NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Continuous riparian vegetation change following a large, infrequent flood along the Sabie River, Kruger National Park

Philip Ayres

B.Sc. Honours

Dissertation submitted in fulfilment of the requirements for the degree

Magister Scientiae in Environmental Sciences at the North-West University

Supervisor: Dr. F. Siebert

Co-supervisor: Prof. S.J. Siebert

November 2012

Abstract

The flood of 2000 caused extensive changes within the riparian landscape of the Sabie River, Kruger National Park (KNP). Changes within the riparian landscape and the removal of vegetation resulted in considerable changes in riparian vegetation characteristics. Open patches created by the flood served as a template for the establishment of new species and the regeneration of existing species, which consequently resulted in a patch mosaic. This memorable event encouraged an investigation into the response of the Sabie River ecosystem to the memorable Large Infrequent Disturbance (LID).

Riparian ecosystems are driven by varying combinations of environmental factors, such as water availability, disturbance, herbivory, fire and river morphology. This complexity depicts unique vegetation structure and assemblages of associated plant species. The lack of sufficient knowledge on the role of riparian vegetation in the health assessment of surrounding ecosystems along semi-arid rivers prompted the establishment of the Kruger Rivers Post Flood Research Program (KRPFRP).

Research conducted through this monitoring program four years after the 2000 flood, revealed no significant changes in the species composition, although the location and density of many common riparian species have been changed. There was a decrease in species density across the macro channel floor (MCF) and an increase in species density across the macro channel bank (MCB). Furthermore, it was reported that the flood altered the distribution of height classes across the macro channel. In general the riparian vegetation was shorter and bushier four years post-flood. These studies furthermore illustrated that the tree to shrub ratio did not change drastically from pre-flood conditions, although a decrease in the number of shrub individuals was reported.

The research presented in this dissertation was designed to further explore changes in woody species composition and structure along the Sabie River, KNP at a post flood temporal interval, i.e. between the last survey in 2004 (by the KRPFRP) and 2010. For data compatibility, the sampling and analytical approach of this study conforms to the approach followed by the KRPFRP. Data were sampled within four preselected belt-transects that form part of the larger KRPFRP. All established woody individuals were counted and measured within each contiguous 10 m x 30 m plot within each of the four belt-transects.

Log transformed species composition data were analysed through the application of the Bray Curtis dissimilarity index in combination with Ward's method of clustering. Statistical significant differences between clusters were tested through the application of the Fisher's exact relationship test. The MIXED Procedure or PROC MIXED model was used to investigate change within the vegetation structural data.

Results obtained through the various analytical methods broadly support the findings of the KRPFRP. No significant change in woody species composition could be detected between 2004 and 2010. However, a change in the density (increase and decrease) of certain species across the MCB and MCF was revealed. Species richness and density increased significantly on the MCF oppose to small changes on the MCB.

A significant increase in the total number of shrubs on the MCF contributed to an overall increase in woody density for the entire study area between 2004 and 2010. Shrubs therefore remained the most dominant growth form in both sampling years. Trees decreased across the MCB although the total number of established trees remained unchanged between 2004 and 2010.

Riparian vegetation structure is directly linked to species assemblages, hence the continued dominance of shrub species along the Sabie River in the KNP The Sabie River riparian landscape is therefore still characterised by short and multi-stemmed woody individuals ten years after the LID.

Keywords: riparian landscapes, river morphology, riparian vegetation, large infrequent disturbances, floods, channel type, species composition, vegetation structure, vegetation dynamics, Bray-Curtis Dissimilarity, Fisher's exact relationship test, PROC MIXED model, NMDS

Uittreksel

Die vloed in 2000 het aansienlike verandering binne die oewerlandskap van die Sabierivier in die Kruger Nasionale Park (KNP) veroorsaak. Veranderinge binne die oewerlandskap en die verwydering van plantegroei het beduidende veranderinge in die eienskappe van die oewerplantegroei veroorsaak. Oop areas wat ontstaan het na die vloed het gedien as ‘n templaat vir die vestiging van nuwe spesies en die regenerasie van bestaande spesies wat kol-mosaïke (‘patch mosaic’) tot gevolg gebring het. Hierdie onvergeetlike gebeurtenis gee aanleiding tot navorsing oor hoe die ekosisteem van die Sabierivier reageer op ‘n Seldsame Omvangryke Versteuring (SOV).

Rivieroewerekosisteme word beïnvloed deur verskeie omgewingsfaktore soos die beskikbaarheid van water, versteurings, herbivorie, vuur en riviermorfologie. Hierdie kompleksiteit verteenwoordig unieke plantegroeistrukture en verwante spesieversamelings. Die tekort aan voldoende inligting oor die rol van oewerplantegroei om die welstand van die omringende ekosisteme langs semi-ariede riviere te bepaal, het aanleiding gegee tot die vestiging van die Kruger River’s Post Flood Research Program (KRPFRP).

Alhoewel die ligging en digtheid van baie algemene oewerspesies verander het, onthul die bogenoemde navorsingsprogram vier jaar na die vloed in 2000 geen noemenswaardige verandering in die samestelling van spesies nie. Laasgenoemde navorsing bevind ‘n afname in die spesiedigtheid oor die makro-kanaalbodem (MKB) en ‘n toename in spesiedigtheid oor die makro-kanaaloewer (MKO). Voorts openbaar die navorsing dat die vloed die verspreiding van hoogteklasse oor die makro-kanaal gewysig het. Oor die algemeen was die oewerplantegroei korter en meer struikagtig vier jaar na die vloed. Hierdie studies het verder illustreer dat die boom-tot-struikverhouding van voor die 2000 vloed nie drasties verander het nie, hoewel daar gevind is dat struikindividue minder geword het.

Die navorsing in hierdie verhandeling wou vasstel watter veranderinge in die samestelling en strukture van houtagtige spesies plaasgevind het langs die Sabierivier in die KNP tydens die post-vloed tydelike interval, d.i. tussen die laaste opnames in 2004 (soos uitgevoer deur die KRPFRP) en 2010. Die opname en analitiese benadering van hierdie studie is sodanig ontwerp om dataversoenbaarheid met die KRPFRP studie te verseker.

Data is opgeneem binne vier voorafgeselekteerde belttransekte wat deel vorm van die groter KRPFRP. Alle gevestigde houtagtige individue is gemeet en getel binne elke aaneenlopende afgebakende 10 m x 20 m plot in elk van die vier belttransekte. Logoritmies getransformeerde spesiesamestellingsdata is ontleed deur middel van die toepassing van die 'Bray Curtis Dissimilarity Index' in kombinasie met Ward se metode van groepering. Statisties betekenisvolle verskille tussen trosse is getoets deur die toepassing van 'Fisher's Exact Relationship Test' om die veranderinge in plantegroeistruktuur te bepaal. Die gemengde prosedure of 'PROC MIXED' model is gebruik om die veranderinge in plantegroeistruktuur te ondersoek.

Die resultate wat deur verskeie analitiese metodes verkry is, ondersteun breedweg die bevindings van die KRPFRP. Geen noemenswaardige veranderinge in die houtagtige spesiesamestelling kon waargeneem word tussen 2004 en 2012 nie. Die verandering in die digtheid (toename en afname) van sekere spesies oor die MKO en MKB is egter onthul. Spesierykheid en –digtheid het aansienlik toegeneem oor die MKB teenoor die klein veranderinge wat plaasgevind het oor die MKO.

'n Noemenswaardige toename in die totale aantal struike op die MKB het bygedra tot 'n algemene toename in die houtagtige digtheid van die algehele studiegebied tussen 2004 en 2010. Gevolglik bly struike die mees dominante groeivorm in beide dataversamelingsjare. Bome se getalle het afgeneem oor die MKO, hoewel die totale aantal gevestigde bome onveranderd gebly het in die tydperk tussen 2004 en 2010.

Oewerplantegroeistruktuur is direk gekoppel aan spesiesamestelling en aangesien struikspesies dominant gebly het langs die Sabierivier in die KNP, word die oewerlandskap steeds gekenmerk deur kort, struikagtige individue.

Sleutelwoorde: oewerlandskap, riviermorfologie, oewerplantegroei, seldsame omvangryke versteurings, vloede, kanaaltipe, spesiesamestelling, plantegroeistruktuur, plantegroeidinamika, 'Bray-Curtis Dissimilarity', Fisher's exact relationship test, PROC MIXED model, NMDS

Acknowledgements

I acknowledged the Lord,
In all my ways.
Awaiting His permission each step.
His divine mercy and infinite grace,
Kept my every move in check.

I followed his advice,
Though mine seemed better.
Executing His every command.
He brought me through an empty ocean,
Removing sin's every letter.

I obeyed Him in destitution,
Though disobedience seemed wiser.
God had the better option.
Taking the unpopular road,
I realised was a lot shorter.

Blessing after blessing,
A continual receiving,
As long as I consulted God.
He gave me the ultimate prize,
His constant presence and perfect guide

By Christian Eliab Ratnam

I would like to thank the following people for their support and contribution to this dissertation:

- My supervisors, Prof. Stefan Siebert and Dr. Frances Siebert for your guidance, time and patience.
- Elaine van den Berg, for your love, support and motivating me throughout the whole process. Without you I would not have been able to come this far.
- Donnavan Kruger, for being a true friend, supporting me and providing endless words of wisdom.
- My parents and family for your support and guidance, not only for this dissertation but throughout my whole live. With your support and love, any obstacles can be overcome.
- The Van den Berg family for your support and encouragement throughout the completion of this dissertation.
- My colleges at E-TEK Consulting for supporting me and providing the space and environment to insure that I completed my dissertation.
- Dr. Suria Ellis from Statistical Consultation Services, North-West University for assisting me with analysing my data.
- The staff at scientific services within the Kruger National Park for assisting in fieldwork logistics.
- Craig Mcloughlin and Karen Kotschy for your general support and assistance with fieldwork and providing background information on past projects.
- Izak Smit for your assistance in gathering and providing general environmental data which insured all aspects of the study area is included.
- Erika Rood for your guidance on proper referencing and scientific writing.
- North-West University for financial assistance and providing an environment where a student can grow.
- Kruger Rivers Post-Flood Research Program, which was established by the KNP in collaboration with the Centre for Water in the Environment (University of the Witwatersrand), for providing information on data sampling methods and data sampled in 2004.

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List of Abbreviations

a.s.l. – above sea level

BA – Bedrock Anastomosing

BMS – Biodiversity Monitoring Systems

Br – Braided

KNMI – Royal Netherlands Meteorological Institute

KNP – Kruger National Park

KNPRRP – Kruger National Park River Research Program

KRPFRP – Kruger River Post-Flood Research Program

LID – Large Infrequent Disturbance

MA – Mixed Anastomosing

MCB – Macro Channel Bank

MCF – Macro Channel Floor

mmp – mean monthly precipitation

NMDS – Non-metric Multi-Dimensional Scaling

PR – Pool-Rapid

SANParks – South African National Parks

SoB – State of Biodiversity

TPC – Threshold of Potential Concern

WfW – Working for Water

Chapter 1: Introduction

1.1. Introduction

1.1.1. The 2000 flood in the Kruger National Park

In February 2000, extreme tropical weather conditions caused severe flooding of the Sabie River in the Kruger National Park (KNP) (Parsons *et al.,* 2006) (Figure 1.1). The flood of 2000 can be considered an infrequent flooding event measured against averages in water depth and volume, which was reported to be far beyond normal figures (Resh *et al*., 1988). At Skukuza rest camp, the Sabie River received 411 mm rain during a single week in February. Compared to the monthly precipitation (mmp) for February of 96 mm, this flooding event was therefore documented as a large infrequent natural events experienced in the KNP. Upstream from KNP, the Graskop catchment area received 1000 mm in a week compared to the mmp of 281 mm for February (Heritage, Moon *et al.,* 2001). The flooding of the Limpopo, Sabie, lower Crocodile and lower Komati Rivers peaked at a base flow of 7000m^3 sec^{-1} with an estimated return interval of 90 – 200 years (Smithers *et al.*, 2001).The flood caused an estimated R73 million of damage within the KNP (Dept. of Public Works, 2000).

Although river flows are normally high during the summer months with several small flooding events, the intensity of the 2000 flood and the damages caused to the environment was exceptional since the flood occurred during the peak growing season making the intensity of the flood more visible (Turner & Dale, 1998). The flood of 2000 stripped most (70%) of the riparian vegetation, transforming the river from highly dense vegetation to a sparsely vegetated state (Parsons *et al.*, 2006, Parsons *et al.,* 2007). The transformation during the 2000 flood was more profound than any other environmental change observed in the last two decades (Parsons *et al.*, 2006, Parsons *et al.,* 2007).

Between 1939 and 1988 the Sabie River landscape went through a directional sequence of changes, from a non-vegetated to a vegetated state (Carter & Rogers, 1995). In 1996 the Sabie River experienced a small flood, (i.e. 1900 m^3s^{-1}). After the flood of 1996 it was

observed that the Sabie River landscape went through another directional sequence of changes, although within this sequence of changes, vegetation density and frequency decreased (i.e. vegetated to a non-vegetated state over time) (Rountree *et al.*, 2000). Although the flood of February 2000 was almost seven times greater than in 1996, the same sequence of events was experienced, although at much higher magnitudes.

Despite the magnitude of the flooding event in 2000, the elevation gradient of vegetation community distribution along the Sabie River, as identified by Van Coller *et al.* (1997), was mostly maintained after the February 2000 flood (Parsons *et al.,* 2006). Although plant communities remained more or less similar after the flood, spatial shifts in species within communities were recorded (Parsons *et al.,* 2006).

The removal of riparian vegetation through floods creates opportunities for plant species to colonize and re-colonize. However, species that are intolerant to seasonal or moderate floods may not be able to re-colonize (Dixon, 2003). Some channel-floor species tend to be displaced to riverbanks after floods, but will be relocated on the channel-floor when conditions are favorable (Henry & Amoros, 1996; Johnson, 2000). These macro-channel floor species mostly do not establish permanently on banks unless environmental conditions have changed to such extent that the habitat is suitable for their survival and establishment (Johnson, 2000).

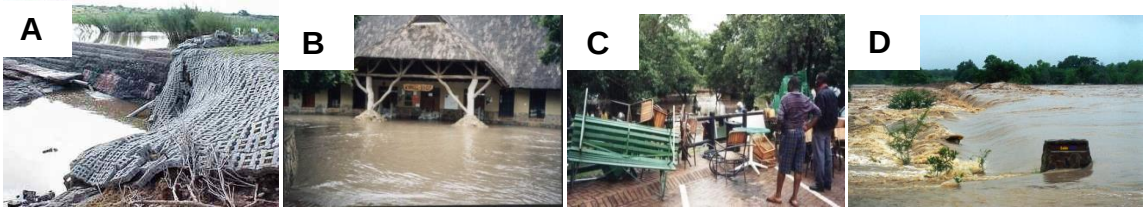


Figure 1.1: (A) Damage caused by the 2000 flood to a gauging station (X3H015) close to Lower Sabie rest camp (DWAF, 2002); (B) and (C) Skukuza Rest Camp under water during the 2000 flood (De Klerk, 2000); (D) The Sabie River in flood at the high water bridge (Bassil, 2000).

1.1.2. *Disturbance as an agent of diversity within a river landscape*

Large infrequent disturbances (LIDs), such as the 2000 flood serve as catalysts for change within ecological systems (Turner & Dale, 1998). Sudden, unique changes are common to

ecosystems exposed to an extreme natural event (Turner & Dale, 1998). Large infrequent floods may, for instance, reintroduce certain species that were missing from the area prior to the flooding event, or may create alternative ecosystem functions and states (Abrams *et al.,* 1985). They are disruptive events, which occur on a much larger scale (spatially) with above average flows, depth or duration than the typical disruptive events within a natural system (Turner & Dale, 1998).

The distribution and organization of vegetation in riparian zones are well documented (e.g. Kalliola *et al*., 1991; Sharitz & Mitsch, 1993; Hupp & Osterkamp, 1996; Crawley, 1997; Hodges, 1997; Bendix & Hupp 2000; Hupp, 2000; Stromberg, 2001; Siebert, 2003; Damasceno *et al*., 2005; Turner *et al*., 2004; Parsons *et al*., 2006; Hupp & Rinaldi, 2007). River dynamics based on geology, topography, hydrology and flow regime can determine patterns of succession and distribution of plant assemblages in a riparian ecosystem (Puhakka & Kalliola, 1995; Schnitzler, 1997). Disturbance is one of the key elements in creating a rich biodiversity in riparian vegetation, as it creates patchiness in the river landscape, promotes the dispersal of propagules and distributes nutrient-rich sediments (Bendix & Hupp, 2000; Parsons *et al*., 2006; Foxcroft *et al*., 2008). Therefore, LIDs have an important influence on the biotic and abiotic structure, composition and function of an ecosystem (Turner & Dale, 1998).

1.1.3. Post-flood biomonitoring along the Sabie River, Kruger National Park

In the early 1990's the establishment of the Kruger National Park Rivers Research Program (KNPRRP) (See Table 1.1for description of research projects) generated a fundamental understanding of the Sabie River landscape, the geomorphological template and the distribution of riparian vegetation across this diverse template (Van Niekerk *et al.*, 1995; Carter & Rogers, 1995; Van Coller *et al*.,1997; Van Niekerk *et al.*, 1999; Mackenzie *et al.*,1999; Heritage & Moon, 2000; Van Coller *et al.*, 2000; Rountree *et al.*, 2000; Heritage, Moon *et al.*, 2001; James *et al.*, 2002; Pollard *et al*., 2011).

The KNPRRP ended in 2000 (Pollard *et al*., 2011), coincidently the year in which KNP experienced a large infrequent flood. As a result, the Kruger Rivers Post-flood Research Program, funded by the Andrew W. Mellon Foundation and in collaboration with the Centre

for Water in the Environment (University of the Witwatersrand), was established to examine the response of rivers to the 2000 flood within the KNP (Parsons, 2004).

Table 1.1: Summary of project history (adapted from Kotschy *et al.*, 2006).

Early 90s (KNPRRP)	**2000 – 2006 (KRPFRP)**	**2010 (Research presented here)**
• Woody and herbaceous species (species composition and structure recorded)	• Woody and herbaceous species (species composition and structure recorded)	• Woody species (species composition and structure recorded)
• Environmental data	• Environmental data	• Environmental data
• 11 Transects, 20 m wide	• 24 Transects, 30 m wide	• Four Transects, 30 m wide
• Transects selected in stratified-random fashion (based on geology and channel type)	• Six Transects in each of the four channel types	• One Transect in each of the four channel types

According to the study performed by the Kruger Rivers Post-flood Research Program (KRPFRP), the macro channel floor (MCF) was the most affected by the 2000 flood. Most of the MCF vegetation was stripped by the water masses since the MCF is in the high active energy zone of a river system (Parsons *et al*., 2006). The KRPFRP concluded that, although the flood dramatically changed the river landscape, the riparian ecosystem did not indicate detrimental changes to the biodiversity and river landscape heterogeneity (Parsons *et al*., 2007). However, the project indicated that the initial disturbance from the flood triggers a sequence of smaller events within the riparian landscape which can only be observed over an extended time (Parsons *et al*., 2007).

Results of a project along the Sabie River after the 2000 flood revealed that the vegetation is at the 'onset of recovery' phase, and further monitoring is needed to monitor the direction of vegetation change after a longer period (Siebert *et al*., 2008). Therefore, continued monitoring within a riparian ecosystem before and after a LID (e.g. flood) might provide an indication of the ecosystem health and its ability to adapt to change.

Biomonitoring, or the monitoring of biodiversity, is an important aspect of the management strategies within South African National Parks (SANParks) (Rogers *et al.,* 2008). Biodiversity is a versatile concept, which can lead to the misunderstanding or abuse of the concept. Rogers *et al.* (2008) stated that biodiversity is not only the number of species in a certain area but also includes the abiotic components of that area. To clarify the concept of biodiversity for management purposes, SANParks uses the following widely accepted definitions for biodiversity:

"The variety and variability among living organisms and the ecological complexes in which they occur" (OTA, 1987).

"Biodiversity refers to the variety of life and its processes: this encompasses compositional (what is there), structural (how it is distributed in space and time) and functional (what it does) elements of ecosystems, each being manifest at multiple levels of interconnected organization ranging from genes to species, communities and ecosystems and landscapes" (Noss, 1990).

"The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part and also includes diversity within species, between species, and of ecosystems" (Biodiversity Act 10 of 2004).

For the purpose of this study, a combination of the above definitions was considered to explain biodiversity. This study has therefore not only focused on which species were present within the riparian ecosystem but also the diversity in vegetation structure and plant growth forms. This provided valuable insight into the post-flood interactions between shrubs, trees and lianas within the riparian ecosystem.

According to Burt *et al*. (2008) the ideal long-term monitoring study should not be shorter than 20-30 years. This is mainly due to complexity of natural systems and how these complex systems react or respond to large disturbances over time (Burt *et al.,* 2008). This project has therefore only identified certain trends. However, continuous monitoring will be beneficial for the adaptive management strategies of SANParks, since the data generated will contribute to our understanding of natural system responses to LIDs (Burt *et al.,* 2008).

1.1.4. The integration of adaptive management and biomonitoring strategies

Monitoring and management of biodiversity within protected areas are aimed at recognizing or identifying unanticipated negative changes within the natural environment (McGeoch *et al*., 2011). Furthermore monitoring contributes to the understanding and better management of disturbances within ecosystems (McGeoch *et al*., 2011). Therefore monitoring must be used to evaluate and identify any shortcomings within policies or management strategies (McGeoch *et al*., 2011).

Most environmental management terms and strategies (e.g. adaptive management strategy) can be interpreted in many different ways, depending on the background of the interpreter and the purpose of using the term (Barrow, 2006). The KNP apply adaptive management strategies which embraces a process of continuous learning and forces researches and regulatory bodies to work together (Barrow, 2006). Adaptive environmental management is therefore a research-orientated approach and will most likely never reach a state where fully satisfactory knowledge for environmental management is acquired (Walters, 1986; McLain & Lee, 1996).

Monitoring is an integral part of adaptive management as it evaluates the outcomes of management actions and determines whether the defined desired state is being achieved (Atkinson *et al*., 2004). Vegetation can serve as a consistent measure of the ecological health of an ecosystem after a small or large scale event, since it integrates all environmental factors working in an ecosystem. Damage to the vegetation, namely the visual impacts of floods, provoked several questions as to the physical and biological impacts of the flood of 2000. Furthermore the impacts of fire, drought and grazing on plant assemblages have been the subject of considerable research over the last few years

although long-term impacts of flooding on plant assemblages in arid environments are less understood (Westbrooke *et al*., 2005). Consequently, these questions and concerns lead to the establishment of various post-flood long-term biomonitoring projects within the KNP. Several vegetation surveys were undertaken along the Sabie River after the 2000 flood to examine the influence of hydrology, river landscape and channel morphology on post-flood vegetation response (Siebert, 2003; Parsons *et al*., 2006; Kotschy & Rogers, 2008; Parsons *et al*., 2007; Siebert *et al.*, 2008; Foxcroft *et al.*, 2008).

This study was broadly based on the project conducted by the Kruger Rivers Post-Flood Research Program (KRPFRP) (See Chapter 3, Table 3.2 for more information concerning the KRPFRP). The results obtained from this study were compared to what was reported by the KRPFRP, and more particularly the papers published by Parsons *et al*. (2006 & 2007).

Parsons *et al*. (2006) reported that the flood of 2000 did not change the riparian vegetation structure and composition drastically, but rather altered certain vegetation structures and species composition density and patterns across the MCB and MCF.

The factors identified and discussed above may restrict the riparian ecosystem to return to pre 2000 flood environmental conditions (Parsons *et al*., 2006). Previous biomonitoring studies have revealed that after certain LIDs (e.g. forest fires in Yellowstone National Park and the 1980 Mt. St. Helen's volcanic eruption) the ecosystems are starting to resemble pre-disturbance states (Dale, 1991; Stone, 1998). Parsons *et al*. (2006) stated that continuous and long-term biomonitoring of the successional dynamics and physical template change might confirm whether the ecosystems of the Sabie River will resemble pre-flood environmental conditions in the distant future.

1.2. Aims and objectives

This long-term monitoring project builds on the work of the KRPFRP and is aimed at addressing and furthering the ecological understanding of LIDs within a semi-arid riparian ecosystems and its surrounding semi-arid environment. The safeguarding of riparian vegetation is recognized as vital to the integrity of river ecosystems (Hancock *et al.*, 1996; Roth *et al.,* 1996) and its conservation importance has repeatedly been emphasised

(Naiman & Décamps, 1997; Gilvear *et al.*, 2000).

The main aim of this study was to assess the response of riparian vegetation to a large, infrequent flood event along a semi-arid riparian ecosystem at an intermediate temporal scale (i.e. 2004 – 2010).

The general objectives of this study were to:

- **Species composition**
    - test whether there is a significant change in woody species composition, frequency and diversity between 2004 and 2010;
    - assess how species composition differ across the different zones of the macro channel (MCB, MCF ephemeral and MCF seasonal / active); and
    - assess the presence, frequency and increase of alien invasive species in 2004 and 2010.
- **Riparian vegetation structure**
    - test if there is a significant change in riparian woody structure between 2004 and 2010;
    - determine the structural characteristics of the macro channel (MCB, MCF ephemeral and MCF seasonal / active) in 2004 and in 2010;
    - report on the frequency of shrubs, trees and lianas across the macro channel in 2004 and in 2010; and
    - determine which growth form (shrub, tree or liana) is the most abundant in the MCB and MCF.

1.3. Hypotheses and key questions

H1: Woody species composition and richness of the macro channel remained constant over an intermediate post-flood interval (2004 – 2010).

Given that analysis of the macro channel could conceal changes at the level of morphological zones, the following sub-hypotheses are postulated:

H1.1: Woody species composition and richness of the macro channel floor (MCF) changed over an intermediate post-flood interval (2004 – 2010).

H1.2: Woody species composition and richness of the macro channel bank (MCB) remained constant over an intermediate post-flood interval (2004 – 2010).

H2: Woody vegetation structure changed in the macro channel over an intermediate post-flood interval.

Given that analysis of the macro channel could conceal changes at the level of morphological zones, the following sub-hypotheses are postulated:

H2.1: Changes in woody vegetation structure occurred on the MCF over an intermediate post-flood interval (2004 – 2010) in terms of density and height.

H2.2: Changes in woody vegetation structure occurred on the MCB over an intermediate post-flood interval (2004 – 2010) in terms of density and height.

To better understand the responses of riparian vegetation to a large, infrequent flood event along a semi-arid riparian ecosystem at an intermediate temporal scale, and to address the above mentioned hypotheses, the project addressed the following key questions:

- What is the response of riparian vegetation to a large, infrequent flood event at an intermediate post flood interval (2004 to 2010)?
- Is there significant variation in species composition, richness and structure across the different morphological zones: MCB vs. MCF?

- Which morphological zone has more profound temporal changes in vegetation composition and structure: MCB vs. MCF?
- Which growth form (shrub, tree or liana) is the most abundant on the MCB and MCF respectively (2004 and 2010)?

1.4. Important definitions

In order to prevent any misinterpretation, the following terms need to be clearly defined:

- Channel type: Channel type refers to the fluvial geomorphology of the Sabie River. There are four distinct channel types which are referred to within this dissertation, namely bedrock anastomosing (BA), mixed anastomosing (MA), braided (Br) and Pool-rapid (PR).
- Macro channel: The macro channels consist of a bank and floor also referred to as the macro channel bank (MCB) and macro channel floor (MCF). The MCB and MCF are referred to as morphological zones. The macro channel is the entire area in which water flows, seasonally and active, including the higher elevated bank areas.
- Geomorphological units: Each channel type consists of different geomorphological units. These geomorphological units can either be bedrock, sandbars or a combination of bedrock and sand.

1.5. Layout of dissertation

This dissertation consists of eight chapters. The two chapters (chapters 5 and 6) in which the results are presented were prepared in manuscript format to facilitate later submission to scientific journals. The structure of these chapters implies that a certain amount of duplication was unavoidable, especially regarding literature, methods and results. All references cited are listed at the end of this dissertation. This dissertation complies with the standard regulations and guidelines provided by the North-West University, Potchefstroom.

The layout of the dissertation is outlined below:

Chapter 2: Literature review

Extensive literature survey relating to the research statement was reviewed and presented. This chapter provides valuable insight and support of the existing ecological principles and research to fully understand the findings described in this study.

Chapter 3: Study area

A detailed overview of the research area, including background on the climate, topography, hydrology, geomorphology, geology, riparian vegetation characteristics and soil types of the KNP and smaller study area is presented. This chapter also sets the scene to further understand and identify ecological patterns which are related to environmental factors.

Chapter 4: Methods

An overview of data sampling and analytical techniques followed in this study is provided. Specific sampling and statistical analyses are also described at the beginning of each results chapter.

Chapter 5: Results – Temporal and spatial changes in woody species composition

Riparian environments are open ecosystems, with high nutrient levels and moist soils providing riparian vegetation the opportunity to establish and flourish. The flood of 2000 changed the biotic and abiotic template of the Sabie River, KNP, creating open niches to be filled by woody riparian species (including alien invasive species). This chapter explores the effects of a large infrequent flood on the woody species composition of riparian vegetation across different morphological zones, at an intermediate post-flood interval (2004 – 2010).

This chapter is constructed in a format to facilitate in the later preparation of a manuscript to be submitted to a peer-reviewed academic journal.

Chapter 6: Results – Temporal and spatial changes in woody structure

Disturbances may have adverse effects on the environment, causing physical changes to the landscape and vegetation. There is an ever growing need to understand how LIDs

(such as floods) change the ecosystem and how the ecosystem responds. This chapter explores the effects of a large infrequent flood on the structure of the riparian vegetation across different morphological zones, at an intermediate post-flood interval (2004 – 2010).

Similar to chapter 5, this chapter is constructed in a format to facilitate in the later preparation of a manuscript to be submitted in a peer-reviewed academic journal.

Chapter 7: General Discussion and Recommendations

This chapter provides an overview of the findings presented in chapters 5 and 6. The relationship between the different findings are discussed and presented to explain the current ecological state observed along a section of the Sabie River, KNP. Shortcomings of this study and the way forward are also presented.

Chapter 8: Conclusion

This chapter provides a final summary of the most important findings. A brief summary for each hypothesis is provided and whether or not the results obtained in this study supports the individual hypotheses.

Chapter 2: Literature review

2.1. Large Infrequent Disturbances (LIDs)

LIDs or natural disasters such as floods, droughts, hurricanes, fires, earth quakes, mudslides and tsunamis are regarded as catastrophic events (Figure 2.1) which are disruptive to societies and the natural environment (Harris *et al.,* 1996; Turner & Dale, 1998; Parsons *et al.*, 2006). White and Pickett (1985) defined a LID as, "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resource availability, substrate availability, or the physical environment." Disturbances are traditionally classified according to their size, spatial distribution, return interval, predictability and magnitude (Turner & Dale, 1998). As the nature of LIDs is generally catastrophic and sporadic, LIDs can also be identified through the statistics of extremes (Gaines & Denny, 1993).

LIDs can also be defined by, “the perception of the event relative to a human scale or to the life span and attribute of the organisms in the ecosystem” (Turner & Dale, 1998). This means that a volcanic eruption is not rare or exceptionally large if compared with geological time, but becomes a LID once compared to human time (Harris, 1986). Therefore LIDs must be considered relative to the organisms and environment being affected (Turner & Dale, 1998).

Disturbances occur across a broad range of sizes, intensities and frequencies. Although much is known about the effect of small disturbances on the environment, little research has been done on the effects of large infrequent disturbances within a natural ecosystem (Turner & Dale, 1998). In the international scientific community, ecologists are becoming increasingly attentive on the role of LIDs within an ecosystem’s structure and functionality (Turner & Dale, 1998).

LIDs are considered important drivers of heterogeneity within an ecosystem (Turner & Dale, 1998). LIDs leave a unique imprint on an ecosystem as the intensity and severity of disturbance varies from one area to another (Turner & Dale, 1998). The irregularity is mainly due to the complexity of the affected landscape (Turner & Dale, 1998), since some

landscapes are more exposed to the LID than other areas (Foster *et al.*, 1998). Romme and Knight (1982) stated that LIDs may become the dominant force structuring an ecosystem because of the large template of change. The large template of landscape change can stimulate species interaction, which in turn may lead to a mosaic of habitats (Romme & Knight, 1982).

Figure 2.1: The disruptive and destructive nature of large infrequent disturbances (copied from Safecom, 2007; Kalathil, 2008; Vencio, 2011).

LIDs, including floods, create an environment that promotes new riparian vegetation growth by dispersing propagules, creating new habitat and depositing sediment rich in nutrients (Bendix & Hupp, 2000). Floods have several long-term impacts, which shape the vegetation structure for many years long after the direct impact of the flood, for example vegetation regression (Harris *et al.,* 1996). Vegetation regression occurs when vegetation, which seems to be flourishing, starts to decline and dieback (Harris *et al.,* 1996). This is directly linked to a change within the environment such as a change in soil pH, soil nutrients, amount and composition of topsoil, soil drainage and water supply (Harris *et al.,* 1996). This process can take place over several seasons or over a short period (Harris *et al.,* 1996).

In riparian vegetation, disturbances are one of the key elements in creating a rich biodiversity, as it creates patchiness in the landscape (Turner & Dale, 1998). The continuous shifting of water flow patterns and volumes over a landscape creates an irregular distribution of biotic and abiotic patches over multiple spatial and temporal scales (Tabacchi *et al*., 1998; Malard *et al*., 2000; Arscott *et al*., 2002; Dixon, 2003). LIDs, such as floods, also completely destroy established riparian vegetation (Bendix & Hupp, 2000) and alter vegetation that is found within the in-stream boundaries (Bischoff & Wolter, 2001).

The construction of dams, weirs and other structures can cause significant changes to the downstream biophysical template of a river ecosystem, i.e. hydrology, geomorphological characteristics, sedimentation and channel type (Katz *et al.,* 2005). The characteristics of the channel type immediately after a newly constructed dam or weir undergoes many morphological and hydrological changes (Katz *et al.,* 2005). In return, these changes eventually lead to the formation of a new channel type (Katz *et al.,* 2005).

Ecologists should consider both natural and human-induced disturbances, since the combination of these anthropogenic and natural disturbances can result in multiple effects within the ecosystem (Turner & Dale, 1998). For example, because of the many biophysical changes occurring after the construction of a manmade structure within a river system, the construction of dams and weirs can be seen as a large disturbance with permanent disruptive consequences.

O'Connor (2010a) noted that the riparian forest of Mapungubwe National Park in South Africa was transformed to woodlands within 15 years because of several environmental factors and water abstraction from mining operations. Water abstraction influences the height of the water table which can influence the composition, structure and function of riparian vegetation (O'Connor, 2010b). Once human activities alter an ecosystem (i.e. altered a watershed or drainage pattern, floodplains, rivers and riparian vegetation), river flow is expected to increase, which will ultimately increase damages by flood waters (Belt, 1975; Leopold, 1994). Although water abstraction is not a manmade structure, but rather an activity or usage of the river as a resource, it emphasizes how sensitive riparian ecosystems are.

Other environmental changes (e.g. global warming) affect the intensity and frequency of LIDs. Schiermeier (2012) reported that since 1980 the frequency of large floods had almost tripled and large storms had doubled. The increase in the number of large floods and storms can directly be linked to global climate change (Schiermeier, 2012). It is believed that the frequency and intensity of LID will increase as the earth's temperature rises (Schiermeier, 2012). Shongwe *et al.* (2010?) at the Royal Netherlands Meteorological Institute (KNMI) stated that the assessment of climate change is often limited to mean temperatures and precipitation with knowledge of extreme climate changes being

inadequate in Africa. It is therefore vital that more research is done on LIDs to fully understand and identify the main drivers and outcomes of extreme weather patterns within Africa and the rest of the world.

2.2. **Riparian vegetation**

2.2.1. Riparian vegetation defined as a wetland

According to the Ramsar Convention Handbook (2010) wetlands include many different habitats, i.e. marshes, peatland, floodplains, rivers, riparian areas, lakes, salt marshes, mangrove swamps, sea grass beds, coral reefs, marine areas not deeper than six meters and manmade wetlands.

Wetlands are vital support systems to many agriculture activities, conservation areas and endemic forests (Ramsar, 2010). The importance of wetlands has been emphasised in worldwide legislations and conservation strategies, such as the Ramsar Convention's Strategic Plan, the *World Conservation Strategy*, *Caring for the Earth*, the report of the Brundtland Commission, and Agenda 21 (Ramsar, 2010). "The importance of our wetlands goes beyond their status as the habitat of many endangered plant and animal species. They are a vital element of national and global ecosystems and economies" (Ramsar, 2010).

The National Water Act 36 of 1998 (NWA 36 of 1998) defines wetlands as "land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil". Wetlands must have hydromorphic soils, and/or hydrophytes and/or a high water table which causes saturation of the top soil leading to anaerobic conditions, to be classified as a wetland (DWAF, 2005). Riparian zones could therefore be classified as wetlands based on one or more of the above-mentioned defining wetland characteristics.

The delineation and classification of riparian zones remains a challenge. Riparian habitats are defined by the NWA 36 of 1998 as "the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial

soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas" (NWA 36 of 1998). Therefore, riparian vegetation is vegetation which borders a water body (e.g. river, stream, lake and dam) and is affected directly or indirectly by the water body (NSW DPI, 2005).

The significant role of riparian vegetation within an ecosystem is well documented. (e.g. Nilsson, 1992; Hancock *et al.*, 1996; Braga, 1999; Van Coller *et al.*, 1997; Soman, 2007). Riparian ecosystems provide several ecosystem services and functions to the structure and function of the surrounding ecosystems (Figure 2.2). Riparian vegetation does not only provide organisms with their basic needs (shelter, food and general habitat) but acts as a corridor for animal movement, it slows down water movement (which allows the groundwater to be replenished), and promotes sediment deposition which in return helps to replenish soil nutrients, creating a unique morphology within river landscapes (Figure 2.2) (Braga, 1999). The riparian zone also acts as an ecological link between the terrestrial and aquatic habitats (Nilsson, 1992).

Riparian ecosystems are considered as very complex systems with numerous environmental factors driving patterns and processes. Composite gradients (i.e. height above the channel, horizontal distance away from the channel) are being considered as one of the major drivers of heterogeneity within the riparian ecosystem (Mackenzie *et al.,* 1999). In combination with environmental gradients, environmental variables (e.g. flooding, water availability, morphology, geology, substrata, soil composition, nutrients and plant assemblages) must also be taken into consideration during environmental monitoring processes (Mackenzie *et al.*, 1999). Due to the complexity of riparian vegetation, it is important to comprehensively understand all possible cycles, gradients and biotic and abiotic factors at all hierarchical levels to ensure proper management of river ecosystems (Sharitz & Mitsch 1993; Hupp & Osterkamp, 1996; Hodges, 1997; Van Coller *et al.*, 1997; Naiman & Bilby, 1998; Hupp, 2000; Hupp & Rinaldi, 2007).

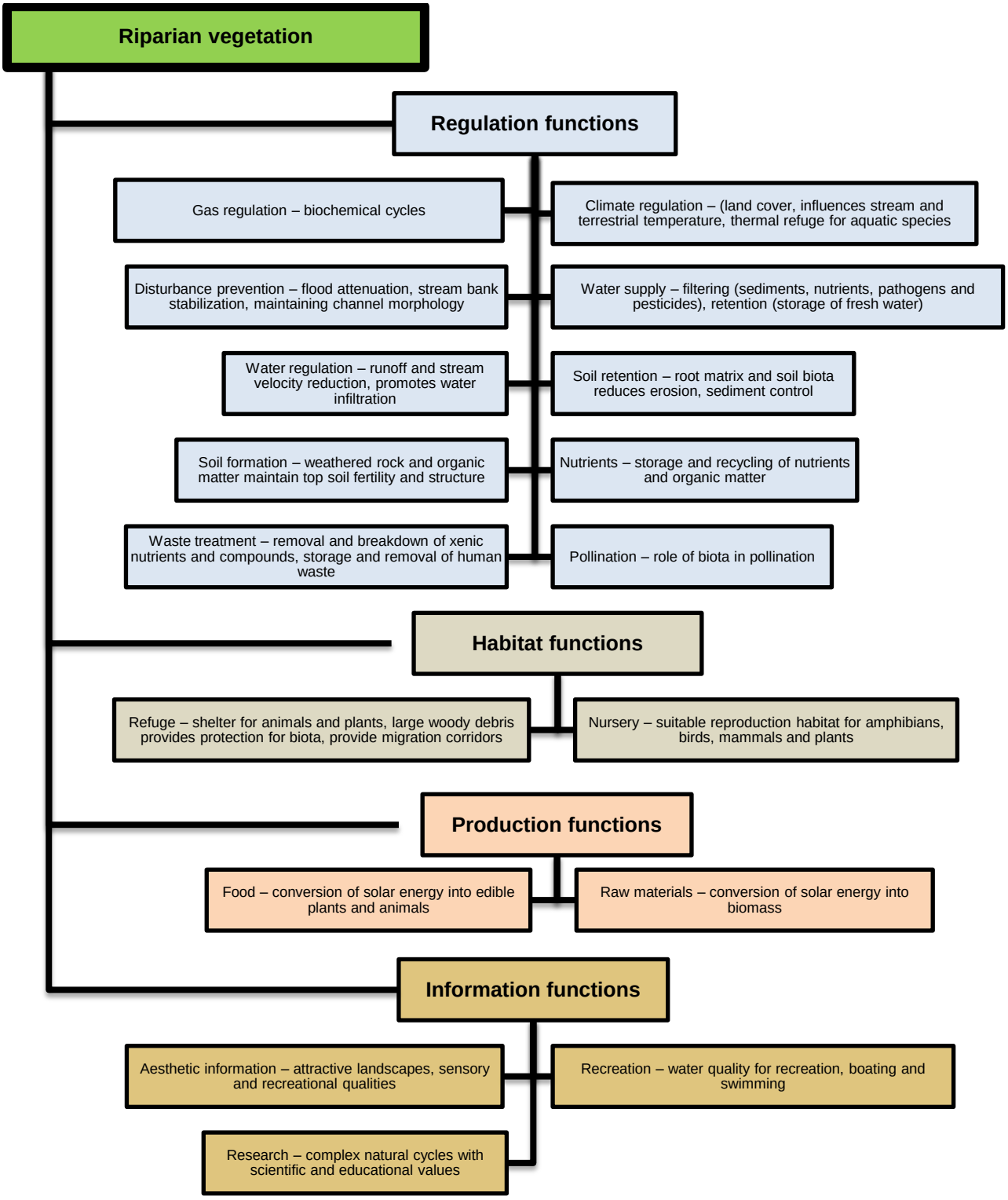


Figure 2.2: Ecosystem functions and services provided by riparian ecosystems (Adapted from Soman, 2007).

