THE LONG-TERM EFFECTS OF FIRE FREQUENCY AND SEASON ON THE WOODY VEGETATION IN THE PRETORIUSKOP SOURVELD OF THE KRUGER NATIONAL PARK

Sean Patrick O'Regan

WitsETD

A dissertation submitted to the faculty of Science, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science.

Johannesburg, February 2005

I declare that this dissertation is my own work. It is being submitted for the Degree of Master of Science at the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

_____

Sean Patrick O'Regan

On this _____ day of _____ 2005

WitsETD

Writing is refined thinking. If your master's thesis is no more organised than a high school essay entitled "Why Shania Twain Turns Me On", you're in big trouble.

Stephen King – On writing: A memoir

WitsETD

ACKNOWLEDGEMENTS

Every traveller on life's journey is a messenger, and every destination is the beginning of a new cycle.

Jamie Sams and David Carson – Medicine Cards

Thanks and appreciation goes to many organizations and individuals, without whom I would never have been able to embark on and complete this Masters Dissertation.

I am deeply in debt to the following people for providing support and guidance while doing this project:

- Thanks to **Belinda** for her kindness, encouragement, motivation, love, energy, support, and for sharing the burden. Also thanks for believing I would finish, and thanks for giving me the opportunity to finish I could never have completed it part-time.
- Thanks to **Prof. Ed Witkowski** my supervisor for guidance, encouragement, funding, and above all patience, many thanks.
- Thanks to **Dr Brian Van Wilgen** for inspiration, guidance, and mentorship, and to **Jane**, **Nicola**, and **Lawrence** with whom I had fun.
- Thanks to **Andre Potgieter** for funding, guidance, patience and for maintaining the experiment in such a meticulous fashion, and to **Maryna Potgieter** for her help and laughter.
- Thanks to **Richard Matthews** and **Angus Moir** for generously giving me the time off work to finish this Masters Dissertation and to **Richard** for pushing me to get it done. I am deeply grateful.
- Thanks to **Rensen Thethe**, **Johan Baloye**, and **Richard Mashabane** for being so dedicated and patient in the field, for teaching me the different tree species, and making the work so effortless and enjoyable.
- Thanks to **Gwinn** and **Nick Zambatis** for their patience in helping me identify trees from scant material and for helping cross-reference the species in the historical surveys.
- Thanks to **Harry** and **Rena Biggs** for inspiration and input.
- Thanks to my parents **John** and **Anne** for their love, kindness, teachings, faith, energy, and prayer.
- Thanks to the rest of my **family** and **friends** for their encouragement, love, and support.
- Thanks to **Andrew Parker** for his input and constant encouragement. We worked together on our dissertations for over seven years and it was good to have someone in the same boat with me.
- Thanks to **Kevin Schoof** for hospitality and friendship.
- Thanks to **Toni Braack** with whom I had so much fun, and who was always on the look out for something new to do or create.
- Thanks to **Kobus Kruger** and **Ben Pretorius** the section rangers of Pretoriuskop for all their assistance and for including me in so much.
- Thanks to all the **staff** at the **University of Witwatersrand** who lectured and tutored me during my studies.
- Thanks to the **staff** of **Scientific Services in Kruger National Park** for the support, guidance and laughs.

WITS ETD

I am deeply in gratitude to the following organizations for providing funding for this project:

- Thanks to the **Council for Scientific and Industrial Research (CSIR)** for their kind funding in 1998, and continued pressure to complete this project.
- Thanks to the **South African National Parks (SANP)** – The Kruger National Park (KNP) Scientific Services for funding in 1997 and 1998.
- Thanks to the **Foundation for Research and Development (FRD)** for funding in 1996 and 1997.
- Thanks to the **University of Witwatersrand** for funding in 1996 and 1997.
- Thanks to **Andre Potgieter** of the Kruger National Park (KNP) Scientific Services for providing funds from his own research budget during 1996.
- Thanks to **Agatha Design** (my current employers) for their kind funding in 2003 and 2004, and pushing me to finish off this MSc.

Without these funds this project would certainly not have been possible, many thanks.

WitsETD

PREFACE

Sitting here in Johannesburg, it is a glorious summer, full of greens and greys, and balmy afternoon heat, with the ever-present afternoon storm pending. It has been almost nine years since I started this MSc in April 1996.

I can clearly remember December 1995 lying in a large tent in Nwaswitshaka Research Camp listening to the night animals. I had arrived in Skukuza to find out more about a fire experiment that had been running for over forty years. The idea of working on one of the world's longest running ecological research programmes was for me the most exciting thing I had ever embarked on, not to mention the opportunity of working (and living) in the Kruger National Park.

Looking back on my proposal, I find myself smiling. The time plan was ambitions, I started the fieldwork in May 1996, and it was to take 3-5 months. This included resurveying the woody vegetation on the Pretoriuskop plots, scanning archived fixed-point photographs of the plots before the treatments were started, and taking another set of fixed-point photographs as an end reference. I was to complete the data capturing and analysis by mid winter 1997, culminating in final product by early 1998. It was all clear cut and clinical.

The fieldwork took the better part of two years, and it was only completed in September 1997. This set the precedent for a much longer project than I had expected, although I suspect that some people had seen this coming.

I started to work full time in October 1998 already having overshot my proposed completion deadline by ten months with still no real end in sight. For any supervisor this is always a heart wrenching time, to be outwardly excited about the student's good job prospects, but knowing that it spells disaster for the project. Ed was supportive, and I clearly remember assuring him that I would complete my MSc soon.

Doing this MSc has not been as easy as I had imagined when I first started it. For most of the time, I have had all the information but lacked the inspiration. Well, some weddings and funerals later with two solar eclipses and a number of lunar eclipses in between, I am finally completing the circle. I no longer have to hang my head in shame when I go to WITS or KNP, I no longer have to say "It's nearly finished … no really it is". There were times when completing this dissertation really took everything out of me and I thought I would never finish it, on the whole, though it has been good, and I am sad that it is over.

Many thanks to all who supported me while completing this MSc, and even more thanks to those who pushed me to finish this MSc.

WITS-ETD

ABSTRACT

O'Regan SP, 2005. **The long-term effects of fire frequency and season on the woody vegetation in the Pretoriuskop sourveld of the Kruger National Park**. MSc Dissertation, University of the Witwatersrand, Johannesburg.

The role of fire in the management of conservation areas has historically been a contentious issue in which traditional agricultural principles and ever-changing conservation principles tend to collide. The Kruger National Park (KNP) in the early 1950s was no exception where the appropriate use of fire and its ecosystem consequences were hotly debated. The controversy surrounding the management of fire in the KNP highlighted the significant lack of understanding of fire and its role in the ecosystem and because of this controversy, the Experimental Burn Plot (EBP) experiment was established in 1954. The EBP experiment comprised 12 treatments, and a pseudo-randomised block design was used in which the 12 fire treatments were replicated four times each in four of the six major vegetation zones identified at the time. The EBP experiment originally comprised 192 experimental plots approximately 7 Ha in size each and covered approximately 12 km^2 in the KNP. The twelve fire treatments were an annual burn in August, biennial and triennial burns in February, April, August, October, and December, and a control on which fire was excluded. Despite having been plagued with negative assessments from internal and external researchers from its inception, the EBP experiment was meticulously maintained, and it has now become a valuable research asset in the KNP.

Four replicates of twelve plots each were located in the Pretoriuskop sourveld landscape of the KNP. These replicates were named Fayi, Kambeni, Numbi, and Shabeni after nearby landmarks. The Pretoriuskop region is a moist infertile mesic-savanna, which experiences on average 744mm of rain annually. The dominant tree species in Pretoriuskop are *Dichrostachys cinerea* and *Terminalia sericea* and the dominant grass species is *Hyperthelia dissoluta*. A baseline survey of the woody vegetation was done on all the Pretoriuskop plots in 1954 by HP Van Der Schijff. A second survey of the woody vegetation on all the Pretoriuskop plots was done in 1996 by SP O'Regan. This provided a 42-year period of treatment application over which the effects of fire frequency and season on the woody vegetation of the Pretoriuskop region were studied.

The aim of this study was to investigate the long-term effects of the twelve fire treatments on the density, structure, and species composition of the woody vegetation in Pretoriuskop. The objectives of this study were:

1. To carry out a complete re-survey of the trees and shrubs on the Pretoriuskop EBPs using similar methods as those used in the baseline survey in 1954.
2. To capture into a digital format pertinent woody vegetation survey data from surveys that had been conducted on the Pretoriuskop EBPs between 1954 and 1996.
3. To compare the density, structure, and composition of the woody vegetation on the Pretoriuskop EBPs between 1954 and 1996, to determine the effects of fire on the woody vegetation of Pretoriuskop.
4. To investigate the history of the Kruger National Park Experimental Burn Plots experiment.

The four replicates in the Pretoriuskop region were found generally to have very similar woody vegetation traits (density, species composition, and structural composition). However, the EBPs were established and surveyed in two distinct phases, the first phase comprised the control, August Annual, and the Biennial plots, and the second phase comprised the Triennial plots. The baseline structural composition of the plots established in the first phase was different from the structural composition of the plots in the second phase.

WISER

Furthermore, the Pretoriuskop EBPs are located in two distinct vegetation types, namely the open and the closed *Terminalia sericea* \ *Combretum* woodlands of the Pretoriuskop region. The Numbi and Shabeni replicates are in the open *Terminalia sericea* \ *Combretum* woodlands, and the Kambeni and Fayi replicates are in the closed *Terminalia sericea* \ *Combretum* woodlands. It was found that the species composition of the plots was influenced by the location of the plots in the different vegetation types.

The exclusion of fire in the Pretoriuskop sourveld results in an increase in the density of the overstorey and understorey woody vegetation, and an increase in the number of species, species diversity, and species evenness. This is because fire sensitive and fire intolerant woody species become more abundant as the period between fires increases. In Pretoriuskop, there is no evidence of relay floristic succession, because fire sensitive and fire intolerant woody species do not replace fire tolerant species. Instead, the floristic succession is accumulative and fire tolerant, fire sensitive, and fire intolerant woody species coexist as the period between fires increases. Woody species tolerant of frequent fires in Pretoriuskop are *Albizia versicolor*, *Catunaregam spinosa*, *Lonchocarpus capassa*, *Pavetta schumanniana*, *Senna petersiana*, *Strychnos madagascariensis*, and *Turraea nilotica*. Woody species that are sensitive or intolerant of fire in Pretoriuskop are *Acacia swazica*, *Bauhinia galpinii*, *Combretum mossambicense*, *Commiphora neglecta*, *Croton gratissimus*, *Dalbergia melanoxylon*, *Diospyros lycioides*, *Diospyros whyteana*, *Euclea natalensis*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Ochna natalitia*, *Olea europaea*, *Psydrax locuples*, *Putterlickia pyracantha*, *Tarenna supra-axillaris*, and *Zanthoxylum capense*. *Dichrostachys cinerea* and *Terminalia sericea* were found to dominate in areas that had been burnt frequently as well as areas where fire has been excluded. The change in the density of the woody vegetation as the inter-fire period increases is not linear but rather J shaped with an initial decrease in the density as the inter-fire period increases from 1 year to 3 years. This initial decrease in density is the result of a loss of very short (<1m tall) woody individuals. In contrast, there is no initial decrease in the number of tree equivalents (phytomass) of the woody vegetation as the inter-fire period increases. After the initial decrease in the density of the woody vegetation, the density increases as the inter-fire period increases beyond 3 years. Generally in Pretoriuskop, post fire age of the vegetation was found to be an important factor affecting the structure of the woody vegetation, and as the inter-fire period increases the number of structural groups, the structural diversity, and the structural evenness of the woody vegetation increases. As the inter-fire period increases the number of single-stem individuals relative to the number of multi-stem individuals increases, and the average height of the woody vegetation increases. The findings regarding the effects of fire frequency on the Pretoriuskop EBPs were similar to the findings on other fire experiments in mesic African savannas. The finding on the Pretoriuskop EBPs differed from the findings in other fire trials that were in arid savannas in Africa. Generally, the exclusion of fire in moist savannas (> 600 mm of rain annually) results in the woody vegetation becoming denser, while the exclusion of fire in arid to semi-arid savannas (< 600mm of rain annually) does not result in the woody vegetation becoming denser.

In Pretoriuskop, fires occurring in summer between December and February have a different impact on the density, species composition, and structure of the woody vegetation than fires occurring in winter between August and October. Furthermore, fires occurring in April have a different impact on the density, species composition, and structure of the woody vegetation in Pretoriuskop. Woody vegetation burnt by summer fires is denser than woody vegetation burnt by winter fires. The number of species and species diversity of the woody vegetation is also higher in vegetation burnt by summer fires in comparison with vegetation burnt by winter fires. The density and species composition of woody vegetation in areas that have been burnt in summer fires is more similar to areas where fire has been excluded than to areas that have been burnt in winter fires. The woody species associated with vegetation burnt in summer fires and where fire has been excluded are *Euclea natalensis*, *Antidesma venosum*, *Diospyros lycioides*, *Phyllanthus reticulatus*, *Grewia flavescens*, *Grewia monticola*, *Ochna natalitia*, *Peltophorum africanum*, *Rhus pyroides*, *Diospyros mespiliformis*, *Rhus transvaalensis*, *Securinega virosa*, *Putterlickia pyracantha*, *Rhus pentheri*, *Commiphora neglecta*, *Heteropyxis natalensis*, and *Olea europaea*. Structurally the average height of the woody vegetation is taller in areas burnt by winter fires than in areas burnt by summer fires. The woody vegetation in areas burnt in summer fires have more single-stem individuals relative to multi-stem individuals than in areas burnt in winter fires. The structural composition of areas burnt in summer fires is more similar to areas

where fire has been excluded than with areas burnt in winter fires. The structure of the woody vegetation in areas burnt in winter fires is generally dominated by multi-stem individuals that are 0-1m tall or 3-5m tall. The structure of the woody vegetation in areas burnt in summer fires or where fire has been excluded is dominated by both single-stem and multi-stem individuals of all heights and basal diameters. Findings regarding the effect of early dry season fires (April) in comparison with late dry season fire (August) on the woody vegetation are consistent with the findings on other fire trails in Africa. However, a comparison of all the fire-timing treatments between the Pretoriuskop and Satara EBPs in the KNP reveals that the timing of fires affects the woody vegetation differently in different areas even when the affects at certain times appear similar.

The data collected on the Pretoriuskop EBPs reveals that there have been significant changes in the woody vegetation in Pretoriuskop between 1954 and 1996. The density of the woody vegetation increased between 1954 and 1996 by almost 200%. The number of species and the species diversity of the woody vegetation also increased between 1954 and 1996. In 1954, there were approximately equal numbers of single-stem and multi-stem individuals, while in 1996 there were more multi-stem individuals than single-stem individuals. The increase in atmospheric CO_2 levels between 1954 and 1996 is believed to have been a factor that has driven the changes in the woody vegetation of Pretoriuskop between 1954 and 1996.

WitsETD

TABLE OF CONTENTS

Acknowledgements ..... **I**
Preface ..... **III**
Abstract ..... **IV**
Table of contents ..... **VII**
List of figures ..... **XII**
List of tables ..... **XVI**
Terms and definitions ..... **XIX**
1 Introduction **1**
1.1 Aims and Objectives 1
2 Literature review **3**
2.1 The determinants of fire 3
2.1.1 The environmental determinants of fire 3
2.1.1.1 Climate and weather 3
2.1.1.2 Soil and Topography 5
2.1.1.3 Herbivory 5
2.1.1.4 Ignition sources 5
2.1.2 The characteristics of vegetation in fire prone ecosystems 5
2.1.2.1 Structure and chemistry of the vegetation 5
2.1.2.2 Species composition of the vegetation 6
2.1.2.3 Density of the vegetation 6
2.1.3 The characteristics of fuel in fire prone ecosystems 6
2.1.3.1 Fuel load 6
2.1.3.2 Chemistry of the fuel 6
2.1.3.3 Particle sizes of the fuel 6
2.1.3.4 The vertical and horizontal arrangement of the fuel 7
2.1.4 The characteristics of fire 7
2.1.4.1 Type of fire 7
2.1.4.2 Timing of fire 7
2.1.4.3 Frequency of fire 7
2.1.4.4 Intensity of fire 7
2.1.4.4.1 The effect of fire frequency and fire timing on fire intensity 8
2.1.4.5 Extent of fire 8
2.2 How do plants survive fire events? 8
2.2.1 Surviving the direct effects of fire 8
2.2.2 Post fire survival strategies 9
2.2.3 Post fire resilience and inertia 10
2.2.4 Understanding species responses under different fire regimes 11
2.3 Savannas as fire prone environments 11
2.3.1 Determinants of southern African savannas 12
2.3.2 The effect of fire on the woody vegetation of savanna ecosystems 12
2.3.3 The role of fire in the management of savanna ecosystems 13
2.4 Elevated CO_2 levels, fire and the management of savanna ecosystems 13
3 Study area **15**
3.1 The Experimental Burn Plot experiment layout and design 15
3.2 The Pretoriuskop landscape 15
3.2.1 Environmental features of the Pretoriuskop region 17
3.2.2 Vegetation description of the Pretoriuskop region 17
3.3 The Layout of the Experimental Burn Plots in the Pretoriuskop region 19
3.3.1 The fire characteristics of the Experimental Burn Plots experiment in the Pretoriuskop region 19
3.3.1.1 The extent or size of the fires on the Pretoriuskop EBP treatments 19
3.3.1.2 The type of fires on the Pretoriuskop EBP treatments 19
3.3.1.3 The intensity of fires on the Pretoriuskop EBP treatments 19
3.3.1.4 The timing of the fires on the Pretoriuskop EBP treatments 22
3.3.1.5 The frequency of the fires on the Pretoriuskop EBP treatments 23
4 Research hypotheses **25**
4.1 Change in the woody vegetation density, structure and composition on the Pretoriuskop Experimental Burn Plots between 1954 and 1996 25
4.2 Differences in the woody vegetation density, structure and composition between the Pretoriuskop Experimental Burn Plot replicates 25
4.3 The effects of fire frequency and timing on the density, structure, and composition of the woody vegetation on the Pretoriuskop Experimental Burn Plots 26
4.4 The effect of not burning on the density, structure and composition of the woody vegetation on the Pretoriuskop Experimental Burn Plots 27
5 Materials and methods **28**
5.1 Methods of historical analysis 28
5.2 Field methods 28
5.3 Capturing and collating historical survey data 29
5.3.1 Cross-referencing species 30
5.4 Estimating height for the 1954 and 1959 data 30
5.4.1 Estimating height class 30

UNISA

5.4.2 Estimating height 31
5.4.3 Assumptions made in estimating height classes for the 1954 data 31
5.5 Data analysis 31
5.5.1 Indices calculated to summarise key vegetation structure and composition characteristics 31
5.5.1.1 Woody plant density 32
5.5.1.2 Mean woody plant height 32
5.5.1.3 Number of tree equivalents 32
5.5.1.4 Single-stem to multi-stem index 32
5.5.1.5 Diversity 33
5.5.1.5.1 Species diversity 33
5.5.1.5.2 Structural diversity 33
5.5.1.5.3 Indices of diversity 33
5.5.1.5.3.1 Number of species or structure groups 33
5.5.1.5.3.2 Menhinick's species or structural richness 33
5.5.1.5.3.3 Shannon's species or structural diversity index 34
5.5.1.5.3.4 Shannon's species or structural evenness index 35
5.5.2 Quantifying the data distributions and testing the vegetation indices calculated per plot for normality 35
5.5.2.1 Skewness and Kurtosis 35
5.5.2.2 Kolmogorov-Smirnov one-sample tests for normality 35
5.5.3 Analysis of Variance (ANOVA) and Analysis of Covariance (ANCOVA) 36
5.5.3.1 The size of the tests 36
5.5.3.2 The data groupings used in the ANOVA and ANCOVA analyses 36
5.5.3.2.1 Testing for differences in the woody vegetation on the Pretoriuskop EBPs between 1954 and 1996 36
5.5.3.2.2 Testing for differences in the woody vegetation between Pretoriuskop EBPs found on the four replicates, Fayi, Kambeni, Numbi and Shabeni 36
5.5.3.2.3 Testing for differences in the woody vegetation between Pretoriuskop EBPs burnt at different frequencies (Annual, Biennial, Triennial and no burn) 37
5.5.3.2.4 Testing for differences in the woody vegetation between the Pretoriuskop EBPs burnt at different times of the year (February, April, August, October, and December) 37
5.5.3.2.5 Testing for differences in the woody vegetation between the Pretoriuskop EBPs burnt at different frequencies and at different times of the year (i.e. between the EBP treatments) 37
5.5.3.2.6 Testing for differences in the woody vegetation on the Pretoriuskop EBP Control (no burn) plots between 1954, 1959 and 1996 37
5.5.3.3 The covariates for the Analysis of Covariance 37
5.5.3.4 Post hoc analyses on the significant results from the ANOVA and ANCOVA analyses 38
5.5.3.5 Graphs showing the least squares means and standard errors of the vegetation indices from the ANOVA and ANCOVA analyses 38
5.5.4 Horn's index of community similarity 38
5.5.4.1 Calculating Horn's index 39
5.5.4.2 Cluster analyses of Horn's similarity indices 40
5.5.4.2.1 Maps of the layout of the Pretoriuskop EBPs with the plots colour coded to the clusters at the second distance (four clusters) 40
5.5.5 Correspondence Analyses (CA) 40
5.5.5.1 Bi-plots of the first two weighted eigenvectors of the species, structure, and plot scores 41
5.5.5.2 Cluster analyses of the first four weighted eigenvectors of the species, structure, and plot scores from the Correspondence Analyses 41
5.5.5.2.1 The stepwise Gamma-Ward cluster method 41
5.5.5.2.2 Maps of the layout of the Pretoriuskop EBPs with the plots colour coded to the level 2 clustering of the plots 42
6 Results 43
6.1 A critical analysis of the history of the Kruger National Park Experimental Burn Plots experiment 43
6.1.1 A brief history of fire management in the Kruger National Park 43
6.1.1.1 The proclamation of the Kruger National Park (1926) 44
6.1.1.2 A new era – Management by intervention 44
6.1.1.3 Abandoning prescribed burning – The wilderness years 45
6.1.2 The KNP experimental burn plots 46
6.1.2.1 Why set up such a large experiment in the early 1950s, and why fire? 46
6.1.2.2 The objective of the experiment 47
6.1.2.3 The experimental layout and design 48
6.1.2.4 The construction of the experimental plots and replicates 51
6.1.2.5 The application of the experimental treatments to the plots treatments 51
6.1.2.6 The application of the first fire treatments on the EBPs between 1954 and 1957 51
6.1.2.7 The collection of the baseline data 52
6.1.2.7.1 The woody vegetation survey - methodology and data 52
6.1.2.7.2 The grass and herb survey - methodology and data 52
6.1.2.8 Assessment of the belt transect baseline survey 53
6.1.2.9 A second assessment of the baseline surveys and further recommendations 54
6.1.2.10 Quadrate middle-point surveys – another method 55
6.1.2.11 Step point method (1970) 55
6.1.2.12 Half hectare survey plot – a permanent monitoring plot 55
6.1.2.13 To continue with the EBPs, or not to continue with the EBPs? 57
6.2 Results from the univariate analysis testing the effects of fire on the density, structure and composition of the woody vegetation of the Pretoriuskop EBP 59
6.2.1 Skewness and kurtosis of the data and the Kolmogorov-Smirnov one sample tests for normality 59
6.2.1.1 Testing the distribution of woody plant density per plot for normality 59
6.2.1.2 Testing the distribution of mean plant height per plot for normality 59
6.2.1.3 Testing the distribution of number of tree equivalents per plot for normality 60
6.2.1.4 Testing the distribution of the single-stem to multi-stem index per plot for normality 61
6.2.1.5 Testing the distribution of the number of species per plot for normality 61
6.2.1.6 Testing the distribution of species richness per plot for normality 61

UNISA

6.2.1.7 Testing the distribution of species diversity per plot for normality 62
6.2.1.8 Testing the distribution of species evenness per plot for normality 63
6.2.1.9 Testing the distribution of the number of structure groups per plot for normality 63
6.2.1.10 Testing the distribution of structural richness per plot for normality 63
6.2.1.11 Testing the distribution of structural diversity per plot for normality 63
6.2.1.12 Testing the distribution of structural evenness per plot for normality 64
6.2.2 Analyses of Variance and Analyses of Covariance statistical analyses 64
6.2.2.1 Testing for differences in the woody vegetation density, structure and composition on the Pretoriuskop EBPs between 1954 and 1996 64
6.2.2.1.1 Change in woody plant density between 1954 and 1996 64
6.2.2.1.2 Change in woody plant mean height between 1954 and 1996 64
6.2.2.1.3 Change in number of tree equivalents between 1954 and 1996 65
6.2.2.1.4 Change in the single-stem to multi-stem ratio between 1954 and 1996 65
6.2.2.1.5 Change in the number of species between 1954 and 1996 65
6.2.2.1.6 Change in the species richness between 1954 and 1996 66
6.2.2.1.7 Change in species diversity between 1954 and 1996 67
6.2.2.1.8 Change in species evenness between 1954 and 1996 67
6.2.2.1.9 Change in number of structure groups between 1954 and 1996 67
6.2.2.1.10 Change in structural richness between 1954 and 1996 67
6.2.2.1.11 Change in structural diversity between 1954 and 1996 68
6.2.2.1.12 Change in structural evenness between 1954 and 1996 68
6.2.2.2 Testing for differences in the woody vegetation density, structure and composition between Pretoriuskop EBPs found on the four replicates, Fayi, Kambeni, Numbi, and Shabeni 68
6.2.2.2.1 Differences in woody plant density between replicates 68
6.2.2.2.2 Differences in woody plant mean height between replicates 68
6.2.2.2.3 Differences in tree equivalents between replicates 69
6.2.2.2.4 Differences in single-stem to multi-stem index between replicates 69
6.2.2.2.5 Differences in the number of species between replicates 70
6.2.2.2.6 Differences in species richness between replicates 70
6.2.2.2.7 Differences in species diversity between replicates 71
6.2.2.2.8 Differences in species evenness between replicates 71
6.2.2.2.9 Differences in the number of structural groups between replicates 72
6.2.2.2.10 Differences in structural richness between replicates 74
6.2.2.2.11 Differences in structural diversity between replicates 75
6.2.2.2.12 Differences in structural evenness between replicates 75
6.2.2.3 Testing for differences in the woody vegetation density, structure and composition between Pretoriuskop EBPs burnt at different frequencies (Annual, Biennial, Triennial and no burn) 75
6.2.2.3.1 Differences in woody plant density between plots burnt at different frequencies 75
6.2.2.3.1.1 ANOVA and ANCOVA analyses on the woody plant density using the No-August-Annual data grouping 75
6.2.2.3.1.2 ANOVA and ANCOVA analyses on the woody plant density using the August-Control data grouping 76
6.2.2.3.1.3 Summary of the general relationship between woody plant density and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 76
6.2.2.3.2 Differences in woody plant height between plots burnt at different frequencies 77
6.2.2.3.2.1 ANOVA and ANCOVA analyses on the mean woody plant height using the No-August-Annual data grouping 77
6.2.2.3.2.2 ANOVA and ANCOVA analyses on the mean woody plant height using the August-Control data grouping 77
6.2.2.3.2.3 Summary of the general relationship between woody plant height and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 78
6.2.2.3.3 Differences in the number of tree equivalents between plots burnt at different frequencies 78
6.2.2.3.3.1 ANOVA and ANCOVA analyses on the number of tree equivalents using the No-August-Annual data grouping 78
6.2.2.3.3.2 ANOVA and ANCOVA analyses on the number of tree equivalents using the August-Control data grouping .. 78
6.2.2.3.3.3 Summary of the general relationship between the number of tree equivalents and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 78
6.2.2.3.4 Differences in the single-stem to multi-stem index between plots burnt at different frequencies 80
6.2.2.3.4.1 ANOVA and ANCOVA analyses on the single-stem to multi-stem index using the No-August-Annual data grouping 80
6.2.2.3.4.2 ANOVA and ANCOVA analyses on the single-stem to multi-stem index using the August-Control data grouping 80
6.2.2.3.4.3 Summary of the general relationship between the single-stem to multi-stem index and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 80
6.2.2.3.5 Differences in the number of species between plots burnt at different frequencies 81
6.2.2.3.5.1 ANOVA and ANCOVA analyses on the number of species using the No-August-Annual data grouping 81
6.2.2.3.5.2 ANOVA and ANCOVA analyses on the number of species using the August-Control data grouping 82
6.2.2.3.5.3 Summary of the general relationship between the number of species and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 82
6.2.2.3.6 Differences in species richness between plots burnt at different frequencies 82
6.2.2.3.6.1 ANOVA and ANCOVA analyses on the species richness using the No-August-Annual data grouping 82
6.2.2.3.6.2 ANOVA and ANCOVA analyses on the species richness using the August-Control data grouping 82
6.2.2.3.6.3 Summary of the general relationship between the species richness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 83
6.2.2.3.7 Differences in species diversity between plots burnt at different frequencies 83
6.2.2.3.7.1 ANOVA and ANCOVA analyses on the species diversity using the No-August-Annual data grouping 83
6.2.2.3.7.2 ANOVA and ANCOVA analyses on the species diversity using the August-Control data grouping 83
6.2.2.3.7.3 Summary of the general relationship between the species diversity and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 83
6.2.2.3.8 Differences in species evenness between plots burnt at different frequencies 84
6.2.2.3.8.1 ANOVA and ANCOVA analyses on the species evenness using the No-August-Annual data grouping 84
6.2.2.3.8.2 ANOVA and ANCOVA analyses on the species evenness using the August-Control data grouping 85
6.2.2.3.8.3 Summary of the general relationship between the species evenness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 85

6.2.2.3.9 Differences in the number of structural groups between plots burnt at different frequencies 85
6.2.2.3.9.1 ANOVA and ANCOVA analyses on the number of structural groups using the No-August-Annual data grouping 85
6.2.2.3.9.2 ANOVA and ANCOVA analyses on the number of structural groups using the August-Control data grouping. 85
6.2.2.3.9.3 Summary of the general relationship between the number of structural groups and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 86
6.2.2.3.10 Differences in structural richness between plots burnt at different frequencies 87
6.2.2.3.10.1 ANOVA and ANCOVA analyses on the structural richness using the No-August-Annual data grouping 87
6.2.2.3.10.2 ANOVA and ANCOVA analyses on the structural richness using the August-Control data grouping 88
6.2.2.3.10.3 Summary of the general relationship between the structural richness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 88
6.2.2.3.11 Differences in structural diversity between plots burnt at different frequencies 88
6.2.2.3.11.1 ANOVA and ANCOVA analyses on the structural diversity using the No-August-Annual data grouping..... 88
6.2.2.3.11.2 ANOVA and ANCOVA analyses on the structural diversity using the August-Control data grouping 88
6.2.2.3.11.3 Summary of the general relationship between the structural diversity and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 89
6.2.2.3.12 Differences in structural evenness between plots burnt at different frequencies 89
6.2.2.3.12.1 ANOVA and ANCOVA analyses on the structural evenness using the No-August-Annual data grouping 89
6.2.2.3.12.2 ANOVA and ANCOVA analyses on the structural evenness using the August-Control data grouping 89
6.2.2.3.12.3 Summary of the general relationship between the structural evenness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses 90
6.2.2.4 Testing for differences in the woody vegetation density, structure and composition between the Pretoriuskop EBPs burnt at different times of the year (February, April, August, October, and December) 91
6.2.2.4.1 Differences in woody plant density between plots burnt at different times of the year 91
6.2.2.4.2 Differences in woody plant height between plots burnt at different times of the year 92
6.2.2.4.3 Differences in the number of tree equivalents between plots burnt at different times of the year 92
6.2.2.4.4 Differences in the single-stem to multi-stem index between plots burnt at different times of the year 92
6.2.2.4.5 Differences in the number of species between plots burnt at different times of the year 94
6.2.2.4.6 Differences in species richness between plots burnt at different times of the year 94
6.2.2.4.7 Differences in species diversity between plots burnt at different times of the year 94
6.2.2.4.8 Differences in species evenness between plots burnt at different times of the year 96
6.2.2.4.9 Differences in the number of structural groups between plots burnt at different times of the year 96
6.2.2.4.10 Differences in structural richness between plots burnt at different times of the year 96
6.2.2.4.11 Differences in structural diversity between plots burnt at different times of the year 98
6.2.2.4.12 Differences in structural evenness between plots burnt at different times of the year 98
6.2.2.5 Testing for differences in the woody vegetation density, structure and composition between the Pretoriuskop EBPs burnt at different frequencies and at different times of the year (i.e. between the EBP treatments) 98
6.2.2.5.1 Differences in woody plant density between plots burnt at different frequencies and at different times of the year.. 99
6.2.2.5.2 Differences in the mean woody plant height between plots burnt at different frequencies and at different times of the year 99
6.2.2.5.3 Differences in the number of tree equivalents between plots burnt at different frequencies and at different times of the year 99
6.2.2.5.4 Differences in the single-stem to multi-stem index between plots burnt at different frequencies and at different times of the year 100
6.2.2.5.5 Differences in the number of species between plots burnt at different frequencies and at different times of the year 101
6.2.2.5.6 Differences in species richness between plots burnt at different frequencies and at different times of the year 104
6.2.2.5.7 Differences in species diversity between plots burnt at different frequencies and at different times of the year 104
6.2.2.5.8 Differences in species evenness between plots burnt at different frequencies and at different times of the year ... 105
6.2.2.5.9 Differences in the number of structural groups between plots burnt at different frequencies and at different times of the year 105
6.2.2.5.10 Differences in structural richness between plots burnt at different frequencies and at different times of the year 106
6.2.2.5.11 Differences in structural diversity between plots burnt at different frequencies and at different times of the year 106
6.2.2.5.12 Differences in structural evenness between plots burnt at different frequencies and at different times of the year 108
6.2.2.6 Testing for differences in the woody vegetation density, structure and composition on the Pretoriuskop EBP Control (no burn) plots between 1954, 1959 and 1996 108
6.2.2.6.1 Differences in woody plant density on the Control treatment between 1954, 1959, and 1996 109
6.2.2.6.2 Differences in the mean woody plant height on the Control treatment between 1954, 1959, and 1996 109
6.2.2.6.3 Differences in the number of tree equivalents on the Control treatment between 1954, 1959, and 1996 109
6.2.2.6.4 Differences in the single-stem to multi-stem index on the Control treatment between 1954, 1959, and 1996 110
6.2.2.6.5 Differences in the number of species on the Control treatment between 1954, 1959, and 1996 110
6.2.2.6.6 Differences in species richness on the Control treatment between 1954, 1959, and 1996 110
6.2.2.6.7 Differences in species diversity on the Control treatment between 1954, 1959, and 1996 110
6.2.2.6.8 Differences in species evenness on the Control treatment between 1954, 1959, and 1996 110
6.2.2.6.9 Differences in the number of structural groups on the Control treatment between 1954, 1959, and 1996 111
6.2.2.6.10 Differences in structural richness on the Control treatment between 1954, 1959, and 1996 112
6.2.2.6.11 Differences in structural diversity on the Control treatment between 1954, 1959, and 1996 112
6.2.2.6.12 Differences in structural evenness on the Control treatment between 1954, 1959, and 1996 112
6.2.3 Analyses of species composition and structure composition on the Pretoriuskop EBPs using Horn's index of similarity 113
6.2.3.1 Pearson-Ward cluster analysis on the similarity of species between EBPs in 1954 113
6.2.3.2 Pearson-Ward cluster analysis on the similarity of species between EBPs in 1996 116
6.2.3.3 Pearson-Ward cluster analysis on the similarity of structure between EBPs in 1954 119
6.2.3.4 Pearson-Ward cluster analysis on the similarity of structure between EBPs in 1996 122
6.3 Results from the multivariate analysis exploring the effects of fire on the composition and structure of the woody vegetation of the Pretoriuskop experimental burn plots 125
6.3.1 Results from the Correspondence Analysis on the 1954 species by plot data 125
6.3.1.1 Bi-plots of the first two weighted species and plot eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1954 125

WISER

6.3.1.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1954 127
6.3.1.3 Summary of the results from the CA's on the 1954 species by plot data 128
6.3.2 Results from the Correspondence Analysis on the 1996 species by plot data 133
6.3.2.1 Bi-plots of the first two weighted species and plot eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996 133
6.3.2.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996 135
6.3.2.3 Summary of the results from the CA's on the 1996 species by plot data 137
6.3.3 Results from the Correspondence Analysis on the 1996 species by plot data with the first eight axes of the CA on the 1954 survey data as covariables 142
6.3.3.1 Bi-plots of the first two weighted species and plot eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996 accounting for the relationship between the species and plots in 1954 142
6.3.3.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996 accounting for the relationship between the species and plots in 1954 144
6.3.3.3 Summary of the results from the CA's on the 1996 species by plot data with covariables 146
6.3.4 Results from the Correspondence Analysis on the 1954 structure by plot data 151
6.3.4.1 Bi-plots of the first two weighted structure and plot eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1954 151
6.3.4.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1954 152
6.3.4.3 Summary of the results from the CA's on the 1954 structure by plot data 154
6.3.5 Results from the Correspondence Analysis on the 1996 structure by plot data 159
6.3.5.1 Bi-plots of the first two weighted structure and plot eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996 159
6.3.5.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996 161
6.3.5.3 Summary of the results from the CA's on the 1996 structure by plot data 162
6.3.6 Results from the Correspondence Analysis on the 1996 structure by plot data with the first eight axes of the CA on the 1954 survey data as covariables 167
6.3.6.1 Bi-plots of the first two weighted structure and plot eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996 accounting for the relationship between the structures and plots in 1954 167
6.3.6.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996 accounting for the relationship between the structures and plots in 1954 168
6.3.6.3 Summary of the results from the CA's on the 1996 structure by plot data with covariables 169

7 Discussion 175
7.1 Similarities and differences in the woody vegetation between the Pretoriuskop EBP replicates 175
7.2 The effect of fire frequency on the woody vegetation of the Pretoriuskop sourveld 175
7.3 The effect of fire timing on the woody vegetation of the Pretoriuskop sourveld 191
7.4 Changes in the woody vegetation of the Pretoriuskop region between 1954 and 1996 197

8 References 201
8.1 Published journal articles and books 201
8.2 Digital and internet references 207
8.3 Unpublished research Reports: South African National Parks Board of Trusties: 208
8.4 Unpublished annual Reports: South African National Parks Board of Trusties: 209
8.5 Unpublished correspondence and comments: South African National Parks Board of Trusties 209
8.6 Unpublished minutes of meetings: South African National Parks Board of Trusties 209
8.7 Personal communication 209

