The desktop study using GIS and Remote Sensing Index (RSI) to indicate the riparian vegetation changes along the Mooi River catchment for the past 10 years was analysed for the six sampled sites as indicated in Figures 4-1 and 4-2 below.

The images were used to produce a land use and riparian vegetation map using the maximum likelihood classification (supervised classification) in ArcMap 10.2. which was obtained from Google Earth. Post classification comparison was used to produce a spatio-temporal change map, where all classified images were overlaid on each other in ArcMap 10.2 using the spatial analyst tools. Thus, spatial extent and rate of riparian vegetation changes have been analysed and quantified using the six sampled sites (Figures 4-1 and 4-2).

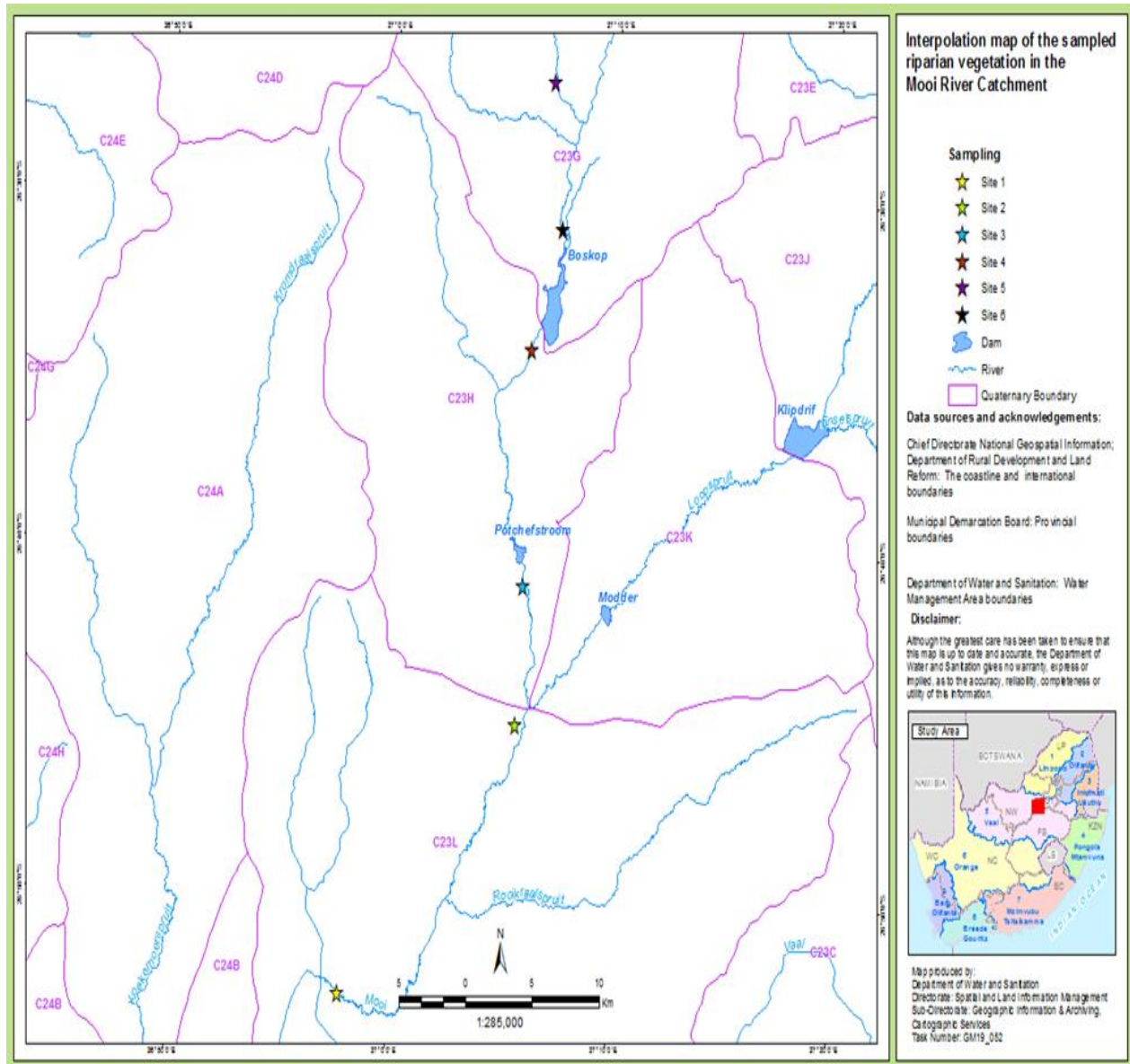


Figure 4- 1: Sampling points along the Mooi River gradient for Site 1, Site 2, Site 3, Site 4, Site 5 and Site 6 (DWS).

4.2.2.1 Vegetation Index Differencing

A post classification comparison technique was used to show the riparian change in ArcMap 10.2. It is the most straightforward and intuitive change detection method (Navalgund *et al.*, 2007). Change detection analyses describe and quantify differences between images of the same scene at different times. The Google Earth images of the three various years were used to show the areas of different land covers during the three years, namely 2009, 2014 and 2019 and to observe the changes that took place over time. In this case, the analysis was used to identify changes in different classes of land use and land cover.

The NDVI images were calculated from the red (0.55 – 0.68 μm) and near infrared (NIR, 0.73 - 1.1 μm) bands using the following equation adopted from Chen (2006).

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

Where

RED = Red reflectance value and

NIR = near infra-red reflectance value

Areas with lower spectral reflectance on the NDVI image are associated with lower vegetation cover or no vegetation cover while areas with higher spectral reflectance are associated with healthy vegetation cover. Once the NDVI images were classified using the Natural breaks or Jenks classification method in ArcMap, areas were assigned different classes in response to their spectral reflectance. The NDVI reflectance was used to assess land use and land cover (Navalgund *et al.*, 2007).

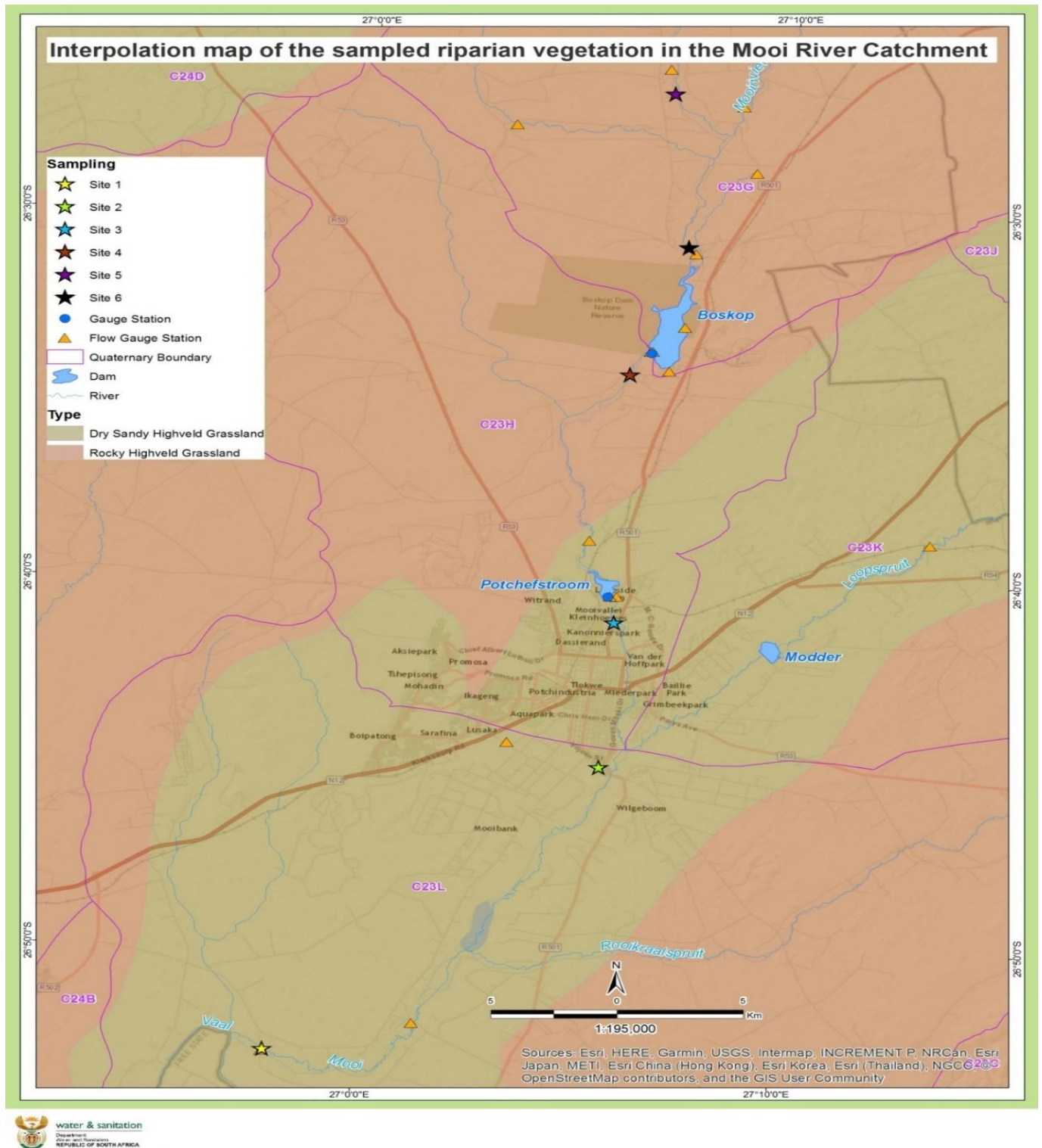


Figure 4- 2: Major vegetation types along sampling points of the Mooi River gradient for Site 1 to Site 6 (DWS).

4.2.2.2 Image classification

Image classification is a relevant method to provide information on the extent and rate of riparian vegetation responses (Navalgund *et al.*, 2007). Landsat images were used for the analysis of the riparian vegetation response trends for the past 10 years. Supervised (maximum likelihood) classification was applied in ArcMap10.2. Images were classified in different riparian vegetation classes. Each land class consists of various land use classes such as farming, grazing, mining and recreation, however, only field survey ground truthing activities took place during the site visit. During the classification, three images were used for each year (2009, 2014 and 2019) which represented the six different sampling points. The image length and breadth for all the images are about 2.4 km by 1.8 km.

Results from the previous scholars as well as the observations and field notes helped the researcher to interpret and explain the quantitative results to address the research objective and question on riparian vegetation responses. The data was analysed in order to draw inferences from the data and apply the information acquired from the representative sample to draw a conclusion about the entire riparian ecosystem.

4.2.2.3 Change detection

According to Singh (1989), change detection is the method of detecting the discrepancies in the state of an object or phenomenon by observing it at different periods. It provides a quantitative analysis of spatial distribution of the population, therefore, it is a significant methodology in the managing and monitoring of natural resources as well as urban development. However, in this study, a change detection methodology was not feasible.

Detection of long-term changes on the riparian zone might bring forward an impression that there might be a shift in local or regional climatic conditions and analysing the basis of terrestrial global monitoring (Navalgund *et al.*, 2007). Land cover mapping and land use serve as basic inventories of land resources for all spheres of government, private industries throughout the world and environmental agencies (Vijith & Satheesh, 2007).

Change detection in land use and land cover may be done on a temporal scale such as a decade to access landscape change caused due to human activities on the land (Gibson & Power, 2000). A post classification comparison technique was used to apply the change detection method in ArcMap 10.2 and it is also said to be the most straightforward and intuitive change detection method (Navalgund *et al.*, 2007).

Change detection analyses define and measure the variances between images of the same scene at different periods. The images of the three different years (i.e. 2009, 2014 and 2019) were used to assess and estimate the area of different land covers and to detect the changes that took place over time in the study area. In this case, the analysis was used to ascertain different changes in different areas with different land use within the Mooi River catchment. According to this analysis, the vegetation cover and changes were detected in percentages within the riparian zone of the delineated six sampled sites per square meter for the years 2009, 2014 and 2019.

4.2.3 Mapping and analysing trends of riparian vegetation

The image classifications were done for the years 2009, 2014, and 2019. The images used for the classification were obtained using Google Earth Pro software on 15 November 2019. The images used for classification were high resolution images taken with Arc Map software to be used for the analysis. The first step performed was the geo-referencing tool, which enabled geometric assignment to the images for further analysis.

It must be noted that, during the mapping processes, it was not possible to cover the entire river reach because it is too long, therefore, an image classification of riverine or riparian vegetation was conducted on a scale which did not cover the whole river. Furthermore, to get the data of that magnitude as well as covering the large scale of the river required an image which had high resolution but was expensive. Thus, Google Earth images were used. There were three images for each year (2009, 2014 and 2019) representing the six different sampling points. The image length and breadth for all the images was about 2.4 km by 1.8 km respectively.

The image geo-referencing which was used was WGS1984 Web Mercator Auxiliary Sphere. This is a projected coordinate with a linear unit of measurement in meters and with regard to image classification, a buffer of 10 meters was used in the river line polygon which was digitised prior classifications. The buffer output polygon served as clipping polygon, hence, after the classification, the buffer polygon was used to clip the classification raster and this enabled the

classification of riparian vegetation which was classified in a proximity of 10 meters away from the river. The distance of 10 meters was not arbitrarily suggested but it was induced from the works of Hawes *et al.* (2005), in which they stipulated that the minimum width of riparian buffers to protect river streams from such things as litter and debris input was about 33 feet, which is equivalent to 10.0584 meters.

4.2.4 VEGRAI data analysis and interpretation

VEGRAI is the assessment system that is used to rate, rank and weigh riparian vegetation changes within the EcoClassification process (Kleynhans *et al.*, 2007). The VEGRAI is a system that is designed for qualitative assessment of the response of riparian vegetation to impact in such a way that those qualitative ratings translate into quantitative and defensible results. Results are defensible because their generation can be traced through an outlined process (a set of rules that converts assessor estimates into ratings and converts multiple ratings into an EC).

In terms of VEGRAI assessment, river health is assessed in two (marginal and non-marginal) or three zones (marginal, lower and upper), depending on the level of assessment in South Africa, using the VEGRAI method (Kleynhans *et al.*, 2007). However, the lower dynamic appears to be an area of preferential recruitment and, as such, its inclusion in an updated VEGRAI is worth consideration. During the early phases of the River Health Programme (RHP) component of the National Aquatic Ecosystem Health Programmer (NAEHP), a riparian vegetation assessment index (RVI) was developed (Kemper, 2001). The RVI was applied during several RHP surveys. However, it was found that it presented several problems (CSIR, 2002).

The riparian vegetation zones (marginal, lower and upper) are used as the metric groups. According to Van Niekerk and Heritage (1993), the marginal zone was described as wet bank or so-called active features. However, Cagney (1993) identifies it as the area from the water level wherein the flow level is low or where the green line starts in the absence of the base flow and the features are hydrologically activated for most of the year.

Van Niekerk and Heritage (1993) further mentioned that the lower zone is described by seasonal features or wet bank, however, the lower zone extends from the marginal zone and ends where the lateral elevation and the features are hydrologically activated on a seasonal basis only when there is high flow.

The upper zone is referred to as ephemeral features or dry bank and it extends from the end of the lower zone to the end of the riparian corridor (Van Niekerk & Heritage, 1993). Its geomorphic features are hydrologically activated on an ephemeral basis, i.e. less than every 3 years. It is usually characterised by steeper slopes and it has the presence of both riparian and terrestrial area.

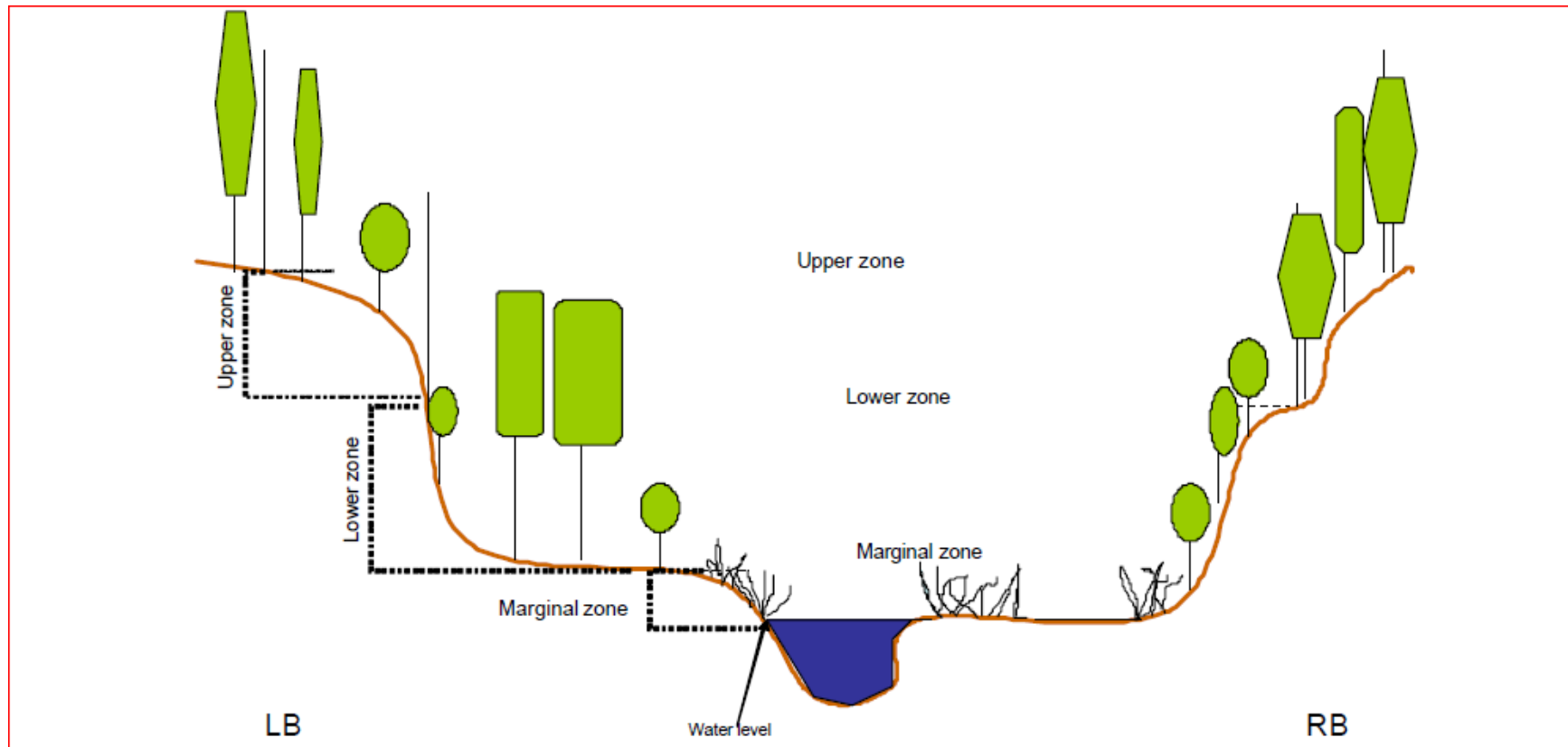


Figure 4- 3: An example of where marginal zone, lower zone and upper zone are placed (Kleynhans *et al.*, 2007).

Figure 4-3 represents the simplified Level 3 version of VEGRAI where the lower and upper zones are combined to form the non-marginal metric group (zone) and metric used in both Level 3 and 4 are woody, non-woody, cover, abundance, population structure, recruitment and species composition. A range of metrics for each metric group is selected of which some are essential for both Levels 3 and 4 (richness and cover) and the others are optional (species composition, population structure and recruitment). Several metrics are defined and used in VEGRAI to describe and rate the riparian vegetation status. These are richness, cover, recruitment, population structure and species composition. Each of these, defined and justified below, is assessed in each of the zones for both a woody and non-woody vegetation component. (Kleynhans, *et al.*, 2005).

The woody vegetation component is defined as a combination of both trees and shrubs, of which trees are defined as woody perennials, usually single stemmed in an undamaged condition and the upper crown should be distinctive. Whereas shrubs are defined as woody perennials, which has two or more stems arising from the ground. Shrubs are generally smaller than trees because they do not have a trunk (Kleynhans, *et al.*, 2005).

On the hand the non-woody vegetation component is comprised of all herbaceous plants including grasses, sedges and forbs. The non-woody vegetation component includes hydrophytes (aquatic grasses and sedges as well as species such as *Phragmites*, *Prionium serratum*, the Restios, *Typha* and *Juncus* (Kleynhans, *et al.*, 2005).

Cover metric addresses the total number of vegetation under present condition as compared to the reference condition. It is defined as a measure of the extent to which the ground is covered by vegetation, and is measured as canopy cover. However, when conducting the cover assessment exotic vegetation is not considered (Kleynhans, *et al.*, 2005).

Abundance metric also addresses the total number of indigenous vegetation under present conditions compared the total number expected under reference conditions. It is measured in terms of density which is the total number of stems/plants per unit area. However, abundance assessment does not consider exotic vegetation as well because they are seen as species that have a negative impact on indigenous vegetation. Hence exotic vegetation are not assessed in this metric but elsewhere only in scenarios where exotic species are available on site the

abundance metric will indicate by showing a marked difference from the reference condition (Kleynhans, *et al.*, 2005).

The population structure assesses the viability and sustainability of populations and only assesses the woody component. It assesses the life stages relative abundance of life stages. Population structure is an assessment of the relative abundance of life stages within respective populations of selected indicator species and life stages used in VEGRAI are juveniles, sub-adults and adults, and represent functionality in the life histories of selected species (Kleynhans, *et al.*, 2005).

The assessment of population structure addresses the viability and sustainability of populations. It is only assessed for the woody component. Population structure is an assessment of the relative abundance of life stages within respective populations of selected indicator species. Life stages used in VEGRAI are juveniles, sub-adults and adults, and represent functionality in the life histories of selected species. A juvenile is an individual that has become dependent on its own resources, but is not yet reproductive. Juveniles are established, and can be considered the first successfully survived generation. Sub-adults are individuals who have not yet reached a maturity status of adults, are not yet fully reproductive (fruits may be minimal), but are also not juveniles. They vary in height and girth between juveniles and adults. An adult is a potentially fully reproductive individual that has reached maturity. Damaged specimens, reduced in size and possibly reproductive functionality, are included (Kleynhans, *et al.*, 2005).