Riparian ecosystems are considered as very complex systems with numerous environmental factors driving patterns and processes. Composite gradients (i.e. height above the channel, horizontal distance away from the channel) are being considered as one of the major drivers of heterogeneity within the riparian ecosystem (Mackenzie *et al.,* 1999). In combination with environmental gradients, environmental variables (e.g. flooding, water availability, morphology, geology, substrata, soil composition, nutrients and plant assemblages) must also be taken into consideration during environmental monitoring processes (Mackenzie *et al.*, 1999). Due to the complexity of riparian vegetation, it is important to comprehensively understand all possible cycles, gradients and biotic and abiotic factors at all hierarchical levels to ensure proper management of river ecosystems (Sharitz & Mitsch 1993; Hupp & Osterkamp, 1996; Hodges, 1997; Van Coller *et al.*, 1997; Naiman & Bilby, 1998; Hupp, 2000; Hupp & Rinaldi, 2007).

2.2.2. Riparian vegetation characteristics

For riparian vegetation to survive in an ever changing environment, they have adapted certain unique morphological, physiological and reproductive adaptations (Malanson, 1993; Mitsch & Gosselink, 1993; Naiman & Decamps, 1997; Naiman & Bilby, 1998). Some of these unique adaptations are to grow in and nearby large woody debris (LWDs) for protection, the ability of hydrophytes to grow in saturated or inundated soils, and the ability to survive flooding, sediment deposition, physical abrasion and stem breakage (Naiman & Bilby, 1998). In addition, the seed dispersal of some riparian plants coincides with the seasonal retreat of flood waters (Naiman & Bilby, 1998).

Within riparian habitats, reeds and certain herbaceous species act as pioneering species which create a suitable environment for the establishment of trees and other plant species (Van Niekerk & Heritage, 1993). Once dynamic riparian plant communities are established, the interaction or competition and distribution of trees and shrubs are closely related through root competition, shading and litter (Monk & Gabrielson, 1985). Monk and Gabrielson (1985) reported that vegetation litter can change the composition and structure of plant communities. This may lead to shrubs being more dominant after large flood events due to their vigorous vegetation growth form and regeneration strategies (Facelli & Pickett, 1991).

There is a strong link between riparian vegetation and fluvial landscapes and its processes (Hupp & Osterkamp, 1985; Van Coller, 1997). The distribution of plant communities within the riparian landscape is influenced by a variety of bio-geomorphic factors at multiple hierarchical scales (Stallins, 2006; Dollar *et al.*, 2007). Therefore, the patchy distribution of geomorphic units can create patchiness within the distribution of riparian vegetation (Hupp & Osterkamp, 1985). Within most alluvial dominated river systems, the distribution of riparian vegetation is closely linked to the sloping distance and height from the active channel and flooding frequency (Parsons *et al*., 2007).

The biotic and abiotic template of the Sabie River changed considerably as a result of the 2000 flood (Parsons *et al.,* 2006). Previous studies (Carter & Rogers, 1995; Parsons *et al.,* 2006) revealed that the Sabie River landscape follows a certain sequence from non-vegetated to vegetated states after large flood events. In 1996 Rountree *et al.* (2000) observed that due to an increase in water flow and sand deposition, reed cover, shrubs and trees decreased after the 1996 flood. Therefore a disequilibrium model was developed to better understand the sequence of landscape change after a large flood event (Parsons *et al.*, 2006). This disequilibrium model describes the shifts within ecosystems as a result of human activities and natural processes (Heshmati & Squires, 2009). Because riparian ecosystems are dynamic and complex, the disequilibrium model and chaos theory can be used to interpret and manage ecological trends within riparian vegetation. According to the disequilibrium model, riparian vegetation structure and composition will most likely not resemble pre-LID (or pre-flood) characteristics but will be characterised by present ecological factors.

2.2.3. Link between riparian vegetation and geomorphology

Thornbury (1969) and Ritter (1978) defined geomorphology as the study of landforms and the associated processes which generate landforms. The three main factors which affect landforms are the geology and climate of the surrounding area (Kovalchik & Chitwood, 1990). Climate determines most chemical and physical processes, which affect the earth's surface. Rainfall provides the necessary energy to shape and drive watershed ecosystems (Kovalchik & Chitwood, 1990). Although climate and geology are the most constant factors

influencing landforms, these factors are not static and homogeneous, which therefore creates a mosaic of landforms and patchy landscapes (Kovalchik & Chitwood, 1990).

Riparian ecosystems are distinguished and characterised by a unique combination of geomorphology, topography, geology, channel type, hydrology, vegetation and anthropogenic factors (Sharitz & Mitsch 1993; Hupp & Osterkamp, 1996; Hodges, 1997; Hupp, 2000; Hupp & Rinaldi 2007). Graf (1985) defined the riparian zone to include the channel and near-channel habitats directly influenced by modern river-related processes.

The Sabie River is characterised by one or more active channels which flow within an incised macro-channel (Van Niekerk *et al.*, 1995). The average Sabie River macro channel is between 250 m to 800 m wide and 8 m to 15 m deep (Van Niekerk *et al.*, 1995). The macro-channel can be divided into the MCB and MCF (Parsons *et al*., 2006). The MCB and MCF are two distinct morphological zones located across the river landscape (Table 2.1). Due to the locality and physical template of the MCB and MCF, the plant communities found on the two separate morphological zones are different in composition and structure (Table 2.1).

Pieterson (2009) reported that riparian vegetation "patterns develop and adapt to the existing environmental processes (i.e. natural flow regime, sediment erosion/deposition dynamics, soil moisture regime) associated with particular fluvial landforms". In addition, riparian vegetation can affect channel process and morphology, which has a direct affect on the establishment of future riparian vegetation (Pieterson, 2009). For example, high density vegetation cover will provide additional bank stability (Rowntree & du Plessis, 2003). However, the type of vegetation cover will determine bank stability. Growth forms, such as grasses and shrubs can mitigate low flow velocities but is washed away with high flows (Rowntree & du Plessis, 2003). Trees which have deep root systems can withstand high flows thereby providing greater bank stability, but once trees are dislodged by high flows, they can cause bank scarring (Thorne, 1990; Trimble, 2004; Rowntree & du Plessis, 2003).

Table 2.1: Comparison between Macro Channel Bank and Macro Channel Floor (Van Niekerk *et al.*, 1996; Van Coller *et al.*, 1997; Marnewecke & Kotze, 1999; Freeman & Rowntree, 2005). Red strips indicate the relevant section within the macro channel.

	Macro Channel Bank (MCB)	Macro Channel Floor	
		Ephemeral	Active / Seasonal
Locality			
Description	• Steep banks on either side of macro channel floor. • Reduced underground water availability relative to MCF.	• Wide, relatively low gradient area. • Consists of alluvial deposits.	• Characterised and channeled by noticeable banks. • Consists of alluvial deposits and patches of exposed bedrock.
Stability	• Relatively stable – only affected by sub-aerial processes, little sedimentation, erosion, and low flooding frequency.	• Relatively unstable – affected by frequent flooding, sedimentation, erosion, irregular topography and a dynamic geomorphologic template.	• More unstable than Ephemeral MCF – highly affected by flow regimes, erosion, irregular topography and a dynamic geomorphologic template.
Inundation period	• Short inundation periods, normally associated with large floods.	• Short to long periods of inundation (seasonally flooded, depending on annual rainfall).	• Periods of inundation at sufficiently regular intervals which maintain channel form and will keep the channel free of established terrestrial vegetation.
Vegetation characteristics	• Species which are more drought tolerant, and less tolerant to flooding conditions.	• Species which are less tolerant to drought stress but, can tolerate frequent flooding conditions.	• Hydrophytic woody species which are restricted to wetland areas. Vegetation has morphological adaptations to survive prolonged wetness (e.g. prop roots).

Van Niekerk *et al*. (1995) identified five dominant channel types within the Sabie River. Each channel type is distinguished and characterised by a specific combination of geomorphic units, i.e. bedrock core bars, sediment bars, distributary channels, lateral bars, pools and riffles (Van Niekerk *et al*., 1995). The five distinct channel types within the Sabie River are: single thread, braided, pool-rapid, mixed anastomosing and bedrock anastomosing.

The flow regime and hydrological characteristics of the Sabie River have been changed by man-made structures, agriculture and other human activities. As a result of these modifications, the Sabie River mostly experiences short and generally unpredictable flood pulses (Naiman & Bilby, 1998). The complexity of riparian landscapes, in combination with the influx of various factors due to its open nature, makes it challenging for ecologists to fully understand and describe changes within. There could be numerous factors contributing to the change in riparian vegetation composition and structure, but due to the complexity of riparian ecosystems, ecologists are only capable to focus on a few of these interactions and factors.

2.2.4. Riparian vegetation regeneration

The establishment and success of vegetation is essentially determined by regeneration processes and their adaptation to long term and short term disturbances, such as floods and browsing (Crawley, 1997). The biophysical template of riparian corridors undergoes continuous change as a result of a continuous disturbance regime (Ward, 1998). Therefore, riparian vegetation must be able to adapt to changes in soil nutrients, water availability and sediment depositions. Large infrequent flooding events accelerate these changes within the biophysical template of the riparian corridor (Kalliola *et al.,* 1991; Ward, 1998).

During LIDs, woody debris piles are formed, which could impact channel pattern evolution, island formation and riparian vegetation establishment (Fetherston *et al*., 1995; Gurnell *et al*., 2001; Naiman *et al.*, 2002; Abbe & Montgomery 2003; Pettit & Naiman, 2005). Sedimentation from rivers and streams is moist, rich in nutrients and has a high concentration of plant propagules, which create favourable conditions for seedling

establishment (Naiman and Décamps 1997; Naiman *et al*., 2005). Furthermore, woody debris piles protect newly established seedlings against erosion, abrasion, drought and herbivory (Naiman & Décamps 1997; Naiman *et al*., 2005).

Little is known about the role of seed banks in the composition of established plant communities within semi-arid riparian zones (Pettit & Naiman, 2006). However, Malanson (1993) suggested that soil seed banks are less important when compared to upland areas as a result of the high frequency of disturbances and regular movement of sediments within the riparian zone. Seed banks can be important to riparian vegetation species that are able to complete a single life cycle (from seed germination to seed dispersal) before seasonal flooding (Pettit & Naiman, 2006). Riparian zones that are subjected to less flooding and disturbances may be more dependent on soil seed banks for new vegetation establishment (Pettit & Naiman, 2006).

The establishment and success or riparian vegetation is largely determined by complex interactions between flow regime, geomorphology, patch history and plant life-history traits (Naiman *et al.*, 2005; Van Pelt *et al.*, 2006, Petit & Naiman, 2006). Therefore, the success of established seedlings is mainly influenced by the surrounding landscape and micro habitats (Crawley, 1997). Micro habitats which are moist, high in nutrients and provide protection, will promote seedling establishment and growth (Petit & Naiman, 2006). The biophysical template of a micro habitat is formed by several environmental drivers, i.e. fluctuating flow regime, sedimentation, soil water availability, herbivory, fire, climate, erosion, drought and patch history (Kalliola *et al*., 1991; Bendix & Hupp 2000; Stromberg, 2001; Cooper *et al*., 2003; Turner *et al*., 2004).

Many riparian vegetation species are dependent on certain environmental conditions (i.e. flow patterns) to successfully establish seedlings (Naiman & Bilby, 1998). The environmental changes caused by floods can cause certain riparian species to disperse there seeds too early or too late for successful seedling establishment (Stromberg *et al*., 1991, Naiman & Bilby, 1998). This creates the gap for other species to establish (Stromberg *et al*., 1991, Naiman & Bilby, 1998), e.g. if the 2000 flood disrupted the establishment of tree seedlings, shrub species could establish more successfully.

2.2.5. Alien invasive species within riparian zones

The success of alien invasive plant species within riparian ecosystems is determined by the available and suitable patches or gaps within the landscape, which can be occupied by alien invasive plants (Richardson *et al.*, 2007). The patches or gaps within the landscape can be created by climate, topography and geology (White & Harrod, 1997) or because of biotic disturbances, e.g. disease outbreak or successional change (Pacala & Crawley, 1992). Pickett and White (1985) suggested that these patches can also be created by abiotic disturbances such as floods, fires, hurricanes and anthropogenic land-surface alterations. As a result of regular disturbances (i.e. flooding, browsing and agricultural activities), high nutrient levels and a dynamic hydrological regime, riparian ecosystems are prone to alien invasive species (Tickner *et al*., 2001). Foxcroft *et al*. (2007) reported that the 2000 flood prompted a significant recruitment of alien invasive plants. The high recruitment rate of alien plants after the flood could be ascribed to several suitable recruitment patches within the riparian landscape, which were created by the flood (Foxcroft *et al.*, 2007).

There are several land uses within the major watersheds draining into the main rivers of the KNP (Foxcroft *et al*., 2007), which makes it challenging to manage the intrusion of alien invasive plants from outside the KNP. Alien invasion poses a serious threat to the biodiversity of riparian zones within the KNP since they also affect the structure, function and composition of riparian ecosystems (Beater *et al*., 2008). The Working for Water (WfW) program was initiated in the mid-90's to combat and clear alien invasive plant species, initially focusing mainly on *Eucalyptus grandis* (Beater *et al*., 2008). Because of the agricultural, human consumption and eco-tourism importance of the Sabie River, the WfW program started its focus in 1995 on clearing and the removal of all alien invasive plants species along the Sabie River, within and outside the KNP (Beater *et al*., 2008). Therefore, because of the successful eradication of alien species by the WfW program, it is expected that the Sabie River would have less alien invasive species (Holmes *et al*., 2008).

2.3. Long-term biomonitoring

Long-term biomonitoring should not only concentrate on a single environmental factor or link, but should have a holistic approach. The functionality of a riparian zone can be seen as three-dimensional with many direct and indirect interactions taking place between the terrestrial and aquatic environment (Swanson *et al.*, 1982; Gregory *et al.*, 1991). Gregory *et al.* (1991) created a conceptual framework that emphasizes the important biotic and abiotic links within a riparian ecosystem. Figure 2.3 illustrates the different environmental links which could possibly have an impact on riparian vegetation. All the components in Figure 2.3 must be taken into consideration in the construction of a long-term biomonitoring research project within a riparian zone.

The conceptual framework created by Gregory *et al*. (1991) can be applied to most land-water interface ecosystems (e.g., estuaries, marine intertidal areas, wetlands, lakes) (Gregory *et al*., 1991). The importance of a specific environmental link or influential component within an ecosystem may vary because of different biotic and abiotic pattern or characteristics (Gregory *et al.*, 1991). Not all linkages are clear and direct, many linkages between components are intertwined and indirect making monitoring and management difficult and complex (Barrow, 2006).

Riparian vegetation tends to restore or adapt quicker than terrestrial vegetation to environmental change or disturbances. This adaptation can be because riparian vegetation has already adapted to a high intensity disturbance regime (e.g. flooding and browsing activities) and is supported by high water and nutrient availability. Therefore, different monitoring approaches and management strategies should be used within terrestrial and riparian environments when constructing or planning a long-term biomonitoring program.

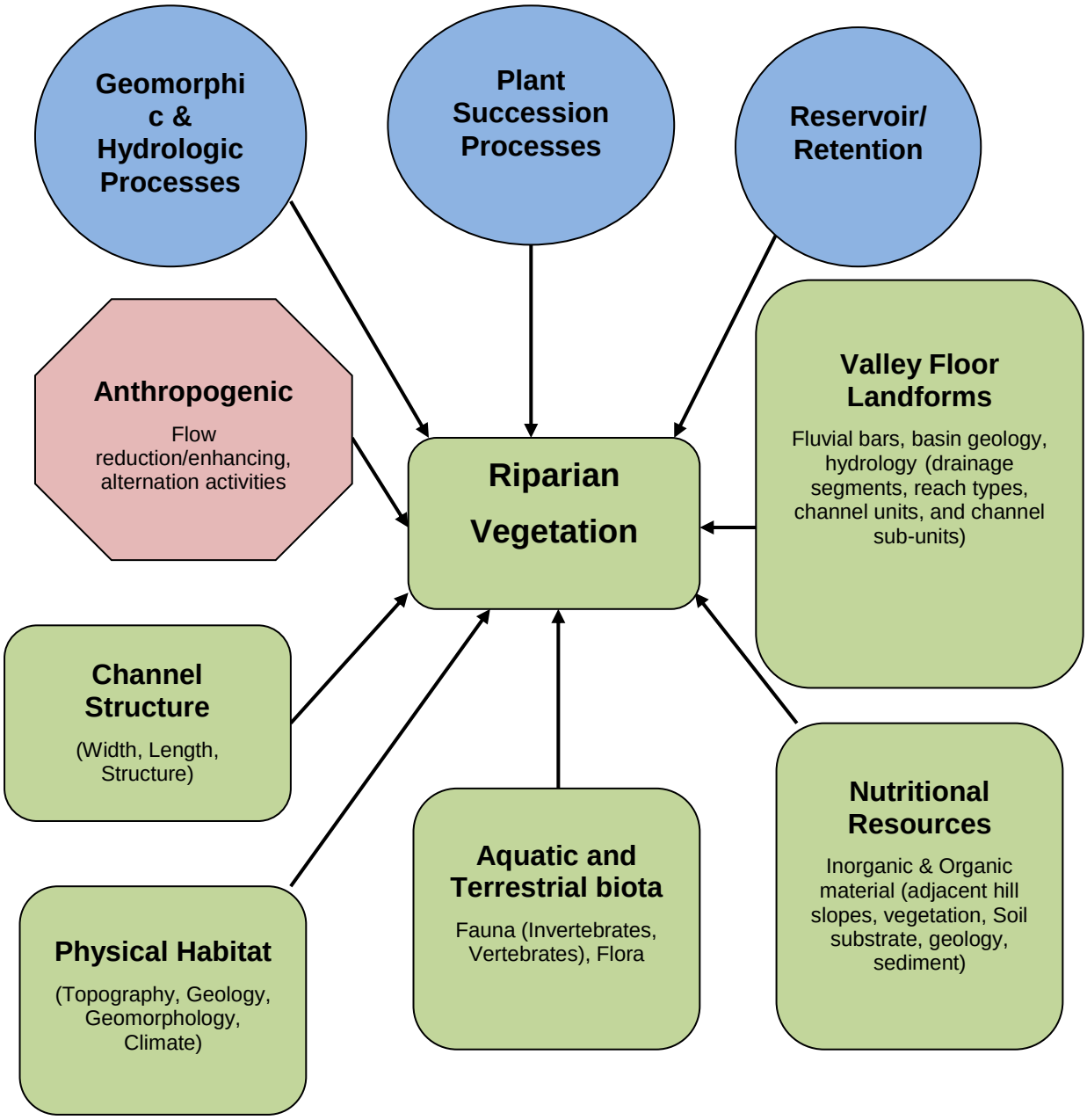


Figure 2.3: External and internal drivers influencing riparian vegetation structure, composition and function (Adapted from Gregory *et al*., 1991). Geomorphic and biological components are represented in the green rectangles, physical and ecological processes represented in the blue circles and anthropogenic component represented with the pink octagon.

2.4. Environmental Management

Environmental and resource managers are increasingly becoming more aware of the ecological, economic and social importance of riparian corridors within management strategies. As a result of the high complexity of riparian ecosystems it is often difficult to predict and establish the vegetation trends of riparian zones and to develop management strategies for these complex systems (Kovalchik & Chitwood, 1990).

Environmental management strategies can effect and promote certain changes within a river system, i.e. the introduction of threshold of potential concerns (TPCs) caused environmental management to change from a reactive management approach to a more proactive sustainable management of rivers within a long-term process (Grobler, 2009).

2.5. Adaptive Management strategies within the Kruger National Park

Biomonitoring forms part of the mission of the adaptive management strategy of SANParks (Rogers *et. al.,* 2008). The adaptive management strategy is designed for the focus of SANParks on biodiversity custodianship, i.e. no activity within SANParks may be undertaken if it has any negative impact on the conservation of biodiversity (Rogers *et. al.,* 2008). To apply the biodiversity custodianship principle, a clear understanding of all ecosystems and cycles or components within each ecosystem is crucial (Rogers *et. al.,* 2008).

Biodiversity, as seen by SANParks, is divided into three main components: structural, compositional and functional (Figure 2.4) (Noss, 1990). Adaptive management provides a platform on which science (biomonitoring and other scientific research methods) and management can be integrated to better understand the three main biodiversity components (Figure 2.4) (CWE, 2003).

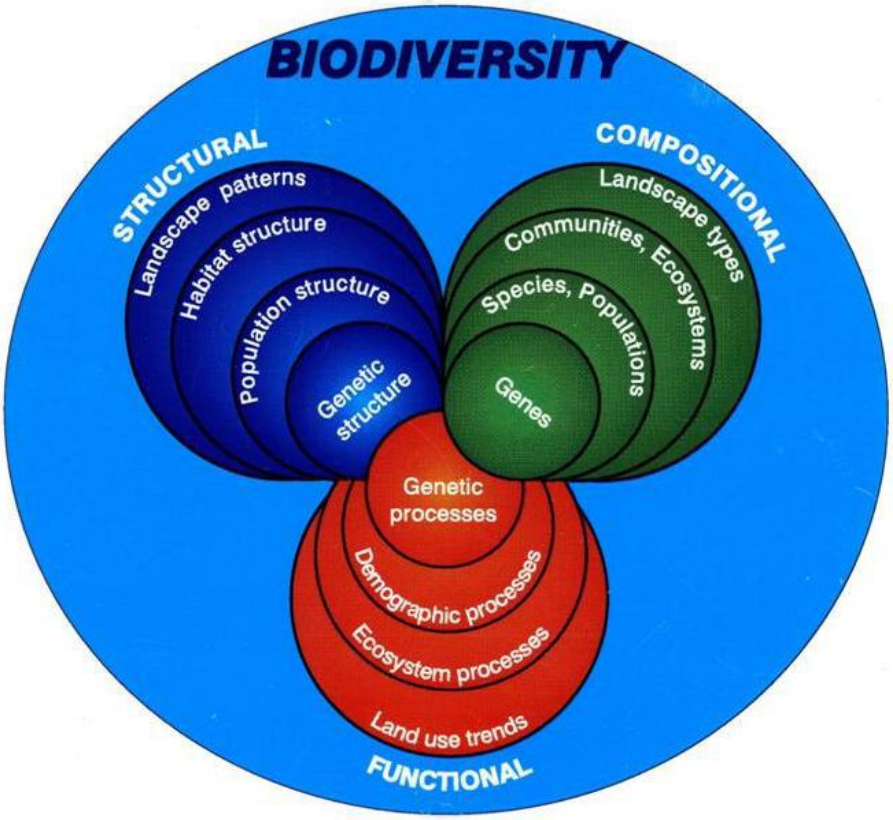


Figure 2.4: Key components of biodiversity as identified within SANParks adaptive management strategy (Noss, 1990).

One of the most important objectives of the KNP management is to ensure a healthy and regular flow of rivers throughout the park (Pollard *et al*., 2011). In the past the KNP was managed as an isolated area but as a result of South Africa's growing water problems, KNP management was persuaded to be involved in catchment policies and implications beyond the borders of the KNP for optimal management solutions (Pollard *et al.*, 2011).

As a result of the transformation of management approaches within the KNP, several management strategies (i.e. adaptive management strategies) have been initiated and incorporated into the management strategies of the KNP. Adaptive management is based on making informed decisions, thereby incorporating research into daily management decisions (Rogers & Biggs, 1999). Therefore, adaptive management uses management actions as opportunities to learn more about the natural environment and thereby improving environmental management (Rogers & Biggs, 1999).

With improved policies, management strategies can develop certain systems to monitor (i.e. TPCs) and evaluate present ecological states. TPCs are statements or hypotheses used to describe the limits of change that can occur within an ecosystem before irreversible environmental degradation occur (Rogers & Biggs, 1999).

Within strategic adaptive management, TPCs for riparian vegetation measures the change in population structure of selected species (Rogers & Biggs, 1999). The changes within the selected riparian species, reflects changes in the physical template of their surrounding environment (Rogers & Biggs, 1999).

To evaluate the success and effectiveness of management strategies within national parks, SANParks has developed a broad based, qualitative assessment or scoring process (i.e. State of Biodiversity (SoB) management reporting) which evaluates whether or not they are meeting their required management goals and objectives (McGeoch *et al*., 2011).

It is vital for any environmental strategy to be flexible to a point where it can accommodate the ever changing environment found within a riparian landscape. This project will play an important role in the management of complex ecosystems within the KNP and might provide valuable insight for the refinement of SANParks' Biodiversity Monitoring Systems (BMS).

2.6. Summary

The complexity of riparian ecosystems and the role LID's have in determining the general characteristics of riparian landscapes, is emphasised within this chapter. As a result of this complexity, it is difficult to isolate and determine the effects a specific component or event has on riparian ecosystems. Therefore, although a multidisciplinary approach is needed to fully describe and interpret changes within riparian ecosystems, it is still important to identify and describe changes within a specific ecosystem component (e.g. vegetation) to facilitate other studies from different disciplines.

Chapter 3: Study area

3.1 Introduction

The study area was situated along the Sabie River within the KNP. The Sabie River is one of the largest rivers within the KNP and therefore provides scientists with unique opportunities to study the ecology of a perennial river. The KNP is one of the largest conservation areas in South Africa (Mucina & Rutherford, 2006), where it is situated in Mpumalanga and Limpopo and bordering on Mozambique and Zimbabwe (Figure 3.1). The study area included sections of the riparian zone along the Sabie River from where the Sabie River enters the KNP in the west, to Lower Sabie rest camp in the east (Figure 3.1).

Four belt-transects were pre-selected by the Kruger Rivers Post-Flood Research Program (KRPFRP) in collaboration with the Centre for Water in the Environment (CWE, University of the Witwatersrand) to ensure that all channel types were represented for the purpose of this study (Figure 3.1) Table 3.1 provides GPS coordinates for each of the four pre-selected belt-transects. Accessibility and logistics were taken into consideration during the selection process. The following channel types were selected and will be defined later (see section 3.5.2 Channel types):

- Belt-transect 2* – Bedrock anastomosing (BA)
- Belt-transect 3 – Pool-rapid (PR)
- Belt-transect 4 – Mixed anastomosing (MA)
- Belt-transect 5 – Braided (Br)

**Numbers represent the fixed long-term monitoring sequence of belt-transects along the Sabie River as part of the Kruger Rivers Post-Flood Research Program, which was established by the KNP in collaboration with the Centre for Water in the Environment.*

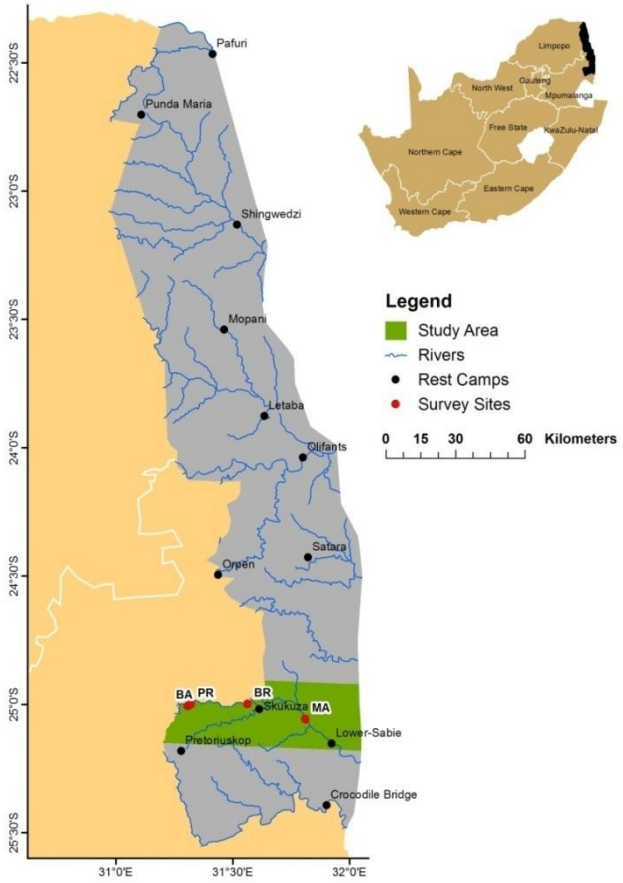


Figure 3.1: Localities of the four sampling sites along the Sabie River, Kruger National Park. The following refers to the four channel types: MA – mixed anastomosing; PR – pool-rapid; BA – bedrock anastomosing; and Br – braided.

Table 3.1: Coordinates of the up-stream, top corner of each of the four belt-transects along the Sabie River, Kruger National Park. The following refers to the four channel types: MA – mixed anastomosing; PR – pool-rapid; BA – bedrock anastomosing; and Br – braided.

Belt-transect no.	Latitude	Longitude
2 (BA)	24°59'21.398"	31°17'13.814"
3 (PR)	24°58'54.565"	31°18'03.106"
4 (MA)	25°01'30.035"	31°47'24.932"
5 (Br)	24°58'22.848"	31°32'31.006"

3.2 Regional Climate

The climate of the KNP varies between warm and humid in summer to mild and mostly dry in winter (Venter & Gertenbach, 1986). In the summer months the day temperatures can reach 44°C and higher and seldom go below 0°C in winter, and therefore frost rarely occurs within the KNP (Venter & Gertenbach, 1986).

Air movement is predominantly controlled by anti-cyclonic and low pressure cells in the summer which originate in the interior of South Africa (Venter & Gertenbach, 1986). These anti-cyclonic conditions create extremely dry and hot conditions with warm winds, which can last for more than two weeks (Venter & Gertenbach, 1986). Heavy thunderstorms are created by the low-pressure cells, which transport warm moist equatorial air inland from the north and northeast (Venter & Gertenbach, 1986).

The climatic conditions in the winter months are characterised and controlled by anti-cyclonic conditions which occur across most of South Africa (Venter & Gertenbach, 1986). As a result, winter months are cool and slightly cloudy, conditions which Venter and Gertenbach (1986) describe as being fine and mild.

The rainfall varies seasonally across the KNP (October to March) with the highest rainfall concentrated within the summer months (December to February) (Venter *et al.*, 2003). It has been shown that the rainfall within the KNP has an 18 year cycle with nine continuous years above average annual rainfall and nine years below average (Gertenbach, 1980). Other natural phenomena, such as the El Niño-Southern Oscillation, also affect the climate of the KNP, which creates fluctuations within the annual rainfall and temperatures (Scholes & Walker, 1993).

The average rainfall of the KNP ranges from 740 mm per annum at Pretoriuskop to 440 mm per annum at Pafuri (Venter & Gertenbach, 1986). Like most of South Africa, the KNP can therefore be categorised as semi-arid.

The mean annual rainfall is closely monitored across the southern section of the KNP (Figure 3.2). The highest rainfall occurs in the south-eastern section of the KNP (Figure 3.2). The four belt-transects fall within two distinct rainfall regions. Each rainfall region has

different soil characteristics, such as clay percentage or pH, mainly due to the quantity of water that flows over the soil (Ashman & Puri, 2005). Leeching also plays an important role in soil formation (Ashman & Puri, 2005).

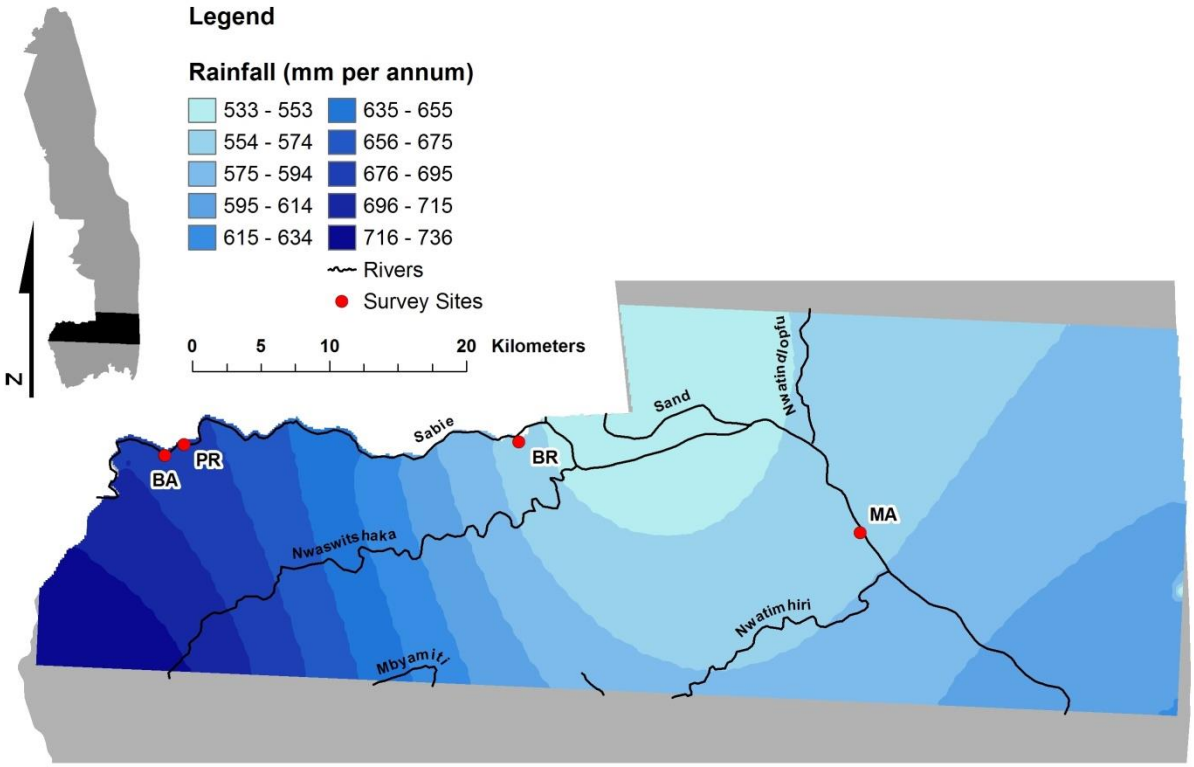


Figure 3.2: Mean annual rainfall zones across the study area (Smit, 2012?). BA and PR lies in the 676-695 mm region and Br and MA in the 554-574 mm region (BA – Bedrock-anastomosing, PR – Pool-rapid, MA – Mixed-anastomosing and Br – Braided).

3.3 Sabie River Catchment

A catchment is defined as the area from which a river is fed (Davies & Day, 1998). There are eight catchment areas within the KNP (a distribution map of the eight catchments within the KNP is provided in Appendix A):

- Crocodile
- Letaba
- Limpopo
- Nwanetsi

- Nwaswitsontso
- Olifants
- **Sabie**
- Shingwedzi

The Sabie catchment falls within the greater Inkomati drainage basin (Sudlow, 2008). The Inkomati drainage basin is recognized as an international drainage basin because it is shared by South Africa, Mozambique and Swaziland (Sudlow, 2008). According to Sudlow (2008), the Sabie River catchment is 7096 km^2, of which 6347 km^2 falls within South Africa. The Sabie River is the main river within the catchment and originates in the north-eastern Drakensberg escarpment, north of the Long Tom Pass (Sudlow, 2008). The Sand and Marite Rivers are two important tributaries within the Sabie catchment (Sudlow, 2008).

The Sabie River has an estimated total length of 230 km, from the north-eastern Drakensberg escarpment to where it meets the Inkomati River in Mozambique (Deacon, 1996). The Sabie catchment has no distinct large flood plains, wetlands or swamps (Deacon, 1996). The catchment is characterised by a physically diverse template with many different channel types due to the variation in the distribution of sediment over bedrock (Van Niekerk & Heritage, 1993).

3.4 Topography and landscape

The Sabie River Catchment has a diverse mosaic of landscapes and topography (Sudlow, 2008) which can be divided into two topographical regions, namely Middleveld and Lowveld regions (Sudlow, 2008). The Middleveld region is characterised by an undulating landscape and mountainous terrain that occupies the western part of the catchment (Sudlow, 2008). The Lowveld region is mostly characterised by flat, slightly undulating landscape, except for the Lebombo Mountains dominating the landscape in the far eastern parts of the catchment (Sudlow, 2008).

The altitude of the KNP declines from west to east with belt-transect 2 (BA) and 3 (PR) located between 361–400 m above sea level (a.s.l.), belt-transect 5 (Br) at 291–330 m a.s.l. and belt-transect 4 (MA) at 157–210 m a.s.l. (Figure 3.3). The relief and sharp decline in altitude results in higher water flow velocities from where the Sabie River enters the KNP

up to its confluence with the Nwatindlopfu River (Figure 3.3). From above mentioned confluence to where the Sabie River enters Mozambique, there is a more gradual decline in altitude which creates wider, slower flowing river channels (Figure 3.3). Therefore, the relief of the KNP's western border contributes substantially to the intensity and destructiveness of large infrequent floods.

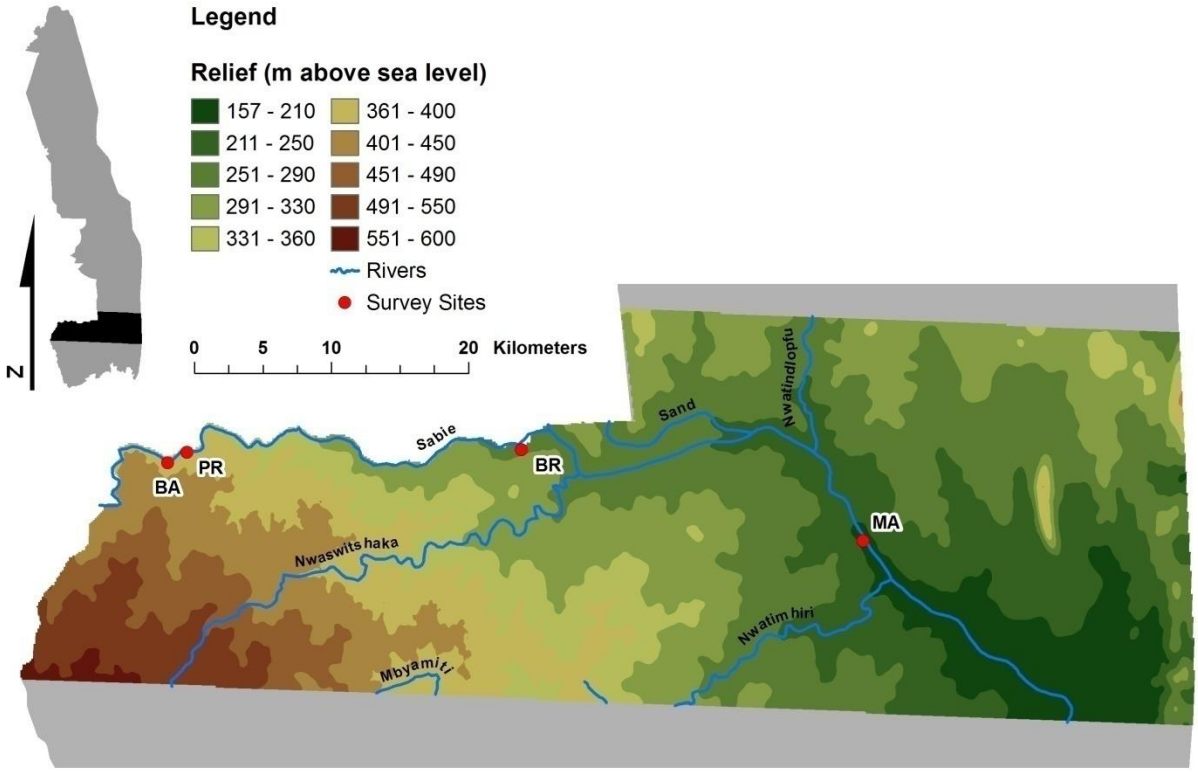


Figure 3.3: Relief (m above sea level) of the Kruger National Park (Adapted from the CDSM) (BA – Bedrock-anastomosing, PR – Pool-rapid, MA – Mixed-anastomosing and Br – Braided).

3.5 Geomorphology

The Sabie River is characterised by anabranching (anastomosing) or multiple active channels which are incised in a macro-channel that is typically 250–800m wide and 8–15m deep (Van Niekerk *et al*., 1995). The macro channel is subdivided into two distinct morphological zones (Van Coller *et al*., 1997): macro channel bank (MCB) and macro channel floor (MCF) (Figure 3.4) (See Chapter 4 for detailed description of MCB and MCF; Table 4.1).