9 Appendix 1: Woody plant Species Lists for the three surveys (1954, 1959 and 1996) conducted on the Pretoriuskop Experimental Burn Plots 210

10 Appendix 2: List of the Pretoriuskop Experimental Burn Plots and treatments 214

11 Appendix 3: Metadata for the surveys of The woody vegetation of The Pretoriuskop EBPs in 1954, 1959 and 1996 215

12 Appendix 4: Vegetation indices calculated to summarise the structure and composition of the woody vegetation on the Pretoriuskop Experimental burn plots 220

13 Appendix 5: Descriptive statistical summary of the data used in the ANOVA and ANCOVA analyses 223

14 Appendix 6: Tukey Studentized *post hoc* analyses on the ANOVA and ANCOVA analyses of the vegetation indices calculated 236

15 Appendix 7: The weighted eigenvector sample scores from the first four ordination axes from correspondence analyses (CA) on the 1954 and 1996 species and structure data 256

16 Appendix 8: Atmospheric CO_2 records from sites in the Scripps Institution of Oceanography (SIO) air sampling network from 1958 to 2003 271

17 Appendix 9: Conference talks, posters, and Papers published 273
17.1 The long-term effect of fire frequency and season on the trees and shrubs in the sourveld savannas of the Kruger National Park. 273
17.2 The role of the Experimental Burn Plots (EBP) in validating woody vegetation Thresholds for Potential Concern (TPC) with respect to the monitoring of management strategies in the Kruger National Park (KNP). 282
17.3 Responses of the woody vegetation, in the Pretoriuskop sourveld savannas of the Kruger National Park (KNP), to fires burnt at different frequencies. 287
17.4 The effect of different fire return periods on the structure and composition of woody vegetation in the Pretoriuskop sourveld 291
17.5 Long-term effects of fire on the species and structural diversity of the trees and shrubs in the sourveld bushveld of the Kruger National Park 295
17.6 The long-term effects of fire frequency and season on the woody vegetation in the Pretoriuskop sourveld of the Kruger National Park 303
17.7 A fire history of The savanna ecosystems in The Kruger National Park, South Africa, between 1941 and 1996 305

WITS

LIST OF FIGURES

Figure 2-1: Model showing the interdependence of the determinants and characteristics of fire. 4
Figure 3-1: The layout of the Experimental Burn Plot experiment in the four broad vegetation communities defined by Van Der Schijff (1958) in the Kruger National Park. 16
Figure 3-2: Pretoriuskop is located in the south west of the Kruger National Park. 17
Figure 3-3: Layout of the Experimental Burn Plots in the Pretoriuskop landscape, showing the placement of the four replicates and the treatments that were applied to each burn plot. 18
Figure 3-4: The fire characteristics of the Experimental Burn Plots (EBPs) based on the model showing the interdependence between the determinants and characteristics of fire shown in Figure 2-1 (p. 4). 24
Figure 5-1: Showing the placement of the two transects along the diagonals of a treatment plot in the 1996 woody vegetation survey of the Pretoriuskop EBPs. The belt transects were divided into six segments each. 29
Figure 5-2: Example of the tree cluster diagram showing the structure plot classification from the stepwise Gamma-Ward cluster analysis of the first four ordination axes from the Correspondence Analyses on the 1954 structure by plot data. 42
Figure 6-1: The layout of the Experimental Burn Plot experiment in the four vegetation communities in the Kruger National Park. 49
Figure 6-2: Oblique and aerial view of the Shabeni replicate, showing how the treatment plots were setup with the single cleared fire breaks between the plots and the two cleared fire breaks surrounding the replicate. 50
Figure 6-3: Showing the typical application of a fire treatment to an EBP, with a protective back burn to prevent the head burn from jumping the firebreak and burning the neighbouring plot or the surrounding landscape. 52
Figure 6-4: Showing the placement of the two transects along the diagonals of a treatment plot in the baseline woody vegetation survey of the EBPs in 1954. 53
Figure 6-5: Normal curves fitted to the distribution of vegetation indices calculated for each plot using the baseline data collected in 1954. The graphs show the Skewness, Kurtosis and Kolmogorov-Smirnov p-values for the data distributions. 60
Figure 6-6: Normal curves fitted to the distribution of vegetation indices calculated for each plot using the baseline data collected in 1996. The graphs show the Skewness, Kurtosis and Kolmogorov-Smirnov p-values for the data distributions. 62
Figure 6-7: The least squares means and standard errors of the vegetation indices from the ANOVA analyses between the 1954 and 1996 data testing for change in woody vegetation over time. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 66
Figure 6-8: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the four replicates in the Pretoriuskop region. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 72
Figure 6-9: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for post treatment differences between the four replicates in the Pretoriuskop region. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 73
Figure 6-10: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for post treatment differences between the four replicates in the Pretoriuskop region taking into account the state of the plots before the treatments began. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 74
Figure 6-11: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots to be burnt at different frequencies using the No-August-Annual data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 79
Figure 6-12: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for the treatment effects between plots burnt at different frequencies using the No-August-Annual data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 81
Figure 6-13: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for the treatment effects between plots burnt at different frequencies taking into account the state of the plots before the treatments began. The No-August-Annual data grouping was used in these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 84
Figure 6-14: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots to be burnt at different frequencies using the August-Control data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 86
Figure 6-15: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for the treatment effects between plots burnt at different frequencies using the August-Control data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 87
Figure 6-16: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for the treatment effects between plots burnt at different frequencies taking into account the state of the plots before the treatments began. The August-Control data grouping was used in these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 90
Figure 6-17: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots to be burnt at different times of the year. The August annual treatments were excluded from these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 93
Figure 6-18: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for the treatment effects between plots burnt at different times of the year. The August annual treatments were excluded from these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 95
Figure 6-19: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for the treatment effects between plots burnt at different times of the year taking into account the state of the plots before the treatments began The August annual treatments were excluded from these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 97
Figure 6-20: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots assigned the different treatments. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 102
Figure 6-21: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing the effect of the different treatments assigned to plots. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 103

UNDER PEER REVIEW

Figure 6-22: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing the effect of the different treatments assigned to plots taking into account the state of the plots before the treatments began. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 107
Figure 6-23: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954, 1959, and 1996 control plot data testing for the effects of not burning. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).....111
Figure 6-24: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in species between Pretoriuskop EBPs in 1954. The codes for the treatment plots are defined in Table 10-1 (p. 214). 114
Figure 6-25: Map showing the clustering of the Pretoriuskop EBPs at distance 2 from the Pearson-Ward cluster analysis on Horn's indices of similarity in species between plots in 1954 shown in Figure 6-24.....115
Figure 6-26: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in species between Pretoriuskop EBPs in 1996. The codes for the treatment plots are defined in Table 10-1 (p. 214) 117
Figure 6-27: Map showing the clustering of the Pretoriuskop EBPs from a Pearson-Ward cluster analysis on Horn's indices of similarity in species between plots in 1996 shown in Figure 6-26.....118
Figure 6-28: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between Pretoriuskop EBPs in 1954. The codes for the treatment plots are defined in Table 10-1 (p. 214) 120
Figure 6-29: Map showing the clustering of the Pretoriuskop EBPs from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between plots in 1954 shown in Figure 6-28.....121
Figure 6-30: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between Pretoriuskop EBPs in 1996. The codes for the treatment plots are defined in Table 10-1 (p. 214) 123
Figure 6-31: Map showing the clustering of the Pretoriuskop EBPs from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between plots in 1996 shown in Figure 6-30.....124
Figure 6-32: Classification of treatment plots and species using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1954 species by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the species are defined in Table 9-1 (p. 210).....129
Figure 6-33: Bi-plot of the first two ordination axes from the CA on the 1954 species by plot data showing variation in species composition between treatment plots. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-32). The codes for the treatments are defined in Table 10-1 (p. 214).....130
Figure 6-34: Bi-plot of the first two ordination axes from the CA on the 1954 species by plot data showing variation in location (plots) between species. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-32). The codes for the species are defined in Table 9-1 (p. 210).....131
Figure 6-35: Map showing the level 2 clusters from the step-wise Gamma-Ward cluster analysis on the first four ordination axes of the CA on the 1954 species by plot data (Figure 6-32). The codes for the treatments are defined in Table 3-1 (p. 15).....132
Figure 6-36: Classification of treatment plots and species using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 species by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the species are defined in Table 9-1 (p. 210).....138
Figure 6-37: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in species composition between treatment plots. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-36). The codes for the treatment plots are defined in Table 10-1 (p. 214).....139
Figure 6-38: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in location (plots) between species. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-36). The codes for the species are defined in Table 9-1 (p. 210).....140
Figure 6-39: Map showing the level 2 groupings of a classification of treatment plots using a stepwise cluster analysis on the first four ordination axes of a CA on the 1996 species by plot data (Figure 6-36). The codes for the treatments are defined in Table 3-1 (p. 15). 141
Figure 6-40: Classification of treatment plots and species using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 species by plot data with the first eight ordination axes of the 1954 species by plot CA as covariables. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the species are defined in Table 9-1 (p. 210). 147
Figure 6-41: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in species composition between treatment plots with the first eight ordination axes of the 1954 species by plot CA as covariables. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-40). The codes for the treatment plots are defined in Table 10-1 (p. 214).....148
Figure 6-42: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in location (plots) between species with the first eight ordination axes of the 1954 species by plot CA as covariables. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-40). The codes for the species are defined in Table 9-1 (p. 210). 149
Figure 6-43: Map showing the level 2 groupings of a classification of treatment plots using a stepwise cluster analysis on the first four ordination axes of a CA on the 1996 species by plot data with the first eight ordination axes of the 1954 species by plot CA as covariables (Figure 6-40). The codes for the treatments are defined in Table 3-1 (p. 15). 150
Figure 6-44: Classification of treatment plots and structures using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1954 structure by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the structure groups are defined in Table 5-3 (p. 34).....155
Figure 6-45: Bi-plot of the first two ordination axes from the CA on the 1954 structure by plot data showing variation in structural composition between treatment plots. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-44). The codes for the treatment plots are defined in Table 10-1 (p. 214). 156
Figure 6-46: Bi-plot of the first two ordination axes from the CA on the 1954 structure by plot data showing variation in location (plots) between structures. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-44). The codes for the structure groups are defined in Table 5-3 (p. 34). 157
Figure 6-47: Map showing the level 2 clusters from the step-wise Gamma-Ward cluster analysis on the first four ordination axes of the CA on the 1954 structure by plot data (Figure 6-44). The codes for the treatments are defined in Table 3-1 (p. 15).....158

Figure 6-48: Classification of treatment plots and structures using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 structure by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the structure groups are defined in Table 5-3 (p. 34).....163
Figure 6-49: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in structural composition between treatment plots. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-48). The codes for the treatment plots are defined in Table 10-1 (p. 214). 164
Figure 6-50: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in location (plots) between structures. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-48). The codes for the structure groups are defined in Table 5-3 (p. 34). 165
Figure 6-51: Map showing the level 2 clusters from the step-wise Gamma-Ward cluster analysis on the first four ordination axes of the CA on the 1954 structure by plot data (Figure 6-48). The codes for the treatments are defined in Table 3-1 (p. 15).....166
Figure 6-52: Classification of treatment plots and structures using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 structure by plot data with the first eight ordination axes of the 1954 structure by plot CA as covariables. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the structure groups are defined in Table 5-3 (p. 34). 171
Figure 6-53: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in structural composition between treatment plots with the first eight ordination axes of the 1954 structure by plot CA as covariables. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-52). The codes for the treatment plots are defined in Table 10-1 (p. 214).....172
Figure 6-54: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in location (plots) between structures with the first eight ordination axes of the 1954 structure by plot CA as covariables. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-52). The codes for the structure groups are defined in Table 5-3 (p. 34).....173
Figure 6-55: Map showing the level 2 groupings of a classification of treatment plots using a stepwise cluster analysis on the first four ordination axes of a CA on the 1996 structure by plot data with the first eight ordination axes of the 1954 structure by plot CA as covariables (Figure 6-52). The codes for the treatments are defined in Table 3-1 (p. 15). 174
Figure 7-1: Model of the change in the density (plants/Ha) and the number of tree equivalents (tree equivalents/Ha) of the woody vegetation in the Pretoriuskop region as the period between fires increases. 176
Figure 7-2: The density (plants/Ha) of the woody vegetation at different height classes of vegetation burnt at different fire frequencies. 177
Figure 7-3: The density (plants/Ha) of the woody vegetation at different heights on the control plots at three different years (1954, 1959, and 1996). 178
Figure 7-4: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being subjected to high frequency (Annual) fires. 179
Figure 7-5: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being subjected to medium frequency (Biennial and Triennial) fires. 180
Figure 7-6: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being protected from fire for 42 years. 181
Figure 7-7: Conceptual model showing the changes in the woody vegetation of the Pretoriuskop region as the fire frequency decreases from high frequency fires to fire exclusion. 182
Figure 7-8: The typical accumulative floristic succession of the woody vegetation in the Pretoriuskop region as the inter-fire period increases. 183
Figure 7-9: The density (plants/Ha) of single-stem and multi-stem woody plants in vegetation burnt at different fire frequencies. 184
Figure 7-10: The density (plants/Ha) of different diameter classes of single-stem woody plants in vegetation burnt at different fire frequencies.....185
Figure 7-11: The density (plants/Ha) of different diameter classes of multi-stem woody plants in vegetation burnt at different fire frequencies.....185
Figure 7-12: The density (plants/Ha) of single-stem and multi-stem woody plants on the control plots at three different years (1954, 1959, and 1996).....186
Figure 7-13: Model showing the combined effect of fire frequency and fire intensity on the height structure of the woody vegetation on the Pretoriuskop EBPs. 186
Figure 7-14: The density (plants/Ha) of the woody vegetation at different height classes burnt under two fire regimes, Fire regime 1 denotes hot fires burnt frequently or cool to moderately hot fires burnt with a medium frequency. Fire regime 2 denotes where fire has been excluded, or hot to extremely hot fires burnt with a medium frequency. 187
Figure 7-15: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Morale Fire experimental plots in 1981 (Sweet 1982). 188
Figure 7-16: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Satara EBPs in 1971 (Gertenbach and Potgieter 1975). 189
Figure 7-17: The density (plants/Ha) of the woody vegetation burnt at different times of the year at different height classes. Note: The August Annual treatment data was excluded. 191
Figure 7-18: The density (plants/Ha) of the woody vegetation burnt with different fire intensities. The fire intensity classes used are those defined in “The intensity of fires on the Pretoriuskop EBP treatments” p. 19.....193
Figure 7-19: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Satara EBPs in 1971 (Gertenbach and Potgieter 1975). Note: The August Annual treatment data was excluded 195
Figure 7-20: The mean density of woody vegetation (plants/Ha) on the Pretoriuskop EBPs in 1954, 1969, and 1996, and the atmospheric CO_2 concentration (ppmv) between 1958 and 2003 taken as the average annual atmospheric CO_2 concentration at 10 Scripps Institution of Oceanography (SIO) air sampling sites (Keeling and Whorf 2004). The annual average atmospheric CO_2 concentration for each SIO site is presented in Appendix 8 Table 16-1 (p.271).....198
Figure 7-21: Graph showing the upper limits of the Thresholds of Potential Concern for the density (plants/Ha) of the woody vegetation within a landscape in the KNP (Provided by N Zambatis KNP Scientific Services). The colours green, orange, and red indicate the level of concern that expressed regarding the magnitude of change, namely green is ok, orange is caution, and red is potential concern.....199
Figure 17-1: Layout of the four blocks of plots in the Pretoriuskop landscape, showing the placement of the six treatments focused on in this presentation.....275

Figure 17-2: Graph showing the relative abundances of woody individuals in each of the five height classes for each of the six treatments. 278
Figure 17-3: Change over area graph modelling the suggested Thresholds of Potential Concern for the density of the woody vegetation in the KNP (Provided by N Zambatis KNP Scientific Services). 283
Figure 17-4: Model showing the effect of fire frequency on the structure and composition of the woody vegetation of the Pretoriuskop sourveld. 290
Figure 17-5: Model showing the effect of fire frequency on the structure and composition of the woody vegetation of the Pretoriuskop sourveld. 294

WitsETD

LIST OF TABLES

Table 3-1: The twelve treatments applied to the plots on four replicates (blocks) within each of the four major plant communities defined at the time by Van Der Schijff (1958). The table also shows the year in which the treatments were started, and the treatment code by which the treatments are referred to throughout this document in tables and figures. 15
Table 3-2: The average length of time (in minutes) taken for a treatment to burn, and the average temperature (°C) of the treatments at different heights. The data was collected in 1969 at the same time as the quadrate middle-point surveys of the EBPs were done (Van Wyk 1971). The data was not presented in Van Wyk (1971) though, and was found in the archive material for the EBPs. 20
Table 3-3: The average fire intensity for the Fayi, Kambeni, Numbi, and Shabeni EBP replicates on the Pretoriuskop region, based on the data that was collected on the five treatments in Table 3-4 in 1983 (Trollope and Potgieter 1983). 20
Table 3-4: The average fire intensity for five of the Pretoriuskop EBP treatments. The data was collected in 1982 (Trollope and Potgieter 1983). 21
Table 3-5: The fire intensity for the August and October Biennial treatments of the Pretoriuskop EBPs. The data was collected in 1992 as part of the ground component projects in SAFARI 92 (Trollope *et al.* 1994) 21
Table 3-6: Five fire categories based on fire intensity (Trollope and Potgieter 1983, Trollope and Potgieter 1985) 21
Table 3-7: Fire treatments of the Experimental Burn Plots ranked from most intense fire treatment to least intense fire treatment based on the timing and frequency of the treatment. 22
Table 5-1: The single-stem and multi-stem diameter classes used to classify individuals during the 1954 baseline survey (Van Der Schijff 1958). 30
Table 5-2: The height classes used to classify individuals in the 1996 survey. 31
Table 5-3: The structural classification used to group the woody plants surveyed in the 1954, 1959, and 1996 surveys. The height and diameter class codes are defined in Table 5-1 and Table 5-2. 34
Table 5-4: Plot groupings used in the Analysis of Variance (ANOVA) and Analysis of Covariance (ANCOVA). 38
Table 5-5: Example of how species, structures, and plots were classified by a stepwise Gamma-Ward cluster analysis of the first four ordination axes from the Correspondence Analyses. 42
Table 6-1: The twelve treatments applied within each of the plant communities. The treatment code refers to the codes used in the database. 48
Table 6-2: Results of the ANOVA analyses on the vegetation indices calculated to test for changes in the woody vegetation on the treatment plots between 1954 and 1996. 65
Table 6-3: The results from correlation and linear regression analyses testing the relationships between the woody vegetation in 1954 and 1996 using the vegetation indices calculated. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10). 67
Table 6-4: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test for homogeneity between the replicates in the Pretoriuskop region. 70
Table 6-5: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the frequency effects of the fire treatments. The August annual treatments were not included in these analyses (No-August-Annual data grouping). 76
Table 6-6: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the frequency effects of the fire treatments. Only the Control treatments and August annual, biennial, and triennial treatments were used in these analyses (August-Control data grouping). 77
Table 6-7: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the timing effects of the fire treatments (the August annual treatments were not included in these analyses). 91
Table 6-8: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the combined effects of timing and frequency of the fire treatments. 100
Table 6-9: Results of the ANOVA analyses on the vegetation indices calculated to test the effects of not burning between 1954 and 1996. 109
Table 6-10: Eigenvalues for the first four ordination axes of a Correspondence Analysis (CA) on the species by plot data collected in 1954. 125
Table 6-11: Eigenvalues for the first four ordination axes of a Correspondence Analysis (CA) on the species by plot data collected in 1996. 133
Table 6-12: Eigenvalues for the first four ordination axes of a Correspondence Analysis (CA) on the species by plot data collected in 1996 with the first eight ordination axes of the 1954 CA as covariables. 142
Table 6-13: Eigenvalues for the first four ordination axes of a Correspondence Analysis on the structure by plot data collected in 1954 151
Table 6-14: Eigenvalues for the first four ordination axes of a Correspondence Analysis on the structure by plot data collected in 1996 159
Table 6-15: Eigenvalues for the first four ordination axes of a Correspondence Analysis on the structure data collected in 1996 with the first four ordination axes of the 1954 Correspondence analysis as covariables. 167
Table 7-1: The average density of woody vegetation (plants/Ha) on the Control EBPs (fire excluded) in the Pretoriuskop region 1954, 1959, 1969, and 1996. The densities of the woody vegetation in 1954, 1959, and 1996 were from belt transect surveys of the Pretoriuskop EBPs. The density of the woody vegetation in 1969 was from a quadrate middle-point survey of the Pretoriuskop EBPs (Van Wyk 1971). 183
Table 7-2: Results from analyses performed on the density (plants/Ha) of the woody vegetation in 1981 on the Morale Fire experimental plots burnt at different frequencies between 1958 and 1981 (Sweet 1982). 187
Table 7-3: Data from five vegetation surveys on the Olokemeji Fire experiment plots showing the density of woody plant (plants/Ha) on plots that were burnt annually at different times of the year (Fuwape 1991). 194
Table 7-4: Data from two vegetation surveys on the Kainji Fire experiment plots showing the density of woody plant (plants/Ha) on plots that were burnt annually at different times of the year (Fuwape 1991). 195
Table 7-5: The average density of woody vegetation (plants/Ha) on the twelve Pretoriuskop EBP treatments in 1954, 1969, and 1996. The densities of the woody vegetation in 1954, and 1996 were calculated from the belt transect surveys of the Pretoriuskop EBPs. The densities of the woody vegetation in 1969 were calculated from the quadrate middle-point survey of the Pretoriuskop EBPs in 1969 (Van Wyk 1971). 197
Table 9-1: List of all woody species found on the Pretoriuskop EBPs in the 1954, 1959, and 1996 surveys with the species nomenclature according to Palgrave (1991). The list shows the species codes used when displaying species data in tables and figures through out this document. 210
Table 9-2: List showing the woody species found on the Pretoriuskop EBPs in the three surveys conducted in 1954, 1959, and 1996. This list links the species code defined in Table 9-1 to the species name used at the time of each of the surveys. 212

Table 10-1: List of the Pretoriuskop Experimental Burn Plots, the treatment assigned to the plot in 1954 and 1956, and the plot code used when displaying plot data in tables and figures through out this document. A description of the treatment codes are presented in Table 3-1 (p. 15). 214
Table 11-1: A list showing the information for each of the survey transects that was used to survey the woody vegetation of the Pretoriuskop EBPs in 1954, 1959, and 1996. 215
Table 12-1: Summary of the vegetation indices calculated from the data collected in the 1954 baseline survey. 220
Table 12-2: Summary of the vegetation indices calculated from the data collected in the 1959 survey on the No burn plots. 221
Table 12-3: Summary of the vegetation indices calculated from the data collected in the 1996 survey. 222
Table 13-1: Summary of data collected on the Pretoriuskop EBPs in 1954 and 1996. This data was used to test for changes in the woody vegetation structure and composition on the Pretoriuskop EBPs between 1954 and 1996. 223
Table 13-2: Summary of data collected on the Pretoriuskop replicates (Fayi, Kambeni, Numbi, and Shabeni) in 1954. This data was used to test for differences between the EBP replicates in the Pretoriuskop region in 1954. 224
Table 13-3: Summary of data collected on the Pretoriuskop replicates (Fayi, Kambeni, Numbi, and Shabeni) in 1996. This data was used to test for differences between the EBP replicates in the Pretoriuskop region in 1996. 225
Table 13-4: Summary of data collected on the Pretoriuskop EBPs to be burnt at different frequencies in 1954 excluding the August annual treatment. This data was used to test for pre-treatment differences between the plots to be burnt at different frequencies in 1954. 226
Table 13-5: Summary of data collected on the Pretoriuskop EBPs burnt at different frequencies in 1996 excluding the August annual treatment. This data was used to test for the treatment effects on the plots burnt at different frequencies between 1954 and 1996. 226
Table 13-6: Summary of data collected on the No burn, August annual, August biennial, and August triennial treatments. This data was used to test for pre-treatment differences between the plots to be burnt at different frequencies in 1954. 227
Table 13-7: Summary of data collected on the No burn, August annual, August biennial, and August triennial treatments. This data was used to test for the treatment effects on the plots burnt at different frequencies between 1954 and 1996. 228
Table 13-8: Summary of data collected on the Pretoriuskop EBPs burnt at different times of the year excluding the August annual treatment. This data was used to test for pre-treatment differences between the plots to be burnt at different times of the year in 1954. 229
Table 13-9: Summary of data collected on the Pretoriuskop EBPs burnt at different times of the year excluding the August annual treatment. This data was used to test for the treatment effects on the plots burnt at different times of the year between 1954 and 1996. 230
Table 13-10: Summary of data used to test for pre-treatment differences between the plots to be burnt with different fire treatments in 1954. 231
Table 13-11: Summary of data used to test for treatment differences between the plots burnt with different fire treatments between 1954 and 1996. 233
Table 13-12: Summary of data used to test the effects of not burning between 1954, 1959, and 1996. 235
Table 14-1: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between the replicates in 1954. 236
Table 14-2: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between the replicates in 1996. 237
Table 14-3: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between the replicates in 1996 using the baseline data (1954) as covariates. 238
Table 14-4: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots to be burnt at different frequencies in 1954 using the No-August-Annual data grouping. 239
Table 14-5: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the No-August-Annual data grouping. 240
Table 14-6: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the baseline data (1954) as covariates. The No-August-Annual data grouping was used in these analyses. 241
Table 14-7: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots to be burnt at different frequencies in 1954 using the August-Control data grouping. 242
Table 14-8: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the August-Control data grouping. 243
Table 14-9: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the baseline data (1954) as covariates. The August-Control data grouping was used in these analyses. 244
Table 14-10: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots to be burnt at different times of the year in 1954 using the No-August-Annual data grouping. 245
Table 14-11: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots burnt at different times of the year between 1954 and 1996 using the No-August-Annual data grouping. 246
Table 14-12: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between plots burnt at different times of the year between 1954 and 1996 using the baseline data (1954) as covariates. The No-August-Annual data grouping was used in these analyses. 248
Table 14-13: Tukey post hoc analyses for the ANOVA analyses testing for differences between plots to be burnt with different fire treatments in 1954. 250
Table 14-14: Tukey post hoc analyses for the ANOVA analyses testing for differences between plots to be burnt with different fire treatments between 1954 and 1996. 251
Table 14-15: Tukey post hoc analyses for the ANCOVA analyses testing for differences between plots to be burnt with different fire treatments between 1954 and 1996 using the baseline data (1954) as covariates. 253
Table 14-16: Tukey post hoc analyses for the ANOVA analyses testing for differences in the plots that were not burnt between 1954, 1959, and 1996. 255
Table 15-1: Weighted eigenvector plot scores from the CA on the 1954 species by plot data. The table also shows the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214). 256
Table 15-2: Weighted eigenvector species scores from the CA on the 1954 species by plot data. The table shows the species weights and the effective number of occurrences of the species (N2 diversity of species) (Hill 1973). The codes for the species are defined in Table 9-1 (p. 210). 257
Table 15-3: Weighted eigenvector plot scores from the CA on the 1996 species by plot data. The table also shows the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214). 259
Table 15-4: Weighted eigenvector species scores from the CA on the 1996 species by plot data. The table shows the species weights and the effective number of occurrences of the species (N2 diversity of species) (Hill 1973). The codes for the species are defined in Table 9-1 (p. 210). 260

UNDER

Table 15-5: Weighted eigenvector plot scores from the CA on the 1996 species by plot data with the first eight weighted eigenvector axes of the CA on the 1954 species by plot data as covariables. The table also shows the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214).....262
Table 15-6: Weighted eigenvector species scores from the CA on the 1996 species by plot data with the first eight weighted eigenvector axes of the CA on the 1954 species by plot data as covariables. The table shows the species weights and the effective number of occurrences of the species (N2 diversity of species) (Hill 1973). The codes for the species are defined in Table 9-1 (p. 210).....263
Table 15-7: Weighted eigenvector plot scores from the CA on the 1954 structure by plot data. The table also shows the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214). 265
Table 15-8: Weighted eigenvector structure scores from the CA on the 1954 structure by plot data. The table shows the structure weights and the effective number of occurrences of the structures (N2 diversity of structures) (Hill 1973). The codes for the structure groups are defined in Table 5-3 (p. 34). 266
Table 15-9: Weighted eigenvector plot scores from the CA on the 1996 structure by plot data. The table also shows the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214). 267
Table 15-10: Weighted eigenvector structure scores from the CA on the 1996 structure by plot data. The table shows the structure weights and the effective number of occurrences of the structures (N2 diversity of structures) (Hill 1973). The codes for the structure groups are defined in Table 5-3 (p. 34). 268
Table 15-11: Weighted eigenvector plot scores from the CA on the 1996 structure by plot data with the first eight weighted eigenvector axes of the 1954 CA of the structure data as covariables. The table also shows the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214). 269
Table 15-12: Weighted eigenvector structure scores from the CA on the 1996 data with the first eight weighted eigenvector axes of the 1954 CA of the structure data as covariables. The table shows the structure weights and the effective number of occurrences of the structures (N2 diversity of structures) (Hill 1973). The codes for the structure groups are defined in Table 5-3 (p. 34).....270
Table 16-1: The mean annual atmospheric CO_2 levels (ppmv) at ten Scripps Institution of Oceanography (SIO) air sampling sites between 1958 and 2003 (Keeling and Whorf 2004).....271
Table 17-1: The single-stem and multi-stem diameter classes used to classify individuals during the 1954 baseline survey (Van Der Schijff 1958). 296
Table 17-2: The height classes used to classify individuals in the 1996 survey. 296

WitSETD

TERMS AND DEFINITIONS

Block – Refers to a string of experimental plots adjacent to one another in the Experimental Burn Plot experiment. There are either 12 or 14 plots in a block (Biggs *et al* 2003). Block is interchangeable with replicate.

Control treatment – Refers to the Experimental Burn Plots treatments in which fire was excluded. Control treatment and no burn treatment are interchangeable.

EBP – Abbreviation for the Experimental Burn Plot experiment. This refers to the fire experiment established in the Kruger National Park in 1954.

Fire frequency –This refers to the regularity with which a fire treatment is applied. Fire frequency is inversely proportional to fire return period (inter-fire period). For example, a treatment that has been applied annually has a higher fire frequency than a treatment that has been applied triennially. Three fire frequencies were applied to the Experimental burn plots, namely Annual (every year), Biennial (every two years), and Triennial (every three years).

Fire return period – This refers to the period, in years, between fire events, namely annual (1 year), biennial (2 years), and triennial (3 years). Fire return period is interchangeable with inter-fire period.

Fire season – This refers to the time of the year of the fire events and is interchangeable with fire timing.

Fire timing – This refers to the time of the year of the fire events, namely February, April, August, October, and December. Fire timing is interchangeable with fire season.

Inter-fire period – This refers to the period, in years, between fire events, and is interchangeable with fire return period.

KNP – Abbreviation for the Kruger National Park.

LS Mean – Abbreviation for the least squares of a mean.

No burn treatment – Refers to the Experimental Burn Plots treatments in which fire was excluded. No burn treatment is interchangeable with control treatment.

Overstorey woody community – Refers to the community of woody individuals taller than 1m.

Plot – Refers to the smallest experimental unit in the Experimental Burn Plot experiment. Each plot is approximately 7ha in size. Treatments are applied to plots, and plots are grouped together in blocks or replicates (Biggs *et al* 2003).

Phytomass – This refers to the amount of vegetation as measured in the number of equivalent 1.5m high savanna trees (Trollope *et al*. 1990). Phytomass is not a measure of biomass. Phytomass is interchangeable with tree equivalents.

Replicate – This refers to a block of plots adjacent to one another in the Experimental Burn Plot experiment. Replicate is interchangeable with block.

ppmv – Abbreviation for parts per million by volume. The concentration of atmospheric CO_2 is measured in these units.

WitsETD

SADF – Abbreviation for the South African Defence Force.

SAFARI 92 – Abbreviation for the South African Fire-Atmosphere Research Initiative (SAFARI) that was conducted during 1992 (Van Wilgen *et al.* 1997).

SCOPE – Abbreviation for Scientific Committee on Problems of the Environment project (SCOPE 1978).

SE – Abbreviation for Standard Error.

SEM – Abbreviation for the Standard Error of the Mean.

SIO – Abbreviation for the Scripps Institution of Oceanography.

Treatment – In the context of the Experimental Burn Plot experiment this refers to a combination of fire timing and fire frequency applied to treatment plots (i.e. Biennial burn in February) (Biggs *et al* 2003).

Tree equivalents – This refers to the measure of the number of equivalent 1.5m high savanna trees there are in a collection. Tree equivalents are interchangeable with phytomass.

Trial – Refers to all the replicates of the Experimental Burn Plots experiment in the Kruger National Park (Biggs *et al* 2003).

Understorey woody community – Refers to the community of woody individuals shorter than 1m.

WitsETD

1 INTRODUCTION

Savanna ecosystems can be broadly described as “tropical grasslands with scattered trees” (Bourliere and Hadley 1970). The term savanna, refers to “a suite of tropical and subtropical vegetation types in which fire-adapted, co-dominant, continuous or discontinuous herbaceous [dominated by C_4 grasses] and largely deciduous woody strata experience markedly seasonal growth patterns and processes in relation to the seasonal delivery of precipitation, which occurs during hot summers, followed by cooler, but warm, dry winters” (Shackleton *et al.* 1999). The co-existence of the tree and grass elements as dominant components is a key factor that distinguishes savannas from other ecosystems (Scholes and Walker 1993, Scholes and Archer 1997). Fire is a dominant feature in savannas and is thought to have played a role in the evolution, establishment, and growth of savanna and grassland ecosystems from their woodland and forest origins (Vogl 1974; Bond and Van Wilgen 1995; Higgins *et al.* 2000, Bond *et al.* 2005). Fire is seen as one of the primary biotic factors, along with soil water depth, that mediates the co-existence between the tree and grass components in savanna ecosystems (Walter 1971, Walker and Noy-Meir 1982, Scholes and Walker 1993, Scholes 1997, Scholes and Archer 1997, Higgins *et al.* 2000, Bond *et al.* 2005).

The use of fire in the conservation management of savanna ecosystems has been and still is a controversial issue. This is mainly because fire has traditionally been used as an inexpensive and powerful management tool, instead of being viewed as an ecosystem process. However, this mindset has changed since the mid 1980’s with process based conservation management objectives having gained ground.

The formulation and implementation of a fire management policy in the Kruger National Park (KNP) in the early 1950's was characterised by controversy and disagreement. This controversy highlighted the lack of data and understanding of the role that fire played in this predominantly arid savanna ecosystem. In response to this controversy, a fire experiment was started in 1954, and the aim of the experiment was to provide a scientific basis for fire management policies within the KNP.

The experimental design of the fire experiment was a pseudo-randomised block design in which 12 fire treatments were replicated four times each, in each of four major veld types defined in the KNP by HP Van Der Schijff who was the resident assistant research biologist in Skukuza at the time (Van Der Schijff 1958). The four major veld types were, the sourveld of Pretoriuskop, the *Combretum* veld surrounding Skukuza, the Knob-thorn - Marula veld near Satara, and the Mopane veld between Shingwedzi and Letaba. The twelve treatments were no fire, annual fire in August, and biennial and triennial fires in February, April, August, October, and December.

In the mid 1990’s the Kruger National Park Scientific Services came under pressure to justify the cost and continued existence of the Experimental Burn Plots (EBP) experiment. Efforts were initiated to consolidate existing data and findings in order to finalise the experiment and provide recommendations regarding the future of the experiment and the experimental infrastructure. This MSc forms part of the finalisation of the Experimental Burn Plot experiment in the Pretoriuskop region of the Kruger National Park.

1.1 AIMS AND OBJECTIVES

The aim of this MSc was to investigate the long-term effects of the twelve fire treatments on the density, structure, and species composition of the woody vegetation in the Pretoriuskop sourveld region of the Kruger National Park.

The objectives of this study were to:

1. Conduct a complete survey of the trees and shrubs on the Pretoriuskop EBPs. In 1954, a baseline survey of the woody vegetation on each of the Pretoriuskop EBPs was conducted before the

experiment was started. Resurveying the Pretoriuskop EBPs in 1996 completed a 42-year period over which the long-term application of the fire treatments on the woody vegetation density, structure, and composition were investigated.

2. Capture into a digital format pertinent woody vegetation survey data from surveys that were conducted on the Pretoriuskop EBPs between 1954 and 1996. Since the inception of the EBP experiment, in 1954 a number of surveys had been conducted on the woody vegetation of the Pretoriuskop EBPs. However, none of the datasets from these surveys were available digitally and these required capturing and formatting.
3. Compare the density, structure, and composition of the woody vegetation on the Pretoriuskop EBPs between 1954 and 1996 to determine the effects of the prolonged application of the fire treatments on the woody vegetation. The Pretoriuskop EBP experiment is unique in the length of time that the experiment has been running and the comprehensive nature of the data available from the experiment. This provided a rare opportunity to investigate the effects of fire frequency and timing on the woody vegetation density, structure, and composition of the Pretoriuskop region.
4. Investigate the history of the Kruger National Park Experimental Burn Plots experiment. It is important to understand the historical context of the EBP experiment because it provides a framework within which the scientific value of the experiment can be assessed.

WitsETD

2 LITERATURE REVIEW

Vegetation fires are a global phenomenon, and although the properties of fire (intensity, type, season, extent, and frequency) vary considerably between ecosystems, the role of fire is often pivotal for ecosystem structure and functioning.

2.1 THE DETERMINANTS OF FIRE

The occurrence of fire in natural vegetation is dependent upon a number of factors (Bond and Van Wilgen 1996; Van Wilgen and Scholes 1997):

- There must be enough suitable fuel to support a fire.
- The climatic and soil conditions must support the growth of a vegetation structure, which provides suitable fuel to support a fire.
- Suitable weather conditions for a fire must be present.
- There must be an ignition source.

These factors vary from ecosystem to ecosystem and contribute to a wide variety of fire regimes globally. The determinants of fire can be broadly categorised into environmental determinants, vegetation determinants, fuel determinants, and fire characteristics (Figure 2-1). Unlike many other disturbance forces, fire is influenced by the biota of an ecosystem and hence the determinants of that ecosystem. Furthermore, each fire event is affected by previous fire events and impacts upon future fire events. This event-system feedback means that the characteristics of each fire event are determinants of the fire regime.