Recruitment is the arrival and establishment of new individuals into riparian populations or communities. Recruitment addresses the viability and sustainability of vegetation components. It is a qualitative estimate of the abundance of established juveniles for the woody component only. Recruitment excludes vegetative reproduction (coppicing, re-sprouting). Established individuals are those juveniles that have completed the process of germination (lost cotyledons) and have developed a visible amount of woodiness, but are not yet contributing reproductively. Recruitment of non-woody vegetation is not included in VEGRAI due to the difficulty of the assessment, and because non-woody plants are generally shorter-lived than woody (annuals, e.g.) and an assessment of cover and abundance is therefore sufficient (Kleynhans, *et al.*, 2005).

Species composition refers to the arrangement of species in the riparian community that comprise the assemblage in the study area. Species composition refers to the presence and absence of

species as well as their relative proportions in the assemblage. The assessment should focus on the change of the indigenous riparian species assemblage. Exotic and terrestrial species are often major contributors to changes in indigenous riparian species composition. The change in species composition for each zone is assessed separately for woody and non-woody vegetation components. This assessment makes use of indicator species and records the change in relative abundance (relative to other indicator species) from present to reference conditions (Kleynhans, *et al.*, 2005).

However, not all the metrics are used in the VEGRAI Level 3. According to Kleynhans, *et al.* (2005), Level 3 is only applied in both River Health Programme (RPH) and for rapid Ecological Reserve purposes and this level only aimed at general aquatic ecologists, whereas Level 4 is applied in the intermediate and comprehensive Ecological Reserve determinations. Level 4 aimed specifically in determining the specialist riparian vegetation ecologists. Kleynhans, *et al.* (2005) further indicated that both Levels 3 and 4 refer to the suitable level of EcoStatus determination.

4.2.4.1 Ranking-weighing principle

The principle of the ranking-weighing approach was used wherein the ranking and weighing were applied for the VEGRAI principles and processes which refer to the amount of vegetation transformation from reference conditions, however, not all groups and metrics (various zones) have the similar relative ecological significance in all types of rivers. During the riparian vegetation impacts assessment, using the VEGRAI model, the following rating system was used in VEGRAI Level 3 assessment model: a six-point rating system (0-5) or (A-F), where metrics were scored in terms of the degree to which they had changed and were ranked, rated and weighed compared to the natural or close-to-natural reference.

4.2.4.2 A-F scoring system

The metrics are rated and weighed and an Ecological Category (A-F) determined which represents the Ecological Category for the riparian vegetation state.

Table 4-2: Classes associated with VEGRAI score of the ecological categories for EcoStatus components (Kleynhans *et al.*, 2007).

CATEGORY	DESCRIPTION	SCORE (% OF TOTAL)
A	Unmodified, natural.	90-100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-89
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39
F	Critically modified. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

4.2.5 Resource Quality Objectives

However, there are different researchers who are considered to have determined the RQO. The RQO has been determined for the Mooi River catchment and the results for this study will be compared with the RQO for the riparian zone. Dickens *et al.* (2011) stated that it is imperative to investigate the different documentations in order to establish the origin of the RQO reasoning as well as to determine how RQO fits into the bigger picture of water resource management such as

the National Water Act (1998), RDM Integration Manual (1999), The National Water Resource Strategy, Resource Quality Objectives, RQO and Ecological Reserve, Eco-classification, Eco-status and Eco-specs. RQO for Mooi River Catchment has been determined and the results for this research will be compared with the RQO for the riparian zone.

According to the National Water Act (No. 36 of 1998), the aim of the RQO is to set clear objectives with regard to the water resources' quality. The NWA stipulates the significance of a balance between the use of the water resources and the need to protect the water resources. It further states that "once the class of a water resource and the RQO has been determined they are binding on all authorities and institutions when exercising any power or performing any duty under this act," (The National Water act, 1998; Dickens *et al.*, 2011).

According to the Resource Directed Measures (RDM) that had the guideline published in 1999, the RQO is explained as a scientifically derived numerical and descriptive statement of the condition to be met in receiving water to ensure water resource protection. The RDM manual describes the objective and the application of RQO as the representative of a goal towards which management can be directed to achieve the desired protection of a resource. It further considers the acceptance or unacceptance of impacts and activities on a water resource such as water abstraction, land use, point sources, non-point sources, etc. It is further described as a tool for the management of source directed control from which its achievement and efficiency and regulated activities can be assessed and reviewed. It will assist with the planning and provision of steady time frames and for the decision-making processes (Dickens *et al.*, 2011).

In terms of the National Water Resource Strategy (NWRS) Section 3.1.2.3, an RQO gives a descriptive numerical account regarding the biological and physical characteristics and chemical composition considering the user requirements as well as the different classes of a particular water resource such as Class I, II, III and IV (Table 4-3). It is further described as the nature and condition of the aquatic biota, habitat, the quantity, pattern and timing of in stream flow and the water quality (Dickens *et al.*, 2011).

Table 4-3: Summary of the management classes developed by the classification system recorded by Dickens *et al.* (2011).

Management Class	Description
Class I	Natural - Minimal impact of humans, natural water quality and safe for most uses, of high significance. Other classes are defined in terms of degree of deviation from the natural class.
Class II	Moderately used/impacted - slightly altered from natural due to human activity.
Class III	Heavily impacted/used - significantly changed from natural due to human activity but nevertheless ecologically sustainable.
Class IV	Unacceptable degraded resources - due to overexploitation. The Management class is set higher in order to rehabilitate.

CHAPTER FIVE: RESEARCH RESULTS AND DISCUSSION

5. RESULTS AND DISCUSSION

5.1 Species composition of sampling sites

Tables 5-1 and 5-2 are summaries from the field survey that focused on gathering information and identifying species composition, different types of vegetation cover such as shrubs, trees, herbs and grass, woody and non-woody vegetation, indigenous and exotic plants species and the spatial changes in the riparian zone area per site, sampled within the Mooi River Catchment.

Table 5-1 is a summary of the riparian zone species data of the six sampling sites along the water course of the Mooi River during 2018. A summary of changes between the reference conditions and the PES is presented in the various figures. Plant species vary in their susceptibility to flood disturbances, although there might be other factors such as anthropogenic activities that contributed towards the changes of the riparian vegetation structure and composition. The different disturbances with varying severity within the riparian zones influence the spatial pattern of the river catchment and changes in reference conditions (Nyemba, 2013). The data collected (Tables 5-1 and 5-2) indicated that there is a decline in the species composition and abundance of the current ecological conditions in terms of richness or diversity of the Mooi River catchment as compared to the previous species composition (reference condition – Table 5-2).

Table 5-1: Sampling sites and the species composition identified along the Mooi River catchment on 10 to 11 October 2018.

*Exotic Species

No.	Species Composition	Kromdraai Site 1	South Bridge Site 2	North Bridge Site 3	Downstream of Boskop Dam Site 4	Muiskraal Farm Site 5	Rysmierbult Site 6
1.	<i>Acacia mearnsii</i> *	0	0	0	2	0	1
2.	<i>Asparagus suaveolens</i>	4	2	2	4	1	0
3.	<i>Bidens pilosa</i> *	0	1	1	0	0	0
4.	<i>Celtis africanus</i>	0	0	3	0	1	2
5.	<i>Cirsium vulgare</i> *	1	0	1	0	0	0
6.	<i>Cynodon dactylon</i>	0	0	3	0	4	0
7.	<i>Ehretia rigida</i>	5	2	6	3	3	3
8.	<i>Eucalyptus grandis</i> *	1	0	0	1	1	1
9.	<i>Grewia flavescens</i>	0	0	2	0	0	1
10.	<i>Grewia occidentalis</i>	0	0	2	0	0	1
11.	<i>Hyparrhenia hirta</i>	1	2	0	1	1	0
12.	<i>Melia azedarach</i> *	2	1	1	3	2	0
13.	<i>Morus alba</i> *	0	0	2	0	0	2
14.	<i>Panicum maximum</i>	0	0	1	1	0	2
15.	<i>Phragmites australis</i>	2	1	1	4	4	4
16.	<i>Populus</i> sp.*	2	2	0	0	0	0
17.	<i>Pteridium aquilinum</i>	0	0	2	0	0	2
18.	<i>Salix babylonica</i> *	5	2	2	6	2	3
19.	<i>Schoenoplectus</i> sp.	2	0	0	0	0	1

20.	<i>Searsia lancea</i>	2	1	3	0	2	1
21.	<i>Typha capensis</i>	2	2	3	1	3	5
22.	Ferns*	0	0	3	0	0	1
Total Number of species distribution per site		29	16	38	26	24	30

5.2 Comparison of PES with riparian zone reference condition of the Mooi River Catchment.

Table 5-2: Species composition of only six (6) sampled sites for the present condition at the Mooi River Catchment in comparison with species abundance with the reference condition (1995 and 2012).

- Exotic Species

No.	Samples	Species Category			Species richness of Reference Condition		Species richness of Present Condition
		Origin	Lifespan	Lifeform	1995	2012	2018
1.	<i>Acacia mearnsii</i> *	Exotic	Annual	Tree	0	0	3
2.	<i>Asparagus suaveolens</i>	Indigenous	Perennial	Shrub	18	21	13
3.	<i>Bidens pilosa</i> *	Exotic	Annual	Herb	0	4	2
4.	<i>Celtis africanus</i>	Indigenous	Perennial	Tree	16	13	6
5.	<i>Cirsium vulgare</i> *	Exotic	Annual	Herb	0	2	2
6.	<i>Cynodon dactylon</i>	Indigenous	Perennial	Grass	37	38	7
7.	<i>Ehretia rigida</i>	Indigenous	Perennial	Shrub	17	14	22
8.	<i>Eucalyptus grandis</i> *	Exotic	Perennial	Shrub	0	1	4
9.	<i>Grewia flavescens</i>	Indigenous	Perennial	Shrub	24	19	3
10.	<i>Grewia Occidentalis</i>	Indigenous	Perennial	Shrub	5	4	3
11.	<i>Hyparrhenia hirta</i>	Indigenous	Perennial	Grass	12	13	5
12.	<i>Melia azedarach</i> *	Exotic	Perennial	Tree	4	10	9

13.	<i>Morus alba</i> *	Exotic	Perennial	Tree	0	1	4
14.	<i>Panicum maximum</i>	Indigenous	Perennial	Grass	13	20	4
15.	<i>Phragmites australis</i>	Indigenous	Perennial	Grass	0	0	16
16.	<i>Populus</i> sp.*	Exotic	Perennial	Tree	0	0	4
17.	<i>Pteridium aquilinum</i>	Indigenous	Perennial	Herb	0	0	4
18.	<i>Salix babylonica</i> *	Exotic	Perennial	Tree	0	0	20
19.	<i>Schoenoplectus</i> sp.	Indigenous	Perennial	Herb	0	0	3
20.	<i>Searsia lancea</i>	Indigenous	Perennial	Tree	4	6	9
21.	<i>Typha capensis</i>	Indigenous	Perennial	Herb	0	0	16
22.	<i>Ferns</i> *	Exotic	Annual	Herb	0	0	4
TOTAL ABUNDANCE					150	166	163

Table 5-2 presents a comparison of the species composition and abundance per reference condition as compared to the present condition's species diversity of riparian vegetation along the Mooi River catchment. Riparian vegetation identified in the previous years was used as reference condition of the study area for species sampled between 1995 and 2012 (Du Toit, 2015). A total number of 22 species identified in 2018 survey was compared with the two surveys conducted by Du Toit in 1995 and 2012. The comparison of Du Toit's study and this study show that the riparian condition at the time of the current study is fluctuating i.e. 163 plant species were identified in 2018, a total of 166 species were identified in 2012 and in 1995 only 150 species were identified which shows less abundance as compared to both 2012 and 2018 studies.

Although, the reference condition study was based on the surveys that were far more comprehensive than the current study, the two studies are still comparable because they were both done at the Mooi River catchment in order to determine the ecological status of its riparian zone. As noted in Table 5-2, it shows that the condition at the time of the study had less species richness as compared to the previous year, i.e. 2012. This shows that the species richness increased in both 2012 and 2018 as compared to 1995 and this could be due to alien invasion within the area due to both natural and anthropogenic activities within the riparian zone.

5.3 Different species identified during the reference condition in 1995 and 2012.

Tables 5-3 and 5-4 show the reference condition based on species identification that was completed in 1995 and 2012 (Du Toit, 2015) of riparian vegetation in the Mooi River catchment which was used as the reference condition. Different transects were identified and used for the research which covered a period of 17 years as compared to the current study of 10 years. According to Du Toit (2015), in 1995 the total species recorded for the 67 sites sampled (resampled in 2012) was 309 (83% indigenous) species.

Table 5-3: The 74 species composition identified and recorded in 1995 yet absent in 2012 (Du Toit, 2015).

*Exotic Species

No.	Species Name	Origin	Lifespan	Life form	N	VL
1.	<i>Pachystigma pygmaeum</i> (Schltr.) Robyns	indigenous	perennial	shrub	4	0
2.	<i>Andropogon schirensis</i> A. Rich.	indigenous	perennial	grass	1	0
3.	<i>Aristida adscensionis</i> L.	indigenous	annual	grass	1	0
4.	<i>Boophone disticha</i> (L.f.) Herb.	indigenous	perennial	herb	5	0
5.	<i>Chlorophytum cooperi</i> (Baker) Nordal	indigenous	perennial	herb	1	0
6.	<i>Crotalaria lotoides</i> Benth.	indigenous	perennial	herb	2	0
7.	<i>Dianthus mooiensis</i> F.N. Williams	indigenous	perennial	herb	1	0
8.	<i>Dicoma macrocephala</i> DC.	indigenous	perennial	herb	2	0
9.	<i>Eragrostis micrantha</i> Hack.	indigenous	perennial	grass	1	0
10.	<i>Gazania krebsiana</i> Less. subsp. <i>serrulata</i> (DC.) Roessler	indigenous	perennial	herb	1	0
11.	<i>Gomphocarpus fruticosus</i> (L.) Aiton f.	indigenous	perennial	shrub	1	1
12.	<i>Haplocarpha scaposa</i> Harv.	indigenous	perennial	herb	2	0
13.	<i>Helichrysum caespitium</i> (DC.) Harv.	indigenous	perennial	herb	1	0
14.	<i>Hibiscus aethiopicus</i> L.	indigenous	perennial	herb	1	0
15.	<i>Hibiscus trionum</i> L.	indigenous	annual	herb	1	0
16.	<i>Kohautia caespitosa</i> Schnizl. subsp. <i>brachyloba</i> (Sond.) D.Mantell	indigenous	annual	herb	1	0
17.	<i>Pearsonia cajanifolia</i> (Harv.) Polhill subsp. <i>cajanifolia</i>	indigenous	perennial	herb	1	0

18.	<i>Polygala amatymbica</i> Eckl. and Zeyh.	indigenous	perennial	herb	4	0
19.	<i>Portulaca quadrifida</i> L.	indigenous	annual	herb	0	1
20.	<i>Ranunculus multifidus</i> Forssk.	indigenous	perennial	herb	1	0
21.	<i>Raphionacme hirsuta</i> (E. Mey.) R.A. Dyer ex E. Phillips	indigenous	perennial	herb	4	0
22.	<i>Seriphium plumosum</i> L.	indigenous	perennial	shrub	2	0
23.	<i>Setaria nigrirostris</i> (Nees) T. Durand and Schinz	indigenous	perennial	grass	1	0
24.	<i>Sonchus oleraceus</i> L.*	exotic	annual	herb	0	1
25.	<i>Stachys spathulata</i> Burch. ex Benth.	indigenous	perennial	herb	0	1
26.	<i>Trichodesma angustifolium</i> Harv. subsp. <i>angustifolium</i>	indigenous	perennial	herb	1	0
27.	<i>Vernonia poskeana</i> Vatke and Hildebr. subsp. <i>botswanica</i> G.V. Pope	indigenous	annual	herb	1	0
28.	<i>Xysmalobium undulatum</i> (L.) Aiton f.	indigenous	perennial	herb	2	0
29.	<i>Ziziphus mucronata</i> Willd. subsp. <i>mucronata</i> (T)	indigenous	perennial	tree	1	0
30.	<i>Helichrysum zeyheri</i> Less.	indigenous	perennial	herb	1	0
31.	<i>Ipomoea oenotheroides</i> (L.f.) Raf. ex Hallier f.	indigenous	perennial	shrub	1	0
32.	<i>Kyphocarpa angustifolia</i> (Moq.) Lopr.	indigenous	annual	herb	3	0
33.	<i>Sporobolus africanus</i> (Poir.) Robyns and Tournay	indigenous	perennial	grass	1	0
34.	<i>Tephrosia burchellii</i> Burt Davy	indigenous	annual	herb	1	0
35.	<i>Tephrosia capensis</i> (Jacq.) Pers.	indigenous	perennial	herb	1	0
36.	<i>Ancylobotrys capensis</i> (Oliv.) Pichon	indigenous	perennial	shrub	1	0

37.	<i>Bewisia biflora</i> (Hack.) Gooss.	indigenous	perennial	grass	2	0
38.	<i>Cenchrus ciliaris</i> L.	indigenous	perennial	grass	1	0
39.	<i>Chamaecrista comosa</i> E. Mey.	indigenous	perennial	herb	1	0
40.	<i>Cleome rubella</i> Burch.	indigenous	annual	herb	2	0
41.	<i>Crotalaria monophylla</i> Germish.	indigenous	perennial	herb	1	0
42.	<i>Crotalaria virgulata</i> Klotzsch subsp. <i>grantiana</i> (Harv.) Polhill	indigenous	annual	herb	3	0
43.	<i>Cyphia assimilis</i> Sond.	indigenous	perennial	herb	1	0
44.	<i>Dichilus lebeckioides</i> DC.	indigenous	perennial	herb	1	0
45.	<i>Eragrostis barbinodis</i> Hack.	indigenous	perennial	grass	2	0
46.	<i>Euclea crispa</i> (Thunb.) Gürke subsp. <i>crispa</i> (T)	indigenous	perennial	shrub	1	0
47.	<i>Flaveria bidentis</i> (L.) Kuntze*	exotic	annual	herb	1	0
48.	<i>Galium spurium</i> L. subsp. <i>africanum</i> Verdc.	indigenous	annual	herb	1	0
49.	<i>Lantana camara</i> L.*	exotic	perennial	shrub	1	0
50.	<i>Ledebouria luteola</i> Jessop	indigenous	perennial	herb	0	1
51.	<i>Maerua cafra</i> (DC.) Pax (S)	indigenous	perennial	shrub	1	0
52.	<i>Mundulea sericea</i> (Willd.) A. Chev.	indigenous	perennial	shrub	1	0
53.	<i>Nolletia ciliaris</i> (DC.) Steetz	indigenous	perennial	shrub	1	0
54.	<i>Oxygonum dregeanum</i> Meisn.	indigenous	annual	herb	1	0
55.	<i>Pearsonia uniflora</i> (Kensit) Polhill	indigenous	perennial	herb	1	0
56.	<i>Phyllanthus incurvus</i> Thunb.	indigenous	perennial	herb	1	0
57.	<i>Rhynchosia venulosa</i> (Hiern) K. Schum.	indigenous	perennial	herb	1	0
58.	<i>Sansevieria aethiopica</i> Thunb.	indigenous	perennial	herb	2	0

59.	<i>Schistostephium heptalobum</i> (DC.) Oliv. and Hiern	indigenous	perennial	shrub	1	0
60.	<i>Searsia undulata</i> (Jacq.) T.S. Yi, A.J. Mill and J. Wen (S)	indigenous	perennial	shrub	2	0
61.	<i>Senecio achilleifolius</i> DC.	indigenous	perennial	herb	1	0
62.	<i>Senecio coronatus</i> (Thunb.) Harv.	indigenous	perennial	herb	1	0
63.	<i>Senegalia hereroensis</i> (Engl.) Kyal. and Boatwr.	indigenous	perennial	tree	1	0
64.	<i>Sisymbrium orientale</i> L.*	exotic	annual	herb	0	1
65.	<i>Solanum mauritianum</i> Scop.*	exotic	perennial	shrub	0	1
66.	<i>Solanum supinum</i> Dunal var. <i>supinum</i>	indigenous	perennial	shrub	2	0
67.	<i>Sonchus asper</i> (L.) Hill subsp. <i>asper</i> *	exotic	annual	herb	0	1
68.	<i>Striga bilabiata</i> (Thunb.) Kuntze subsp. <i>bilabiata</i>	indigenous	annual	herb	1	0
69.	<i>Talinum arnotii</i> Hook.f.	indigenous	annual	shrub	5	0
70.	<i>Tarchonanthus camphoratus</i> L. (S)	indigenous	perennial	shrub	1	0
71.	<i>Verbascum virgatum</i> Stokes*	exotic	perennial	herb	0	1
72.	<i>Viscum rotundifolium</i> L.f.	indigenous	perennial	shrub	2	0
73.	<i>Xenostegia tridentata</i> (L.) D.F. Austin and Staples subsp. <i>angustifolia</i> (Jacq.) Lejoly and Lisowski	indigenous	perennial	herb	2	0
74.	<i>Zornia capensis</i> Pers. subsp. <i>capensis</i>	indigenous	perennial	herb	4	0

Table 5-4: A total number of 61 species recorded in 2012 were not present in 1995 (Du Toit, 2015).