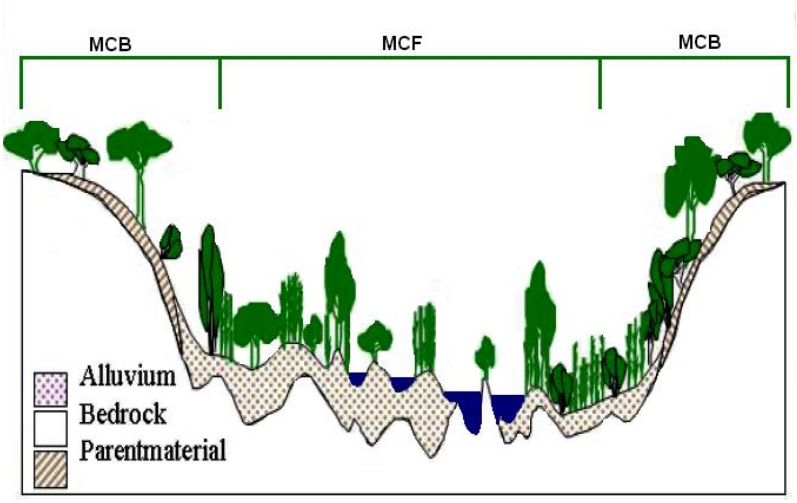


Figure 3.4: Cross-section of a Mixed Anastomosing channel type indicating the locality of the macro channel bank (MCB) and macro channel floor (MCF) (Adapted from McLoughlin *et al*., 2007).

The MCB is located at a much higher elevation (Figure 3.4.) than the MCF (Parsons *et al*., 2006). The MCF is inundated seasonally for short or long periods depending on the annual rainfall (Heritage *et al*., 1999). The MCB only becomes inundated during extreme floods as it is located at the highest points within the macro channel (Parsons *et al*., 2006).

3.5.1 Geomorphological units

According to Heritage, Broadhurst *et al*. (2001), the Sabie River and its fluvial cycles is controlled and restricted by an incised floodplain, which creates diverse geomorphological units. The diversity of geomorphological units is created by alluvial processes which disperse sediment over underlying bedrock (Heritage, Broadhurst *et al*., 2001). The geomorphological units within the Sabie River are undergoing continuous change because of an alternating flow regime (Heritage, Broadhurst *et al*., 2001). Each geomorphological unit has unique characteristics, which influences the establishment of riparian vegetation, water flow and water availability (Table 3.2).

Each channel type within the Sabie River has a unique combination of sandbars and bedrock outcrops (Figure 3.5). The MCF consists of a mosaic of geomorphological units, which is formed by alluvial processes (Figure 3.5) (Heritage, Broadhurst *et al*., 2001). In

this study the MCF of the BA channel type has the most diverse and integrated geomorphological units, and the MCF of the PR channel type only consists of one geomorphological unit (Figure 3.5).

Within belt-transect 2 (BA), 3 (PR) and 4 (MA) a large bedrock core bar was present (Figure 3.5). A bedrock core bar consists of a build-up of fine sediment on top of bedrock anastomosing and pool-rapid areas (Table 3.2). If the bedrock core bars are not flooded frequently, the bars can be covered by dense riparian vegetation when sediment rich in nutrients creates a favourable environment. However if the bedrock core bars are flooded frequently the riparian vegetation does not establish successfully.

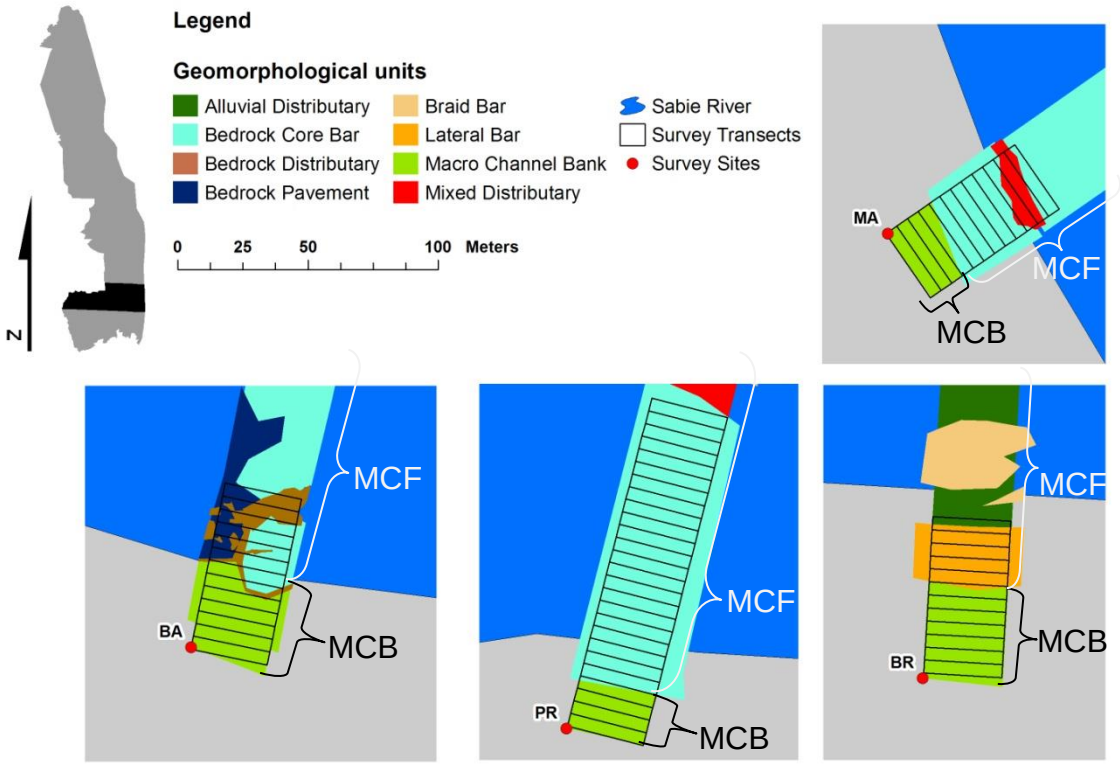


Figure 3.5: The geomorphological units present within each of the channel types / belt-transects (Adapted from datum received from the SANParks, GIS laboratory, 2009b) (BA – Bedrock-anastomosing, PR – Pool-rapid, MA – Mixed-anastomosing and Br – Braided).

Table 3.2: Description of geomorphological units associated with the four belt-transects (Adapted from Van Coller *et al*., 1997).

Geomorphological unit	Description
Alluvial distributary	Extensive sedimentation with distinctive low flow channels which are diverged by large sediment bars.
Bedrock core bar	Build-up of fine sediment on top of bedrock anastomosing and pool-rapid areas.
Bedrock distributary	Outcrops of resistant rock or unweathered bedrock, which creates multiple channels.
Bedrock pavement	Lateral outcrop of bedrock across the MCF.
Braid bar	Also known as a mid-channel bar, because a bar is formed from the accumulation of sediment in the middle of a channel.
Lateral bar	Build-up of sediment to the side of a channel. Can also occur consecutively downstream as an alternate bar.
Mixed distributary	Alluvial processes and bedrock outcrops, which form multiple channels.

3.5.2 Channel types

There are five channel types within the Sabie River although only four channel types have been sampled in this study (Van Coller *et al*., 1997):

- Bedrock Anastomosing (BA) (Figure 3.6A);
- Braided (Br) (Figure 3.6B);
- Mixed Anastomosing (MA) (Figure 3.6C); and
- Pool-rapid (PR) (Figure 3.6D).

Each of the channel types are defined by the proportion and combination of geomorphic units, e.g. bedrock core bars, distributary channels, lateral bars, pools, riffles, mid-channel bars and benches (Figure 3.6) (Parsons *et al*., 2006).

The BA channel type (Figure 3.6A) is characterised by outcrops of resistant rock or unweathered bedrock, which creates multiple channels (Van Coller *et al*., 1997). There is numerous bedrock features found within a BA channel (Heritage *et al*., 2003):

- Pools;
- Rapids;
- Cataracts and small waterfalls;
- Sediment accumulation restricted to lee bar deposits after bedrock obstructions;
- Armoured areas; and
- Fine sediment accumulation in low areas of flow.

Bedrock core bars are formed when higher elevated bedrock pavements accumulate sediment and are normally colonized by plant species, such as *Breonadia salicina, Diospyros mespiliformis* and *Phragmites mauritianus* (Van Niekerk *et al*., 1995; Heritage *et al*., 2003).

MA channel types (Figure 3.6C) normally develop over extensive time when widespread sedimentation has occurred within a BA reach (Van Coller *et al*., 1997). Therefore, MA channel types are predominantly characterised and controlled by alluvial processes and bedrock outcrops (Van Coller *et al*., 1997).

MA channels are extremely stable because of the wide macro channel and low flow gradient within the channels, which disperse flow energy during floods (Van Coller *et al*., 1997; Parsons *et al*., 2006). Dense populations of *Phragmites mauritianus* and certain shrub species (i.e. *Phyllanthus reticulatus*, *Flueggea virosa* and *Gymnosporia* senegalensis) aid the stability of the islands and channel banks within a macro channel (Van Coller *et al*., 1997; Heritage *et al*., 2003).

PR (Figure 3.6D) usually comprises of single, wide channels created by weathering resistant geological units (i.e. dykes, sills and general weather resistant bedrock) (Van Coller *et al*., 1997). The resistant nature of the bedrock creates short, high-energy rapids followed by low energy pools (Van Coller *et al*., 1997).

Little sedimentation occurs within rapids but is characterised by large boulders and small-scale bedrock core bars (Heritage *et al*., 2003). The pools found within a PR channel are very dynamic, with certain pools being sediment-free bedrock areas and others dominated by sediment with a range of bars (Heritage *et al*., 2003). Because of the high velocity within a PR channel, it is difficult for most plants to establish across the sediment bars (Heritage *et al*., 2003). *Phragmites mauritianus, Ziziphus mucronata* and *Dichrostachys cinerea* are plant species that are commonly associated with PR channel types (Heritage *et al*., 2003).

Lastly, Br channel (Figure 3.6B) types are characterised by extensive sedimentation with distinctive low flow alluvial channels which are diverged by large sediment bars (Van Coller *et al*., 1997). Therefore, the number of channels within Br channel types is dependent on the quantity of deposition within the active channel, which in turn creates a mid-channel and lateral bars (Heritage *et al*., 2003). The banks and islands within a Br channel are stabilized by dense populations of riparian vegetation (i.e. *Ficus sycomorus*, *Combretum erythrophyllum* and *Gymnosporia senegalensis*) (Heritage *et al*., 2003).

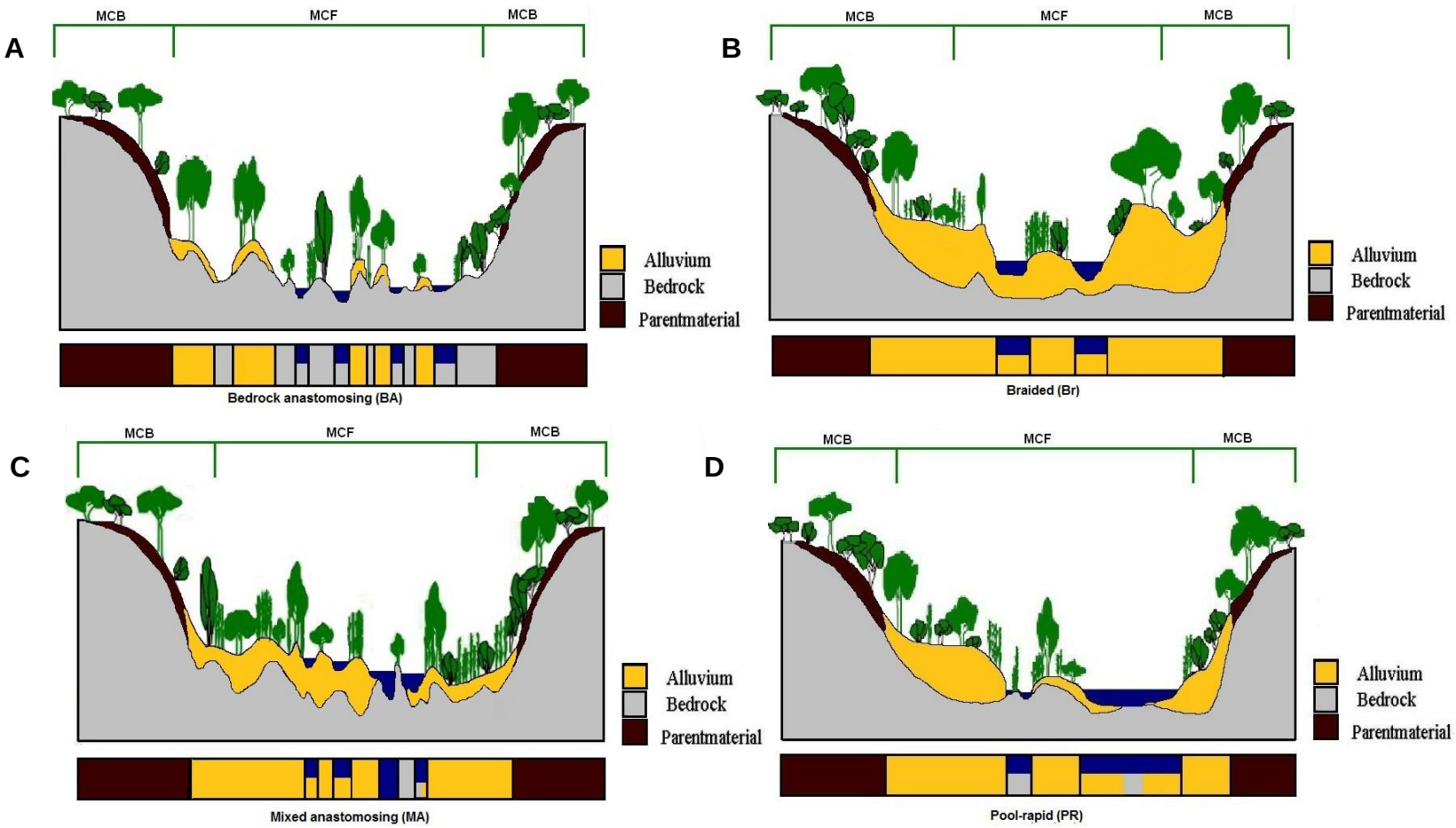


Figure 3.6: Cross sections of the four principle channel types within the Sabie River, KNP. A – Bedrock anastomosing; B – Braided; C – Mixed anastomosing; D – Pool-rapid (Adapted from McLoughlin *et al*., 2007).

3.6 Fire frequency

Between 1926 and 1954 fire was applied to create grazing lawns for wildlife in the KNP (Enslin *et al*., 2000). During the mid-1950's the knowledge of the effects of fire on vegetation increased which lead to SANPark's management suppressing fire frequency within the KNP (Enslin *et al*., 2000). The KNP initiated a long-term fire research program in 1954, aimed at furthering their knowledge of fire as a management tool and to develop a fire management program (Enslin *et al*., 2000). It was found that areas which endured fires frequently from 1954 to 1998 had no significant change in woody species composition, although there was a decrease in species density in certain areas (Enslin *et al*., 2000). However, the structure of woody vegetation had changed because of fire and other environmental factors (i.e. herbivory, water availability and climate) (Enslin *et al*., 2000), namely that the basal area of woody individuals increased but the general height of woody individuals decreased.

The effect of fire on vegetation structure and composition depends on several components (i.e. fire frequency, fire intensity and season of the year), but it has been found that the vegetation in the KNP is very resistant to fire (Trollope *et al*., 1999; Enslin *et al*., 2000). However, if a fire occurs after a long dry season, and in combination with other environmental factors, it can cause high tree and shrub mortalities (Enslin *et al*., 2000).

Most of the belt-transects chosen for this study by the KRPFRP were located in areas which did not experience as many fires as the rest of the KNP from 1941 to 2006 (Figure, 3.7). The surrounding area beyond belt-transects 2 (BA) and 3 (PR) had experienced multiple fires (between 1941 and 2006) (Figure 3.7). The higher fire frequency is ascribed to the close proximity to the park border and exposure to runaway fires entering the Park. The likelihood of unnatural fires occurring along the Park border, roads and camps of the KNP are much higher than in natural areas towards the centre of the Park (Smit *et al*., 2012).

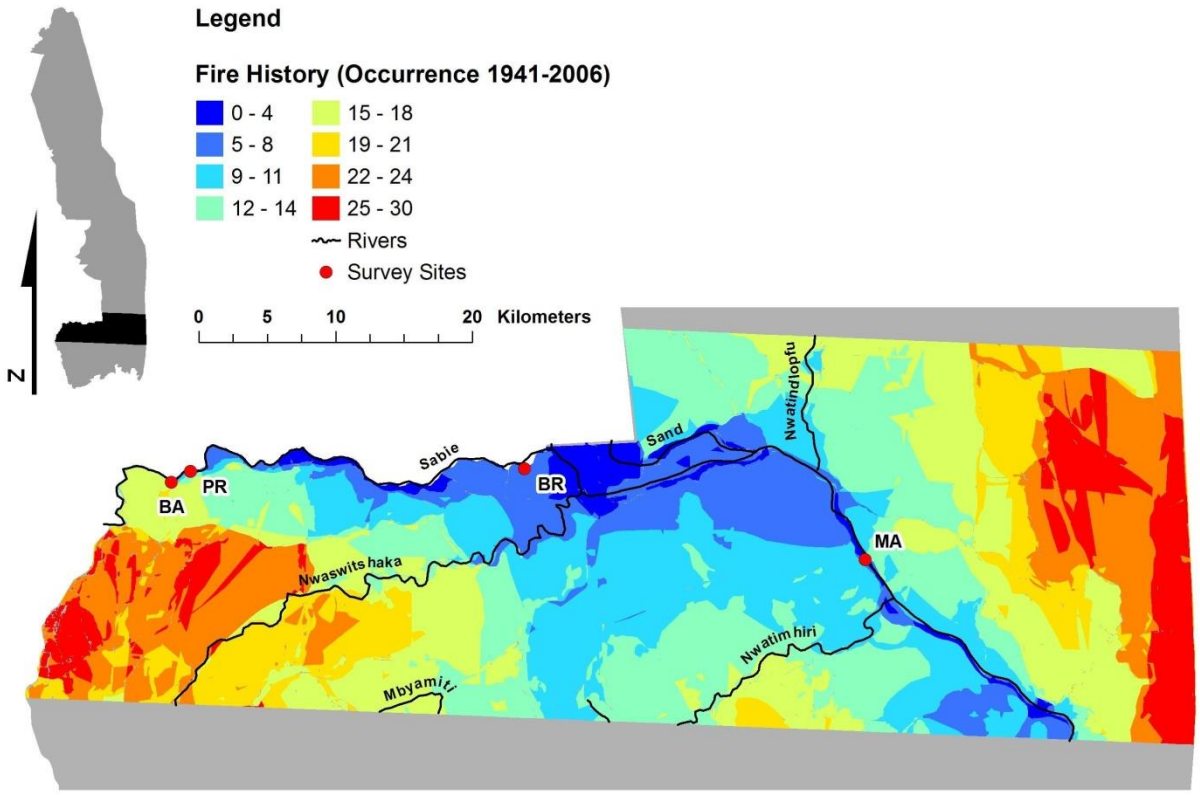


Figure 3.7: Fire frequency from 1941 – 2006 along the Sabie River, Kruger National Park (Smit *et al*., 2012) (BA – Bedrock-anastomosing, PR – Pool-rapid, MA – Mixed-anastomosing and Br – Braided).

3.7 Geology and Soils

3.7.1 Geology

The underlying bedrock lithology of the Sabie River is a complex mixture of sedimentary, intrusive and extrusive igneous and metamorphic rocks (Sudlow, 2008). The four belt-transects were within two distinct geological units (Figure 3.8):

- Timbavati Gabbro (belt-transects 2 and 3), and
- Nelspruit Suite (belt-transects 4 and 5).

The Timbavati Gabbro suit, previously known as Tsango Gabbro, is described as a suite with basic intrusive sills located within and outside the KNP (Walraven, 1986). The

Timbavati Gabbro is estimated to be a young suite, with rocks predating the Karoo Sequence (Walraven, 1986).

Timbavati Gabbro is characterised by prominent koppies and turf-like soils with noticeably less dense vegetation than the adjoining landscape (Walraven, 1986). There are three types of rocks within the Timbavati Gabbro: Olivine gabbro, Quartz gabbro and Gabbro (Walraven, 1986). Each rock type has its own unique trace elements and structure, which translates to a range of different soils during weathering (Walraven, 1986).

The Nelspruit Suite (or Nelspruit Granite Suite) is the most dominant geological unit within the southern section of the KNP (Figure 3.8). Schutte (1986) described the Nelspruit Suite to be a mixture of banded gneiss, gneiss and porphyritic granite. Other rocks found across the Nelspruit Suite varies from granitic to tonalitic and consists of quartz, microcline, feldspar, biotite and accessory minerals (Schutte, 1986).

Most of the granite based landscape is concave to relatively flat and is characterised by numerous small streams, such as the Nwaswitshaka, Nwatimwambo, Nwatimhiri, Lubyelubye, Bume and Mlambane (Gertenbach, 1983).

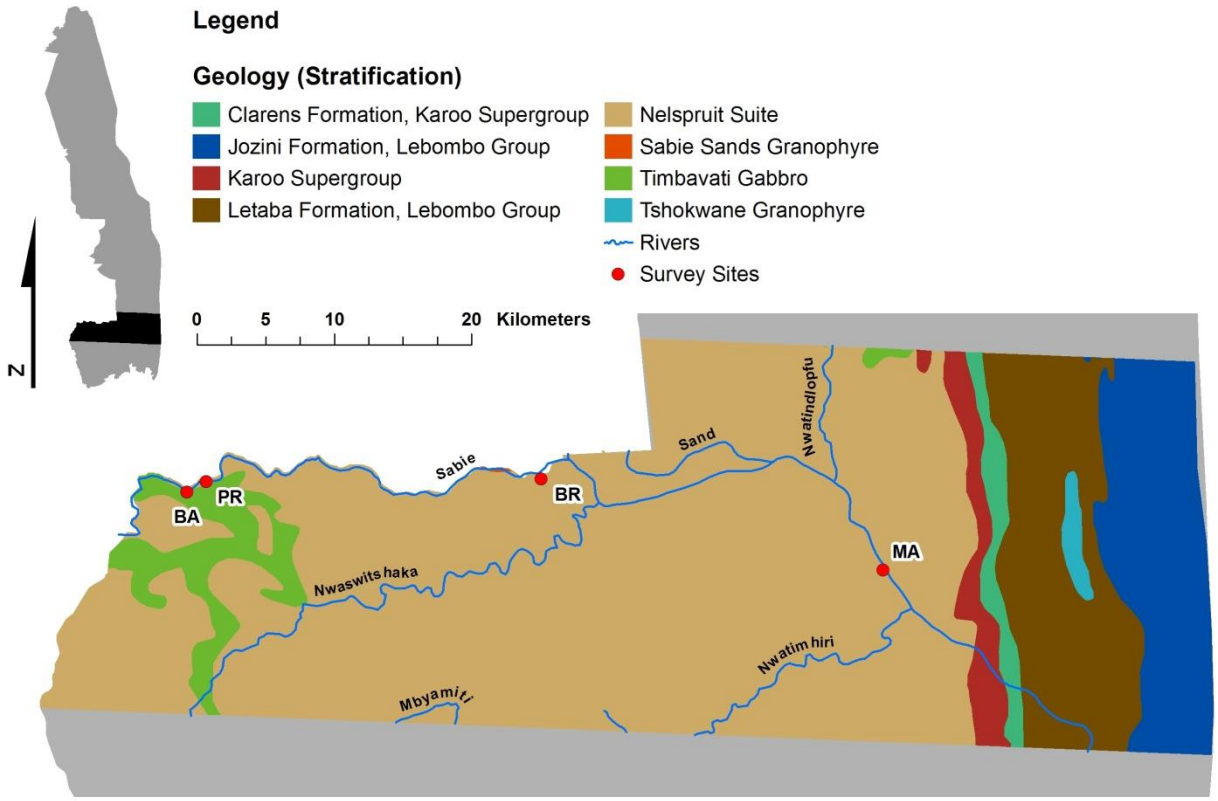


Figure 3.8: Geological map of the study area (Adapted from Venter, 1990) (BA – Bedrock-anastomosing, PR – Pool-rapid, MA – Mixed-anastomosing and Br – Braided).

3.7.2 Soils

The soil patterns within the KNP are mainly dependent on the area's geology (Gertenbach, 1983). Granite and gneiss, in general, weather to form deep sandy soils in high, uplifted areas and clay soils in the low-lying regions (Mucina & Rutherford, 2006).

The soil characteristics of the KNP are reflected within the biotic component of the park (Venter, 1986). Soil properties such as soil depth, structure and texture determine the availability of soil water, nutrients and oxygen to vegetation (Venter, 1986).

The four belt-transects were located in areas of similar soil composition (Figure 3.9). Sterkspruit and Darling were the most dominant soil types within belt-transect 2 (BA), 3 (PR) and 5 (Br), although Mispah soils may also have been present at belt-transect 5 (Br).

The dominant Sterkspruit soils have high clay content and can have a high concentration of lime (Dept. van Landbou-Ontwikkeling, 1991).

The soils associated with belt-transect 4 (MA) were Milkwood, Glendale, Darling and Mayo (Figure 3.9). These soils are dark coloured with a B-horizon which can consist of up to 70% eroded parent material which creates a hard structured soil in dry, humid and wet conditions (Dept. van Landbou-Ontwikkeling, 1991).

According to Gertenbach (1986) the soils in the study area have a unique centenary sequence which is directly linked to the topography of the area. The dominant soils in the uplands are sandy with low clay percentages and because clay particles are moved downhill by environmental factors (e.g. erosion) towards the low-lying areas of landscapes, the bottomland areas are characterised by soils with a high percentage clay (Gertenbach, 1986). The bottomland soils often have high concentrations of sodium with large prismacutanic structures in the underground horizons (Gertenbach, 1986).

3.8 Vegetation

3.8.1 Savanna biome

The study area is located within the Savanna Biome. The Savanna Biome occupies 32.8% or 399 600 km^2 of South Africa (Mucina & Rutherford, 2006). The vegetation within the Savanna Biome varies significantly in structure and composition at a local scale (Venter *et al.*, 2003). The heterogeneity found within the Savanna Biome and the KNP is directly linked to the varying geology, soil types, fire regimes and climate conditions across the region (Venter *et al.*, 2003).

According to Mucina and Rutherford (2006) the study area is specifically situated within the Granite Lowveld (SVI 3) vegetation unit. The Granite Lowveld, in the Lowveld Bioregion, is found throughout Limpopo, Mpumalanga, Swaziland and also Kwazulu-Natal. The Granite Lowveld region is characterised by tall shrubland, few trees and reasonably dense low woodland that is mostly dominated by *Terminalia sericea*, *Combretum zeyheri* and *Combretum apiculatum* (Mucina & Rutherford, 2006). The bottomlands of the Granite

Lowveld are characterised by dense thickets dominated by *Acacia nigrescens*, *Dichrostachys cinerea* and *Grewia bicolor* (Mucina & Rutherford, 2006).

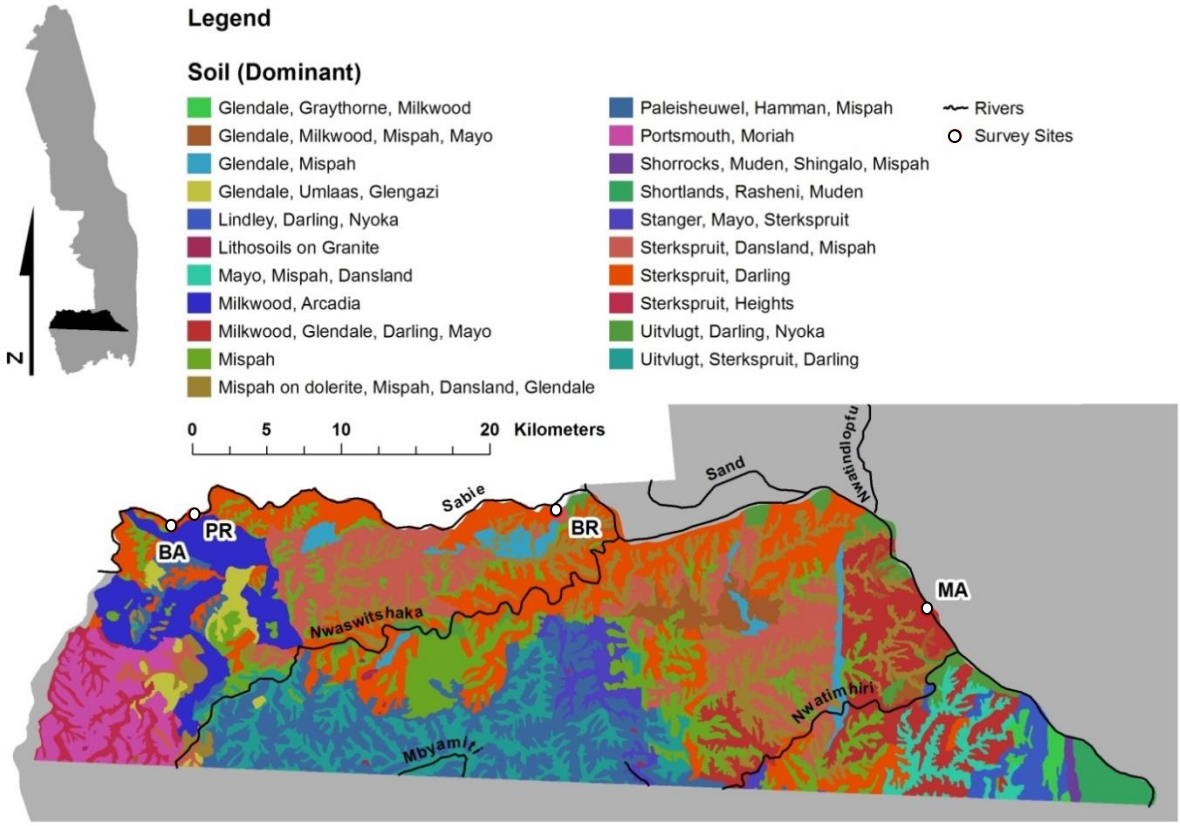


Figure 3.9: Soil types of the study area (Adapted from GIS datum provided by SANParks, GIS laboratory, 2009b) (BA – Bedrock-anastomosing, PR – Pool-rapid, MA – Mixed-anastomosing and Br – Braided).

The close correlation between the geology and vegetation of the KNP (Venter *et al.*, 2003) is ascribed to the unique Lowveld erosion surface and the moderate rainfall of the area (Venter 1986, 1990). A discontinuous layer of woody plants and a herbaceous layer dominated by C4 grasses characterises the biome (Mucina & Rutherford, 2006).

The woody plant cover within the savanna of the KNP ranges from widely scattered individuals (5 % canopy cover) to dense woodlands (60% canopy cover) (Venter *et al.*, 2003). In general the KNP has a dry and long winter, which makes the area susceptible to high frequency fires (Van Wilgen *et al.*, 2003).

According to Huntley (1982), the savannas found in the southern parts of Africa can be subdivided into two groups: arid and moist. These two groups are also known as the infertile and fertile groups based on the soils on which they occur (Venter *et al.*, 2003). The woody species found on the infertile soils is mainly from the Combretaceae and Caesalpinioideae (Fabaceae), which are deciduous, with broad leaves and no thorns (Venter *et al.*, 2003). The woody species associated with fertile soils, consists mostly of the Mimosoideae (Fabaceae), which are deciduous with fine, compound leaves and many thorns (Venter *et al.*, 2003).

Gertenbach (1983) identified 36 land types within the KNP based on dominant soil types and vegetation patterns (Gertenbach, 1983). The Gertenbach (1983) vegetation and land classification system is one of the most widely used by researchers and environmental managers in the KNP. The land types have a relatively unique ecology, geology, soils, temperature and topography (Gertenbach, 1983). Within this study, all four belt-transects fell within Land Type 4 (Thickets of the Sabie and Crocodile Rivers).

The Thickets of the Sabie and Crocodile Rivers are also known as the *Acacia nigrescens-Combretum apiculatum* association (Gertenbach, 1983). Gertenbach (1983) identified several dominant woody species within the Thickets of the Sabie and Crocodile Rivers: *Acacia robusta*, *Berchemia discolor*, *Breonadia salicina*, *Combretum erythrophyllum*, *Diospyros mespiliformis*, *Ekebergia capensis*, *Ficus sycomorus*, *Kigelia africana*, *Nuxia oppositifolia* and *Trichilia emetica*.

3.8.2 Riparian vegetation

Riparian ecosystems are of the most complex systems within the biosphere and play a key role in maintaining the vitality of river landscapes (Naiman & Decamps, 1997). Riparian ecosystems, and more specifically riparian vegetation, provide several ecosystem functions and services to the river landscape (See chapter 4 for a detailed description of the importance of riparian vegetation within an ecosystem).

There are four different riparian zones found along the Sabie River, which correspond to the variation in elevation along the river catena (Figure 3.10; Siebert, 2003):

- Dry riparian zone (characterised by species such as *Combretum imberbe, Gymnosporia senegalensis, Philenoptera violacea* and *Acacia spp.*)*;*
- Wet riparian forest (characterised by species such as *Diospyros mespiliformis, Ficus spp.* and *Trichilia emetica*);
- Shrubby reed scrub (characterised by species such as *Trema orientalis, Flueggea virosa, Gymnosporia spp., Grewia* spp. and Phragmites mauritianus); and
- Reed scrub (characterised by species such as *Combretum* spp., *Ficus* spp. and *Phragmites mauritianus*).

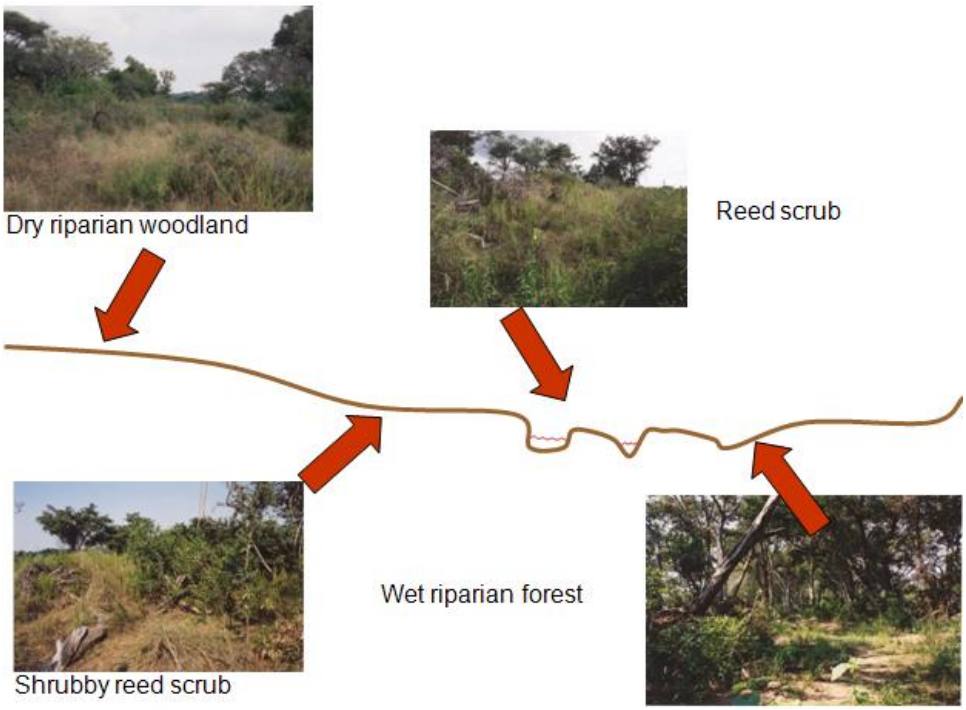


Figure 3.10: The four riparian zones and their position within the macro channel (Siebert, 2003).

The establishment of the four riparian zones is dependent on water availability, flooding frequency, sedimentation and nutrient availability, which is in turn influenced by the distance and elevation from the main active channel (Friedman & Auble, 2000). LIDs can cause the distribution or order of the four riparian zones to change over time (i.e. a wet riparian forest can change to a shrubby reed scrub) (Siebert, 2003). These changes occur because a LID (i.e. floods) causes not only large landscape changes, but also multiple environmental micro conditions (See chapter 4 for a detailed description of the impacts LIDs have on the environment).

Chapter 4: Methods

4.1 Introduction

In the early 1990's the establishment of the KNPRRP (See chapter 1, Table 1.1 for summary of relevant river research projects within the KNP) generated a fundamental understanding of the Sabie River landscape, the geomorphological template and the distribution of riparian vegetation across this diverse template (Van Niekerk *et al.*, 1995; Van Niekerk *et al.*, 1999; Carter & Rogers, 1995; Van Coller *et al*.,1997; Mackenzie *et al.*,1999; Rountree *et al*., 2000; Van Coller *et al*., 2000; Heritage & Moon, 2000; Heritage, Moon *et al*., 2001; James *et al.*, 2002; Pollard *et al*., 2011).

The KNPRRP ended in 2000 (Pollard *et al.*, 2011), coincidently the year in which KNP experienced a large infrequent flood. As a result, the Kruger Rivers Post-flood Research Program (KRPFRP) was established to examine the response of rivers to the 2000 flood within the KNP (Parsons, 2004). The research presented here forms part of the long-term river research monitoring program which focuses not only on riparian vegetation but on the river landscape as a whole.

Data sampling for this study followed the approach developed by Parsons *et al*. (2006) and other studies, which are summarized in Appendix B. Previous studies (e.g. Van Coller *et al.*, 1997; Parsons *et al*., 2006) identified several permanent belt-transects within the Sabie River, each of which is associated with one of the river channel types described by Van Niekerk and Heritage (1993) (Figure 3.6) (See chapter 3 for a detailed description of the four main river channel types). This study re-sampled four of these belt-transects, one in each of the four main river channel types, to quantify possible changes in vegetation composition and structure between 2004 and 2010 using similar sampling techniques. Belt transects are labour-intensive and time-consuming field surveying techniques and therefore four transects were considered to be adequate for a preliminary assessment of changes over a relatively short temporal scale.

Although this study and sampling methods were based on Parsons *et al*. (2006), some small amendments were needed to be made. Parsons *et* al. (2006) used real-time GPS

equipment to locate each woody individual within each plot of the different belt-transects. Due to its accuracy, it was therefore not necessary to demarcate each plot in the field since it could be done afterwards using GIS software. Due to financial limitations, such equipment could not be used during field surveying. GPS readings from the historical datum set (i.e. the KNP-post-flood river research datum set of 2004) were therefore used as reliable landmarks to relocate transects. After transect borders were located successfully, they were subdivided into equally-sized 5 m x 30 m plots, similar to the procedure followed by Parsons *et al*. (2006).

The herbaceous layers was not sampled due to its dynamic nature, time constraints and since the objective of this study was to specifically study the intermediate response of woody riparian vegetation composition and structure.

4.2 Data sampling

Each belt-transect was subdivided into contiguous 150 m^2 plots (5 m x 30 m), running perpendicular to the river, along the river catena, i.e. from the top of the MCB across the MCF with the first plot located at the top of the MCB (Figure 4.1). The belt-transects are orientated perpendicular to the river, since riparian vegetation is characterised by a decline of water availability, flood frequency and stream power away from the main active channel (Bendix, 1999). A belt-transect also provides scientists with an opportunity to sample vertical, lateral and all other physical variables within a certain area (Van Coller *et al*., 2000).

Field forms were designed to capture all the data required to answer the research questions (Appendix C). Within each of the four belt-transects the following data sampling process was followed (Figure 4.1):

1st step: The general location and boundaries of each transect were located with a GPS.

2nd step: Plot locality was confirmed with the assistance of a hand-held GPS unit and aerial images of the sampling area. Ropes and surveying poles were then used to demarcate the 30x5 m plot in which data were to be recorded.

3rd step: Sampling started at a specific side (i.e. MCB) of a plot and proceeded in a typical 'S' formation to ensure that no woody individuals were missed or counted twice. All woody individuals which were rooted within the plot were recorded.

4th step: Each woody individual was identified, counted and classified as established or non-established (juvenile / seedling) according to the methods used in previous studies (e.g. Van Coller *et al*., 2000; Parsons *et al*., 2006).

5th step: The height (with height adjusting measuring pole) and basal diameter (with caliper) was measured and noted for each established woody individual.

6th step: Damage caused by browsing and other animal activity were identified, described and placed into different categories.

7th step: General observations of the area were recorded, which included disturbances such as recent fire damage, trampling by animals, and anthropogenic disturbances, e.g. tourist or management roads and alien invasion. Alien species in the area were identified and GPS-coordinates taken.

8th step: Habitat photos were taken.

9th step: After all the necessary data were sampled, the sampling team moved to the next 30 x 5m plot and the data sampling process was repeated.

Within each 150 m^2 plot, all established woody individuals were identified, measured (basal diameter, height) and the numbers of stems were counted. The stem diameter of large (i.e. >15 cm) trees was measured at 100 cm above ground level, but the basal diameter of smaller woody individuals was measured just above basal swelling.

Voucher specimens of unknown species were collected for identification and deposition at the A.P. Goossens Herbarium (PUC) of the North-West University and Skukuza Herbarium of South African National Parks.

High water levels during vegetation surveys in March 2010 necessitated that only the southern banks of the Sabie River could be sampled.