2.1.1 The environmental determinants of fire

Environmental characteristics such as climate, weather, soil, topography, herbivores, and ignition sources are the primary determinants of an ecosystem's fire regime (Figure 2-1). These characteristics determine whether fire will occur in an ecosystem, how regularly, and at what time of the year. Almost all vegetation types will burn if there is sufficient fuel to burn and if the fuel is dry enough to burn (Bond and Van Wilgen 1996; Van Wilgen and Scholes 1997). Therefore, the occurrence of fire is dependant on the soil, topography, and climate, which create an environment in which the primary production of the vegetation is high enough to produce suitable fuel to burn. The primary production of the vegetation must be greater than herbivore consumption and organic decomposition of the vegetation so that there is sufficient fuel accumulation to sustain fire. Furthermore, there must also be adequate dry periods so that the fuel is sufficiently dry to ignite, and finally, there must be ignition sources.

2.1.1.1 Climate and weather

Fires can occur under most climate regimes so long as there are periodic dry spells (Bond and Van Wilgen 1996). Climatic conditions also play an important role in determining when (season) and how often (frequency) fires occur, this is because climatic conditions are primary determinants of vegetation productivity. However, the weather plays an even more significant role in determining the exact occurrence and behaviour of fire. Apart from anthropogenic ignition sources, lightning, which is a weather related phenomenon, is considered the most widespread ignition source of wildfires (Komarek 1968, Komarek 1971). Furthermore, the moisture content of the fuel (living and moribund), which is also weather related, significantly affects the intensity and behaviour of fire (Trollope 1999b).

WISETD

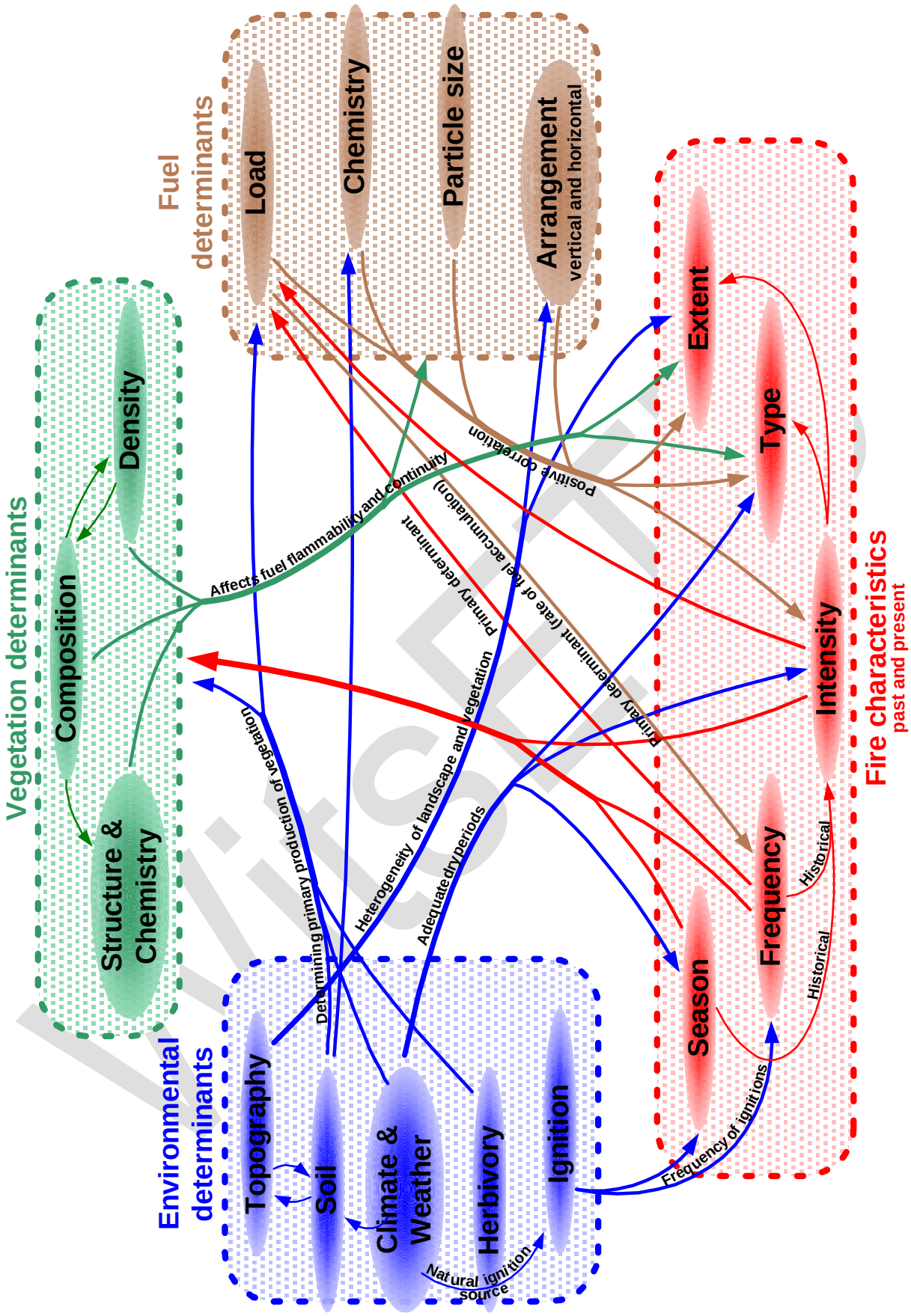


Figure 2-1: Model showing the interdependence of the determinants and characteristics of fire.

2.1.1.2 Soil and Topography

Soil and topography shape an ecosystem's fire regime in various ways. Both soil and topography determine the structure, composition, and density of the vegetation in an ecosystem (Witkowski and O'Connor 1996). For example, climatic conditions being similar, the primary production of vegetation is higher in ecosystems with fertile soils than in ecosystems with nutrient poor soils (Van Wilgen and Scholes 1997). This directly affects the amount of fuel and the fuel continuity within an ecosystem, which determines how a fire spreads through a landscape (Whelan 1995). Furthermore, topographic features such as rock outcrops, or less flammable plant communities can act as natural fire barriers hindering and even preventing the spread of fire within the landscape (Whelan 1995, Stalmans 2002).

2.1.1.3 Herbivory

Herbivores and fire are considered competitors for fuel, and so ecosystems with high levels of herbivory are less likely to burn than ecosystems with lower levels of herbivory (Van Wilgen and Scholes 1997). The converse is also true in that fires may have devastating effects on herbivore populations if they occur when food is scarce. These fire-herbivore interactions are mostly prevalent in grass-dominated ecosystems such as grasslands and savannas.

2.1.1.4 Ignition sources

All else being conducive, fire can only occur when there is an ignition source. The primary source of wildfire ignitions in most regions of the world in the last 10 to 20 thousand years has been anthropogenic (Komarek 1968, Komarek 1971). Lightening is the most general and widespread of the non-anthropogenic sources of ignition for wildfires (Komarek 1968, Komarek 1971). There are also records of less common sources of ignition such as rock falls and volcanic activity (Whelan 1995).

2.1.2 The characteristics of vegetation in fire prone ecosystems

The morphological, chemical, and structural properties of plants and plant communities play a significant role in the seasonal variability of their flammability (Whelan 1995, Bond and Van Wilgen 1996). This is because these characteristics influence the fuel properties of the vegetation, which determine whether, how and when an ecosystem will burn.

2.1.2.1 Structure and chemistry of the vegetation

The structure and chemistry of individual plants determines the structure and chemistry of fuel available to burn. The retention of dead plant parts is an important structural property that affects flammability (Bond and Van Wilgen 1996). The flammability of live plant material is much lower than that of dead plant material since the moisture content can be in excess of 200% greater in live plant material (Bond and Van Wilgen 1996). The physical structure of plants also contributes to their potential to burn. Fine leaves, stems and other plant parts, maximise the fuel surface area to air ratio, which optimises combustion of the fuel.

Furthermore, the chemical composition of plants also affects their flammability. Many plants have high concentrations of flammable oils and turpentines, which are effective herbivore deterrents. However, while protecting the plants from herbivory these chemicals make them highly susceptible to burning, and often at a higher intensity than if the chemicals were not present.

This poses the very interesting and tricky evolutionary question of whether flammability is an adaptive trait. This topic has been argued, with one notable hypothesis standing out, being that of Mutch (1970). Mutch proposed that the evolution of flammability was indeed an adaptive trait, the benefit being the exclusion of fire intolerant species within flammable communities. This hypothesis is fundamentally flawed since natural selection does not occur at the species or community level but rather at the level of the individual.

WISETD

Bond and Midgley (1995) rephrase Mutch's hypothesis to argue for the individual benefits of enhanced flammability. The essence of the individual benefits for enhanced flammability are "kill thy neighbour" and in doing so free up space and local resources for a more effective post fire recovery. Furthermore, in freeing up local resources and space the individual provides preferential sites for post fire recruitment into previously unoccupied space. This model predicts that enhanced flammability is most likely to evolve in dense tree populations such as conifer and eucalyptus forests, as opposed to in solitary trees such as in savanna ecosystems.

2.1.2.2 Species composition of the vegetation

The species composition of vegetation communities is critical to their flammability. Communities comprising flammable species, that is species with low moisture content and fine plant parts (leaves and stems), are likely to burn more vigorously than communities with less flammable species (Bond and Van Wilgen 1996).

2.1.2.3 Density of the vegetation

The density of the vegetation also plays a role in the flammability of vegetation since the homogeneity of fuel determines the rate of spread and extent of a fire.

2.1.3 The characteristics of fuel in fire prone ecosystems

Fuel is dead and/or live plant material that will burn. Fuel characteristics are a function of vegetation and environmental characteristics. Besides the quantity of material available to burn, the size, arrangement, and chemistry of the fuel are also important in determining the behaviour of fire within an ecosystem (Bond and Van Wilgen 1996) (Figure 2-1).

2.1.3.1 Fuel load

Fuel load is measured as the total dry weight of fuel per unit of surface area, and this is used as a surrogate measure of the amount of energy stored in the fuel (Whelan 1995). There is a strong positive correlation between fuel load and fire intensity (Whelan 1995). Fuel load is a function of time since the last fire, until the rate of fuel accumulation is balanced by the rate of fuel decomposition (Whelan 1995; Bond and Van Wilgen 1996). Decomposition is like herbivory in that it competes with fire for fuel, and ecosystems with high decomposition rates are less likely to burn than ecosystems with lower decomposition rates (Bond and Van Wilgen 1996). Hence nutrient rich ecosystems, in which the decomposition rates are fast, are less likely to burn than nutrient poor ecosystems, in which decomposition rates are slow.

2.1.3.2 Chemistry of the fuel

The chemical composition of the fuel affects the flammability of the fuel. The presence of oils, fats, waxes, and terpenes in dead and/or live fuel makes them more susceptible to fire (Whelan 1995; Bond and Van Wilgen 1996). These chemicals are volatile and are driven out of the plants at relatively low temperatures and then burn as gasses, this makes the fuel more flammable (Bond and Van Wilgen 1996). Furthermore, oils and waxes have up to two times the combustion heat values of other plant constituents resulting in more intense burning (Bond and Van Wilgen 1996).

2.1.3.3 Particle sizes of the fuel

The size distribution of fuel affects the likelihood of an ignition occurring (Whelan 1995; Bond and Van Wilgen 1996). The fuel size distribution also affects fire intensity because the size distribution affects the fuel surface area to air ratio (Whelan 1995; Bond and Van Wilgen 1996). The more fuel surface area that is in contact with air the more oxygen there is available to promote the combustion reaction. Once a fire has started the size of the fuel particles affects the rate of spread of the fire, the fire intensity, and the local

WISER

persistence of high temperatures. This is because there are three stages when vegetation burns (Trollope 1983; Whelan 1995):

1. Preheating of the fuel just ahead of the fire front, in which the fuel is dried and slightly burnt.
2. Flaming combustion in which flammable hydrocarbon gasses are released and ignited
3. Glowing combustion phase in which the remaining charcoal is consumed leaving ash.

The fine fuels are consumed in the flaming combustion phase and are responsible for the spatial propagation of the fire (Whelan 1995), while the larger fuel particles are burnt more slowly in the glowing combustion phase and are responsible for the temporal longevity of the fire.

2.1.3.4 The vertical and horizontal arrangement of the fuel

The arrangement of the fuel is important in determining how hot a fire will be (intensity) and how extensively the fire will burn (size). Fuel that is packed tightly affects the aeration, and the combustion rate of the fuel (Whelan 1995), while fuel packed loosely affects the propagation of fire. The horizontal arrangement of fuel affects the rate of spread of fire and the fire size, while the vertical distribution of fuel is important in determining the type and intensity of a fire (Whelan 1995).

2.1.4 The characteristics of fire

As with most other recurrent disturbances, fire can be classified by a regime (Sousa 1984). The most important characteristics of a fire regime are type, intensity, timing, frequency, and extent (Figure 2-1).

2.1.4.1 Type of fire

There are three main types of vegetation fire, namely ground fires, surface fires and canopy fires (Trollope 1983, Albini 1993; Whelan 1995, Bond and Van Wilgen 1996). Ground fires occur in subsurface organic fuels, surface fires occur above ground in grass and litter layers, and crown fires spread through the canopy layer in stands of trees (Trollope 1983, Albini 1993; Whelan 1995, Bond and Van Wilgen 1996). The type of fire that occurs in an area depends on the type of vegetation and climate of the area (Whelan 1995). Furthermore, in fire managed areas the ignition procedure, namely point versus perimeter ignition, also determines the type of fire.

2.1.4.2 Timing of fire

The timing is when the fire occurs. This is important because soil moisture, vegetation moisture, humidity, and temperature change both daily and seasonally, and these are key factors in determining the behaviour of the fire and its intensity. The primary determinant of season is climate since this determines the season of natural ignition sources like lightning (Whelan 1995).

2.1.4.3 Frequency of fire

Frequency is how often fire events occur, which is generally a function of two factors: the rate of fuel accumulation since the last fire event and the frequency of ignitions (Whelan 1995).

2.1.4.4 Intensity of fire

Intensity is a measure of how fiercely a fire burns (Bond and Van Wilgen 1996). A number of characteristics are used to measure fire intensity, namely vertical distribution (mean flame height) of the fire, the rate of spread of the fire, the rate of heat release of the fire, and the total heat release (energy) of the fire (Trollope 1983, Whelan 1995). Once a fire has started, a range of factors affect the intensity of the fire like weather, topography (slope and aspect), fuel load, fuel distribution, and fuel chemistry (Whelan 1995; Bond and Van Wilgen 1996). Fire history will also have an affect on intensity (Whelan 1995).

2.1.4.4.1 The effect of fire frequency and fire timing on fire intensity

The intensity of a fire event is affected by the time of the fire event and the period since the last fire event. Fire frequency affects fire intensity because the amount of fuel accumulated before a fire event is related to the time since the previous fire event. This is because after a fire the fuel load increases until the rate of fuel decomposition equals the rate of fuel accumulation. Ecosystems that have high decomposition rates have lower fuel loads and ecosystems with low decomposition rates have higher fuels loads (Whelan 1995; Bond and Van Wilgen 1996). Fuel load determines the maximum energy available to a fire (Whelan 1995). This means that the higher the fuel load the more intense a fire is likely to be. Therefore, the intensity of a fire is related, among other things, to the time since the previous fire event. Fire timing affects fire intensity because soil, air, and fuel moisture are linked to season. These factors affect fire intensity directly and the higher the soil, air and fuel moisture the less intense a fire is likely to be.

2.1.4.5 Extent of fire

The extent of the fire is the size of the fire, or the surface area in space that is burnt by the fire. This is influenced by many of the characteristics that determine an ecosystem's fire regime. Topography and vegetation can create natural barriers to passage of fire in the landscape (Whelan 1995; Bond and Van Wilgen 1996). Fire history also plays a role because an area that has been burnt recently may be less flammable because of the patchy nature of the fuel (Whelan 1995).

The characteristics and determinants of fire are spatially and temporally interdependent on one another (Figure 2-1), and variations in these fire characteristics define the fire regimes for different ecosystems.

Fuel comprises both dead and/or live vegetation. It is quite interesting that the higher the productivity of a system, all-else being conducive, the higher the probability of fire. Plants ultimately contribute to their own conflagration.

2.2 HOW DO PLANTS SURVIVE FIRE EVENTS?

When considering the survival of plants in fire events there are two components to consider: (1) surviving the direct effects of fire, and (2) surviving in the post fire conditions (Whelan 1995).

2.2.1 Surviving the direct effects of fire

The direct effects of fire on plants are the result of raising the temperature of the living tissue. These can range from brief disruption of biochemical pathways to the complete combustion of the tissue resulting in mortality (Whelan 1995). The physical effects of fire on woody plants are burning the bark and killing cambium, leaves, buds, twigs, and branches (West 1969). Plants are made up of repeating units (modules) that make up the entire plant (genet) (Begon *et al.* 1986). Some modules can be damaged or even die without resulting in the death of the genet. This equips plants for a sessile existence in fire prone environments, where part of a plant may be burnt and die but the entire plant does not necessarily die. Some tissues are however critical to the survival of plants. For example damage to or death of meristematic tissue, which is important for new growth, is critical to the post fire persistence of a plant (Whelan 1995). Damage to the vascular tissue found in the cambium, which transports minerals and nutrients throughout the plant body, can result in the mortality of entire modules of a plant through starvation (Whelan 1995). Mortality of seeds, which are one of the mobile phases in a plant's life history, has a large impact on the continued persistence of individual plant genets and even that of the species within a fire prone environment (Mbalo and Witkowski 1997, Garner and Witkowski 1997).

There are two ways plants critical tissues survive fire:

1. The critical tissues can have higher lethal temperatures, which allow the tissues to survive exposure to heat. The lethal temperature of a tissue is affected by a number of factors, for example the state of

metabolic activity of the cells, and the level of hydration of the cells (Whelan 1995; Bond and Van Wilgen 1996). Lethal temperatures of a plant however, do not vary much regardless of the metabolic or hydration state of the plant (Whelan 1995; Bond and Van Wilgen 1996).

2. The critical tissues can be physically protected from fire damage, for example, cambium and meristematic tissues are protected from heat damage by bark (Whelan 1995; Bond and Van Wilgen 1996, Wilson and Witkowski 2003). Critical tissues can also be protected from heat damage by being placed out of harms way, for example, subterranean meristematic tissue and nutrient storage tissues are insulated against heat radiation by overlying soil, or meristematic tissues occur at a height that effectively protects them from being damaged by heat radiation (Whelan 1995). Seeds are protected from heat damage in a variety of ways such as having a protective fruit covering or being buried in the ground (Whelan 1995, Garner and Witkowski 1997).

Protecting critical tissue is not enough to ensure that a plant survives fire. Plants also require adequate non-structural carbohydrate reserves, which are necessary for them to sprout from meristematic tissues (Ligavha *et al.* 1999, Hoffmann *et al.* 2000). These non-structural carbohydrate reserves are replenished between fire events, and the replenishment of carbohydrate reserves following burning or cutting of woody plants may take 1 to 2 years (Miyanishi and Kellman 1986). Many woody fire tolerant savanna species form underground carbohydrate storage organs called ligno-tubers, which provide the necessary non-structural carbohydrates for sprouting after fire damage.

Having protected the critical tissues from the direct effects of fire and stored enough carbohydrate reserves to sprout after a fire, what post fire survival strategies do plants have?

2.2.2 Post fire survival strategies

There are wide varieties of plant responses to fire. These responses can however, be categorised into four plant types (Whelan 1995; Bond and Van Wilgen 1996):

1. Annual and pauciennial plants: The life histories of these plants are not linked to fire because their life spans often occur completely between the fire events.
2. Fire ephemeral plants: These plants depend on fire for regeneration, and usually appear after fire events, have a short life span, and are usually dead before the next fire event.
3. Obligate seeding or non-sprouting plants: These plants usually die after a fire event without sprouting. The persistence of these species in an ecosystem rests solely on the production and germination of seeds. There are two main categories of non-sprouting plants, namely non-fire-recruiting non-sprouters and fire-recruiting non-sprouters.
    a. Non-fire-recruiting non-sprouters are plants that die after fire events and whose reproductive recruitment is not linked to fire events. These plants are not common in fire prone environments, however where the inter-fire periods are long enough they may become dominant, and can even transform the fuel properties of a community (Bond and Van Wilgen 1996).
    b. Fire-recruiting non-sprouters are plants that die after fire events and whose reproductive recruitment is linked to fire events. These plants have discrete populations of even-age cohorts with non-overlapping generations between fire events, and the populations usually decline between fires (Bond and Van Wilgen 1996). The main concern about the persistence of these species is the size of their seed banks. These species can become locally extinct when the inter-fire periods are too short or too long, when in both cases their seed banks become exhausted through seed germination without replacement or seeds losing viability (Bond and Van Wilgen 1996).
4. Sprouters: These plants survive fire events by sprouting from protected meristematic tissue. These plants may also rely on seeds for persistence. There are two main categories of sprouters, namely non-fire-recruiting and fire-recruiting sprouters.

WISETD

a. Non-fire-recruiting sprouters are plants that sprout in response to fire events and whose reproductive recruitment is not linked to fire events. Fire sensitive seedlings often die in fire events, and short inter-fire periods often eliminate fire sensitive juveniles. These populations often comprise overlapping generations because seed germination is not linked to discrete fire events. The populations usually increase between fire events (Bond and Van Wilgen 1996).
b. Fire-recruiting sprouters: These plants sprout in response to fire events and their reproductive recruitment is linked to fire events. These species have discrete population growth after fire events and the populations usually decline between fires (Bond and Van Wilgen 1996).

2.2.3 Post fire resilience and inertia

Plant life history phases can be classified as being resilient or inert to disturbance events such as fire (Malanson 1987). Resilient life history phases are those in which disturbance events affect the individuals in some way and the individuals then recover from the disturbance. Inert life history phases are those in which individuals resist the disturbance event in some way, and failure to resist the disturbance event results in mortality.

Sprouting species in fire prone ecosystems go through a number of life history phases such as the seedling phase, the suppressed juvenile phase, and adult phase. Each of these life history phases is different regarding their resilience or inertia to fire events. In the seedling phase, individuals are generally fire intolerant, and the post-fire mortality rate for these individuals is high. The seedling phase of sprouting species is an inertial phase in which individuals that fail to resist the disturbance event die. In the suppressed juvenile phase, individuals are fire tolerant but not sexually mature. Fire resistance and sexual maturity of individuals in the suppressed juvenile phase have been linked to the stem height of the plants and the thickness of the bark on the stems (Trollope 1999a, Higgins *et al.* 2000, Wilson and Witkowski 2003). Plants in the suppressed juvenile phase are often burnt back before their stems reach a height at which their bark is thick enough to protect the underlying cambium tissue. Bond and Van Wilgen (1996) call these suppressed individuals “gullivers” and they may persist in a stunted sexually inactive form in the herbaceous layer for many years constantly being suppressed by fire before escaping to a fire resistant height. Gullivers recover quickly from fire events even when they experience total top kill. The suppressed juvenile phase of sprouting species is a resilient phase in which the individuals are affected by the disturbance but they recover. In adult phase, individuals are fire resistant and sexually mature. Unless a fire event is unusually intense, the adults seldom die because of fire. The adult phase of sprouting species is an inertial phase in which the individuals resist the fire and most often survive. Very intense fire events may result in the mortality of adult sprouters because in the adult phase they seldom sprout after top kill (Whelan 1995).

Non-sprouting species in fire prone ecosystems are fire sensitive in all their life history phases. These individuals have an inertial response to fire throughout their lifetime and inevitably die when the fire events are too intense.

In a fire prone environment, frequent low intensity fires favour inert life history phases where individuals survive and persist after the fire events over resilient life history phases where the individuals must recover after the fire event (Malanson 1987). Very infrequent low intensity fires also favour inert life history phases, and high intensity fires at medium inter-fire periods favour resilient life history phases (Malanson 1987). Intermediate fire regimes comprising high and low intensity fires at a range of return periods favour the coexistence of resilient and inertial life history phases (Malanson 1987). Therefore, diversity is expected to be highest when a mixture of inertial and resilient responding individuals coexists. This occurs under an intermediate fire disturbance regime.

WITHDRAWN

2.2.4 Understanding species responses under different fire regimes

The make up of a woody community determines the effect fire events have on the vegetation density, structure, and composition of the woody vegetation. Post fire survival strategies of woody species describe the main effects fire events have on individuals. Resilience and inertia refine the description concerning the individuals' response to disturbance timing, frequency, intensity, and size. Post fire survival strategies and inertia and resilience responses of life history stages provide a convenient model for predicting community response to fire regimes. For example:

- When inter-fire periods are medium and fire intensities are high, resilient fire responses are expected to dominate over inert fire responses. The higher the intensity of a fire the higher the likelihood a woody plant has of being severely damaged. Inert individuals damaged by high intensity fires may be unable to recover and might die, whereas resilient individuals damaged by high intensity fires are able to recover, given adequate time between fire events.
- When the inter-fire periods are long, obligate seeders that reach sexual maturity between fire events are expected to coexist with sprouters.
- When the inter-fire periods are similar in length of time to the age of sexual maturity then fire-recruiting individuals (obligate seeders and sprouters), are expected to dominate over non-fire-recruiting individuals (obligate seeders and sprouters). This is because the reproductive potential of fire-recruiting individuals is maximised by their recruitment being synchronised with the inter-fire periods, and their potential for reaching fire resistant or fire tolerant heights between fire events is maximised.
- When the inter-fire periods are medium and the fire intensities are high, fire-recruiting sprouters are expected to dominate as fire suppressed juveniles, which are resilient life history phases.

2.3 SAVANNAS AS FIRE PRONE ENVIRONMENTS

Fire is a ubiquitous phenomenon and in comparison with other herbivorous activities can consume up to 80% of above ground primary production in some ecosystems (Bond and Van Wilgen 1996). Many ecosystems have developed with fire playing an integral and often pivotal role within the ecosystem's functioning, structure and composition. There are as many fire regimes as there are vegetation types and climate regimes, and they range from annual fires in grasslands to crown fires occurring every 100 – 1000 years in the North American coniferous forests (Bond and Van Wilgen 1996). The focus of this study is savanna ecosystems, in particular the southern African savannas.

Savannas are characterised by the coexistence of both grasses and trees. The tree-grass mix in savanna ecosystems ranges from woodlands with grass, to grasslands with trees, from near desert arid lands, to near tropical woodlands (Scholes and Walker 1993).

Globally savannas occupy some twenty percent of the earths land surface, and are second to tropical forests in contributing to terrestrial primary production. They occupy more than 40% of the land surface of Africa (Scholes and Walker 1993).

Savannas are difficult to define precisely, however, one common characteristic is that both the grass and woody components affect ecological processes, such as primary production, hydrology and nutrient cycling, above all other vegetation components (Scholes and Walker 1993).

Savannas are found on varied soil types however, soil organic matter content is generally low. They occur in the hot regions of the world that have highly seasonal rainfall and prolonged dry seasons, which permit frequent hot fires (Scholes and Walker 1993).

Fire plays a vital role in savanna ecosystem structure and function. It varies in return period from annual to more than ten years and up to fifty years between fire events. The main season for fire occurrence is the dry

WISER

season. However, fires do occur all year round, with their intensity being lower and their size (extent) being smaller in the wet season (Scholes and Walker 1993; Bond and Van Wilgen 1996).

2.3.1 Determinants of southern African savannas

Four main factors (water supply, nutrient supply, herbivory and fire) determine savanna structure and function (Scholes and Walker 1993). These four factors have been used in trying to understand and model, savanna ecosystem dynamics, especially the seemingly unstable coexistence between trees and grass.

As water is a strong determinant in savanna ecosystems, they are found in areas whose average rainfall ranges from 350 to 1800 mm (Scholes and Walker 1993). The water requirements of savanna plants has been found to be a main determinant of the spatial plant patterns in savannas, which often closely match the pattern of subsurface water supply in space (Scholes and Walker 1993). Water availability also plays an important function because it determines the length of the period during which primary production and nutrient mineralization can occur in savanna ecosystems (Scholes and Walker 1993).

Savannas in Southern Africa have been classified into two main groups based on biotic patterns that coincide primarily with moisture availability (Huntley 1982). These two groups are arid savannas and moist savannas. Arid savannas are those that receive less than 650 mm rainfall annually, and moist savannas receive more than 650 mm rainfall annually (Huntley 1982). Moist savannas tend to be infertile with deeply leached soils, whereas arid savannas tend to be fertile (Scholes and Walker 1993; Van Wilgen and Scholes 1997). This association between savanna ecosystems and water appears to be quite clear. However, at finer scales plant water relationships have been used unsuccessfully in trying to model the tree-grass coexistence in savannas (Bond and Van Wilgen 1996).

2.3.2 The effect of fire on the woody vegetation of savanna ecosystems

The effect of fire on woody vegetation is dependent on the amount of heat energy released by the fire, the rate of spread, and the vertical profile of the heat distribution (Trollope 1984). The post fire survival strategy and resilience or inertia regarding fire of the life history phase of a plant determines the plant's response to fire.

The woody component of savanna ecosystems is dominated by species that sprout in response to fire damage (Scholes and Walker 1993; Bond and Van Wilgen 1996). The resilience or inertia to fire of the life history phases of sprouters determines their response to fire events. Seedlings usually die in fire events, however the mortality rates of suppressed juveniles, and adults are typically low but increase with increasing fire intensity (Higgins *et al.* 2000).

Frequent fire events appear to favour grassland and savanna ecosystems in regions with climates that are capable of supporting woodland and forest ecosystems (Vogl 1974). Fire interrupts the competitive advantage of the woody species and provides for the coexistence of both the woody and grass elements as dominant components (Malanson 1987, Scholes and Walker 1993, Scholes 1997, Higgins *et al.* 2000). Higgins *et al.* (2000) argue that variation in the abundance of trees in savanna ecosystems is dependant on demographic bottlenecks at the seedling recruitment or sapling release stage. Fire frequency regulates these demographic bottlenecks. The more frequent the fires the lower the chance of seedlings and saplings growing to a mature adult in between fire events. Mortality of these seedlings and saplings is not necessarily high and consequently a seedling and sapling "bank" develops. Sporadic favourable conditions (i.e. an unusually long period between successive fires) result in the release of seedlings and saplings, and these individuals grow to mature reproductive adults resulting in the density of adult tree population increasing to form savanna woodlands or forests. Periodically events occur (i.e. very intense fires) in which the mortality of the mature adult trees is high and the savanna woodlands and forests are converted to open savanna grasslands. Generally, the most universal effect of fire frequency on savanna woody plant communities is

WISER

that as the fire interval increases, the density, height, canopy volume and biomass of the woody vegetation tends to increase (Scholes and Walker 1993).

2.3.3 The role of fire in the management of savanna ecosystems

Because the coexistence of trees and grass in savanna ecosystems is perceived to be so unstable, the role of management in maintaining the stasis in conservation areas has been a conscious and often controversial one. In many ecosystems not much can be controlled, however, fire has proved to be a very powerful and cost-effective management tool for both agricultural and conservation purposes. It can be used to prevent uncontrolled fires by reducing the fuel load, or to control parasite populations. However, even more importantly fire can be used to alter the vegetation structure and composition and has frequently been prescribed as a low cost means of opening up woodlands for pastoral purposes or opening up wooded areas that were not previously wooded (Trollope 1980, Sweet 1982).

The use of fire in conservation management has long been a controversial issue. The reason for this is that the role of fire within these ecosystems is not always clearly understood, and it was from these roots of disagreement and uncertainty that the Kruger National Park Experimental Burn Plots experiment was established in 1954.

2.4 ELEVATED CO_2 LEVELS, FIRE AND THE MANAGEMENT OF SAVANNA ECOSYSTEMS

C_4 grass dominated grasslands and savanna ecosystems appeared in the late Miocene period some six to eight million years ago (Cerling *et al.* 1997). The Miocene was a time of warmer global climates than those in the proceeding Oligocene, or the following Pliocene, and atmospheric CO_2 levels dropped below 500ppm during this period (Cerling *et al.* 1997). This drop in CO_2 levels favoured the expansion of C_4 grass dominated ecosystems over C_3 tree dominated ecosystems (Ehleringer *et al.* 1997). The widespread post industrialisation combustion of fossil fuels has resulted in a dramatic increase on the levels of tropospheric CO_2 (Ludewig *et al.* 1998). An increase in the levels of atmospheric CO_2 is expected to affect not only savanna ecosystems but also all vegetation ecosystems globally.

CO_2 is a major source of organic carbon, which is assimilated by plants during photosynthesis (Ludewig *et al.* 1998). Since CO_2 limits the rate of photosynthesis it is expected that vegetation will respond to elevated CO_2 with enhanced rates of photosynthesis and greater production of carbohydrates leading to a significant increase in plant growth and crop yield (Ludewig *et al.* 1998). Excess non-structural carbohydrates are converted to starch and are stored in leaves and roots for future use (Idso *et al*. 2000b). Furthermore, a strong correlation has been found in the size and number of tubers and elevated CO_2 levels, in plants that produce underground starch storage organs (Bhattacharya *et al.* 1985, Ludewig *et al.* 1998, Miglietta *at al.* 1998, Idso *et al*. 2000a). Some plants respond to elevated CO_2 conditions by reducing their stomatal apertures because the inward diffusion of CO_2 for photosynthesis is adequate at smaller apertures (Idso *et al*. 2002a). The net result is that plants are able to assimilate enough CO_2 while reducing their loss of water via transpiration effectively increasing their water use efficiency (Idso *et al*. 2000b). Bond *et al.* (2002 and 2003) suggest that the increased water use efficiency of C_3 plants under elevated CO_2 conditions in savanna ecosystems effectively creates moister conditions for the plants. For example, 500mm of rainfall experienced at CO_2 levels of 370 ppm would be equivalent to about 300mm of rainfall at CO_2 levels of 180 ppm (Bond *et al.* 2002). As the CO_2 levels in the earths atmosphere increase and plants loose less water and produce more biomass it is expected that perennial woody species will become more dominant relative to annual herbaceous plants (Idso *et al*. 2003). Furthermore, these perennial woody species are expected to expand their ranges more than non-woody species with future increases in the levels of CO_2 (Idso *et al*. 2003).

Many woody savanna species respond to fire damage by sprouting from undamaged meristematic tissue, which requires non-structural carbohydrate reserves. Elevated CO_2 levels result in an increase in the storage of non-structural carbohydrates in many C_3 plants, and it is proposed that this will enhance the post-fire

recovery of some savanna trees (Bond and Midgley 2000, Hoffman *et al.* 2000). Simulations using Sheffield Dynamic Global Vegetation Model (DGVM) with fire predict that trees would be eliminated from mesic savannas at low CO_2 levels (180 ppm) (Bond *et al.* 2003). This is because the post-fire recovery rate of the trees is slow (15 years) in comparison with the potential fire return period (2 years) (Bond *et al.* 2003). Further simulations predict that the density of trees should increase in mesic savannas at current CO_2 levels (360 ppm) (Bond *et al.* 2003).

This creates a fascinating management dilemma for the conservation management of mesic savannas. Does one allow mesic savannas to become more wooded as the global CO_2 levels increase, or does one actively intervene in the management of the system, using fire for example to manipulate the vegetation and create desired vegetation state.

WitsETD

3 STUDY AREA

3.1 THE EXPERIMENTAL BURN PLOT EXPERIMENT LAYOUT AND DESIGN

The Experimental Burn Plot (EBP) experiment was set-up in a pseudo-randomised block design. Four replicates of treatments were placed in each of four major plant communities that had been defined by Van Der Schijff (1958) at the time (Figure 3-1), namely the *Terminalia- Dichrostachys* sourveld with long grass of Pretoriuskop, the *Combretum* veld between Skukuza and Pretoriuskop, the Knob-thorn – Marula veld near Satara, and the Mopane veld between Shingwedzi and Letaba. In 1954, each replicate comprised seven plots to which seven fire treatments had been randomly assigned (Annual report 1954, Van Der Schijff 1958). These treatments were no burning at all, annual fire in August, and biennial fire in August, October, December, February, and April (Table 3-1). In 1956 the experiment was expanded, and a further five treatments were added and randomly assigned to each of the replicates. The treatments were triennial burns in August, October, December, February, and April (Table 3-1) (Annual report 1955, Annual report 1956, Van Der Schijff 1958). In total the EBP experiment comprised twelve fire treatments, replicated four times each in each of the four major vegetation zones (Figure 3-1 and Table 3-1) making a total of 192 plots covering 12km^2 in the KNP. Biggs *et al*. (2003) concluded that, since the treatments had not been allocated to the replicates completely randomly, the EBP experiment was not a true randomised block design and could only be considered pseudo-randomised.

A detailed description of the layout and application of the experiment is presented in the Results chapter in "A critical analysis of the history of the Kruger National Park Experimental Burn Plots experiment" (p. 43).

Table 3-1: The twelve treatments applied to the plots on four replicates (blocks) within each of the four major plant communities defined at the time by Van Der Schijff (1958). The table also shows the year in which the treatments were started, and the treatment code by which the treatments are referred to throughout this document in tables and figures.

Year started	Return period	Timing	Description	Treatment code
1954	None	None	No Burn (Control)	Con0
	Annual	August	Annual burn in mid-winter	Aug1
	Biennial	August	Biennial burn in mid-winter	Aug2
	Biennial	October	Biennial burn after the first rains	Oct2
	Biennial	December	Biennial burn in mid-summer	Dec2
	Biennial	February	Biennial burn in late summer	Feb2
	Biennial	April	Biennial burn in Autumn	Apr2
1956	Triennial	August	Triennial burn in mid-winter	Aug3
	Triennial	October	Triennial burn after the first rains	Oct3
	Triennial	December	Triennial burn in mid-summer	Dec3
	Triennial	February	Triennial burn in late summer	Feb3
	Triennial	April	Triennial burn in Autumn	Apr3

This project deals with that part of the EBP experiment that was laid out in the Pretoriuskop sourveld.

3.2 THE PRETORIUSKOP LANDSCAPE

The Pretoriuskop sourveld is a moist infertile or mesic savanna, and is located in the south west of the Kruger National Park (KNP) (31°10'E, 25°10'S) (Figure 3-2) (Acocks 1953, Van Wilgen and Scholes 1997, Scholes 1997). As with many mesic savanna ecosystems, it is characterised by the predominance of broad-leaved thorn-less trees, relatively high annual rainfall, and nutrient poor soils.