No.	All species	Origin	Lifespan	Life form	NS	VLS
1.	<i>Alcea rosea</i> L.*	exotic	perennial	herb	0	1
2.	<i>Ammi majus</i> L. var. <i>glaucifolium</i> (L.) Godr.*	exotic	annual	herb	0	1
3.	<i>Anisodonteia capensis</i> (L.) Bates	indigenous	perennial	shrub	0	5
4.	<i>Anredera cordifolia</i> (Ten.) Steenis*	exotic	perennial	herb	0	1
5.	<i>Aristida stipitata</i> Hack.	indigenous	perennial	grass	1	0
6.	<i>Arundo donax</i> L.*	exotic	perennial	grass	0	1
7.	<i>Bidens pilosa</i> L.*	exotic	annual	herb	4	0
8.	<i>Bonatea speciosa</i> (L.f.) Willd.	indigenous	perennial	herb	2	0
9.	<i>Bromus catharticus</i> Vahl*	exotic	annual	grass	0	1
10.	<i>Celtis sinensis</i> Pers.*	exotic	perennial	tree	0	1
11.	<i>Cestrum aurantiacum</i> Lindl.*	exotic	perennial	shrub	0	3
12.	<i>Cirsium vulgare</i> (Savi) Ten.*	exotic	annual	herb	2	0
13.	<i>Citrus limon</i> (L.) Burm.f.*	exotic	perennial	shrub	0	1
14.	<i>Convolvulus arvensis</i> L.*	exotic	perennial	herb	1	1
15.	<i>Coreopsis lanceolata</i> L.*	exotic	perennial	herb	0	2
16.	<i>Cryptolepis oblongifolia</i> (Meisn.) Schltr	indigenous	perennial	shrub	1	0
17.	<i>Cymbopogon caesius</i> (Hook. and Arn.) Stapf *	indigenous	perennial	grass	11	0
18.	<i>Cynodon hirsutus</i> Stent	indigenous	perennial	grass	0	1
19.	<i>Datura ferox</i> L.*	exotic	annual	herb	0	1

20.	<i>Datura stramonium</i> L.*	exotic	annual	herb	0	2
21.	<i>Dicerocaryum eriocarpum</i> (Decne.) Abels	indigenous	perennial	herb	1	0
22.	<i>Dichondra micrantha</i> Urb.*	exotic	perennial	herb	2	9
23.	<i>Eucalyptus camaldulensis</i> Dehnh.* (S)	exotic	perennial	shrub	1	0
24.	<i>Euphorbia heterophylla</i> L.*	exotic	annual	herb	0	1
25.	<i>Euphorbia prostrata</i> Aiton*	exotic	annual	herb	0	2
26.	<i>Foeniculum vulgare</i> Mill. var. <i>vulgare</i> *	exotic	perennial	herb	0	2
27.	<i>Gynmosporia tenuispina</i> (Sond.) Szyszyl.	indigenous	perennial	shrub	1	0
28.	<i>Haplocarpha lyrata</i> Harv.	indigenous	perennial	herb	1	0
29.	<i>Helichrysum rugulosum</i> Less.	indigenous	perennial	herb	5	1
30.	<i>Hibiscus engleri</i> K. Schum.	indigenous	perennial	herb	2	0
31.	<i>Indigofera vicioides</i> Jaub. and Spach var. <i>vicioides</i>	indigenous	perennial	herb	1	0
32.	<i>Ipomoea ommaneyi</i> Rendle	indigenous	perennial	herb	1	0
33.	<i>Kohautia amatymbica</i> Eckl. and Zeyh.	indigenous	annual	herb	1	0
34.	<i>Lotononis calycina</i> (E. Mey.) Benth.	indigenous	perennial	herb	1	0
35.	<i>Loudetia simplex</i> (Nees) C.E. Hubb.	indigenous	perennial	grass	1	0
36.	<i>Macleodium zeyheri</i> (Sond.) S. Ortiz subsp. <i>Zeyheri</i>	indigenous	perennial	herb	3	0
37.	<i>Malva parviflora</i> L. var. <i>parviflora</i> *	exotic	annual	herb	0	1
38.	<i>Melilotus alba</i> Desr.*	exotic	annual	herb	2	3
39.	<i>Mirabilis jalapa</i> L.*	exotic	perennial	herb	0	3
40.	<i>Moraea thomsonii</i> Baker	indigenous	perennial	herb	0	1

41.	<i>Morus alba</i> L. var. <i>alba</i> *	exotic	perennial	tree	0	1
42.	<i>Neorautanenien ficifolius</i> (Benth.) C.A.Sm.	indigenous	perennial	herb	1	0
43.	<i>Nothoscordum gracile</i> (Aiton) Stearn*	exotic	perennial	herb	0	1
44.	<i>Ornithogalum viride</i> (L.) J.C. Manning and Goldblatt	indigenous	perennial	herb	0	4
45.	<i>Oxalis obliquifolia</i> Steud. ex Rich.	indigenous	perennial	herb	0	1
46.	<i>Paspalum distichum</i> L.	indigenous	perennial	grass	0	1
47.	<i>Phyllanthus parvulus</i> Sond.	indigenous	perennial	herb	2	0
48.	<i>Picris echioides</i> L.*	exotic	annual	herb	0	1
49.	<i>Prunus armeniaca</i> L.*	exotic	perennial	tree	1	0
50.	<i>Salvia splendens</i> Sellow ex Roem. and Schult.*	exotic	perennial	shrub	0	1
51.	<i>Saponaria officinalis</i> L.*	exotic	perennial	herb	0	1
52.	<i>Senna didymobotrya</i> (Fresen.) Irwin and Barneby*	exotic	perennial	shrub	0	1
53.	<i>Setaria lindenbergiana</i> (Nees) Stapf	indigenous	perennial	grass	2	0
54.	<i>Setaria pumila</i> (Poir.) Roem. and Schult.	indigenous	annual	grass	1	1
55.	<i>Sida alba</i> L.	indigenous	annual	shrub	0	1
56.	<i>Sorghum halepense</i> (L.) Pers.*	exotic	perennial	grass	0	1
57.	<i>Sutera caerulea</i> (L.f.) Hiern	indigenous	annual	herb	1	0
58.	<i>Talinum cafferum</i> (Thunb.) Eckl. and Zeyh.	indigenous	annual	herb	1	5
59.	<i>Tragia rupestris</i> Sond.	indigenous	perennial	herb	7	0
60.	<i>Tristachya leucothrix</i> Nees	indigenous	perennial	grass	1	0
61.	<i>Verbena officinalis</i> L.*	exotic	annual	herb	0	7

The 2012 sites contained a total of 298 (74% indigenous) species (Tables 5-3 and 5-4 show the list of all recorded species in 1995 and 2012 respectively). According to Du Toit (2015), 235 of the species recorded occurred in both 1995 and 2012. Twenty-four (24) of the species recorded in 2012 are listed as declared invasive plants according to the Conservation of Agricultural Resources Act, 1983 (Act No 43 of 1983) (CARA) amended in 2001 in and around the Potchefstroom area (Du Toit, 2015). However, during the current study, a total of 22 different species was identified in only six sampling sites. The sample sizes of the species composition of the reference condition as compared to the present ecological condition are different, therefore, the results may not be the same. However, comparison was done with the same type of species identified in the current study to assess total richness.

According to the comparison made for the years 1995-2012 and 2018, it shows that there was a decline in indigenous species from 2012 to 2018 along the Mooi River and the six sites evaluated in this study area had low numbers and/or diversity as compared with the previous study done in 1995 and 2012 in the Mooi River catchment. The decline was due to anthropogenic activities such as stock farming, grazing, development (construction of activities such as roads, bridges, wastewater treatment plants, recreational areas). A further decline in indigenous species could be due to exotic species that were found such as *Acacia mearnsii*, *Salix babylonica*, *Bidens pilosa*, *Cirsium vulgare*, *Eucalyptus grandis*, *Morus alba*, *Melia azedarach* and ferns which were identified along the riparian zone. However, *Salix babylonica* was identified as one of the exotic species establishing at an alarming rate within the Mooi River catchment as compared to other exotic species (Table 5-3).

The study further indicated that the riparian zone had been fluctuating in species distribution in different years. Subsequently, species such as *Acacia mearnsii*, *Cirsium vulgare*, *Eucalyptus grandis*, *Hyparrhenia hirta*, *Morus alba*, *Phragmites australis*, *Populus* sp., *Pteridium aquilinum*, *Salix babylonica*, *Schoenoplectus* sp., *Searsia lancea*, *Typha capensis* and ferns had high richness in 2018 as compared to both 1995 and 2012. This shows that exotic species had taken over because the Mooi River catchment is predominantly covered with exotic species, having a negative impact on the surrounding ecosystem functions. If exotic species are not controlled and eradicated, they will end up outcompeting indigenous species.

It is discouraging to observe that indigenous species richness is declining, as confirmed by Chen *et al.* (2017) and that the riparian zone areas are susceptible to species invasion due to a variety

of anthropogenic disturbances and landscape patterns as well as adjacent land use which may also be significant drivers in the process (Chen *et al.*, 2017).

Table 5-2 shows that indigenous species such as *Asparagus suaveolens*, *Cynodon dactylon*, *Celtis africana*, *Grewia flavescens*, *Grewia occidentalis*, *Melia azedarach* and *Panicum maximum* had low richness in species distribution in 2018 as compared to both 1995 and the year 2012 respectively (reference condition). A similar type of species was of high richness in both 1995 and the year 2012 respectively. This is an indication that exotic species are taking over the Mooi River catchment because there is a major decline in most of the indigenous species along area.

It was further found that there were different species identified in all six (6) sampled sites in 2018, however, the overall species composition and total richness in and around the six sampled sites were 163, whereas the reference condition showed that, in 1995, the same species had a total richness of 150 and in 2012, they were 166. According to Table 5-3, species richness was more in 2012 and 2018, however, an increase in proliferation of exotic plants species was evident. There was a disparity between the numbers of plant species composition of riparian vegetation identified in both 1995 and 2012 as compared to the present conditions. Indigenous and exotic species such as *Acacia mearnsii*, *Phragmites australis*, *Populus* sp., *Pteridium aquilinum*, *Salix babylonica*, *Schoenoplectus* sp., *Typha capensis* and ferns were not identified in both 1995 and 2012.

The transformation in plant species along the riparian zone could be since there were physical alterations in the physical ecosystem processes of the area by both anthropogenic and natural activities, even though the causes of the changes could be difficult to confirm (the changes were estimated not measured). This was confirmed by Richardson *et al.* (2000), who stated that changes in plant species composition might be because of the alterations in the physical ecosystem processes of the area. Furthermore, Dark (2004) indicated that, when riparian areas are disturbed, they usually become unstable and more susceptible to erosion and invasion of alien plants.

5.2.4 Species distribution at the sampling sites

According to Figure 5-1, in all six sampled sites, *Salix babylonica* is the dominant species at 13% which means all six sampled sites are dominated by trees, followed by *Ehretia rigida* at 12%, then *Phragmites australis* at 10%, thereafter *Typha canpesis*, *Searsia lancea* and *Asparagus Suaveolens* at 8%, then *Celtis africanus*, *Cynodon dactylon* and *Melia azedarach* at 4%, then *Pteridiun aquilinum*, *Populus sp.*, *Panicum maximum*, *Morus alba*, *Hyparrhenia hirta*, *Eucalyptus grandis* and ferns at 3%, followed by *Acacia mearnsii*, *Bidens pilosa*, *Grewia Flavescent*, *Grewia Occidentals* and *Schoenoplectus sp.* and finally *Cirsium Vulgare* at 1%.

It is evident from the current study that riparian vegetation along Mooi River catchment is dominated by trees and shrubs, which confirms the conclusion by Nilsson and Svedmark (2002) who confirmed that riparian vegetation often has diverse tree and shrub vegetation, which serves as habitat for mammals and birds and woody debris that provides suitable conditions for both terrestrial and aquatic invertebrates.

Average of species composition for six (6) sampled sites along the Mooi River Catchment.

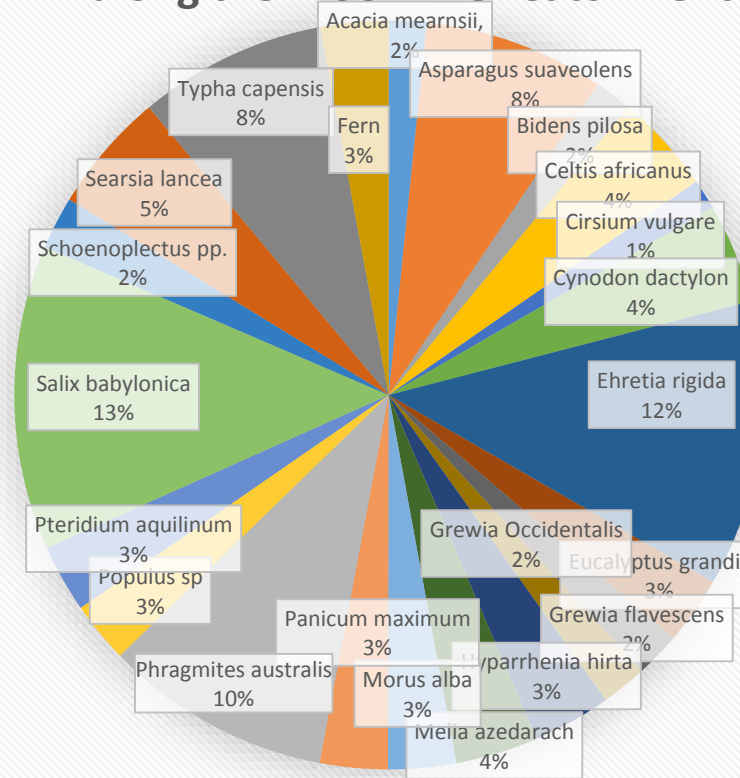


Figure 5- 1: Species distribution to determine different species occurrence for the combined sampled sites around the Mooi River catchment on 10 and 11 October 2018.

5.2.5 Percentage of species distribution for each specific site along the riparian zone of the Mooi River catchment.

Figure 5-2 represents a percentage distribution of species recorded of the Mooi River catchment as per the sampled area. For the Kromdraai area, the results show species composition identified along the Mooi River catchment and both *Ehretia rigida* and *Salix babylonica* have the highest distribution of 18%, followed by *Asparagus suaveolens* at 11%, thereafter *Typha capensis*, *Searsia lancea*, *Schoenoplectus* sp., *Populus* sp., *Phragmites australis*, *Melia azedarach* at 7% and lastly *Hyparrhenia hirta*, *Eucalyptus grandis* and *Cirsium vulgare* at the lowest richness a with 4%. It is evident from the observations that both *Salix babylonica* and *Ehretia rigida* are dominating in the Kromdraai site of the Mooi River catchments.

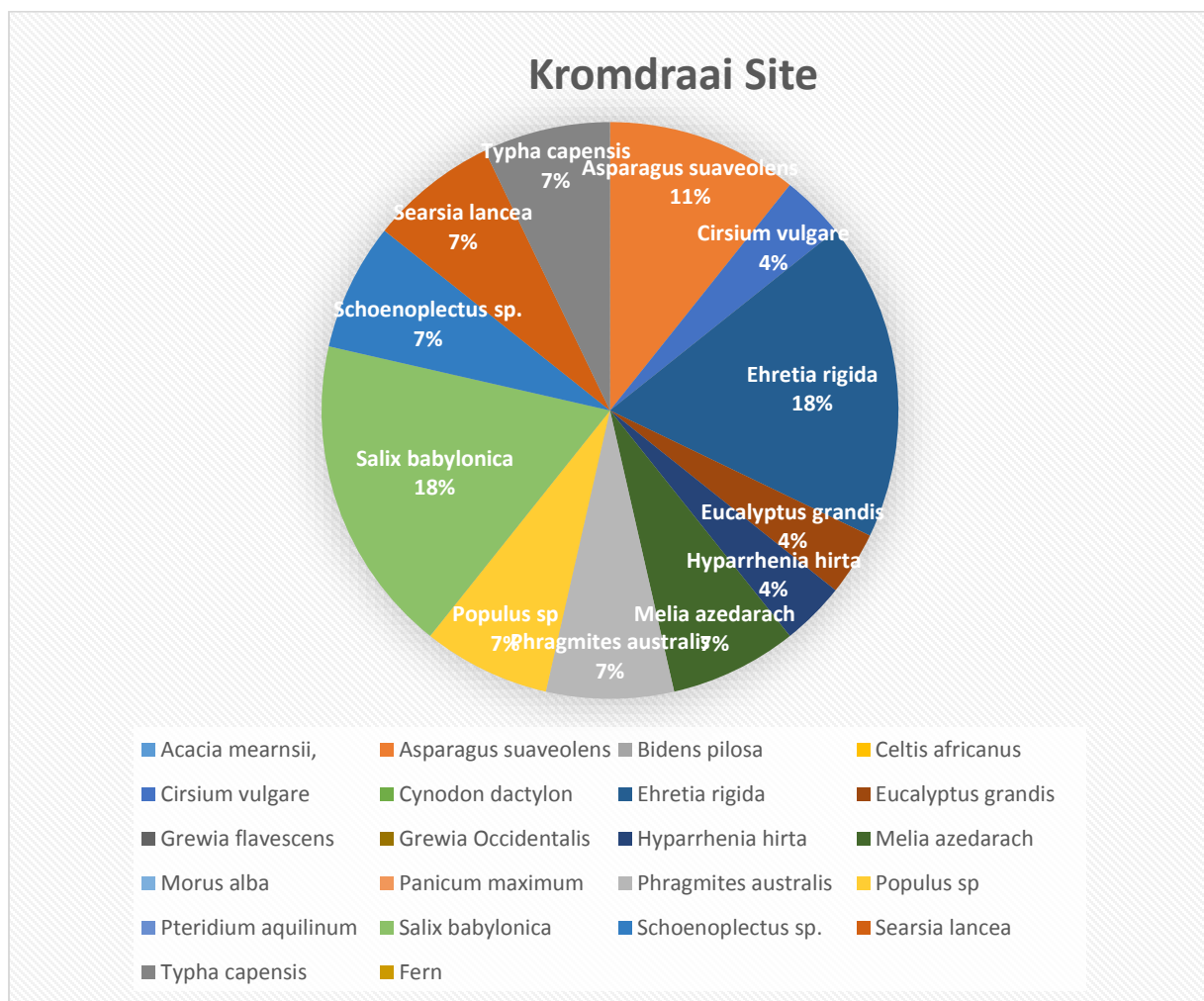


Figure 5- 2: Specimens per species (in %) for Kromdraai Site for the survey undertaken on 10 October 2018.

Figure 5-3 represents the species richness of the South Bridge site along the Mooi River catchment. The results indicate that there are different species distribution whereby *Ehretia rigida*, *Salix babylonica*, *Typha capensis*, *Populus sp.* and *Asparagus suaveolens* have the highest species distribution at a percentage of 13%, thereafter *Searsia lancea*, *Phragmites australis*, *Melia azedarach*, *Bidens pilosa* and *Hyparrhenia hirta* at the lowest dominance of 7%. It is evident from the observations that *Salix babylonica*, *Ehretia rigida*, *Typha Capensis*, *Populus sp.* and *Asparagus suaveolens* are dominating in the South Bridge site of the Mooi River catchment. Riparian vegetation has a diversity of trees and shrubs vegetation which serves as habitat for mammals and birds as well as woody debris that provides suitable conditions for both terrestrial and aquatic invertebrates.

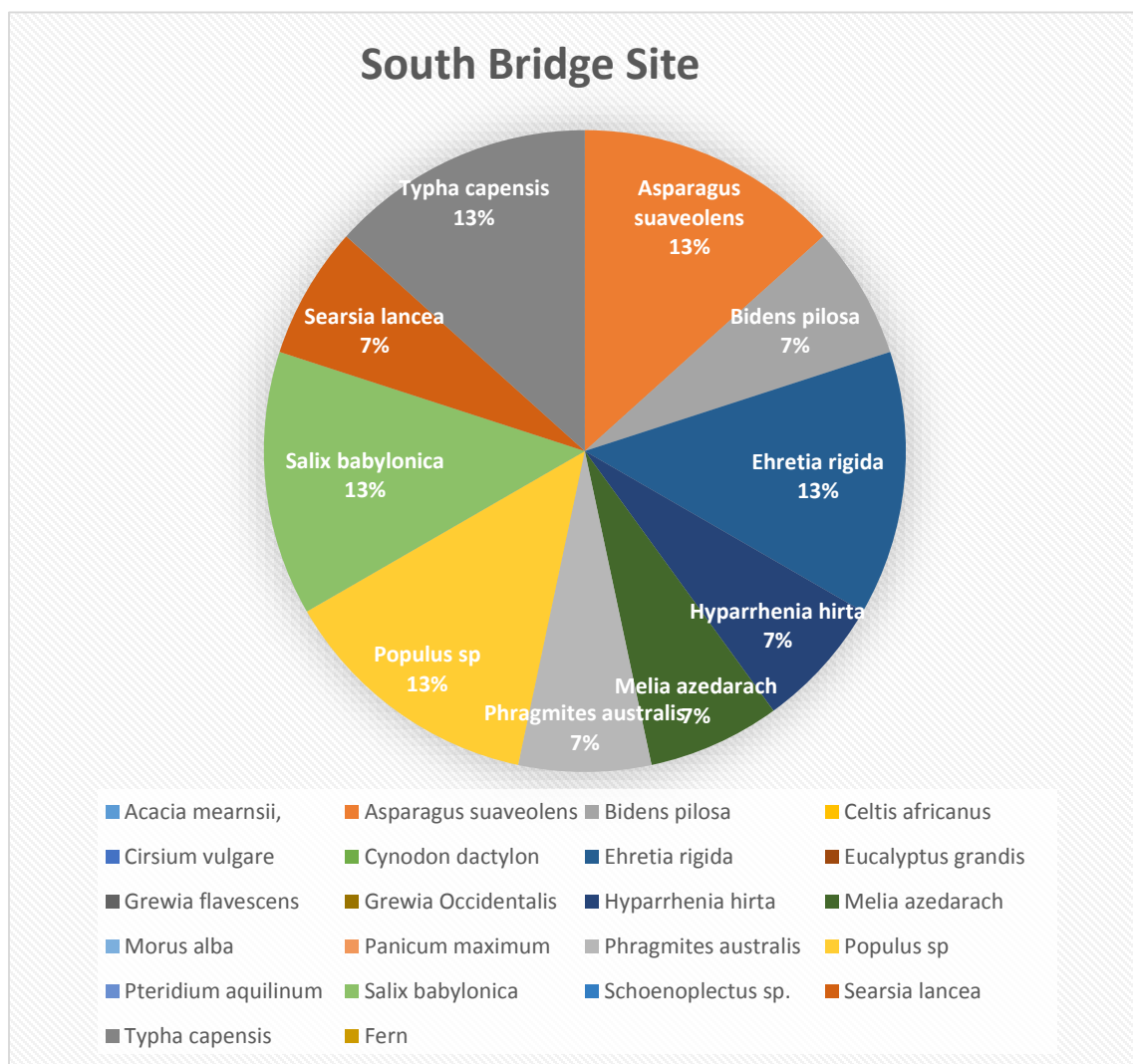


Figure 5- 3: Specimens per species (in %) for South Bridge Site for the survey undertaken on 10 October 2018.