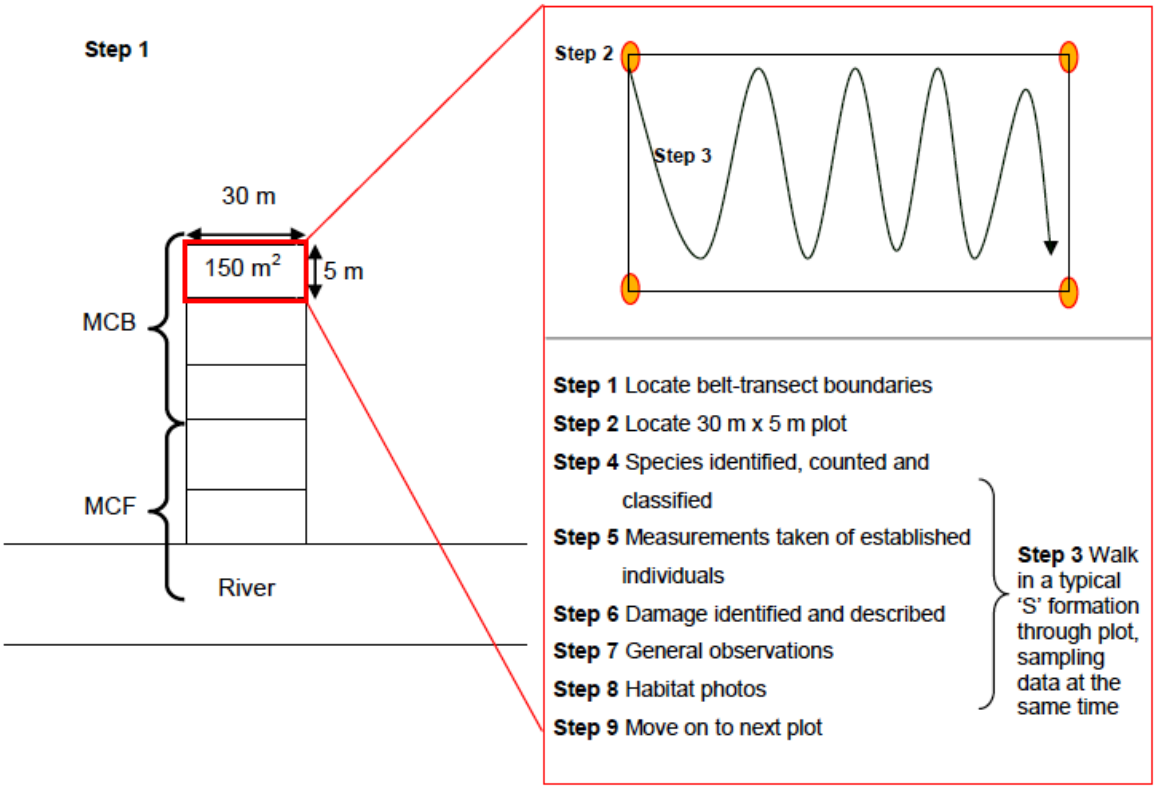


Figure 4.1: An outline of the standard data sampling procedure.

4.3 Data analysis

4.3.1 Data preparation (cleaning, filtering, sorting and classification of data)

The KNP Scientific services provided the 2004 datum set which was sampled by the Centre for Water in the Environment (University of the Witwatersrand) and the KNP. The 2004 and 2010 data sets were consolidated and made compatible by merging synonyms according to Germishuizen *et al*. (2006). A fault analysis was performed to identify species which were named inconsistently, or species names which were entered incorrectly, i.e. typing errors. After all incompatibilities were rectified, the data analysis was performed.

Table 4.1 provides a summary and comparison of the two data sets for the southern banks of the Sabie River (2004 and 2010).

Table 4.1: Summary of two data sets.

Description	Data sets	
	2004	2010
Total number of botanical families	25	30
Total number of species	69	78
Total number of trees	223	223
Total number of shrubs	768	913
Total number of lianas	83	146
Empty plots	20	11

4.3.2 Partitioning of data

The MCB and MCF of each belt-transect was analysed separately due to the physical differences in the landscape (see Chapter 2 for detail description of MCB and MCF; Table 2.1). GIS datum provided by South African National Parks was used to delineate transects into plots representing MCB and MCF respectively. The MCF is inundated seasonally for extended periods or episodically by small floods; therefore the MCF can further be divided into the active and seasonal MCF (Parsons *et al*., 2006). The MCB is the highest elevated areas within the macro channel and therefore is only inundated during large infrequent floods (Parsons *et al*., 2006).

4.3.3 Setting categories for structural vegetation data

Since one of the objectives of this study is to identify certain trends in woody structural vegetation change, each recorded woody individual was categorized as follow to facilitate statistical data analyses:

- Woody growth form – As a result of the flood and heavy browsing, certain woodies have a growth form that is normally associated with shrubs (short, multi-stemmed growth form) or scrambling/climbing lianas. Therefore, it was decided to use field guides (Palgrave, 2005; Germishuizen *et al*., 2006; Schmidt *et al*., 2007) and field observations to classify the woody individuals as trees, shrubs or lianas.
- Height class – The five height classes (Table 4.2) were selected to represent the different age or establishment classes within the woody riparian vegetation (Brown & Bredenkamp, 2004; Parsons *et al*., 2007).
- Stem class – Five stem classes (Table 4.2) were based on the number of stems recorded (Götze, *et al*., 2003).

The five classes (Table 4.2) were selected to represent the different age or establishment classes within the woody riparian vegetation. The use of structural classes made it possible to identify certain trends within the structural datum and made the analytical process easier. The increase of multi-stemmed individuals can be an indication of certain disturbance causing the woody individuals to coppice or re-sprout.

Table 4.2: Woody structural classes based on height and the number of stems counted per individual.

Woody structural classes	**Number of stems**
	1
	2–3
	4–6
	7–10
	≥11
	Height (m)
	>0–1.5
	>1.5–3
	>3–5
	>5–10
	>10

4.3.4 Statistical analyses

The structural and compositional data for trees, shrubs and lianas were analysed separately using a variety of visual and statistical techniques. The composition datum was analysed using multivariate analysis. Multivariate analytical techniques are used to simplify large data sets by providing identifiable patterns within the data (Höft *et al*., 1999). All statistical analysis was performed under supervision of the Statistical Consultation Service of the North-West University, Potchefstroom campus.

4.3.4.1 Analysis of species composition

The total combined species composition of 2004 and 2010 was first analysed using the Bray-Curtis (Belbin & McDonald, 1993; Clarke *et al*., 2006) index of dissimilarity to construct the distance matrix together with Ward's method of clustering (Everitt *et al*., 2011). Using Fisher's exact relationship test (Fisher, 1922), the relationships between the clusters and the year and morphological zones was identified. The statistical packages SAS (SAS Institute Inc., 2008) and R-Package (Casgrain, 1999) were used for the analysis of the data. The R-Package was used to construct the appropriate data matrix for input into the Bray-Curtis index of dissimilarity.

The species composition datum were firstly log transformed to accommodate for all the zero values (transformed data is required where correlations were calculated for which normality is a requirement) and to ensure that the two datasets (2004 and 2010) could be compared statistically. However, the untransformed data were also analysed to identify whether there is significant differences between the transformed and normal datasets. The Central Limit Theorem states that if the sample size is large enough, the means are normally distributed even though data are non-normal (Rice, 1995).

Classification methods, such as the Bray-Curtis index of dissimilarity (Equation 4.1), are fundamental tools for analyzing ecological data and identifying patterns across the landscape (Belbin & McDonald, 1993, Höft *et al*., 1999; Clarke *et al*., 2006). The Bray-Curtis index of dissimilarity equation (Belbin & McDonald, 1993; Clarke *et al*., 2006) divides the sum of the two plots to identify the degree of dissimilarity between the two plots which are being compared. In comparing a plot with itself, the Bray-Curtis value is zero, and

therefore if a plot with a zero value (plot containing no woody individuals) is compared to another plot with a zero value the Bray-Curtis value would also be zero, which would result in a misrepresentation of the overall dissimilarity. Therefore, to obtain accurate results from the Bray-Curtis index of dissimilarity, thirty-two empty plots (plots with zero values in **both** 2004 and in 2010) were removed from the two data sets before analysis.

Equation 4.1: $$d(i,i') = \frac{\sum_j [x_{ij} - x_{i'j}]}{x_i + x_{i'}}$$

The index i represents the plots and the index j the plant species, therefore the formula calculates the dissimilarities between the plots i and i'.

If a plot was empty in either 2004 **or** 2010, but not in both, the data had to be considered since any change from 0 to x or from x to 0 is of ecological significance. To ensure accurate and reliable results from the Bray-Curtis index of dissimilarity, the zero-adjusted Bray-Curtis index of dissimilarity formula (Equation 4.2) was used to accommodate all the zero values (plots with zero values in 2004 or 2010) within the datasets. The zero-adjusted Bray-Curtis index of dissimilarity approach adds a constant to the denominator of the Bray-Curtis coefficient (Belbin & McDonald, 1993; Clarke *et al*., 2006). This implies that a dummy species or individual is added to all the plots with a value of one. The effect of this extra species or individual on the dissimilarity between two plots will make no difference to the numerator. Therefore the denominator is increased by two (Belbin & McDonald, 1993; Clarke *et al*., 2006).

Equation 4.2: $$d\left(i,i'\right) = \frac{\sum_j [x_{ij} - x_{i'j}]}{2 + x_i + x_{i'}}$$

Ward's method (Everitt *et al*., 2011) is an example of a hierarchical, agglomerative method (Everitt *et al*., 2011). In a hierarchical method, the clustering process yields a hierarchy in which subsets of clusters at one level are aggregated to form the clusters at the next level (Everitt *et al.,* 2011). Furthermore, Ward's clustering method is based on minimizing the loss of information during the analyses of two groups or datasets (Johnson & Wichern, 2007). The loss of information is seen as the error sum of square (ESS) (Johnson & Wichern, 2007). Therefore, within Ward's method, at each analytical step the grouping of

every single cluster possible is considered and the grouping of the clusters with the lowest *ESS* is used (Johnson & Wichern, 2007). When all clusters are grouped together in a single large cluster, *ESS* is given by (Johnson & Wichern, 2007):

$$\textbf{Equation 4.3:} \qquad ESS = \sum_{j=1}^{N} (x_j - \dot{X})$$

Where N equals the total amount within each cluster and x is the mean of all the items.

The results of Ward's hierarchical clustering method are presented in the form of a dendrogram (See Chapter 5, Figure 5.2 for an example of a dendrogram). The horizontal axis of a dendrogram lists all the plots used in the analysis. The vertical-axis of a dendrogram represents the measure of similarity at which the clusters join. In this study a hierarchical, agglomerative method is used, in which clusters that join very low on the vertical axis are more similar than clusters forming higher up on the vertical-axis.

Fisher's exact relationship test (Fisher, 1922) has the capabilities to analyse and identify statistical significance of data with small sample sizes. Other relationship tests, such as the Chi-squared test, fail to analyse data with small sample sizes and multiple zero values. Within Fisher's exact relationship test the hypothesis were tested at a significant level of α=0.05.

Fisher's exact relationship test takes into consideration the label or name allocated to a specific plot and not the species composition itself to calculate the relations between the plots. This means that Fisher's exact relationship test will automatically place two MCF plots together, rather than a MCB and MCF plot based on their labelling. However, because the data was first analysed and organised by the Bray-Curtis index of dissimilarity, before using the Fisher's exact relationship test, the results obtained from Fisher's exact relationship test are directly linked to the species composition of the two datasets (2004 and 2010). In short, Fisher's exact relationship test uses the dendrograms created by SAS to measure the relationships between the clusters within the dendrograms.

4.3.4.2 Analysis of woody structure

The MIXED Procedure or PROC MIXED model was used to investigate change within the structural datum. PROC MIXED, is a process where several mixed linear models are used to analyse data (SAS Institution Inc., 2008). By definition “a mixed linear model is a generalization of the standard linear model used in the general linear modelling (GLM) procedure, the generalization being that the data are permitted to exhibit correlation and non-constant variability” (SAS Institution Inc., 2008). The greatest advantages of using mixed linear models, is that the process provides researchers with a certain amount of flexibility to model not only the means of datasets but the variance and covariance as well (SAS Institution Inc., 2008). In this study the correlation between plants within a belt-transect was believed to be larger than between belt-transects and PROC MIXED can take this dependency into account when calculating differences between the time points/other groups of data (SAS Institution Inc., 2008).

According to the SAS Institution Inc. (2008), the PROC MIXED analysis is based on three assumptions; the data used for the analyses are normally distributed, the means of the data are linear to certain parameters and the variance and covariance of the data have several different parameters that can be analysed within PROC MIXED. With these three assumptions, PROC MIXED can calculate a range of statistics suitable for hypothesis testing and confidence intervals (SAS Institution Inc., 2008).

Most ecologists are interested in determining if an observed effect (i.e. change or impact) is of ecological importance and not only if the effect is of statistical significance (Di Stefano *et al*., 2005). Therefore it has been proposed that ecological studies must not only use *P-values* for summarising results, but should address the ecological significance of effects by “estimating the size of effects, and presenting this information with an associated measure of precision” (Di Stefano *et al*., 2005). Because the *P-values* could not be calculated in some instances due to empty cells in cross-tabulations, Confidence Intervals (CI) were used in this study to identify and address the ecological and statistical significance of change within riparian vegetation structure over time. *P*-values were used where possible in conjunction with CI.

Stewart-Oaten *et al*. (1986) discussed the experimental design, difficulties and possible solutions to data sets consisting of only one control and impact area available for analysis. As this study is restricted only to the plots within the four channel types and morphological zones, and examines change over time within the same areas, there is a potential problem with temporal pseudo-replication as discussed by Stewart-Oaten *et al*. (1986). Although Stewart-Oaten *et al*. (1986) does propose using the before-after-control-impact (BACI) method, whereby the control and impacted sites are sampled simultaneously, to resolve any temporal-pseudo-replication, it was still decided to consult with the statistical consultation services of the NWU – Potchefstroom before sampling and analytical methods were chosen. After consultation the sampling and analytical methods described within this chapter was chosen.

Because of the nature of the data, it was not possible to calculate a *P-values* to summarise certain results (i.e. the shift of frequencies in height classes between 2004 and 2010 for trees on the MCF). The main reason for this complexity was that the two datasets were not the same size and the presence of many zero values could overestimate the importance of the change observed within the data.

Cumming and Finch (2005) emphasised the importance and advantages of using CI values for testing statistical significance and providing additional insight into the results obtained from statistical analyses. According to Hancock and Mueller (2010), CI values can be highly successful in reporting results as they combine information on location and precision. Furthermore, narrow CI is an indication of more precise estimates (Hancock & Mueller, 2010).

There are several ways to interpret and use confidence intervals (CI) to identify a statistically significant effect, with most methods needing further calculations (Di Stefano *et al*., 2005). In the past researchers examined the overlap between two related CI to identify a significant effect (Schenker & Gentleman, 2001). It is important to note that there is a false assumption that if two independent groups have overlapping CI, it is always an indication of no significant effect (Van Belle, 2002; Di Stefano *et al*., 2005). However, this can be true if there is a considerable overlapping of CI (Van Belle, 2002). Van Belle (2002) illustrated that CI could overlap as much as 29% and still have a significant difference.

Because of the complexity of the structural datum, it was decided that the focus would be placed on the ecological significance of certain effects, rather than the statistical significance. However, as vital information is provided by identifying statistical significant effects, CI and *P-values* (if available) were used to guide and assist with the interpretation of the results.

4.3.4.3 Calculating basal density and individuals per hectare

The number of stems, basal area, height and the number of individuals per hectare are all functions of density. This means that the relation between the number of stems, height, basal area and individuals per hectare will differ according to the state of the ecosystem. A system, which is under severe stress, may be prone to bush encroachment. Therefore, the woody vegetation will in general be shorter with multiple thin stems.

The total basal area per plot was calculated in two steps:

1. The basal area of each individual was first calculated.
2. The basal area of each individual within a plot was added together to calculate the basal area of the entire plot. This process was then repeated for all the plots.

This calculation of the basal area presents under estimations of density for some species, and over-estimations for others. However, since the data were analysed similarly for the two survey years, patterns in basal area per plot can be identified and explained.

Densities of trees, shrubs and lianas per hectare were calculated for each plot using the following formula (Gandiwa & Kativu, 2009):

$$\text{Density } (y/\text{ha}) = [(x \times 10{,}000\ \text{m}^2) / (\text{plot area, m}^2)]$$

where y denotes the density of either trees, shrubs and lianas and x is the recorded number of trees, shrubs and stems per plot.

Chapter 5: Results

Temporal and spatial changes in woody species composition

5.1 Introduction

Riparian vegetation along the Sabie River in the Kruger National Park (KNP) has been classified and mapped extensively (e.g. Gertenbach, 1983; Coetzee, 1983, Bredenkamp & Van Rooyen, 1991; Van Coller *et al*., 1997; Mucina & Rutherford, 2006; Parsons *et al.*, 2006; Siebert *et al.,* 2010). This knowledge base of plant species composition contributed to a better understanding of the importance of the physical template, such as geology, geomorphology and water availability as drivers of riparian vegetation heterogeneity within the KNP (Parsons *et al.*, 2006).

At landscape level, the Sabie River valley is located within the Tropical Arid Granitic region, which includes five different landscapes or vegetation units (Coetzee, 1983) (See Chapter 2 for a detailed description of the different landscape types). Various abiotic processes sustain riparian vegetation such as the inundation of floodplains or sedimentation (Trush *et al*., 2000). Large infrequent floods are also important mechanisms for rejuvenating mature riparian vegetation across the macro channel by maintaining side channels and distributing sediments that are rich in nutrients and propagules (Trush *et al*., 2000; Parsons *et al*., 2006). The magnitude, frequency and duration of a flooding event determine the severity of sedimentation, vegetation clearing and floodplain and bar scouring (Trush *et al*., 2000).

The elevation and distance across the macro channel, away from the river or main channel, is another factor driving spatial and temporal distribution of plant communities (Van Coller *et al.,* 2000). Therefore, different plant communities of riparian vegetation correlate closely with flooding frequency and water availability, which characterizes the macro channel (Van Coller *et al*., 2000).

In a first attempt to quantify changes in riparian vegetation after the large flooding event of the Sabie River in 2000, Parsons *et al*. (2006) reported that individual riparian species responded differently to the flood. Post-flood densities of common riparian species were dependent on their pre-flood densities and location. Furthermore, it was reported that

densities of species that were common to the macro channel floor (MCF) decreased whereas macro channel bank (MCB) species increased in density after the flood (Parsons *et al*., 2006).

Plant species composition and densities are therefore being considered as reliable measures of vegetation change in response to disturbance events. Diagnostic species, i.e. species that favour certain environmental conditions and only occur within a single or few vegetation units, can be used in comparative studies since they are good indicators of changes in plant species assemblages in response to a disturbance event (Chytry *et al*., 2002). For the purpose of this study, diagnostic species of different spatially differentiated vegetation units were identified to assist in identifying changes within the woody riparian vegetation along the Sabie River after the large flooding event of 2000.

Parsons *et al*. (2006) describes the MCB as a high recruitment zone, however, they also found in certain conditions that the MCF could also be a high recruitment zone. The patterns described by Parsons *et al*. (2006) was based on an analysis of data from 24 belt-transects. This study reported on four of these 24 transects, which were sampled six years after the study by Parsons *et al.* (2006) and 10 years after the flood. These results should be viewed as an attempt to document vegetation changes along a semi-arid riparian zone within a small time-scale. Intermediate temporal patterns, which are commonly used in text, refer to patterns that are evident between two sampling events, but on an intermediate temporal scale (i.e. less than 10 years).

To test whether the vegetation patterns identified by Parsons *et al*. (2006) were still evident 10 years post-flood, this chapter aimed to address the following:

- Determine the **overall temporal** change in woody plant species composition and -richness at a post-flood temporal interval (2004 to 2010);
- Quantify the **spatial** variation in woody plant species composition and -richness across the different morphological zones;
- Quantify **temporal** changes in woody plant species composition and -richness within the different morphological zones: i.e. compare temporal changes in woody plant species composition at macro-channel-bank (MCB) and macro-channel-floor (MCF) respectively; and

- Assess which channel type has the highest increase in alien invasive species between 2004 and 2010.

5.2 Methods

5.2.1 Data sampling

All established woody individuals were identified and counted within each 150 m^2 plot of the four belt-transects (See Chapter 4 for a detailed description of sampling methods).

5.2.2 Data analyses

The 2004 and 2010 datasets were combined and synonyms for plant species were merged according to Germishuizen *et al*. (2006) for data compatibility.

To test for overall temporal changes in woody species composition, the Bray-Curtis Dissimilarity index was applied to the pooled datum (2004 and 2010 datasets combined) along with non-metric multi-dimensional scaling (NMDS) in PRIMER Ver. 5 (Clarke & Gorley, 2001). Clustering results are presented in an ordination-type scatter-plot (Figure 5.1).

Species composition was also analysed through the application of the Bray-Curtis Index of Dissimilarity to construct a distance matrix for each sampling occasion respectively (i.e. 2004 and 2010). The statistical packages SAS (SAS Institute Inc., 1999) and R (Casgrain, 1999) were used during these analyses (see Chapter 4 for detailed description of analytical methods). Each sampling occasion data matrix was analysed with Ward's Method of Clustering, a hierarchical, agglomerative method (Everitt *et al*., 2011). In this hierarchical method, the clustering process yields a hierarchy in which subsets of clusters at one level are aggregated to form the clusters at the next level (Everitt *et al*., 2011) (see chapter 4 for detailed description of analytical methods).

Using the Fisher's exact relationship test (Fisher, 1922), the relationship between clusters (identified with Bray-Curtis dissimilarity test) could be identified and described according to its temporal (i.e. year of sampling) and spatial (i.e. morphological zone) relationship.

To test for significant variance in woody plant species richness across the clusters (i.e. morphological zones), which was identified through various clustering techniques, a One-Way ANOVA was applied in Statistica version 10 (StatSoft Inc., 2010). To further examine significant differences between the respective morphological zones, *post hoc* t-tests were applied to the dataset. An unequal N HSD Tukey t-test was applied, of which results were later confirmed by the application of a non-parametric Kruskal Wallis test. Similar analyses were undertaken to test for significant differences in species richness between years of sampling (i.e. 2004 versus 2010).

5.3 Results

5.3.1 Temporal shifts in plant species composition

Results obtained through the application of the Bray Curtis Dissimilarity Index along with NMDS illustrated limited temporal shifts in plant species assemblages (Figure 5.1). Clustering of the 2004 and 2010 plots on the ordination-type scatter-plot (Figure 5.1) suggested no distinct separation between sampling events (i.e. 2004 and 2010), which indicate limited changes in species composition over the intermediate time scale of six years. The outlier plots were mostly associated with the MCF. The clustering of MCF plots was further supported through different statistical measures (i.e. Ward's method and Fisher's exact relationship test) (Figure 5.2).

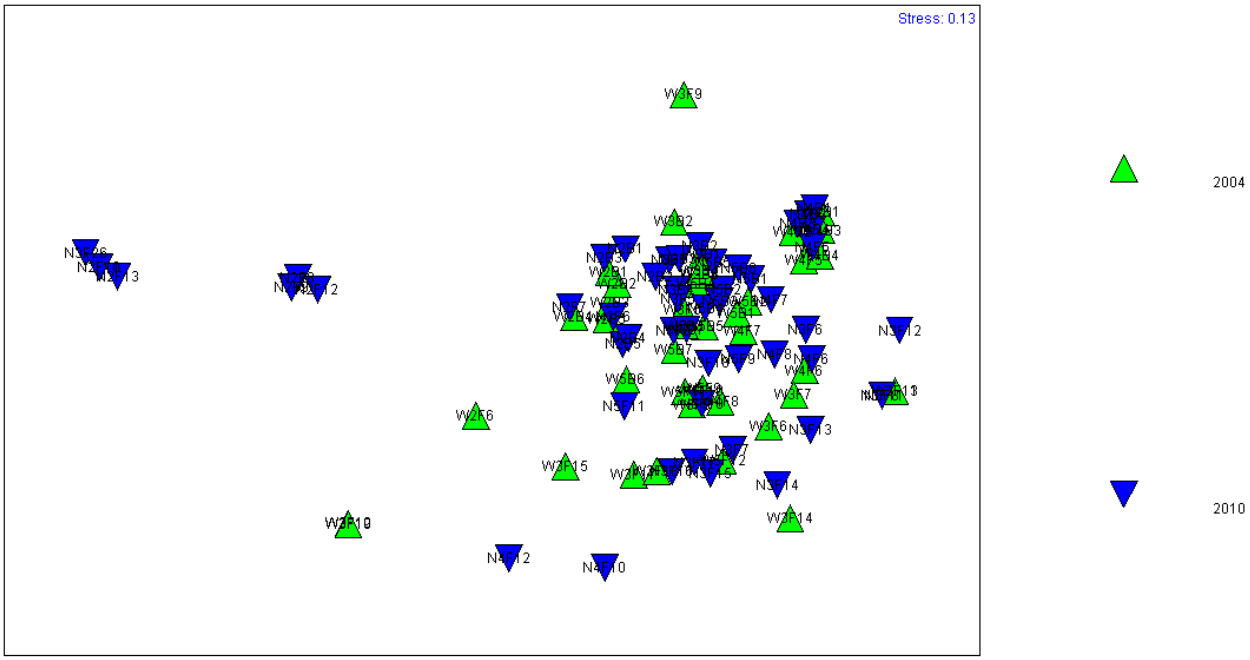


Figure 5.1: Non-metric multi-dimensional scaling (NMDS) scatter plot presenting the distribution of species assemblages in 2004 (green triangles) and 2010 (blue triangles).

5.3.2 Spatial variation in plant species composition of pooled temporal data

After depicting limited temporal changes in species composition, the pooled datum (2004 and 2012 datasets combined) was subjected to cluster analyses to test for spatial variation in species composition over an intermediate post-flood time scale. Results obtained through a Bray-Curtis dissimilarity analysis along with Ward's method of clustering and the Fisher's exact relationship test corresponded with the findings of Parsons *et al*. (2006). The vegetation of the Sabie River has been classified independently to present woody plant assemblages typical of the MCB, Ephemeral MCF and Active/Seasonal MCF (Figure 5.2), which was evident through the formation of such clusters, which is consistent with the classification by Parsons *et al*. (2006).

According to Ward's clustering, the first division in the dendrogram separated the Active/Seasonal MCF from the Ephemeral MCF and MCB. This separation supports the species composition link between the Ephemeral MCF and MCB, which was significantly different from the species associated with the Active/Seasonal MCF (Figure 5.2). Further clustering of the Active/Seasonal MCF does not support separation according to channel

types, which illustrates similar species composition within the four different channel types on the Active/Seasonal MCF (Figure 5.2). The lower-order clustering of the combined MCB and Ephemeral MCF, however supported clustering according to channel type since the mixed anastomosing (MA) channel type (belt-transect 4) was separated from the other clusters according to species composition. This separation may have been attributed to different environmental conditions at belt-transect 4, such as heavy browsing and high animal activity or extensive sedimentation over an extensive time (see Figure 3.6 for detailed description of the MA channel characteristics).

Consistent with divisions produced by Bray Curtis and Ward's method, the four clusters produced by Fisher's Exact Relationship Test were distinguished by the morphological zones rather than the year of sampling, and to a lesser extent the channel type (Figure 5.3). In addition to the three main clusters (MCB, Ephemeral MCF and Active/Seasonal MCF) identified through initial clustering analysis, which supported the findings by Parsons *et al*. (2006), the Fisher's Exact Relationship Test subdivided the Ephemeral MCF into two clusters (F – 2 and F – 3) (Figure 5.2). The Ephemeral MCF was subdivided because of a unique clustering of plots from belt-transect 4 which were all situated within cluster F – 3.

There was a highly significant difference ($p<0.005$) in the morphological zones (MCB and MCF) of the four clusters identified by Fisher's Exact Relationship Test (Figure 5.3A) with no relation ($p> 0.05$) to the year of sampling (Figure 5.3B).

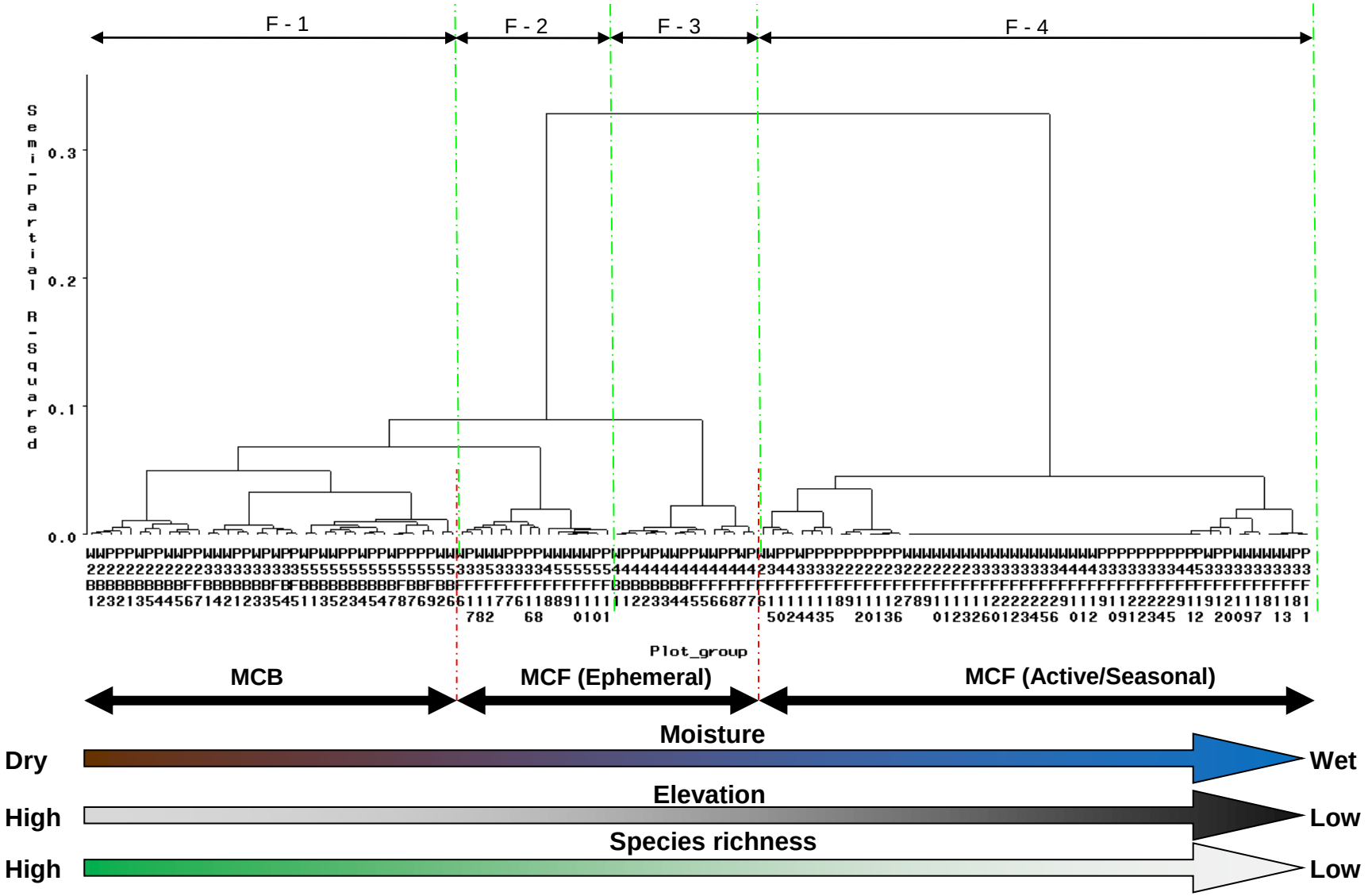


Figure 5.2: Dendrogram constructed with Ward's method in a Bray Curtis distance matrix of riparian plant communities. The first letter or row of the label identifies sampling occasions (W = 2004, P = 2010), second row identifies the channel type (2 = bedrock-anastomosing, 3 = pool-rapid, 4 = mixed-anastomosing, 5 = braided), third row identifies the morphological zone (B = macro channel bank, F = macro channel floor) and last row identifies the unique plot number per transect. F (1 – 4) indicates the clustering as indicated by Fisher's exact relationship test.

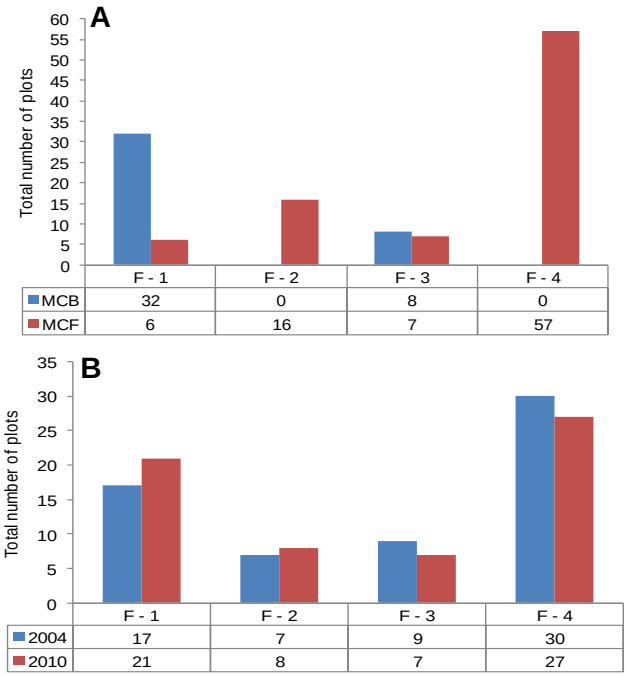


Figure 5.3: Relationship of the clusters with morphological zones and year of sampling: (A) highly significant ($p < 0.001$) variance between morphological zones (MCB and MCF) identified by Fisher's exact relationship test; and (B) non-significant ($p = 0.8265$) variance between the year of sampling identified by Fisher's exact relationship test.

The first cluster (MCB and F – 1) was predominantly associated with the MCB with only a few MCF plots, which could be explained by significant differences in species composition between 2004 and 2010 in these plots (Figure 5.3A).

Clusters F – 2 and F – 3 (sub-division of the Ephemeral MCF) represented transition clusters between typical MCB and MCF, which could be depicted from their species composition in Table 5.1. Cluster F – 3 (sub-division of the Ephemeral MCF) was unique since it was made up by plots from only the MA channel type (belt-transect 4), which represented both MCB- and MCF classified plots.

Therefore, although high-order clustering was associated with morphological zones, channel types were separated at the lower hierarchical levels of the cluster analysis (Figure 5.2), suggesting that the importance of channel types in plant species composition should not be neglected.

5.3.3 Diagnostic species

Species that were considered as diagnostic were identified for each of the clusters in the dendrogram (Figure 5.2). The most important diagnostic species were identified by a frequency of greater than 10 individuals per cluster, followed by secondary diagnostic species, which has a frequency lower than 10.

The MCB / F – 1 cluster contained 53 species that were mostly confined to this cluster (Table 5.1). Conspicuous diagnostic species included *Euclea natalensis*, *Acacia schweinfurthii*, *Dalbergia armata*, *Acacia robusta*, *Monanthotaxis caffra*, *Kraussia floribunda*, *Eugenia mossambicensis*, *Mystroxylon aethiopicum*, *Ochna natalitia*, *Capparis fascicularis* and *Rhoicissus tridentata* (Table 5.1).

For the MCF Ephemeral / F – 2 cluster no diagnostic species were identified. *Syzygium cordata* was, however, the only species that was unique to this cluster (Table 5.1), which might have induced its unique clustering. This cluster could be classified as a transition zone where typical MCF species, such as *Ficus capreifolia*, *Senna occidentalis* are joined by typical MCB species, such as *Gymnosporia senegalensis*, *Diospyros mespiliformis*, *Lippia javanica* and *Peltophorum africanum* (Table 5.1).

The Ephemeral MCF / F – 3 cluster was characterised by typical dry riparian woodland species. There were fifteen species that were diagnostic for the Ephemeral MCF / F – 3 cluster with *Combretum mossambicense, Grewia bicolor* and *Pristimera longipetiolata* being the most dominant species (Table 5.1).

Mimosa pigra was the only species that was considered diagnostic for the Active/Seasonal MCF (F – 4) cluster with only two individuals (Table 5.1). Other conspicuous species in this cluster included *Rhus pyroides*, *Ficus capreifolia* and *Tacazzea apiculata* (Table 5.1).

All diagnostic species were shrub species, which indicated the importance of shrubs in woody plant species composition along the Sabie River (Table 5.1). Tree species were much lower in frequency (<10), although tree species such as *Kigelia africana*, *Mimusops zeyheri* were important contributors to the MCB. *Diospyros mespiliformis* and *Philenoptera violacea* were important trees across all morphological zones (Table 5.1).

Table 5.1: Two-way plant species composition table presenting individual counts for all species in each of the clusters identified through Bray-Curtis dissimilarity (MCB and MCF (Ephemeral and Active/Seasonal)) and Fishers exact relationship test (F1, F2, F3 and F4). (S–Shrub, T–Tree, L–Liana; green coloured columns indicate conspicuous diagnostic species, whereas blue coloured columns indicate secondary diagnostic species).

Fishers exact relationship test		**F-1**	**F-2**	**F-3**	**F-4**
Bray-Curtis dissimilarity test		**MCB**	**MCF (Ephemeral)**		**MCF (Active/Seasonal)**
No. of plots present within each cluster		31	15	15	57
Diagnostic species for MCB (F-1) *(Total number of individuals (2004 and 2010))*					
Species		**Total number of individuals (2004 and 2010)**			
Euclea natalensis	S	162	4	0	0
Acacia schweinfurthii	S	134	0	0	2
Dalbergia armata	L	122	0	2	0
Acacia robusta	T	64	2	2	1
Monanthotaxis caffra	S	51	0	0	2
Kraussia floribunda	S	46	0	0	1
Eugenia mossambicensis	S	30	0	0	0
Ochna natalitia	S	30	0	0	0
Rhoicissus tridentata	L	29	0	0	0
Mystroxylon aethiopicum	S	28	0	0	0
Capparis fascicularis	L	23	0	0	0
Bridelia cathartica	S	18	1	3	1
Acacia nigrescens	T	17	0	0	0
Cocculus hirsutus	L	17	0	0	0
Euclea divinorum	S	16	0	5	0
Chaetachme aristata	S	14	0	0	0
Syzygium guineense	T	13	1	0	6
Trichilia emetica	T	12	0	0	0
Grewia hexamita	S	12	0	0	0
Bauhinia galpinii	S	10	1	0	0
Cordia ovalis	S	10	1	1	0
Grewia occidentalis	S	9	0	0	0

Kigelia africana	T	7	0	0	0
Mimusops zeyheri	T	7	0	0	0
Senna septemtrionalis	S	7	1	0	0
Gymnosporia harveyana	S	6	0	0	0
Clerodendrum glabrum	T	5	0	0	0
Crotalaria capensis	S	5	0	0	0
Combretum zeyheri	T	5	0	0	1
Ziziphus mucronata	S	5	0	2	0
Acacia welwitschii	T	4	0	0	0
Breonadia salicina	T	4	0	0	0
Plectroniella armata	S	4	0	0	0
Scolopia zeyheri	S	4	0	0	0
Bridelia micrantha	T	3	0	0	0
Combretum molle	T	3	0	0	0
Chromolaena ordata	S	3	0	0	0
Strychnos madagascariensis	T	2	0	0	0
Diospyros whyteana	S	2	0	0	0
Duranta erecta	S	2	0	0	0
Euclea schimperi	S	2	0	0	0
Grewia flava	S	2	0	0	0
Strychnos spinosa	S	2	0	0	0
Tecomaria capensis	S	2	0	0	0
Acacia grandicornuta	T	1	0	0	0
Manilkara mochisia	T	1	0	0	0
Sclerocarya birrea	T	1	0	0	0
Terminalia sericea	T	1	0	0	0
Caesalpinia decapetala	S	1	0	0	0
Carissa edulis	S	1	0	0	0
Maytenus undata	S	1	0	0	0
Psoralea latifolia	S	1	0	0	0
Tricalysia junodii	S	1	0	0	0
Diagnostic species for MCF - Ephemeral (F-2) *(Total number of individuals (2004 and 2010))*					
Syzygium cordata	T	0	1	0	0

Diagnostic species for MCF - Ephemeral (F-3) *(Total number of individuals (2004 and 2010))*					
Combretum mossambicense	S	0	0	62	0
Grewia bicolor	S	15	0	58	0
Pristimera longipetiolata	S	0	0	47	0
Ehretia amoena	S	5	1	17	0
Gymnosporia heterophylla	S	3	0	17	0
Combretum imberbe	T	0	0	11	0
Grewia villosa	S	1	0	6	0
Terminalia prunioides	S	0	0	4	0
Elaeodendron transvaalense	S	1	0	4	0
Pavetta cataractarum	S	1	0	3	0
Schotia brachypetala	T	0	0	2	0
Commiphora neglecta	T	0	0	1	0
Ehretia obtusifolia	S	0	0	1	0
Combretum microphyllum	S	0	0	1	0
Schotia capitata	S	0	0	1	0
Diagnostic species for MCF – Active/Seasonal (F-4) *(Total number of individuals (2004 and 2010))*					
Mimosa pigra	S	0	0	0	2
Shared species for MCB (F-1) and MCF - Ephemeral (F-2) *(Total number of individuals (2004 and 2010))*					
Peltophorum africanum	T	3	3	0	0
Shared species for MCB (F-1) and MCF - Ephemeral (F-3) *(Total number of individuals (2004 and 2010))*					
Dichrostachys cinerea	S	62	3	135	6
Berchemia zeyheri	T	3	0	2	0
Pavetta lanceolata	S	4	0	6	0
Combretum hereroense	L	4	0	5	0
Shared species for MCB and MCF – Active/Seasonal (F-4) *(Total number of individuals (2004 and 2010))*					
Rhus pyroides	S	8	0	0	10
Shared species for MCF - Ephemeral (F-2) and MCF – Active/Seasonal (F-4) *(Total number of individuals (2004 and 2010))*					
Ficus capreifolia	T	0	2	0	6
Senna occidentalis	S	0	2	0	1
Shared species for MCB, MCF - Ephemeral (F-2) and MCF – Ephemeral (F-3) *(Total number of individuals (2004 and 2010))*					
Gymnosporia senegalensis	S	105	55	19	1
Grewia flavescens	S	99	4	37	0
Jasminum fluminense	L	17	3	4	0
Gardenia volkensii	T	1	1	1	0

Shared species for MCB, MCF - Ephemeral (F-2) and MCF – Active/Seasonal (F-4) *(Total number of individuals (2004 and 2010))*					
Tacazzea apiculata	L	2	4	0	6
Trema orientalis	S	1	2	0	4
Species common to all clusters *(Total number of individuals (2004 and 2010))*					
Diospyros mespiliformis	T	179	20	11	1
Lippia javanica	S	50	13	6	2
Phyllanthus reticulates	S	38	6	17	1
Lantana camara	S	34	3	1	2
Flueggea virosa	S	12	3	10	3
Philenoptera violacea	T	3	3	6	3

5.3.4 Temporal floristic changes (i.e. 2004 – 2010) at respective morphological zones

Plant family distribution

A greater representation of different woody families across the four belt-transects was recorded during 2010. In 2004, species representing 25 plant families were recorded, whereas 30 different plant families were represented in the 2010 dataset of the same area of study. Between 2004 and 2010, species from two plant families (Lamiaceae and Sapotaceae) disappeared from the study area, although seven additional families (Apocynaceae, Begoniaceae, Burseraceae, Euphorbiaceae, Flacourtiaceae, Menispermaceae and Sapindaceae) were represented in the 2010 dataset, which were absent from the 2004 dataset. Despite the increase in plant family records in 2010, the Fabaceae family remained the dominant plant family at both the MCB and MCF in 2010 (Table 5.2). The highest increase in species was also recorded within the Fabaceae family, which increased with six species on the MCF between 2004 and 2010.