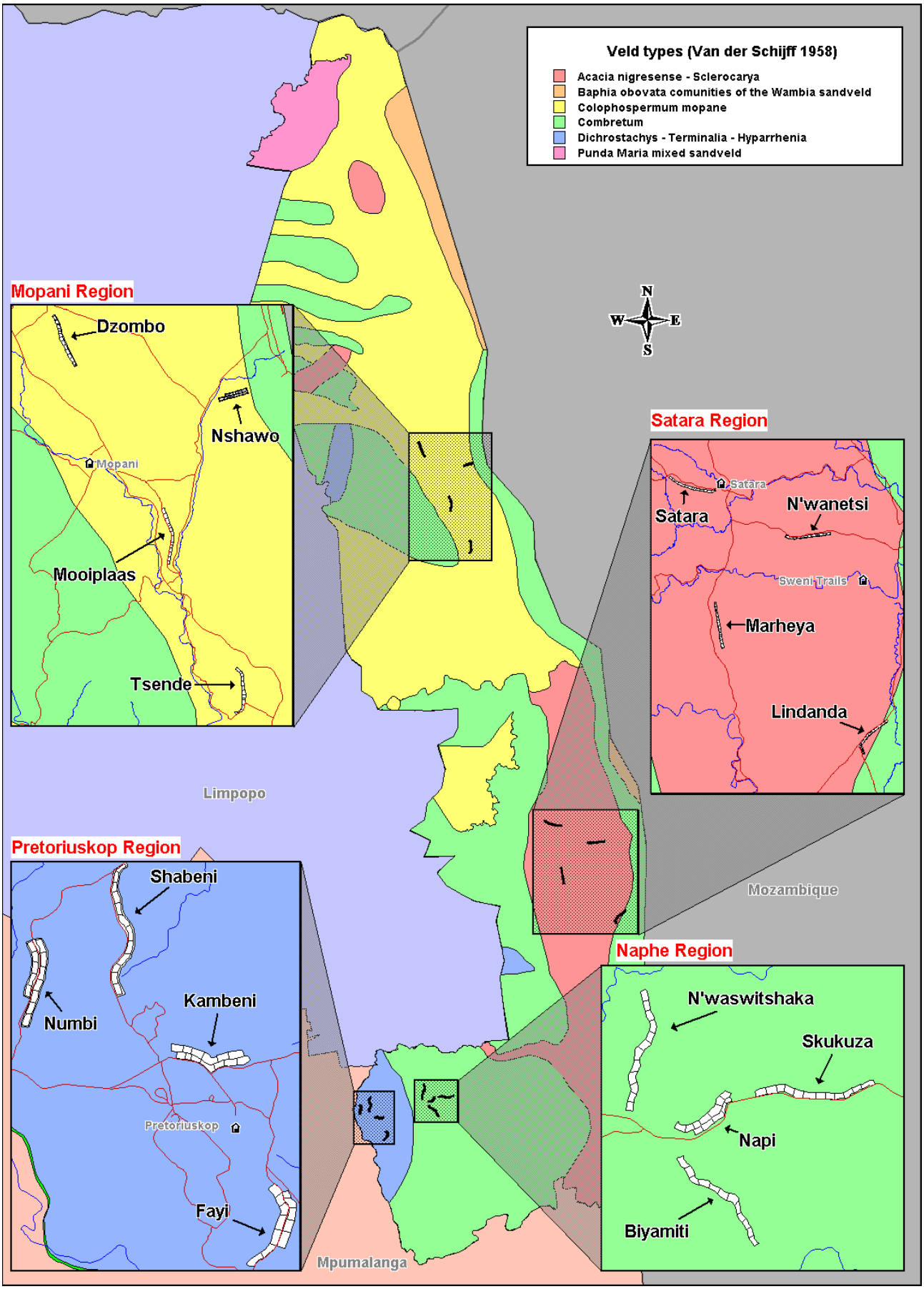


Figure 3-1: The layout of the Experimental Burn Plot experiment in the four broad vegetation communities defined by Van Der Schijff (1958) in the Kruger National Park.

3.2.1 Environmental features of the Pretoriuskop region

Pretoriuskop has a warm subtropical climate, with annual temperatures that range from 4-39 °C (Gertenbach 1983). The average summer (December – February) temperatures in the Pretoriuskop region vary from 18-30 °C, and the average winter (June- August) temperatures vary from 10-25 °C (Gertenbach 1983).Annual rainfall in the Pretoriuskop region ranges from 600-1000mm with an average of about 744mm, which is higher than for the rest of the KNP (Gertenbach 1980a, Venter and Gertenbach 1986). The wet season is during summer with 85% of total annual rainfall occurring between October and March (Munnick *et al*. 1990).

The terrain is moderately undulating, with isolated steep rocky outcrops and a dendritic drainage pattern (Munnick *et al.* 1990). The soils on the watersheds vary from sandy to loam, and are deeply leached. In the drainage lines, the soils are well developed with an accumulation of clays and minerals (Gertenbach 1983).

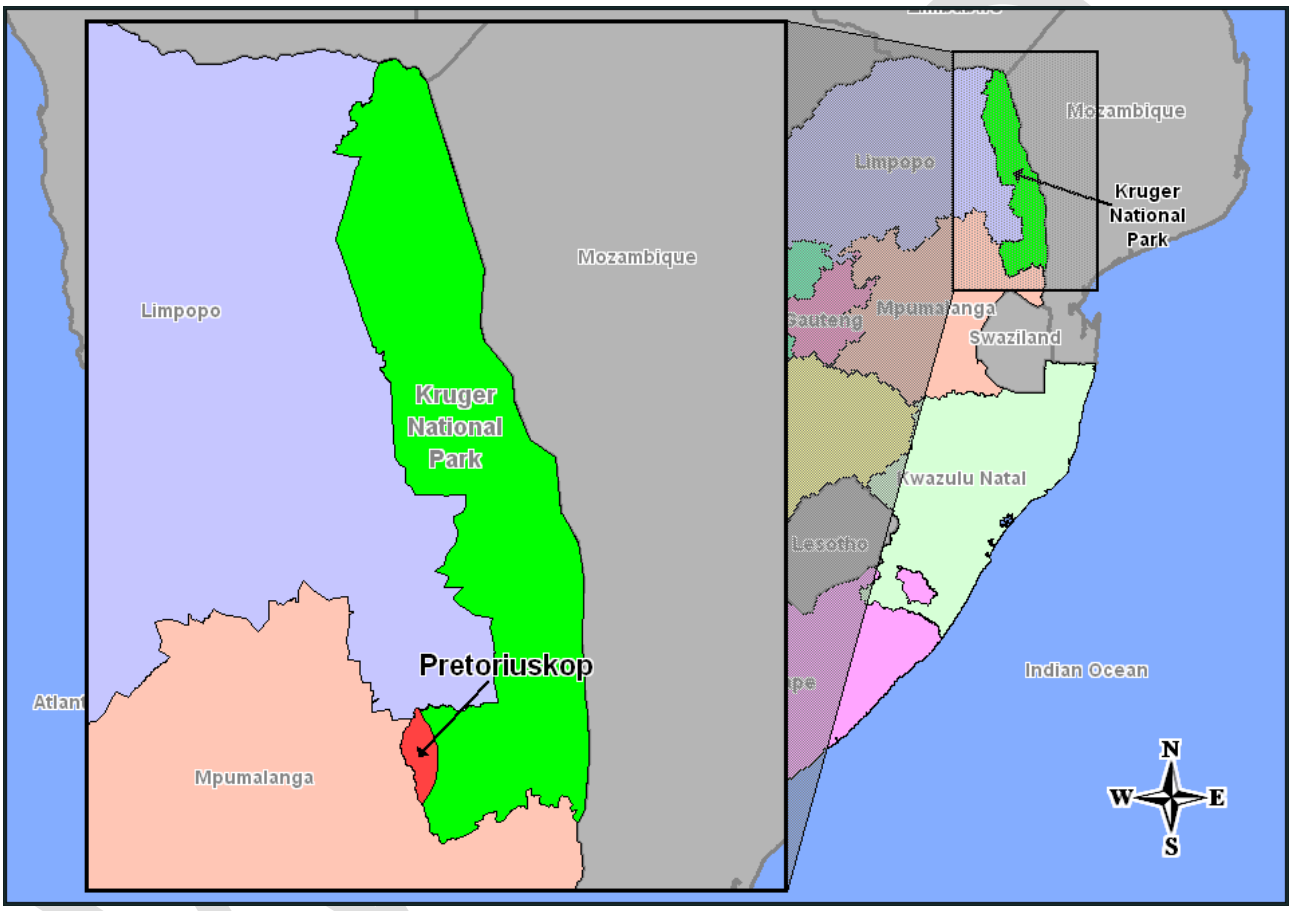


Figure 3-2: Pretoriuskop is located in the south west of the Kruger National Park.

3.2.2 Vegetation description of the Pretoriuskop region

Acocks (1953) describes the vegetation of this area as the Lowveld Sour Bushveld. It has also been described as broad-leaved deciduous woodland with tall grass (Van Der Schijff 1958). The vegetation on the watersheds is predominantly open woodland, while the low-lying areas and drainage lines are more densely covered with trees and shrubby vegetation (Gertenbach 1983). The dominant tree species in this area are *Terminalia sericea* and *Dichrostachys cinerea* subsp. *Nyassana*, and the dominant grass species is *Hyperthelia dissoluta* (Van Der Schijff 1958, Gertenbach 1983). Post fire recovery of the grass and herbaceous vegetation in the Pretoriuskop region tends to be quicker than in other areas of the KNP, because the Pretoriuskop region is a mesic savanna in comparison with other areas of the KNP, which are arid savannas (Van Wilgen and Scholes 1997).

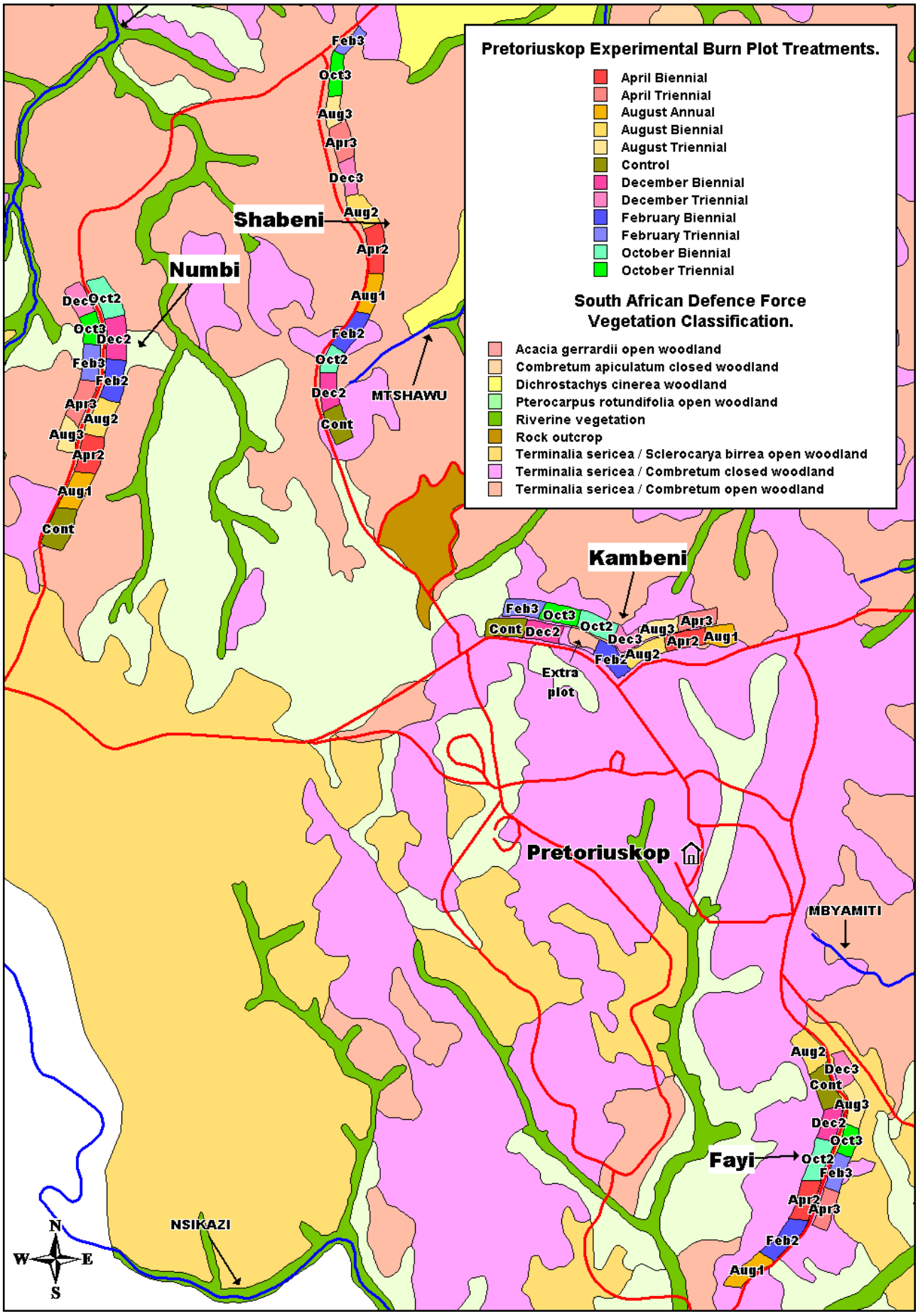


Figure 3-3: Layout of the Experimental Burn Plots in the Pretoriuskop landscape, showing the placement of the four replicates and the treatments that were applied to each burn plot.

3.3 THE LAYOUT OF THE EXPERIMENTAL BURN PLOTS IN THE PRETORIUSKOP REGION

Four replicates of twelve plots each were laid out in the Pretoriuskop sourveld. The four replicates, named after nearby landmarks, were Numbi, Shabeni, Kambeni, and Fayi (Figure 3-3). The Numbi and Shabeni replicates are located in predominantly *Terminalia sericea* - *Combretum* open woodlands of Pretoriuskop and the Kambeni and Fayi replicates are located in predominantly *Terminalia sericea* - *Combretum* closed woodlands of Pretoriuskop (Figure 3-3).

The twelve treatments were assigned in a pseudo-random manner to the plots within each replicate, and these treatments have been applied since 1954. There is an extra plot in the Kambeni replicate (coloured white in Figure 3-3). This is because soil from this plot was used to construct the road between Numbi gate and Pretoriuskop rest camp in 1954 (Annual report 1955). The affected treatment was the October biennial treatment, which was relocated to the second row of the Kambeni replicate in 1956.

3.3.1 The fire characteristics of the Experimental Burn Plots experiment in the Pretoriuskop region

Fires in the Pretoriuskop region are typically surface fires in the grass and herbaceous layer. Fires typically occur during the dry winter months in the Pretoriuskop region, they have intensities that range from 100-6000 kJ/s/m and return periods that range 1-6 years (Van Wilgen and Scholes 1997). In the Pretoriuskop region fire intensity (kJ/s/m) is approximately 3000 kJ/s/m and is significantly correlated with flame height ($r = 0.5883$, $DF = 78$, $p < 0.01$) and with rate of spread ($r = 0.8768$, $DF = 80$, $p < 0.01$) (Trollope and Potgieter 1983, Trollope and Potgieter 1985).

3.3.1.1 The extent or size of the fires on the Pretoriuskop EBP treatments

The extent (size) of the treatment fires and the types of treatment fires in the EBP experiment are constant. The extent of the fires in the experiment is controlled by the size of the experimental plots, which are approximately six and a half hectares in size (Figure 3-4). The grass and herbaceous layer does not burn completely during treatments applied in the wet season months (February, April, and December) and there are often islands of un-burnt grass (Van Wyk 1971). Treatments applied during the dry months often result in the complete combustion of the grass and herbaceous layer (Van Wyk 1971).

3.3.1.2 The type of fires on the Pretoriuskop EBP treatments

The fire types of the treatment fires applied to the plots are surface fires that move through the grass and herbaceous layer (Figure 3-4). Even though the canopies of some trees burn, the surface fire front in the grass layer sustains the flame front and this determines the type of fire.

3.3.1.3 The intensity of fires on the Pretoriuskop EBP treatments

Fire intensity is not controlled on the EBP experiment. However, the fire intensity is affected by the frequency and timing of fire events. Fire frequency affects fire intensity because the amount of fuel accumulated before a fire event is related to the time since the previous fire event. Fire intensity is affected by the fire timing because soil, air and fuel moisture are linked to the timing of the fire, and these factors affect fire intensity.

The fire intensity of the EBP treatments have been quantified a number of times since the inception of the experiment in 1954. In 1969, the temperatures of the fires on each EBP treatment in the Pretoriuskop region were measured at four heights above the ground, namely 0.5m, 0.9m, 1.8m, and 3.7m (Van Wyk 1971). Van Wyk (1971) found that fires during August and October were very hot (Table 3-2). Fires in December and February were cooler and burnt slower than fires in August and October even though high temperatures were sometimes recorded at 0.5m above ground (Table 3-2). The April treatments burnt slowly and

WISER

unevenly, and did not generate much heat (Table 3-2). Generally, the grass and herbaceous layers were burnt completely on treatments that were applied during the dry season (i.e. August and October), and smaller trees and shrubs were burnt back to the ground, and larger trees were scorched. During wet season treatments (i.e. December, February, and April), the grass did not completely burnt and islands of un-burnt grass and grass stalks remained.

In 1982, the fire behaviour on the Pretoriuskop EBP treatments was characterised by Winston Trollope and Andre Potgieter (Trollope and Potgieter 1983). The fire intensities (kJ/s/m) on the Fayi (1940), Kambeni (4059), Numbi (3438), and Shabeni (3120) replicates did not differ significantly (Table 3-3) (Trollope and Potgieter 1983). The Kambeni replicate had the highest average fire intensity and the Fayi replicate had the lowest average fire intensity. The mean fuel moisture content was significantly higher in April than in August and December ($p < 0.01$), and the fire intensity on the April Triennial treatments (1787) was significantly lower than on the August and October Triennial treatments (5155 and 2854 respectively) ($p < 0.05$) (Table 3-4) (Trollope and Potgieter 1983). The fire intensity was higher on the August Triennial treatment (5155) than on the August Biennial treatment (3518), and the fire intensity was higher on the August biennial treatment (3518) than on the August Annual treatment (2567) (Trollope and Potgieter 1983).

Table 3-2: The average length of time (in minutes) taken for a treatment to burn, and the average temperature (°C) of the treatments at different heights. The data was collected in 1969 at the same time as the quadrate middle-point surveys of the EBPs were done (Van Wyk 1971). The data was not presented in Van Wyk (1971) though, and was found in the archive material for the EBPs.

Treatment	Burn time (minutes)	0.5m (°C)	0.9m (°C)	1.8m (°C)	3.7m (°C)	Average temperature (°C)
Apr2	36	121	93	< 93	< 93	65
Apr3	34	149	121	< 93	< 93	93
Aug1	24	232	232	149	93	176
Aug2	16	399	260	232	177	266
Aug3	25	316	232	204	177	232
Dec2	30	232	149	121	< 93	141
Dec3	26	288	177	121	< 93	162
Feb2	29	149	93	< 93	< 93	72
Feb3	38	93	121	< 93	< 93	79
Oct2	21	343	260	204	149	239
Oct3	15	316	232	177	149	218

Table 3-3: The average fire intensity for the Fayi, Kambeni, Numbi, and Shabeni EBP replicates on the Pretoriuskop region, based on the data that was collected on the five treatments in Table 3-4 in 1983 (Trollope and Potgieter 1983).

Replicate	Intensity (kJ/s/m)
Fayi	1940
Kambeni	4059
Numbi	3438
Shabeni	3120

In 1992, the fire behaviour on two of the Pretoriuskop EBP treatments (August and October biennial treatments) was characterised as part of the ground component projects of the SAFARI 92 (South African Fire-Atmosphere Research Initiative conducted in 1992) project (Trollope *et al*. 1994). The Fayi replicate had the lowest fire intensity (kJ/s/m) in both the Aug2 (93) and Oct2 (474) treatments (Table 3-5). The Shabeni replicate had the highest fire intensity in the Aug2 treatment (1703), and the Kambeni replicate had the highest fire intensity in the Oct2 treatment (3644). The average fire intensity on the October Biennial treatment (1988) was more than double the average fire intensity on the August Biennial treatment (930) in the Pretoriuskop region.

WISER

Table 3-4: The average fire intensity for five of the Pretoriuskop EBP treatments. The data was collected in 1982 (Trollope and Potgieter 1983).

Treatment	Intensity (kJ/s/m)
Aug1	2567
Aug2	3518
Aug3	5155
Oct3	2854
Apr3	1787

Fires in the KNP have been classified into five categories based on fire intensity, namely very cool fire, cool fire, moderately hot fire, hot fire, and extremely hot fire (Table 3-6) (Trollope and Potgieter 1983, Trollope and Potgieter 1985). These categories provide a convenient framework to rank the EBP treatments in the Pretoriuskop region from very cool fire to extremely hot fire (Table 3-7). The ranking of the treatments uses the data collected on the Pretoriuskop EBPs regarding the intensity of the different fire treatments presented above, and conventional thought regarding the relationship between fire intensity and fire timing and frequency.

Table 3-5: The fire intensity for the August and October Biennial treatments of the Pretoriuskop EBPs. The data was collected in 1992 as part of the ground component projects in SAFARI 92 (Trollope *et al*. 1994)

Treatment	Replicate	Fire intensity (kJ/s/m)	Treatment	Replicate	Fire intensity (kJ/s/m)
August Biennial	Fayi	93	**October Biennial**	Fayi	474
	Kambeni	1182		Kambeni	3644
	Numbi	742			
	Shabeni	1703		Shabeni	1846
	Average	**930**		**Average**	**1988**

Regarding the fire frequency of the EBP treatments, an annual fire is less intense than a biennial fire at the same time of the year because more fuel accumulates over two years than over one year. Furthermore, a triennial fire is more intense than a biennial fire at the same time of the year because more fuel accumulates over three years than over two years. Regarding the timing of the EBP treatments, an August fire is more intense than an October fire because the soil, air, and fuel moisture levels are lower in August at the end of the dry season than in October, which is at the beginning of the wet season. An October fire at the beginning of the wet season is more intense than an April fire, which is at the beginning of the dry season. An April fire at the beginning of the dry season is more intense than a February fire, which is toward the end of the wet season. A February fire toward the end of the wet season is more intense than a December fire, which is in the middle of the wet season.

Table 3-6: Five fire categories based on fire intensity (Trollope and Potgieter 1983, Trollope and Potgieter 1985)

Fire Intensity (kJ/s/m)	Description
> 3001	Extremely hot fire
2001-3000	Hot fire
1001-2000	Moderately hot fire
501-1000	Cool fire
< 500	Very cool fire

The frequency of the treatments was ranked from low intensity fires being Annual (1), medium intensity fires being Biennial (2), and high intensity fires being Triennial (3) (Table 3-7). The timing of the treatments was

WISETD

ranked from low intensity fires occurring in December (1), medium-low intensity fires occurring in February (2), medium intensity fires occurring in April (3), medium-high intensity fires occurring in October (4), and high intensity fires occurring in August (5) (Table 3-7). Using the data presented above, a rank correction factor was then applied to account for any perceived timing and frequency rank inconsistencies (Table 3-6 and Table 3-7). For example, one rank point was subtracted from the Aug3 treatment because it was believed that the Aug3, Oct3, and Aug2 treatments were similar in intensity, and one rank point was added to the Dec3 treatment because it was believed to be hotter than the Feb2 treatment (Table 3-7). The timing intensity rank, frequency intensity rank, and intensity rank correction for each treatment were then summed to give a treatment intensity rank which was used to rank the EBP treatments from most intense treatment (Aug3) to the least intense treatment (Dec2) (Table 3-7). The treatments were then assigned to one of the five fire intensity categories described by Trollope and Potgieter (1983 and 1985), based on the fire intensity rank of the treatment (Table 3-7).

Table 3-7: Fire treatments of the Experimental Burn Plots ranked from most intense fire treatment to least intense fire treatment based on the timing and frequency of the treatment.

Treatment	Timing intensity rank	Frequency intensity rank	Intensity Rank Correction	Treatment intensity rank (Time + Freq + Correction)	Type of fire
Aug3	5	3	-1	7	Extremely hot fire
Oct3	4	3	0	7	Extremely hot fire
Aug2	5	2	0	7	Extremely hot fire
Oct2	4	2	0	6	Hot fire
Apr3	3	3	0	6	Hot fire
Aug1	5	1	0	6	Hot fire
Apr2	3	2	0	5	Moderately hot fire
Feb3	2	3	0	5	Moderately hot fire
Dec3	1	3	1	5	Moderately hot fire
Feb2	2	2	0	4	Cool Fire
Dec2	1	2	0	3	Very cool fire
Con0	0	0	0	0	No fire

3.3.1.4 The timing of the fires on the Pretoriuskop EBP treatments

Fire timing on EBP treatments is manipulated. Fire treatments are applied at five different times of the year, namely February, April, August, October, and December (Figure 3-4).

The February treatments are less intense than the April, August, and October treatments and more intense than the December treatments. The February treatments tend to burn slowly, and the grass and herbaceous layer burns patchily with tall grass stalks of *Hyparrhenia dissoluta* and *Trachypogon capense* remaining un-burnt. Top kill of shrub forms is low in February fires but leaves are often severely singed. The *Panicum maximum* (Buffalo grass) growing under large trees is green at this time of the year and so the large trees and under-canopy seedlings are protected from the fire in February. Regeneration and recovery of the vegetation is relatively quick if rains continue into autumn however, if the rains end early in the wet season the plots are grazed, browsed, and trampled heavily through out the winter and only recover in the following wet season.

The April treatments are less intense than the August, and October treatments, and more intense than the February and December treatments. The April treatments tend to burn slowly. Conditions are dryer than in February, and the grass and herbaceous layer burns less patchily than in February. Top kill of shrub forms is low in April fires but higher than in February. The *Panicum maximum* growing under large trees is still green at this time of the year protecting the large trees and under-canopy seedlings from fire. The conditions are dryer in April than February and regeneration and recovery of the vegetation is slower. The plots are grazed, browsed, and trampled heavily through out the winter generally only recovering in the following wet season.

The August treatments tend to be very intense, and the grass and herbaceous layer is burnt completely in August. *Panicum maximum*, which is occurs under large trees, is dry in August and these fires tend to scorch

the trunks and lower branches of large trees. Top kill of shrub forms on these treatments is very high. Many trees and shrubs are less susceptible to fire damage in August because August is a time of dormancy and low resource utilisation for these species. However, grazing, browsing, and trampling of both grass and basal tree and shrub shoots is high after August fires. Post fire recovery of the vegetation after August fires in the Pretoriuskop region is slow because the first rains usually occur in October.

The October treatments tend to be very intense fires in which the grass and herbaceous layer is burnt completely. *Panicum maximum*, which is occurs under large trees, is often still dry in October and these fires tend to scorch the trunks and lower branches of large trees. Top kill of shrub forms in these treatments is very high. West (1965) postulated that many trees and shrubs would be susceptible to fire damage in October because their carbohydrate reserves would be deleted by new spring growth. However, Trollope, Potgieter and Zambatis (1990) found that post fire tree-shrub mortality was low in the Kruger National Park (1.3%), regardless of the season in which the fire was applied. They concluded that the tree-shrub component of the vegetation did not appear to be sensitive to burning at the end of the dry season when they were in the spring flush. Post fire grazing, browsing, and trampling of both grass and basal tree and shrub shoots is low after October fires in comparison with after August fires. Game do not concentrate much in areas burnt in October because the surrounding vegetation is in spring flush providing alternative graze and browse material. As the first rains in the Pretoriuskop region usually occur in October, regeneration and recovery of vegetation after October fires is relatively quick.

The December treatments are less intense than the February, April, August, and October treatments. The December treatments tend to burn slowly, and the grass and herbaceous layer burns patchily with tall grass stalks of *Hyparrhenia dissoluta* and *Trachypogon capense* remaining un-burnt. Top kill of shrub forms is very low in December fires. The *Panicum maximum* growing under large trees is green at this time of the year and so the large trees and under-canopy seedlings are protected from the fire in December. Regeneration and recovery of the vegetation is relatively quick because fires occurring in December are in the middle of the wet season. Post fire grazing, browsing, and trampling of both grass and basal tree and shrub shoots is low as game does not concentrate in areas burnt during December.

3.3.1.5 The frequency of the fires on the Pretoriuskop EBP treatments

Fire frequency on the EBP treatments is manipulated. Fire treatments are applied at three frequencies, namely Annual, Biennial, and Triennial (Figure 3-4). The Annual treatment is applied only in August, and the Biennial and Triennial treatments are applied at all five times of the year. There is also a Control treatment in where fire is excluded from the plots.

The Annual treatments are less intense than the Biennial and Triennial treatments at the same time of the year. Annual treatments tend to burn more slowly than Biennial and Triennial treatments at the same time of the year because the fuel accumulation on the Annual treatments is low in comparison with the Biennial and Triennial treatments. Trees and shrubs tend not to recover completely between fires on the Annual treatments, there is a bottleneck effect in which seedlings, and saplings are stunted by repetitive burning and prevented from becoming mature adult trees.

WITSETD

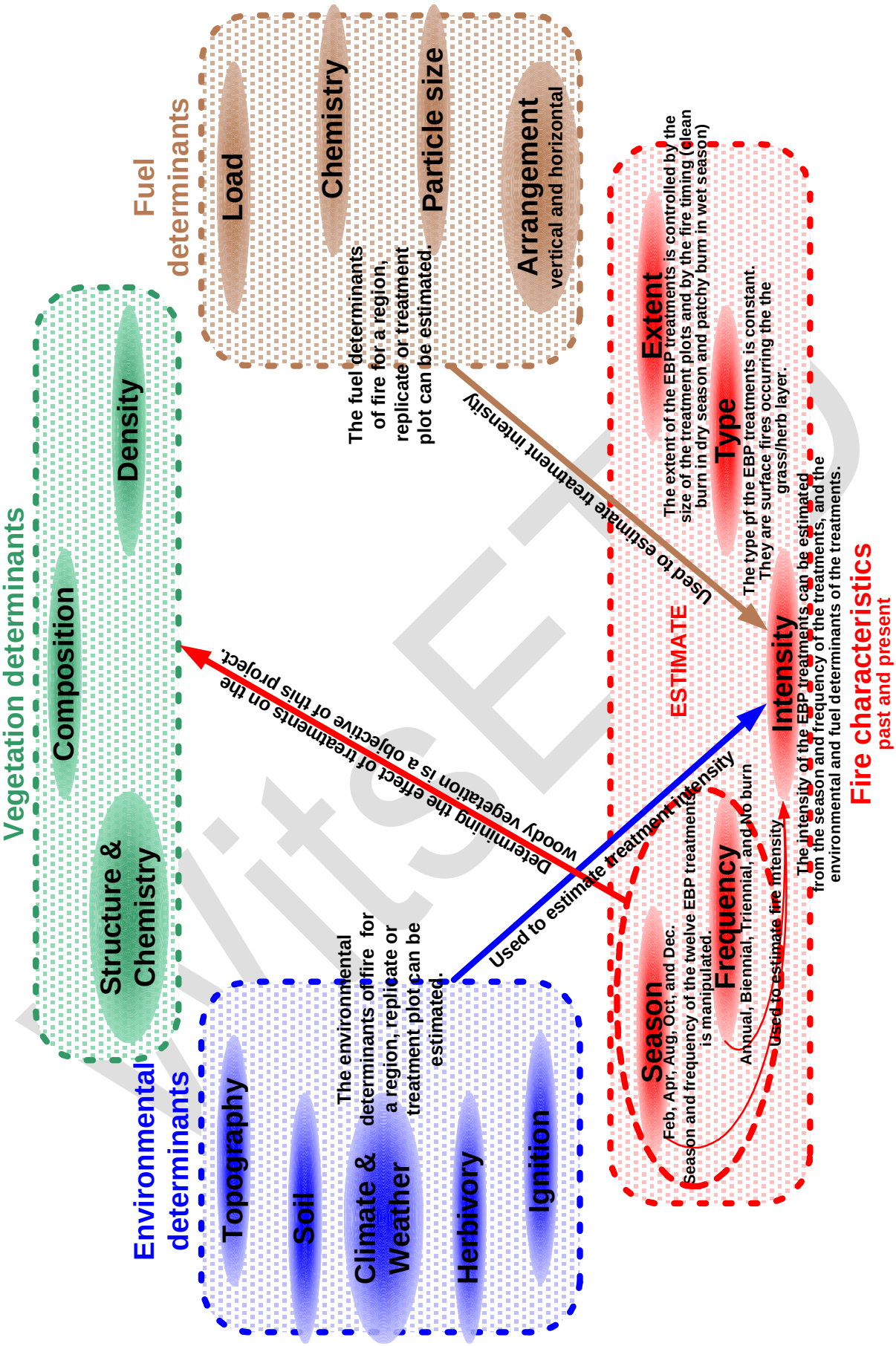


Figure 3-4: The fire characteristics of the Experimental Burn Plots (EBPs) based on the model showing the interdependence between the determinants and characteristics of fire shown in Figure 2-1 (p. 4).

4 RESEARCH HYPOTHESES

A diachronic (longitudinal) research approach was used in this project, in which the effects of fire on woody vegetation were investigated over time within the structure of a long-term controlled experiment (Trabaud and Lepart 1981). Data collected at the start of the experiment in 1954 was used as a baseline against which data collected in 1996, 42 years later, was compared. Differences between the treatment plots in 1954 and 1996 were used to determine the effects of the prolonged application of the fire treatments on the woody vegetation in the Pretoriuskop region.

The hypotheses stated have been deliberately constructed as broad statements regarding a particular problem domain to avoid being bogged down in the detail of the methods and analyses used to investigate the problem domain.

4.1 CHANGE IN THE WOODY VEGETATION DENSITY, STRUCTURE AND COMPOSITION ON THE PRETORIUSKOP EXPERIMENTAL BURN PLOTS BETWEEN 1954 AND 1996

Using the Sheffield Dynamic Global Vegetation Model (DGVM), Bond *et al.* (2003) predict that the density of trees in mesic savannas will have increased as the atmospheric CO_2 levels have increased from pre-industrial levels (270 ppm) to current levels (360 ppm) over the last 150 years. Over the past half a century, rangers and researchers have made anecdotal observations that the vegetation in the Pretoriuskop region appears to be gradually becoming more wooded (Annual Report 1951, Van Der Schijff 1958, Brynard 1964). It is assumed that broad trends in woody vegetation change occurring in the Pretoriuskop region between 1954 and 1996 has also occurred on the Pretoriuskop Experimental Burn plots over the same period. The basis for this assumption is that the layout of the EBP replicates in the Pretoriuskop region is considered representative of the landscape, and the experimental treatments applied to the EBPs between 1954 and 1996 cover the same range of fire frequencies and timing that have occurred in the Pretoriuskop landscape for the same period.

Using the data collected on the Pretoriuskop EBP experiment in 1954 and 1996, the anecdotal observations that have been made regarding the woody vegetation in the Pretoriuskop region can be tested.

Hypothesis 1: Savanna ecosystems are not static state ecosystems and the density, structure, and composition of the woody vegetation in these systems changes in time and space. The global increase in atmospheric CO_2 is expected to drive change in mesic savannas like Pretoriuskop. The first hypothesis is that the density of the woody vegetation on the Pretoriuskop EBPs increased between the inception of the experiment in 1954 and 1996.

4.2 DIFFERENCES IN THE WOODY VEGETATION DENSITY, STRUCTURE AND COMPOSITION BETWEEN THE PRETORIUSKOP EXPERIMENTAL BURN PLOT REPLICATES

The EBP replicates were placed in four representative locations within each of four landscapes within the KNP. Many factors such as soil, catenal position, grazing pressure, and the structure and composition of the vegetation vary between the replicates. The magnitudes of these non-experimental differences between the replicates are in some cases large and are cause for concern when analysing the treatment effects on the woody vegetation density, structure, and composition (Van Der Schijff, 1958, Van Wyk 1975, Trollope *et al.* 1998).

WITSETD

Using the data collected in the 1954 and 1996 surveys, differences in the density, structure, and composition of the woody vegetation between the replicates can be tested.

Hypothesis 2: True replication in uncontrolled heterogeneous ecological ecosystems is difficult. This often leaves ecologists with non-experimental variation, which can confound true pattern. The second hypothesis is that there was no difference in the density, structure, and composition of the woody vegetation between the four Pretoriuskop EBP replicates in 1954 or in 1996.

4.3 THE EFFECTS OF FIRE FREQUENCY AND TIMING ON THE DENSITY, STRUCTURE, AND COMPOSITION OF THE WOODY VEGETATION ON THE PRETORIUSKOP EXPERIMENTAL BURN PLOTS

In savanna ecosystems, frequent fire events appear to favour grassland over woodland in regions with climates that are capable of supporting woodland and forest ecosystems (Vogl 1974). Most woody plants in savanna ecosystems are fire resistant to some degree, and fire does not so much kill fire resistant woody species as reduce the above ground woody biomass through scorching and top kill. Furthermore, the intensity of a fire event is related to the time since the previous fire event because the amount of fuel accumulated is related to the time since the previous fire event. Some woody species are more susceptible to top kill or total mortality after high intensity fire events than less intense fire events. This affects the structure, composition, and density of the woody vegetation.

Using the data collected in the 1954 and 1996 surveys, differences in the density, structure, and composition of the woody vegetation on the Pretoriuskop Experimental Burn Plots burnt at different frequencies can be tested.

Hypothesis 3: In savanna ecosystems, frequent fire kills fire intolerant woody species, and suppresses fire tolerant woody species preventing them from reaching fire resistant heights. The third hypothesis is that the woody vegetation on plots burnt less frequently or not at all will be denser, comprise taller less shrubby trees, and have more fire intolerant species than plots burnt more frequently.

The season of burning in relation to the phenology of plant non-structural carbohydrate reserves determines the degree of damage caused by fire to the plant (West 1965, Bond and Van Wilgen 1996). Fire directly after a non-structural carbohydrate resource depleting phenological phase (i.e. after the spring flush of leaves or flower blooming) is more detrimental to the persistence of a woody plant than fire during or directly after a resource-accumulating phenological phase (i.e. during or at the end of the rainy season) (West 1965, Bond 1997). Furthermore, soil, air, and fuel moisture is linked to the timing of a fire and these factors affect the intensity of a fire. Some woody species are more susceptible to top kill or total mortality after high intensity fire events than less intense fire events. This affects the structure, composition, and density of the woody vegetation. Season has been found to be one of the most important aspects of a fire regime affecting plant species diversity (Malanson 1982). Regarding the fire timing of the EBPs the most intense treatments are those occurring during and at the end of winter (August and October). The October treatments occur at a time when plants are phenologically most sensitive in comparison with the treatments that occur in August, which is a time of dormancy (December and February). The relationship between the frequency, timing, and the intensity of the EBP treatments is discussed in more detail in “The fire characteristics of the Experimental Burn Plots experiment in the Pretoriuskop region” p. 19.