Figure 5-4 represents the diversity or richness of species along the Mooi River catchments at the site. The North Bridge results indicate that there are various species distribution along the Mooi River catchment whereby the *Ehreti rigida* species have the highest percentage at 16%, followed by *Cynodon dactylon*, *Celtis africanus*, ferns, *Typha capensis*, *Searsia lancea* at 8%, thereafter *Salix babylonica*, *Morus alba*, *Grewia* sp., *Grewia fluvescens* and *Asparagus suaveolens* at 5% and lastly *Cirsium vulgare*, *Bidens pilosa*, *Melia azedarach*, *Panicum maximum*, *Phragmites australis* and *Pteridium aquilinum* with the lowest distribution of 3%. It is evident from the observations that *Ehretia rigida* are dominating along site 3 of the Mooi River catchment, followed by *Typha Capensis*, *Celtis africanus*, *Searsia lancea* and ferns at the North Bridge site. This study suggests that the fern species (herb) are also part of the second dominant species in the area.

Figure 5-4 further shows that ferns are the second highest in terms of species richness. This confirms that the Mooi River catchment has its own ecological conditions different from other catchments, as stated by Corenblit *et al.* (2017), who concluded that riparian vegetation forms a mosaic of vegetated patches that can have a different physiognomy, structure and composition because of local variability in physical conditions such as flow velocity during floods and elevation above water level, including landform age and land use.

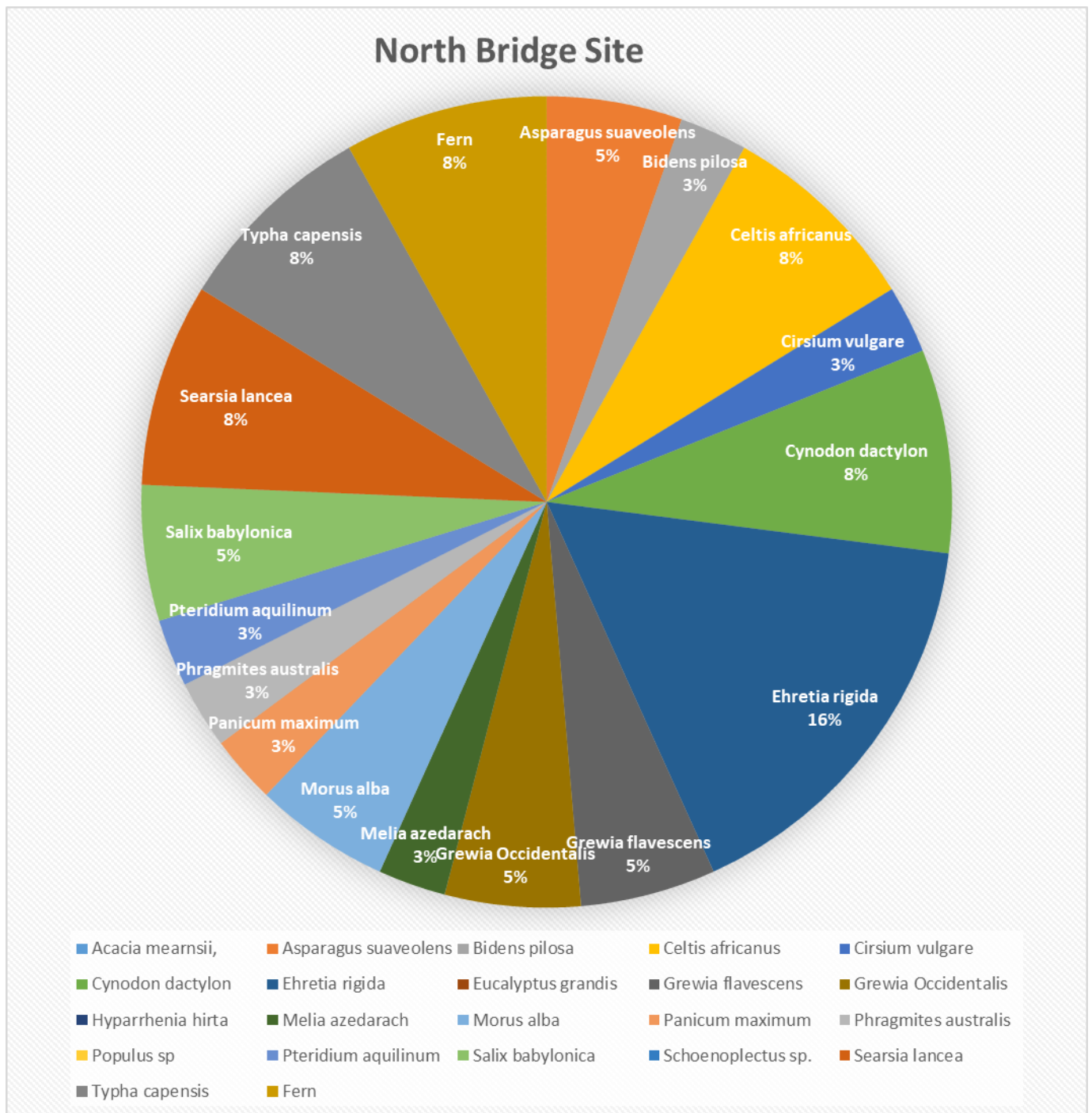


Figure 5- 4: Specimens per species (in %) for North Bridge Site for the survey undertaken on 10 October 2018.

Figure 5-5 below represents the present ecological condition of the Mooi River catchment. Downstream of Boskop Dam shows that there were different species distribution along the Mooi River whereby *Salix babylonica* has the highest distribution of 24%, followed by *Asparagus*

suaveolens and *Phragmites australis* at 16%, thereafter *Ehretia rigida* and *Melia azedarach* both with 12% and *Acacia mearnsii*, *Hyparrhenia hirta*, *Eucalyptus grandis*, *Typha capensis*, *Panicum maximum* at the lowest distribution with 4%.

It is evident from the observations that *Salix babylonica* is dominating downstream of Boskop Dam site of the Mooi River, followed by *Asparagus suaveolens* and *Phragmites australis*. It should be noted that the prevalence of *Salix babylonica* species was also observed in the Kromdraai and South Bridge sites as per Figures 5-2 and 5-3 above.

The results confirm the conclusion that riparian vegetation often has a diversity of tree and shrub vegetation which serves as habitat for mammals and birds as well as woody debris that provides suitable conditions for both terrestrial and aquatic invertebrates (Nilsson & Svedmark, 2002). However, the study suggests that *Phragmites australis* (which is a grass) is also part of the second dominant species in the area. It was also identified that the Downstream of Boskop Dam area is used for stock farming and land use in and around is grazing, thus, the confirmation that the *Phragmites australis* species is the second dominant species in the area because it is used by livestock as food. Figure 5-5 shows the results of the Downstream of Boskop Dam site. The first dominance is *Salix babylonica*, followed by the *Phragmites australis* species which gives a different perspective from the Kromdraai, South Bridge and North Bridge sites above. However, *Salix babylonica* has been dominating in most of the sampled areas such as the Kromdraai and South Bridge sites respectively.

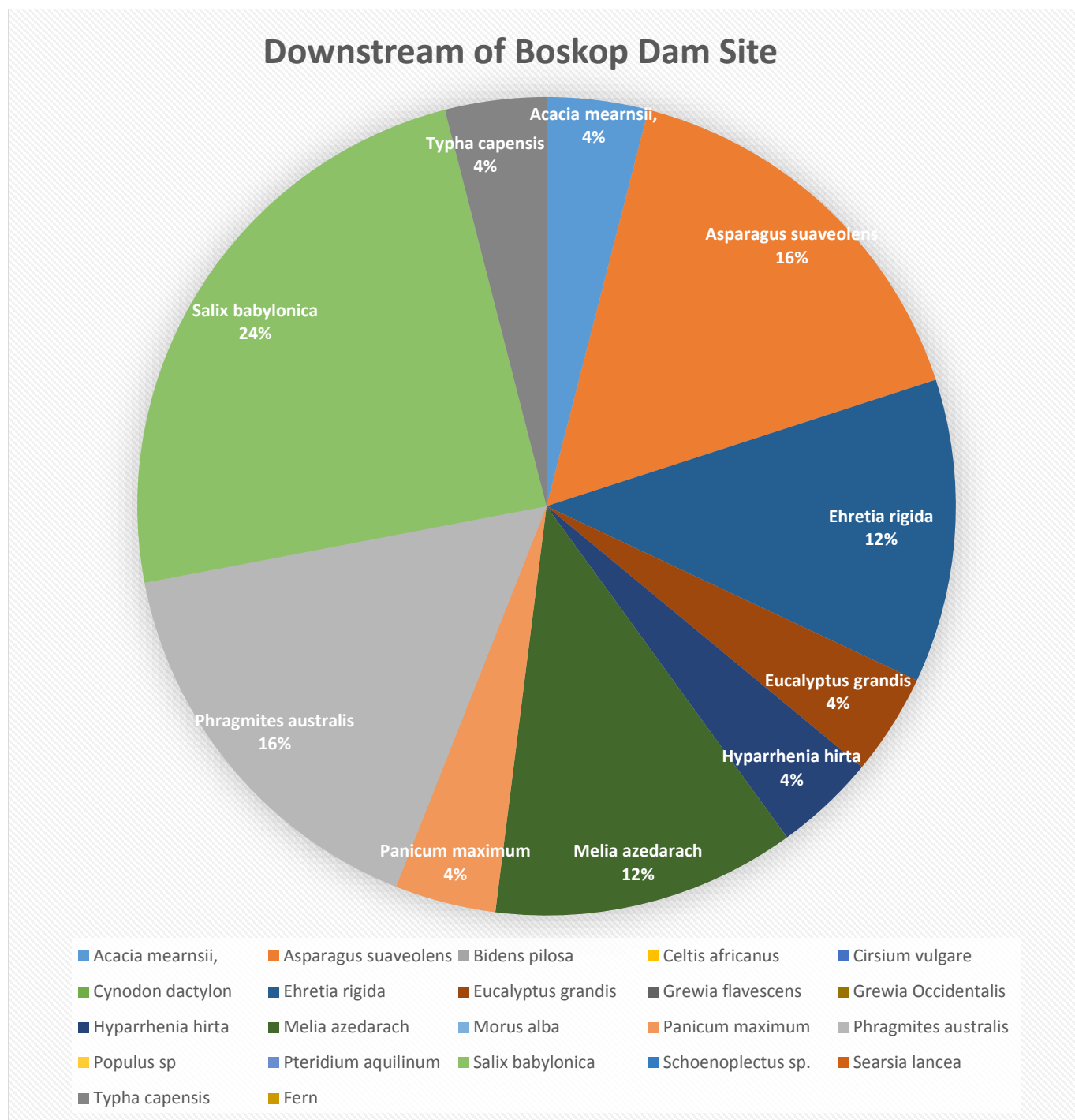


Figure 5- 5: Various species occurrence Downstream of Boskop Dam during a survey undertaken on 11 October 2018.

Figure 5-6 below shows that, in the Muiskraal site, there are different species richness along the Mooi River catchment whereby *Cynodon dactylon* has the highest distribution of 17%, followed by *Typha Capensis* and *Ehretia Rigida* with 13% respectively, thereafter *Searsia Lancea*, *Salix*

babylonica and *Melia Azedarach* at 8% and *Hyparrhenia hirta*, *Eucalyptus grandis*, *Asparagus suaveolens* and *Celtis africanus* at the lowest distribution with 4%.

The results in Figure 5-6 further show that the first dominating plant species were *Cynodon dactylon* which are grasses, followed by *Typha capensis* and *Ehretia rigida* which are shrubs. This is different from the Kromdraai, South Bridge, North Bridge and Downstream of Boskop Dam sites. This could mean that the physical ecosystem process of the sampled area has been transformed which has led to major changes in plant species composition as confirmed by Richardson *et al.* (2000), who stated that changes in plant species composition may be because of the alterations in the physical ecosystem processes of the area. However, the causes of the changes can be difficult to determine. In the Muiskraal Farm site, grazing by livestock has been identified as a contributing factor to the major change in species composition in the area.

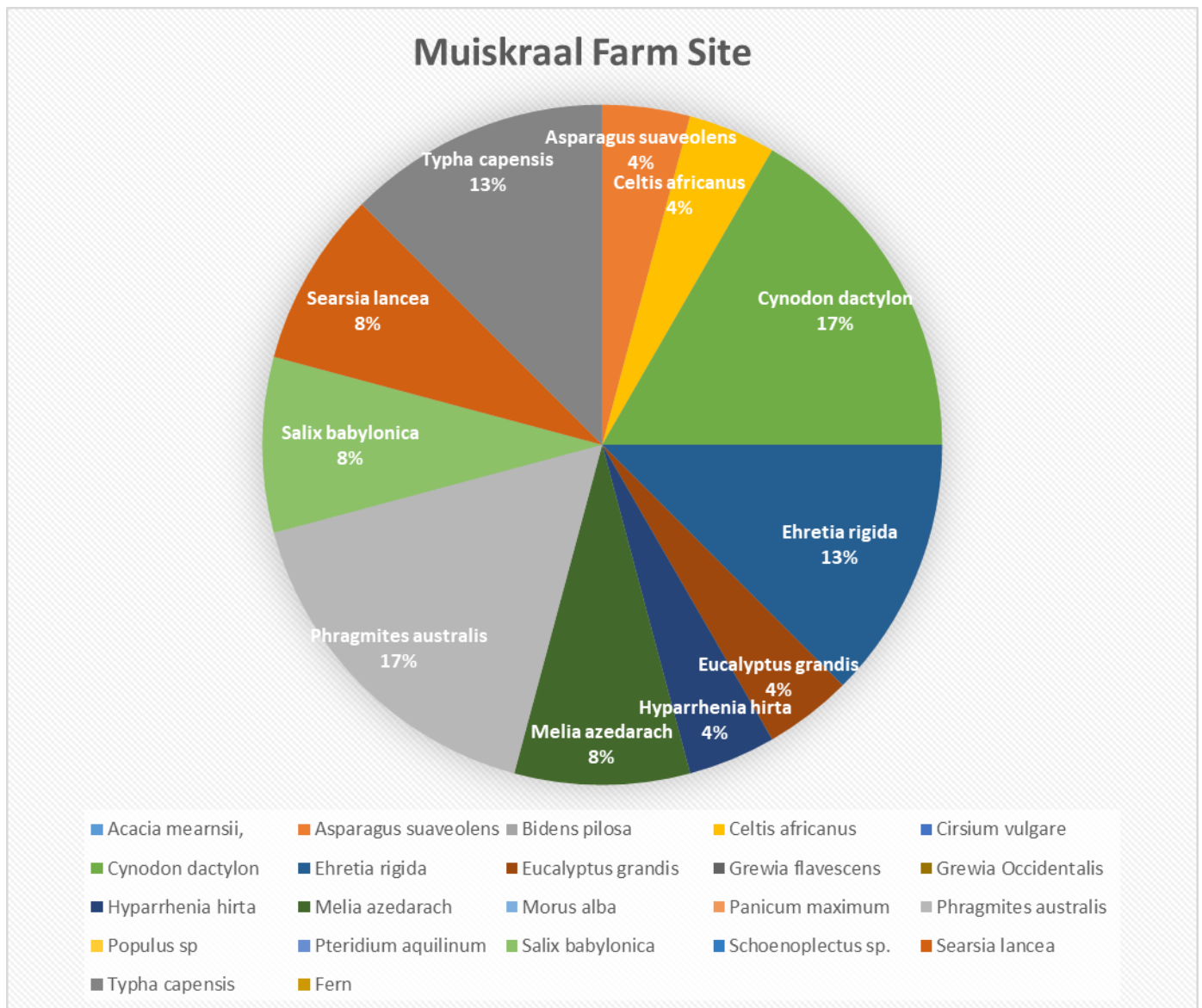


Figure 5- 6: Various species occurrence around Muiskraal Farm site for a survey undertaken on 11 October 2018.

Figure 5-7 below shows that the present ecological condition of the Mooi River catchment has the following findings: there are different species distributed along the Mooi River whereby *Typha capensis* have the highest species distribution of 17%, followed by *Phragmites australis* at 13%, then followed by *Ehretia rigida* and *Salix babylonica* at 10% respectively, thereafter *Pteridium aquilinum*, *Panicum maximum*, *Morus alba*, *Celtis africanus* at 7% and lastly *Hyparrhenia hirta*, Ferns, *Searsia lancea*, *Grewia* sp., *Grewia flavescens*, *Eucalyptus grandis*, *Acacia mearsii* and *Schoenoplectus pp.* at the lowest species distribution of 3%.

Figure 5-7 shows that the Rysmierbult site is dominated by a shrub called *Typha capensis*, followed by grass called *Phragmites australis*. The results further show a conclusion which is different from Kromdraai, South Bridge, North Bridge, Downstream of Boskop Dam and Muiskraal Farm. This could mean that the environmental conditions of the sampled areas are a bit different which has led to different plant species composition along the sampled areas as confirmed by Naiman *et al.* (1998), who mentioned that most of the riparian vegetation species are dependent on certain environmental conditions such as flow patterns for the success of seedlings establishment.

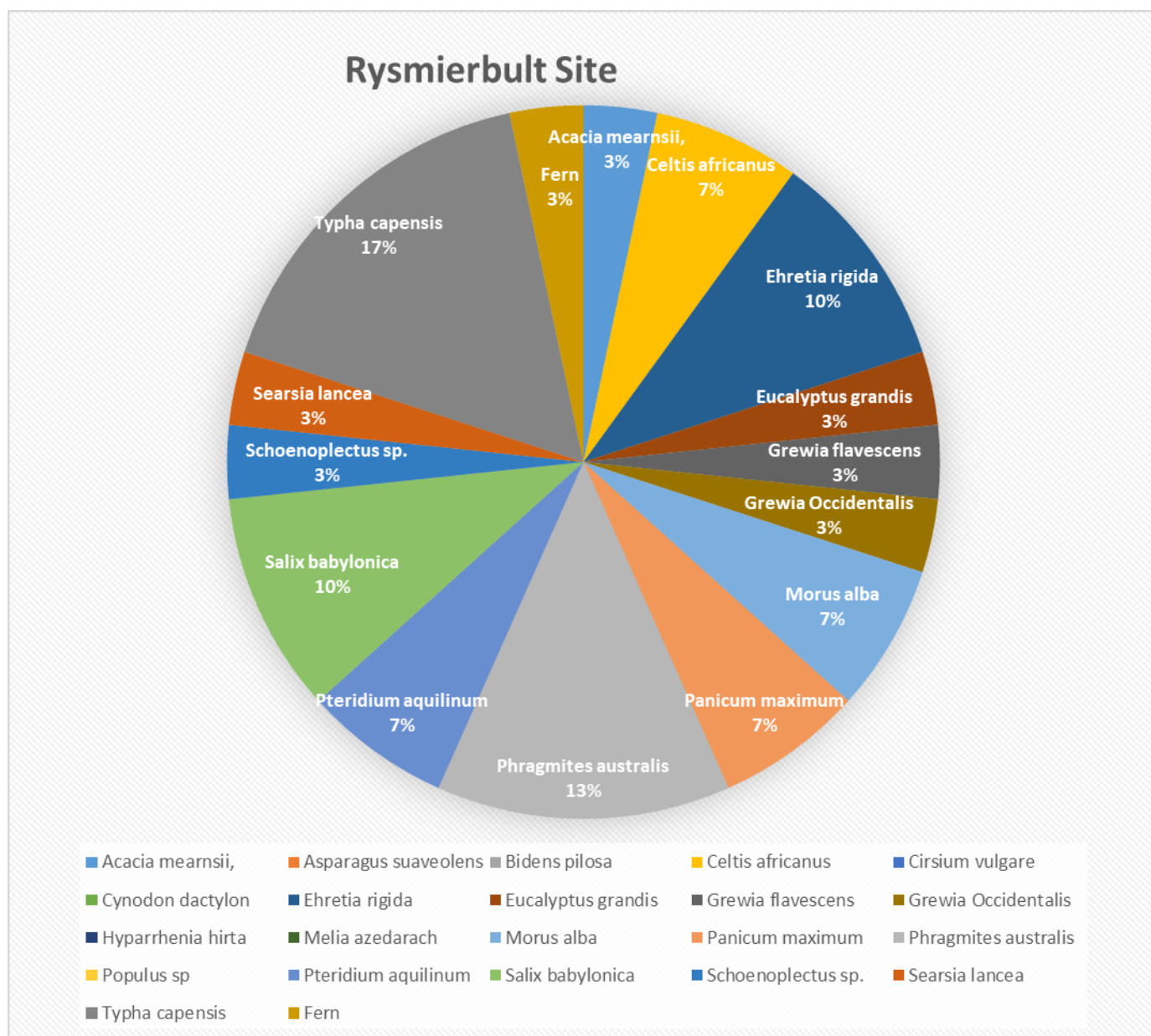


Figure 5- 7: Various species abundance around the Mooi River catchments for the Rysmierbult site during a survey undertaken on 11 October 2018.