Table 5.2: Plant families across the different morphological zones (MCB and MCF) and years of sampling (2004 and 2010). Red indicates a substantial (≥2 species) decrease in the number of species per family, whereas green indicates a substantial (≥2 species) increase in the number of species per family.

Family	Number of species represented								
	MCB			MCF			All		
	2004	2010	Diff	2004	2010	Diff	2004	2010	Diff
Anacardiaceae	2	1	-1	1	1	0	2	1	-1
Annonaceae	1	1	0	0	1	+1	1	1	0
Apocynaceae	0	1	+1	0	1	+1	0	2	+2
Asteraceae	1	1	0	0	0	0	1	1	0
Begoniaceae	0	1	+1	0	0	0	0	1	+1
Bignoniaceae	1	1	0	0	1	+1	2	2	0
Boraginaceae	2	2	0	1	3	+2	2	3	+1
Burseraceae	0	1	+1	0	0	0	0	1	+1
Capparaceae	1	1	0	0	1	+1	1	1	0
Celastraceae	7	6	-1	3	3	0	7	6	-1
Celtidaceae	2	1	-1	2	2	0	2	2	0
Combretaceae	6	6	0	4	3	-1	7	6	-1
Ebenaceae	3	4	+1	3	4	+1	3	5	+2
Euphorbiaceae	0	1	+1	0	1	+1	0	1	+1
Fabaceae	12	12	0	7	13	+6	12	17	+5
Flacoutiaceae	0	1	+1	0	0	0	0	1	+1
Lamiaceae	1	0	-1	1	0	-1	1	0	-1

Meliaceae	1	1	0	0	1	+1	1	1	0
Menispermaceae	0	1	+1	0	1	+1	0	1	+1
Moraceae	1	0	-1	1	1	0	1	1	0
Myrtaceae	2	2	0	2	2	0	3	2	-1
Ochnaceae	1	1	0	0	0	0	1	1	0
Oleaceae	1	1	0	1	1	0	1	1	0
Phyllanthaceae	3	3	0	3	3	0	3	3	0
Rhamnaceae	2	2	0	1	2	+1	2	2	0
Rubiaceae	5	2	-3	2	5	+3	5	5	0
Sapindaceae	0	1	+1	0	0	0	0	1	+1
Sapotaceae	1	0	-1	0	0	0	1	0	-1
Strychnaceae	2	1	-1	0	0	0	2	1	-1
Tiliaceae	5	5	0	2	3	+1	5	5	0
Verbenaceae	2	3	+1	2	2	0	2	3	+1
Vitaceae	1	1	0	0	1	+1	1	1	0
Total	66	65	-1	36	56	+20	69	79	+10

Species richness and frequency

Temporal variation in species richness and frequency

According to statistical results, there was a non-significant ($p>0.05$) increase in the gamma diversity (total woody species richness) between 2004 and 2010 (Table 5.3). Species richness was higher on the MCB than on the MCF (Figure 5.3), which could be ascribed to the dynamic nature of the MCF, where even small flooding events can create open patches. Overall species richness on the MCB showed no significant changes over time

(p>0.05), whereas an increase in species richness, although also non-significant (p>0.05) was evident on the MCF (Figure 5.4).

Table 5.3: Summary table obtained through the application of a t-test in Statistica version 10 (StatSoft Inc., 2010), which indicates the non-significant (p>0.05) increase in species richness between 2004 and 2010.

Variable	Mean number of species per plot		t-value	df	p	Valid N		Std.Dev. 2004
	2004	2010				2004	2010	
Total number of species	5.920635	7.444444	-1.26854	124	0.206980	69	79	6.835160

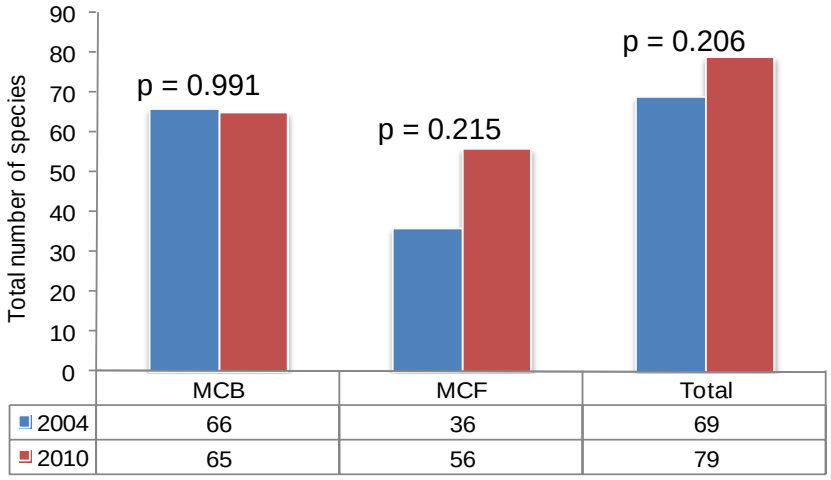


Figure 5.4: Changes in total species richness over time on the MCB and MCF respectively.

In 2004, 1074 individual plants were counted and measured. This total increased with 208 individuals across the four belt-transects (i.e. channel types) in 2010 (Table 5.4). Although more individuals were recorded on the MCB in both sampling occasions, there was an increase of 183 woody individuals on the MCF between 2004 and 2010 (Table 5.5).

In 2004, 69 woody riparian species were recorded across the four belt-transects, which increased to 79 after six years (Table 5.4). Since 2004, 13 species have disappeared and in 2010 an additional 23 new species were recorded (Table 5.4).

Table 5.4: Summary table of temporal floristic changes.

Year	Total no. of plant families represented	Total no. of species (species richness)	Total no. of individuals recorded	Species loss (2004 – 2010)	Species gain (2004 – 2010)
2004	25	69	1074	13	23
2010	30	79	1282		

Spatial changes in floristic composition

With reference to Table 5.5, conspicuous temporal changes in the number of individuals of certain species on the MCB and MCF respectively could be summarised as follow:

- *Grewia flavescens* was the species that showed the highest increase in individuals between 2004 and 2010, with the majority of new individuals establishing on the MCB.
- *Diospyros mespiliformis* increased substantially on both the MCB and MCF.
- Other species with a substantial increase in individuals between 2004 and 2010 included shrubs such as *Combretum mossambicense*, *Flueggea virrosa*, *Lippia javanica*, *Phyllanthus reticulatus*, *Pristimera longipetiolata*, the alien invasive shrub *Sesbania punicea* and liana such as *Cocculus hirsutus*, *Dalbergia armata*, *Jasminum fluminense* and *Tacazzea apiculata.*
- The number of individuals increased substantially on the MCF.
- *Dichrostachys cinerea*, *Acacia schweinfurthii*, *Euclea natalensis* and *Dalbergia armata* were considered dominant MCB species in both 2004 and 2010.
- *Gymnosporia senegalensis* and *Monanthotaxis caffra* showed a substantial decrease in numbers between 2004 and 2010. The number of *Gymnosporia senegalensis* individuals was stable on the MCB, but decreased substantially on the MCF. Despite its decrease in numbers on the MCF, *Gymnosporia senegalensis* remained one of the most dominant MCF species.

- *Monanthotaxis caffra* numbers increased slightly on the MCF, but decreased substantially on the MCB.
- Other species with a profound decline in numbers between 2004 and 2010 were *Acacia robusta*, *Syzygium guineense* and *Trichilia emetica*. *Acacia robusta* had the highest decline of individuals on the MCB but increased slightly on the MCF. *Syzygium guineense* had the second highest decline of individuals on the MCB but slightly increased on the MCF. *Syzygium guineense* was also recorded by Parsons *et al*. (2006) as one of the species that had the highest decline of individuals from 2000 to 2004. Species such as *Acacia robusta* and *Trichilia emetica* are associated with the transition zone between the MCB and MCF (Parsons *et al*., 2006).
- The decline in individuals of *Kraussia floribunda* on the MCB could be explained by its ecology as a forest pioneer.
- Typical of the dynamics of riparian ecosystems, lianas increased in numbers since 2004, except for *Rhoicissus tridentata*, which declined substantially in numbers on the MCB. This decline cannot be linked to riparian vegetation dynamics.

Table 5.5: Changes in frequencies of riparian species across the different morphological zones (MCB and MCF) and year of sampling. Red indicates a substantial (≥4 individuals) decrease in individuals; and green indicates a substantial (≥4 individuals) increase in individuals.

Species	Growth form	Macro channel bank			Macro channel floor			Combined		
	Tree/Shrub/Liana	2004	2010	Diff	2004	2010	Diff	2004	2010	Diff
Trees										
Acacia grandicornuta	T	0	1	+1	0	0	0	0	1	+1
Acacia nigrescens	T	7	10	+3	0	0	0	7	10	+3
Acacia robusta	T	39	23	-16	3	4	+1	42	27	-15
Acacia welwitschii	T	4	0	-4	0	0	0	4	0	-4
Berchemia zeyheri	T	2	2	0	0	1	+1	2	3	+1
Breonadia salicina	T	2	0	-2	0	2	+2	2	2	0
Bridelia micrantha	T	0	2	+2	0	1	+1	0	3	+3
Clerodendrum glabrum	T	1	0	-1	4	0	-4	5	0	-5
Combretum imberbe	T	3	2	-1	4	2	-2	7	4	-3
Combretum molle	T	0	3	+3	0	0	0	0	3	+3
Commiphora neglecta	T	0	1	+1	0	0	0	0	1	+1
Combretum zeyheri	T	2	1	-1	2	1	-1	4	2	-2
Diospyros mespiliformis	T	75	83	+8	21	32	+11	96	115	+19
Ficus capreifolia	T	2	0	-2	4	6	+2	6	6	0
Gardenia volkensii	T	2	0	-2	0	1	+1	2	1	-1
Kigelia africana	T	3	3	0	0	1	+1	3	4	+1
Manilkara mochisia	T	1	0	-1	0	0	0	1	0	-1
Mimusops zeyheri	T	0	7	+7	0	0	0	0	7	+7
Peltophorum africanum	T	1	2	+1	1	2	+1	2	4	+2
Philenoptera violacea	T	4	4	0	3	4	+1	7	8	+1
Schotia brachypetala	T	0	0	0	0	2	+2	0	2	+2
Sclerocarya birrea	T	1	0	-1	0	0	0	1	0	-1
Strychnos madagascariensis	T	2	0	-2	0	0	0	2	0	-2
Syzygium cordata	T	0	0	0	1	0	-1	1	0	-1
Syzygium guineense	T	10	1	-9	1	8	+7	11	9	-2

Terminalia sericea	T	1	0	-1	0	0	0	1	0	-1
Trichilia emetica	T	8	3	-5	0	1	+1	8	4	-4
Ziziphus mucronata	T	3	2	-1	1	1	0	4	3	-1
Shrubs										
Acacia schweinfurthii	S	66	62	-4	2	6	+4	68	68	0
Bauhinia galpinii	S	4	4	0	0	3	+3	4	7	+3
Bridelia cathartica	S	13	3	-10	3	4	+1	16	7	-9
**Caesalpinia decapetala*	S	1	0	-1	0	0	0	1	0	-1
Carissa edulis	S	0	1	+1	0	0	0	0	1	+1
Chaetachme aristata	S	3	7	+4	2	2	0	5	9	+4
**Chromolaena ordata*	S	1	2	+1	0	0	0	1	2	+1
Combretum microphyllum	S	0	0	0	1	0	-1	1	0	-1
Combretum mossambicense	S	9	20	+11	15	18	+3	24	38	+14
Cordia ovalis	S	4	7	+3	0	1	+1	4	8	+4
Crotalaria capensis	S	0	5	+5	0	0	0	0	5	+5
Dichrostachys cinerea	S	85	85	0	13	23	+10	98	108	+10
Diospyros whyteana	S	0	2	+2	0	0	0	0	2	+2
**Duranta erecta*	S	0	2	+2	0	0	0	0	2	+2
Ehretia amoena	S	12	5	-7	2	4	+2	14	9	-5
Ehretia obtusifolia	S	0	0	0	0	1	+1	0	1	+1
Elaeodendron transvaalense	S	3	2	-1	0	0	0	3	2	-1
Euclea divinorum	S	6	10	+4	3	2	-1	9	12	+3
Euclea natalensis	S	64	64	0	14	24	+10	78	88	+10
Euclea schimperi	S	0	0	0	0	2	+2	0	2	+2
Eugenia mossambicensis	S	17	8	-9	0	5	+5	17	13	-4
Flueggea virosa	S	3	8	+5	5	12	+7	8	20	+12
Grewia bicolor	S	29	37	+8	2	5	+3	31	42	+11
Grewia flava	S	0	2	+2	0	0	0	0	2	+2
Grewia flavescens	S	38	79	+41	6	17	+11	44	96	+52
Grewia hexamita	S	4	8	+4	0	0	0	4	8	+4
Grewia occidentalis	S	9	0	-9	0	0	0	9	0	-9
Grewia villosa	S	1	3	+2	0	3	+3	1	6	+5
Gymnosporia harveyana	S	4	2	-2	0	0	0	4	2	-2
Gymnosporia heterophylla	S	9	11	+2	0	0	0	9	11	+2

Gymnosporia senegalensis	S	43	44	+1	60	33	-27	103	77	-26
Kraussia floribunda	S	28	7	-21	2	10	+8	30	17	-13
**Lantana camara*	S	16	13	-3	3	8	+5	19	21	+2
Lippia javanica	S	18	31	+13	10	12	+2	28	43	+15
Maytenus undata	S	1	0	-1	0	0	0	1	0	-1
**Mimosa pigra*	S	0	0	0	0	2	+2	0	2	+2
Monanthotaxis caffra	S	38	12	-26	0	3	+3	38	15	-23
Mystroxylon aethiopicum	S	14	7	-7	3	4	+1	17	11	-6
Ochna natalitia	S	17	13	-4	0	0	0	17	13	-4
Pavetta cataractarum	S	2	0	-2	2	0	-2	4	0	-4
Pavetta lanceolata	S	0	6	+6	0	4	+4	0	10	+10
Phyllanthus reticulatus	S	12	17	+5	7	26	+19	19	43	+24
Plectroniella armata	S	4	0	-4	0	0	0	4	0	-4
Pristimera longipetiolata	S	9	26	+17	3	9	+6	12	35	+23
Psoralea latifolia	S	0	1	+1	0	0	0	0	1	+1
Rhus pyroides	S	4	3	-1	4	7	+3	8	10	+2
Schotia capitata	S	0	0	0	0	1	+1	0	1	+1
Scolopia zeyheri	S	0	4	+4	0	0	0	0	4	+4
**Senna occidentalis*	S	0	0	0	0	3	+3	0	3	+3
**Senna septemtrionalis*	S	5	1	-4	1	1	0	6	2	-4
**Sesbania punicea*	S	1	0	-1	0	25	+25	1	25	+24
Strychnos spinosa	S	1	1	0	0	0	0	1	1	0
Tecomaria capensis	S	0	2	+2	0	0	0	0	2	+2
Terminalia prunioides	S	2	2	0	0	0	0	2	2	0
Trema orientalis	S	1	0	-1	4	2	-2	5	2	-3
Tricalysia junodii	S	0	0	0	0	1	+1	0	1	+1
Lianas										
Capparis fascicularis	L	7	11	+4	0	5	+5	7	16	+9
Cocculus hirsutus	L	0	12	+12	0	5	+5	0	17	+17
Combretum hereroense	L	5	4	-1	0	0	0	5	4	-1
Dalbergia armata	L	52	57	+5	1	14	+13	53	71	+18
Jasminum fluminense	L	1	14	+13	1	8	+7	2	22	+20
Rhoicissus tridentata	L	21	7	-14	0	1	+1	21	8	-13

Tacazzea apiculata	L	0	0	0	0	12	+12	0	12	+12
Total		860	885	+25	214	397	+183	1074	1282	+208

***Alien invasive species**

Spatial variation in species richness

Statistical variance among the different morphological zones, as identified through the application of a Bray Curtis distance matrix (see Figure. 5.2), was tested through the application of a Welch One-Way ANOVA in STATISTICA version 10 (StatSoft Inc., 2010). Statistical results revealed highly significant variance ($p<0.005$) in species richness across the different morphological zones of the Sabie River (Figure 5.5; Table 5.6).

Table 5.6: Summary of results obtained through the application of the Welch One-Way ANOVA in STATISTICA version 10 (StatSoft Inc., 2010) for the variance among different morphological zones (i.e. MCB, MCF (Ephemeral) and MCF (Active/Seasonal)).

Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p	Welch df Effect	Welch df Error	Welch F	Welch p
Total number of species	4171.72	2	2085.86	1537.58	123	12.5	166.86	0.00	2	49.66	175.05	0.000

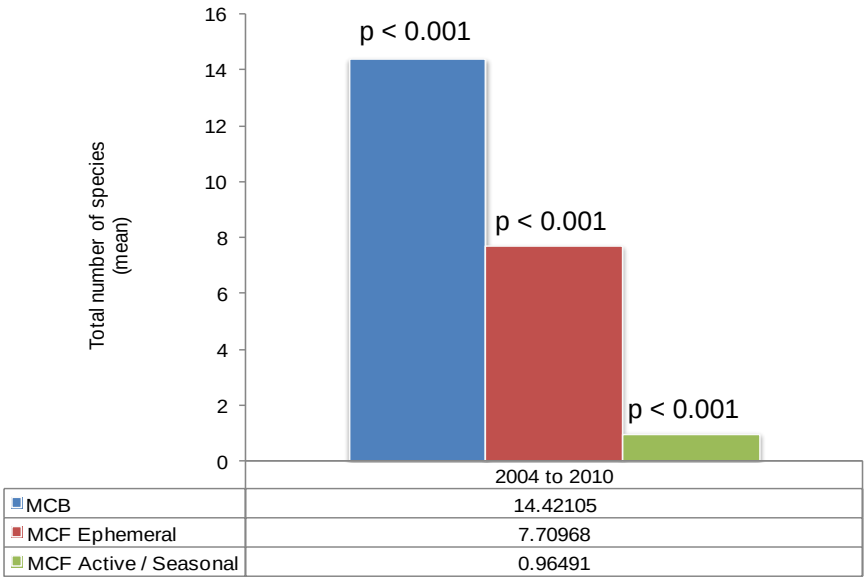


Figure 5.5: Highly significant variance (p<0.005) in the mean number of species per plot was revealed through the application of a Welch One-Way ANOVA.

A Kruskal Wallis test revealed highly significant differences in plant species richness between MCB and MCF Active/Seasonal morphological zones (Table 5.7), and significant differences between the MCB and MCF Ephemeral.

Table 5.7: Summary table of results obtained through the application of a Kruskal Wallis test. Significant differences are indicated at p<0.05; highly significant differences are marked with red.

Kruskal Wallis test: H (2, N = 126) = 96.38373; p = 0.000			
Depend: Total number of species	**MCB R: 102.46**	**MCF Ephemeral R: 76.903**	**MCF Active/Seasonal R: 30.237**
MCB		0.011492	<0.001
MCF Ephemeral	0.011492		<0.001
MCF Active/Seasonal	<0.001	<0.001	

5.3.5 Alien invasive riparian vegetation

A total increase of 29 alien invasive individuals occurred between 2004 and 2010. Alien invasive species were more abundant upstream where the Sabie River enters the KNP, i.e. at transects 2 (channel type PR) and 3 (channel type BA) (Figure 5.6, Table 5.8). In 2010, *Sesbania punicea* was the most abundant alien invasive species, which is best associated with the MCF of belt-transect 2 (BA) (Table 5.8).

Lantana camara was another abundant alien invasive species, with no specific preference to a channel type (Table 5.8). There was an overall increase of alien invasive species, with specifically an increase (with 35 individuals) of alien invasive species on the MCF (Table 5.9). There was a slight decrease in alien invasive species on the MCB with six individuals (Table 5.9). In 2004 *Lantana camara* was the most abundant alien invasive species across all four belt-transects, with most individuals recorded on the MCB (Table 5.9).

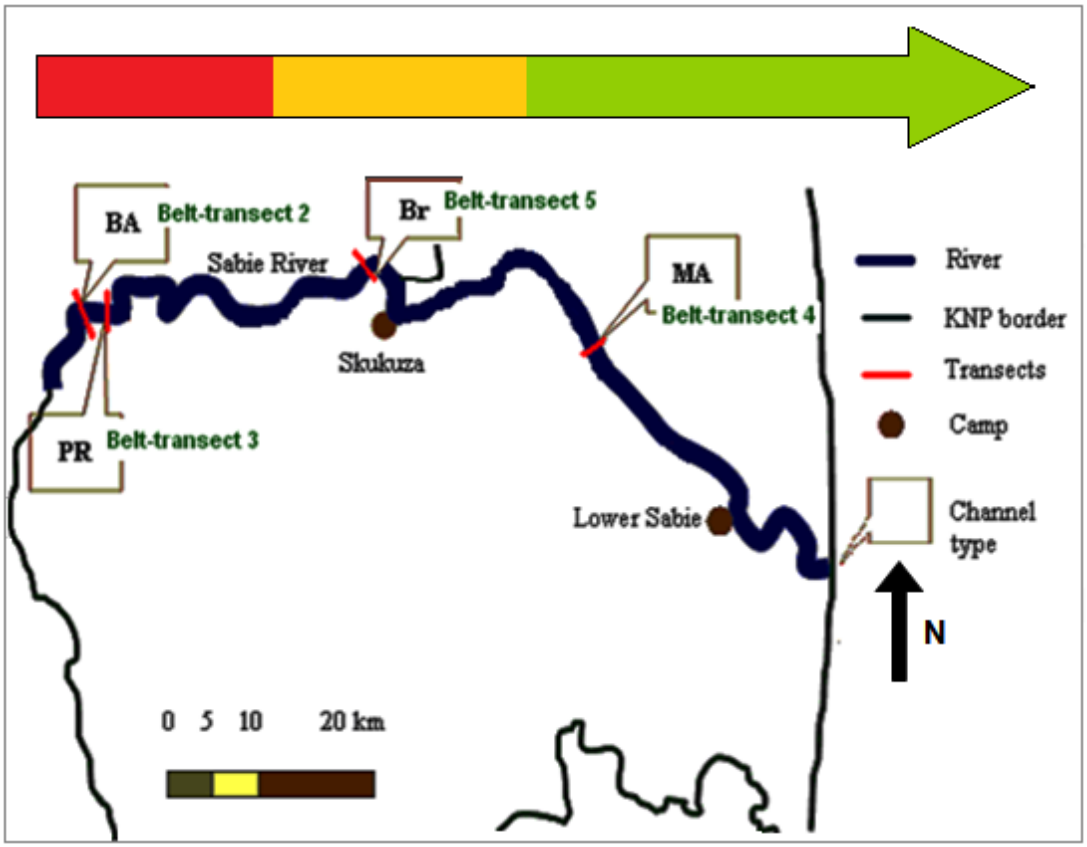


Figure 5.6: Distribution of alien invasive riparian woody species, from high density (red) to low density (green) across the four belt-transects (BA – Bedrock-anastomosing, PR – Pool-rapid, MA – Mixed-anastomosing and Br – Braided).

Table 5.8: Distribution of all alien invasive riparian woody species recorded across the macro channel bank (MCB) and macro channel floor (MCF) within each of the four belt-transects; 2 (BA = Bedrock-anastomosing), 3 (PR = Pool-rapid), 4 (MA = Mixed-anastomosing) and 5 (Br = Braided). Red indicates a substantial decrease (with more than 3) in individuals; and green indicates a substantial increase (with more than 3) in individuals. Within the table: 04 = 2004 year of sampling and 10 = 2010 year of sampling.

Belt-transect	**2 (BA)**						**3 (PR)**						**4 (MA)**						**5 (Br)**					
MCB/MCF	**MCB**		**Dif**	**MCF**		**Dif**	**MCB**		**Dif**	**MCF**		**Dif**	**MCB**		**Dif**	**MCF**		**Dif**	**MCB**		**Dif**	**MCF**		**Dif**
Year	**04**	**10**		**04**	**10**		**04**	**10**		**04**	**10**		**04**	**10**		**04**	**10**		**04**	**10**		**04**	**10**	
Caesalpinia decapetala	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chromolaena ordata	1	2	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duranta erecta	0	2	+2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lantana camara	11	7	-4	0	1	+1	0	3	3	0	6	+6	0	0	0	1	0	-1	5	3	-2	2	1	-1
Mimosa pigra	0	0	0	0	0	0	0	0	0	0	2	+2	0	0	0	0	0	0	0	0	0	0	0	0
Senna occidentalis	0	0	0	0	0	0	0	0	0	0	3	+3	0	0	0	0	0	0	0	0	0	0	0	0
Senna septemtrionalis	5	1	-4	0	1	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1
Sesbania punicea	1	0	-1	0	24	+24	0	0	0	0	1	+1	0	0	0	0	0	0	0	0	0	0	0	0
Total	19	12	-7	0	26	+26	0	3	+3	0	12	+12	0	0	0	1	0	-1	5	3	-2	3	1	-2

Table 5.9: Distribution of alien invasive riparian woody species across the macro channel bank (MCB) and macro channel floor (MCF) in both 2004 and 2010. Red indicates a substantial decrease (with more than 3) in individuals; and green indicates a substantial increase (with more than 3) in individuals.

Species	**2004 MCB**	**2010 MCB**	**Dif**	**2004 MCF**	**2010 MCF**	**Dif**	**Total 2004**	**Total 2010**	**Total Dif**
Caesalpinia decapetala	1	0	-1	0	0	0	1	0	-1
Chromolaena ordata	1	2	1	0	0	0	1	2	1
Duranta erecta	0	2	2	0	0	0	0	2	2
Lantana camara	16	13	-3	3	8	5	19	21	2
Mimosa pigra	0	0	0	0	2	2	0	2	2
Senna occidentalis	0	0	0	0	3	3	0	3	3
Senna septemtrionalis	5	1	-4	1	1	0	6	2	-4
Sesbania punicea	1	0	-1	0	25	25	1	25	24
Total	24	18	-6	4	39	35	28	57	29

5.4 Discussion

5.4.1 Temporal changes in woody riparian species composition and richness

The spatial distribution of plots on an ordination-type scatter plot, produced after the application of NMDS (Figure 5.1 and Figure 5.2), indicated limited temporal shifts in plant species assemblages. The clustering of 2010 MCF plots indicated a possible shift in species composition between 2004 and 2010 (Figure 5.1), which supports the dynamic character of the MCF, which is commonly associated with a high species turnover (Parsons *et al*., 2006). This temporal shift in species composition could be ascribed to the establishment of several woody species in 2010 in plots that were empty on the MCF in 2004.

The response of woody species to the 2000 flood after an intermediate time interval (i.e. ten years post-flood) varied among the different morphological zones and even between each of the 150 m^2 plots. The overall increase in riparian woody individuals could be explained by the dominance of a few species. An increase in single species could result in a homogenous system and consequently change the dynamics of the riparian vegetation structure and composition. Ten years after the large, infrequent flooding event along the Sabie River, riparian vegetation was dominated by shrub species (Table 5.5), which indicate that shrubs and trees respond differently to the same underlying environmental disturbances or factors over time. This may be as result of patch history and the life-history strategies of the individual riparian plant species (Holmes *et al*., 2005).

Gamma diversity increased substantially on the MCF but only slightly on the MCB (see Figure 5.4 and 5.5). The distribution of species on either the MCB or MCF (Ephemeral and Active/Seasonal) is dependent on the specific environmental conditions, such as hydrology and sedimentation. Elevation and water availability serves as an important environmental driver, which creates an environment characterised by different plant communities (Parsons *et al*., 2006). The establishment of new riparian species are often abundant, but is restrained by water availability and hydrological cycles (e.g. regular inundation)

(Mackenzie *et al*., 1999). Therefore, the Ephemeral MCF and MCB are more stable than the Active/Seasonal MCF, which is inundated on a regular basis.

5.4.2 Spatial variation in species composition and richness at am intermediate post-flood temporal interval

Ward's clustering of plots corresponded with the clusters identified by Parsons *et al*. (2006) (i.e. MCB, Ephemeral MCF and Active/Seasonal MCF) (Figure 5.2). Parsons *et al*. (2006) recorded separate clustering of the pre- and post-flood plots within subgroups. This study, however, revealed that there is no distinct separation between years of sampling or between channel types (Figure 5.2). As expected, the changes in species composition without the intervention of a LID are not as dramatic as reported by Parsons *et al* (2006), who reported changes before and after the flood.

The Sabie River is characterised by a mosaic of patchy landscapes (Parsons *et al.*, 2006). The species composition of each patch is strongly influenced by several factors, for example the history of a patch, location of a patch within the physical landscape, interaction between a patch and the surrounding environment and the size of a specific patch (Parsons *et al*., 2006). The additional cluster (F – 3) identified by Fisher's Exact Relationship Test within the dendrogram (Figure 5.2 and Figure 5.3) may be as a result of several unique patch specific factors influencing the species composition within belt-transect 4 (MA). Van Coller *et al.* (1997) reported that the MA channel type normally develop over an extensive time with widespread sedimentation, and is predominantly controlled by alluvial processes and bedrock outcrops. During field surveys it was observed that belt-transect 4 (MA) had higher animal activity and browsing damage, compared to other belt-transects (Figure 5.7).

The intermediate disturbance hypothesis is often used to explain the ecological importance of disturbances to generate vegetation species diversity and richness (Malanson, 1993). This is supported by the irregularly flooded MCF of the Sabie River, where species diversity and richness increased between 2004 and 2010. The MCF and especially the Ephemeral MCF can therefore be considered an important source of plant propagules, which are distributed during flood events.

The clustering of all MCB plots towards the left of the dendrogram, and the clustering of MCF (Active/Seasonal) plots towards the right almost illustrate the distribution of plots along a moisture and elevation gradient (Figure 5.2). Moisture dependent species were mostly found on the right side of the dendrogram, whereas species less dependent on moisture were mostly found in the clusters on the left side (see Appendix D for a detailed description of species distribution within the dendrogram). The clusters on the left side of the dendrogram also had higher species richness than the plots to the right (Figure 5.2; Table 5.1 and Appendix D). Therefore, similar to the findings by Parsons *et al*. (2006), the arrangement of plots in the dendrogram was an indirect illustration of the relative role of environmental factors (e.g. water availability, flood frequency and elevation) in determining groups of samples with similar plant communities.

Figure 5.7: Signs of animal activity observed within belt-transect 4 (MA) during field surveys.

Species composition and frequency

Changes in species composition and frequency were more evident on the MCF than on the MCB. This may be because of open patches created by the 2000 flood (Parsons *et al*.,

2006), which favoured only certain species to establish and increase in frequency. The increase in shrubs on the MCF could indicate that shrubs responded best to flooding and exhibited greater adaptability to environmental change. In certain areas, MCF species were still restricted to the MCB in 2010 (Table 5.1 and Table 5.5), which may be because of an intermediate flooding event which occurred in 2006. This flooding event may have deposited certain MCF species propagules onto the MCB, which developed into small populations of MCF species on the MCB.

MCF species are commonly found on the MCB after a flooding event and gradually die back over time (Henry & Amoros, 1996). Several species, which are normally associated with the MCF, decreased across the MCB. This supports the theory that MCF species might not establish permanently on the MCB because of drier, elevated conditions becoming unsuitable (Johnson, 2000). Some of these species were:

- *Breonadia salicina* (decreased with two individuals),
- *Kraussia floribunda* (decreased with 21 individuals); and
- *Syzygium guineense* (decreased with nine individuals).

Although there were certain species that decreased in frequency across the MCB, the MCB still had higher species richness than the MCF in both sampling occasions (Figure 5.4 and Figure 5.5). However, the MCF experienced a greater increase in species compared to the MCB. The significant variation in species richness across all morphological zones supports the high species turnover a riparian corridor normally experiences (Sabo *et al*., 2005).

Diagnostic species

The diagnostic species identified within each cluster (Figure 5.2) are associated with different riparian zones (Bredenkamp & Van Rooyen, 1991). Cluster MCB / F – 1 was characterised by typical dry riparian woodland species (e.g. *Acacia robusta, Euclea natalensis* and *Monanthotaxis caffra*). However, there were also species (e.g. *Kraussia floribunda* and *Trichilia emetica*) present in cluster MCB / F – 1 that were associated with wet riparian forests. The presence of both dry riparian woodland and wet riparian forest species may be an indication that the environmental conditions (e.g. water availability) on the MCB varied between the four belt-transects that were sampled.

The Ephemeral MCF / F – 3 was characterised by *Combretum mossambicense, Grewia bicolor* and *Pristimera longipetiolata* which are all shrubs that are associated with the dry riparian woodland zone. The dynamic environmental conditions of the Ephemeral MCF are ideal growing conditions for shrubs, which are fast growing with high seed dispersal.

5.4.3 Alien invasive riparian vegetation

Foxcroft *et al.* (2008) reported that woody alien density and species richness is different among channel types, geological zones and geomorphological units within the Sabie River, Kruger National Park. It was found that woody alien species are lower in density and richness across the PR, while the BR, MA and BA channel types have a higher density and richness in alien invasive species (Foxcroft *et al*., 2008). Foxcroft *et al*. (2008) also reported that the braided channel type has the highest woody alien density and species richness.

Contrary to the findings of Foxcroft *et al*. (2008), the highest frequency of woody alien vegetation occured within the bedrock-anastomosing followed by the pool-rapid channel type (Table 5.8).

Overall, the most change in alien species composition and frequency occurred in belt-transect 2 (BA) and belt-transect 3 (PR). Both these belt-transects were located on a deposit bank (field observation only). A deposit bank is normally characterised by considerably high sedimentation, because of change in the water flow, such as the inside of a river bend or an obstruction within the river (Strahler & Strahler, 2005). Although a BA channel type is characterised by multiple channels flowing through bedrock, sedimentation does occur.

Upstream activities, such as agriculture, forestry and human settlement have an impact on the mean annual flow and hydrological cycles of the Sabie River (Heritage & Van Niekerk, 1995). Changes and interventions to the flow regime of the Sabie River cause alterations to the distribution of sediment, exposed bedrock and watercourses, which ultimately change riparian vegetation and composition (Heritage & Van Niekerk, 1995).

An increase in sedimentation creates bars that are ideal for the establishment of alien vegetation (Foxcroft *et al.,* 2008). This may explain the increase in alien invasive frequency and richness at the pool-rapid channel type.

Given that belt-transect 2 (BA) is very close to where the Sabie River enters the KNP, this area may have inflated levels of alien invasive species. Many alien invasive species are washed into the KNP by main watercourses that are infested by alien species upstream from the park (Foxcroft *et al*., 2008). This suggests that propagules from alien invasive species are most abundant where the Sabie River enters the KNP, but decreases through sedimentation as the river continuous to flow through the KNP.

The distribution of alien invasive plants are also influenced by the continuous clearing operations of Working for Water (WfW), which have several clearing projects along the Sabie River (Beater *et al*., 2008). This has potentially affected the results given in this study. The distribution of alien invasive plants across the four belt-transects support the findings of previous projects (Figure 5.8).

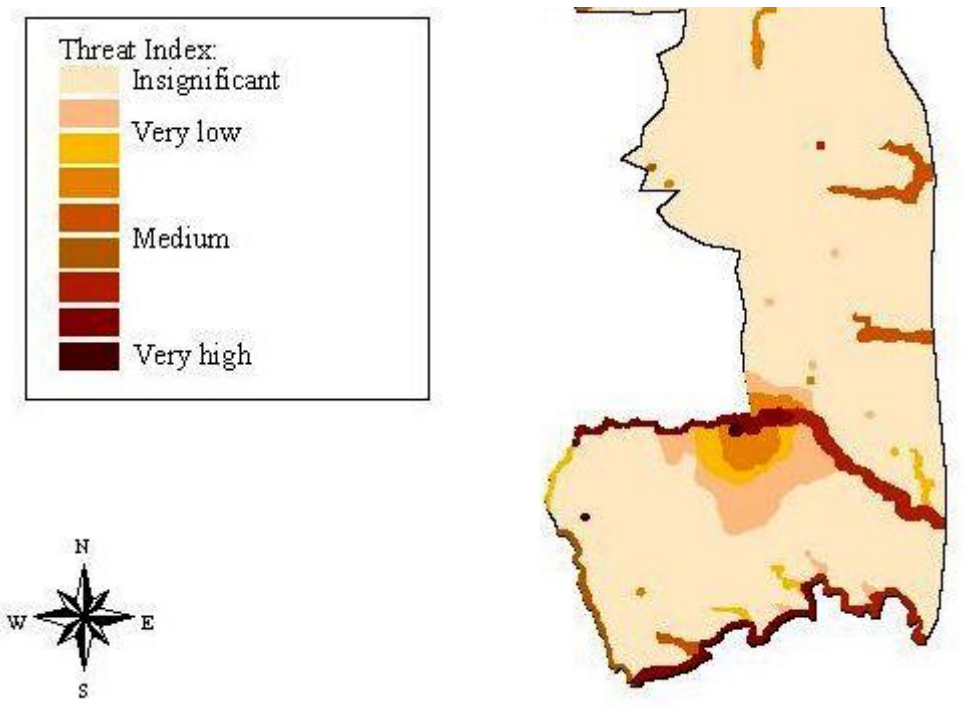


Figure 5.8: Distribution of alien invasive plants within the Kruger National Park (Adapted from SANParks, GIS laboratory, 2009c).

The high frequency of alien invasive plants within belt-transect 2 (BA) may also be due to disturbance caused by fires. In comparison to the other three belt-transects, the area surrounding belt-transect 2 (BA) had a higher frequency of fires since 1941 (See chapter 2 for detailed description of the fire frequency across the southern section of the KNP; Figure 2.3). Although fire is used as a management tool to combat the encroachment of alien invasive species, it can also cause an increase of alien invasive plants if the fire frequency and intensity is too high, especially within an ecosystem which is already under continuous pressure (i.e. herbivory and floods) (Trollope *et al.*, 1999).

The ecosystem objectives, specifically alien impact objectives, of the KNP aims at anticipating, preventing and controlling invasive alien plants in order to preserve indigenous biodiversity (SANParks, 2008). Foxcroft (2010) identified four thresholds of potential concerns (TPC's) which explains the invasive process of alien invasive species. The first TPC deals with newly invasive species that are an imminent threat from outside the KNP boundaries (Foxcroft, 2010). The second TPC deals with an increase in the distribution of a species and the third TPC deals with an increase in the density of a species, such as was recorded in belt-transect 2 and 3.

5.5 Summary

Results presented in this chapter support the hypothesis that no significant change in woody species composition is evident between 2004 and 2010. However, a shift in riparian vegetation species frequency along a temporal gradient was observed. The riparian vegetation along the Sabie was dominated by shrub species in 2004, which proved to be even greater in 2010 (i.e. species richness and frequency). Even with the increase of shrub species and individuals, the woody species composition has not changed significantly between 2004 and 2010.

Although no significant changes in overall species composition could be detected, there were some spatial shifts in species composition when the datasets were "unpacked" into the morphological zones. This emphasises the importance of including morphological zones to explain the dynamics of riparian vegetation. It furthermore supports the theory that riparian zones increase the Beta-diversity and regional species richness.

Species composition within the four belt-transects were very similar. There were small differences within the four belt-transects which may be linked to different channel types, but they were most likely driven by other environmental factors (i.e. herbivory, roads, proximity to the parks border, animal density and patch history – field observations only) which need to be identified and managed by SANParks. These unknown environmental factors may also play an important role in determining the future plant communities and restoration processes after a disturbance event.

The diagnostic species identified within each of the clusters (Figure 5.2) suggest that the different riparian zones as identified by Bredenkamp and Van Rooyen (1991) are re-establishing. It is envisaged that future studies will find a more distinguished separation of riparian zones across the macro channel. However, if the Sabie River experiences another large infrequent flooding event or severe drought conditions, this may not occur.

The introduction of alien invasive species from outside the KNP will remain a major threat to the biodiversity of the riparian vegetation along the Sabie River and the greater Kruger National Park. The distribution of alien invasive species is influenced by multiple environmental factors, of which many are still unknown. This further complicates alien invasive management. Tourists and local communities must be made aware of the affects alien invasive species have on the biodiversity of the KNP, and this may even lessen the number of garden escapees entering the conservation area.

Ecologists are merely scratching at the surface of understanding and describing the interactions between riparian vegetation and disturbances over time. Therefore, the importance of long-term biomonitoring projects within river ecosystems should not be neglected.