Using the data collected in the 1954 and 1996 surveys, differences in the density, structure, and composition of the woody vegetation on the Pretoriuskop Experimental Burn Plots burnt at different times of the year can be tested.

Hypothesis 4: In savanna ecosystems, fire occurring during different phenological phases of woody plants impacts upon the post-fire persistence of the woody plants differentially. The fourth hypothesis is that the woody vegetation on the plots burnt during and at the end of winter will be less dense, comprise shorter more shrubby trees, and have less fire intolerant species than plots burnt during and at the end of summer or not burnt at all.

4.4 THE EFFECT OF NOT BURNING ON THE DENSITY, STRUCTURE AND COMPOSITION OF THE WOODY VEGETATION ON THE PRETORIUSKOP EXPERIMENTAL BURN PLOTS

In general, when fire is excluded from Southern African savanna ecosystems, the woody plant biomass increases (Scholes 1997). In mesic savannas such as Pretoriuskop, the long-term exclusion of fire can also result in species change with fire intolerant species becoming more prominent (Scholes 1997).

Using the data collected in the 1954, 1959, and 1996 surveys, differences in the density, structure, and composition of the woody vegetation on the Pretoriuskop Experimental Burn Plots excluded from fire for different lengths of time can be tested.

Hypothesis 5: In savanna ecosystems, in the absence of fire, the woody biomass increases because suppressed woody plants are able to escape the fire zone and fire intolerant species are able to establish themselves. The fifth hypothesis is that the woody vegetation on the control (no burn) plots will be denser, comprise taller less shrubby trees, and have more fire intolerant species as the time since the inception of the experiment in 1954 increases.

WitsETD

5 MATERIALS AND METHODS

5.1 METHODS OF HISTORICAL ANALYSIS

An understanding of the historical background of the Experimental Burn Plots (EBP) experiment provides a context within which the worth of the experiment can be assessed.

Management philosophy in the KNP has changed over the last half century since the inception of the EBP experiment in 1954. During the early 1950's the romanticised notion of man's subservience to "Mother Nature" was replaced by scientific rationality and administrative dominance (Carruthers 1995). Teams of scientists studying all elements within the ecological landscape replaced the solitary game warden and custodian (Carruthers 1995). Maintaining the physical state of the ecosystem became the main management focus. In the mid 1990's, management by intervention gave way to a wilderness approach in which management intervention was limited. This approach prescribed an understanding of ecosystem processes and the scale at which these processes occur. Ecosystem processes have come to be considered as important to the conservation management of an ecosystem as maintaining the physical state. It is important to understand how changing attitudes and motives of scientists and management have influenced the KNP EBP experiment over time.

The aim of this historical analysis was to investigate how and why the EBP experiment was started. Furthermore, how the EBP experiment was maintained and how it persisted between its inception in 1954 and the mid 1990's. Finally, what attitudes prevailed concerning the experiment, and how these affected the credibility and integrity of the experiment?

To answer these questions archive materials from both the Kruger National Park and South African National Parks head offices were collated and analysed. Most of the archive material was recorded in Afrikaans and required translation. The archive material included Annual Reports (from 1951 to 1990), Minutes of Meetings, Unpublished Reports, and miscellaneous notes. The collation of archived material took eight months from May 1996 to December 1996.

These data were used in conjunction with published material to construct a historical analysis of the EBP experiment, which is presented in the Results chapter in "A critical analysis of the history of the Kruger National Park Experimental Burn Plots experiment" (p. 43).

5.2 FIELD METHODS

The main criterion in choosing a method to survey the woody vegetation in 1996 was that the data collected was comparable to the baseline (1954) data. A number of survey methods were assessed including those previously used to survey the EBPs, like the quadrate middle-point and step-point methods and the half-hectare plots. The belt transect method used in the baseline (1954) survey was selected as being most suitable.

The different survey methods used to survey the woody vegetation on the EBPs between 1954 and 1996 are discussed in more detail in "A critical analysis of the history of the Kruger National Park Experimental Burn Plots experiment" (p. 43) in the Results chapter.

The survey methodology used in 1996 differed slightly from that used in the baseline (1954) survey. The differences were in the size of the sampling transects which was a result of the imperial unit measure system (inches and feet) being used in 1954 and the metric unit measure system (centimetres and meters) used in 1996.

WISETD

Two transects, each 2m wide by 300m in length, were laid along the diagonals of each experimental plot (Figure 5-1). Each transect was subdivided into six 50 m sample units (segments), and the woody vegetation in each segment within each belt transect was surveyed (Figure 5-1).

The following woody vegetation data were recorded:

- Every woody plant within each sample unit was recorded and identified.
- The height of the living part of the woody plant in meters was measured.
- The height of the dead part of the woody plant in meters was measured. This was recorded if the woody plant was dead or if one of the main stems of the woody plant was dead.
- Whether the plant had a single stem or many stems at the base was recorded.
- Stem diameter in centimetres for single-stem individuals was measured.
- Basal diameter in centimetres (coppice diameter) for multi-stem individuals was measured.
- Whether the individuals were live or dead was recorded.
- The magnitude and type of damage other than fire (i.e. animal or wind) to the plant, where evident, was recorded.

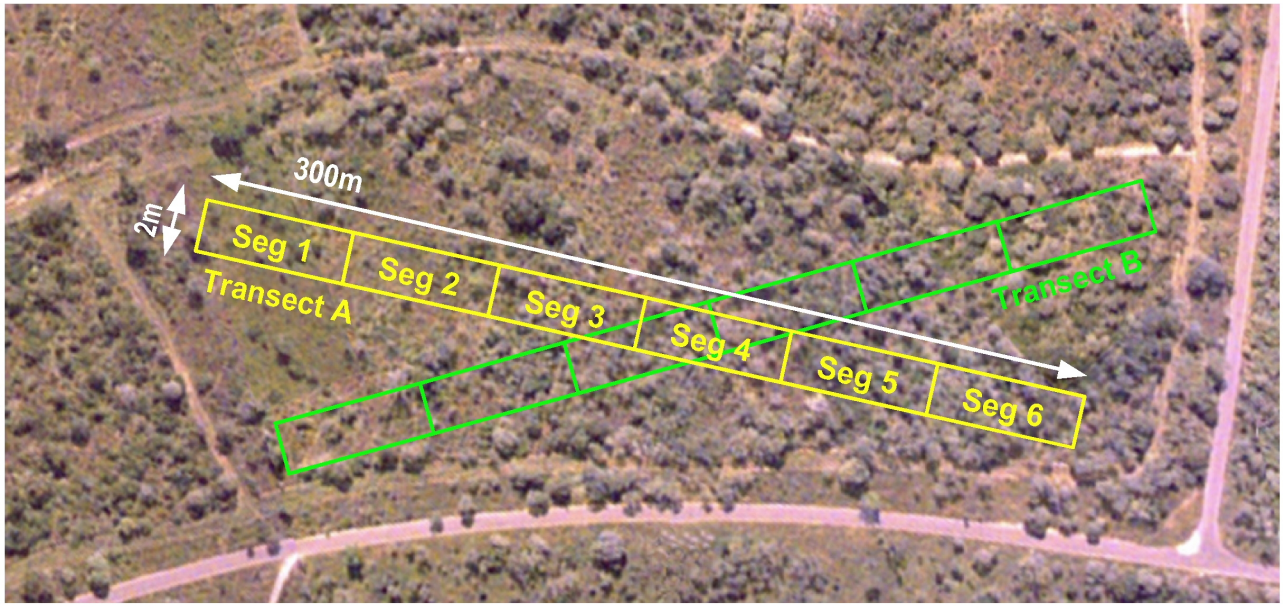


Figure 5-1: Showing the placement of the two transects along the diagonals of a treatment plot in the 1996 woody vegetation survey of the Pretoriuskop EBPs. The belt transects were divided into six segments each.

The resurvey of the woody vegetation on the Pretoriuskop EBPs took seventeen months from May 1996 to September 1997. This survey concluded a 42-year period, between 1954 and 1996, over which the effects of the fire treatments were investigated.

5.3 CAPTURING AND COLLATING HISTORICAL SURVEY DATA

Four complete surveys of the woody vegetation on the EBPs in the Pretoriuskop region were conducted from the inception of the experiment in 1954 to 1996. These were the baseline survey (1954), the quadrate middle-point survey (1967-1968), the step point survey (1970), and the half-hectare monitor plots (1971-1973). In 1959 a belt transect survey was also conducted on the control plots of the Pretoriuskop and Naphe regions of the EBP experiment. None of the data from these surveys was available in digital format.

The data from two surveys, in 1954 and 1959 belt transect surveys, were selected to meet the third objective of this study, namely to "…compare the density, structure, and composition of the woody vegetation on the Pretoriuskop EBPs between 1954 and 1996…" (Aims and Objectives p. 1)

The data from the three other surveys were not selected for the following reasons:

- The quadrate middle-point survey (1967-1968), because the data collected during this survey was not directly comparable with the data collected using the belt-transect method in 1954 and 1959.
- The step point survey (1970), because the distance from the point to the nearest individual was not recorded, and density calculations are not possible.
- The half-hectare plot survey (1971-1973), because the control plots of the Pretoriuskop region were not surveyed.

The data from the 1954 and 1959 surveys took five months to capture from January 1997 to May 1997. The data collected during the 1996 survey took eight months to capture from July 1997 to February 1998.

5.3.1 Cross-referencing species

Between 1954 and 1996 the taxonomic classification of some of the woody species occurring on the Pretoriuskop Experimental Burn Plots changed. A number of species names changed and other species were reclassified as new species or as sub-species. The survey data collected in each of the surveys (1954, 1959, and 1996) was cross-referenced to standardise the species identification and naming.

The species designations in Palgrave (1991) were used as a reference for the standardisation of the species found in each survey. Refer to Appendix 1 (p. 210) for a complete list of species identified in the surveys conducted in 1954, 1959 and 1996.

5.4 ESTIMATING HEIGHT FOR THE 1954 AND 1959 DATA

The heights of the plants were not measured in the 1954 and 1959 surveys. Plant height is a useful measurement of dominance or importance of an individual. It is also useful for quantifying the effect of fire on the physical structure of the vegetation. Plant heights for the 1954 and 1959 survey data were estimated using the plant diameter and height measurements collected in the 1996 survey.

5.4.1 Estimating height class

1. Each individual in the 1996 survey was classified into one of the eight single-stem or multi-stem basal diameter classes used in the 1954 and 1959 surveys. These classes are displayed in Table 5-1.

Table 5-1: The single-stem and multi-stem diameter classes used to classify individuals during the 1954 baseline survey (Van Der Schijff 1958).

Basal stem class	Diameter class (cm)	Diameter class code
Multi	0.00 – 30.48	**S01**
	30.48 – 91.44	**S13**
	> 91.44	**S3**
Single	0.00 – 2.54	**T01**
	2.54 – 7.62	**T13**
	7.62 – 12.7	**T35**
	12.7 – 17.78	**T57**
	> 17.78	**T7**

WITSETD

2. Each individual in the 1996 survey was also classified into one of four height classes shown in Table 5-2.

Table 5-2: The height classes used to classify individuals in the 1996 survey.

Height class (m)	Height class code
0 – 1	**H01**
1 – 3	**H13**
3 – 5	**H35**
> 5	**H5**

3. The species height classes for the 1954 and the 1959 data were estimated using one of two methods:

   a. The procedure used for species common to the 1954, 1959 and 1996 surveys:
   The species-height-class ratios (the relative number of individuals per height class) were calculated for each diameter class from the 1996 data. These ratios were used to estimate the number of individuals in each height class within each diameter class for each species in the 1954 and 1959 data.

   b. The procedure used for species present in the 1954 and 1959 surveys but not present in 1996:
   The height class ratios for each diameter class were calculated for the entire 1996 dataset. These ratios were used to estimate the number of individuals in each height class within each diameter class for those species present in the 1954 and 1959 surveys and not in the 1996 survey.

5.4.2 Estimating height

The mean height for each of the four height classes (0-1 m, 1-3 m, 3-5 m and >5 m) was calculated using the 1996 data. These mean heights were used to estimate the height of each individual in the 1954 and 1959 surveys based on the individuals estimated height class.

5.4.3 Assumptions made in estimating height classes for the 1954 data

- The height class ratio at the species level for a given diameter class remains constant over time i.e. the relative number of individuals in each height class for each diameter class for each species in 1954 and 1959 were the same as those in 1996.
- In the absence of species level height ratios, the average height class ratios for the entire data set are good approximations of the species level height class ratios for a given diameter class.

5.5 DATA ANALYSIS

The data collected during the three surveys conducted in 1954, 1959 and 1996 was used to investigate the long-term effects of the fire treatments on the woody vegetation of the Experimental Burn Plots (EBPs) in the Pretoriuskop region. This data comprised records on more than 45 000 individuals from 97 woody species.

5.5.1 Indices calculated to summarise key vegetation structure and composition characteristics

Twelve vegetation indices were used to summarise the data collected in the 1954, 1959, and 1996 surveys. These indices were calculated for each treatment plot at each survey and were then used to compare the woody vegetation density, structure, and composition between the plots.

5.5.1.1 Woody plant density

The density of woody individuals per hectare was calculated per treatment plot.

$$d_j = \frac{n_j \times 10000}{a_j}$$ **Equation 1: Woody plant density per hectare.**

Where d_j is density (*n*/*ha*), n_j is the number of individuals, 10000 is the number of square meters per hectare, and a_j is the survey area (m^2) for treatment plot *j*. The survey area of each of the survey transects in the 1954, 1959, and 1996 surveys are presented in Appendix 3, Table 11-1 (p. 215).

5.5.1.2 Mean woody plant height

The arithmetic mean height of woody individuals was calculated per treatment plot. Mean height was used to quantify the woody plant height structure on each treatment plot as a single value.

$$\bar{h}_j = \frac{\sum h_i}{n_j}$$ **Equation 2: Mean woody plant height.**

Where $\bar{h}_j$ is the mean height (m), h_i is the height of individual trees or shrubs (m), and n_j is the number of individuals for treatment plot *j*.

5.5.1.3 Number of tree equivalents

The tree equivalents index is a composite measure of the number of individuals in a collection and the height structure of that collection. The index expresses the total height of a collection of individuals as the potential number of tree equivalents (trees that are 1.5 m tall) within the collection (Trollope *et al*. 1990).

$$te_j = \frac{(\frac{\sum h_i}{1.5}) \times 10000}{a_j}$$ **Equation 3: Number of tree equivalents.**

Where te_j is the number of tree equivalents per hectare, h_i is the height of individual trees or shrubs (m), 1.5 is the height (m) of an equivalent tree, 10000 is the number of square meters per hectare, and a_j is the survey area (m^2) for treatment plot *j*.

This index is useful because it combines the height structure and density of a collection of individuals into a single quantity. Tree equivalents are an estimate of the phytomass (plant mass) of the woody vegetation, measured as the equivalent number of 1.5 m tall trees (Trollope *et al*. 1990).

5.5.1.4 Single-stem to multi-stem index

Many woody plants respond to fire damage by sprouting at the base of the plant. This often results in the plants having more than one stem. The single-stem to multi-stem index is used to quantify the physical structure of the woody vegetation with respect to the basal sprouting response of individuals to fire damage.

The single-stem to multi-stem index is calculated as the proportion of single-stem individuals relative to the total number of individuals. The ratio ranges from zero to one, where zero indicates the absence of single-stem individuals and one indicates the absence of multi-stem individuals.

WiSETD

$$sm_j = \frac{ds_j}{n_j}$$ **Equation 4: Single-stem to multi-stem index.**

Where sm_j is the single-stem to multi-stem index, ds_j is the density of single-stem individuals, and n_j is the density of woody individuals on treatment plot *j*.

5.5.1.5 Diversity

Diversity is a measure of the variability of composition (Pielou 1975). Composition can comprise any categorization or grouping used to classify a collection of individuals. Diversity has two distinct components: 1) the number of different groups in a collection, and 2) the relative amount in each group in a collection (Huston 1994).

Many indices have been developed to estimate the separate and combined components of diversity. For the sake of clarity, indices that quantify the first component of diversity are referred to as "count" or "richness" indices, and indices that quantify the second component of diversity are referred to as "evenness" indices, while indices that quantify the first and second components of diversity combined are referred to as "diversity" indices.

Two aspects of woody vegetation diversity were investigated, namely species diversity and structural diversity.

5.5.1.5.1 Species diversity

Palgrave's "Trees of Southern Africa" (Palgrave 1991) taxonomic nomenclature was used as the naming convention of woody species in the Pretoriuskop region. A complete list of woody species identified in the 1954, 1959, and 1996 surveys is presented in Appendix 1, Table 9-1 (p. 210).

5.5.1.5.2 Structural diversity

The structural diversity of the woody vegetation was investigated using a structural classification comprising 32 structural groups. The structural groups included three aspects of woody vegetation structure, namely number of basal stems (single-stem or multi-stem), basal diameter (5 single-stem classes and 3 multi-stem classes Table 5-1), and height (4 classes Table 5-2). The 32 structural groups are shown in Table 5-3.

5.5.1.5.3 Indices of diversity

The diversity of the woody vegetation on the Pretoriuskop EBPs was measured for each plot using four indices that quantify the different components of diversity. The indices calculated were number of groups, Menhinick's richness index, Shannon's diversity index, and Shannon's evenness index.

5.5.1.5.3.1 Number of species or structure groups

The number of groups (s_j) is a count of the number of species or structural groups on plot *j*. This index is used to quantify the first component of diversity.

5.5.1.5.3.2 Menhinick's species or structural richness

Menhinick's index of richness (sm_j) calculates the number of species or structural groups (s_j) relative to the square root of the number of individuals (n_j) on a plot *j* (Brower and Zar 1977).

$$sm_j = \frac{s_j}{\sqrt{n_j}}$$ **Equation 5: Menhinick's richness index.**

This index quantifies the first component of diversity relative to the sample size, and consequently standardises the estimation for different collection sizes.

Table 5-3: The structural classification used to group the woody plants surveyed in the 1954, 1959, and 1996 surveys. The height and diameter class codes are defined in Table 5-1 and Table 5-2.

Basal stem class	Height class code	Diameter class code	Structure class code
Multi-stem classes	**H01**	**S01**	H01_S01
		S13	H01_S13
		S3	H01_S3
	H13	**S01**	H13_S01
		S13	H13_S13
		S3	H13_S3
	H35	**S01**	H35_S01
		S13	H35_S13
		S3	H35_S3
	H5	**S01**	H5_S01
		S13	H5_S13
		S3	H5_S3
Single-stem classes	**H01**	**T01**	H01_T01
		T13	H01_T13
		T35	H01_T35
		T57	H01_T57
		T7	H01_T7
	H13	**T01**	H13_T01
		T13	H13_T13
		T35	H13_T35
		T57	H13_T57
		T7	H13_T7
	H35	**T01**	H35_T01
		T13	H35_T13
		T35	H35_T35
		T57	H35_T57
		T7	H35_T7
	H5	**T01**	H5_T01
		T13	H5_T13
		T35	H5_T35
		T57	H5_T57
		T7	H5_T7

5.5.1.5.3.3 Shannon's species or structural diversity index

Shannon's index of diversity was used to quantify the species and structural diversity on the treatment plots. This index is a measure of the uncertainty of predicting the identity (class) of an individual chosen randomly from a population (Brower and Zar 1977). It quantifies the combined components of diversity, namely the number of groups and relative abundance of each group in a collection of individuals.

Regarding species diversity, Shannon's index is a measure of α-diversity on the plots, where α-diversity is defined as diversity of species within a community (Southwood and Henderson, 2000).

This index was chosen over Simpson's index of diversity because it is unaffected by absolute species abundances as long as the relative abundances remain the same.

WitsETD

$H'_j = -\sum p_i \ln p_i$ **Equation 6: Shannon's diversity index.**

Where H'_j is Shannon's diversity, and p_i is calculated as $p_i = \frac{n_i}{n_j}$, where n_i is the number of individuals in species or structural group *i* and n_j is the number of individuals on plot *j*.

5.5.1.5.3.4 Shannon's species or structural evenness index

Shannon's evenness is also known as Pielou's J index (Huston 1994). This index is a measure of the nearness of the calculated diversity index to the maximum possible diversity, where maximum diversity occurs when all species are evenly proportioned (Brower and Zar 1977). Pielou's *J'* quantifies the evenness of the relative abundance of species.

$J'_j = \frac{H'_j}{H\max'_j}$ **Equation 7: Shannon's evenness index.**

Where J'_j is Shannon's evenness and H'_j is Shannon's diversity. $H\max'_j$ is calculated as $H\max'_j = \ln s_j$, where s_j is the number of species or structural groups on plot *j*.

5.5.2 Quantifying the data distributions and testing the vegetation indices calculated per plot for normality

The distribution of each of the twelve vegetation indices calculated for each plot was quantified using skewness and kurtosis statistics. Deviation from normality by each of these distributions was tested using Kolmogorov-Smirnov one-sample tests (KS) for normality.

5.5.2.1 Skewness and Kurtosis

Skewness quantifies the deviation of the data distribution from symmetry and is a measure of the distribution of the data around the arithmetic mean (Cangelosi *et al.* 1983, Systat 1998, StatSoft 1999). A positive skewness value indicates a long right tail and a negative skewness value indicates a long left tail. Skewness shows how the data conforms to a symmetrical bell shaped curve.

Kurtosis measures the peakedness of a distribution near its central mode (Cangelosi *et al.* 1983, StatSoft 1999). It is a measure of the magnitude of the peak and the spread around the arithmetic mean (Systat 1998). A value greater than zero indicates that the distribution is more peaky than a normal distribution and a value less than zero indicates that the distribution is flatter than a normal distribution. Kurtosis indicates how the data conforms to the requirements of the standard normal curve.

Skewness and kurtosis values were calculated for the distributions of the twelve vegetation indices that were estimated from the 1954 and 1996 survey data, and were used to describe the distribution of the vegetation indices. The skewness and kurtosis values were also used in conjunction with Kolmogorov-Smirnov analyses to determine whether the vegetation index distributions differed from normality and in what way they differed from normality. The skewness and kurtosis values were also used to compare the data distributions between the 1954 and 1996 surveys to give an indication to the kind of change that had occurred in the woody vegetation over time.

5.5.2.2 Kolmogorov-Smirnov one-sample tests for normality

The Kolmogorov-Smirnov one-sample test for normality is based on the maximum difference between a samples' cumulative distribution (frequency distribution) and the hypothesized cumulative distribution (standard normal distribution) (Systat 1998, StatSoft 1999).

WISETD

almost annually (Brynard 1964, Brynard 1971). Woods *et al.* (2002) described the fire policy between 1912 and 1926 as haphazard and indecisive, and that the perception of fire was that it was bad for the environment.

6.1.1.1 The proclamation of the Kruger National Park (1926)

With the passing of the National Parks Act, the objectives of a National Park were changed from preserving large herbivorous mammals only, to the preservation of the flora, fauna, and the environment within the National Park (Carruthers 1995). While ecological thinking had not yet developed within the KNP, the management objectives in 1926 had a much broader focus than previously.

Between 1926 and 1934, no strict fire policy was pursued, mainly because there was a drought in the Lowveld. Any grass that had escaped accidental fires was burnt annually in autumn to provide grazing during the winter and to prevent uncontrolled wildfires burning through the KNP (Brynard 1964, Brynard 1971). Controlled burning of the veld in the KNP between 1926 and 1939 was difficult because there were no firebreaks that could be used to control runaway fires. In 1934, firebreaks were prepared and between 1934 and 1946, which was the end of Stevenson-Hamilton's term as warden, the policy regarding fire management was to burn biennially in autumn (Brynard 1964, Brynard 1971). The general focus in the management of the KNP during this period was still fauna-centric, and Stevenson-Hamilton stated that burning long old grass regularly was necessary, because long grass did not provide nourishment for animals. Furthermore, long grass was a danger to animals as it provided sites for ambush of grazers by predators and it harboured ticks (Brynard 1964, Brynard 1971).

In 1946, Col. JAB Sandenberg succeeded Stevenson-Hamilton as the warden of the KNP. He took over at a time of drought and so large areas of the vegetation did not burn for a number of years. In 1949 and 1950, uncontrolled fires burnt large areas in the park (Annual report 1951). This occurred at a time when the National Parks Board had just passed a resolution “that no veld shall be burnt more than once every five years”, primarily because Col. Sandenberg believed that deliberately burning the veld in the KNP upset the natural balance (Brynard 1964, Brynard 1971).

6.1.1.2 A new era – Management by intervention

The early 1950’s were a major inflection point concerning the management of the KNP, in which human intervention in the management of the ecology of the system increased. This period marked a transition in philosophy from a romanticised notion of man’s subservience to “Mother Nature” to a dominant ideological stance in which scientists and administrators worked together to manage KNP (Carruthers 1995). The change in management philosophy at this is aptly described as being “command-and-control"-centred with the main floral focus being on maintaining the KNP in a “pristine state” (Mentis and Bailey 1990, Holling and Meffe 1996).

In 1950, a research department was established in the KNP (Annual Report 1951). In October 1950, Dr TG Nel was appointed as the first research biologist in Skukuza, and HP Van Der Schijff was appointed as the research assistant based in Pretoriuskop in June 1951 (Annual report 1951). The role of the research department was to classify, quantify, categorise, and describe the area that is the KNP and to guide its management. The first task was to create animal and plant species lists, and to get a better understanding of the floral and faunal distributions in the KNP (Annual Report 1951).

At this time, controversy surrounded the issue of veld burning in the KNP. Pretoriuskop featured prominently in that there was disagreement over the successional path the lowveld sourveld was likely to follow in the absence of fire, namely bush encroachment, or a more desirable sweetveld (Annual report 1951). These dichotomous views highlighted the need for a better understanding of the role of fire in the KNP. By 1953, sufficient progress in the floral and faunal investigations had been made, and a proposal to research the

effect of fire on the vegetation in the KNP was presented to the National Parks Board Advisory Committee (Annual report 1953). The fire research proposal was accepted in the same year (Annual report 1953).

During 1954, the fire experiment was set up and started. In December 1954, the National Parks Board amended the then current fire policy and instated an interim policy, which was as follows (Minutes 1962):

> "…… until it is proved to be wrong, it be laid down by the Board as an interim policy that the whole of the Kruger National Park be divided into sections separated by properly constructed fire breaks, and that all grass which has become long and rank be burnt every three years on the understanding that only one third of each section be burnt annually and as late as possible in the spring after the first rains."

Practically, sections were burnt in spring after the first 50ml of rain had fallen (Gertenbach 1980b). The rational behind burning every three years in spring was that these fires were low intensity fires that would cause the least amount damage to the vegetation while removing moribund biomass (Govender 2003). Furthermore, these low intensity fires in spring posed little threat to the fauna of the KNP (Govender 2003).

Extensive firebreaks were created and the amended interim fire policy was started (Brynard 1964, Brynard 1971). Data from the EBP experiment was to be used to guide KNP management in the further formulation and implementation of fire policies that were in keeping with the spirit and purpose of a National Park (Annual report 1951). So began a new era of "management by intervention" in the KNP (Carruthers 1995).

In 1962, because of severe drought conditions prevailing in the KNP, it was necessary to revisit the fire management policy (Minutes 1961). The fire policy was amended as follows (Brynard 1971):

- Certain areas might be temporarily withdrawn or permanently withdrawn from the programme.
- The ideal size of discrete sections to be burnt at one time was about 60 km^2.
- No burning should be done before mid October.
- Fifty millimetres of rain had to have fallen in an area before it could be burnt.

Between 1962 and 1975, other minor changes were made to the 3-year rotation schedule. In 1975 in response again to drought conditions, the fire management policy was amended to allow for longer periods between fires in drier areas and season varied from between late winter to mid-summer to autumn (Van Wilgen *et al.* 2000). This policy built upon on the previous rotation burning policy, and instead of the frequency and timing of the prescribed burns being fixed, they were made more flexible. The timing and frequency of prescribed burns was determined by post fire age of the vegetation, fuel loads, and rainfall (Van Wilgen *et al.* in press). The application of fire over longer periods and at different times of the year spread the workload easing the intensity of the burden of prescribed burning (Van Wilgen 2002). Furthermore, it was felt that the diversity in timing and frequency resulted in "better utilisation" of post fire grazing (Van Wilgen 2002).

6.1.1.3 Abandoning prescribed burning – The wilderness years

In the early 1990's came another inflection point in the management philosophy of the KNP. There was a shift in attitude from managing by intervention toward a non-interventionist wilderness approach. This shift was reflected in a decision to abandon prescribed burning in 1992 in favour of a more natural lightning driven fire policy (Trollope *et al.* 1995; Biggs and Potgieter 1999). This policy became dubbed the *laissez-faire* approach to controlled burning (Trollope *et al.* 1995). This change in policy was once again in response to a drought in which the prescribed rotational burning policy appeared to be excessive (Biggs and Potgieter 1999; Van Wilgen *et al.* 2000). Effectively this policy prescribed that, within reason, lightning fires should be allowed to burn freely to their complete extent, and fires from all "non-natural" ignition sources (especially anthropogenic) should be extinguished. The network of firebreaks in the KNP was reduced by half to reduce the number of manmade barriers in the landscape that could hinder the spread of a fire (Van Wilgen *et al.* in

press). In 1997, a few refinements to the policy were made regarding the maximum percentage of a landscape unit that was permitted to bum during one season and rules stipulating facilitating the spread of fire across manmade barriers by KNP management (Potgieter 1997). This policy was difficult to implement. Controlling, “non-natural” fires with the reduced network of firebreaks proved to be difficult. Spatial analysis revealed that the boundaries of most fire scars during this period were either tourist roads or management roads (Govender 2003). Furthermore, it was found that after 10 years of the policy being in effect approximately 24% of the KNP had burnt in lighting ignited fires, and most fires had in effect been anthropogenic in origin (Van Wilgen *et al.* in press).

In April 2002, the wilderness or *laissez-faire* approach to controlled burning in the KNP was abandoned (Van Wilgen *et al.* in press). A new adaptive fire management policy was formulated, in which rainfall and the biomass of grass are used to prescribe fire quotas for specific landscapes at different times of the year (Brockett *et al.* 2001, Van Wilgen *et al.* in press, Trollope *et al.* 2003). This new approach is known as the Integrated Fire Management System (Trollope *et al.* 2003). The Integrated Fire Management System incorporates the application of point ignitions similar to that used in the patch mosaic burning system used in the Pilansberg National Park, while areas to be burnt are selected based on the condition of the vegetation (Trollope *et al.* 2003). The fire quotas for a landscape comprise the percentage of the area to burn, the time of the year the percentage should burn by, and the number of fires in which the area should be burnt. The prescribed percentage of an area to be burnt is a function of the fuel load in that area, and the numbers of fires that make up that percent are a function of the percentage of the area burnt in each fire (Brockett *et al.* 2001, Trollope *et al.* 2003). It is believed that this adaptive fire management policy is more aligned to the current mission of the KNP, which is to “To maintain biodiversity in all its natural facets and fluxes …” (Braack 1997), than previous fire management policies.

One detail that is glaringly obvious when looking at the history of fire management in the KNP is how little data from the EBP experiment has been used to guiding the formulation of fire management policies over past five decades.

6.1.2 The KNP experimental burn plots

In this section, the history of the KNP Experimental Burn Plots (EBPs) is examined, and changes in attitude toward the EBP experiment and its credible standing within the research community over time are exposed. Furthermore, the role the experiment has played in the understanding of fire in the KNP from a management perspective is explored.

Many issues have been controversial during the history of the management of the KNP. So the question begs asking, why set up such a large experiment and why fire?

The answer lies in the fact that the dominant vegetation type of the KNP is a tropical savanna with varying mixes of grasses and trees. Fire is a dominant feature of tropical savannas, and is recognised as playing an integral role in the dynamic relationship between the grasses and trees (Bond and Van Wilgen 1996). Furthermore, the early 1950s marked a transition from management by custodianship to management by intervention. Science, research, and empirical data were the means toward a rational and objective approach to the ecological management of the KNP.

6.1.2.1 Why set up such a large experiment in the early 1950s, and why fire?

There is no such thing as a savanna that does not burn (Scholes and Walker 1993). Therefore, when it comes to the management of fire in savanna ecosystems there are only two choices, planned fires and unplanned fires (Scholes and Walker 1993). In the early 1950s, the managing body of the KNP was faced with fire as a powerful ecological force, and a powerful management tool. Management philosophy had changed since the proclamation of KNP in 1926, from the preservation of a select few animals to the

WISER

preservation of the ecosystem in its entirety. The key word here being preservation, and management focus was on preserving the state of the system.

Even though the role of fire in African savannas was recognised as being ancient and pivotal (Van Der Schijff 1958), the vegetation state was seen as being a vulnerable sub-climax state between grassland and woodland, maintained by fire. This differs from current perceptions in which savanna ecosystems are not seen as unstable midpoints between grassland and woodland ecosystems. Rather savannas are seen as independent ecosystem entities in which the role of fire is one of mediating the coexistence of the tree-grass components. Savanna ecosystems are characterised by having grass and trees as main components, and the complex interaction between these components gives savanna ecosystems integrity of their own (Scholes and Walker 1993). Furthermore, the species composition of savannas does not often represent an intermediate vegetation state of locally occurring grassland or woodland ecosystems, and savannas are seldom geographically placed at a transition between grasslands and woodlands.

The role of fire in altering the structure and composition of the vegetation was well recognised in 1954. However, the practicalities of fire management were filtered through an agricultural mindset. In 1947, Scott gave four reasons for the use of fire in veld management (Scott 1947, West 1965):

1. To burn off the unpalatable growth left over from the previous season's growth which would not be touched by livestock and which, if not removed, would tend to become moribund and die out.
2. To stimulate growth during seasons when there is little green grazing and thus provide green food for stock at a time when it does not occur naturally.
3. To destroy parasites such as ticks which carry and transmit stock diseases.
4. To control the encroachment of undesirable plants in the veld.

In 1960, Campbell endorsed these reasons for using fire in veld management and contributed six additional reasons (Campbell 1960, West 1965):

5. To aid better distribution of animals on the range. Livestock tend to concentrate on favourite areas. Judicious burning of outlying areas attracts the herds and promotes an even distribution of grazing over the range as a whole.
6. To remove the fire hazard of accumulated old grass.
7. To establish fire breaks in developing a system of protection from fire.
8. To prepare a seedbed for natural or artificial seeding of desired forage species.
9. To stimulate range or pasture species to produce seed.
10. To encourage the growth of native legumes for forage and soil improvement.

While the use of fire in an agricultural environment seemed to be clear-cut, the use of fire within the ecosystem of the KNP, which had different objectives, was certainly not (Van Der Schijff 1958).

The debate surrounding fire management within the KNP was contentious. There were two main camps regarding the management of fire, there were those who believed that the vegetation should not be allowed to burn, and those that believed that fire was necessary (Van Der Schijff 1958). However, even those who believed that fire was necessary could not agree on the precise effects of fire applied at different times of the year or at different return periods.

Opinions differed so much, that the KNP experimental burn plots experiment was proposed in 1953 (Annual report 1953; Van Der Schijff 1958).

6.1.2.2 The objective of the experiment

The objective of this research was to study the effect of fire on the natural plant communities of the KNP under the grazing pressure of wild animals (Van Der Schijff 1958). This was in contrast to the fire research

WISER

that had been undertaken by the Department of Agriculture at that time, which considered livestock and not wild animals (Van Der Schijff 1958).

In 1954, the experiment was laid out in four of the six major plant communities identified in the KNP by the assistant biologist HP Van Der Schijff (Annual Report 1954, Van Der Schijff 1958). The four major veld types were (Figure 6-1):

1. The broad leaf deciduous woodlands with long grass of Pretoriuskop.
2. The Combretum veld of Naphe.
3. The Knob thorn - Marula veld near Satara.
4. The Mopane woodlands between Shingwedzi and Letaba.

6.1.2.3 The experimental layout and design

The experiment was set-up in a randomised block design. Four replicates of treatments were placed in each of the four main plant communities defined within the KNP at the time by Van Der Schijff (1958) (Figure 6-1). In 1954, each replicate comprised seven plots to which seven fire treatments were randomly assigned (Annual report 1954, Van Der Schijff 1958). These treatments were no burning at all, annual fire in August, and biennial fire August, October, December, February, and April (Table 6-1).

In 1955, the Parks Board proposed expanding the experiment to incorporate treatments that were applied every three years (Annual Report 1955). In 1956, five more plots were added to each of the replicates, and five treatments were randomly assigned to these replicates, namely triennial burns in August, October, December, February, and April (Table 6-1) (Annual report 1955, Annual report 1956, Van Der Schijff 1958).

In total, there were twelve fire treatments, replicated four times each in each of the four major vegetation zones (Figure 6-1, Table 6-1). The experiment finally comprised 192 plots, each approximately 6.5 hectares in size, the whole experiment covering approximately 1248 hectares in the KNP. Biggs *et al*. (2003) have concluded that, because the treatments were not allocated to the replicates completely randomly, the EBP experiment cannot be considered a true randomised block design and can only be considered pseudo-randomised.

Table 6-1: The twelve treatments applied within each of the plant communities. The treatment code refers to the codes used in the database.