The results in Figure 5-8 below indicate species origin in comparison with the distribution along the catchment, i.e. exotic versus indigenous species, amongst the six sampled sites. In all six sampled sites it was found that there are fewer exotic species and more indigenous species. The main exotic species was identified at Boskop Dam at 46%, followed by both the Kromdraai and South Bridge sites at 38% respectively.

Figure 5-8 further shows that Muiskraal Farm has the highest percentage of indigenous species at 79%, followed by the North Bridge site at 74%, then the Rysmierbult site at 73%, thereafter the Kromdraai and South Bridge sites at 62% and lastly Downstream of Boskop Dam at 54%. With regard to exotic species, the Downstream of Boskop Dam site is the site with the highest exotic species percentage at 46%, followed by the Kromdraai and South Bridge sites at 38%, then the Rysmierbult site at 27%, thereafter the North Bridge site at 26% and lastly Muiskraal Farm at 21%.

This could mean there are certain areas along the Mooi River catchment that have been invaded by alien species. Hupp and Rinaldi (2007) indicated that most river catchments have been invaded by exotic vegetation. They also respond differently due to the magnitude of the invasion in a particular area. Pivec (2002) mentioned that native vegetation can consume less water than exotic species which can compete with societal needs between different species.

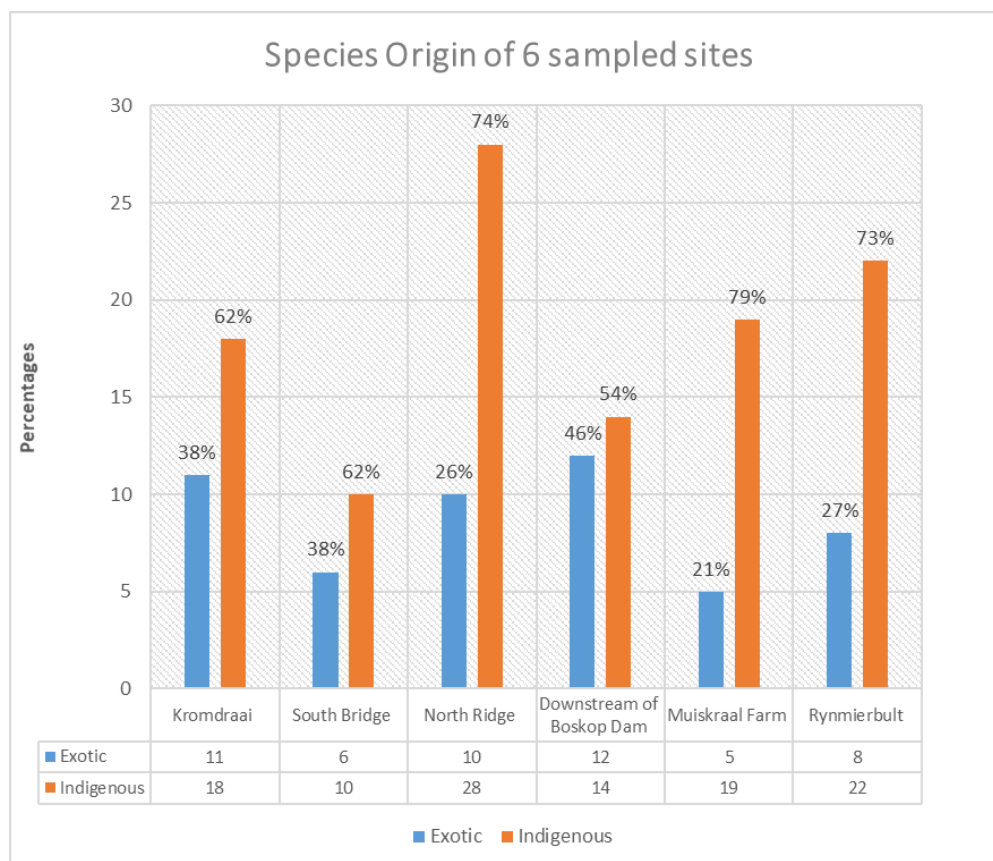


Figure 5- 8: The species origin (exotic and indigenous species) of the vegetation sampled around the Mooi River catchment for the following sites: Kromdraai, South Bridge, North Ridge, Downstream of Boskop Dam, Muiskraal Farm, and Rysmierbult.

Figure 5-9 below represents the life form of the Mooi River catchment as per all six sites. The results indicate that, in terms of life form species, the Kromdraai site is more dominated by trees, followed by shrubs, thereafter, herbs and lastly grass. South Bridge shows that the dominant life form species are trees, followed by shrubs, herbs and grass. North Bridge is dominated by shrubs, followed by herbs, trees and grass. Downstream of Boskop Dam is dominated by trees and shrubs with grass and herbs taking a smaller portion. Muiskraal Farm is dominated by grass, followed by trees, while shrubs and herbs have the lowest proportion. In Rysmierbult, trees and herbs dominate the area, followed by shrubs and grass.

Therefore, out of six sampled sites, three sites are dominated by trees, i.e. the Kromdraai, South Bridge and Downstream of Boskop Dam sites, whereas the North Bridge site is dominated by shrubs, however Rysmierbult farm site has two dominants which are trees and herbs and Muiskraal farm has grass dominating. This could be due to the different landscapes within the riparian zone or catchment area, as confirmed by Parsons *et al.* (2007), who stated that the distribution of riparian vegetation is linked to the height as well as the sloping distance from the active channel and flooding frequency.

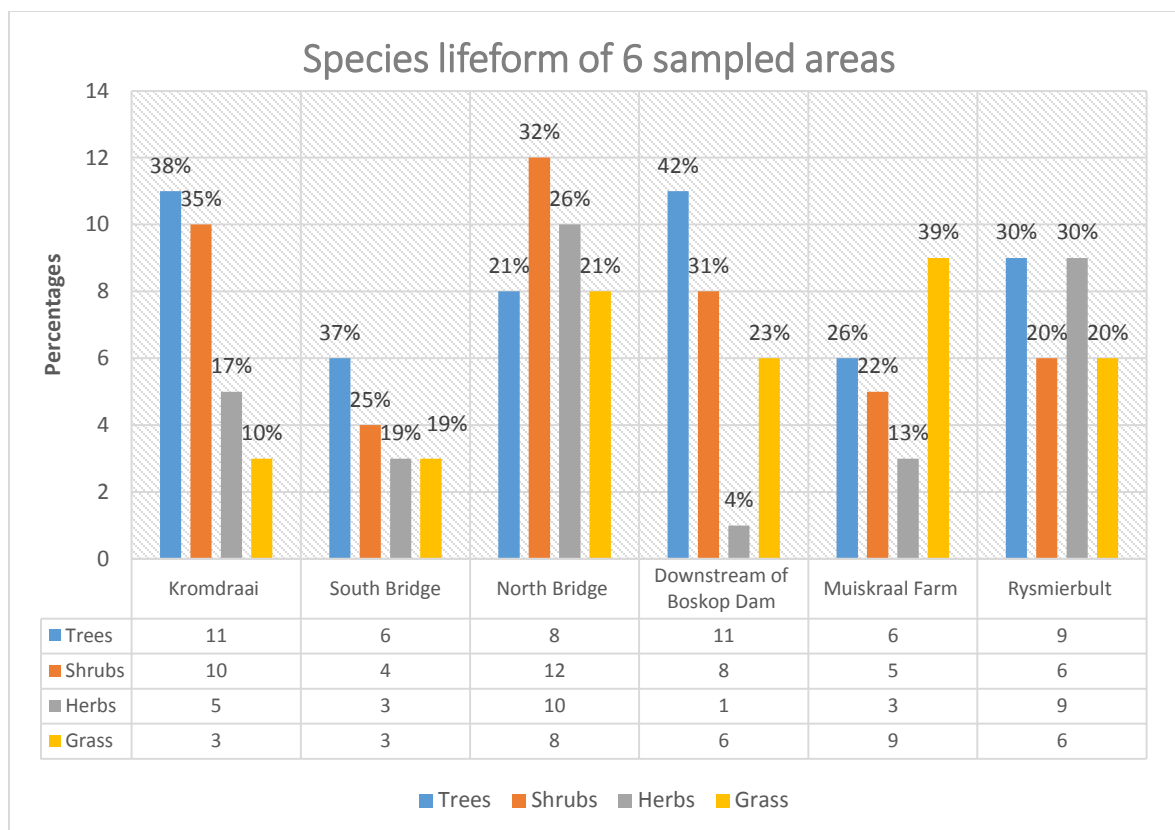


Figure 5- 9: Species lifeform and distribution for the sampled areas around the Mooi River for the following sites: Kromdraai, South Bridge, North Ridge, Downstream of Boskop Dam, Muiskraal Farm, Rysmierbult.

5.2.6 Maps analysing riparian vegetation changes for the past 10 years.

The study framework was developed around the use of progressive aerial photography taken at different stages which covered the years 2009, 2014 and 2019. The progressive aerial photos on Figure 5-10 to Figure 5-15 and Annexure A-1 to Annexure A-6 taken were used as the primary sources to evaluate the spatial and temporal changes in the riparian zone of the Mooi River.

After the aforementioned process, the total surface area covered by the classification of the riparian vegetation was calculated using the zonal geometry as a table tool and accuracy assessment post classification. It must be noted that, for the sake of accuracy assessment, four (4) classes were distinguished, namely vegetation, bare soil, water and built-up area. This means that, after thresholding only three classes were left i.e. after selecting the riparian vegetation out, three class were made arbitrarily. Figure 5-10- Figure 5-15 and Annexure A-1 to A-6 below are the riparian zone image classifications in different years, i.e. from 2009-2014 and 2019 respectively, from downstream to upstream of the Mooi River. The results of this study show that

the spatial extent of the riparian zone was fluctuating in different years and within different sampled sites.

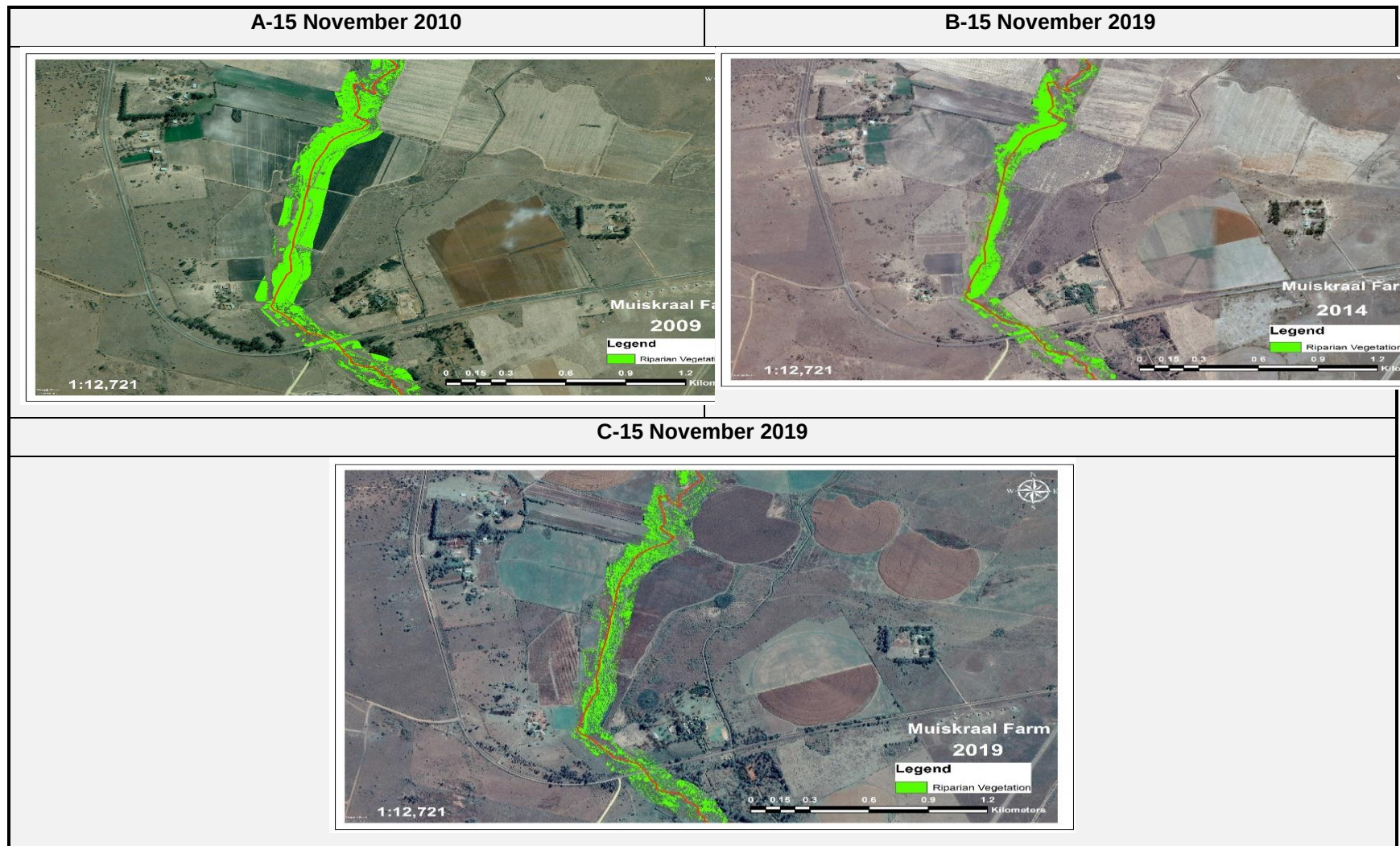


Figure 5- 10: Map (layout) representing the riparian vegetation extent of the Mooi River Catchment during each year in the Muiskraal Farm.

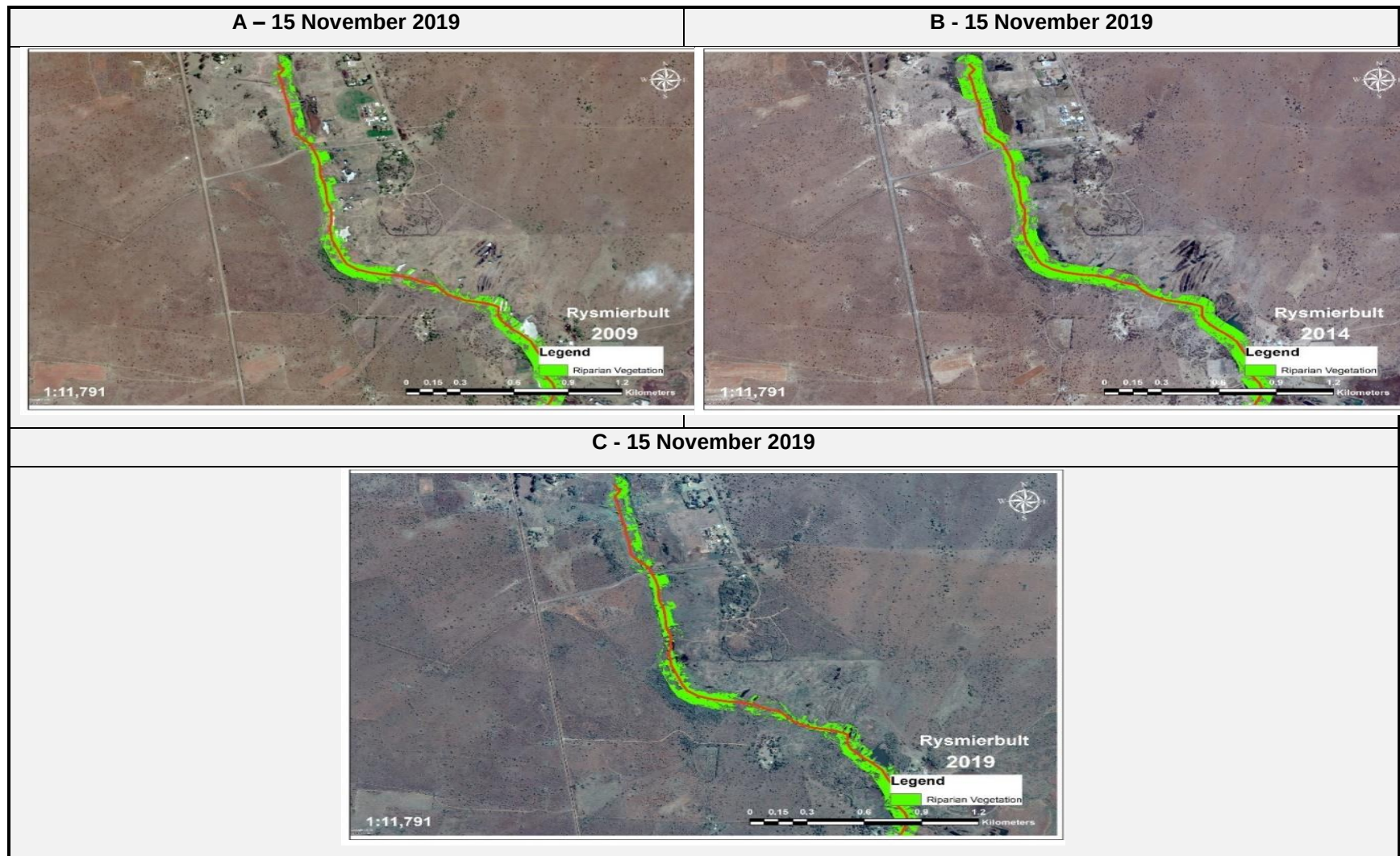


Figure 5- 11: Map (layout) representing the riparian vegetation extent of the Mooi River Catchment during each year around Rysmierbult site.

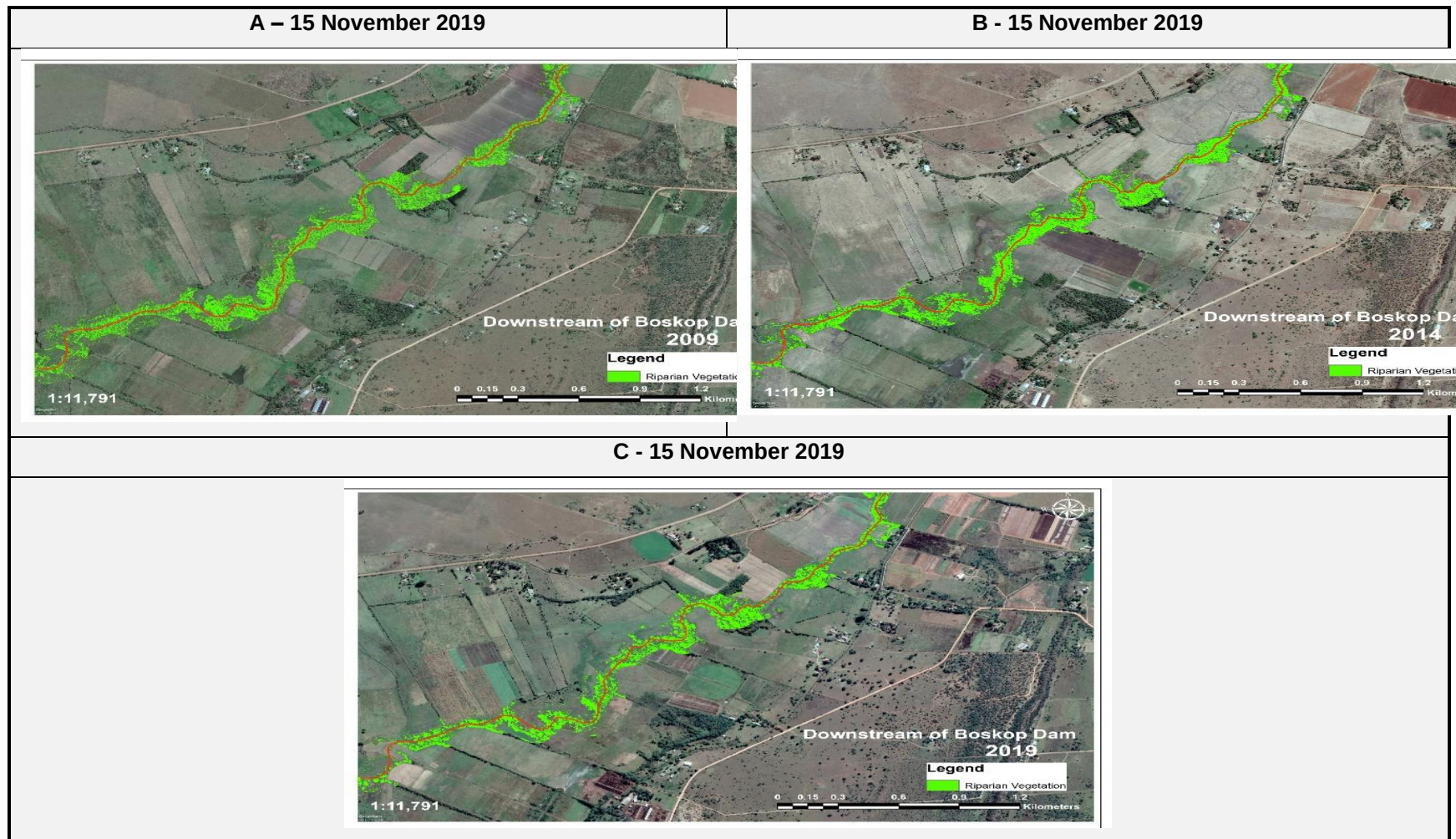


Figure 5- 12: Map (layout) representing the riparian vegetation extent of the Mooi River Catchment during each year in Downstream of Boskop Dam.