Chapter 6: Results – Temporal and spatial changes in woody structure

6.1. Introduction

Rivers and streams are considered complex mosaics of habitat types and environmental gradients, characterised by high connectivity and spatial complexity creating a unique landscape (Schlosser, 1991; Fausch *et al.*, 2002). They are strongly influenced by the surrounding landscape (Schlosser, 1991; Allan *et al.,* 1997; Fausch *et al.*, 2002; Townsend *et al.,* 2003; Allen, 2004), which includes various external and internal factors (Figure 6.1) that contribute to heterogeneity in the river ecosystem structure, composition and function (Turner & Dale, 1998; Kotschy *et al*., 2006).

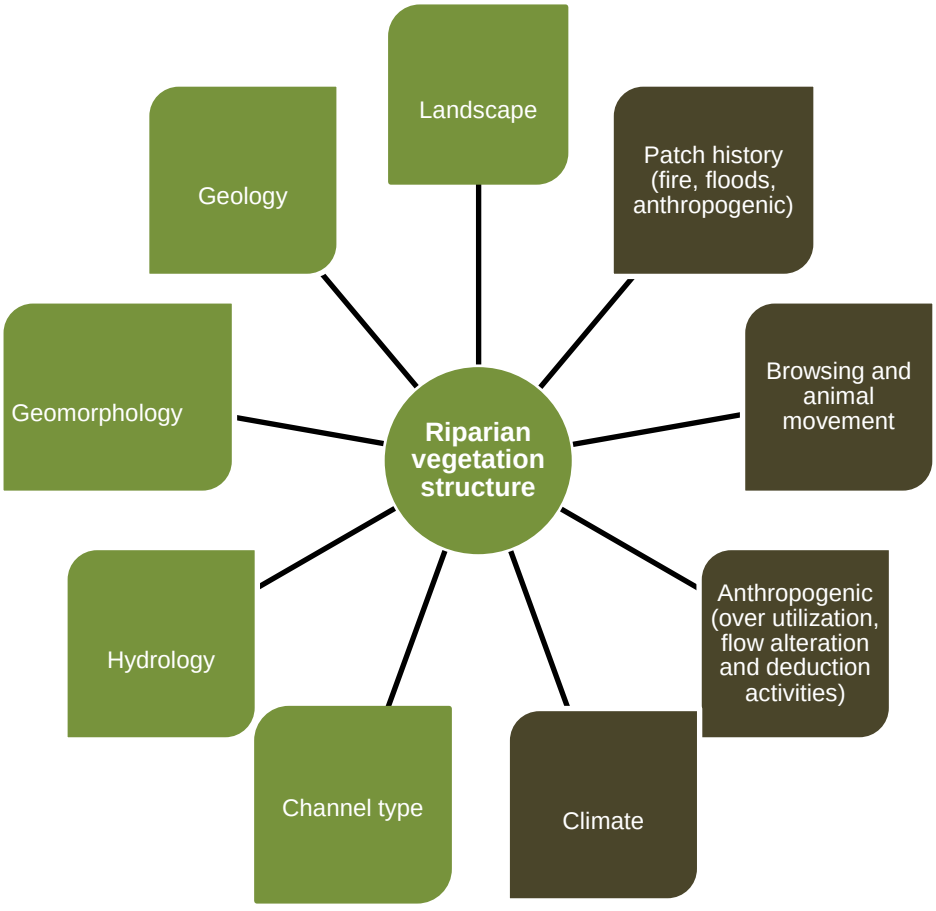


Figure 6.1: External (indicated by dark green blocks) and internal (indicated by green blocks) drivers influencing riparian vegetation structure (Adapted from Kotschy *et al.,* 2006).

Changes in woody vegetation structure have various implications for wildlife habitat and biotic diversity (Peterson & Reich, 2001), e.g. an increase in riparian vegetation undergrowth will provide better shelter for birds, rodents and other organisms (Catteral *et al*., 2007). The capability of riparian vegetation to buffer against disturbances is also affected by woody vegetation structure within the riparian ecosystem (Peterson & Reich, 2001). For example, certain species which grow in dense clusters with large thorns may restrict or deter animals from browsing.

Riparian landscapes are an important natural resource for humans and provide several ecosystem services (Soman, 2007). Ecosystem services, such as withdrawal of water for drinking and irrigation purposes, flood mitigation, enhanced aesthetics, consumptive and non-consumptive activities and providing habitats for a variety of fauna and flora and are all dependent on the riparian vegetation structure, composition and function (Soman, 2007). As a result, ecosystem goods and services provided by riparian landscapes can be influenced and modified by herbivory and large flooding events. For example, extensive grazing by mega-herbivores will decrease the number of individual woodies which in return will decrease bank stability.

In their study on woody structural change in response to the 2000 flood, Parsons *et al*. (2007) reported that the flood altered the distribution of height classes across the macro channel, although most tall trees were still present after the flood. It was, however, reported that the riparian vegetation along the Sabie River was shorter and bushier in 2004 after the flood compared to the 1990, pre-flood vegetation state (Parsons *et al*., 2007). Furthermore, the basal area of the vegetation was also affected by the flood, although it was indicated that the mean basal area slightly increased as a result of the re-sprouting of damaged individuals post-flood. Lastly Parsons *et al*. (2007) reported that the tree to shrub ratio was not altered substantially by the flood, although they've predicted an increase in shrub density, hence a return to a bushier growth form dominance over time (Parsons *et al*., 2007).

To compare such patterns of woody structural response directly after the flood with patterns identified after 10 years of recovery, this chapter aimed at presenting the following:

- To test for significant differences in riparian woody structure between
    - 2004 and 2010 (**temporal changes**);
    - the MCB and MCF (**spatial changes**);
    - 2004 and 2010 at each of the morphological zones (**spatial changes**), and
- To test for significant differences in frequencies between shrubs, trees and lianas
    - across the MCB and MCF, (spatial) and
    - between 2004 and 2010 (temporal)

6.2. Methods

6.2.1 Data sampling

All established woody individuals were identified and measured (basal diameter, height, number of stems) within each 150 m^2 plot of the four belt-transects (see chapter 4 for a detailed description of sampling methods).

For the purpose of presenting an overview of changes in vegetation structure, the macro-channel was delineated into the higher elevation MCB and lower elevation MCF. Lower order delineation into flow inundation zones was avoided, to present changes across the most confined morphological zones (i.e. MCB and MCF) rather than across all transition zones.

6.2.2 Data analyses

The 2004 and 2010 datasets were combined after which synonyms of plant species were merged according to Germishuizen *et al*. (2006) to ensure compatibility.

The MIXED Procedure model, also known as PROC MIXED, was used to investigate change within the structural data. PROC MIXED, is a statistical approach in which several mixed linear models are used to analyse data (see Chapter 4 for a detailed description of data analyses) (SAS Institution Inc., 2008).

6.3. Results

The presentation of results for this chapter is outlined in Figure 6.2. Firstly, results from the pooled data set will be presented, which was designed to investigate overall temporal changes (6.3.1). The second section of this chapter (6.3.2) will present spatial changes in vegetation structure (i.e. changes between 2004 and 2010 on MCB and MCF respectively). Within each section, temporal changes in density (i.e. individuals/ha and basal area/ha), abundances of growth forms (i.e. shrubs, trees and lianas) and structural height classes (i.e. height) were presented.

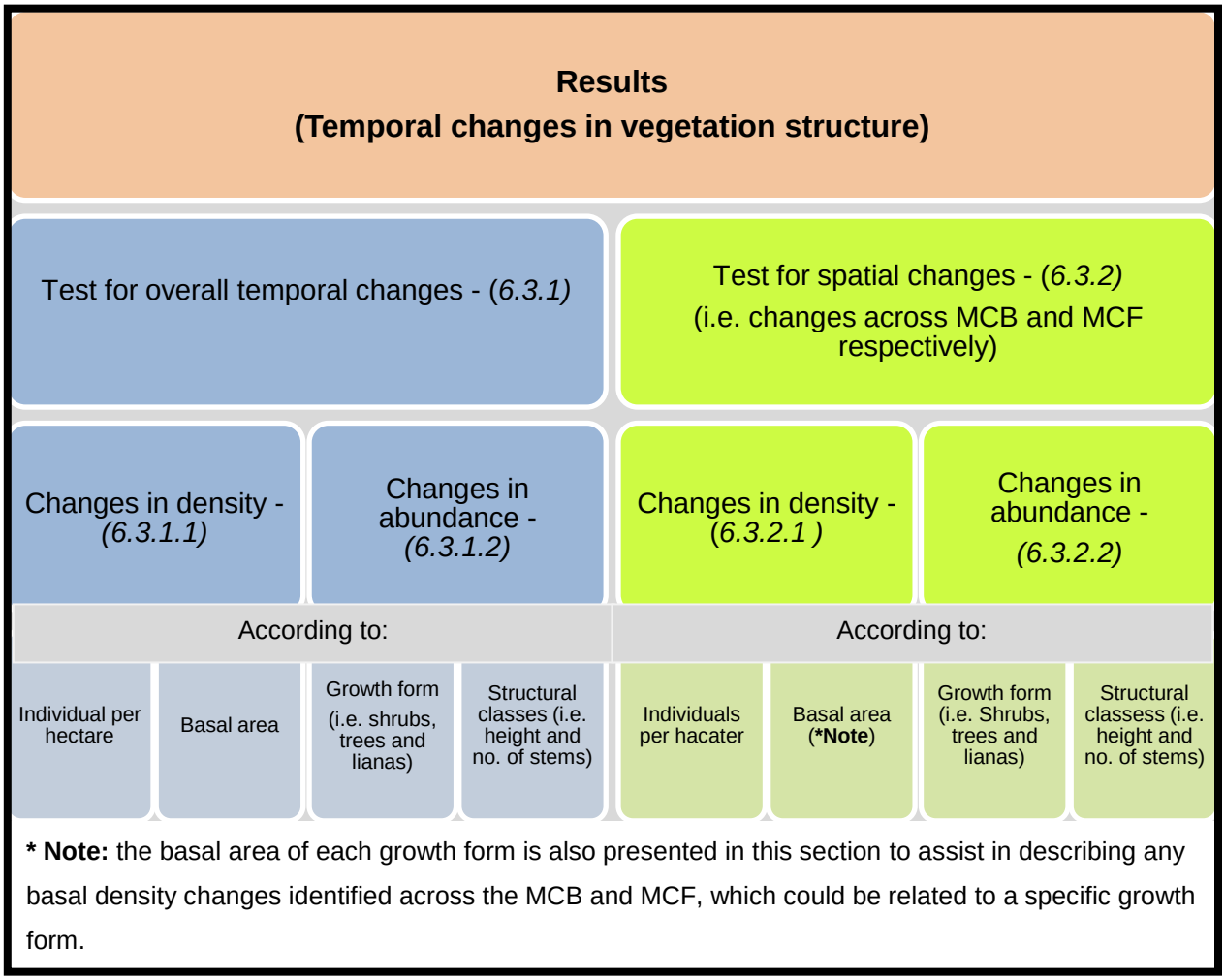


Figure 6.2: Outline of presentation of results obtained in vegetation structure analysis.

6.3.1. Overall temporal changes in vegetation structure between 2004 and 2010

6.3.1.1. Temporal change in woody density

Individuals per hectare

Mean woody individuals per hectare as a function of density increased significantly ($p<0.05$) between 2004 (1136.5 individuals / ha) and 2010 (1356.6 individuals / ha) (Figure 6.3).

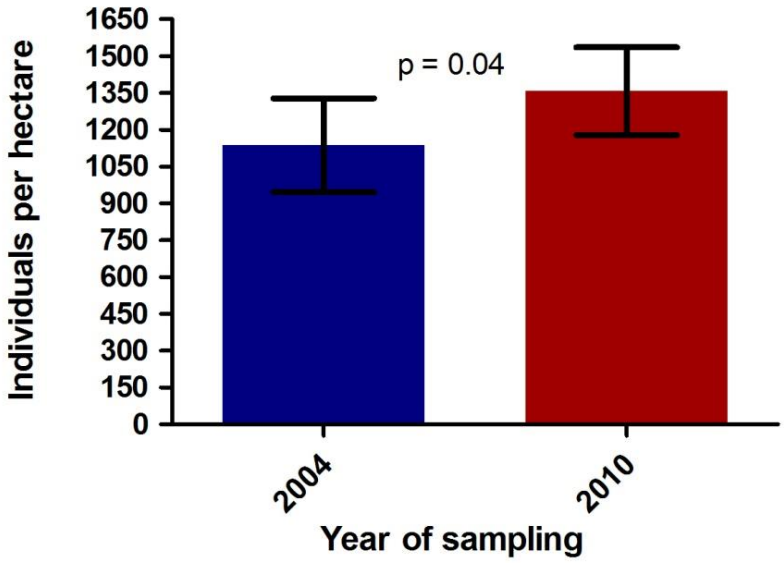


Figure 6.3: Changes ($p<0.05$) in woody density, reported as individuals/ha between 2004 (Standard Error Mean (SEM) – 191.4 individuals/ha) and 2010 (SEM – 178.7 individuals/ha).

Basal area (cm^2) of woody individuals

Woody density, reported as basal area (cm^2) per plot, increased between 2004 (114 cm^2) and 2010 (127.38 cm^2), although statistically non-significant ($p>0.05$) (Figure 6.4). The increase in overall basal area could be ascribed to an increase in basal area on the MCF (see Figure 6.9 within section 6.3.2.1 for description of basal area across MCB and MCF).

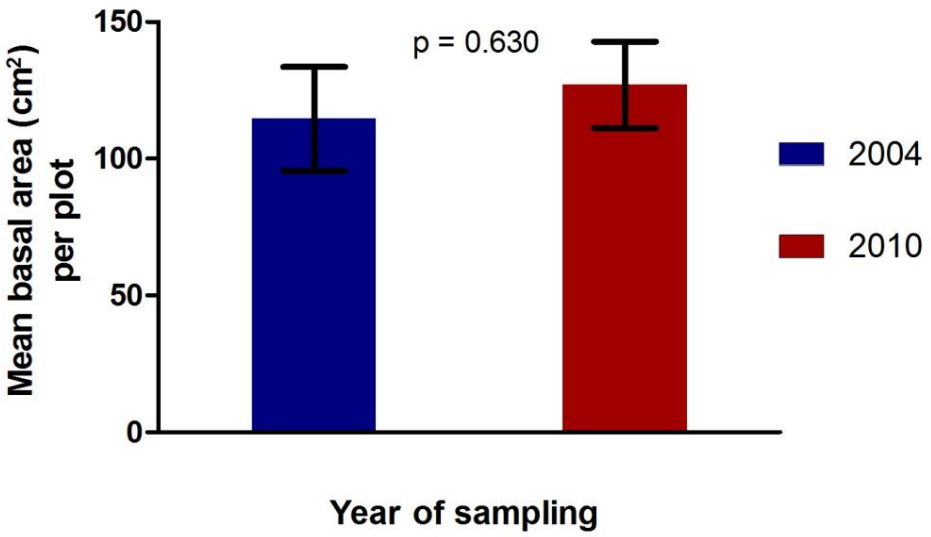


Figure 6.4: Mean basal area (cm^2) per plot in 2004 and in 2010.

6.3.1.2. Temporal changes in woody individual abundances

Growth forms (Shrubs, trees and lianas)

The total number of individual shrubs and lianas increased between 2004 and 2010, whereas tree individual counts remained unchanged (Figure 6.5). Shrubs remained the most abundant growth form in 2010 and even increased in numbers between 2004 and 2010 (i.e. an increase of 145 individuals) (Figure 6.5).

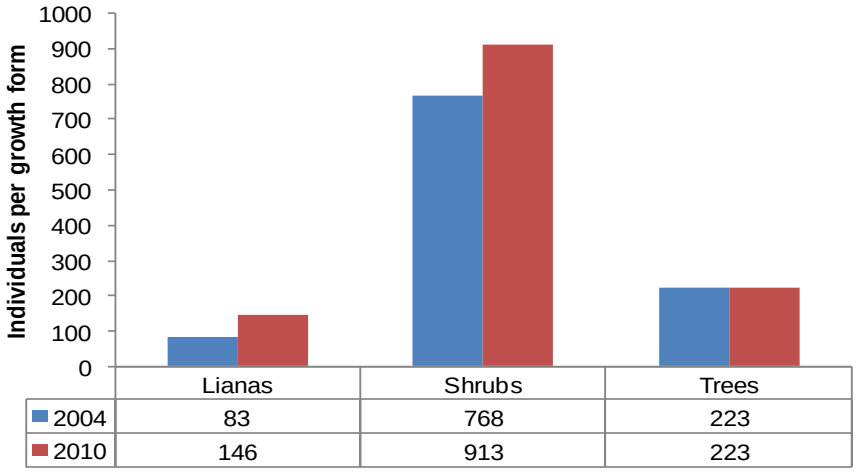


Figure 6.5: Temporal changes in abundance of selected growth forms.

Structural classes: Abundance of individuals per height class

Highly significant differences in individuals per height class ($p<0.005$) was reported. Although a decrease of 246 individuals in the juvenile (i.e. >0–1.5 m) woody height class was reported, the decrease is statistically reported as non-significant according to the 95% Confidence limits (Figure 6.6). The increase of 310 individuals in the >1.5–3 m height class was however statistically significant. In the >3–5 m height class, an increase was reported. Such increases in the lower height classes (i.e. >1.5–5 m) supported the higher abundance of shrubs in 2010. The distribution of individuals among the remaining height classes was rather stable, although slightly fewer individuals in the highest (i.e. adult) height class were reported here (Figure 6.6).

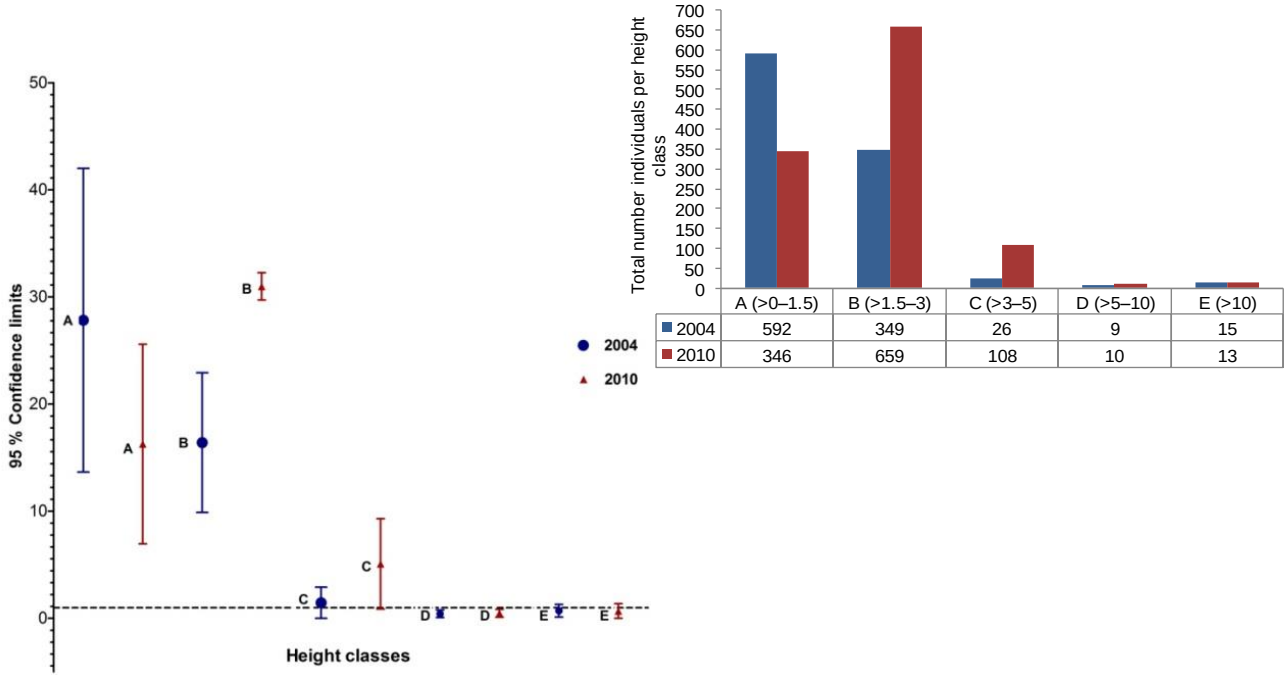


Figure 6.6: Woody individual abundances recorded within each height class ($p = 0.002$) for each year.

Structural classes: Abundance of individuals per stem class

There was an overall significant variance ($p <0.05$) in individuals per stem class between 2004 and 2010. As a result, the woody riparian vegetation was in general bushier in 2010 than in 2004. The 2–3 stem class was the only stem class in which individuals decreased between 2004 and 2010 (Figure 6.7). The highest increase of 108 individuals was recorded

for the 4–6 stem class followed by the ≥11 stem class, in which an increase of 97 individuals was reported.

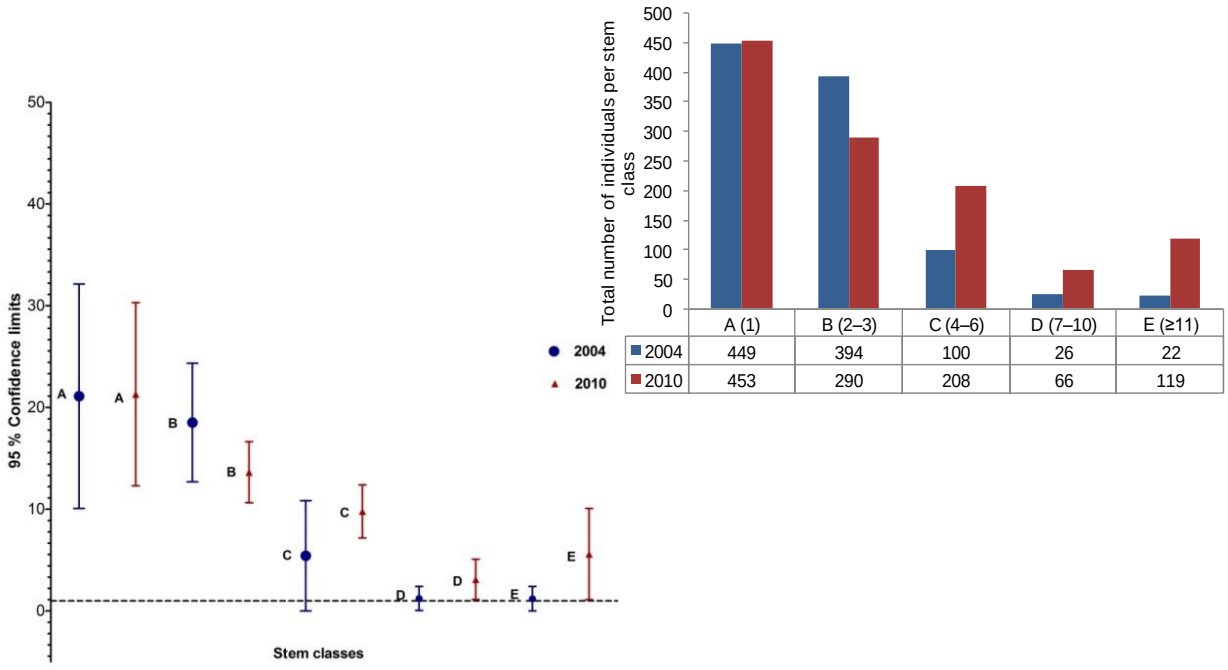


Figure 6.7: Woody individual abundance recorded within each stem classes (p = 0.008) for each sampling year.

6.3.2. Spatial changes in vegetation structure (MCB vs. MCF)

6.3.2.1. Spatial change in woody density

Individuals per hectare

Mean woody individuals per hectare as a function of density increased significantly ($p<0.05$) on the MCB between 2004 (2866.8 individuals/ha) and 2010 (2950 individuals/ha) (Figure 6.8). A highly significant increase was reported on the MCF between 2004 (331.8 individuals/ha) and 2010 (615.5 individuals/ha), which could be attributed to the increase in shrub individuals on the MCF. Changes in abundances per growth form are presented in section 6.3.2.2.

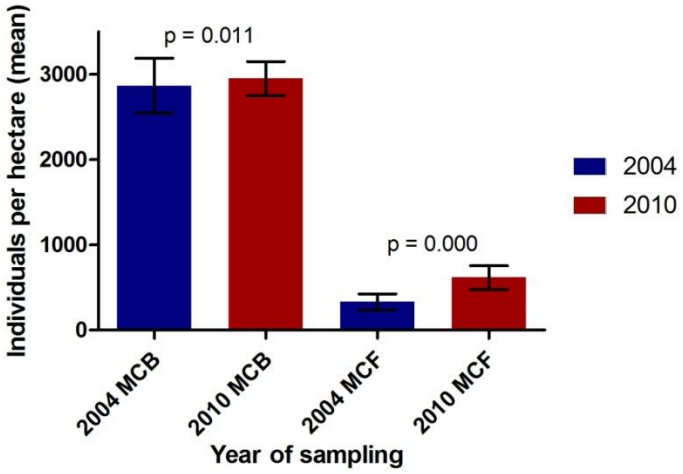


Figure 6.8: Changes in individuals per hectare as a function of density across the different morphological zones between 2004 and 2010.

Basal area (cm^2) per plot of woody individuals

There was no significant change in basal area between 2004 and 2010 on both the MCB and MCF (Figure 6.9). The basal area was higher on the MCB although a decrease was reported between 2004 and 2010. The MCF showed a substantial increase in basal area since 2004, although the difference in basal area was non-significant (Figure 6.9).

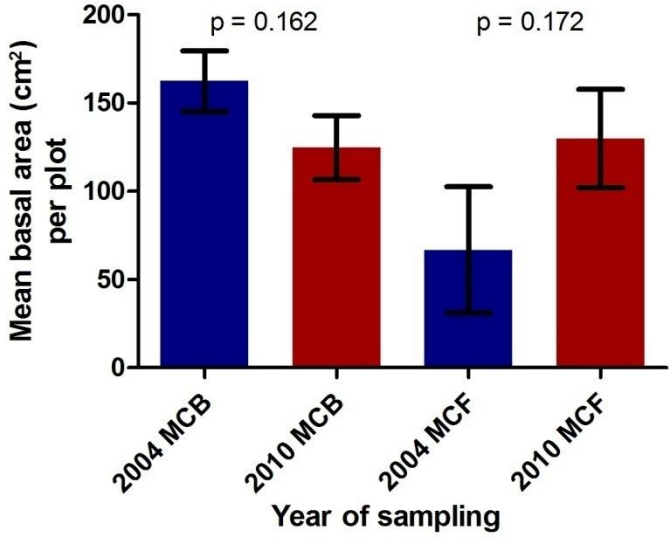


Figure 6.9: Changes in basal area (cm^2) per plot as a function of density across the different morphological zones between 2004 and 2010.

Basal area (cm^2) per plot of woody individuals per growth form (i.e. shrubs, trees and lianas)

Basal area as a function of woody density was furthermore investigated by analysing the contribution by trees and shrubs respectively to density changes on the MCB and MCF.

No significant differences in densities were revealed ($p>0.05$). Density of trees however increased on the MCF and decreased on the MCB (Figure 6.10). This correlates with the results obtained for the individual tree counts, which also showed a decrease on the MCB and an increase on the MCF (Figure 6.11).

Also consistent with the increase of the total number of shrubs between 2004 and 2010 (Figure 6.10), the basal area (cm^2) per plot of shrubs increased on both morphological zones (Figure 6.10), of which the increase on the MCF was noteworthy although statistical non-significant (Figure 6.10).

The density of lianas was also measured, despite their minor contribution to overall woody basal density. The average basal density of lianas, however increased on both morphological zones.

6.3.2.2. Spatial changes in woody individual abundances

Growth forms (Shrubs, trees and lianas)

An increase in lianas and shrubs on both the MCB and MCF is reported in Figure 6.11. However, the number of individual trees decreased on the MCB but increased on the MCF between 2004 and 2010 (Figure 6.11). Shrubs showed the highest increase over a six year period on both the morphological zones with an increase of 29 individuals on the MCB and a substantial increase of 116 individuals on the MCF, which further supports the dynamic character of the MCF (Figure 6.11).

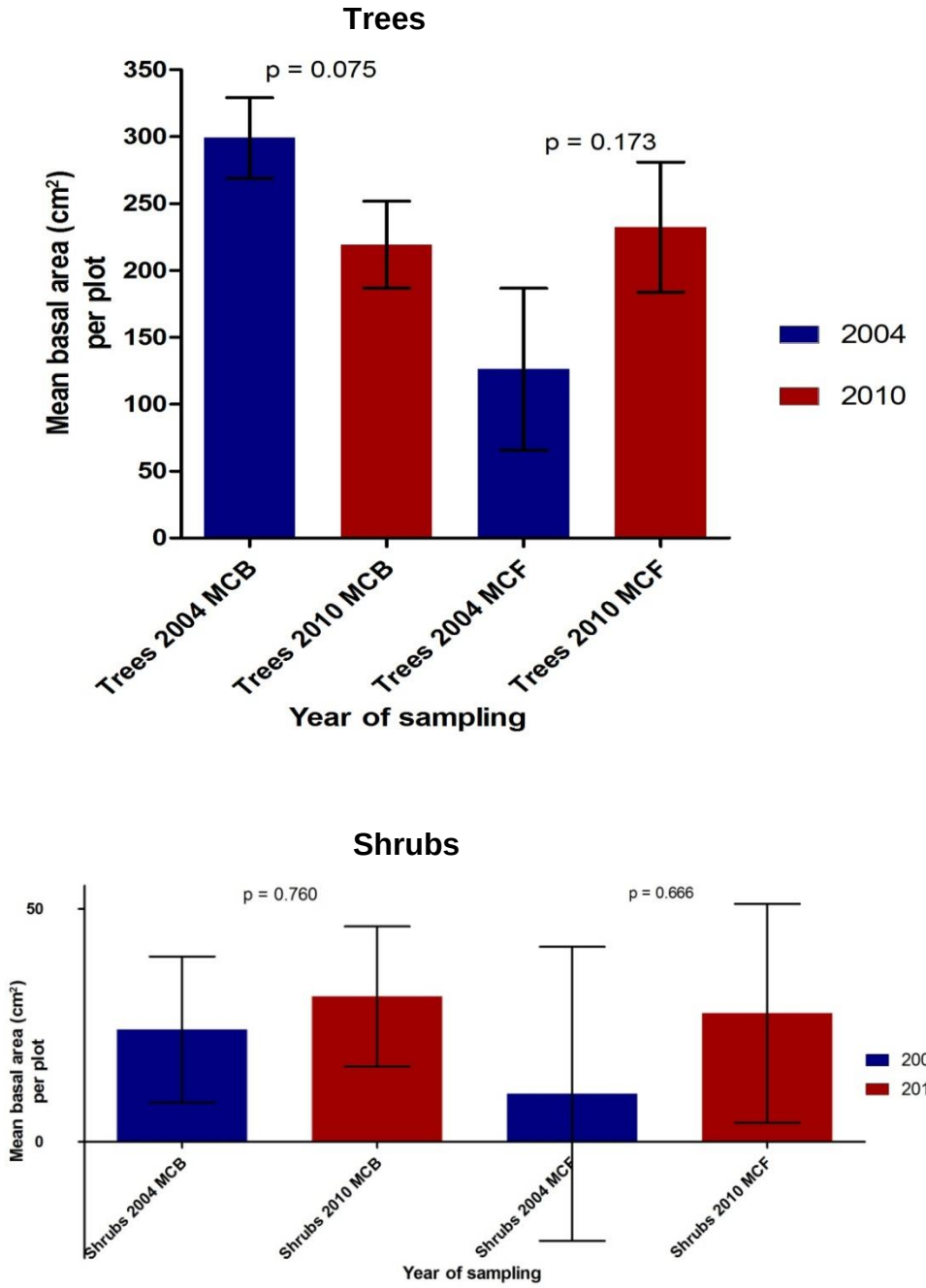
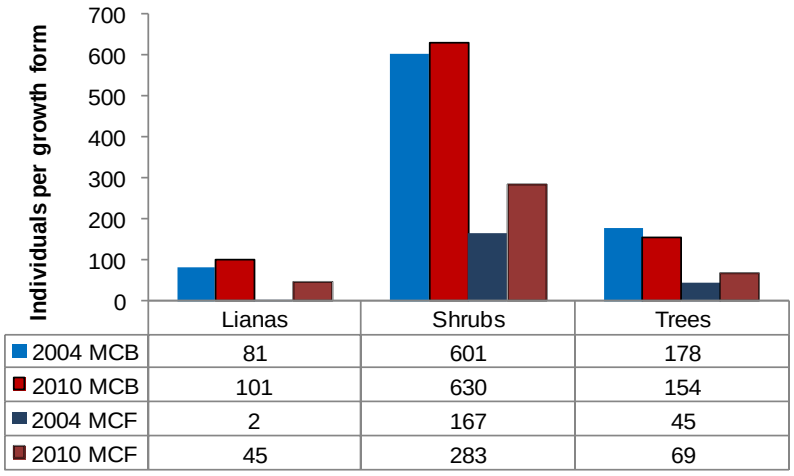


Figure 6.10: Changes in tree and shrub basal area (cm^2) per plot as a function of density across the different morphological zones between 2004 and 2010.



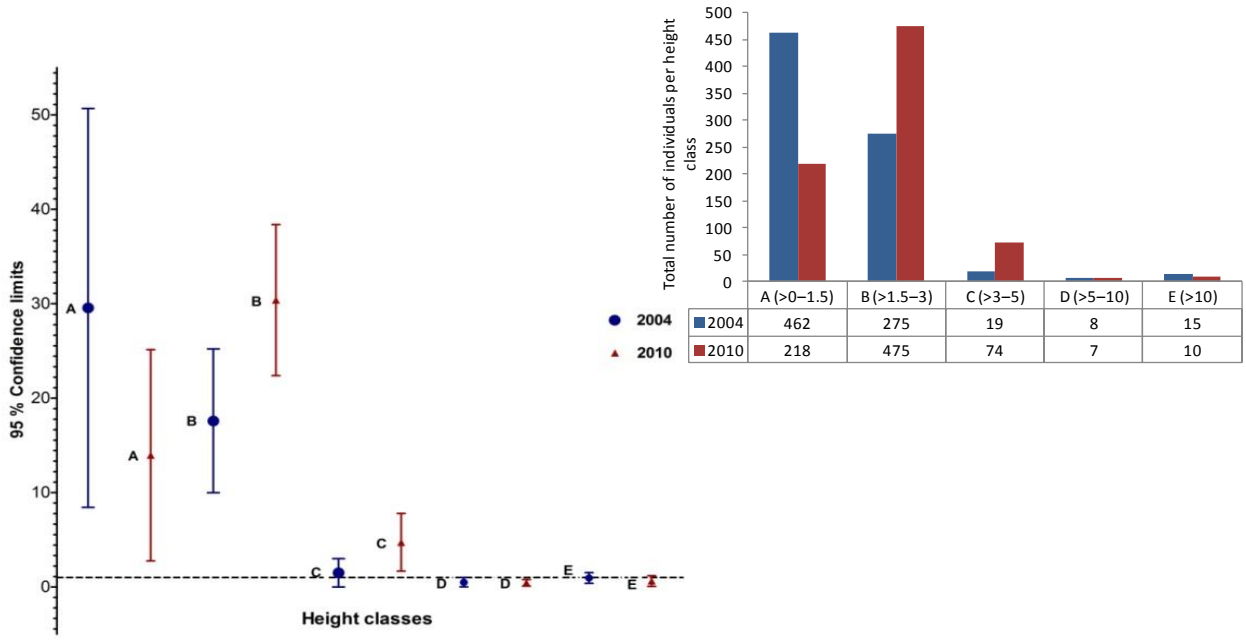
	Lianas	Shrubs	Trees
2004 MCB	81	601	178
2010 MCB	101	630	154
2004 MCF	2	167	45
2010 MCF	45	283	69

Figure 6.11: Temporal changes in abundance of selected growth forms on the MCB and MCF respectively.

Structural classes: Abundance of individuals per height classes

Changes in abundance of individuals per height class on the MCB

Most of the woody individuals on the MCB were between 0–3 m tall (Figure 6.12). There was an increase in individuals within the >1.5–3 m and >3–5 m height class but a decrease in individuals within the >0–1.5 m height class (Figure 6.12).

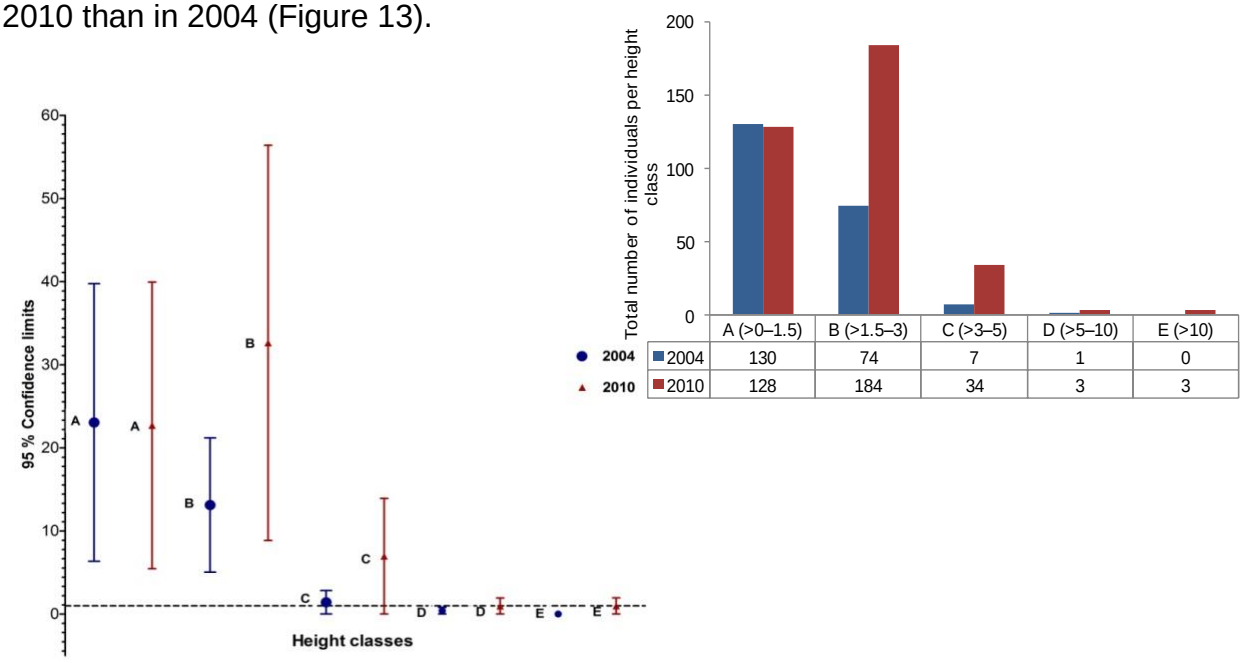


	A (>0–1.5)	B (>1.5–3)	C (>3–5)	D (>5–10)	E (>10)
2004	462	275	19	8	15
2010	218	475	74	7	10

Figure 6.12: Woody individual abundances recorded within each height class across the MCB.

Changes in abundance of individuals per height class on the MCF

Individuals increased in all height classes between 2004 and 2010 on the MCF, except in the >0–1.5 m height class, where only a slight decrease of 18 individuals were reported (Figure 6.13). As a result, the woody riparian vegetation was in general taller on the MCF in 2010 than in 2004 (Figure 13).



	A (>0–1.5)	B (>1.5–3)	C (>3–5)	D (>5–10)	E (>10)
2004	130	74	7	1	0
2010	128	184	34	3	3

Figure 6.13: Woody individual abundances recorded within each height class across the MCF.

Changes in abundance of individuals per height class for each growth form (i.e. trees, shrubs and lianas)

Trees

The most noteworthy changes in the tree stratum occurred in the lower height classes (i.e. >0–3 m). Although not significant, a decrease in individuals in the >0–1.5 m height class was reported, most specifically on the MCB. A substantial increase in individuals was however reported in the >1.5–3 m height class. It is therefore suggested that there was simply a shift between the two lower height classes as a result of tree growth in the lower classes between 2004 and 2010.

Decreases were reported mainly on the MCB in both the lowest and highest height classes. The decrease in the lowest height class has been explained, whereas the decrease in the

highest (i.e. >10 m) height class on the MCB could possibly be explained by a delayed impact of the flood.

Overall, most of the trees on the MCB and MCF were taller than 1.5 m but shorter than 10 m. As a result, the most noticeable increases between 2004 and 2010 on both the MCB and MCF occurred within the middle height classes (>1.5–10 m trees) (Table 6.1).

Shrubs

Since shrubs generally do not exceed heights of 10 m, it could be expected that the most considerable changes would occur in the >0–5 m height classes.

A considerable loss of individuals in the >0–1.5 m height class was noteworthy, especially on the MCB. Again, the loss of individuals in the lower classes could be linked to the significant increase in individuals in the >1.5–3 m class as a result of normal growth between 2004 and 2010.

Overall the shrubs on the MCB and MCF were mostly between 1.5–5 m tall. Therefore, the most noticeable height changes between 2004 and 2010 on both the MCB and MCF were recorded within the 1.5–3 m height classes (Table 6.1).

Lianas

Similar trends that were obtained in the tree height classes were obtained in the distribution of individuals in the different height classes for the lianas, although increases in the >1.5–3 m height class were all reported as statistically significant.

Lianas show similar size class patterns than trees, possibly due to their dependence on trees for stabilization. There was an increase in individuals in the 1.5–3 m class, but a decrease in the lowest (>0–1.5 m) and highest (>10 m) size classes individuals (Table 6.2). *Chaetachme aristata* was the tallest liana species recorded in 2004 and 2010.

Table 6.1: Breakdown of overall individuals per height class over the two sampling years for each growth form and per morphological zone (Macro Channel Floor (MCF) and Macro Channel Bank (MCB). If the CI values of 2004 and 2010 do not overlap, it is considered a significant difference and is highlighted in yellow; Increases are indicated in green and decreases in red. (b-a) is the formula used to calculate the difference in frequency. CI refers to the Confidence Interval.