Year	Treatment code	Timing	Return period	Description
1954	Cont	None	0	No Burn – control
	Aug1	August	1	Annual burn in mid-winter
	Aug2	August	2	Biennial burn in mid-winter
	Oct	October	2	Biennial burn after the first rains
	Dec2	December	2	Biennial burn in mid-summer
	Feb2	February	2	Biennial burn in late summer
	Apr2	April	2	Biennial burn in Autumn
1956	Aug3	August	3	Triennial burn in mid-winter
	Oct3	October	3	Triennial burn after the first rains
	Dec3	December	3	Triennial burn in mid-summer
	Feb3	February	3	Triennial burn in late summer
	Apr3	April	3	Triennial burn in Autumn

WISER

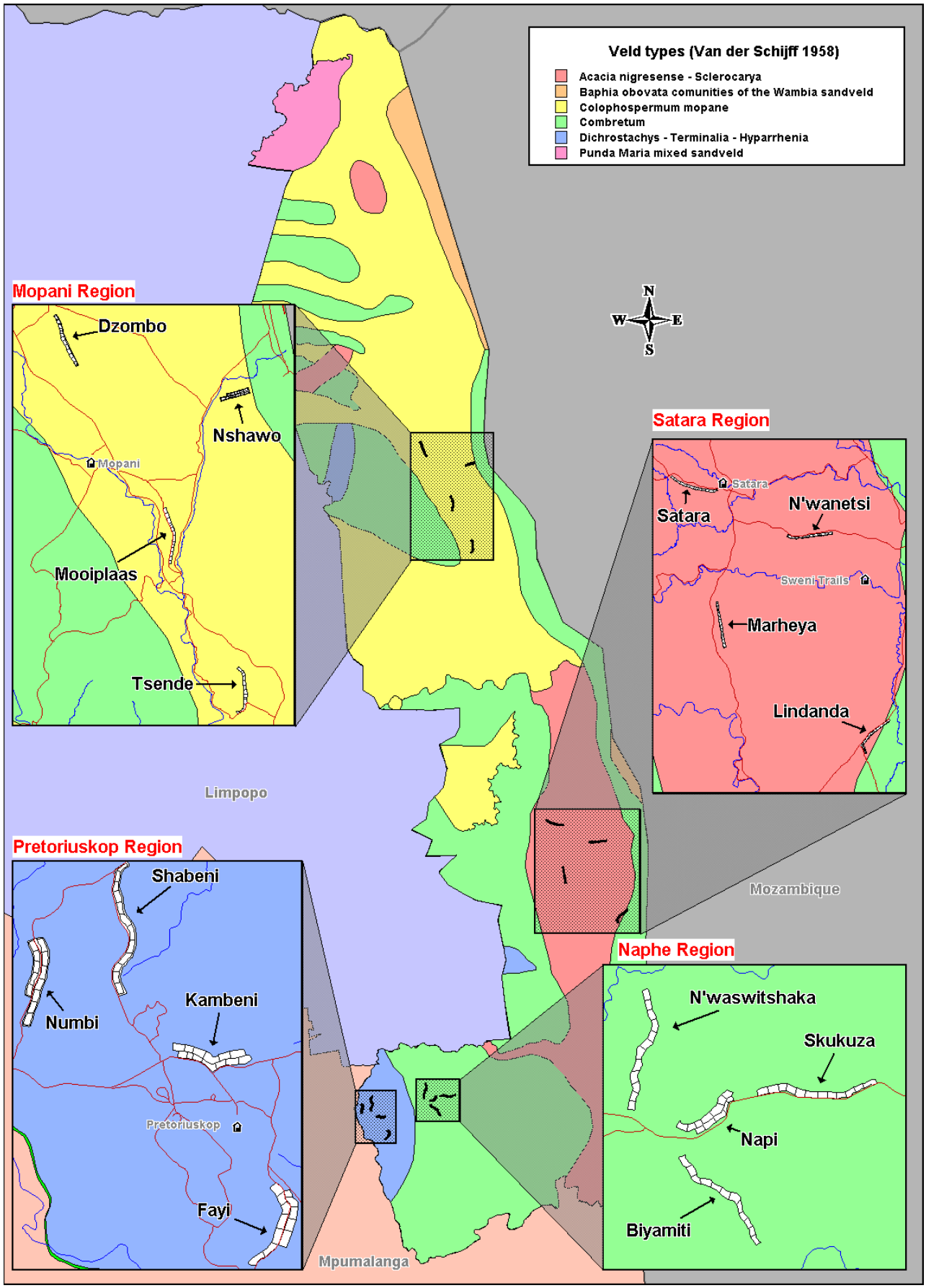


Figure 6-1: The layout of the Experimental Burn Plot experiment in the four vegetation communities in the Kruger National Park.

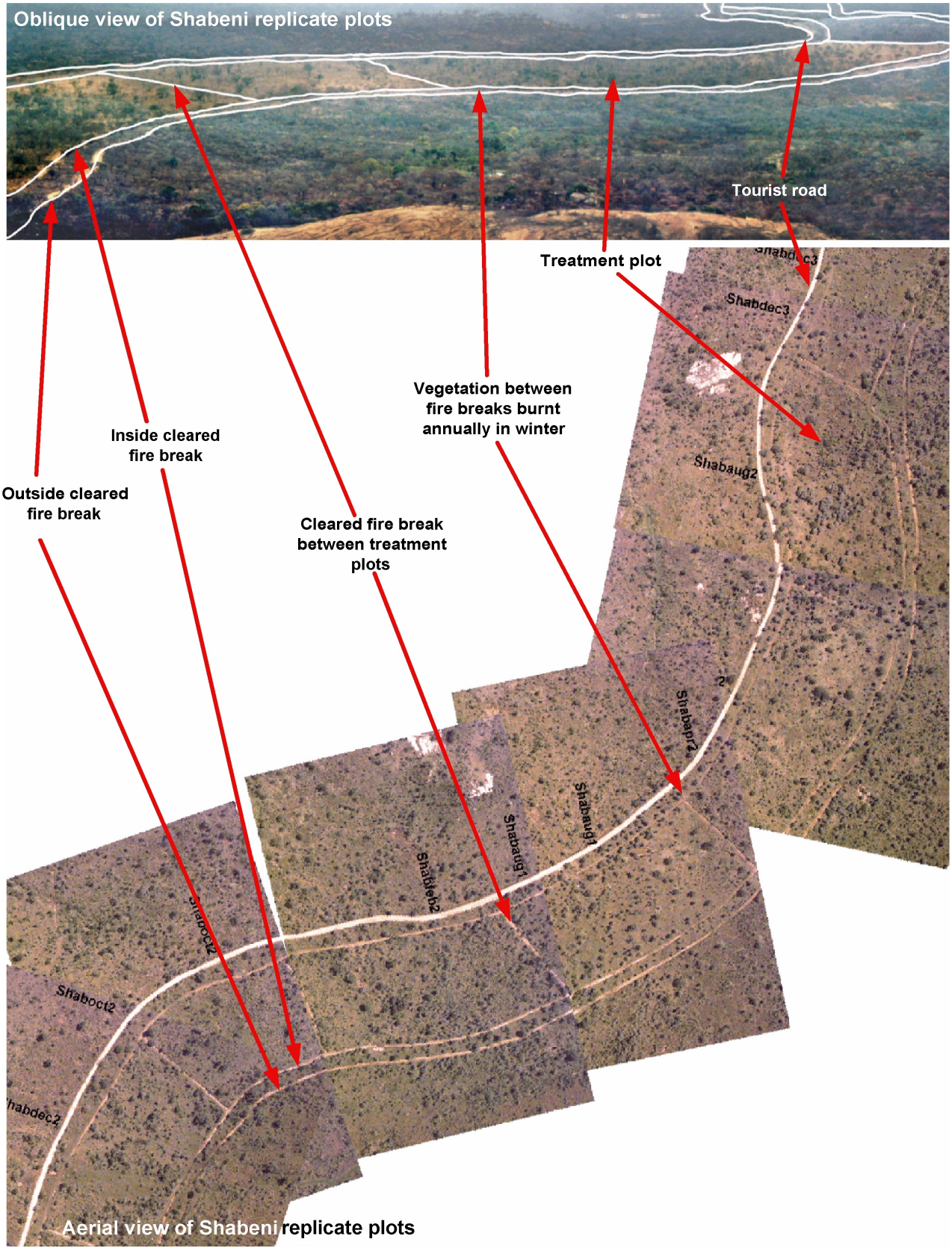


Figure 6-2: Oblique and aerial view of the Shabeni replicate, showing how the treatment plots were setup with the single cleared fire breaks between the plots and the two cleared fire breaks surrounding the replicate.

6.1.2.4 The construction of the experimental plots and replicates

Single cleared firebreaks separated each plot within a replicate from one another (Figure 6-2). Two cleared firebreaks protected each replicate on all sides from fires within the surrounding landscape (Figure 6-2). The vegetation between the firebreak roads was burnt annually towards the end of autumn, further protecting the replicates from untimely fires during the dry season (Annual Report 1954; Van Der Schijff 1958).

6.1.2.5 The application of the experimental treatments to the plots treatments

To contain the fire when applying a treatment to a plot, a back burn was burnt on the leeward (downwind) side of the plot before the fire front was lit on the upwind side of the plot (Figure 6-3). Furthermore, two lines of fire were ignited down the sides of the plot connecting the back burn and the head burn. The function of the back burn and two side burns was to prevent the head fire from escaping into adjacent areas. The size of the back burn was usually dependant on the strength of the prevailing wind, and the subjective estimation by the researcher of the likely intensity of the treatment. The stronger the wind and the more intense a treatment was likely to be the bigger the back burn was made.

The fire treatments were applied to the treatment plots regularly, and Biggs *et al*. (2003) found that less than twenty percent of the scheduled treatments between 1954 and 2001 were not applied. Some of these application errors were teething problems and occurred at the beginning of the experiment, and many others occurred at times of drought when the fuel levels on the plots were too low to sustain the fire treatments.

6.1.2.6 The application of the first fire treatments on the EBPs between 1954 and 1957

The first treatments (Table 6-1) were started in 1954, and the August Annual and Biennial, October Biennial, and the December Biennial treatments were applied in the Pretoriuskop and Naphe regions (Figure 6-1) (Annual Report 1954). The treatments were not applied to the EBPs in the Satara and Mopane regions (Figure 6-1) because the fuel levels were low and would not sustain a fire (Annual Report 1954). The treatments in the Satara and Mopane regions were rescheduled for 1955 (Annual Report 1954). During the application of the October Biennial treatments, in the Pretoriuskop region, the fire jumped in on the fourth replicate and burnt two adjacent treatment plots (Annual Report 1954). However, it is unclear which replicate (Fayi, Kambeni, Numbi, or Shabeni) the four replicate refers to, or which of the adjacent plots were burnt.

In 1955, the Annual and Biennial treatments were applied to the EBPs in the Pretoriuskop and Naphe regions without any mishaps (Annual Report 1955). The treatments in the Satara region were scheduled to be restarted in 1956, because many of the treatment plots were burnt out of schedule by fires in the Satara region in 1955 (Annual Report 1955). A photographic record of the plots was begun in 1955 (Annual Report 1955). These photographs included general photos showing veld condition and specific photos of research interest (Annual Report 1955). Unfortunately, these photographs were not catalogued and so they are of limited use (Annual Report 1957).

In 1956, the Biennial and Annual treatments were applied to the EBPs in the Pretoriuskop, Naphe, and Satara regions (Annual Report 1956). The treatments in the Mopane region were not started because some of the Dzombo replicate plots were burnt out of schedule when a firebreak fire accidentally burnt the plots (Annual Report 1956). The additional Triennial treatments were added to the existing replicates, but the treatments were not started because the vegetation surveys of these plots had not been completed (Annual Report 1956).

In 1957, the firebreaks roads around the EBP plots and replicates were made broader to approximately 7m (Annual Report 1957). This was done because of the spate of unscheduled fires on the treatment plots that had occurred between 1954 and 1957 (Annual Report 1957). The plots in each replicate were allocated numbers in 1957 to prevent plots from being burnt out of schedule by the application of the incorrect treatment (Annual Report 1957). The Annual and Biennial treatments were applied to the EBPs in the Pretoriuskop, Naphe, Satara and Mopane regions, and the triennial treatments were started in 1957 (Annual

Report 1957). A new photographic record was begun in which the photographs were catalogued (Annual Report 1957). The photographs were taken just before the application of each treatment. Furthermore, the data recorded before the application of each treatment was applied was systemised.

This marked the beginning of the Kruger National Park Experimental Burn Plots experiment.

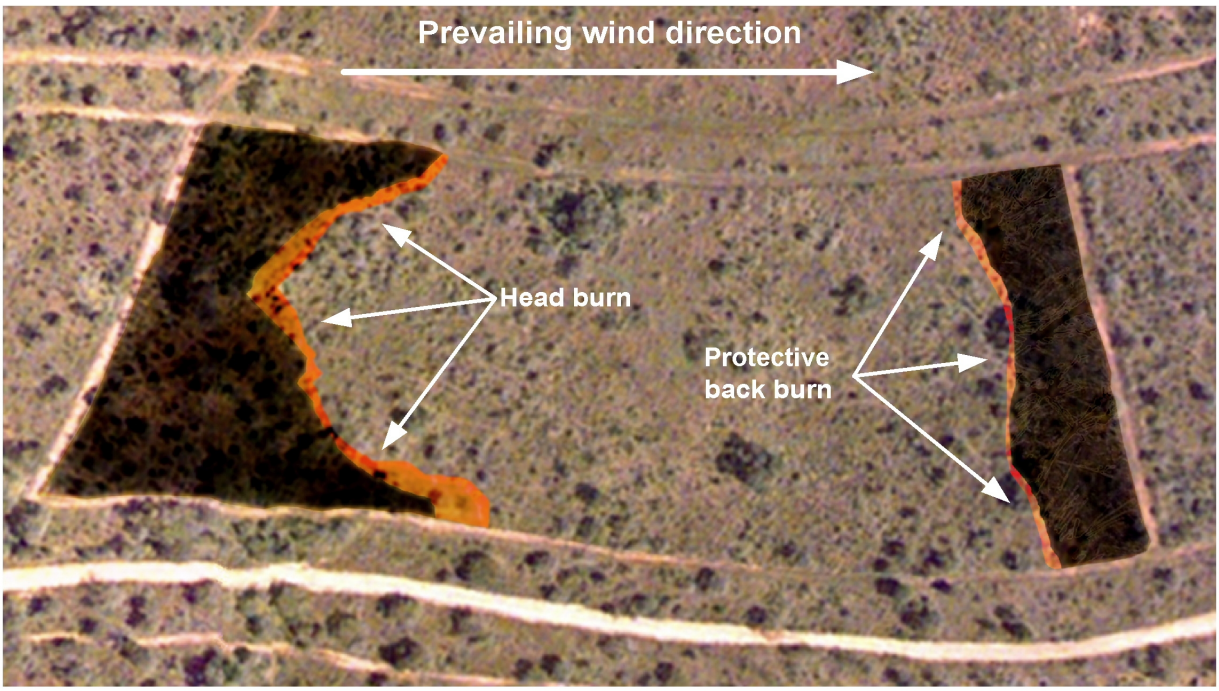


Figure 6-3: Showing the typical application of a fire treatment to an EBP, with a protective back burn to prevent the head burn from jumping the firebreak and burning the neighbouring plot or the surrounding landscape.

6.1.2.7 The collection of the baseline data

Before applying the treatments to the plots, a survey of the woody vegetation and grasses was conducted on each plot, and a photographic survey of the plots was conducted (Van Der Schijff 1958).

6.1.2.7.1 The woody vegetation survey - methodology and data

Using a surveyor cable laid along the diagonals of each plot, a 5-foot wide (1.5m) transect was surveyed for 1000 feet (305m) along each diagonal (Figure 6-4). All woody vegetation was identified and recorded. The basal diameter of single-stem individuals was recorded in one of five stem diameter classes, namely 0-1 inches (0-2.5 cm), 1-3 inches (2.5-7.6 cm), 3-5 inches (7.6-12.7 cm), 5-7 inches (12.7-17.8 cm) and greater than 7 inches (17.8 cm) (Van Der Schijff 1953). The coppice diameter of multi-stem individuals (i.e. coppicing individuals) was recorded in one of three classes: 0-1 feet (0-30 cm), 1-3 feet (30-91 cm) and greater than 3 feet (91 cm) (Van Der Schijff 1953).

6.1.2.7.2 The grass and herb survey - methodology and data

A Levy bridge with ten points, 5 cm (2 inches) apart, was used to survey the grasses on the plots. The bridge was placed approximately at 6 m (20 feet) intervals along each diagonal. Fifty placements, and not 100 as reported by Van Der Schijff (1958), were made per diagonal and a total of 1000 survey points were recorded for each plot.

The data for these surveys was tabulated and the raw data no longer exists. It was proposed that these surveys should be conducted once every ten years (Van Der Schijff 1958).

By 1959, the experiment was set-up and people began to review the methods and methodology. The first to be assessed were the baseline surveys of the woody vegetation.

6.1.2.8 Assessment of the belt transect baseline survey

In 1959 a calibration of the belt transect method was done on the Naphe plots of the Combretum veld (Brynard *et al.* 1960, Davidson *et al.* 1961). It was concluded that the belt transect survey was adequate for floristic studies and for the determination of the general structure of the vegetation on the plots. However, at the species level whether this method was adequate depended on the number of individuals surveyed in each transect. Furthermore, in an area where the vegetation diversity and woody species richness was high this method may prove to be poor.

It was concluded that the baseline survey should not be used as a direct comparison to subsequent surveys, and that subsequent surveys should be analysed using Analysis of Variance (ANOVA) by randomised blocking. Davidson *et al.* (1961) suggested that, depending on the needs of the experiment, either the area sampled on each plot could be increased (i.e. 3 x 310 m (10 x 1000 ft) transects), or a different survey method could be used, or a fixed transect or plot survey could be used. It was also suggested that a more meaningful measure of importance other than coppice diameter classes be used for the survey of the shrub forms (Brynard *et al.* 1960, Davidson *et al.* 1961).

The control plots in both the Pretoriuskop and Naphe regions were also resurveyed in 1959 using the same methodology as in 1954 (Annual Report 1959).

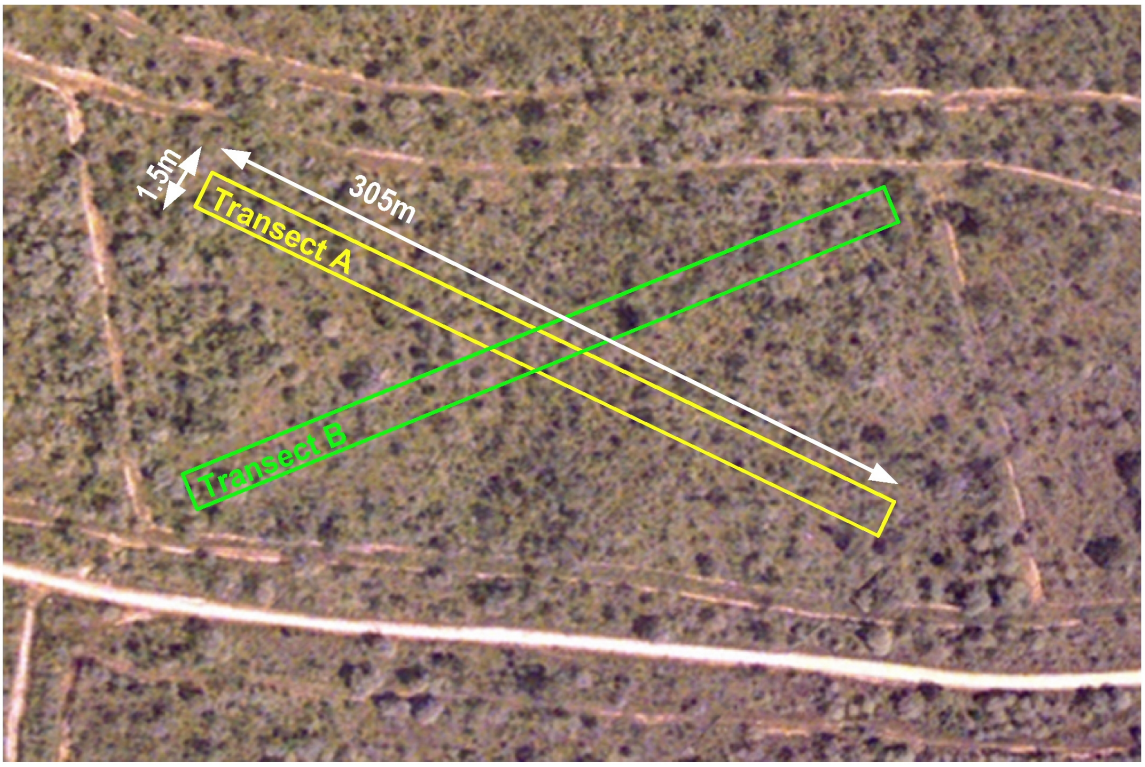


Figure 6-4: Showing the placement of the two transects along the diagonals of a treatment plot in the baseline woody vegetation survey of the EBPs in 1954.

This evaluation of the baseline data started a trend of criticism of the KNP EBP experiment that ultimately led to the credibility and perceived worth of the experiment being compromised. Follow up surveys (proposed every 10 years) were not conducted with any regularity or consistency. Furthermore, none of the follow up survey methodologies was the same as the baseline survey or the same as any of the other follow up surveys on the plots. This has made comparison and trend analysis over time challenging. However, regardless of the criticism aimed at the experiment, the same integrity of the experiment was maintained and treatments were faithfully applied.

Outside the daily maintenance of the experiment, research work and data collection continued on the plots, and in 1960 aerial photographs were taken of all the plots. Unfortunately, many of the photographs either were of poor quality or were not successfully processed, and the photographic material is no longer available (Annual Report 1960).

6.1.2.9 A second assessment of the baseline surveys and further recommendations

In 1962, the KNP research department began collaborating with HH Von Broembsen of the Agricultural Department of the University of Pretoria (Annual Report 1962). The aims of this collaboration were (Annual Report 1962):

1. To examine the vegetation of some of the plots in the EBP experiment in order to make recommendations about the analysis and assessment of data obtained from previous surveys.
2. To test various survey methods for the tree and shrub components of the EBPs.
3. Make recommendations regarding future sampling methods of the woody vegetation. The aim was to identify methods that were both easily repeatable and comparable to the baseline survey data.

Based on the collaboration it was decided that further surveys of the EBPs would be postponed until suitable survey methods had been decided upon (Annual Report 1962).

In 1963, HH Von Broembsen and P Muller submitted a report on their findings regarding the EBP experiment (Annual report 1963). They found that there was no way in which to examine the effect of fire on the vegetation pattern. Furthermore, it was doubtful whether the relative species contribution to the total population could be used in comparing the data between surveys. They concluded, "…that the sampling data derived from the two previous surveys [1954 and 1959] are useless as far as statistical evaluation is concerned" (Von Broembsen 1963).

Again, the validity of the experiment, or at least the validity of the assessment of the experiment, was challenged. This time the assessment was certainly more cutting, although Von Broembsen does hasten to clarify that "…the criticism expressed here is not intended to imply that this situation arose through negligence on the part of any officer of the National Parks Board" (Von Broembsen 1963).

Von Broembsen (1963) recommended the use of the wheel point method developed by Tidmarsh and Havenga (1955). This method of sampling could be used to survey both the tree-shrub and grass components. For the grasses and herbs, 2000 sampling points would be required, however for the trees and shrubs between 16000 and 32000 sample points were recommended for the different vegetation types (Von Broembsen 1963).

In contrast with the baseline surveys, this approach uses a point method to estimate the cover of vegetation and not the density of the vegetation. These two measures of vegetation abundance are difficult to compare.

In 1965, the Satara plots were surveyed following the recommendations of Von Broembsen and Muller (Annual report 1965). No clear pattern was found in the grass-herb data and it was thought that heavy grazing might be confounding the treatment effects on these plots (Annual report 1965). This was not the first time that concern had been expressed over the potential confounding effects of grazing. In the 1964

Annual report, P Van Wyk commented that grazing was certainly heavier on the experimental plots than in the surrounding areas (Annual report 1964).

By the mid 1960's the credibility of the EBP experiment especially within the KNP administration was in question. The experimental design appeared to be flawed, and so too was any attempt at assessing the experiment. However, despite the criticism aimed at the EBP experiment it had the inertia of ten years of operation that kept it going. Furthermore, it was recognised that the EBP experiment was a long-term experiment.

In 1966, the grasses and herbs on the Pretoriuskop plots were surveyed using the Tidmarsh wheel method. It was found that there was a remarkable decrease in *Hyparrhenia dissoluta* (Annual report 1966).

6.1.2.10 Quadrate middle-point surveys – another method

In 1967 and 1968 the woody vegetation on the plots in the Pretoriuskop and Mopane regions were surveyed using the quadrate middle point method developed by Cottam and Curtis (1956) (Annual report 1967, Van Wyk 1971). A 1000 plants were sampled on thirteen transects, per plot. Data recorded were the identity and distance of the nearest plant in each quadrate, stem diameter of single-stem trees, multi-stem individuals were recorded in one of four coppice diameter classes (0-15 cm (0-6"), 15-31 cm (7-12"), 31-91 cm (13-36") and greater than 91 cm (36")), and the height to which plants had been scorched in the previous treatment. A density estimate can be calculated from the data collected using this method (Brower and Zar 1977).

Findings from these surveys were presented at the 11th Annual Tall Timbers Fire and Ecology Conference in Florida, USA.

6.1.2.11 Step point method (1970)

In 1970, the woody vegetation of the Pretoriuskop region was surveyed by means of a step point method. Twelve transects, with points ten yards apart, were walked for each plot. The identity of the nearest plant on either side of the line transect was recorded. Single-stem individuals were classified into six height classes (0-1 m, 1-2 m, 2-4 m, 4-6 m, 6-9 m and 9-12 m), seven canopy diameter classes ("no leaves", 0-1 m, 1-2 m, 2-4 m, 4-6 m, 6-9 m and 9-12 m), and six stem diameter classes (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-30 cm and 30-40 cm). Multi-stem individuals were classified into the same height canopy diameter classes, but only four coppice basal diameters were defined (0-0.5 m, 0.5-1 m, 1-2 m, and >2 m).

Unfortunately, the distance from point to plant was not measured. Without the distance measures density cannot be estimated. Using this data for comparative analyses is limited.

6.1.2.12 Half hectare survey plot – a permanent monitoring plot

In 1971, permanent monitoring plots were placed on each EBP (Annual report 1971, Gertenbach and Potgieter 1975, Gertenbach and Potgieter 1979 a & b). These monitor plots were setup firstly because repeating the baseline survey was believed to be impractical, and secondly to address criticism that had been levelled the monitoring of the vegetation on the EBPs (Annual report 1971, Gertenbach and Potgieter 1975). Gertenbach and Potgieter (1975) report that the size of the monitor plots was 100m x 50m (½ hectare), while Gertenbach and Potgieter (1979a & b) report that the size of the monitor plots was 50m x 50 m (¼ hectare). These monitor plots were 100m x 50m and only half the data was used in the analyses reported in Gertenbach and Potgieter (1979a & b). The monitor plots comprised 20 transects of 5m wide and 50m long, and the following woody vegetation data were recorded on them: species, position, height, canopy diameter, number of stems and stem diameter (Gertenbach and Potgieter 1975, Gertenbach and Potgieter 1979 a & b). The herbaceous vegetation on these plots was surveyed using a Tidmarsh wheel, and one thousand points was recorded on each monitor plot (Gertenbach and Potgieter 1975, Gertenbach and Potgieter 1979 a & b).

While the monitor plot did not necessarily represent the whole experimental plot, it made up for this by enabling time series analysis on the effects of the treatments on the vegetation, accomplished by repeatedly surveying the exact same patch of vegetation (Annual report 1971). Furthermore, the measurement of the treatment effects on individuals could also be done since the location of individuals was recoded in 1m x 1m grids (Annual report 1971). It was also felt that this method would be quicker than the belt-transect method or the quadrate-middle-point method, which had been used to survey the vegetation previously.

As it turned out the half-hectare survey was just as time consuming and it took three years, from 1971 to 1973 to survey all the plots. Furthermore, the control plots for the Pretoriuskop area were not surveyed, because the researcher surveying the plots "didn't have the heart" to go into those dense plots after surveying the EBPs for three years (Potgieter pers. com. 1998). From 1973 onward, no complete vegetation surveys were conducted on the EBPs. The main reason for this was the sheer size of the task.

In 1972, Prof JD Scott from the University of Natal assessed the EBP experiment and added further criticism (Scott 1972, Annual report 1972). He stated, "One very important fact that emerged was that differences in soils had a far greater effect on the vegetation than treatments". Furthermore, he felt that the timing of the treatments were not ecologically significant since the first rains of the wet season did not conform to the Gregorian calendar.

Now not only did grazing confound the treatment effects but so too did the underlying soil pattern.

In 1973 a series of plots were laid out in the Knob thorn veld near Crocodile Bridge. These plots were smaller than the existing EBPs, but were fenced in to control for the effects of post-fire grazing and trampling (Annual report 1973). It was proposed that three more "camps" were laid out in the Naphe, Satara, and Pretoriuskop regions. These plots, it was hoped, would help quantify the post-fire grazing and trampling effects on the EBPs.

In 1976, Prof AM Starfield, of the University of Witwatersrand, assisted the KNP Research Department in analysing some of the data collected in the ¼ hectare monitoring plots (Annual report 1976). They concluded that the experiment was "…. severely hampered by the fact that there was no proper base-line" (Sarnak *et al.* 1977). Furthermore, the broad trends that were evident from the analyses "…should have been obvious to the trained eye in the first place without going through the process of collecting and analysing the data" (Sarnak *et al.* 1977).

They recommended that the monitor plots should be surveyed regularly, and that game free enclosures be built to remove the confounding effects of post fire grazing (Sarnak *et al.* 1977).

It is not clear in the report to what extent the previous data collected on the plots was actually scrutinised. However, it now became "fact" that surveys prior to 1971 were of little use and might as well not exist. Furthermore, discounting 3 years of surveying the monitor plots was certain to demoralise those involved with the groundwork on the EBP experiment.

Some comments regarding the recommendations in the report give an idea of the feeling in the KNP at the time towards the EBP experiment. In response to the suggestion of using enclosures to mitigate the high post-fire grazing pressure on the EBPs, one researcher commented that the KNP should "Rather spend the effort and exploit better what we do have (than start another big circus)" (Comments on archived copy of Sarnak *et al.* 1977).

In 1978, the KNP was incorporated into the "Ecological effects of fire" Scientific Committee on Problems of the Environment project (SCOPE). The aim of the programme was to collate current research and understanding of the ecological effects of fire in South African Ecosystems (SCOPE 1978).

WISETD

During 1980, in response to the change in the prescribed burning policy, it was decided that two more frequencies should be added to the EBP experiment in the Mopane and Satara regions (Annual report 1980). This was done by dividing the February 2 and 3 year burn plots in half and applying an October 4 and 6 year burns respectively (Annual report 1980).

The year 1982 marked the beginning of a long-term collaboration between WSW Trollope and the KNP research department. Since 1982, there has been a concentrated focus on fire research using the EBPs and other areas in the KNP by Trollope and the KNP research. Research focus has ranged from calibrating grass fuel load assessments, to fire behaviour studies, to post fire mortality of trees under different fire conditions. This research improved the image of the EBPs. However, the fact that these studies were not the original objective of the experiment seemed to discount the value of the EBPs. Therefore, the negative perception of the EBP experiment persisted.

6.1.2.13 To continue with the EBPs, or not to continue with the EBPs?

In 1989, N Tainton conducted grass and tree surveys on a number of plots in the Pretoriuskop and Naphe regions (Annual report 1989). He concluded that to resurvey and analyse the data of the EBPs would be an enormous task (Annual report 1990).

The question was posed, whether it was worth resurveying the plots (Annual report 1990). This question was put forward in light of the effects of heavy post-fire grazing on the plots.

Tainton recommended that if the KNP Research Department did not intend to resurvey the plots then the continuation of the EBP experiment might not be justified (Annual report 1990). This was the first time that a recommendation mentioned terminating the experiment.

In 1992, the EBP experiment featured in the KNP portion of the South African Fire-Atmosphere Research Initiative (SAFARI). SAFARI 1992 provided a holistic approach to researching for the cause and effect relationships between changes in the earth's atmosphere and African savanna ecosystem structure and functioning, with particular reference to fire (Van Wilgen *et al.* 1997).

Between 1995 and 1997, the KNP undertook a reassessment of their vision, mission, and objectives as part of a greater transformation process within the South African National Parks. This required a complete review of research policy and current research activities in the Park (Trollope *et al.* 1998).

During this assessment, the future of the KNP EBPs came under scrutiny. The perception of the EBP experiment by this time was that it was fundamentally flawed (Van Wilgen *et al.* 1998). Rather than waste resources on maintaining an experiment with limited prospects for profit, "…it would seem sensible to terminate this experiment after an analysis of the data collected to date" (Van Wilgen *et al.* 1998).

It is interesting that a long-term experiment such as the EBP experiment should fall victim to such negativity at a time when "…the establishment of long-term research sites subjected to a range of carefully applied fire regimes is urgently required" (Whelan 1995). Since 1959, almost every external scientific assessment of the experiment created and added to a critical mass of negativity, which then surrounded EBP experiment. This long history of critical evaluation of the EBP experiment, which focused on the negative aspects, resulted in the EBP experiment by slow degrees becoming an embarrassment instead of a point of pride.

However, long-term ecological experiments that have been maintained rigorously are rare, and the EBP experiment is one such experiment. While many of the criticisms of the experiment are valid, modern computational power and analytical techniques make the early data very valuable. Furthermore, the computational power available currently makes readily useable many analytical techniques that provide the means this factoring and accounting for non-treatment variance on the EBP experiment such as grazing and

WISETD

soil substrate. Finally, regardless of the original objectives of the experiment the value of a +40-year database in light of global climate change research is immeasurable.

In February 1997, a fire workshop was held in Skukuza to discuss the future of the EBP experiment. The following recommendations were made (Trollope *et al.* 1998):

1. Complete a final woody and grass survey of the EBPs.
2. Analyse and interpret the findings, and digitise all existing survey data.
3. Collate existing published and unpublished information on the EBPs.
4. Make recommendations regarding the scaling down of the EBP experiment.

In a follow-up to this workshop, it was recommended that the experiment be continued until mid-2003 in its current form (Trollope *et al.* 1998). This period was to serve as a wrapping-up period of conducting final surveys, capturing data, and exploring further potential use for the EBP infrastructure (Trollope *et al.* 1998). Since the 1997 workshop, the future of the EBP experiment has become solidified. The 1997 workshop bought the EBP experiment into the scientific mainstream, and the value of this long-term experiment has become apparent to scientists locally and globally who are clamouring to get at the data and to become involved in the future of the EBP experiment.

WitsETD

6.2 RESULTS FROM THE UNIVARIATE ANALYSIS TESTING THE EFFECTS OF FIRE ON THE DENSITY, STRUCTURE AND COMPOSITION OF THE WOODY VEGETATION OF THE PRETORIUSKOP EBP

In this section, the results from the Kolmogorov-Smirnov tests for normality, the ANOVA and ANCOVA analyses on the vegetation indices, and the Pearson-Ward cluster analyses on the Horn's similarity indices are presented.

6.2.1 Skewness and kurtosis of the data and the Kolmogorov-Smirnov one sample tests for normality

The results of the Kolmogorov-Smirnov (KS) one-sample tests for normality on the twelve vegetation indices calculated from the 1954 and 1996 survey data are presented in Figure 6-5 (p. 60) and Figure 6-6 (p. 62). The skewness and kurtosis statistics of the distributions are also presented in Figure 6-5 and Figure 6-6. The values of the vegetation indices calculated for each plot from the 1954 and 1996 survey data are presented in Appendix 4 in Table 12-1 (p. 220) and Table 12-3 (p. 222) respectively.

6.2.1.1 Testing the distribution of woody plant density per plot for normality

The distributions of the woody vegetation densities per plot in 1954 and 1996 were not significantly different from a normal distribution having Kolmogorov-Smirnov p-values of 0.810 and 0.306 respectively (Figure 6-5 and Figure 6-6). The skewness values of the plot densities in 1954 and 1996 (0.516 and 1.124 respectively) showed that the distributions had longer right tails than a normal distribution. The kurtosis values of the plot densities in 1954 and 1996 (1.084 and 2.645 respectively) showed that the distributions were more peaky than a normal distribution. The average density (plants/Ha) per plot in 1954 was 2094.5 and ranged from 401 on the Numbi February biennial plot to 4648 on the Shabeni February biennial plot (Table 12-1 and Table 13-1). The average density per plot in 1996 was 6012.7, which was 2.87 times higher than the average density per plot in 1954 (Table 12-3 and Table 13-1). The density per plot in 1996 ranged from 2298 on the Shabeni December triennial plot to 14163 on the Numbi no burn (control) plot. The lowest plot density in 1996 (2298), was greater than the average plot density in 1954 (2094.5). In general, the woody plant density increased on the Pretoriuskop EBPs between 1954 and 1996.

6.2.1.2 Testing the distribution of mean plant height per plot for normality

The distributions of the mean plant height per plot in 1954 and 1996 did not differ significantly from normality with Kolmogorov-Smirnov p-values of 0.452 and 0.221 respectively (Figure 6-5 and Figure 6-6). The skewness of the mean heights in 1954 and 1996 (0.722 and 0.587 respectively) showed that the distributions had longer right tails than a normal distribution. The kurtosis values showed that the magnitude of the distribution was slightly more peaky than a normal distribution in 1954 (0.541), and was similar to a normal distribution in 1996 (0.038). The average plant height on the plots in 1954 was 1.076m and ranged from 0.629m on the Shabeni August biennial plot to 1.668m on the Fayi December triennial (Table 12-1 and Table 13-1). The average plant height on the plots in 1996 was 1.041m and ranged from 0.640m on Numbi August annual to 1.574m on the Kambeni October triennial plot (Table 12-3 and Table 13-1).

Although the mean wood plant height frequency distribution in 1996 did not differ significantly from normality, the frequency histogram in Figure 6-6 showed that the distribution might be binomial. The first peak occurred between 0.6m and 1.05m with a highest point of 12 plots having average woody plant heights between 0.8m to 0.9 m. The second peak occurred between 1.05m and 1.7m with a highest point of 9 plots having average woody plant heights between 1.1m and 1.2m. The first peak (0.6m to 1.05m) comprised the Fayi Dec2, Feb2, Aug1, Oct3, Feb3, and Apr3 plots, the Kambeni Dec2, Feb2, Apr2, Aug1, Feb3, and Apr3 plots, the Numbi Dec2, Feb2, Aug2, Apr2, Aug1, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Apr2, Aug1, Feb2, Oct2, Dec2, and Apr3 plots. The second peak (1.05m to 1.7m) comprised the Fayi Aug2, Con0, Oct2, Apr2, Dec3, and Aug3 plots, the Kambeni Con0, Oct2, Aug2, Oct3, Dec3, and Aug3 plots, the Numbi

Oct2 and Con0 plots, and the Shabeni Aug2, Con0, Dec3, Aug3, Oct3, and Feb3 plots. All the August Annual treatments occurred in the first peak and all the Control (no burn) treatments occurred in the second peak. Fourteen of the sixteen Biennial and Triennial February and April treatments and all of the December Biennial treatments occurred in the first peak. Eleven of the sixteen biennial and triennial August and October treatments and three of the four December Triennial treatments occurred in the second peak.