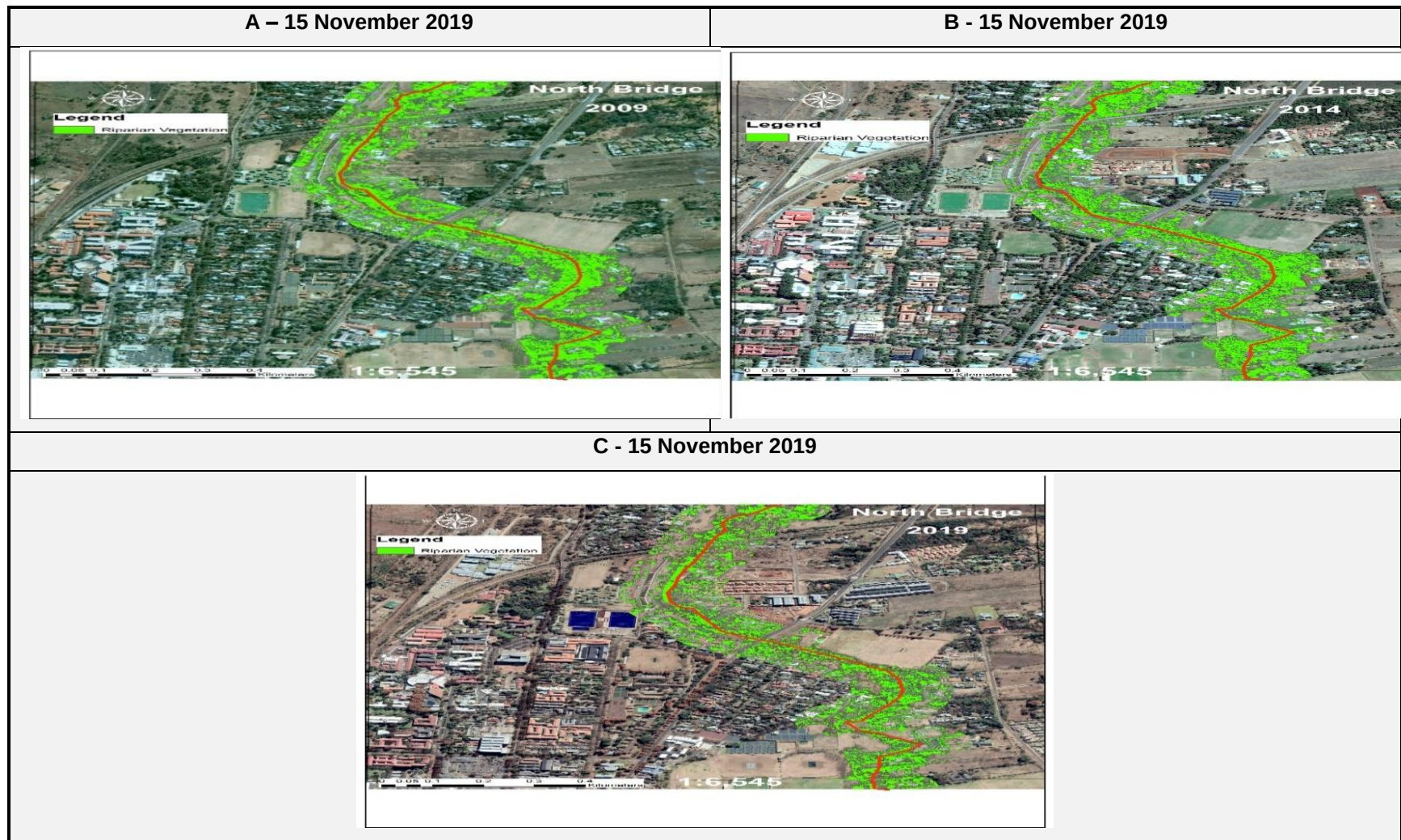


Figure 5- 13: Map (layout) representing the riparian vegetation extent of the Mooi River Catchment during each year in North Bridge site.

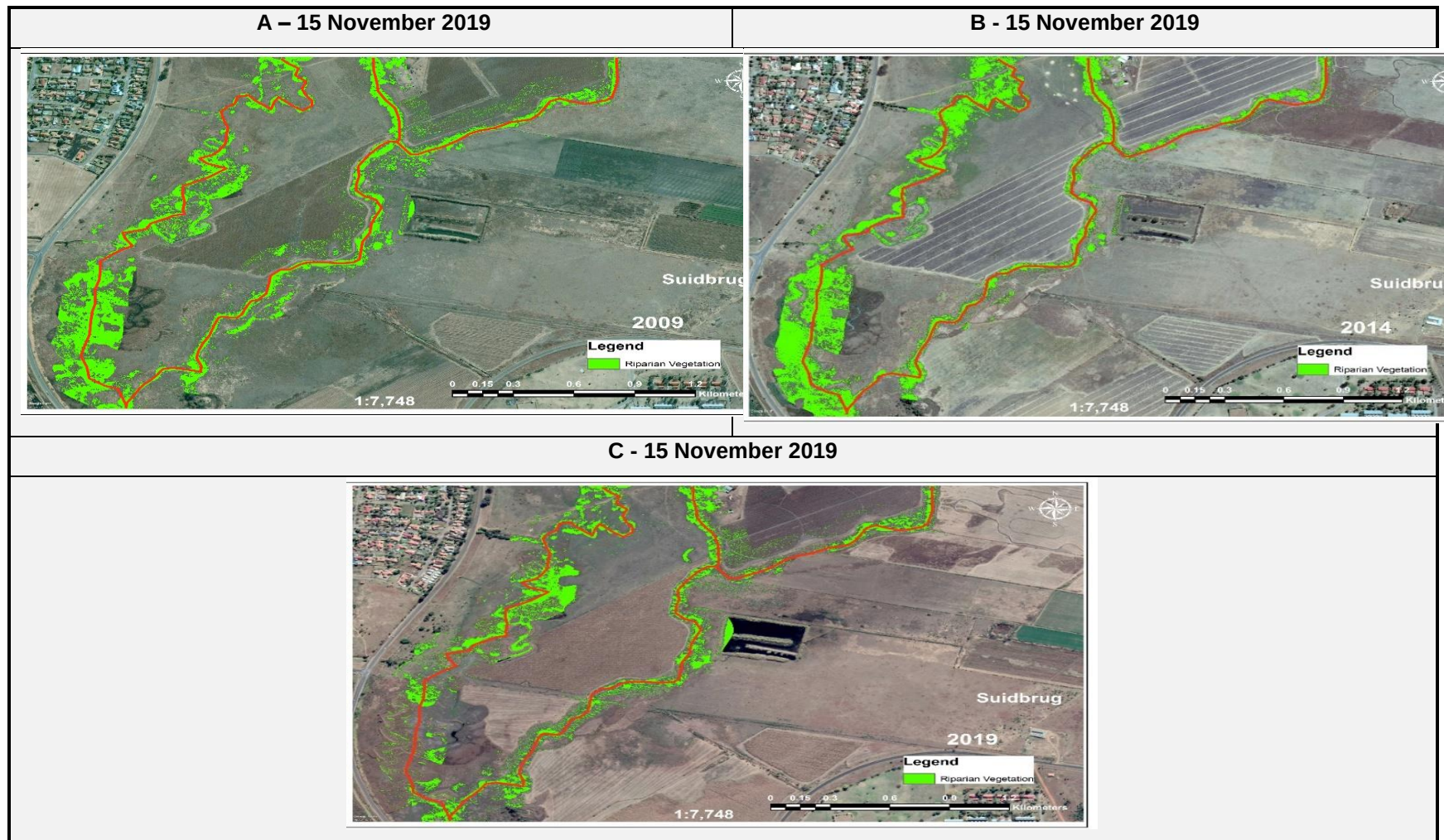


Figure 5- 14: Map (layout) representing the riparian vegetation extent of the Mooi River Catchment during each year around the South Bridge site.

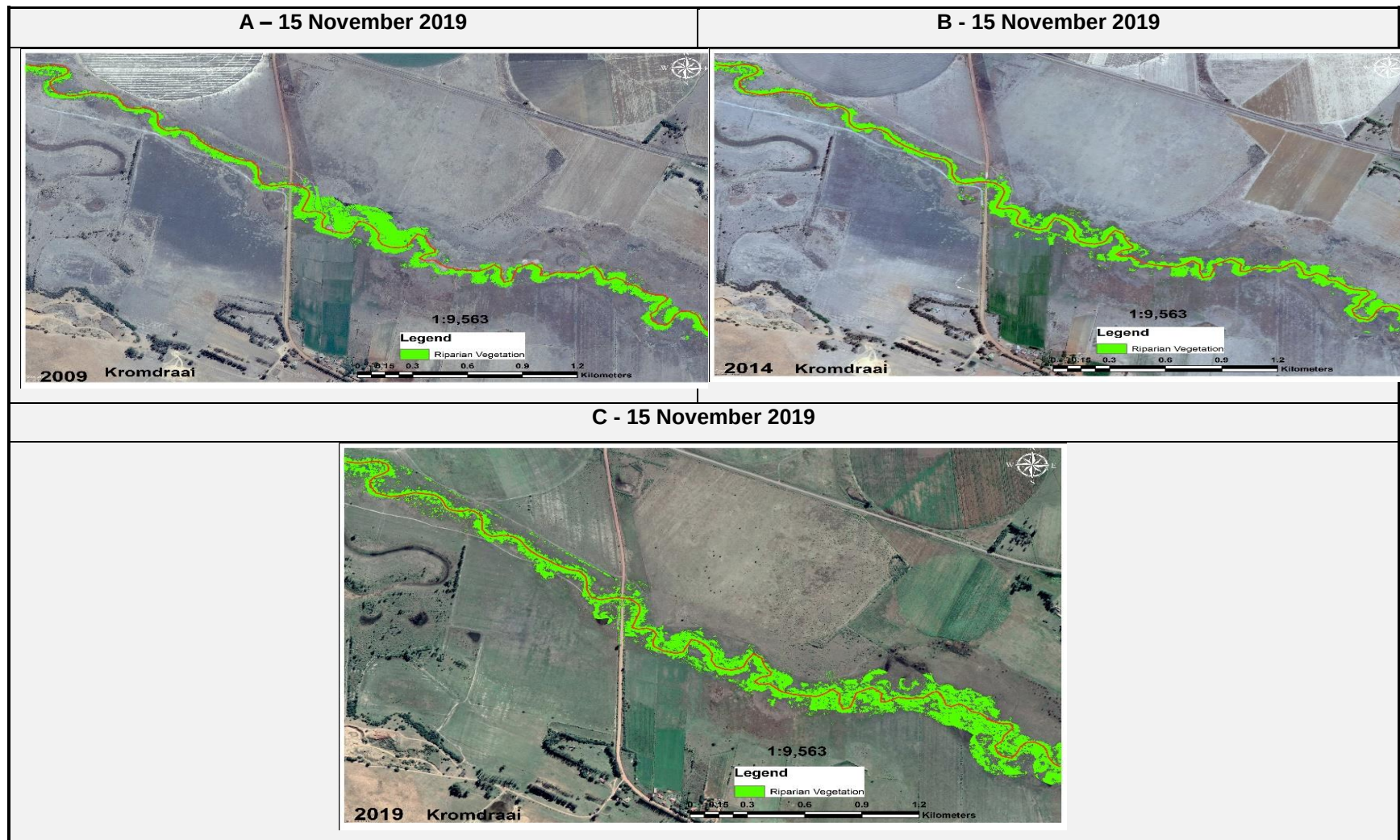


Figure 5- 15: Map (layout) representing the riparian vegetation extent of the Mooi River Catchment during each year around Kromdraai site.

Table 5-5: Vegetation cover and changes in percentages within the riparian zone of the six sampled sites delineated in each sampled area per square meter for 2009, 2014 and 2019.

Sample Sites	Areas in m²							
	Years			Percentage Changes		Percentage Changes		Actuals
	2009	2014	2019	2009	2014	2014	2019	2009-2019
Kromdraai	224296.8	210417.2	314797.5	- 9.5%		+14.1%		+ 90500.7
South Bridge	241831.1	220629.6	166404.5	- 91.2%		- 75.4%		- 75526.6
North Bridge	138903.6	129412.6	102892.5	- 93.1%		- 75.4%		- 36011.1
Downstream of Boskop Dam	216119.3	225816.5	212771.6	+ 95.7%		- 94.2%		- 3347.7
Muiskraal Farm	372458.3	243398.5	219932.6	- 65.3%		- 90.4%		- 152525.7
Rysmierbult	452371.8	64184.79	213039.1	- 14.2%		+30.1%		- 239332.7

According to Table 5-5, there has been a confirmation that riparian vegetation has been variable through the years along the Mooi River catchment. It was found that the Kromdraai site had decreased its riparian vegetation zone by 9.5% between 2009 and 2014, however, there was an increase between 2014 and 2019 of 14.1%. The South Bridge site showed a decline for all the years - between 2009 and 2014 it declined by 91.2% and between 2014 and 2019 by 75%. North Bridge had a decline of 93.1 % between 2009 and 2014 and 75.4% between 2014 and 2019 respectively. Downstream of Boskop Dam showed an increase between 2009 and 2014 by 95.7%, however, it showed a decline of the riparian vegetation zone between 2014 and 2019 by 94.2%. In Muiskraal Farm, a decline was observed between 2009 and 2014 by 65.3% as well as between 2014 and 2019 by 90.4%. Thereafter, Rysmierbult showed that there was a decline between 2009 and 2014 by 14.2% and an increase in riparian vegetation between 2014 and 2019 by 30.1%.

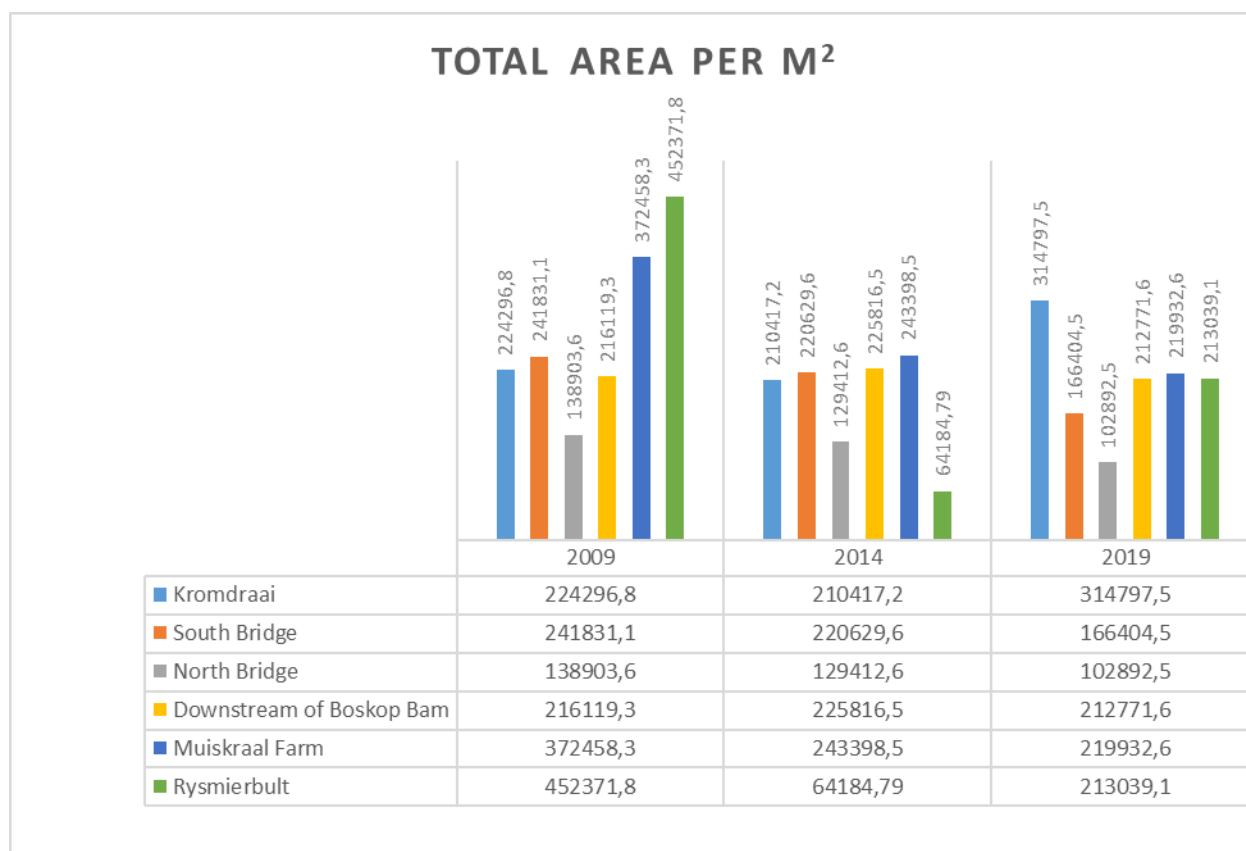


Figure 5- 16: Vegetation cover of the six sampled sites (Kromdraai, South Bridge, North Bridge, Downstream of Boskop Dam, Muiskraal Farm and Rysmierbult sites along the Mooi River catchment) per square meter for 2009, 2014 and 2019.

Riparian vegetation cover was estimated per square meter. The field survey was undertaken to assess and measure the riparian vegetation cover, however, the images were extrapolated in years (Figure 5-16), i.e. the Kromdraai site shows that, in 2009, the vegetation was at 224296 m² whereas in 2014, the vegetation cover declined to 210417 m² and increased again in 2019 to 314797 m². The decrease in riparian vegetation at this site was due to anthropogenic activities such as agriculture and development around the area and an increase in the establishment of exotic species in the riverine environment was also observed. During the site visit, it was identified that the area was transformed and evidence of some recreational activities were observed.

On the other hand, the South Bridge site reveals that riparian zone cover was at 241831 m² in 2009, then, in 2014, it decreased to 220629 m² and declined again in 2019 to 166404 m². A decline of riparian vegetation was also shown at the North Bridge site. In 2009, riparian vegetation cover was 138903 m², whereas, in 2014, it was at 129412 m² and in 2019, it further dropped to

102892 m². This was also due to anthropogenic activities such as development or road and bridge construction undertaken along the riparian zone.

In 2009, downstream of Boskop Dam, vegetation cover within the riparian zone was at 2116119 m² and this increased in 2014 to 225816 m². In 2019, vegetation cover showed a decline to 212771 m². The Muiskraal site showed that vegetation cover in 2009 was at 372458 m² and this decreased in 2014 to 243398 m² and further decreased in 2019 to 219932 m².

The Rysmierbult site showed vegetation cover of 452371 m² in 2009 which increased in 2014 to 641847 m² and further increased to 2130391 m² in 2019. Between 2009 and 2019, the Rysmierbult area changed from 452371 m² to 213039 m². This is a decline of a total surface area of 239332 m² as (Figure 5-16). This is because the Rysmierbult area is used for farming. There were different anthropogenic activities identified on site such as livestock, grazing, construction and recreational activities. It was found during the site visit that riparian vegetation along the Mooi River catchment has been drastically degraded and modified.

According to the above assessment, it can be confirmed that there has been transformed because there are a lot of fluctuations in riparian vegetation. Different land use activities along the water course such as mining, agricultural activities, livestock, developments (roads bridges, and wastewater treatment works etc.) have been identified as well as alien invasive propagation due to anthropogenic disturbances which led to riparian zone degradation.

5.2.7 Ranking, rating and weighing riparian vegetation changes using VEGRAI assessment.

This part describes the ranking, rating and weighing of riparian zones using the VEGRAI assessment system. The VEGRAI was used to rate, rank and weigh riparian vegetation changes along the Mooi River. VEGRAI is a system that is designed for the qualitative assessment of the response of riparian vegetation to impact in such a way that those qualitative ratings translate into quantitative and defensible results (Kleynhans *et al.*, 2007). Results are defensible because their generation can be traced through an outlined process (a set of rules that converts assessor estimates into ratings and multiple ratings into an EC).

Figure 5-17 indicates that the vegetation was assessed in different vegetation zones such as the marginal, lower and upper zones of the Mooi River catchment, based on woody and non-woody

components depending upon the level of assessment in South Africa, using the VEGRAI method. According to van Niekerk and Heritage (1993), the marginal zone referred to the active features or wet bank of the river, however, according to Cagney (1993), it consists of the areas where the water level was low.

The lower zone is referred to as seasonal features or the wet bank of the river, where it extends from the marginal zone and ends in a lateral elevation (Van Niekerk & Heritage, 1993). However, the elevation changes may or may not be associated with the changes in species distributions but is associated with the geomorphic features which are hydrologically activated on an annual basis or every two to three years, more especially during high flow.

On the other hand, the upper zone may continue along the elevated side and look for a sharp increase in lateral slope and is frequently characterised by a change in species composition. The upper zone's soil surface is saturated at least every one to three years. It has more terrestrial species and finer sediments than the lower zone (Van Niekerk & Heritage, 1993).



Figure 5- 17: The riparian zone assessed during the site visit following the VEGRAI method, showing the Marginal zone, Lower zone as well as the Upper zone of the riparian zone along the Mooi River.