	Height class		[a]2004	%	95% CI	[b]2010	%	95% CI	[(b - a)] Diff. in frequency
Trees	>0–1.5	Total	123	27.58	14.96 ; 40.20	75	16.82	36.01 ; 52.78	-48
		MCB	103	31.02	15.06 ; 46.99	53	15.96	0 ; 36.80	-50
		MCF	20	17.54	0 ; 36.83	22	19.30	12.13 ; 26.47	+2
	>1.5–3	Total	71	15.92	12.90 ; 18.94	105	23.54	34.52 ; 44.41	+34
		MCB	50	15.06	11.32 ; 18.80	73	21.99	14.50 ; 29.47	+23
		MCF	21	18.421	13.84 ; 22.99	32	28.07	13.07 ; 43.07	+11
	>3–5	Total	11	2.47	0 ; 5.74	24	5.38	0 ; 15.69	+13
		MCB	8	2.41	0 ; 6.62	15	4.52	0.09 ; 8.94	+7
		MCF	3	2.63	0 ; 6.83	9	7.89	2.08 ; 13.71	+6
	>5–10	Total	5	1.12	0 ; 2.28	9	2.02	0.67 ; 5.61	+4
		MCB	4	1.20	0 ; 2.87	6	1.81	0 ; 4.18	+2
		MCF	1	0.88	0 ; 3.37	3	2.63	0 ; 7.44	+2
	>10	Total	13	2.91	1.85 ; 3.98	10	2.24	3.15 ; 7.17	-3
		MCB	13	3.92	2.43 ; 5.40	7	2.11	0.90 ; 3.31	-6
		MCF	0	0	0 ; 0	3	2.63	0 ; 8.27	+3
Shrubs	>0–1.5	Total	469	27.90	13.26 ; 42.54	271	16.12	7.08 ; 25.16	-198
		MCB	359	29.16	6.60 ; 51.72	165	13.40	5.06 ; 21.75	-194
		MCF	110	24.44	8.90 ; 39.99	106	23.56	2.40 ; 44.71	-4
	>1.5–3	Total	278	16.54	8.36 ; 24.72	554	32.96	31.07 ; 34.84	+276
		MCB	225	18.28	8.76 ; 27.80	402	32.66	24.78 ; 40.54	+177
		MCF	53	11.78	2.88 ; 20.67	152	33.78	4.71 ; 62.85	+99
	>3–5	Total	15	0.89	0 ; 2.25	84	5.00	0.96 ; 9.03	+69
		MCB	11	0.89	0 ; 2.48	59	4.79	2.05 ; 7.54	+48
		MCF	4	0.89	0 ; 2.33	25	5.56	0 ; 14.04	+21
	>5–10	Total	4	0.24	0 ; 0.67	1	0.06	0 ; 0.25	-3
		MCB	4	0.32	0 ; 0.91	1	0.08	0 ; 0.32	-3
		MCF	0	0	0 ; 0	0	0	0 ; 0	0
	>10	Total	2	0.12	0 ; 0.49	3	0.18	0 ; 0.74	+1
		MCB	2	0.16	0 ; 0.64	3	0.24	0 ; 0.97	+1
		MCF	0	0	0 ; 0	0	0	0 ; 0	0
Lianas	>0–1.5	Total	60	26.20	12.66 ; 39.74	18	7.86	0 ; 16.24	-42
		MCB	58	31.87	12.38 ; 51.35	14	7.69	1.96 ; 13.43	-44
		MCF	2	4.26	0 ; 20.30	4	8.51	0 ; 28.84	+2
	>1.5–3	Total	18	7.86	0 ; 17.44	108	47.16	42.01 ; 52.31	+90
		MCB	18	9.89	0.88 ; 18.90	76	41.76	35.13 ; 48.39	+58
		MCF	0	0	0 ; 0.00	32	68.09	33.89 ; 100.00	+32
	>3–5	Total	1	0.44	0 ; 1.95	16	6.99	0 ; 15.01	+15
		MCB	1	0.55	0 ; 2.61	10	5.49	0 ; 11.82	+9
		MCF	0	0	0 ; 0	6	12.77	5.41 ; 20.12	+6
	>5–10	Total	0	0	0 ; 0	4	1.75	0 ; 8.65	+4
		MCB	0	0	0 ; 0	1	0.55	0 ; 2.79	+1
		MCF	0	0.00	0 ; 0	3	6.38	0 ; 29.96	+3
	>10	Total	4	1.75	0 ; 8.65	0	0	0 ; 0	-4
		MCB	4	2.20	0 ; 11.16	0	0	0 ; 0	-4
		MCF	0	0	0 ; 20.30	0	0	0 ; 0	0

Structural classes: Abundance of individuals per stem class

Changes in abundance of individuals per stem class on the MCB

A decrease in individuals in the lower stem classes (i.e. 1–3) were observed on the MCB between 2004 and 2010. However, statistical results revealed an increase in individuals in all stem-count classes >4 stems per individual (Figure 6.14). The majority of woody individuals recorded in 2010 were, however, still in the lower stem classes.

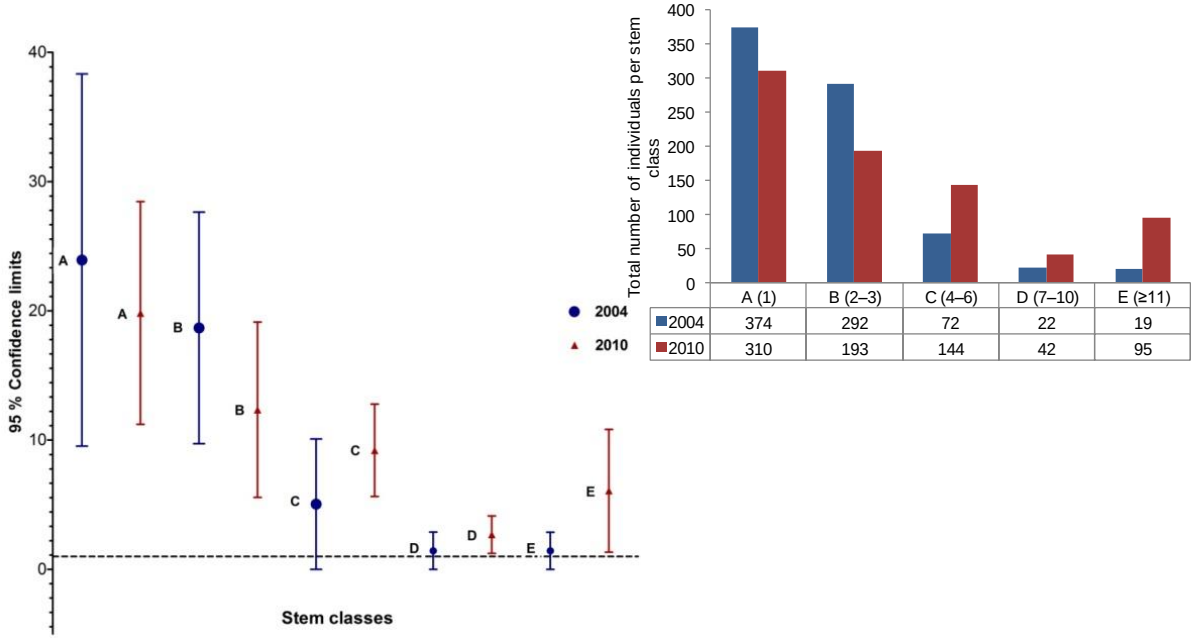


Figure 6.14: Woody individual abundances recorded within each stem class across the MCB.

Changes in abundance of individuals per stem class on the MCF

An increase in individuals on the MCF in most of the stem classes were revealed, although a slight decrease in individuals was reported in the 2–3 stem class. In both 2004 and 2010 most woody individuals on the MCF were 1–3 stemmed individuals (Figure 6.15). However, the woody individuals on the MCF were more evenly represented across the five stem classes in 2010 compared to 2004. Although most of the individuals recorded on the MCF occured within a multi-stemmed class, the highest increase of individuals recorded between 2004 and 2010 was within the single stemmed class with 68 individuals.

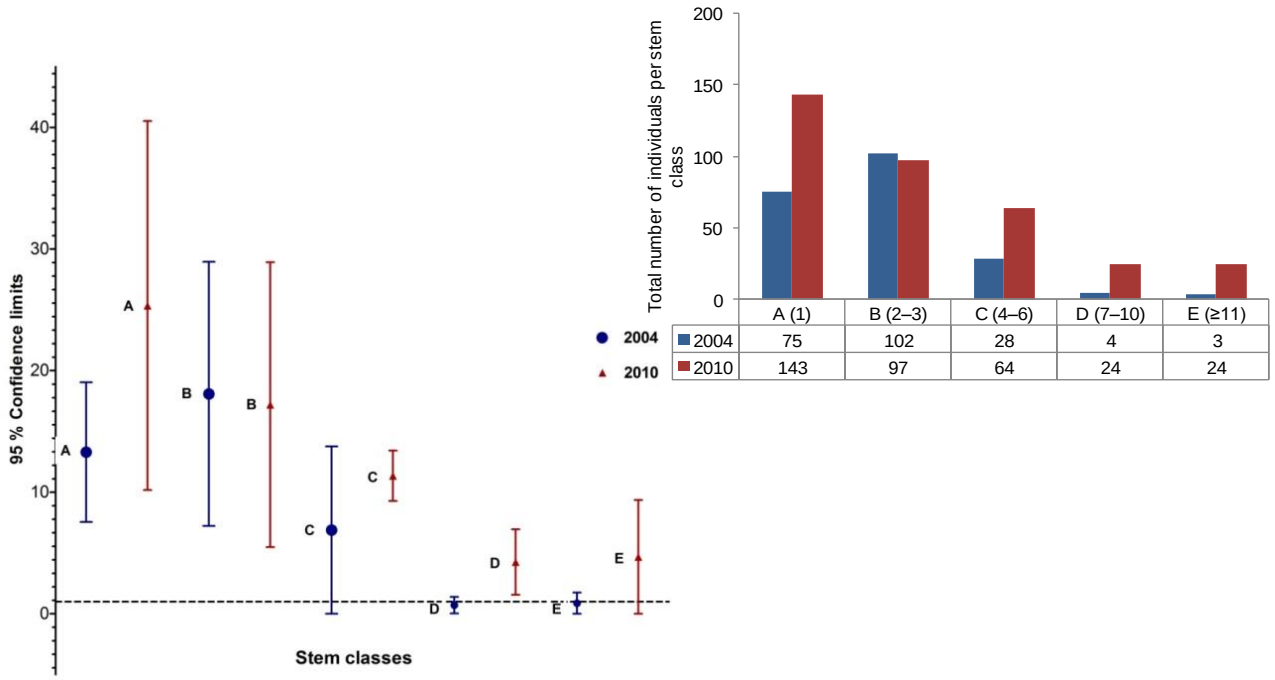


Figure 6.15: Woody individual abundance recorded within each stem class across the MCF.

Changes in height according to growth forms (i.e. trees, shrubs and lianas)

Trees

In both 2004 and 2010 most trees were recorded within the single-stem class and the least in the >11 stem class (Table 6.2).

The trees recorded on the MCB were mostly 1–6 stemmed individuals within 2004 and 2010 (Table 6.2). As expected, no trees were recorded within the ≥11 stem class in both 2004 and 2010 (Table 6.2). Single-stemmed trees were the most abundant on the MCB in 2004 and 2010, although the highest decrease in individuals (18) was reported for this class (Table 6.10).

Consistent with tree's growth form classification and comparing the 2010 dataset to the 2004 dataset, most tree individuals were represented in the single-stemmed class on both the MCB and MCF (Table 6.2). Although most trees were singled-stemmed, a substantial decrease in singled-stemmed individuals was evident on the MCB, whereas an increase was evident on the MCF.

Shrubs

On the MCB shrubs were distributed much wider across the five stem classes in 2010, compared to the distribution of shrubs in 2004 (Table 6.2). There was a considerable increase in the number of shrubs in the different multi-stemmed classes (i.e. 4–≥11 stems) and a decrease in the 1–3 stem classes, especially on the MCB.

The shrubs recorded on the MCF were much wider spread across the five stem classes in 2010, compared to 2004 (Table 6.2). As a result of the overall increase of shrubs on the MCF, there was an increase of individual shrubs across most of the stem classes. The 2–3 stem class was the only stem class which showed a decrease in individual shrubs between 2004 and 2010 with 6 individuals (Table 6.2). Despite higher numbers of single-stemmed individual shrubs counted in 2010, there was a significant increase in individuals in the 7–10 stem class between 2004 and 2010 on the MCF (Table 6.2).

Lianas

In 2004 and 2010 the single-stemmed class had the most individual lianas recorded, although this class experienced a slight decrease in individuals between the two sampling years (Table 6.2). There were no lianas recorded within both the 7–10 stem class and ≥11 stem class in 2004 (Table 6.2). Six years later both the 7–10 stem class and ≥11 stem class showed an increase of 4 and 12 individuals respectively. Therefore the 7–10 stem class had the least number of lianas recorded in 2010 (Table 6.2).

Most of the changes in the distribution of individual lianas across the different stem classes occurred on the MCB, although a significant increase in individuals in the lower stem classes (i.e. 1–3 stems) occurred on the MCF.

Table 6.2: Breakdown of individuals per stem class over the two sampling years for each growth form and per morphological zone (Macro Channel Floor (MCF) and Macro Channel Bank (MCB). If the CI values of 2004 and 2010 do not overlap, it is considered a significant difference and is highlighted in yellow; Increases are indicated in green; and decreases in red. (b-a) is the formula used to calculate the difference in frequency. CI refers to the Confidence Interval.

	Number of Stems (Stem Class)		[a]2004	%	95% CI	[b]2010	%	95% CI	[(b - a)]Diff. in frequency
Trees	1	Total	163	36.55	26.73 ; 46.35	167	37.44	18.57 ; 56.31	+4
		MCB	138	41.57	4.15 ; 41.57	120	36.14	5.80 ; 36.14	-18
		MCF	25	21.93	12.71 ; 31.15	47	41.23	11.70 ; 70.76	+22
	2–3	Total	46	10.31	4.36 ; 16.26	40	8.97	4.01 ; 13.92	-6
		MCB	33	9.94	2.22 ; 9.94	26	7.83	1.54 ; 7.83	-7
		MCF	13	11.40	4.60 ; 18.21	14	12.28	0 ; 33.76	+1
	4–6	Total	13	2.91	0 ; 7.82	13	2.91	0 ; 8.22	0
		MCB	6	1.81	0.85 ; 1.81	7	2.11	1.32 ; 2.11	+1
		MCF	7	6.14	0 ; 17.75	6	5.26	0 ; 14.22	-1
	7–10	Total	1	0.22	0 ; 7.82	2	0.45	0 ; 1.94	+1
		MCB	1	0.30	0.29 ; 0.30	1	0.30	0.30 ; 0.33	0
		MCF	0	0	0 ; 0	1	0.88	0 ; 3.58	+1
	≥11	Total	0	0	0 ; 0.93	1	0.22	0 ; 0.81	+1
		MCB	0	0	0 ; 0	0	0	0 ; 0	0
		MCF	0	0	0 ; 0	1	0.88	0 ; 3.37	+1
Shrubs	1	Total	286	17.01	6.58 ; 27.44	286	17.01	9.68 ; 24.34	0
		MCB	236	19.17	4.85 ; 33.49	190	15.43	8.05 ; 22.82	-46
		MCF	50	11.11	4.84 ; 17.38	96	21.33	10.23 ; 32.44	+46
	2–3	Total	348	20.70	16.36 ; 25.04	250	14.87	10.38 ; 19.36	-98
		MCB	259	21.04	12.67 ; 29.41	167	13.57	5.45 ; 21.68	-92
		MCF	89	19.78	7.83 ; 31.73	83	18.44	8.42 ; 28.47	-6
	4–6	Total	87	5.18	0 ; 11.58	195	11.60	8.78 ; 14.41	+108
		MCB	66	5.36	0 ; 11.53	137	11.13	6.74 ; 15.51	+71
		MCF	21	4.67	0 ; 12.80	58	12.89	9.60 ; 16.18	+37
	7–10	Total	25	1.49	0.05 ; 2.91	64	3.81	2.07 ; 5.54	+39
		MCB	21	1.71	0 ; 3.50	41	3.33	1.96 ; 4.71	+20
		MCF	4	0.89	0.04 ; 1.74	23	5.11	3.09 ; 7.13	+19
	≥11	Total	22	1.31	0 ; 3.14	118	7.02	1.32 ; 12.70	+96
		MCB	19	1.54	0 ; 3.68	95	7.72	1.62 ; 13.81	+76
		MCF	3	0.67	0 ; 2.31	23	5.11	0 ; 11.57	+20
Lianas	1	Total	58	25.33	15.51 ; 35.15	55	24.02	0 ; 53.74	-3
		MCB	56	30.77	10.56 ; 50.98	37	20.33	0 ; 44.54	-19
		MCF	2	4.26	0 ; 20.30	18	38.30	5.71 ; 70.89	+16
	2–3	Total	17	7.42	0 ; 17.67	47	20.52	15.72 ; 25.33	+30
		MCB	17	9.34	0 ; 19.36	30	16.48	7.46 ; 25.51	+13
		MCF	0	0.00	0 ; 0	17	36.17	14.46 ; 57.88	+17
	4–6	Total	8	3.49	0 ; 8.05	28	12.23	0 ; 25.59	+20
		MCB	8	4.40	0 ; 8.86	23	12.64	0 ; 27.59	+15
		MCF	0	0	0 ; 0	5	10.64	0 ; 25.30	+5
	7–10	Total	0	0	0 ; 0	4	1.75	0 ; 5.06	+4
		MCB	0	0	0 ; 0	3	1.65	0 ; 4.27	+3
		MCF	0	0	0 ; 1	1	2.13	0 ; 8.73	+1
	≥11	Total	0	0	0 ; 0	12	5.24	0 ; 11.87	+12
		MCB	0	0	0 ; 0	8	4.40	0 ; 9.77	+8
		MCF	0	0	0 ; 1	4	8.51	0 ; 28.59	+4

6.4. Discussion

6.4.1. *Temporal changes in abundance of woody individuals*

The overall density of woody individuals per hectare increased between 2004 and 2010 (Figure 6.3). However, shrubs were the most important contributor to the overall increase of individuals per hectare (Figure 6.5). Both the MCB and MCF were dominated by shrubs with the most shrub individuals recorded on the MCB. Although there was an increase in individual woodies recorded between 2004 and 2010 on the MCB, there was also a decrease in basal area (Figure 6.9). The decrease in basal area indicated a decrease in woody individuals with large basal areas on the MCB. This decline in woody individuals with large basal areas can be as a result of a delayed response (e.g. vegetation regression) to the 2000 flood by large trees (see section 6.4.2 for further discussion on the decrease of tall woody individuals).

The interaction between shrubs and trees play a vital role in the structure and composition of the riparian vegetation along the Sabie River in the KNP. The interaction and distribution of trees and shrubs are closely related through root competition, shading and plant litter (Monk & Gabrielson, 1985). Monk and Gabrielson (1985) reported that vegetation litter can change the composition and structure of plant communities. This may lead to shrubs being more dominant after large flood events due to their forceful vegetation growth form and regeneration strategies (Facelli & Pickett, 1991).

The woody vegetation within and around the riparian landscape are mostly characterised by deciduous species (Palgrave, 2005; Schmidt *et al.,* 2007). Combined with the annual deciduous leaf litter and the daily litter caused by browsing and animal movement, a thick mat of vegetation litter is a characteristic feature in some parts of the riparian corridor (Figure 6.16) (Monk & Gabrielson, 1985). Only species with large seeds, seedlings with a long hypocotyl (Figure 6.16) and species with vigorous vegetation growth patterns may have the ability to penetrate the thick litter mat (Tao *et al*., 1987; Molofsky & Augspurger, 1992; Facelli & Pickett, 1991; Monk & Gabrielson, 1985). Therefore, the leaf litter caused by shrubs (e.g. *Grewia* spp.) may alter and affect the structure and composition of riparian plant communities and further promoting the establishment of shrub species.

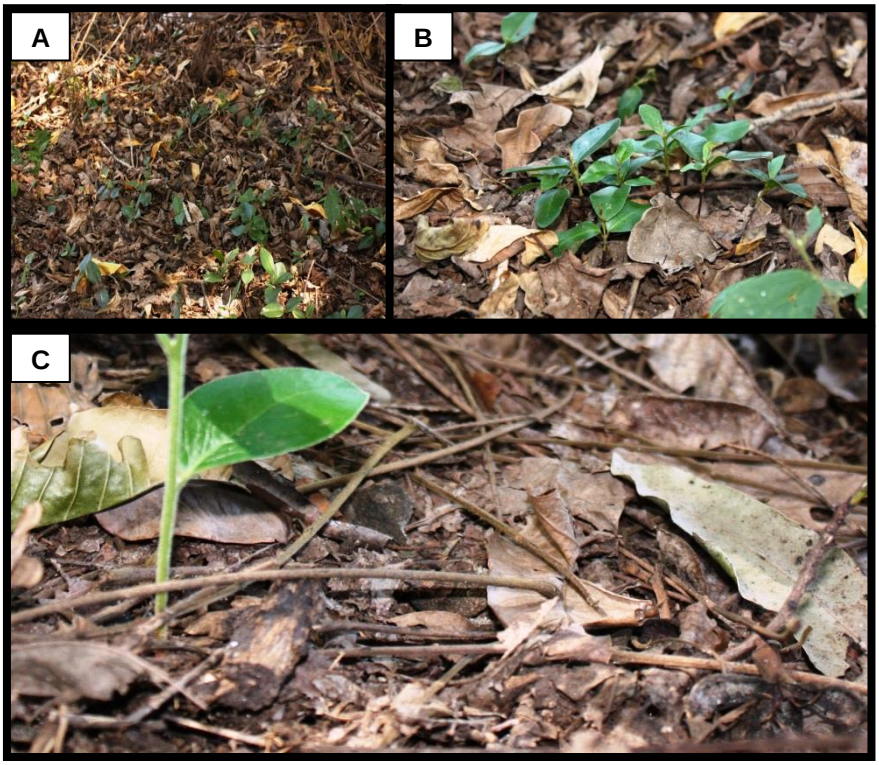


Figure 6.16: Leaf litter accumulation within the riparian landscape.

In general, the production of leaf litter is highest at the transition zone, between the MCB and the uplands (Shure & Gottschalk, 1985). The high leaf litter production on the MCB may be the reason for the decline in the total number of individual trees found on the MCB. The overall decline (Figure 6.6) in newly established individual woodies (>0–1.5 m) also supports this hypothesis.

From the results, it can be concluded that the decrease in individual trees on the MCB can be related to browsing activities by large herbivores. “Herbivory acts as a disturbance by reducing the biomass and canopy cover of specific plants and increasing spatial heterogeneity, thus enabling more species to co-exist” (Olff & Ritchie, 1998). Extensive browsing damage was recorded across the MCB (Figure 6.17) which has an effect on the riparian vegetation structure and composition. Certain tree species are browsed more heavily than others (e.g. *Philenoptera violacea*) which lead directly to a decrease in the individual numbers of that specific species, especially young established trees and juveniles. Many trees coppice or re-sprout (Figure 6.18) after or in response to structural

damage, which creates a riparian system that is denser due to an increase in multi-stemmed individuals.

Figure 6.17: Evidence of animal movement (A) and browsing activities (B and C).

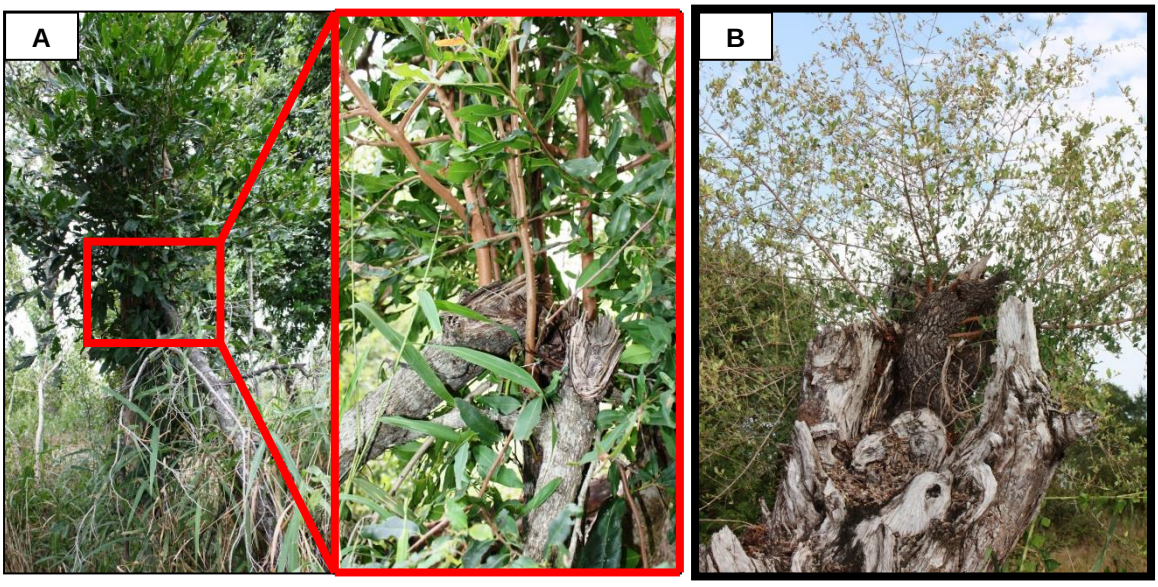


Figure 6.18: Re-sprouting (A) and coppicing (B) trees.

Although no quantitative data can support our field observations, the decrease in trees on the MCB, could be explained by the high herbaceous biomass, which was found in certain belt-transects within the field layer (Figure 6.19). There were also high-density populations of alien invasive species (e.g. *Lantana camara* and *Sesbania punicea*) across certain channel types (i.e. BA and PR) within the MCB. Due to competitive exclusion, high numbers of alien invasive species and high grass biomass, tree seedlings had less success in establishing along certain areas of the MCB. Alien plants cause numerous problems in agriculture, biodiversity conservation, fire and water management and rehabilitation following disturbance or clearing of vegetation (Milton, 2004).

The BA channel type, which is also one of the channel types with the most profound landscape change after the 2000 floods (Parsons *et al.,* 2006), could account for the high number of alien invasive plants and a decrease in trees due to vegetation regression.

Figure 6.19: Undergrowth on the MCB of belt-transect 2 (BA) dominated by grasses.

In general the woody vegetation recorded within this study was bushier in 2010 than in 2004. It was recorded that the 2–3 stem class was the only stem class in which individuals decreased in abundance between 2004 and 2010 (Figure 6.7). The highest increase in woody individuals was recorded within the 4–6 stem class and the ≥11 stem class (Figure 6.7). The increase of multi-stemmed individuals can be directly linked to the overall increase of shrubs between 2004 and 2010. The increase in multi-stemmed individuals may also be as a result of disturbances (e.g. flooding and browsing activities) stimulating re-sprouting or coppicing of woody vegetation (Figure 6.19).

6.4.2. *Temporal changes in abundance and structure of woody individuals on the MCF*

According to the literature the MCB is mostly recognized to be the high recruitment and regeneration zone within the macro channel. In some instances the MCF can also be a high recruitment and regeneration zone (Parsons *et al.,* 2006)

Four years after the 2000 flood, the MCB of the Sabie River was more densely covered by woody riparian vegetation, than the MCF (Parsons *et al.,* 2006). This difference in vegetation density could mainly be attributed to the loss of vegetation cover by the main channel flow in 2000 on the MCF (Parsons *et al.,* 2006). However, it appears that 10 years after the flood, the MCF was a higher recruitment and regeneration zone (Figure 6.11). It could be explained by more large open areas created by the flood, which resulted in the most significant structural changes to occur on the MCF, rather than the MCB 10 year post-flood (Table 6.1; Table 6.2).

There was an overall decrease in individuals in the >0–1.5 m height class which could be explained by the possible decrease in woody recruitment (Figure 6.6). This decrease in >0–1.5 m individuals may be because of browsing or other disturbances such as fire, intermediate flooding and drought. The decrease in individuals within the >0–1.5 m can furthermore be as a result of individual plant growth.

The overall increase in individual woodies (Figure 6.5) and basal density (Figure 6.9) on the MCF, suggests that the MCF provided better establishment opportunities or niches for riparian vegetation. LIDs create open niches within the river landscape (Turner & Dale, 1998) which gives aggressive growers (such as shrubs) the opportunity to increase in numbers.

6.4.3. *Changes in abundance of individuals per height class*

Vegetation regression is defined as a situation in which well-established vegetation progressively decline and die out completely (Harris *et al*., 1996). The slight decrease in tall trees and shrubs (>10 m) (Table 6.1) between 2004 and 2010, could be explained by vegetation regression or other environmental factors, such as termites, parasites and general aging.

Regression can occur through several factors (Harris *et al.,* 1996):

- change in soil pH,
- loss of proper nutrient cycles,
- over utilization by animals and humans,
- changes in soil structure,
- change in drainage basin, and
- inappropriate materials.

It is well documented that LIDs change the physical landscape template (physically and chemically) of riparian zones (Van Coller, 1997; Parsons *et al*., 2006). As a result of the physical landscape changes caused by LIDs, many micro habitats undergo a physical and chemical change which could explain vegetation regression patterns as seen in the results.

Asner and Levick (2012) recorded an average decrease in height within areas accessible to large herbivores, especially a significant decrease of maturing trees between 5–9 m in height. However, it was reported that within herbivore exclosures a substantial increase in the abundance of trees within the 2–4 m height classes was recorded (Asner & Levick, 2012). Although Asner and Levick (2012) quantified the impact of large herbivores (i.e. elephants) on woody vegetation over time using high-resolution light detection and ranging (LiDAR) at several herbivory exclosures in the KNP, similar patterns were revealed in this study. This study focuses mainly on the 2000 flood as a disturbance agent although the impacts of large herbivores on riparian vegetation have not been eliminated.

Parsons *et al*. (2007) reported that after the 2000 flood there were more individuals recorded within the 1–2 m height class, fewer individuals within the 3–4 m height class and the proportion of tall trees (>10 m) remained the same in 2004. Therefore, the increase in individuals within the 1.5–5 m height classes between 2004 and 2010, recorded in this study, may be as a result of individual plant growth since 2004.

6.5. Summary

The general woody riparian vegetation was taller but bushier ten years after the 2000 flood (Table 6.1 and Table 6.2). The decrease in short (below 1.5 m) woody individuals could be

as a result of competition between other large, well established woody individuals and high herbaceous biomass, or as a result of over-utilization. Parsons *et al*. (2007) reported that the riparian landscape of the Sabie River was dominated by shrubs prior to the 2000 flood and also suggested that shrubs will once again be the dominating growth form over time. The results presented here strongly support their hypothesis.

The decrease in trees on the MCB may be due to a regime of small frequent disturbances. “Whether large, infrequent disturbances are qualitatively different from small frequent disturbances remains an unresolved issue in ecology, in part, because of a paucity of long-term data on the effects of broad-scale disturbances” (Turner & Dale, 1998). Therefore, the ecological importance of small frequent disturbances must be taken into consideration in any environmental management plan. The frequency of small frequent disturbances should be mitigated and managed especially in a sensitive riparian ecosystem where over utilization of natural resources can lead to environmental degradation.

The riparian vegetation of the MCB and MCF does not respond the same way to a disturbance over time. Instead, a mosaic of vegetation structure was created by a shrub-dominated system.

The structure of riparian vegetation is directly linked to the composition of the riparian vegetation. Therefore, in an ecosystem where shrubs are the dominant species or growth form, the ecosystem will automatically be characterised by short and multi-stemmed woody individuals.

In conclusion, the hypothesis that woody vegetation structure has changed in the macro channel over an intermediate post-flood interval, is supported by the results. Most of the structural changes occurred within the MCF in terms of density and height, indicating that the MCF is more dynamic than the MCB.

Chapter 7: General Discussion and Recommendations

7.1 Introduction

The safeguarding of riparian vegetation is vital to the integrity of river ecosystems (Hancock *et al.*, 1996; Roth *et al*., 1996) and its conservation importance has repeatedly been emphasised (Naiman & De´camps, 1997; Gilvear *et al*., 2000). However, the safeguarding of riparian vegetation is complicated by the complex biotic and abiotic components which are present within a riparian ecosystem (Figure 2.3). Not all interactions are clear and direct (Barrow, 2006) and the importance of each environmental link or influential component within an ecosystem may vary from one micro habitat to the other (Gregory *et al*., 1991). Therefore a change to one environmental link or influential component within an ecosystem may alter the characteristics or environmental conditions of several micro habitats.

7.2 Summary of temporal and spatial vegetation changes

An overview of the results is presented in Table 7.1. There was an overall increase in most components of woody structure within the riparian vegetation along the Sabie River, KNP since the previous sampling occasion in 2004. These increases were mainly driven by a significant growth and establishment of woody individuals on the MCF (Table 7.1).

The MCB showed substantial decreases, which may be an indication of instability (Table 7.1). Firstly, the instability within the MCB may be as a result of heavy browsing (over utilization), drought conditions or a change in flow regimes caused by water extraction by agricultural activities outside the KNP. O'Connor (2010a) noted that the riparian forest of Mapungubwe National Park in South Africa was transformed to woodlands within 15 years because of several environmental factors (flooding, drought, large herbivore browsing activities, and water extraction). It was also found that the combination of a drought followed by a flood and creeper infestation caused most of the tree mortalities (O'Connor, 2010a).

Secondly, the decrease in species and individuals on the MCB may be as a result of MCF species which have established on the MCB after the 2000, dying back because of unfavorable conditions (Johnson, 2000). Henry and Amoros (1996) reported that after a flooding event “channel-floor species are often found on the banks after floods but gradually expand back onto the channel floor”.

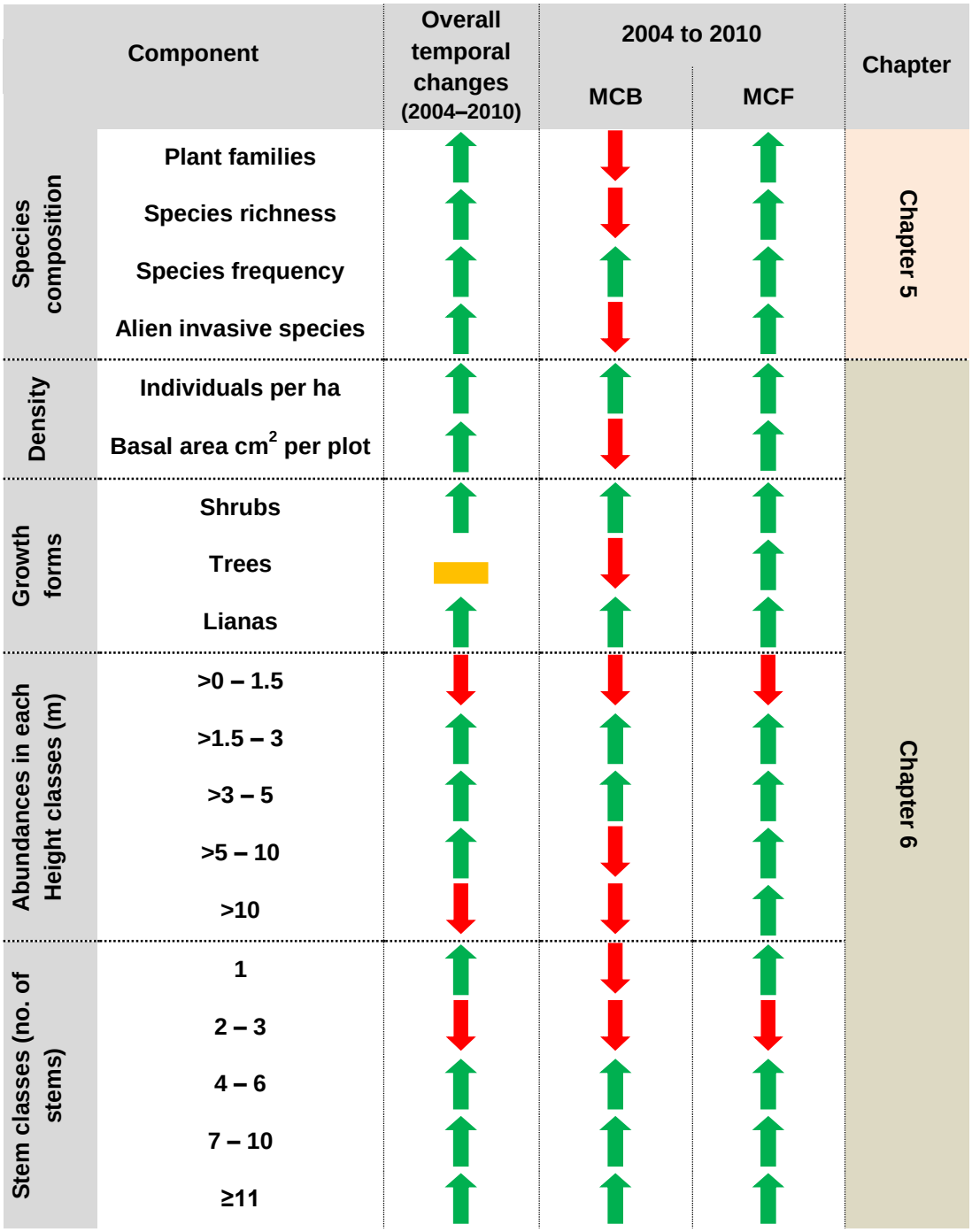
In contrast to the MCB, the MCF showed overall increases in species richness and individual woody density. Parsons *et al.* (2006) reported that in certain circumstances the MCF can be an area of high recruitment. This may be accentuated during periods where the water availability within the MCB has decreased and additional stress is placed on the vegetation by large herbivores. When semi-arid to arid riparian ecosystems experience reduced base flows for extended periods it could result in an encroachment of riparian species from the MCB towards the stream channel and onto in-stream channel bars (Zaimes, 2007). The overall decrease of woody individuals (<1.5 m) on the MCB could therefore indicate that the current environmental conditions are unfavourable for the establishment of new woody recruits.

It is recorded that the flood had a variable affect on riparian species density, although there was an overall loss of vegetated areas (Parsons *et al*., 2006). The results obtained in this study support the above findings reported by Parsons *et al*. (2006).

7.3 The effects of a large infrequent flood event on riparian vegetation structure and composition

Bendix and Hupp (2000) reported that floods promote the establishment of riparian vegetation through the dispersal of propagules, creating niches for colonization and depositing sediment rich in nutrients. Therefore, “increases in plant density after the 2000 flood were probably influenced by these factors” (Parsons *et al*., 2006). The overall increase in woody individuals and species richness recorded within this study supports this theory.

Table 7.1: Summary of most profound findings. A red arrow indicates a decrease, a green arrow indicates an increase, and an orange block indicates no change has taken place (blue fill indicates a significant change).



It is recorded that after certain flooding events, the Sabie River followed a sequence from non-vegetated to a vegetated state (Carter & Rogers, 1995; Parsons *et al*., 2006). However, Rountree *et al*. (2000) reported that after the 1996 flood, a reversal of this sequence occurred since some areas that were covered by reeds, shrubs and trees were replaced by open sand and water on the MCF. The results obtained in this study correlates with the findings from previous studies (i.e. Carter & Rogers, 1995; Parsons *et al*., 2006) as it is evident that the vegetation density increased between 2004 and 2010.

Species that share similar traits can react differently to disturbances and might have different regeneration strategies and requirements to survive disturbances (Grubb, 1977; Bond & Midgley, 2001). For example, between 2004 and 2010 shrubs species increased noteworthy compared to tree species. As a result, shrubs species were the most important contributor to the overall increase of individuals per hectare recorded within this study.

The interaction and distribution of trees and shrubs are closely related through root competition, shading and plant litter (Monk & Gabrielson, 1985). Monk and Gabrielson (1985) reported that vegetation litter can change the composition and structure of plant communities. This may lead to shrubs being more dominant after large flood events due to their forceful vegetation growth form and regeneration strategies (Facelli & Pickett, 1991). Therefore, the specific regeneration strategies and survival requirements have a direct influence on riparian vegetation structure and composition.

7.4 Riparian vegetation regeneration and sprouting

Species that share similar traits can react differently to disturbances and have different regeneration strategies and requirements to survive disturbances (Grubb, 1977; Bond & Midgley, 2001). The regeneration niche is used to explain the interactions and coexistence of species within the same ecosystem (Grubb, 1977). For example, a flood or fire can remove dense vegetation creating a bare landscape and gaps. As a result, the bare landscape would promote the establishment of light-demanding species (Bond & Midgley, 2001). Therefore, the interaction and dependence of vegetation structure and composition on regeneration and sprouting may be the most important driver in determining future vegetation structure and composition trends.

7.5 Management implications

Environmental management is a complex, broad and ever changing discipline (Barrow, 2006). Each environment has its own unique environmental issues (i.e. pollution, erosion, traditional practices, agriculture, and conservation) which forces environmental managers to tailor their management strategies to best suit that environment best. Environmental issues are given more coverage by the media and are supported by environmental legislations which place organizations, such as SANParks under severe scrutiny and pressure (Barrow, 2006). For this reason it is vital that SANParks has a clear understanding of the different environmental issues within and around all national parks (Barrow, 2006).

Natural ecosystems do not need human intervention to be self-sustaining, however in modern times the natural environment is placed under severe pressure resulting in the degradation of ecosystems. The Sabie River is being placed under severe pressure by industrial, agricultural and tourism activities. As a result certain human intervention may be needed after a large infrequent flood event (e.g. the removal of alien invasive species). Even so, human intervention should not become a surrogate for a specific component within an ecosystem.

Currently SANParks has a broad environmental strategy which is driven by research and finding the balance between human consumption and conservation. It is proposed that because of the complex nature of riparian landscapes, a specific management strategy should be developed for riparian ecosystems. If a riparian landscape management strategy already exists, it should be tailored for a specific river system and not be a generic management strategy for all river systems within national parks. The current adaptive management strategy adopted by SANParks provides the platform for developing and implementing a sustainable management strategy for riparian landscapes.