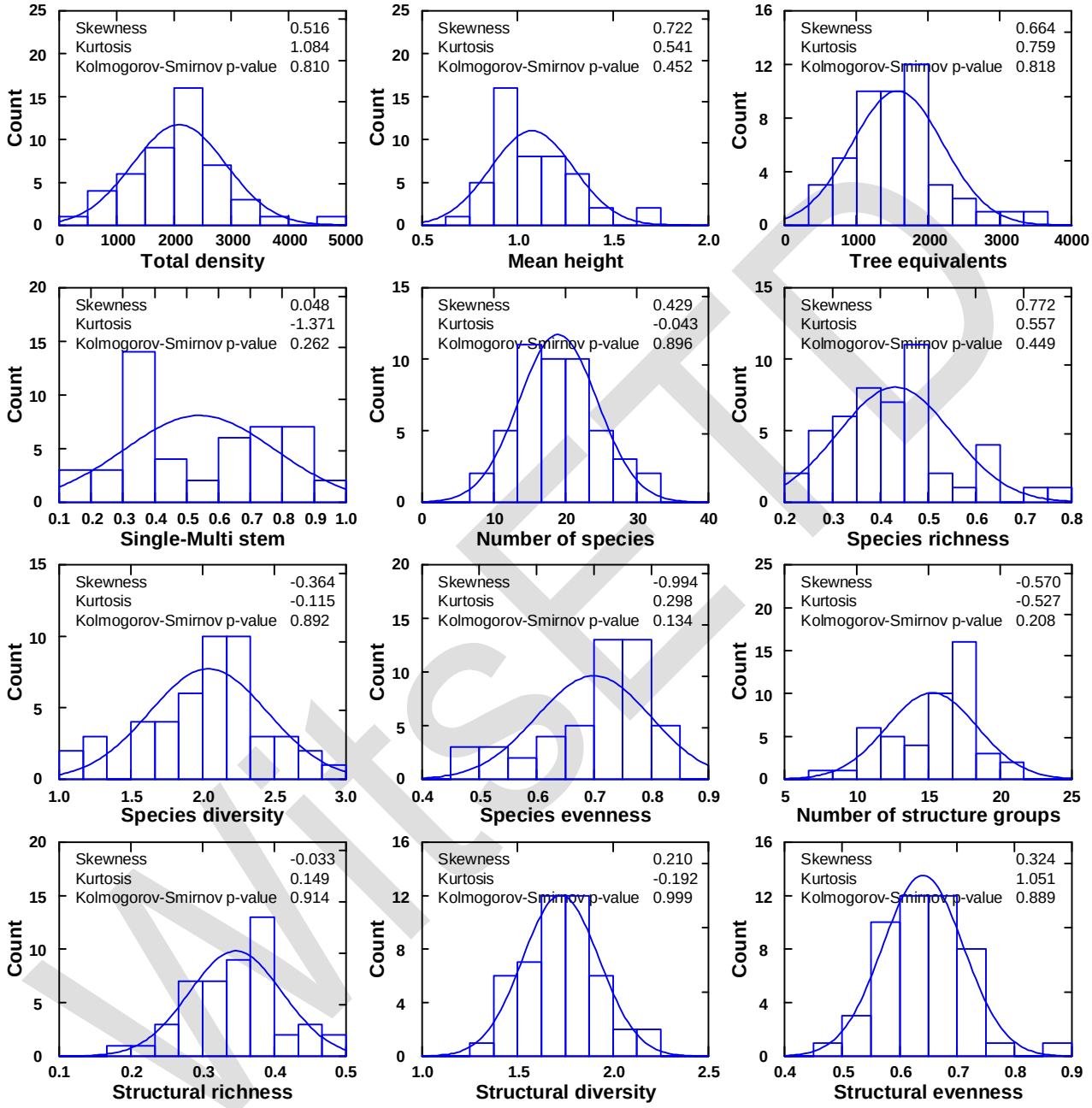


Figure 6-5: Normal curves fitted to the distribution of vegetation indices calculated for each plot using the baseline data collected in 1954. The graphs show the Skewness, Kurtosis and Kolmogorov-Smirnov p-values for the data distributions.

6.2.1.3 Testing the distribution of number of tree equivalents per plot for normality

The distributions of the number of tree equivalents per plot in 1954 and 1996 did not differ significantly from normality with Kolmogorov-Smirnov p-values of 0.818 and 0.967 respectively (Figure 6-5 and Figure 6-6). The skewness of number of tree equivalents in 1954 and 1996 (0.664 and 0.875 respectively) show that the distributions had longer right tails than a normal distribution. The kurtosis values show that the distributions

WISER

in 1954 and 1996 were peakier than a normal distribution with values of 0.759 and 1.255 respectively. The average number of tree equivalents (tree equivalents/Ha) in 1954 was 1571.7 and 4285.9 in 1996, which was 2.73 times higher than in 1954. In 1954, the tree equivalents ranged from 398 to 3431 on the Numbi February biennial and Shabeni February biennial plots respectively. The same plots (Numbi February biennial and Shabeni February biennial) had the lowest and highest woody plant densities respectively in 1954 (Table 12-1 and Table 13-1). In 1996, the tree equivalents per plot ranged from 1551 to 10323 on Shabeni April biennial and Numbi no burn (control) plots respectively (Table 12-3 and Table 13-1).

6.2.1.4 Testing the distribution of the single-stem to multi-stem index per plot for normality

The distributions of the single-stem to multi-stem index calculated for the 1954 and 1996 surveys were not significantly different from a normal distribution with Kolmogorov-Smirnov p-values of 0.262 and 0.632 respectively (Figure 6-5 and Figure 6-6). The skewness values of the single-stem to multi-stem index in 1954 and 1996 (0.048 and -0.057 respectively) showed that the distributions were similar to a normal distribution and symmetrical about their arithmetic means. The kurtosis values in 1954 and 1996 (-1.371 and -0.263 respectively) showed that the distributions were flatter than a normal distribution. In 1954, the distribution of single-stem to multi-stem index was flatter than in 1996. In 1954, the number of single-stem individuals was approximately the same as the number of multi-stem individuals with a mean single-stem to multi-stem index of 0.541. However, in 1996 mean single-stem to multi-stem index was 0.324 which was almost half that of 1954, revealing a proportionally higher number of multi-stem individuals relative to single-stem individuals in 1996. In 1954, the single-stem to multi-stem index ranged from 0.132 (few single-stem individuals) on the Kambeni December triennial plot to 0.922 (few multi-stem individuals) on the Fayi February biennial plot (Table 12-1 and Table 13-1). In 1996, the distribution of the single-stem to multi-stem index ranged from 0.065 (very few single-stem individuals) on the Kambeni August biennial plot to 0.613 (even number of single-stem and multi-stem individuals) on the Shabeni no burn (control) plot (Table 12-3 and Table 13-1).

6.2.1.5 Testing the distribution of the number of species per plot for normality

The distributions of the number of species per plot in 1954 and 1996 were not significantly different from a normal distribution with Kolmogorov-Smirnov p-values of 0.896 and 0.145 respectively (Figure 6-5 and Figure 6-6). The skewness of the number of species per plot in 1954 and 1996 showed that the distributions had longer right tails than a normal distribution (0.429 and 0.488 respectively). The kurtosis values showed that the magnitude of the peak in 1954 was similar to that of a normal distribution (-0.043), while in 1996 it was considerably greater than that of a normal distribution (1.271). The average number of species per plot was 19.0 in 1954 and 29.6 in 1996, which is 10.667 species per plot more than in 1954. In 1954, the distribution ranged from 9 species per plot on the Kambeni August biennial and Shabeni August triennial plots to 33 species on the Numbi October triennial plot (Table 12-1 and Table 13-1). In 1996, the distribution of the number of species per plot ranged from 14 on the Fayi October triennial plot to 47 on the Numbi April triennial plot (Table 12-3 and Table 13-1). In general, the number of species recorded per plot increased between 1954 and 1996.

6.2.1.6 Testing the distribution of species richness per plot for normality

The distributions of the species richness per plot in 1954 and 1996 did not differ significantly from a normal distribution with Kolmogorov-Smirnov p-values of 0.449 and 0.557 respectively (Figure 6-5 and Figure 6-6). The skewness values of the species richness in 1954 and 1996 (0.772 and 0.632 respectively) showed that the distributions had longer right tails than a normal distribution. The kurtosis values for 1954 and 1996 (0.557 and 0.172 respectively) showed that the distributions were slightly more peaky than a normal distribution. The mean species richness on the plots was 0.431 in 1954 and 0.396 in 1996. In 1954, the species richness ranged from 0.228 to 0.763 on the Kambeni August biennial plot and the Numbi April triennial plots respectively (Table 12-1 and Table 13-1). In 1996, the species richness per plot ranged from 0.218 to 0.593 on the Fayi October triennial and the Numbi December triennial plots respectively (Table 12-3 and Table 13-1). In 1954, the Kambeni August biennial plot had the lowest species richness and it had the

lowest number of species (9). In 1996, the Fayi October triennial plot had the lowest species richness and it had the lowest number of species (14).

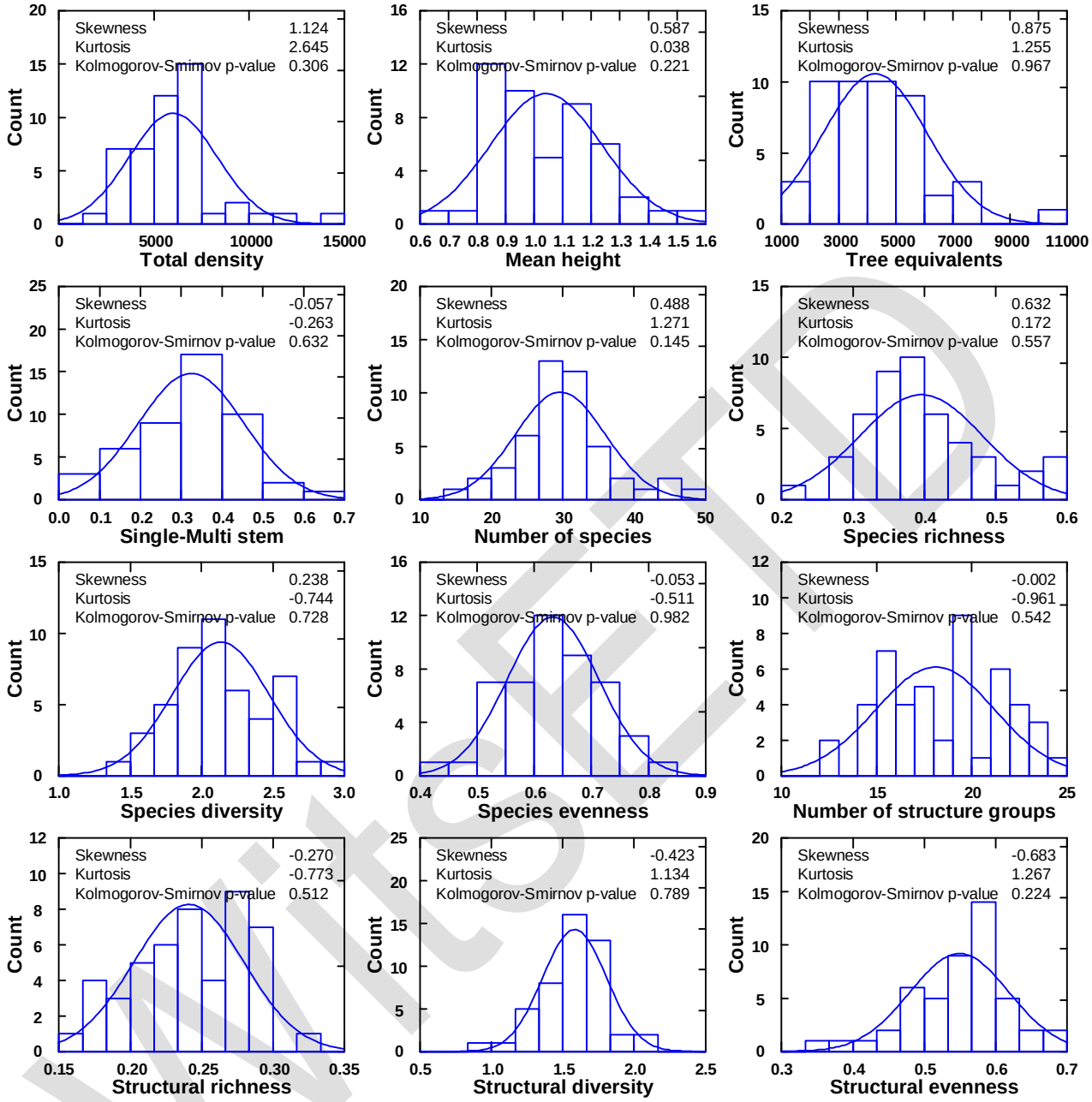


Figure 6-6: Normal curves fitted to the distribution of vegetation indices calculated for each plot using the baseline data collected in 1996. The graphs show the Skewness, Kurtosis and Kolmogorov-Smirnov p-values for the data distributions.

6.2.1.7 Testing the distribution of species diversity per plot for normality

The distributions of the species diversity per plot in 1954 and 1996 were not significantly different from a normal distribution with Kolmogorov-Smirnov p-values of 0.892 and 0.728 respectively (Figure 6-5 and Figure 6-6). The skewness of the species diversity in 1954 showed that the distribution had a longer left tail than the normal distribution (-0.364), and in 1996 it had a longer right tail than a normal distribution (0.238). The kurtosis values for 1954 and 1996 (-0.115 and -0.744 respectively) showed that the distributions were slightly flatter than a normal distribution. The average species diversity per plot in 1954 was 2.042 and 2.132 in 1996. In 1954, the species diversity ranged from 1.157 to 2.880 on the Kambeni August biennial and the Numbi October triennial plots respectively (Table 12-1 and Table 13-1). In 1996, the species diversity ranged

from 1.481 to 2.849 on the Kambeni August biennial and Numbi December triennial plots respectively (Table 12-3 and Table 13-1). In 1954, the Kambeni August biennial plot had the lowest species diversity and it had the lowest number of species, and the lowest species richness. The Numbi October triennial plot had the highest species diversity in 1954 and it had the highest number of species. In 1996, Numbi December triennial plot had the highest species diversity and it had the highest species richness.

6.2.1.8 Testing the distribution of species evenness per plot for normality

The distributions of the species evenness per plot in 1954 and 1996 did not differ significantly from normality with Kolmogorov-Smirnov p-values of 0.134 and 0.982 respectively (Figure 6-5 and Figure 6-6). The skewness of the species evenness in 1954 showed that the distribution has a longer left tail than the normal distribution (-0.994), and in 1996 it was symmetrical about the arithmetic mean (-0.053). The kurtosis showed that the distribution in 1954 was slightly peakier than a normal distribution (0.298), and in 1996, the distribution was flatter than a normal distribution (-0.511). The average species evenness on the plots in 1954 was 0.700, and in 1996, it was 0.633. In 1954, the species evenness ranged form 0.453 on the Kambeni December triennial plot to 0.844 on the Numbi August biennial plot (Table 12-1 and Table 13-1). In 1996, the species evenness ranged from 0.444 to 0.801 on the Kambeni August biennial and Numbi December triennial plots respectively (Table 12-3 and Table 13-1). In 1996, the Numbi December triennial plot had the highest species evenness and it had the highest species richness (0.593), and species diversity (2.849). The Kambeni August biennial plot had the lowest species evenness in 1996 and it had the lowest species diversity (1.481).

6.2.1.9 Testing the distribution of the number of structure groups per plot for normality

The distributions of the number of structure groups per plot in 1954 and 1996 were not significantly different from a normal distribution with Kolmogorov-Smirnov p-values of 0.208 and 0.542 respectively (Figure 6-5 and Figure 6-6). The skewness value of the number of structure groups in 1954 showed that the distribution had a longer left tail than a normal distribution (-0.570), and in 1996 it was symmetrical about the arithmetic mean (-0.002). The kurtosis values for 1954 and 1996 (-0.527 and -0.961 respectively) showed that the distributions were flatter than a normal distribution. The average number of structure groups per plot in 1954 was 15.3 while it was 18.1 in 1996. In 1954, the number of structure groups ranged from 8 to 21 groups on the Numbi August triennial and Fayi August annual plots respectively (Table 12-1 and Table 13-1). In 1996, the number of structure groups ranged from 12 on the Numbi August triennial and Shabeni April biennial plots to 24 on the Kambeni December triennial plot (Table 12-3 and Table 13-1).

6.2.1.10 Testing the distribution of structural richness per plot for normality

The distributions of the structural richness per plot in 1954 and 1996 did not differ significantly from normality with Kolmogorov-Smirnov p-values of 0.914 and 0.512 respectively (Figure 6-5 and Figure 6-6). The skewness of the structural richness in 1954 showed that the distribution was symmetrical about the arithmetic mean (-0.033), and in 1996 it had a slightly longer left tail than a normal distribution (-0.270). The kurtosis value in 1954 showed that the distribution was slightly more peaky than a normal distribution (0.149), and that the distribution was flatter than a normal distribution (-0.773) in 1996. The mean structural richness on the plots in 1954 was 0.347 and ranged from 0.184 to 0.494 on the Numbi August triennial plot and the Kambeni October triennial plots respectively (Table 12-1 and Table 13-1). The mean structural richness on the plots in 1996 was 0.241, and ranged from 0.158 to 0.320 on the Shabeni October biennial plot and the Numbi October biennial plot respectively (Table 12-3 and Table 13-1). In 1954, the Numbi August triennial plot had the lowest structural richness and it had the lowest number of structure groups (9).

6.2.1.11 Testing the distribution of structural diversity per plot for normality

The distributions of the structural diversity per plot in 1954 and 1996 were not significantly different from a normal distribution with Kolmogorov-Smirnov p-values of 0.999 and 0.789 respectively (Figure 6-5 and Figure 6-6). The skewness value of the structural diversity in 1954 showed that the distribution had a slightly

longer right tail than a normal distribution (0.149), and in 1996 the distribution had a longer left tail than a normal distribution (-0.423). The kurtosis value in 1954 showed that the distribution was slightly flatter than a normal distribution (-0.192), and in 1996 the distribution was more peaky than a normal distribution (1.134). The average structural diversity per plot in 1954 was 1.726, and in 1996, it was 1.582. In 1954, the structural diversity ranged from 1.313 to 2.200 on the Fayi February biennial plot and the Kambeni no burn (control) plot respectively (Table 12-1 and Table 13-1). In 1996, the structural diversity ranged from 0.912 to 2.081 on the Numbi August annual and the Shabeni no burn (control) plots respectively (Table 12-3 and Table 13-1).

6.2.1.12 Testing the distribution of structural evenness per plot for normality

The distributions of the structural evenness per plot in 1954 and 1996 did not differ significantly from normality with Kolmogorov-Smirnov p-values of 0.889 and 0.224 respectively (Figure 6-5 and Figure 6-6). The skewness of the structural evenness in 1954 showed that the distribution had a slightly longer right tail than a normal distribution (0.324), and in 1996 it had a longer left tail than that of a normal distribution (-0.683). The kurtosis values in 1954 and 1996 (1.051 and 1.267 respectively) showed that the distributions were more peaky than a normal distribution. The average structural evenness on the plots in 1954 was 0.641 and it was 0.549 in 1996. In 1954, the structural evenness ranged from 0.463 to 0.858 on the Fayi February biennial plot and the Kambeni no burn (control) plot respectively (Table 12-1 and Table 13-1). In 1996, the structural evenness ranged from 0.337 to 0.698 on the Numbi August annual and the Kambeni no burn (control) plots respectively. In 1954, the Fayi February biennial plot had the lowest structural evenness and it had the lowest structural diversity. The Kambeni no burn (control) had the highest structural evenness in 1954 and it had the highest structural diversity. In 1996, the Numbi August annual plot had the lowest structural evenness and it had the lowest structural diversity. These associations are because Shannon's diversity index is a measurement of both the number of groups and the abundance evenness of the groups. When the abundance evenness or is low, the diversity tends to be low even if the number of groups is high.

None of the distributions of the indices that were calculated from the data collected in the 1954 and 1996 surveys on the Pretoriuskop EBP experiment differed significantly from normality, and this justified the use of parametric analyses for testing the experimental hypotheses.

6.2.2 Analyses of Variance and Analyses of Covariance statistical analyses

6.2.2.1 Testing for differences in the woody vegetation density, structure and composition on the Pretoriuskop EBPs between 1954 and 1996

The results from the Analysis of Variance testing for change in the woody vegetation between 1954 and 1996 are displayed in Table 6-2 (p. 65) and Figure 6-7 (p. 66). A summary of the data used in these analyses is presented in Appendix 5 in Table 13-1 (p. 223). The results of correlation and regression analyses testing for linear relationships between the woody vegetation in 1954 and 1996 are displayed in Table 6-3 (p. 67).

6.2.2.1.1 Change in woody plant density between 1954 and 1996

The average woody plant density (plants/Ha) on the Pretoriuskop EBPs increased from 2094.5 in 1954 to 6012.7 in 1996 (Figure 6-7 and Table 13-1). This increase of 187 % was statistically significant at $p < 0.001$ (Table 6-2). The correlation and regression analyses show that there was a very weak relationship ($r^2 = 0.064$) between the plot densities in 1954 and 1996, however, this relationship was significant at $p = 0.084$ (Table 6-3).

6.2.2.1.2 Change in woody plant mean height between 1954 and 1996

The mean height of the woody vegetation on the Pretoriuskop EBPs decreased from 1.076m to 1.041m (Figure 6-7 and Table 13-1), however this decrease was not statistically significant (Table 6-2).The correlation and regression analyses suggest that there was no relationship ($r^2 = 0.003$) between the woody vegetation height in 1954 and 1996 (Table 6-3).

Table 6-2: Results of the ANOVA analyses on the vegetation indices calculated to test for changes in the woody vegetation on the treatment plots between 1954 and 1996.

					Taxonomic diversity				Structural diversity			
Statistic	Density	Mean height	Tree equivalents	Single:Multi-stem	Number of species	Species richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
df	1	1	1	1	1	1	1	1	1	1	1	1
df error	94	94	94	94	94	94	94	94	94	94	94	94
F-ratio	122.834	0.665	95.417	78.449	30.821	2.673	1.438	13.108	19.124	93.505	11.035	40.697
p value	< 0.001	0.417	< 0.001	< 0.001	< 0.001	0.105	0.233	< 0.001	< 0.001	< 0.001	0.001	< 0.001

Note: The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.1.3 Change in number of tree equivalents between 1954 and 1996

The number of tree equivalents increased significantly on the Pretoriuskop EBPs from 1954 to 1996 ($p < 0.001$) (Table 6-2 and Figure 6-7). There was a 173 % increase in the average number of tree equivalents per hectare from 1571.7 in 1954 to 4285.9 in 1996 (Table 13-1). This increase in the number of tree equivalents between 1954 and 1996 was expected because the number of tree equivalents is a composite measure of the number of individuals relative to the total height that those individuals represent. The woody plant density increased significantly from 1954 to 1996 and the mean plant height remained the same, therefore the number of tree equivalents was expected to increase between 1954 and 1996. The correlation and regression analyses show that there was no relationship ($r^2 = 0.040$) in the number of tree equivalents between 1954 and 1996 (Table 6-3).

6.2.2.1.4 Change in the single-stem to multi-stem ratio between 1954 and 1996

In 1954, there were approximately equal numbers of single-stem and multi-stem individuals on the Pretoriuskop EBPs with a single-stem to multi-stem ratio of 0.541 (Table 13-1). In 1996, the single-stem to multi-stem index was 0.324 showing that in 1996 there were more multi-stem individuals than there were single-stem individuals (Table 13-1). This decrease in the relative numbers of single-stem to multi-stem individuals from 1954 to 1996 was significant at $p < 0.001$ (Table 6-2 and Figure 6-7). The correlation and regression analyses show that there was no relationship ($r^2 = 0.001$) in the single-stem to multi-stem ratios between 1954 and 1996 (Table 6-3).

6.2.2.1.5 Change in the number of species between 1954 and 1996

The mean number of species per plot increased significantly ($p < 0.001$) between 1954 and 1996 from 19.0 to 29.6 (Table 6-2, Figure 6-7, and Table 13-1). The number of species found in a vegetation survey is related to the sample area, and as the sample area increases the likelihood of finding more species increases. The survey area per plot was 29% bigger in 1996 ($1200m^2$) than in 1954 ($929.64m^2$). This increase in sample area may account for part of the increase in the number of species observed per plot. However, the number of species observed per plot increased by 42% from 1954 to 1996. It is believed that part of this increase was due to the increase in sample area and part was due to an actual increase in the number of species found on the plots between 1954 and 1996. The correlation and regression analyses suggest that there is a very weak yet significant relationship ($r^2 = 0.091$, $p = 0.037$) in the number of species per plot between 1954 and 1996 (Table 6-3).

WISER

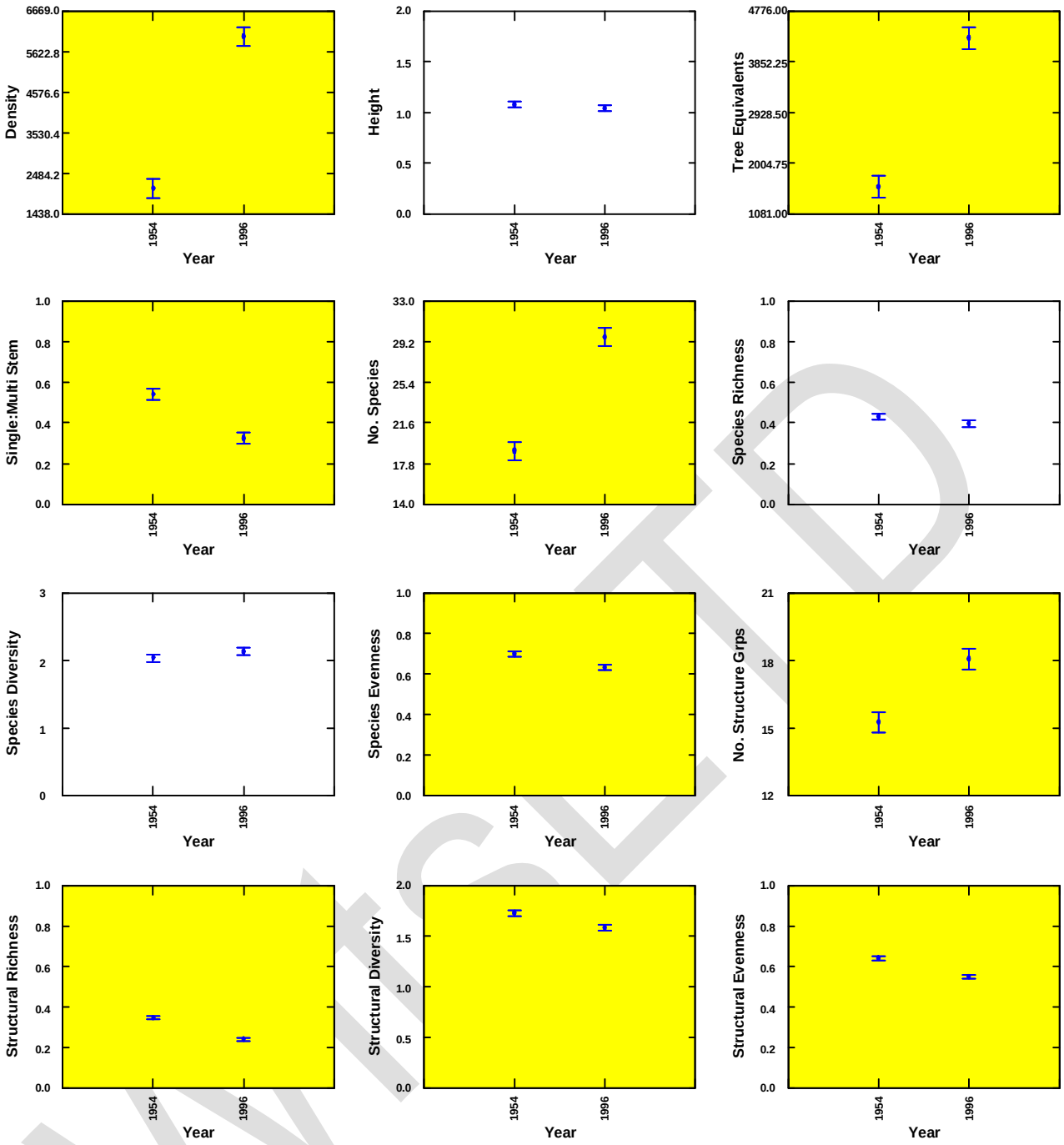


Figure 6-7: The least squares means and standard errors of the vegetation indices from the ANOVA analyses between the 1954 and 1996 data testing for change in woody vegetation over time. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.1.6 Change in the species richness between 1954 and 1996

The species richness on the Pretoriuskop EBP experiment decreased slightly from 0.431 in 1954 to 0.396 in 1996 (Figure 6-7 and Table 13-1). This decrease in species richness was not significant (Table 6-2). Species richness is a measure of the number of species observed relative to the size of the sample. The total sample size in 1954 was 9294 woody plants, and in 1996, the total sample size was 35111 woody plants. It is because of the simultaneous increase in the number of species observed and the number of plants surveyed that the species richness decreases slightly between 1954 and 1996. The correlation and regression analyses suggest that there is a very weak yet significant relationship (r^2 = 0.097, p = 0.031) in the species richness per plot between 1954 and 1996 (Table 6-3).

Table 6-3: The results from correlation and linear regression analyses testing the relationships between the woody vegetation in 1954 and 1996 using the vegetation indices calculated. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

	r	r^2	p-value	Regression equation
Density	0.252	0.064	0.084	$y = 4520.721 + 0.712 * x$
Mean height	0.051	0.003	0.730	$y = 0.992 + 0.046 * x$
Tree equivalents	0.199	0.040	0.175	$y = 3394.607 + 0.567 * x$
Single:Multi stem	-0.030	0.001	0.849	$y = 0.333 + -0.015 * x$
Number of species	0.301	0.091	0.037	$y = 23.002 + 0.35 * x$
Species richness	0.312	0.097	0.031	$y = 0.298 + 0.227 * x$
Species diversity	0.486	0.236	< 0.001	$y = 1.317 + 0.4 * x$
Species evenness	0.229	0.479	0.001	$y = 0.361 + 0.389 * x$
Number of structural groups	0.418	0.175	0.003	$y = 11.77 + 0.413 * x$
Structure richness	0.053	0.003	0.721	$y = 0.23 + 0.031 * x$
Structure diversity	0.102	0.010	0.489	$y = 1.384 + 0.115 * x$
Structure evenness	0.081	0.007	0.582	$y = 0.498 + 0.08 * x$

6.2.2.1.7 Change in species diversity between 1954 and 1996

The species diversity on the Pretoriuskop EBP experiment increased slightly from 2.042 in 1954 to 2.135 in 1996 (Figure 6-7 and Table 13-1). However, the increase in species diversity was not statistically significant (Table 6-2). The correlation and regression analyses suggest that there is a significant relationship (r^2 = 0.236, $p < 0.001$) between the species diversity on the plots in 1954 and 1996 (Table 6-3).

6.2.2.1.8 Change in species evenness between 1954 and 1996

There was a significant ($p < 0.001$) decrease in species evenness on the Pretoriuskop EBPs from 0.700 in 1954 to 0.633 in 1996 (Table 6-2, Figure 6-7, and Table 13-1). The correlation and regression analyses show that the correlation between the species evenness in 1954 and 1996 was the strongest of all the vegetation indices with an r^2 value of 0.479 ($p = 0.001$) (Table 6-3). This is interesting because there has been a significant change in species evenness between 1954 and 1996, but almost 50% of the variation in species evenness between plots in 1996 is attributable to the species evenness before the experiment began 42 years earlier.

6.2.2.1.9 Change in number of structure groups between 1954 and 1996

The average number of structure group per plot increased significantly ($p < 0.001$) from 15.3 in 1954 to 18.1 in 1996 (Table 6-2, Figure 6-7, and Table 13-1). The correlation and regression analyses suggest that there was a significant relationship (r^2 = 0.175, $p = 0.003$) in the number of structure groups per plot between 1954 and 1996 (Table 6-3).

6.2.2.1.10 Change in structural richness between 1954 and 1996

The structural richness on the Pretoriuskop EBP experiment decreased significantly ($p < 0.001$) from 0.347 in 1954 to 0.241 in 1996 (Table 6-2, Figure 6-7, and Table 13-1). The correlation and regression analyses suggest that there was no relationship (r^2 = 0.003) in the structural richness on the Pretoriuskop EBPs between 1954 and 1996.

WISETD

6.2.2.1.11 Change in structural diversity between 1954 and 1996

There was a significant ($p = 0.001$) decrease in structural diversity on the Pretoriuskop EBPs from 1.726 in 1954 to 1.582 in 1996 (Table 6-2, Figure 6-7, and Table 13-1). The correlation and regression analyses show that there was no relationship ($r^2 = 0.010$) in the structural diversity between 1954 and 1996 (Table 6-3).

6.2.2.1.12 Change in structural evenness between 1954 and 1996

The structural evenness on the Pretoriuskop EBP experiment decreased significantly ($p < 0.001$) from 0.641 in 1954 to 0.549 in 1996 (Table 6-2, Figure 6-7, and Table 13-1). The correlation and regression analyses show that there was no relationship ($r^2 = 0.007$) in the woody vegetation structural evenness between 1954 and 1996 (Table 6-3).

6.2.2.2 Testing for differences in the woody vegetation density, structure and composition between Pretoriuskop EBPs found on the four replicates, Fayi, Kambeni, Numbi, and Shabeni

The results of the Analysis of Variance and Analysis of Covariance testing for differences in woody vegetation between the four Pretoriuskop EBP replicates (Fayi, Kambeni, Numbi and Shabeni) in 1954 and 1996 are presented in Table 6-4 (p. 70), Figure 6-8 (p. 72), Figure 6-9 (p. 73), and Figure 6-10 (p. 74). Results of Tukey Studentized *post hoc* analyses that were performed when significant differences were found between replicates are presented in Appendix 6 in Table 14-1 (p. 236), Table 14-2 (p. 237) and Table 14-3 (p. 238). Summaries of the 1954 and 1996 data used in these analyses are presented in Appendix 5 in Table 13-2 (p. 224) and Table 13-3 (p. 225) respectively.

6.2.2.2.1 Differences in woody plant density between replicates

There was no significant difference in the woody plant density per plot between the four EBP replicates in the Pretoriuskop region in 1954 and in 1996 (Table 6-4). In 1954, the density (plants/Ha) of woody vegetation per plot was highest on the Fayi replicate (2338.9), and lowest on the Kambeni replicate (1846.2), the Shabeni replicate had the second highest woody vegetation density per plot (2204.0), and the Numbi replicate had the second lowest woody density per plot (1988.8) (Table 13-2 and Figure 6-8). In 1996, the woody vegetation density per plot was highest on the Fayi replicate (6564.3) and lowest on the Shabeni replicate (5126.3), the Kambeni replicate had the second highest woody vegetation density per plot (6281.0), and the Numbi replicate had the second lowest woody vegetation density per plot (6079.0) (Table 13-3 and Figure 6-9).

The density of the woody vegetation increased on all of the Pretoriuskop EBP replicates between 1954 and 1996. The annual rate of increase in the woody plant density (plants/Ha/year) between 1954 and 1996 was highest on the Kambeni replicate (105.6), second highest on the Fayi replicate (100.6), second lowest on the Numbi replicate (97.4), and lowest on the Shabeni replicate (69.6). The Fayi replicate had the highest woody plant density in 1954 and 1996. The Kambeni replicate had the lowest woody plant density in 1954, and it had the second highest woody plant density in 1996. The Shabeni replicate had the second highest woody plant density in 1954 and the lowest woody plant density in 1996. Despite these large changes in the woody plant density between 1954 and 1996, the density between the four Pretoriuskop replicates remained remarkably similar. This suggests that the changes that were observed may well reflect the kind and magnitude of change that occurred in the vegetation of the Pretoriuskop landscape between 1954 and 1996.

6.2.2.2.2 Differences in woody plant mean height between replicates

There was no significant difference between mean plant heights of the Pretoriuskop EBP replicates in 1954 (Table 6-4). In 1954, the Numbi replicate had the tallest mean plant height per plot (1.215m), and the Kambeni replicate had the shortest mean plant height per plot (1.041m) (Table 13-2 and Figure 6-8). The Fayi replicate had the second tallest mean plant height per plot (1.160m) in 1954, and the Shabeni replicate had the second shortest mean plant height per plot (1.045m) (Table 13-2 and Figure 6-8). In 1996, the

WISER

Kambeni replicate had the tallest mean plant height per plot (1,111m), and the Numbi replicate had the shortest mean plant height per plot (0.925m) (Table 13-3 and Figure 6-9). The Fayi replicate had the second tallest mean plant height per plot (1.084m) in 1996, and the Shabeni replicate had the second shortest mean plant height per plot (1.045m) (Table 13-3 and Figure 6-9). ANOVA and ANCOVA analyses showed that there was a significant difference in the mean plant height between the Pretoriuskop EBP replicates in 1996 (ANOVA: p = 0.092, ANCOVA: p = 0.096) (Table 6-4). Tukey Studentized *post hoc* analyses showed that the mean plant height on the Kambeni replicate was significantly taller than the mean plant height on the Numbi replicate in 1996 (ANOVA: p = 0.087, ANCOVA: p = 0.091) (Table 14-2 and Table 14-3).

Between 1954 and 1996, mean plant height per plot increased on the Kambeni replicate, decreased on the Fayi and Numbi replicates, and remained the same on the Shabeni replicate. The annual rate of increase in the woody plant height (mm/year) between 1954 and 1996 was highest on the Kambeni replicate (1.68), second highest on the Shabeni replicate (-0.01), second lowest on the Fayi replicate (-1.83), and lowest on the Numbi replicate (-6.90). The Kambeni replicate had the shortest mean plant height per plot in 1954 and the tallest mean plant height in 1996, and the Numbi replicate had the tallest mean plant height in 1954 and the shortest mean plant height in 1996.

6.2.2.2.3 Differences in tree equivalents between replicates

There was no significant difference in the number of tree equivalents between the four Pretoriuskop EBP replicates in 1954 (Table 6-4). In 1954, the Fayi replicate had the highest number of tree equivalents per plot (tree equivalents/Ha) (1893.2), and the Numbi replicate had the lowest number of tree equivalents per plot (1449.5) (Table 13-2 and Figure 6-8). The Shabeni replicate had the second highest number of tree equivalents per plot (1555.6) in 1954, and the Kambeni replicate had the second lowest number of tree equivalents per plot (1521.0) (Table 13-2 and Figure 6-8). In 1996, the Kambeni replicate had the highest number of tree equivalents per plot (5343.7), and the Shabeni replicate had the lowest number of tree equivalents per plot (3248.2) (Table 13-3 and Figure 6-9). The Fayi replicate had the second highest number of tree equivalents per plot (4766.2) in 1996, and the Numbi replicate had the second lowest number of tree equivalents per plot (3785.6) (Table 13-3 and Figure 6-9). In 1996, the number of tree equivalents between the replicates was significantly different (ANOVA: p = 0.016, ANCOVA: p = 0.019) (Table 6-4). Tukey Studentized *post hoc* analyses showed that the Kambeni replicate had significantly more tree equivalents than the Shabeni replicate in 1996 (ANOVA: p = 0.018, ANCOVA: p = 0.016) (Table 14-2 and Table 14-3).