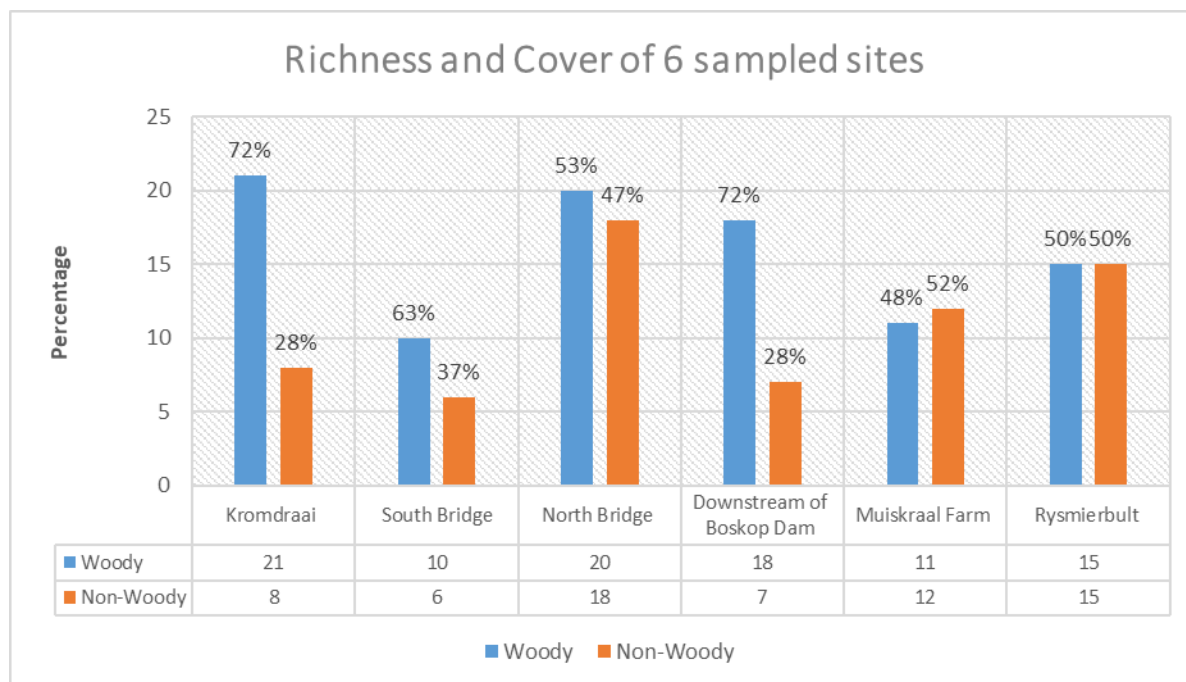


Figure 5- 18: Woody and non-woody species distribution of both marginal and non-marginal zones around the Mooi River for the following sites: Kromdraai, South Bridge, North Ridge, Downstream of Boskop Dam, Muiskraal Farm, and Rysmierbult.

Figure 5-18 shows that the woody and non-woody components in respective sites were assessed for both marginal and non-marginal sites and it is evident that most areas or sites have woody vegetation than non-woody vegetation i.e. Kromdraai, South Bridge, North Bridge and Downstream of Boskop Dam sites. However, the Muiskraal Farm site on the other hand has a high richness of non-woody vegetation over woody vegetation and Rysmierbult has equivalent richness in both woody and non-woody vegetation respectively. The difference between woody and non-woody vegetation could be due to different land uses within the riparian zone. According to Du Toit (2015), the results of life form changes from dominant trees to shrubs indicate that there has been an impact on woody vegetation. This could be due to firewood collection and other disturbances within the area. Furthermore, firewood harvesting has been identified as one of the contributing factors of these changes in some parts of South Africa, despite large scale availability of electricity (Madubansi & Shackleton, 2007).

VEGRAI results were compared with the changes in different years, i.e. 1995, 2012 and 2019 respectively and during this study, six sites were sampled and analysed along the Mooi River.

According to an ecological assessment undertaken per sampled site from the reference condition to the present ecological condition, different ecological conditions were identified (Table 4-2). It was evident in VEGRAI assessment done on Table B-1 (Appendix B) that the Kromdraai site has been partially degraded due to different land use activities such as road constructions, farming and other recreational activities in the area. It was also found that the area falls within C/D Ecological Category, which means it is moderately to largely modified (Figure 5-19).



Figure 5- 19: Ecological status of the Kromdraai site as described in terms of ecological categories using the VEGRAI assessment (DWA, 2016).

The South Bridge, North Bridge and Downstream of Boskop Dam sites fall within an EC “C”, due to the natural habitats and ecosystem services that are moderately changed. According to the assessment done on Table B-2, B-3 and B-4 (Appendix B), this means the area is moderately modified. However, there were recreational and construction related activities identified on the site or along the Mooi River catchment riparian zone as well as development that led to some transformation in the area. Alien invasive were also identified in study area as per Figure 5-20 below.



Figure 5- 20: Ecological status of South Bridge, North Bridge and Downstream of Boskop Dam described in terms of ecological categories as per VEGRAI assessment. These categories are further depicted on a continuum (DWA, 2016).

The Muiskraal site was categorised as D/E according to the assessment done on Table B-5 (Appendix B) and it was largely to seriously modified due to a large loss of biota, natural habitat and its basic ecosystem functions. The figure shows the representation of the integrity of riparian vegetation and the area has been transformed.



Figure 5- 21: Ecological status of the Muiskraal site described in terms of ecological categories as per VEGRAI assessment. These categories are further depicted on a continuum (DWA, 2016).

Subsequently, Rysmierbult site falls within D according to VEGRAI assessment done on Table B-6 (Appendix B), which means the area is largely modified and there is a large loss of biota, natural habitat and its basic ecosystem functions (Figure 5-22).



Figure 5- 22: Ecological status of the Rysmierbult site described in terms of ecological categories as per VEGRAI assessment. These categories are further depicted on a continuum (DWA, 2016).

There have been moderate changes of the natural habitats and biota due to anthropogenic activities such as construction, development, livestock, grazing and recreational activities which also exacerbated the proliferation of alien invasive species, contributing to change in the ecosystem functions of the Mooi River Catchment.

According to the overall assessment of the study area, it was found that the overall riparian zone of the Mooi River catchment is transformed. According to Figure 5-23, it was established that the overall Mooi River catchment falls within a C/D Ecological Category. The results of the current study further reveal that there is a high need for mitigation measures to safeguard the river system and its riparian zones. Implementation of the mitigation measures should be done as soon as possible to ensure that the Mooi River catchment does not deteriorate to a more negative state where it will fall within an E/F category which is a critically and seriously modified area.



Figure 5- 23: Overall ecological status of the Mooi River catchment as described in terms of ecological categories as per VEGRAI assessment. These categories are further depicted on a continuum (DWA, 2016).

The RQO gives a descriptive of the numerical account regarding the physical and biological characteristics and chemical composition considering the user requirements as well as the different classes of a particular water resource, such as Class I, II, III and IV (Table 4-3) in terms of the National Water Resource Strategy (NWRS). Dickens *et al.* (2011) further described RQO as the nature and condition of the aquatic biota, habitat, the quantity, pattern and timing of in stream flow and the water quality. According to the assessment done on this study, it was found that the Mooi River catchment is in a Class III category which means it is heavily impacted or used and significantly changed from its natural condition due to human activity but if mitigation measures such as rehabilitation are implemented and maintained, the ecological status of the catchment can be sustainable (Dickens *et al.*, 2011).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Riparian zones represent enormously valuable natural ecological systems on a global, regional and national scale (Naiman *et al.*, 2005; Kanasashi & Hattori, 2011; Virbickas *et al.*, 2011). These zones make provision for ecosystem and services such as the stabilisation of riverbanks and filtration of pollutants from the discharge flowing from upland areas. It also provides an ecological corridor for wildlife movement, a habitat for wildlife, food for aquatic macro invertebrates in the form of leaf litter and it controls the stream temperature (Richardson *et al.*, 2012). Riparian vegetation also provides a variety of habitats that serve as niche areas for birds. Anthropogenic factors can exploit the natural resources if not managed properly, depending on the way they are conducted.

Therefore, the main aim of this study was to determine the status of the riparian zone of the Mooi River Catchment. Six sites were utilised and aerial imagery over a period of 10 years, i.e. in 2009, 2014 and 2019, were used in order to assess the changes that are confronting the catchment. Three images were obtained using Google Earth Pro software which were high resolution images taken from ArcMap and they were classified and analysed between the years 2009, 2014 and 2019. A site visit was undertaken along the Mooi River and six sites were visited, namely Kromdraai, South Bridge, North Ridge, Downstream of Boskop Dam, Muiskraal and Rysmierbult to determine the severity of modification along the catchment as a ground truthing exercise. In addition the Mooi River riparian zone changes were assessed, ranked, rated and weighed using the VEGRAI assessment.

The results presented in Chapter 5 indicated that the riparian zone along the Mooi River Catchment is moderately to largely modified due to both anthropogenic and some natural activities. The aim of the study was also achieved by determining the present ecological status of the Mooi River catchment in comparison with the reference condition thereof. It is evident from the current study that the riparian zone is neglected. A lack of conservation of natural resources in the South African government has been identified as a contributing factor to the poor management of the natural resources. Furthermore, a lack of coordination amongst different government departments to manage the riparian zones has been confirmed (Everson, 2007). The results of the VEGRAI assessment as per the six (6) sampled sites further reveal that the overall ecological status of the Mooi River is transformed because the assessment established that the

catchment falls within C/D ecological status. This means that the present ecological status of the Mooi River catchment is in a moderately to largely modified status.

According to the assessment done, the results of the study confirm and accept the hypothesis of the study which stated that the present ecological status of the riparian vegetation in the Mooi River is largely modified. This is due to natural and anthropogenic activities such as development, constructions, mining and agricultural activities in the area, as can be seen in the increase in extent of the invasion of alien vegetation along the catchment.

6.2 RECOMMENDATIONS

It is recommended that mitigation measures to safeguard the river health system and its riparian zones are implemented as soon as possible to ensure that the Mooi River catchment does not deteriorate to a state where it will fall within an E/F ecological category as per VEGRAI assessment which is a critically and seriously modified status (Kleynhans *et al.*, 2007).

Furthermore, studies on riparian vegetation responses and its potential ecosystem service delivery should be prioritised and riparian vegetation should be conserved in order to limit any further loss of the delivery of ecosystem services, but also so that best practice management be implemented by government in collaboration with the local municipalities, surrounding residences or farm owners to conserve the natural resources. In addition, awareness's about the benefits of riparian vegetation, assessment and conservation may help to improve how government manages the natural resources.

Subsequently, since this study was the first of its kind in terms of using the VEGRAI assessment six scoring system along the Mooi River catchment, future studies are recommended which could be beneficial to further assess the catchment by including additional areas within the Mooi River to verify the results of this study with those of future studies. However, different studies were undertaken within the Mooi River reach which were not specifically concentrating on VEGRAI methods of assessment but rather on the different species richness and distribution along the catchment, which also assisted in determining the extent of transformation of the Mooi River catchment. If larger belt transects and more sites could be surveyed along the Mooi River catchment, it could also yield additional information on the structures affecting the delivery of ecosystem services within the riparian zones.

However, other functional traits should also be considered in determining the functional diversity of the vegetation in river catchments. Plant height and leaf traits such as dry leaf matter content and leaf nitrogen or phosphorus concentration are considered by Lavorel *et al.* (2011) to be strongly influenced by the surrounding land-use and abiotic environment. Determining the rate at which riparian vegetation was transformed as well as evaluating its ecosystem services in this study was highly subjective. Future studies should consider other data collection methods such as fully fledged ground truthing, indicating what was actually estimated around riparian vegetation. Questionnaires directed at residents near the river could also be helpful in order to gain additional perspectives on what their views are concerning riparian vegetation and its responses to different land use activities.

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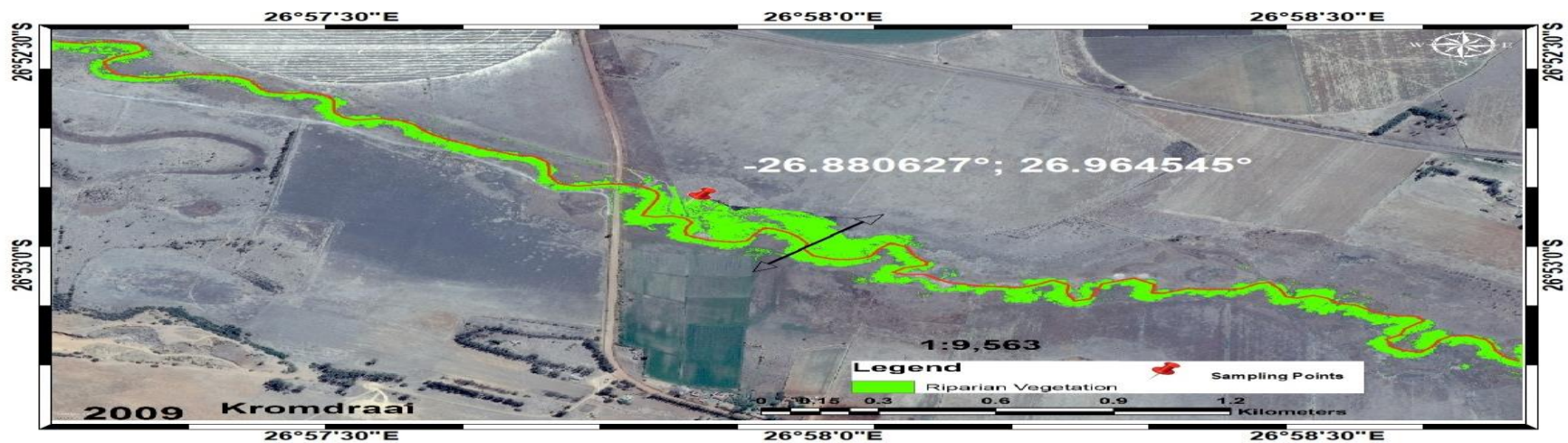
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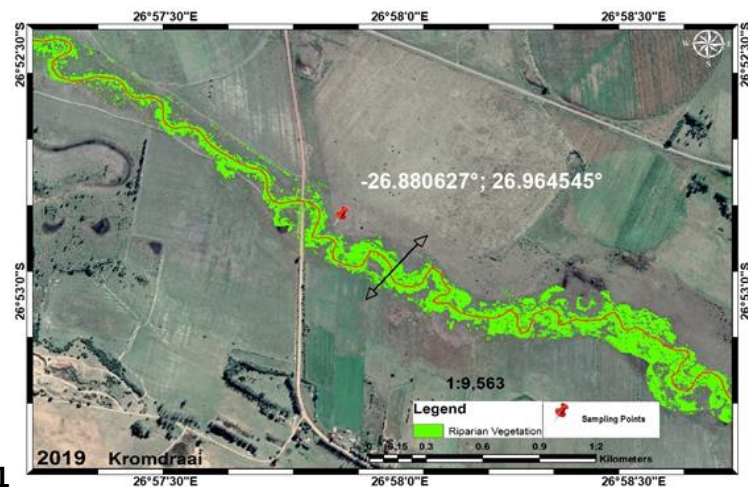
APPENDICES

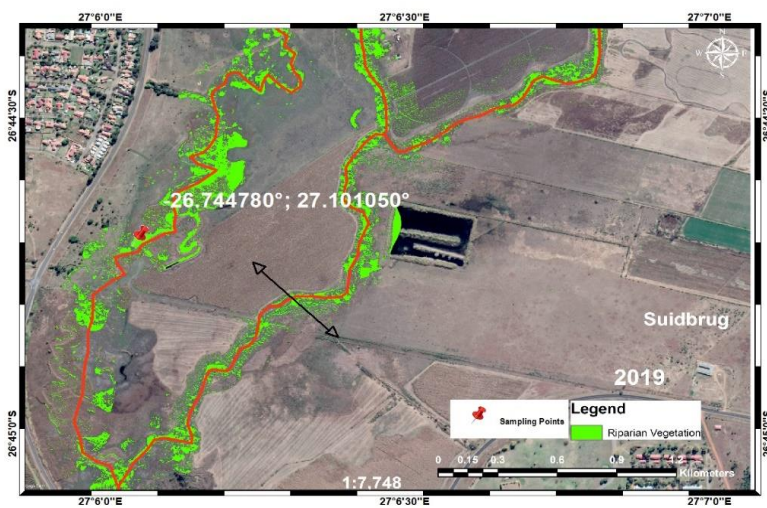
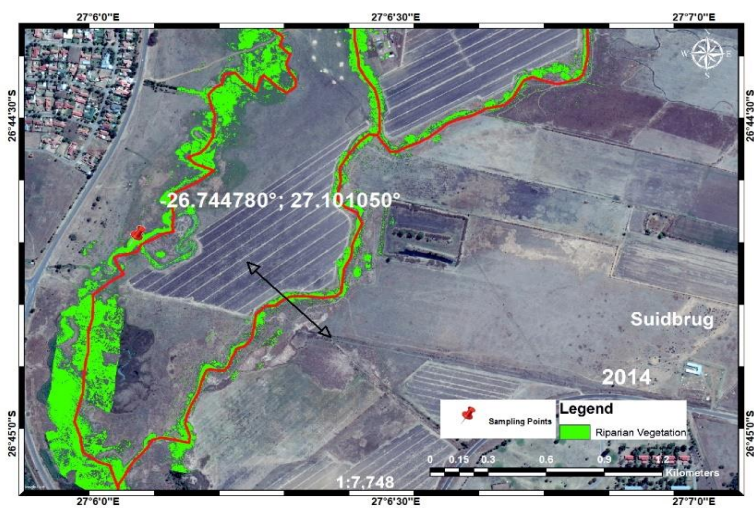
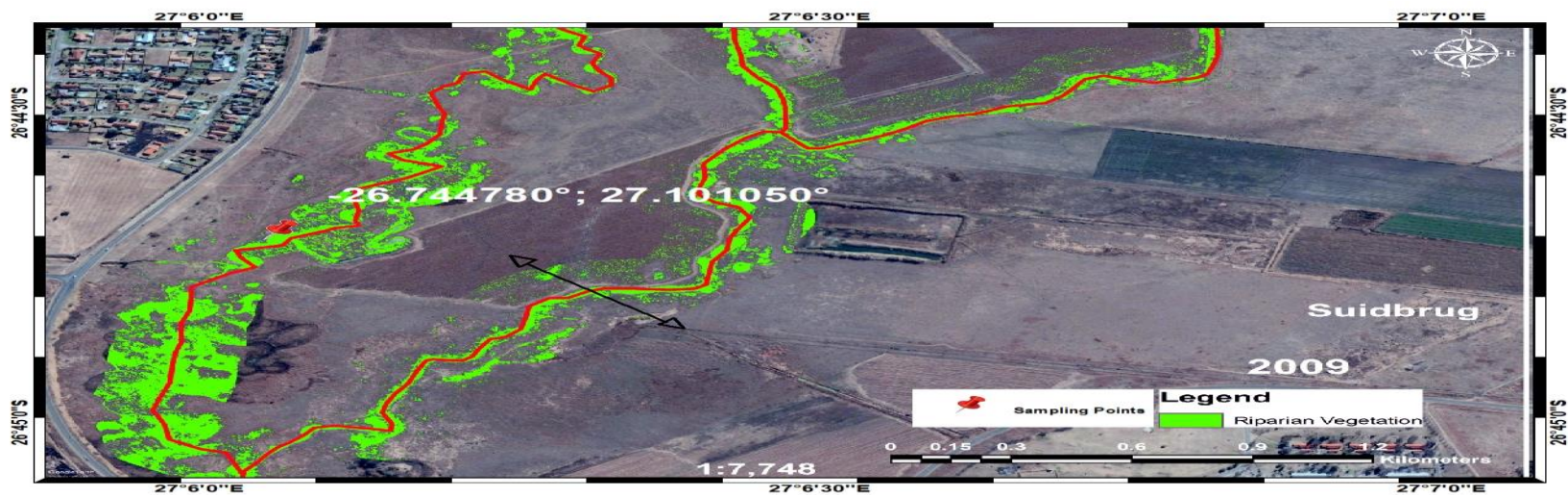
APPENDIX A

Appendix A is Maps representing the riparian zones for the six sampled sites during data collection methods from the upstream to downstream of the Mooi River Catchments which are Kromdraai, North Bridge, South Bridge, Downstream of Boskop Dam, Rysmierbult and Muiskraal Farm.