7.6 Recommendations and the way forward

Recommendations

- In early January 2012 the KNP experienced another flooding event. Although its magnitude was smaller than what was recorded for the 2000 flood, this intermediate flood may have caused several biophysical changes and/or disturbances along the Sabie River. The data presented in this dissertation do not include an assessment of the 2012 flood. A comparison of the pre- and post 2012-flood state of the vegetation would provide further insight into the dynamic response of riparian vegetation along a semi-arid riparian ecosystem.
- The classification of growth forms must be addressed and all future studies should use the same classification system. This will ensure that changes within vegetation structure can be linked to changes in frequency of certain growth forms.
- Specific research sites within river landscapes should be identified and used by research groups from different disciplines. This will provide the opportunity to identify environmental factors which play a vital role in maintaining the integrity of riparian ecosystems.
- All 24 belt-transect established by the Kruger Rivers Post-Flood Research Program (KRPFRP) in collaboration with the Centre for Water in the Environment (University of the Witwatersrand) should be re-sampled. The re-sampling of all 24 belt-transects will provide valuable insight into changes which have occurred over time within the riparian landscape.
- The interaction between the herbaceous and woody components of the riparian zone should be identified and described.

The way forward

The results presented in this study are merely explaining a fragment of the data which were sampled in 2010. Parsons *et al*. (2007) reported that a substantial change in woody plant demographics occurred after the flood. Once further data analyses have been completed, additional patterns and change in the woody plant demographics will be identified. In addition, change in species frequency and richness will be further investigated (e.g. investigate correlation between palatability and reduction of species).

The regeneration data collected during 2010 has already been analysed. Preliminary results indicate that there is an increase of 584 woody recruits on the MCB which is more than twice the increase of recruits on the MCF (increased with 295 recruits). This indicates that although the MCB has less established woody individuals than the MCF, the MCB can be seen as a high recruitment area. This also supports the findings of Parsons *et al*. (2006) in which it was reported that the highest number of woody recruits occurs on the MCB.

According to Burt *et al*. (2008) the ideal long-term monitoring study should not be shorter than 20–30 years due to the complexity of natural systems and how these complex systems react or respond to large disturbance over time. Therefore, this study, in collaboration with the KRPFRP, forms the foundation for a long-term monitoring study. The knowledge gained through this long-term monitoring study will provide better insight into riparian ecosystem resilience to withstand a large, infrequent flood. Furthermore, this knowledge should be incorporated into future management strategies to ensure that well informed decisions are made.

Chapter 8: Conclusion

8.1 Introduction

Understanding and describing the sequence of events which follow after a LID within a riparian landscape, is considered as extremely relevant to conservation and management. This study highlights the complexity of riparian ecosystems and to what extent a LID could impact on riparian vegetation structure and composition over a relatively short time interval. Apart from recovering from an extreme natural event, additional impacts of water extraction and over utilization from large herbivores (e.g. elephants) and agricultural activities could further affect the characteristics (e.g. composition and structure) of riparian vegetation, although these effects will only be addressed in future studies.

After the study by Parsons *et al*. (2006), certain issues were raised concerning long-term responses of riparian vegetation to an extreme flood. This study aimed at addressing some of these factors which may influence long-term responses to the flood:

- Biotic and abiotic legacies (e.g. geomorphology, riparian vegetation density and location) may alter the physical template and successional dynamics of riparian vegetation independently or dependently from each other.
- Riparian ecosystems, with similar abiotic characteristics, may respond differently to the same LID as a result of variability within the residual mosaic of biotic and abiotic landscape states (e.g. the effects riparian vegetation has on bank stability).
- Alterations to key drivers of vegetation change have occurred over the last few decades. These alterations are as a result of change within the hydrological regime and sediment transport dynamics of the Sabie River, through catchment landuse and management practices (Moon *et al*., 1997). In addition the alterations are driven by an increase of alien invasive vegetation (Foxcroft, *et al*., 2003), herbivore densities and global climate change.

Although this study only focused on temporal riparian vegetation change, the factors described by Parsons *et al*. (2006) are used to interpret patterns identified through statistical analyses. The main aim of this study was to assess the response of riparian

vegetation to a large, infrequent flood event along a semi-arid riparian ecosystem at an intermediate temporal scale (i.e. 2004 – 2010).

8.2 Temporal and spatial changes in woody species composition – Chapter 5

H1: Woody species composition and richness of the macro channel remained constant over an intermediate post-flood interval (2004 – 2010).

Results presented in this chapter support the hypothesis that the woody species composition and richness of the macro channel remained constant over an intermediate post-flood interval (2004 – 2010). However, a shift in riparian vegetation species frequency along a temporal gradient was observed. Parsons *et al.* (2006) reported that "in the Sabie River, the pre-flood elevation gradient of vegetation community distribution identified by Van Coller *et al*. (1997) was strongly maintained after the flood. However, the flood changed the location of many individual species in relation to their pre-flood position within the channel, which has implications for vegetation succession". The shift in species frequencies could therefore be explained by the relocation of certain species.

The riparian vegetation along the Sabie River was dominated by shrub species in 2004, which proved to be even greater in 2010 (i.e. species richness and frequency). Even with the increase in shrub species and individuals, the woody species composition has not changed significantly between 2004 and 2010.

H1.1: Woody species composition and richness of the macro channel floor (MCF) changed over an intermediate post-flood interval (2004 – 2010).

The results presented in this chapter support the sub-hypothesis that woody species composition and richness of the MCF changed over an intermediate post-flood interval (2004 – 2010). The spatial distribution of plots on an ordination-type scatter plot produced after the application of NMDS, indicates a clustering of 2010 MCF plots. This clustering indicates a possible shift in species composition between 2004 and 2010. Furthermore, the gamma diversity increased substantially on the MCF.

H1.2: Woody species composition and richness of the macro channel bank (MCB) remained constant over an intermediate post-flood interval (2004 – 2010).

The results presented in this chapter support the sub-hypothesis that woody species composition and richness of the MCB remained constant over an intermediate post-flood interval (2004 – 2010). The spatial distribution of plots on an ordination-type scatter plot produced after the application of NMDS, indicates a clustering of all MCB plots (2004 and 2010). This clustering indicates that the species composition of the MCB has remained constant between 2004 and 2010.

8.3 Temporal and spatial changes in woody structure – Chapter 6

H2: Woody vegetation structure changed in the macro channel over an intermediate post-flood interval (2004 – 2010).

The results presented in this chapter support the hypothesis that woody vegetation structure changed in the macro channel over an intermediate post-flood interval (2004 – 2010). The general woody riparian vegetation was taller but bushier ten years after the 2000 flood. Parsons *et al*. (2007) reported that the average post-flood vegetation is shorter and bushier compared to pre-flood vegetation.

The overall density of woody individuals per hectare increased between 2004 and 2010. The increase in density is mostly as a result of high increases in shrub individuals.

H2.1: Changes in woody vegetation structure occurred on the MCF over an intermediate post-flood interval (2004 – 2010) in terms of density and height.

The results presented in this chapter support the sub-hypothesis that changes in woody vegetation structure occurred on the MCF over an intermediate post-flood interval (2004 – 2010) in terms of density and height. Most of the structural changes occurred within the MCF in terms of density and height which indicates the dynamic nature of the MCF. Four years after the 2000 flood, the MCB was more densely covered by woody riparian vegetation, than the MCF (Parsons *et al.,* 2006). This difference in vegetation density could mainly be attributed to the loss of vegetation cover by the main channel flow in 2000 on the

MCF (Parsons *et al.,* 2006). However, it appears that 10 years after the flood, the MCF was a higher recruitment and regeneration zone (see Chapter 6, Figure 6.11).

The overall increase in individual woodies and basal density on the MCF, suggests that the MCF provided better establishment opportunities or niches for riparian vegetation.

H2.2: Changes in woody vegetation structure occurred on the MCB over an intermediate post-flood interval (2004 – 2010) in terms of density and height.

The results presented in this chapter support the sub-hypothesis that changes in woody vegetation occurred on the MCB over an intermediate post-flood interval (2004 – 2010) in terms of density and height. Both the MCB and MCF were dominated by shrubs with the most shrub individuals recorded on the MCB. Although there was an increase in individual woodies recorded between 2004 and 2010 on the MCB, there was also a decrease in basal area.

The decrease in trees on the MCB may be due to a regime of small frequent disturbances (e.g. browsing activities of elephants). “Whether large, infrequent disturbances are qualitatively different from small frequent disturbances remains an unresolved issue in ecology, in part, because of a paucity of long-term data on the effects of broad-scale disturbances” (Turner & Dale, 1998).

In conclusion, even at an intermediate post-flood interval (i.e. 2004 – 2010), certain significant structural and compositional changes within the riparian vegetation have been revealed along the Sabie River, KNP. This supports the theory that riparian ecosystems are dynamic in nature, and should be monitored regularly to identify and understand ecological trends within the broader riparian landscape.

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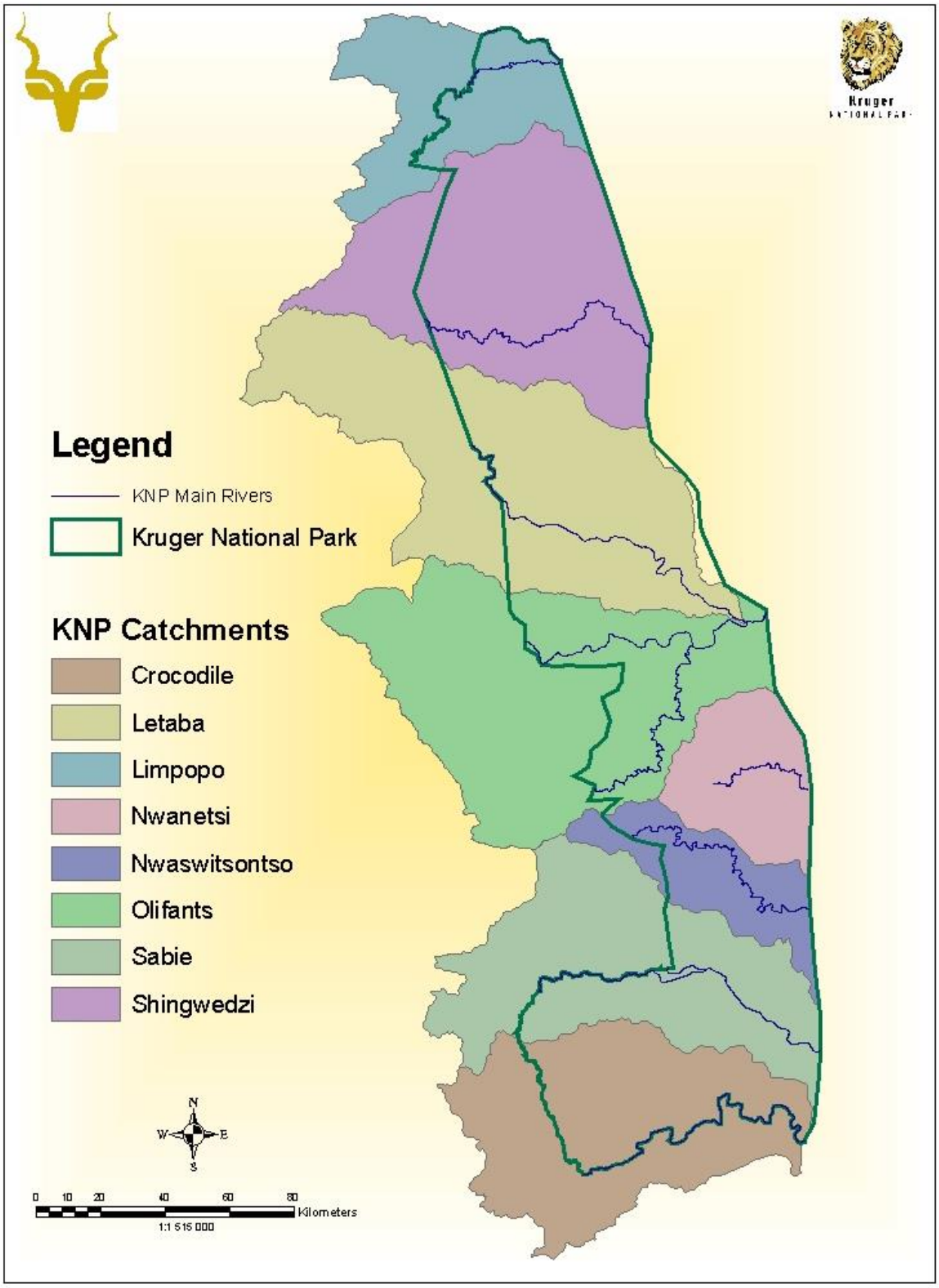
Appendices

Appendix A: Distribution map of the eight catchments within the KNP.

Appendix A: Catchments of the Kruger National Park (Adapted from SANParks, GIS laboratory, 2009a).



Appendix B: Summary of historical projects used for reference purposes

Appendix B: Summary of historical projects used for reference purposes.

Author/s	Title	Study Question and main objectives	Sampling	Analyses
*Van Coller *et al*., 2000	Riparian vegetation-environment relationships: complimentarily of gradients versus patch hierarchy approaches	The main objective of this paper is to use "traditional ordination techniques to simultaneously describe vegetation patterns through environmental gradients and patchy mosaics" (at multiple spatial and temporal scales), and in so doing, "enhance the overall understanding of vegetation pattern and possible underlying processes. This approach is carried out on a riparian system in a semi-arid region of South Africa".	• ***Belt transects, perpendicular to the river***, taken from the top of one macro-channel bank to the top of the other macro-channel bank (***the full extent of flood levels***), were used to ***sample the vegetation*** across the river at eleven localities. • All ***woody individuals*** with a stem ***diameter 3 cm (regarded as established individuals***), as well as the reed species *Phragmites mauritianus* were sampled. • Each transect was divided into ***equal sized contiguous plots.*** • A transect ***width of 20 m***	• ***Ordination analyses*** were used to analysed the species matrix (258 plots and 113 species) with the ***four separate environmental data*** sets representing the dominant gradients and the geomorphic hierarchy at the three different scales. • ***Each environmental data set was analysed separately*** (patterns and variation of each gradient, hierarchical level & correlation between variables of the different data sets could be avoided and pattern could be detected at

Author/s	Title	Study Question and main objectives	Sampling	Analyses
			was used. • ***Contiguous plots on each transect were divided every 15 m.*** • The ***basal stem diameters*** of each woody individual (≥3 cm) was measured in each plot. • ***sub-sampling was adopted*** to sample the reeds (percentage basal cover of reeds was estimated for each plot) A subsample of nine smaller quadrates of ***30 cm by 30 cm was then randomly placed*** amongst the reeds in the plot.	different spatial scales. • ***Unconstrained and constrained ordinations*** were used (relate vegetation to four environmental sets). • ***Indirect gradient – floristic data.*** • ***Constraint ordination – linear combinations of environmental variables.*** • CANOCO ***– CA*** most appropriate & ***CCA*** for relating vegetation distribution to the environment. • CCA first axes tested with ***Monte Carlo restricted permutation test*** (for transects).

Author/s	Title	Study Question and main objectives	Sampling	Analyses
*Parsons *et al.*, 2006	The biotic & abiotic legacy of a large infrequent flood disturbance in the Sabie river, SA.	The aim of the study was to "determine the biotic and abiotic legacy of the 2000 flood." Post-flood legacies are quantified against pre-flood-data, by which they evaluated the effects of the flood on the river template (in relation to pre-flood spatial character and dynamism).	• Each transect was divided into ***contiguous plots (15x20m)*** and all woody species with a ***basal diameter ≥ 3cm*** were identified and counted within each plot.	• Classification ordination. • ***Log transformed vegetation density*** were classified using the ***flexible-UPGMA fusion strategy***, following association using the ***Bray & Curtis similarity measure.***
*Foxcroft *et al*., 2008	Patterns of alien plant distribution in a river landscape following an extreme flood.	"This study examines the distribution of alien plants in relation to patchiness of the Sabie River landscape following the 2000 floods." The study is aimed at developing a "understanding of the role of barriers to invasive plants in the invasion	• ***Twelve sampling sites*** were stratified across zones and channel types. • Woody riparian vegetation was sampled at each site (June – July) in ***30x5m*** plots running ***contiguously along the transects***	• ***One-way ANOVA*** – examine difference in density and species richness. • ***Regression tree models*** used to examine the influence of patches on individual alien species.

Author/s	Title	Study Question and main objectives	Sampling	Analyses
		process."	***placed across*** the river (perpendicularly). • Herbaceous was sampled in ***5x5m plots, placed every 20m.*** • GIS and real time differential GPS was used to mark accurate plot boundaries. • There are 548 woody plots and 156 herbaceous plots.	• Chose 12 species. • Tree-based models provide an alternative to linear and additive logistic models for regression analysis. • ***S-Plus 200 Professional Release 3*** was used to fit and examine the regression trees.
*Damasceno *et al*., 2005	Structure, distribution of species and inundation in a riparian forest of Rio Paraguai, Pantanal, Brazil.	The aim of this study was to describe the tree community structure of the Rio Paraguai riparian forest and to investigate the relationships of structure between the topographic distribution of species and the timing of	• ***108 contiguous 10 x 10m plots*** was systematically established to sample all locations of the riverbank. • Plots were placed in ***blocks spaced at 1 or 2m intervals.***	• To ***verify the horizontal distribution of species***, a ***classification and ordination of the plots according to species groups was performed***.

Author/s	Title	Study Question and main objectives	Sampling	Analyses
		floods.	• All individuals with ***stems or at least one branch of 15 cm or more of girth at breast height (1.3m above the ground level)*** were sampled, including palms. • The ***circumferences*** of all branches in individuals that ramified ***below 1.3m were noted.*** • The ***basal areas were calculated separately***, and the sum of these measures was considered as one individual (For ***density calculations***, each individual was considered as one,	• ***Classify plots*** – a matrix of density of stems per species by plot was used. • Plots were classified using the ***Bray Curtis distance***, clustered using ***Ward's method***, and ordered using the ***principal coordinate analysis (PCO)*** ordination method with correction for negative eigenvalues. • Analyses were done with ***FITOPAC, version 1.0 and DistPCoA***.

Author/s	Title	Study Question and main objectives	Sampling	Analyses
			independent of its number of branches.). • Tree heights – measuring pole.	
*Cowell *et al*., 2009	Vegetation development in a modified Riparian environment: Human imprints on an Allegheny River ilderness.	The aim of the study was to use "vegetation dynamics as an indicator to how dams affect the disturbance regime of riparian zone" in a deciduous forest. Furthermore the "study identifies the landscape patches present on the site to determine the disturbance- related successional pathways operating in them, the life-history characteristics they favor, and the resultant implications for species composition." The study was completed in the	• ***Seven 20-m-wide transects*** (spaced 75 m apart). • Each ***transect was subdivided into contiguous 20 X 20 m quadrats***, where in all ***woody stems ≥ 1 cm diameter at breast height (dbh)*** were identified and measured and ***herbaceous species presence recorded***.	• ***Species importance values*** within each of the ***73 quadrats were calculated by averaging*** the ***relative density*** and ***relative dominance of all stems***. These values were used to ***generate an ordination of sites*** (quadrats) and species by ***canonical corre-spondence analysis (CCA)*** within the PC-ORD

Author/s	Title	Study Question and main objectives	Sampling	Analyses
		Allegheny River of northwestern Pennsylvania.		soft- ware package.
Götze *et al*., 2003	Analysis of the riparian vegetation (Ia land type) of proposed Vhembe-Dongola National Park, Limpopo Province, South Africa.	"The aim of this study is to identify, classify and describe the plant communities present" in the Vhembe-Dongola National Park, Limpopo Province, South Africa. The study is focused on several riparian zones within the park. These riparian zones are degraded and in need of innovative management. This study is part of a bigger project which focuses on the vegetation and land types of the	• ***Braun-Blanquet*** method was used (70 releves). • ***Trees are classified*** as ***rooted, woody, self-supporting, multi-stemmed*** or ***singled-stemmed plants more than 2 m high.***	• All data imported into the database ***TURBOVEG.*** • Numerical classification technique ***TWINSPAN*** was used. • Subsequently ***Braun-Blanquet*** procedures were used to refine the data using a visual editor ***MEGATAB***. • An ***ordination algorithm, DECORANA*** was

Author/s	Title	Study Question and main objectives	Sampling	Analyses
		Vhembe-Dongola National Park.		applied to the ***floristic data*** in order to illustrate floristic relationships between plant communities and to detect possible habitat gradients and/or disturbance gradients associated with vegetation gradients.

**Articles were used extensively as guidelines for developing the projects data sampling methods.*

Appendix C: Filed forms used for data sampling.

Appendix C: Field forms used for data sampling (Adapted from KRPFRP, 2010?).

Channel type _____ Transect No. _____ Date _____ Page _____ Comments _____

GIS No.	Plot no.	Species	Protect-ion	Substrate	Debris assoc.	Reed assoc.	Damage	Response	Form of resprouting	Height (m)	Basal diameter(s) (cm)	No. stems
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			
			P UnP	Bed. Cobb Sand Fines			No damage PshOvr MSBkn CrwLos BrkStrp	Resprouting Not resprouting Dead	StemBase BurMS UnBurMS BurBch UnBurBch			

Appendix D:

Distribution of species per plot within the dendrogram constructed by Ward's method in a Bray Curtis distance matrix of riparian plant communities.

Appendix C: Distribution of species per plot within the dendrogram constructed by Ward's method in a Bray Curtis distance matrix of riparian plant communities

	Cluster	Year	Transect	Plot	MCB / MCF	Plot_group	*Acacia schweinfurthii*	*Acacia grandicornuta*	*Acacia nigrescens*	*Acacia robusta*	*Acacia welwitschii*	*Bauhinia galpinii*	*Berchemia zeyheri*	*Breonadia salicina*	*Bridelia cathartica*	*Bridelia micrantha*	*Caesalpinia decapetala*	*Capparis fascicularis*	*Carissa edulis*	*Chaetachme aristata*	*Chromolaena ordata*	*Clerodendrum glabrum*	*Cocculus hirsutus*	*Combretum hereroense*	*Combretum imberbe*	*Combretum microphyllum*	*Combretum molle*	*Combretum mossambicense*	*Commiphora neglecta*	*Combretum zeyheri*
MCB	F -1 / MCB	2004	2	1	B	W2B1	1	0	0	1	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		2004	2	2	B	W2B2	1	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
		2010	2	3	B	N2B3	1	0	0	0	0	1	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		2004	2	2	B	N2B2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		2010	2	1	B	N2B1	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
		2004	2	3	B	W2B3	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
		2010	2	5	B	N2B5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	4	B	N2B4	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		2004	2	4	B	W2B4	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	5	B	W2B5	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	6	F	N2F6	1	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	7	F	N2F7	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	1	B	W3B1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	4	B	W3B4	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		2004	3	2	B	W3B2	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		2010	3	1	B	N3B1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
		2010	3	2	B	N3B2	1	0	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1
		2004	3	3	B	W3B3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		2010	3	3	B	N3B3	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0
		2004	3	5	F	W3F5	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1
		2010	3	4	B	N3B4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	3	5	F	N3F5	1	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1
		2004	5	1	B	W5B1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	1	B	N5B1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
		2004	5	3	B	W5B3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	5	B	W5B5	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	2	B	N5B2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	3	B	N5B3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	4	B	W5B4	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	5	B	N5B5	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	4	B	N5B4	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	7	B	W5B7	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	8	F	N5F8	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	7	B	N5B7	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	6	B	N5B6	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	9	F	N5F9	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
		2004	5	2	B	W5B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	6	B	W5B6	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F - 2 / MCF seasonal	2004	3	6	F	W3F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	17	F	N3F17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	18	F	W3F18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	12	F	W5F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	7	F	W3F7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	7	F	N3F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	6	F	N3F6	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	16	F	N3F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	18	F	N3F18	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	8	F	W4F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	8	F	W5F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	9	F	W5F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	10	F	W5F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	11	F	W5F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	10	F	N5F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	11	F	N5F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F - 3 / MCF seasonal	2004	4	1	F	W4B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		2010	4	1	B	N4B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		2010	4	2	B	N4B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
		2004	4	2	B	W4B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0
		2010	4	3	B	N4B3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0
		2004	4	3	B	W4B3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
		2004	4	4	B	W4B4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
		2010	4	4	B	N4B4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
		2010	4	5	B	N4F5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
		2004	4	5	F	W4F5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
		2004	4	6	F	W4F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
		2010	4	6	F	N4F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		2010	4	8	F	N4F8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		2004	4	7	F	W4F7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
		2010	4	7	F	N4F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MCF	F - 4 / MCF active	2004	2	6	F	W2F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		2004	3	15	F	W3F15	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	10	F	N4F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	12	F	N4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	14	F	W3F14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	14	F	N3F14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	13	F	N3F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	15	F	N3F15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	8	F	N2F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	9	F	N2F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	12	F	N2F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	10	F	N2F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	11	F	N2F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	13	F	N2F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	26	F	N3F26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	7	F	W2F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	8	F	W2F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	9	F	W2F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	10	F	W2F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	11	F	W2F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	12	F	W2F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	13	F	W2F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	12	F	W3F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	16	F	W3F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	20	F	W3F20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	21	F	W3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	22	F	W3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	23	F	W3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	24	F	W3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	25	F	W3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	26	F	W3F26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	9	F	W4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	10	F	W4F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	11	F	W4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	12	F	W4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	9	F	N3F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	10	F	N3F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	19	F	N3F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	21	F	N3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	22	F	N3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	23	F	N3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	24	F	N3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	25	F	N3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	9	F	N4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	11	F	N4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	12	F	N5F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	9	F	W3F9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	12	F	N3F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	20	F	N3F20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	10	F	W3F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	19	F	W3F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	17	F	W3F17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	8	F	W3F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	11	F	W3F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	13	F	W3F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	8	F	N3F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	11	F	N3F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Cluster	Year	Transect	Plot	MCB / MCF	Plot_group	*Cordia ovalis*	*Crotalaria capensis*	*Dalbergia armata*	*Dichrostachys cinerea*	*Diospyros mespiliformis*	*Diospyros whyteana*	*Duranta erecta*	*Ehretia amoena*	*Ehretia obtusifolia*	*Elaeodendron transvaalense*	*Euclea divinorum*	*Euclea natalensis*	*Euclea schimperi*	*Eugenia mossambicensis*	*Ficus capreifolia*	*Fluegga virosa*	*Gardenia volkensii*	*Grewia bicolor*	*Grewia flava*	*Grewia flavescens*	*Grewia hexamita*	*Grewia occidentalis*
MCB	F- 4 / MCF active	2004	2	1	B	W2B1	0	0	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
		2004	2	2	B	W2B2	0	0	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1
		2010	2	3	B	N2B3	0	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0
		2010	2	2	B	N2B2	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1
		2010	2	1	B	N2B1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
		2004	2	3	B	W2B3	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
		2010	2	5	B	N2B5	0	1	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
		2010	2	4	B	N2B4	0	1	1	1	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0
		2004	2	4	B	W2B4	0	0	1	0	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
		2004	2	5	B	W2B5	0	0	1	0	1	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
		2010	2	6	F	N2F6	0	0	1	0	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	1	0	0
		2010	2	7	F	N2F7	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
		2004	3	1	B	W3B1	0	0	1	1	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
		2004	3	4	B	W3B4	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	1	0	0
		2004	3	2	B	W3B2	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	1	0
		2010	3	1	B	N3B1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0
		2010	3	2	B	N3B2	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0
		2004	3	3	B	W3B3	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0
		2010	3	3	B	N3B3	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0
		2004	3	5	F	W3F5	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0
		2010	3	4	B	N3B4	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0
		2010	3	5	F	N3F5	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	1	0
		2004	5	1	B	W5B1	1	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1
		2010	5	1	B	N5B1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0
		2004	5	3	B	W5B3	1	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
		2004	5	5	B	W5B5	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1
		2010	5	2	B	N5B2	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	0	0
		2010	5	3	B	N5B3	1	0	0	1	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	0	0
		2004	5	4	B	W5B4	1	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
		2010	5	5	B	N5B5	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0
		2010	5	4	B	N5B4	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0
		2004	5	7	B	W5B7	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		2010	5	8	F	N5F8	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
		2010	5	7	B	N5B7	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		2010	5	6	B	N5B6	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
		2010	5	9	F	N5F9	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
		2004	5	2	B	W5B2	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1
		2004	5	6	B	W5B6	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
	F - 2 / MCF seasonal	2004	3	6	F	W3F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		2010	3	17	F	N3F17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	18	F	W3F18	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		2004	5	12	F	W5F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	7	F	W3F7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	7	F	N3F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	6	F	N3F6	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0
		2010	3	16	F	N3F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
		2010	3	18	F	N3F18	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0
		2004	4	8	F	W4F8	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	8	F	W5F8	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		2004	5	9	F	W5F9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	10	F	W5F10	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	11	F	W5F11	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	10	F	N5F10	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		2010	5	11	F	N5F11	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	F - 3 / MCF seasonal	2004	4	1	F	W4B1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0
		2010	4	1	B	N4B1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0
		2010	4	2	B	N4B2	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0
		2004	4	2	B	W4B2	0	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	1	1	0	1	0	0
		2010	4	3	B	N4B3	1	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0
		2004	4	3	B	W4B3	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0
		2004	4	4	B	W4B4	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0
		2010	4	4	B	N4B4	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0
		2010	4	5	B	N4F5	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0
		2004	4	5	F	W4F5	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
		2004	4	6	F	W4F6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
		2010	4	6	F	N4F6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	8	F	N4F8	0	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0
		2004	4	7	F	W4F7	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
		2010	4	7	F	N4F7	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0
	F - 4 / MCF active	2004	2	6	F	W2F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2004	3	15	F	W3F15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		2010	4	10	F	N4F10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		2010	4	12	F	N4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		2004	3	14	F	W3F14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2010	3	14	F	N3F14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	13	F	N3F13	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2010	3	15	F	N3F15	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	8	F	N2F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	9	F	N2F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	12	F	N2F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	10	F	N2F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	11	F	N2F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	13	F	N2F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	26	F	N3F26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	7	F	W2F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	8	F	W2F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	9	F	W2F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	10	F	W2F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	11	F	W2F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	12	F	W2F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	13	F	W2F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	12	F	W3F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	16	F	W3F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	20	F	W3F20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	21	F	W3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	22	F	W3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	23	F	W3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	24	F	W3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	25	F	W3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	26	F	W3F26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	9	F	W4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	10	F	W4F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	11	F	W4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	12	F	W4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	9	F	N3F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	10	F	N3F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	19	F	N3F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	21	F	N3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	22	F	N3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	23	F	N3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	24	F	N3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	25	F	N3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	9	F	N4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	11	F	N4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	12	F	N5F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	9	F	W3F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	12	F	N3F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	20	F	N3F20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	10	F	W3F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	19	F	W3F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	17	F	W3F17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2004	3	8	F	W3F8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	11	F	W3F11	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	13	F	W3F13	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	8	F	N3F8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	11	F	N3F11	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Cluster	Year	Transect	Plot	MCB / MCF	Plot_group	Grewia villosa	Gymnosporia harveyana	Gymnosporia heterophylla	Gymnosporia senegalensis	Jasminum fluminense	Kigelia africana	Kraussia floribunda	Lantana camara	Lippia javanica	Manilkara mochisia	Maytenus undata	Mimosa pigra	Mimusops zeyheri	Monanthotaxis caffra	Myxtroxylon aethiopicum	Ochna natalitia	Pavetta cataractarum	Pavetta lanceolata	Peltophorum africanum	Philenoptera violacea	Phyllanthus reticulatus	Pistimera longipetiolata	Plectroniella armata	Psoralea latifolia	Rhoicissus tridentata	Rhus pyroides	Schotia brachypetala	Schotia capitata
MCB	F -1 / MCB	2004	2	1	B	W2B1	0	1	0	0	1	0	1	1	1	0	1	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0
		2004	2	2	B	W2B2	0	1	0	0	0	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0
		2010	2	3	B	N2B3	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	2	B	N2B2	0	1	0	0	1	0	1	1	1	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	1	1	0	0
		2010	2	1	B	N2B1	0	1	0	1	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	3	B	W2B3	0	1	0	1	0	0	1	0	0	1	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0
		2010	2	5	B	N2B5	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	4	B	N2B4	0	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
		2004	2	4	B	W2B4	0	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	5	B	W2B5	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	2	6	F	N2F6	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	2	7	F	N2F7	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
		2004	3	1	B	W3B1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0
		2004	3	4	B	W3B4	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
		2004	3	2	B	W3B2	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
		2010	3	1	B	N3B1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0
		2010	3	2	B	N3B2	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	3	B	W3B3	0	0	1	1	0	0	1	0	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0	0
		2010	3	3	B	N3B3	0	0	0	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0	0
		2004	3	5	F	W3F5	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		2010	3	4	B	N3B4	0	0	0	1	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	3	5	F	N3F5	0	0	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	0
		2004	5	1	B	W5B1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	1	B	N5B1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	3	B	W5B3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2004	5	5	B	W5B5	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
		2010	5	2	B	N5B2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	3	B	N5B3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
		2004	5	4	B	W5B4	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	5	B	N5B5	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	5	4	B	N5B4	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
		2004	5	7	B	W5B7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	8	F	N5F8	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	7	B	N5B7	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	6	B	N5B6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
		2010	5	9	F	N5F9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2004	5	2	B	W5B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	6	B	W5B6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F - 2 / MCF seasonal	2004	3	6	F	W3F6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		2010	3	17	F	N3F17	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	18	F	W3F18	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	12	F	W5F12	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	7	F	W3F7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
		2010	3	7	F	N3F7	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		2010	3	6	F	N3F6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		2010	3	16	F	N3F16	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	3	18	F	N3F18	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2004	4	8	F	W4F8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2004	5	8	F	W5F8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	9	F	W5F9	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	10	F	W5F10	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	5	11	F	W5F11	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	10	F	N5F10	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	5	11	F	N5F11	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F - 3 / MCF seasonal	2004	4	1	F	W4B1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2010	4	1	B	N4B1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2010	4	2	B	N4B2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
		2004	4	2	B	W4B2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
		2010	4	3	B	N4B3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2004	4	3	B	W4B3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2004	4	4	B	W4B4	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
		2010	4	4	B	N4B4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0
		2010	4	5	B	N4F5	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0
		2004	4	5	F	W4F5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	6	F	W4F6	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		2010	4	6	F	N4F6	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		2010	4	8	F	N4F8	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0
		2004	4	7	F	W4F7	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
		2010	4	7	F	N4F7	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1
	F - 4 / MCF Active	2004	2	6	F	W2F6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	15	F	W3F15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		2010	4	10	F	N4F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	12	F	N4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	14	F	W3F14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		2010	3	14	F	N3F14	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		2010	3	13	F	N3F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0
		2010	3	15	F	N3F15	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		2010	2	8	F	N2F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	9	F	N2F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	12	F	N2F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	10	F	N2F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	11	F	N2F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	2	13	F	N2F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	26	F	N3F26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	7	F	W2F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	8	F	W2F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	9	F	W2F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	10	F	W2F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	11	F	W2F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	12	F	W2F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	2	13	F	W2F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	12	F	W3F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	16	F	W3F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	20	F	W3F20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	21	F	W3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	22	F	W3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	23	F	W3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	24	F	W3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	25	F	W3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	3	26	F	W3F26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	9	F	W4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	10	F	W4F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	11	F	W4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2004	4	12	F	W4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	9	F	N3F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	10	F	N3F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	19	F	N3F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	21	F	N3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	22	F	N3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	23	F	N3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	24	F	N3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	3	25	F	N3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	9	F	N4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		2010	4	11	F	N4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Cluster	Year	Transect	Plot	MCB / MCF	Plot_group	*Sclerocarya birrea*	*Scolopia zeyheri*	*Senna occidentalis*	*Senna septemtrionalis*	*Sesbania punicea*	*Strychnos madagascariensis*	*Strychnos spinosa*	*Syzygium cordata*	*Syzygium guineense*	*Tacazzea apiculata*	*Tecomaria capensis*	*Terminalia prunioides*	*Terminalia sericea*	*Trema orientalis*	*Tricalysia junodii*	*Trichilia emetica*	*Ziziphus mucronata*	Total number of species
MCB	F - 1 / MCB	2004	2	1	B	W2B1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	6043
		2004	2	2	B	W2B2	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	1	6047
		2010	2	3	B	N2B3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	6067
		2010	2	2	B	N2B2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6061
		2010	2	1	B	N2B1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	6056
		2004	2	3	B	W2B3	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	6047
		2010	2	5	B	N2B5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	6063
		2010	2	4	B	N2B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6064
		2004	2	4	B	W2B4	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	6046
		2004	2	5	B	W2B5	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0	0	6049
		2010	2	6	F	N2F6	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	6070
		2010	2	7	F	N2F7	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	6071
		2004	3	1	B	W3B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6040
		2004	3	4	B	W3B4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	6051
		2004	3	2	B	W3B2	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	6045
		2010	3	1	B	N3B1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6059
		2010	3	2	B	N3B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6061
		2004	3	3	B	W3B3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6048
		2010	3	3	B	N3B3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	6066
		2004	3	5	F	W3F5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6051
		2010	3	4	B	N3B4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	6065
		2010	3	5	F	N3F5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	6074
		2004	5	1	B	W5B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6040
		2010	5	1	B	N5B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6060
		2004	5	3	B	W5B3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6046
		2004	5	5	B	W5B5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6055
		2010	5	2	B	N5B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6061
		2010	5	3	B	N5B3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6067
		2004	5	4	B	W5B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6053
		2010	5	5	B	N5B5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6075
		2010	5	4	B	N5B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6070
		2004	5	7	B	W5B7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6054
		2010	5	8	F	N5F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6079
		2010	5	7	B	N5B7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6075
		2010	5	6	B	N5B6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6074
		2010	5	9	F	N5F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6081
		2004	5	2	B	W5B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6038
		2004	5	6	B	W5B6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6050
	F - 2 / MCF seasonal	2004	3	6	F	W3F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6042
		2010	3	17	F	N3F17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6092
		2004	3	18	F	W3F18	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6078
		2004	5	12	F	W5F12	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6067
		2004	3	7	F	W3F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6047
		2010	3	7	F	N3F7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	6064
		2010	3	6	F	N3F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6064
		2010	3	16	F	N3F16	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6093
		2010	3	18	F	N3F18	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	6104
		2004	4	8	F	W4F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6052
		2004	5	8	F	W5F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6054
		2004	5	9	F	W5F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6057
		2004	5	10	F	W5F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6060
		2004	5	11	F	W5F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6064
		2010	5	10	F	N5F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6079
		2010	5	11	F	N5F11	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6081
	F - 3 / MCF seasonal	2004	4	1	F	W4B1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6035
		2010	4	1	B	N4B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6052
		2010	4	2	B	N4B2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6058
		2004	4	2	B	W4B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6044
		2010	4	3	B	N4B3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6069
		2004	4	3	B	W4B3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6043
		2004	4	4	B	W4B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6049
		2010	4	4	B	N4B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6067
		2010	4	5	B	N4F5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6071
		2004	4	5	F	W4F5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6047
		2004	4	6	F	W4F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6049
		2010	4	6	F	N4F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6066
		2010	4	8	F	N4F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6078
		2004	4	7	F	W4F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6061
		2010	4	7	F	N4F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6077
MCF	F - 4 / MCF active	2004	2	6	F	W2F6	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	6041
		2004	3	15	F	W3F15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6070
		2010	4	10	F	N4F10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	6074
		2010	4	12	F	N4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6079
		2004	3	14	F	W3F14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6065
		2010	3	14	F	N3F14	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	6084
		2010	3	13	F	N3F13	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	6084
		2010	3	15	F	N3F15	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	6091
		2010	2	8	F	N2F8	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	6062
		2010	2	9	F	N2F9	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	6065
		2010	2	12	F	N2F12	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	6074
		2010	2	10	F	N2F10	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6067
		2010	2	11	F	N2F11	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6070
		2010	2	13	F	N2F13	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6076
		2010	3	26	F	N3F26	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6118
		2004	2	7	F	W2F7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6039
		2004	2	8	F	W2F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6042
		2004	2	9	F	W2F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6045
		2004	2	10	F	W2F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6048
		2004	2	11	F	W2F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6051
		2004	2	12	F	W2F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6054
		2004	2	13	F	W2F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6057
		2004	3	12	F	W3F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6057
		2004	3	16	F	W3F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6069
		2004	3	20	F	W3F20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6081
		2004	3	21	F	W3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6084
		2004	3	22	F	W3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6087
		2004	3	23	F	W3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6090
		2004	3	24	F	W3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6093
		2004	3	25	F	W3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6096
		2004	3	26	F	W3F26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6099
		2004	4	9	F	W4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6051
		2004	4	10	F	W4F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6054
		2004	4	11	F	W4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6057
		2004	4	12	F	W4F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6060
		2010	3	9	F	N3F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6066
		2010	3	10	F	N3F10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6069
		2010	3	19	F	N3F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6096
		2010	3	21	F	N3F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6102
		2010	3	22	F	N3F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6105
		2010	3	23	F	N3F23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6108
		2010	3	24	F	N3F24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6111
		2010	3	25	F	N3F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6114
		2010	4	9	F	N4F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6069
		2010	4	11	F	N4F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6075
		2010	5	12	F	N5F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6081
		2004	3	9	F	W3F9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6049
		2010	3	12	F	N3F12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6076
		2010	3	20	F	N3F20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6100
		2004	3	10	F	W3F10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6052
		2004	3	19	F	W3F19	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6079
		2004	3	17	F	W3F17	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6075
		2004	3	8	F	W3F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6046
		2004	3	11	F	W3F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6055
		2004	3	13	F	W3F13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6061
		2010	3	8	F	N3F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6065
		2010	3	11	F	N3F11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6074