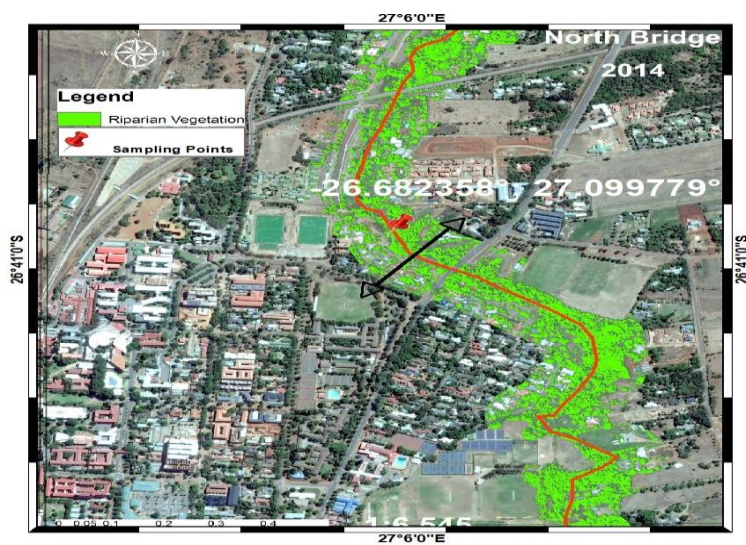
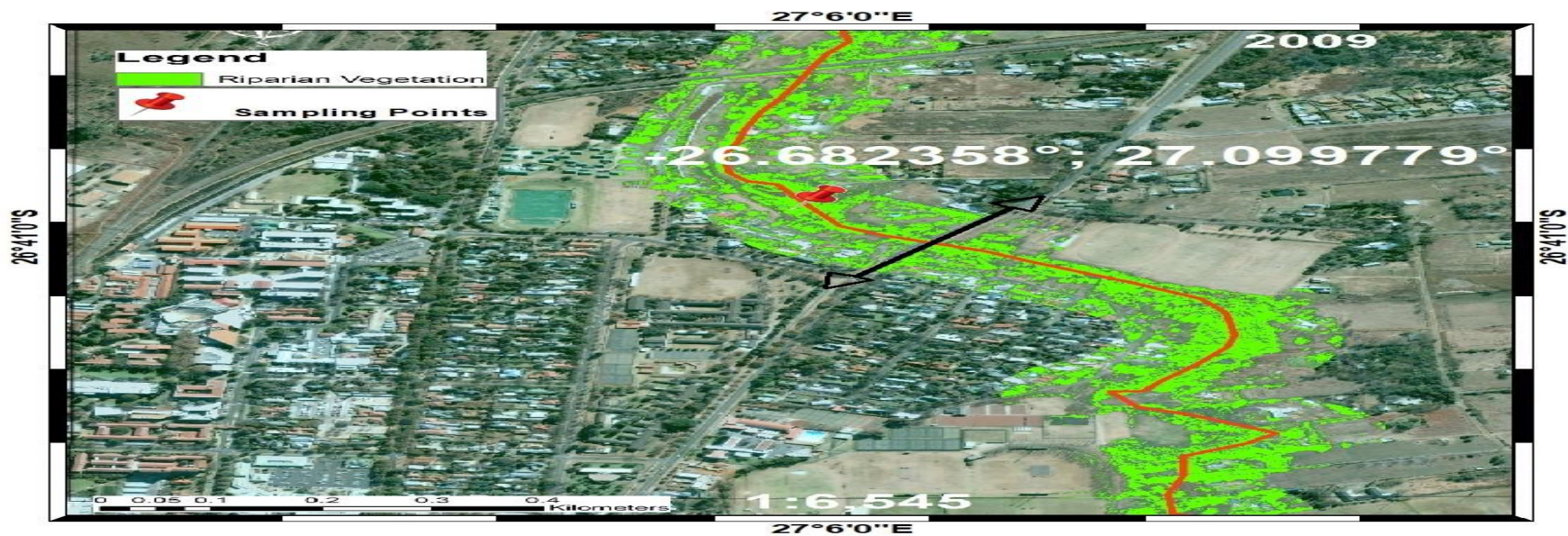


Map A-1

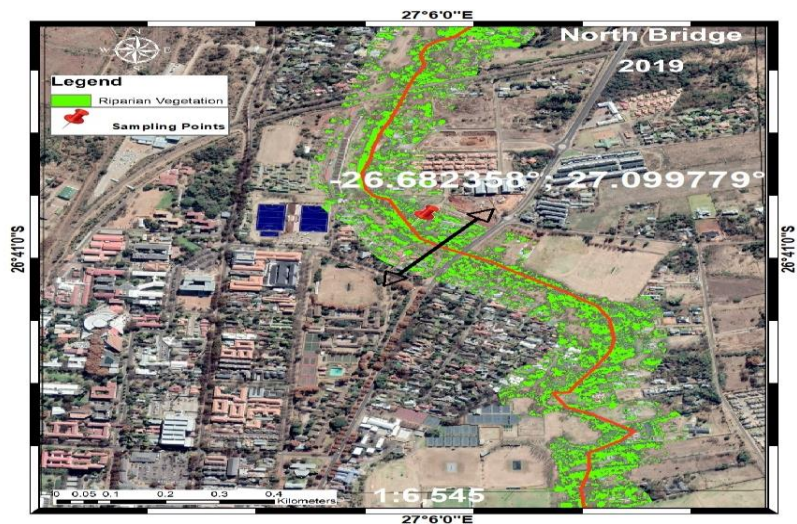


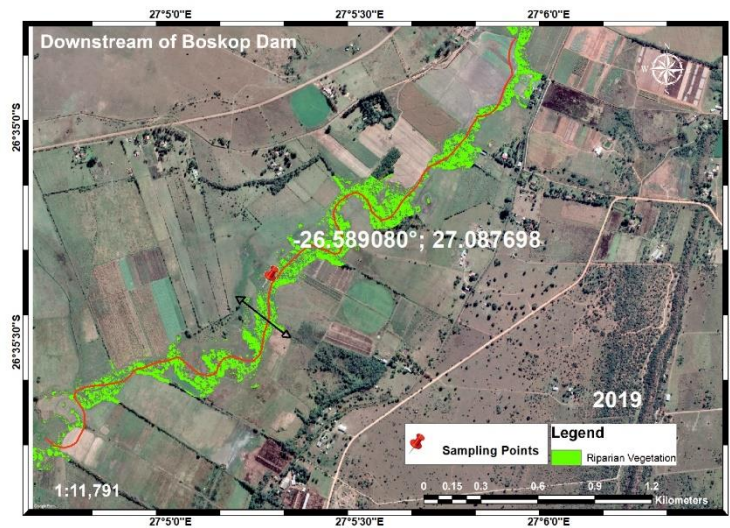
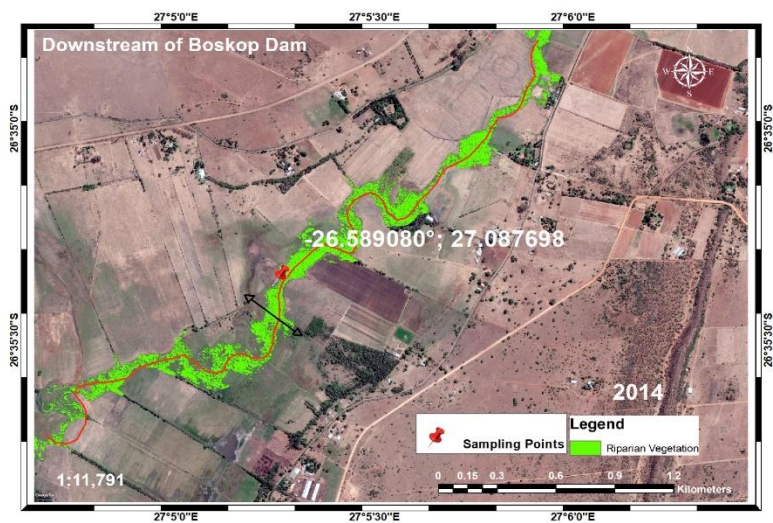
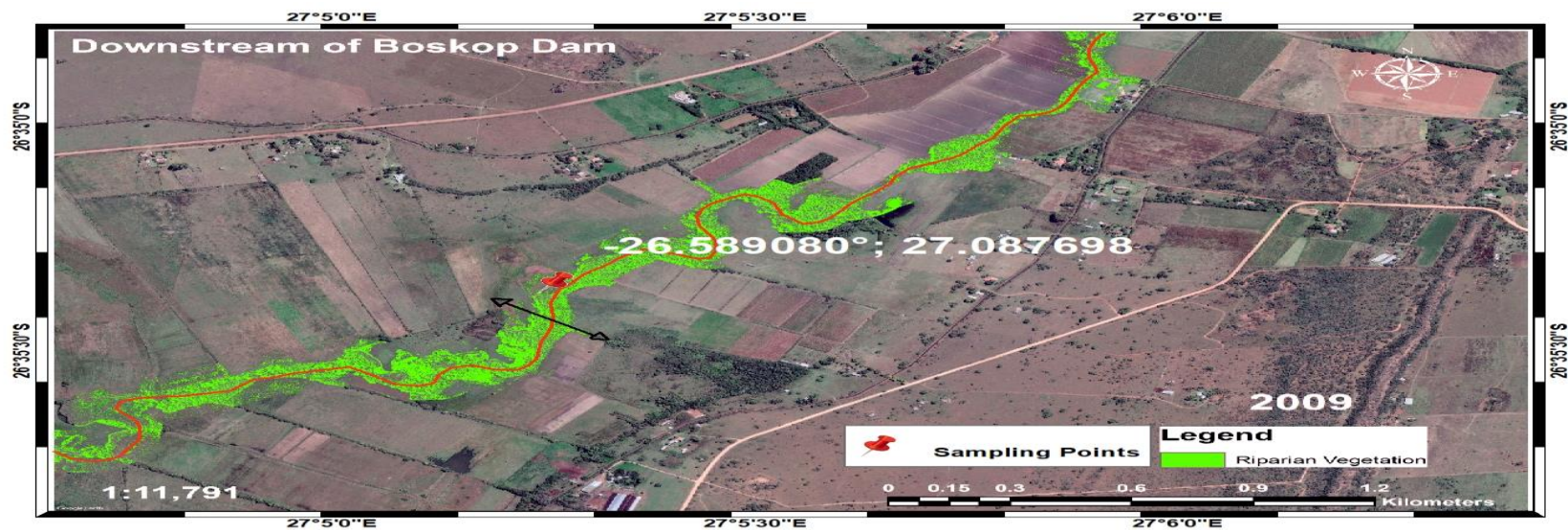


Map A-2

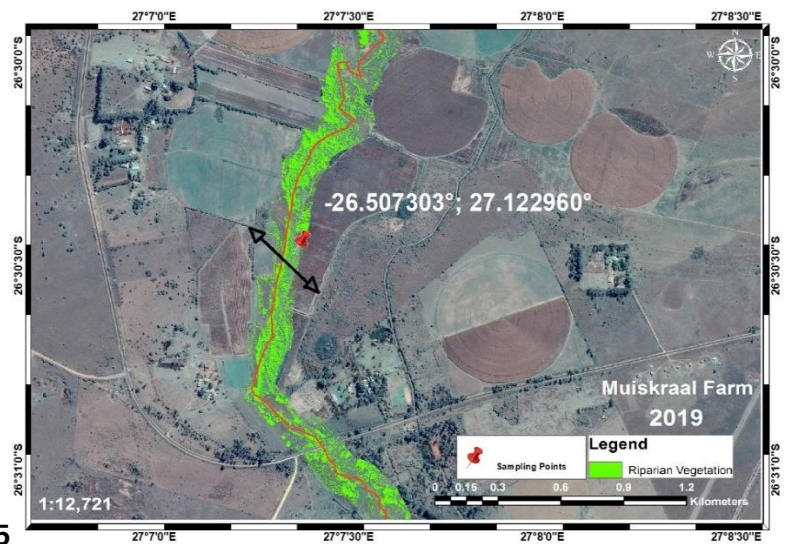
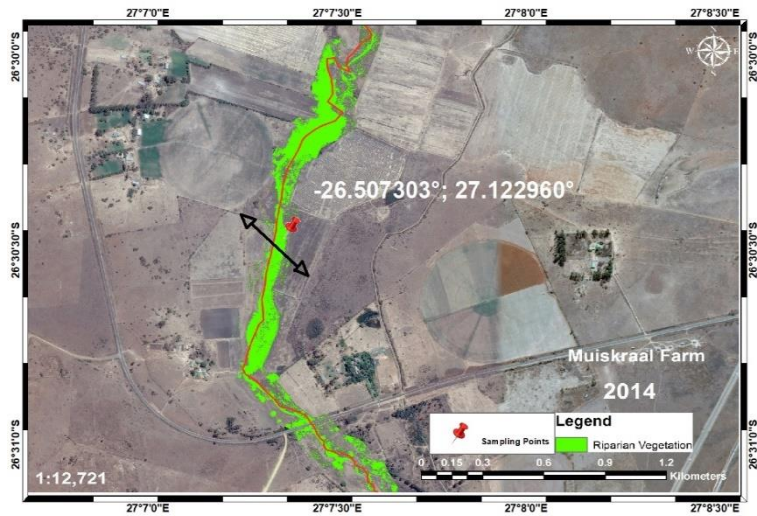
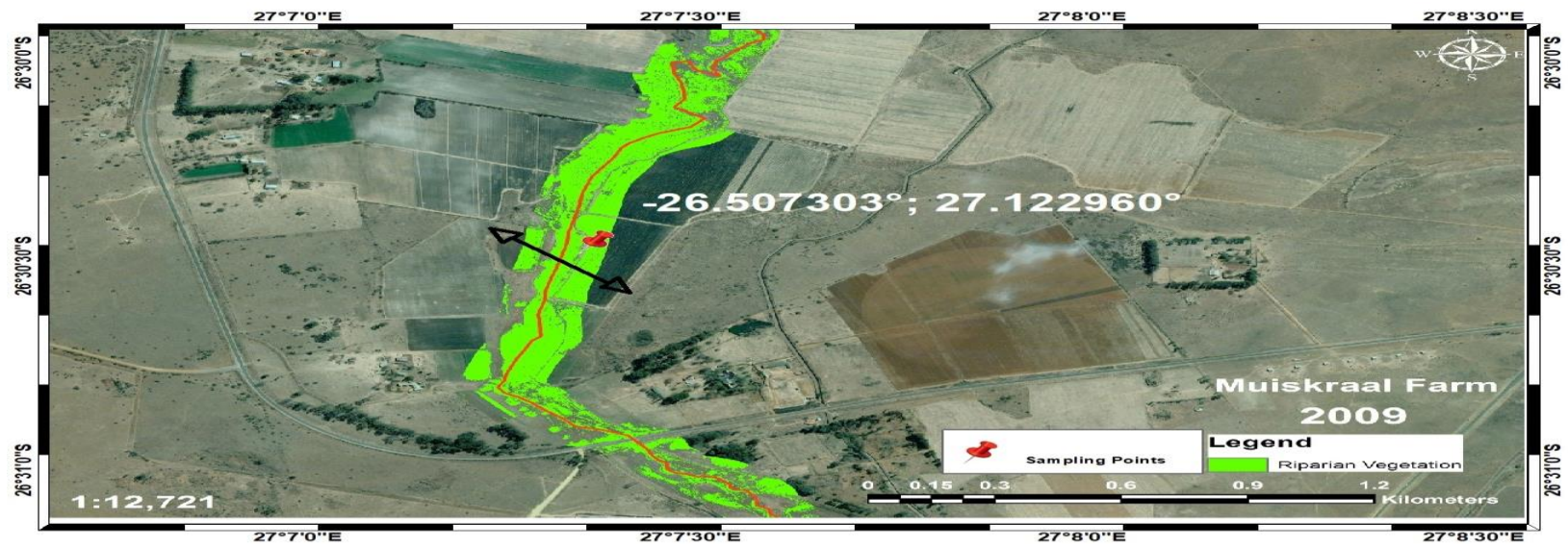


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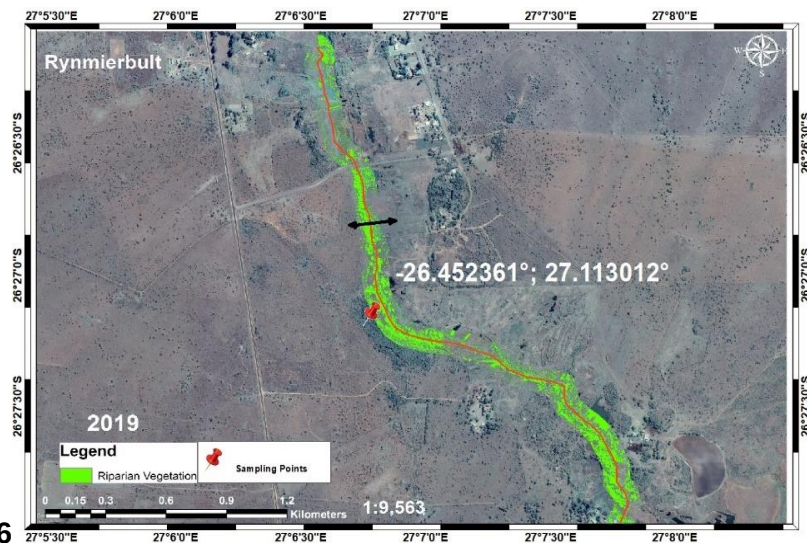
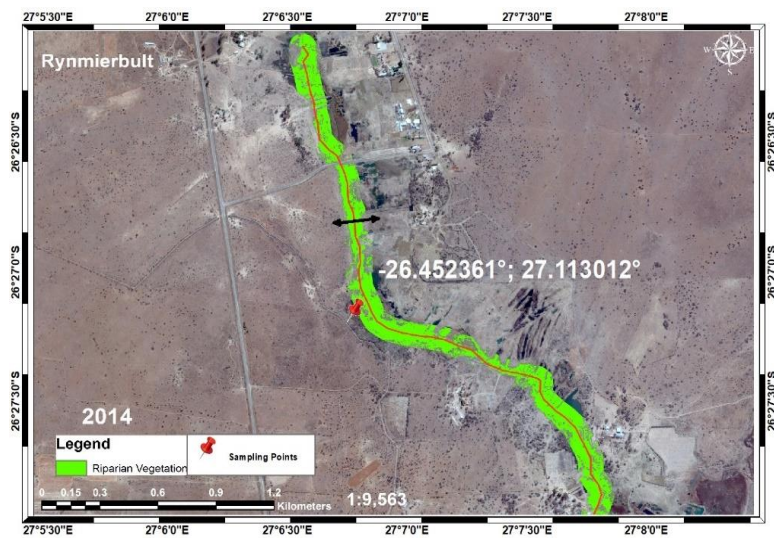
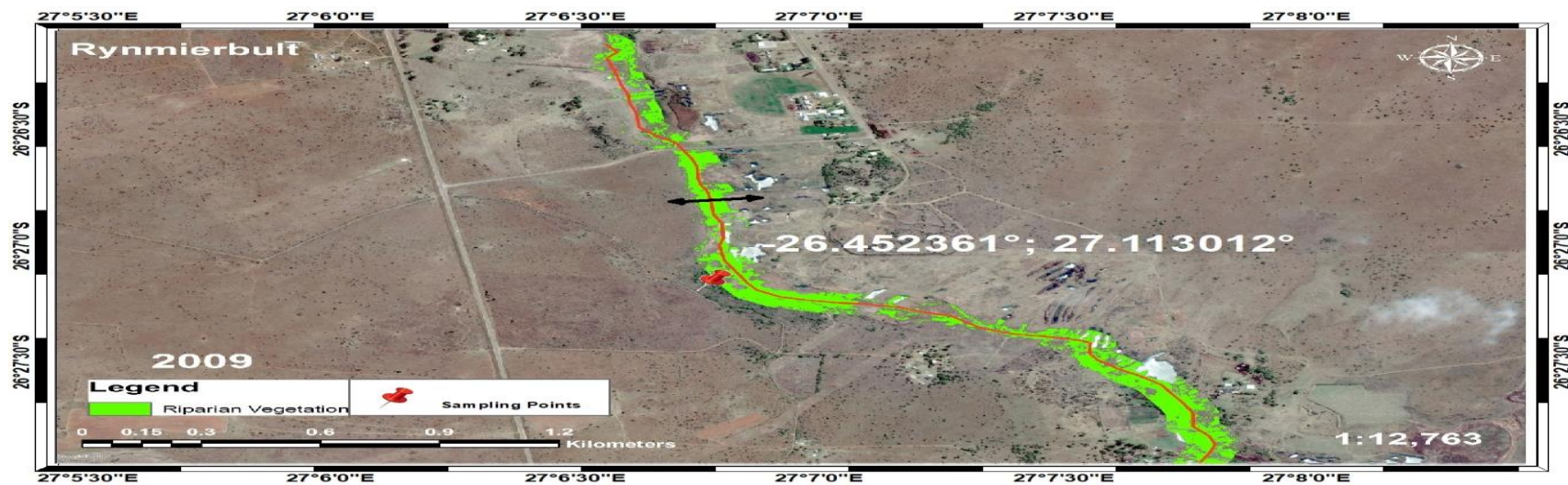




Map A-4



Map A- 5



Map A-6

APPENDIX-B

Appendix B shows VEGRAI Level 3 assessment for six (6) sampled sites which are Kromdraai , North Bridge, South Bridge, Downstream of Boskop Dam, Rysmierbult and Muiskraal Farm along the Mooi River Catchments as per six (A-F) scoring system of the ecological categories for EcoStatus components (Kleynhans *et al.*, 2007).

Table B1- Kromdraai

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	40.0	21.1	0.0	2.0	100.0	Moderately to largely modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged and a large loss of natural habitat, biota and basic ecosystem functions has occurred.
NON-MARGINAL	80.0	37.9	1.5	1.0	90.0	
	2.0				190.0	
LEVEL 3 VEGRAI (%)				58.9		
VEGRAI EC				C/D		
AVERAGE CONFIDENCE				0.8		

Table B2 – South Bridge

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	40.0	17.8	0.0	2.0	80.0	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
NON-MARGINAL	80.0	44.4	1.5	1.0	100.0	
	2.0				180.0	
LEVEL 3 VEGRAI (%)				62.2		
VEGRAI EC				C		
AVERAGE CONFIDENCE				0.8		

Table B3 – North Bridge

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	40.0	17.8	0.0	2.0	80.0	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
NON-MARGINAL	80.0	44.4	1.5	1.0	100.0	
	2.0				180.0	
LEVEL 3 VEGRAI (%)				62.2		
VEGRAI EC				C		
AVERAGE CONFIDENCE				0.8		

Table B4– Downstream of Boskop Dam

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	40.0	17.8	0.0	2.0	80.0	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
NON-MARGINAL	80.0	44.4	1.5	1.0	100.0	
	2.0				180.0	
LEVEL 3 VEGRAI (%)				62.2		
VEGRAI EC				C		
AVERAGE CONFIDENCE				0.8		

Table B5 - Rysmierbult

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	40.0	28.6	0.0	2.0	100.0	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
NON-MARGINAL	80.0	22.9	1.5	1.0	40.0	
	2.0				140.0	
LEVEL 3 VEGRAI (%)				51.4		
VEGRAI EC				D		
AVERAGE CONFIDENCE				0.8		

Table B6 – Muiskraal Farm

LEVEL 3 ASSESSMENT						
METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	% WEIGHT	NOTES: (give reasons for each assessment)
MARGINAL	40.0	38.1	0.0	2.0	100.0	Largely to seriously modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred and the loss of natural habitat, biota and basic ecosystem functions is extensive.
NON-MARGINAL	80.0	3.8	1.5	1.0	5.0	
	2.0				105.0	
LEVEL 3 VEGRAI (%)				41.9		
VEGRAI EC				D/E		
AVERAGE CONFIDENCE				0.8		

APPENDIX - C

Appendix C is photos representing different vegetation cover (Marginal, Lower and Upper zones) for six sampled sites during data collection methods from the upstream to downstream of the Mooi River Catchments which are Kromdraai, North Bridge, South Bridge, Downstream of Boskop Dam, Rysmierbult and Muiskraal Farm.



Photo C1-Kromdraai Site



Photo C2 - South Bridge



Photo C3-North Bridge



Photo C4- Down stream of Boskop Dam



Photo C5- Rysmierbult



Photo C6- Muiskraal Site



Photo C-7 Alien encroachment along Mooi River catchment