Number of tree equivalents increased on all replicates between 1954 and 1996. The annual rate of increase in the number of tree equivalents (tree equivalents/ha/year) between 1954 and 1996 was highest on the Kambeni replicate (91.0), second highest on the Fayi replicate (68.4), second lowest on the Numbi replicate (55.6), and lowest on the Shabeni replicate (40.3). In 1954, the Kambeni replicate had the lowest number of tree equivalents, and in 1996, it had the highest number of tree equivalents. The increase in the number of tree equivalents on the Kambeni replicate between 1954 and 1996 was related to the increase in woody plant density and an increase in mean plant height on the Kambeni replicate between 1954 and 1996.

6.2.2.2.4 Differences in single-stem to multi-stem index between replicates

In 1954, the single-stem to multi-stem index per plot was significantly different between the four EBP replicates in the Pretoriuskop region (p = 0.027) (Table 6-4). Tukey Studentized *post hoc* analyses showed that the Fayi and Numbi replicates had significantly higher single-stem to multi-stem indices than the Kambeni replicate with p values of 0.035 and 0.083 respectively (Table 14-1). In 1954, the single-stem to multi-stem index per plot was highest on the Fayi replicate (0.652), and lowest in the Kambeni replicate (0.398), the Numbi replicate had the second highest value (0.618) and the Shabeni replicate had the second lowest value (0.494) (Table 13-2 and Figure 6-8). The single-stem to multi-stem index was not significantly different between the four Pretoriuskop EBP replicates in 1996 (Table 6-4). In 1996, the single-stem to multi-stem indices were very similar ranging from 0.311 on the Fayi replicate to 0.338 on the Numbi replicate in comparison with 1954, which ranged from 0.398 on Kambeni replicate to 0.652 on the Fayi replicate (Table 13-3 and Figure 6-9).

The single-stem to multi-stem index decreased on all replicates between 1954 and 1996. This indicates that there was a relative increase in the number of multi-stem individuals relative to single-stem individuals between 1954 and 1996 on all the Pretoriuskop EBP replicates. The Fayi replicate had the largest decrease in the number of single-stem individuals relative to multi-stem individuals of the four Pretoriuskop EBP replicates between 1954 and 1996.

6.2.2.2.5 Differences in the number of species between replicates

In 1954, the Numbi replicate had the highest number of survey species per plot (20.5), and the Kambeni replicate had the lowest number of species per plot (16.8) (Table 13-2 and Figure 6-8). The Shabeni replicate had the second highest number of species per plot (20.3), and the Fayi replicate had the second lowest number of species per plot (18.3) (Table 13-2 and Figure 6-8). In 1996, the Numbi replicate had the highest number of species per plot (31.8), and the Fayi replicate had the lowest number of species per plot (28.1) (Table 13-3 and Figure 6-9). The Shabeni replicate had the second highest number of species per plot (30.0), and the Kambeni replicate had the second lowest number of species per plot (28.7) (Table 13-3 and Figure 6-9). The number of species was not significantly different between the four Pretoriuskop EBP replicates in 1954 or 1996 (Table 6-4).

Between 1954 and 1996, the number of species per plot increased on all the replicates. The Numbi replicate had the highest number species per plot and the Shabeni replicate had the second highest number of species per plot in 1954 and 1996. The Kambeni replicate had the lowest number of species per plot in 1954 and had the second lowest number of species per plot in 1996. The Fayi replicate had the second lowest number of species per plot in 1954 and had the lowest in number of species in 1996.

Table 6-4: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test for homogeneity between the replicates in the Pretoriuskop region.

						Taxonomic diversity				Structural diversity			
Year	Statistic	Density	Mean height	Tree equivalents	Single:Multi stem	Number of species	Species richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
1954 (ANOVA)	df	3	3	3	3	3	3	3	3	3	3	3	3
	df error	44	44	44	44	44	44	44	44	44	44	44	44
	F-ratio	0.858	0.929	1.088	3.369	1.275	1.233	3.277	4.049	1.381	1.188	2.22	0.424
	p value	0.470	0.435	0.364	0.027	0.295	0.309	0.030	0.013	0.261	0.325	0.099	0.737
1996 (ANOVA)	df	3	3	3	3	3	3	3	3	3	3	3	3
	df error	44	44	44	44	44	44	44	44	44	44	44	44
	F-ratio	0.868	2.282	3.832	0.836	0.822	4.047	6.674	8.345	4.021	0.609	1.222	0.844
	p value	0.465	0.092	0.016	0.481	0.489	0.013	0.001	< 0.001	0.013	0.613	0.313	0.477
1996:1954 (ANCOVA)	df	3	3	3	3	3	3	3	3	3	3	3	3
	df error	43	43	43	43	43	43	43	43	43	43	43	43
	F-ratio	1.02	2.252	3.663	0.752	0.484	3.093	3.627	4.663	2.726	0.606	1.042	0.793
	p value	0.393	0.096	0.019	0.528	0.695	0.037	0.020	0.007	0.056	0.614	0.384	0.504

Note: The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.2.6 Differences in species richness between replicates

The species richness per plot between replicates was not significantly different in 1954 (Table 6-4). In 1954, the species richness per plot was highest on the Numbi replicate (0.474) and lowest in the Fayi replicate (0.395) (Table 13-2 and Figure 6-8). The species richness per plot was second highest on the Shabeni

replicate (0.451) and second lowest on the Kambeni replicate in 1954 (0.403) (Table 13-2 and Figure 6-8). In 1996, the species richness per plot was highest on the Shabeni replicate (0.444) and lowest on the Fayi replicate (0.346) (Table 13-3 and Figure 6-9). The species richness per plot was second highest on the Numbi replicate (0.425) and second lowest on the Kambeni replicate in 1996 (0.369) (Table 13-3 and Figure 6-9). The species richness per plot was significantly different between the Pretoriuskop EBP replicates in 1996 (ANOVA: $p = 0.013$, ANCOVA: $p = 0.037$) (Table 6-4). Tukey Studentized *post hoc* analyses showed that the species richness was significantly lower on the on the Fayi replicate than on the Shabeni (ANOVA: $p = 0.021$, ANCOVA: $p = 0.040$) and Numbi (ANOVA: $p = 0.087$) replicates in 1996 (Table 14-2 and Table 14-3).

Species richness decreased on all the Pretoriuskop EBP replicates between 1954 and 1996. As explained above (p. 66), this decrease in species richness may be an artefact of the calculation of species richness, which is the number of species observed relative to the sample size. The Numbi replicate had the highest species richness in 1954 and the Shabeni replicate had the highest species richness in 1996. The Fayi replicate had the lowest species in 1954 and in 1996.

6.2.2.2.7 Differences in species diversity between replicates

Species diversity increased on all the Pretoriuskop EBP replicates between 1954 and 1996. The rank of each replicate from lowest species diversity to highest species diversity remained the same between 1954 and 1996. In 1954 and 1996, the Numbi replicate had the highest species diversity per plot with a diversity value of 2.287 in 1954 and 2.380 in 1996 (Table 13-2, Table 13-3, Figure 6-8 and Figure 6-9). The Kambeni replicate had the lowest species diversity per plot in 1954 and 1996 with a diversity value of 1.835 in 1954 and 1.946 in 1996. The Shabeni replicate had the second highest species diversity per plot in 1954 and 1996 with a diversity value of 2.118 in 1954 and 2.256 in 1996. In 1954 and 1996, the Fayi replicate had the second lowest species diversity per plot with a diversity value of 1.927 in 1954 and 1.957 in 1996. In 1954, species diversity on the Pretoriuskop EBP replicates was significantly different ($p = 0.030$) (Table 6-4). Tukey Studentized *post hoc* analyses showed that the species diversity was significantly higher on the Numbi replicate than on the Kambeni ($p = 0.031$) replicate in 1954 (Table 14-1). The species diversity was also significantly different between the Pretoriuskop EBP replicates in 1996 (ANOVA: $p < 0.001$, ANCOVA: $p = 0.020$) (Table 6-4). *Post hoc* analyses showed that the species diversity was significantly higher on the Numbi replicate than on the Fayi (ANOVA: $p = 0.005$, ANCOVA: $p = 0.040$) and Kambeni (ANOVA: $p = 0.004$, ANCOVA: $p = 0.062$) replicates in 1996 (Table 14-2 and Table 14-3). In 1996, the Shabeni replicate also had a significantly higher species diversity than the Fayi (ANOVA: $p = 0.036$) and Kambeni (ANOVA: $p = 0.014$) replicates (Table 14-2 and Table 14-3).

6.2.2.2.8 Differences in species evenness between replicates

Species evenness decreased on all the Pretoriuskop EBP replicates between 1954 and 1996. The rank of each replicate from lowest species evenness to highest species evenness was the same in 1954 and 1996. The Numbi replicate had the highest species evenness per plot in 1954 and 1996 with an evenness value of 0.769 in 1954 and 0.693 in 1996 (Table 13-2, Table 13-3, Figure 6-8, and Figure 6-9). The Kambeni replicate had the lowest species evenness per plot in 1954 and 1996 with an evenness value of 0.653 in 1954 and 0.581 in 1996. The Shabeni replicate had the second highest species evenness per plot in 1954 and 1996 with an evenness value of 0.711 in 1954 and 0.667 in 1996. In 1954 and 1996, the Fayi replicate had the second lowest species evenness per plot with an evenness value of 0.665 in 1954 and 0.591 in 1996. In 1954, species evenness on the Pretoriuskop EBP replicates was significantly different ($p = 0.013$) (Table 6-4). Tukey Studentized *post hoc* analyses showed that the species evenness was significantly higher on the Numbi replicate than on the Fayi ($p = 0.035$) and Kambeni ($p = 0.016$) replicates in 1954 (Table 14-1). In 1996, species evenness in the Pretoriuskop EBP replicates was significantly different (ANOVA: $p < 0.001$, ANCOVA: $p = 0.007$) (Table 6-4). *Post hoc* analyses show that the species evenness was significantly higher on the Numbi replicate and than on the Fayi (ANOVA: $p = 0.003$, ANCOVA: $p = 0.039$) and Kambeni (ANOVA: $p = 0.001$, ANCOVA: $p = 0.023$) replicates in 1996 (Table 14-2 and Table 14-3). Species evenness was also significantly higher on the Shabeni replicate than on the Fayi (ANOVA: $p = 0.036$, ANCOVA: $p =$

0.079) and Kambeni (ANOVA: p = 0.014, ANCOVA: p = 0.044) replicates in 1996 (Table 14-2 and Table 14-3).

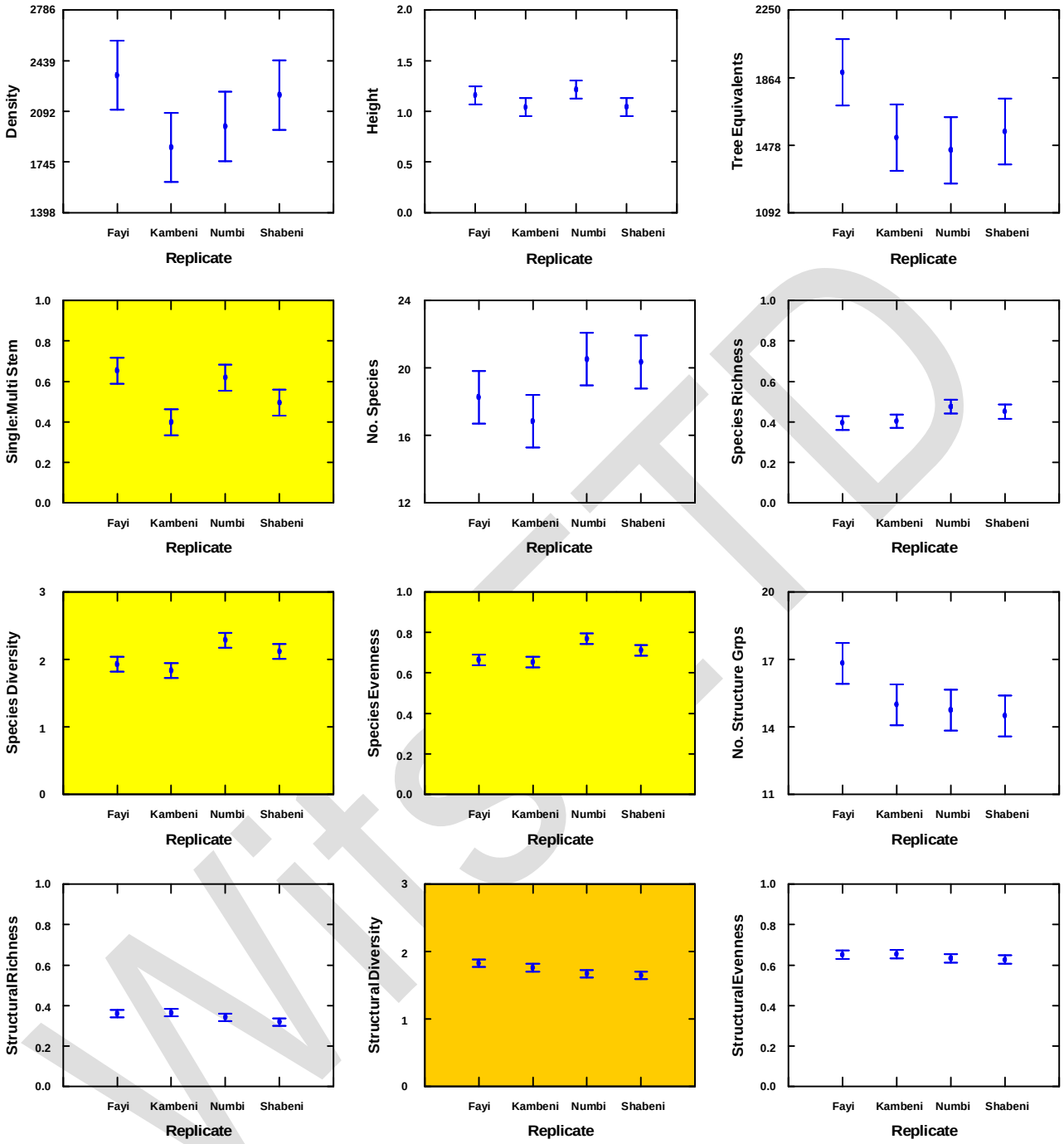


Figure 6-8: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the four replicates in the Pretoriuskop region. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.2.9 Differences in the number of structural groups between replicates

The number of structure groups per plot increased on all the Pretoriuskop EBP replicates between 1954 and 1996. The rank of each replicate from highest to lowest number of structure groups per plot was the same in 1954 and 1996. The Fayi replicate had the highest number of structure groups per plot with 16.833 in 1954 and 20.250 in 1996 (Table 13-2, Table 13-3, Figure 6-8, and Figure 6-9). The Shabeni replicate had the lowest number of structure groups per plot in 1954 and 1996 with 14.500 in 1954 and 16.417 in 1996. The

Kambeni and Numbi replicates had the second and third highest number of structure groups per plot. There was no significant difference in the number of structure groups between the replicates in 1954 (Table 6-4). However in 1996, there was a significant difference in the number of structure groups between the Pretoriuskop EBP replicates (ANOVA: p = 0.013, ANCOVA: p = 0.056) (Table 6-4). Tukey Studentized *post hoc* analyses showed that the Fayi replicate had a significantly higher number of structure groups than the Numbi (ANOVA: p = 0.064) and Shabeni (ANOVA: p = 0.011, ANCOVA: p = 0.048) replicates (Table 14-2 and Table 14-3).

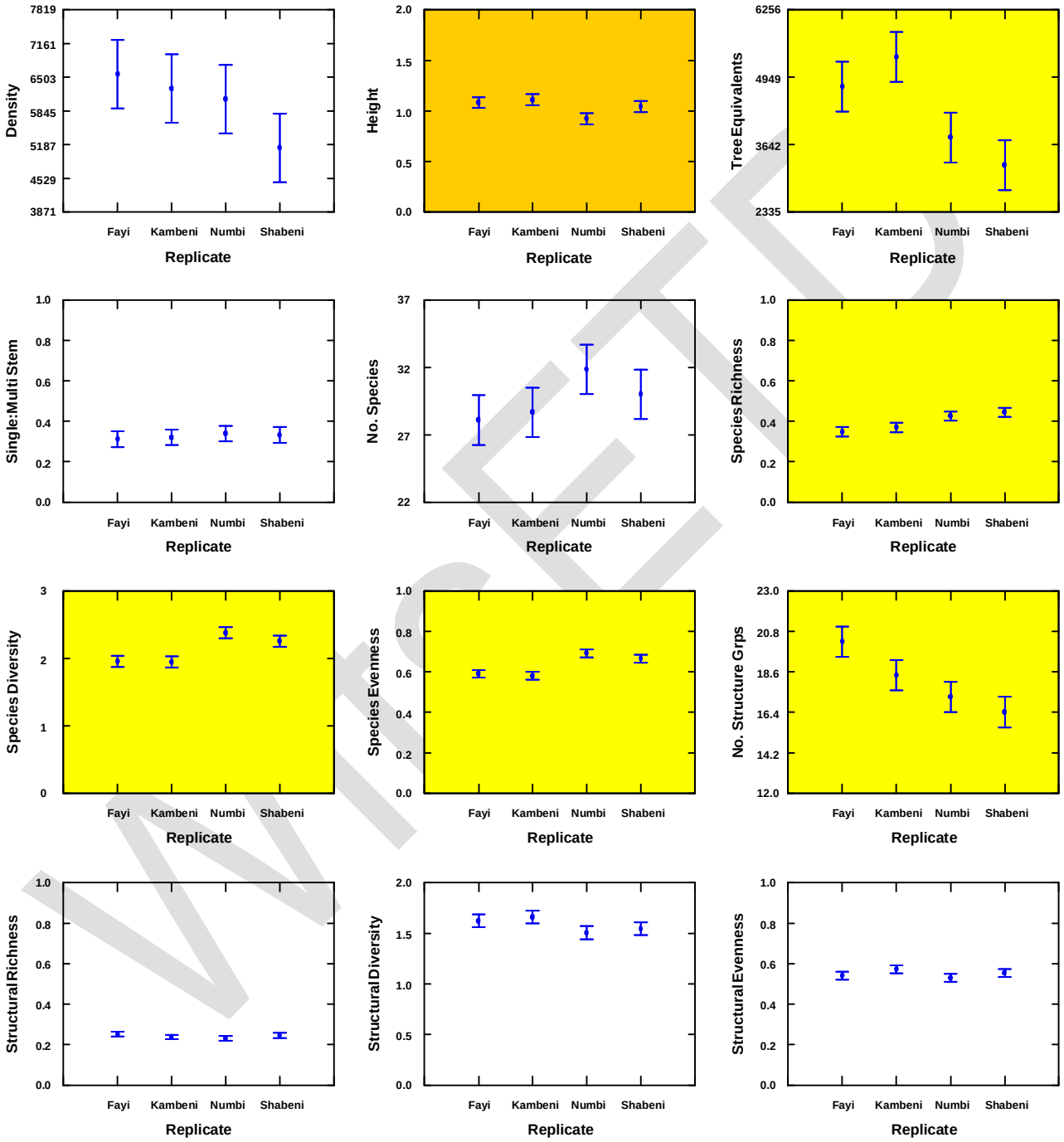


Figure 6-9: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for post treatment differences between the four replicates in the Pretoriuskop region. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.2.10 Differences in structural richness between replicates

The structural richness was very similar between the Pretoriuskop EBP replicates in 1954 and in 1996 and there was no statistical significant difference between replicates in 1954 and 1996 (Table 6-4). The Kambeni replicate had the highest structural richness in 1954 (0.364), and the Shabeni replicate had the lowest structural richness (0.319) (Table 13-2 and Figure 6-8). The Fayi replicate had the highest structural richness in 1996 (0.251), and the Numbi replicate had the lowest structural richness (0.231) (Table 13-3 and Figure 6-9). The structural richness decreased on all the Pretoriuskop EBP replicates between 1954 and 1996.

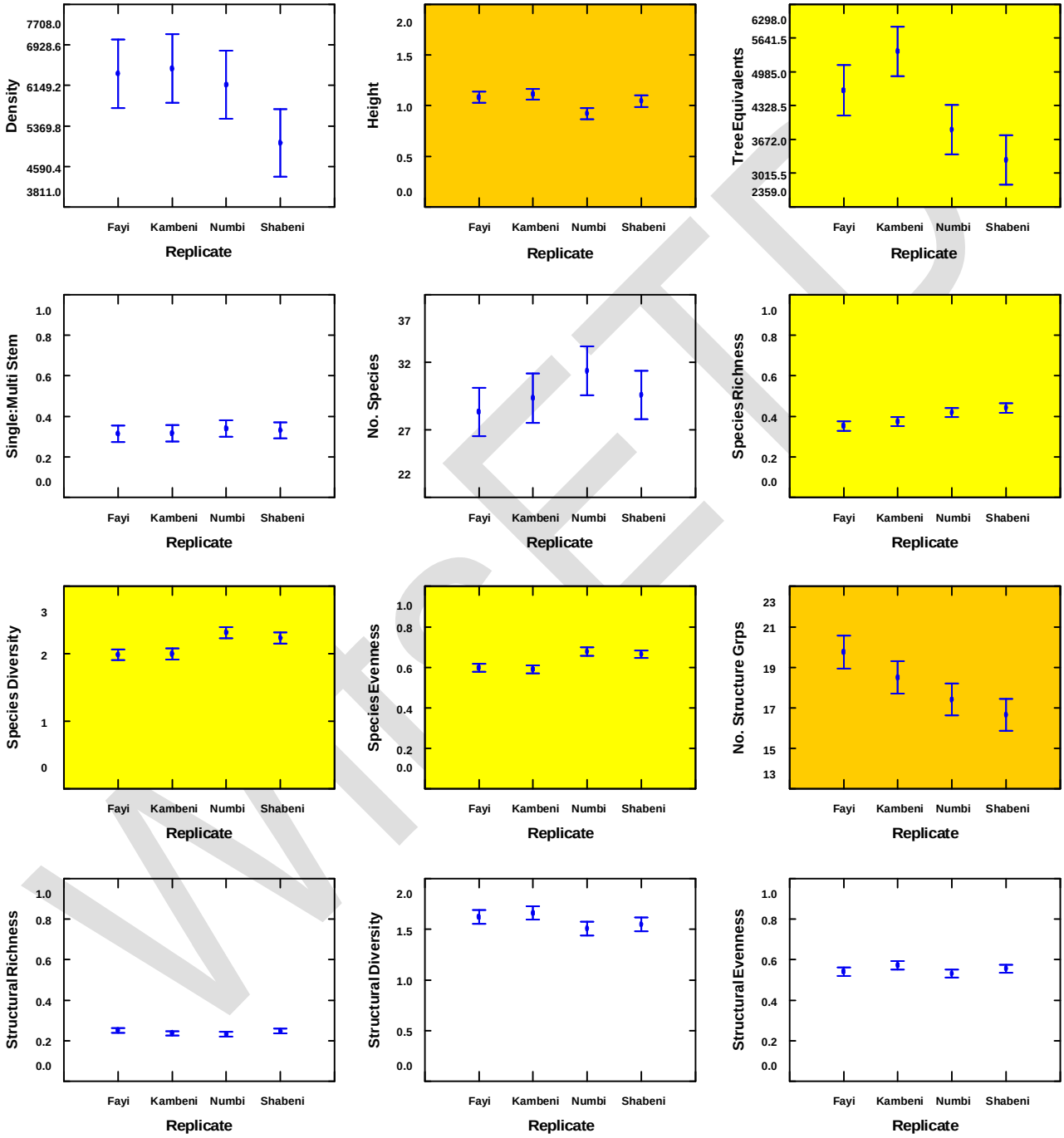


Figure 6-10: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for post treatment differences between the four replicates in the Pretoriuskop region taking into account the state of the plots before the treatments began. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.2.11 Differences in structural diversity between replicates

In 1954, there was a significant difference in structural diversity between the Pretoriuskop EBP replicates (p = 0.099) (Table 6-4). Tukey Studentized *post hoc* analyses show no significant differences in 1954 (Table 14-1). The Fayi replicate had the highest structural diversity in 1954 (1.826), and the Shabeni replicate had the lowest structural diversity (1.647) (Table 13-2 and Figure 6-8). There was no significant difference between the replicates in 1996 (Table 6-4). The Kambeni replicate had the highest structural diversity in 1996 (1.660), and the Numbi replicate had the lowest structural diversity (1.504) (Table 13-3 and Figure 6-9). The structural diversity decreased on all the Pretoriuskop EBP replicates between 1954 and 1996.

6.2.2.2.12 Differences in structural evenness between replicates

The structural evenness was very similar between the Pretoriuskop EBP replicates in 1954 and in 1996 and there was no statistical significant between the replicates in 1954 and 1996 (Table 6-4). In 1954, the Kambeni replicate had the highest structural evenness (0.654), and the Shabeni replicate had the lowest structural evenness (0.626) (Table 13-2 and Figure 6-8). The structural evenness was very similar between the replicates in 1954. In 1996, the Kambeni replicate had the highest structural evenness (0.573), and the Numbi replicate had the lowest structural evenness (0.530) (Table 13-3 and Figure 6-9). The Kambeni replicate had the highest structural evenness in 1954 and in 1996. The structural evenness decreased on all the Pretoriuskop EBP replicates between 1954 and 1996.

6.2.2.3 Testing for differences in the woody vegetation density, structure and composition between Pretoriuskop EBPs burnt at different frequencies (Annual, Biennial, Triennial and no burn)

The results of the Analysis of Variance and Analysis of Covariance testing for differences in woody vegetation between the frequencies of the fire treatments (annual, biennial, triennial, and no burn) on the Pretoriuskop EBPs using the No-August-Annual data grouping are presented in Table 6-5 (p. 76), Figure 6-11, Figure 6-12, and Figure 6-13. The results of the ANOVA and ANCOVA analyses using the August-Control data grouping are presented in Table 6-6 (p. 77), Figure 6-14, Figure 6-15, and Figure 6-16. The results of the Tukey *post hoc* analyses using the No-August-Annual grouping are presented in Appendix 6 Table 14-4 (p. 239), Table 14-5 (p. 240), and Table 14-6 (p. 241). The results of the Tukey *post hoc* analyses using the August-Control grouping are presented in Table 14-7 (p. 242), Table 14-8 (p. 243), and Table 14-9 (p. 244) in Appendix 6. Summaries of the 1954 and 1996 data used in the No-August-Annual analyses are presented in Appendix 5 in Table 13-4 (p. 226) and Table 13-5 (p. 226) respectively. Summaries of the 1954 and 1996 data used in the August-Control analyses are presented in Appendix 5 in Table 13-6 (p. 227) and Table 13-7 (p. 228) respectively.

For each vegetation index, the results of the No-August-Annual and August-Control ANOVA and ANCOVA analyses on the vegetation indices are presented separately. The general patterns and relationships between the vegetation index and fire frequency from these analyses are presented in a separate summary. Many of the results and patterns from the No-August-Annual and August-Control ANOVA and ANCOVA analyses are similar.

6.2.2.3.1 Differences in woody plant density between plots burnt at different frequencies

6.2.2.3.1.1 ANOVA and ANCOVA analyses on the woody plant density using the No-August-Annual data grouping

In 1954, the woody plant density was not significant difference between the treatments burnt at different frequencies (Table 6-5). The woody plant density (plants/Ha) was highest on the biennial treatments (2209.9) and lowest in the control treatments (1721.5) in 1954 (Table 13-4). In 1996, the woody plant density was highest on the control treatments (8696.0) and lowest on the triennial treatments (5376.0) (Table 13-5). In 1996, the woody plant density was significantly different between the fire frequency treatments (ANOVA p = 0.035, ANCOVA p = 0.018) (Table 6-5). Tukey Studentized *post hoc* analyses show that density was significantly higher on the control treatments than on the biennial (ANCOVA: p = 0.044) and triennial

WISETD

(ANOVA: p = 0.028, ANCOVA: p = 0.013) treatments (Table 14-5 and Table 14-6). Woody plant density increased on all the Pretoriuskop EBP frequency treatments between 1954 and 1996.

6.2.2.3.1.2 ANOVA and ANCOVA analyses on the woody plant density using the August-Control data grouping

There was no significant difference in the woody plant density between the treatments burnt at different frequencies in 1954 and 1996 (Table 6-6). In 1954, the woody plant density was highest on the biennial treatments (2433.5) and lowest on the control treatments (1721.5) (Table 13-6). In 1996, woody plant density was highest on the control treatments (8696.0) and lowest on the triennial treatments (5217.3) (Table 13-7). Woody plant density increased on all the Pretoriuskop EBP frequency treatments between 1954 and 1996.

Table 6-5: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the frequency effects of the fire treatments. The August annual treatments were not included in these analyses (No-August-Annual data grouping).

						Taxonomic diversity				Structural diversity			
Year	Statistic	Density	Mean height	Tree equivalents	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
1954 (ANOVA)	df	2	2	2	2	2	2	2	2	2	2	2	2
	df error	41	41	41	41	41	41	41	41	41	41	41	41
	F-ratio	0.653	0.497	0.325	26.126	2.338	3.829	0.444	0.138	2.010	3.246	1.201	0.933
	p value	0.526	0.612	0.725	< 0.001	0.109	0.030	0.644	0.872	0.147	0.049	0.311	0.402
1996 (ANOVA)	df	2	2	2	2	2	2	2	2	2	2	2	2
	df error	41	41	41	41	41	41	41	41	41	41	41	41
	F-ratio	3.631	1.809	5.162	8.907	3.400	0.593	2.264	0.993	1.737	0.434	10.667	6.779
	p value	0.035	0.177	0.010	0.001	0.043	0.558	0.117	0.379	0.189	0.651	< 0.001	0.003
1996:1954 (ANCOVA)	df	2	2	2	2	2	2	2	2	2	2	2	2
	df error	40	40	40	40	40	40	40	40	40	40	40	40
	F-ratio	4.430	1.788	6.487	8.688	4.589	0.221	2.965	0.838	1.500	0.569	9.149	6.293
	p value	0.018	0.180	0.004	0.001	0.016	0.802	0.063	0.440	0.235	0.570	0.001	0.004

Note: The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.3.1.3 Summary of the general relationship between woody plant density and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

Generally, the least squared means and standard errors of the woody plant density on the treatments burnt at different frequencies, relative to one another, were similar in the No-August-Annual and August-Control ANOVA and ANCOVA analyses on the Pretoriuskop EBPs in 1954 and 1996 (Figure 6-11 to Figure 6-16). In 1954, the biennial treatments had the highest density and the control treatments had the lowest density, the annual treatments had the second highest density and the triennial treatments had the second lowest density. In 1996, the control treatments had the highest density, and the triennial treatment had the lowest density, the annual treatment had the second highest density and the biennial treatment had the second lowest. Over time, the woody plant density increased on all the fire frequency treatments. Generally, as the inter-fire period increases from 1 year to 3 years, there is a decrease in woody plant density, and then as the inter-fire period increases beyond 3 years to 42 years there is an increase in the woody plant density.

WITP

6.2.2.3.2 Differences in woody plant height between plots burnt at different frequencies

6.2.2.3.2.1 ANOVA and ANCOVA analyses on the mean woody plant height using the No-August-Annual data grouping

In 1954 and 1996, the mean woody plant height was not significantly different between the treatments burnt at different frequencies (Table 6-5). In 1954, the control treatments had the tallest mean plant height (1.116m), and the triennial treatments had the shortest mean plant height (1.038m) (Table 13-4). In 1996, the control treatments had the tallest mean plant height (1.202m) and the biennial treatments had the shortest mean plant height (1.013m) (Table 13-5). Between 1954 and 1996, the mean plant height increased on the control and triennial treatments and decreased on the biennial treatments.

Table 6-6: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the frequency effects of the fire treatments. Only the Control treatments and August annual, biennial, and triennial treatments were used in these analyses (August-Control data grouping).

						Taxonomic diversity				Structural diversity			
Year	Statistic	Density	Mean height	Tree equivalents	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
1954 (ANOVA)	df	3	3	3	3	3	3	3	3	3	3	3	3
	df error	12	12	12	12	12	12	12	12	12	12	12	12
	F-ratio	0.821	0.987	0.867	4.155	0.093	0.840	0.300	0.689	4.731	9.300	1.011	0.252
	p value	0.507	0.432	0.485	0.031	0.963	0.498	0.825	0.576	0.021	0.002	0.422	0.858
1996 (ANOVA)	df	3	3	3	3	3	3	3	3	3	3	3	3
	df error	12	12	12	12	12	12	12	12	12	12	12	12
	F-ratio	1.730	3.833	2.725	15.161	4.197	0.472	3.104	1.161	2.333	0.200	11.585	9.868
	p value	0.214	0.039	0.091	< 0.001	0.030	0.708	0.067	0.365	0.126	0.894	0.001	0.001
1996:1954 (ANCOVA)	df	3	3	3	3	3	3	3	3	3	3	3	3
	df error	11	11	11	11	11	11	11	11	11	11	11	11
	F-ratio	1.932	3.650	3.253	13.635	4.036	0.659	2.831	0.867	3.147	1.349	12.095	8.948
	p value	0.183	0.048	0.064	0.001	0.037	0.594	0.088	0.487	0.069	0.309	0.001	0.003

Note: The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.3.2.2 ANOVA and ANCOVA analyses on the mean woody plant height using the August-Control data grouping

In 1954, the mean woody plant height was not significantly different between the treatments burnt at different frequencies (Table 6-6). The control treatments had the tallest mean plant height (1.116m), and the triennial treatments had the shortest mean plant height (0.882m) (Table 13-6). In 1996, the control treatments had the tallest mean plant height (1.202m), and the annual treatments had the shortest mean plant height (0.859m) (Table 13-7). The mean plant heights were significantly different between the frequency treatments in 1996 (ANOVA: p = 0.039, ANCOVA: p = 0.048) (Table 6-6). Tukey Studentized *post hoc* analyses show that the mean woody plant height was significantly shorter on the annual treatments than on the control treatments in 1996 (ANOVA: p = 0.035, ANCOVA: p = 0.048) (Table 14-8 and Table 14-9). Between 1954 and 1996, the mean plant height increased on the control, biennial, and triennial treatments and decreased on the annual treatments.

6.2.2.3.2.3 Summary of the general relationship between woody plant height and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

Generally, the least squared means and standard errors of the mean woody plant height on the treatments burnt at different frequencies, relative to one another, were similar in the No-August-Annual and August-Control ANOVA and ANCOVA analyses on the Pretoriuskop EBPs in 1954 and 1996 (Figure 6-11 to Figure 6-16). In 1954, the woody vegetation on the control treatments was the tallest and on the triennial treatments was the shortest, the woody vegetation on the annual treatments was the second tallest and on the biennial treatments was the second shortest. In 1996, the woody vegetation on the control treatments was the tallest and on the annual treatments was the shortest. In the No-August-Annual grouping in 1996, the woody vegetation was second tallest on the triennial treatments and second shortest on the biennial treatments. In the August-Control grouping in 1996, the woody vegetation was second tallest on the biennial treatments and second shortest on the triennial treatments. Generally, as inter-fire period increases from 1 year to beyond 3 years and up to 42 years the mean height of the woody vegetation increases.

6.2.2.3.3 Differences in the number of tree equivalents between plots burnt at different frequencies

6.2.2.3.3.1 ANOVA and ANCOVA analyses on the number of tree equivalents using the No-August-Annual data grouping

In 1954, the mean number of tree equivalents was not significantly different between the treatments burnt at different frequencies (Table 6-5). In 1954, the mean number of tree equivalents (tree equivalents/Ha) was highest on the biennial treatments (1603.5) and was lowest on the control treatments (1315.3) (Table 13-4). In 1996, the control treatments had the highest number of tree equivalents (6963.3), and the biennial treatments had the lowest number of tree equivalents (4109.4) (Table 13-5).In 1996, the mean number of tree equivalents was significantly different between the treatments burnt at different frequencies (ANOVA: $p = 0.010$, ANCOVA: $p = 0.004$) (Table 6-5). Tukey Studentized *post hoc* analyses show that the control treatments had a significantly higher number of tree equivalents than the biennial (ANOVA: $p = 0.009$, ANCOVA: $p = 0.003$) and triennial (ANOVA: $p = 0.011$, ANCOVA: $p = 0.005$) treatments in 1996 (Table 14-5 and Table 14-6). Between 1954 and 1996, the mean number of tree equivalents increased on all the fire frequency treatments

6.2.2.3.3.2 ANOVA and ANCOVA analyses on the number of tree equivalents using the August-Control data grouping

In 1954, the mean number of tree equivalents was not significantly different between the treatments burnt at different frequencies (Table 6-6). In 1954, the mean number of tree equivalents was highest on the annual treatments (1854.8), and was lowest on the control treatments (1315.3) (Table 13-6). In 1996, the mean number of tree equivalents was highest on the control treatments (6963.250) and lowest on the annual treatments (3051.5) (Table 13-7). The mean number of tree equivalents was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: $p = 0.091$, ANCOVA: $p = 0.064$) (Table 6-6). Tukey Studentized *post hoc* analyses show that the mean number of tree equivalents in 1996 was significantly higher on the control treatments than on the annual treatments in 1996 (ANOVA: $p = 0.071$, ANCOVA: $p = 0.048$) (Table 14-8, and Table 14-9). Between 1954 and 1996, the mean number of tree equivalents increased on all of the fire frequency treatments.

6.2.2.3.3.3 Summary of the general relationship between the number of tree equivalents and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the mean number of tree equivalents and fire frequency on the Pretoriuskop EBPs was similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1954, the number of tree equivalents was highest in the annual treatments and lowest on the control treatments, the biennial treatments had the second highest number of tree equivalents and the triennial treatments had the second lowest. In 1996, the control treatments had the highest number of tree equivalents and the annual treatments had the lowest, the triennial treatments had the second highest

WISER

number of tree equivalents and the biennial had the second lowest. Generally, as the period between fires increases from 1 year to beyond 3 years, the number of tree equivalents increases. Tree equivalents are an estimate of the phytomass (plant mass) of the woody vegetation, and as the period between fire events increases the woody plant phytomass increases.

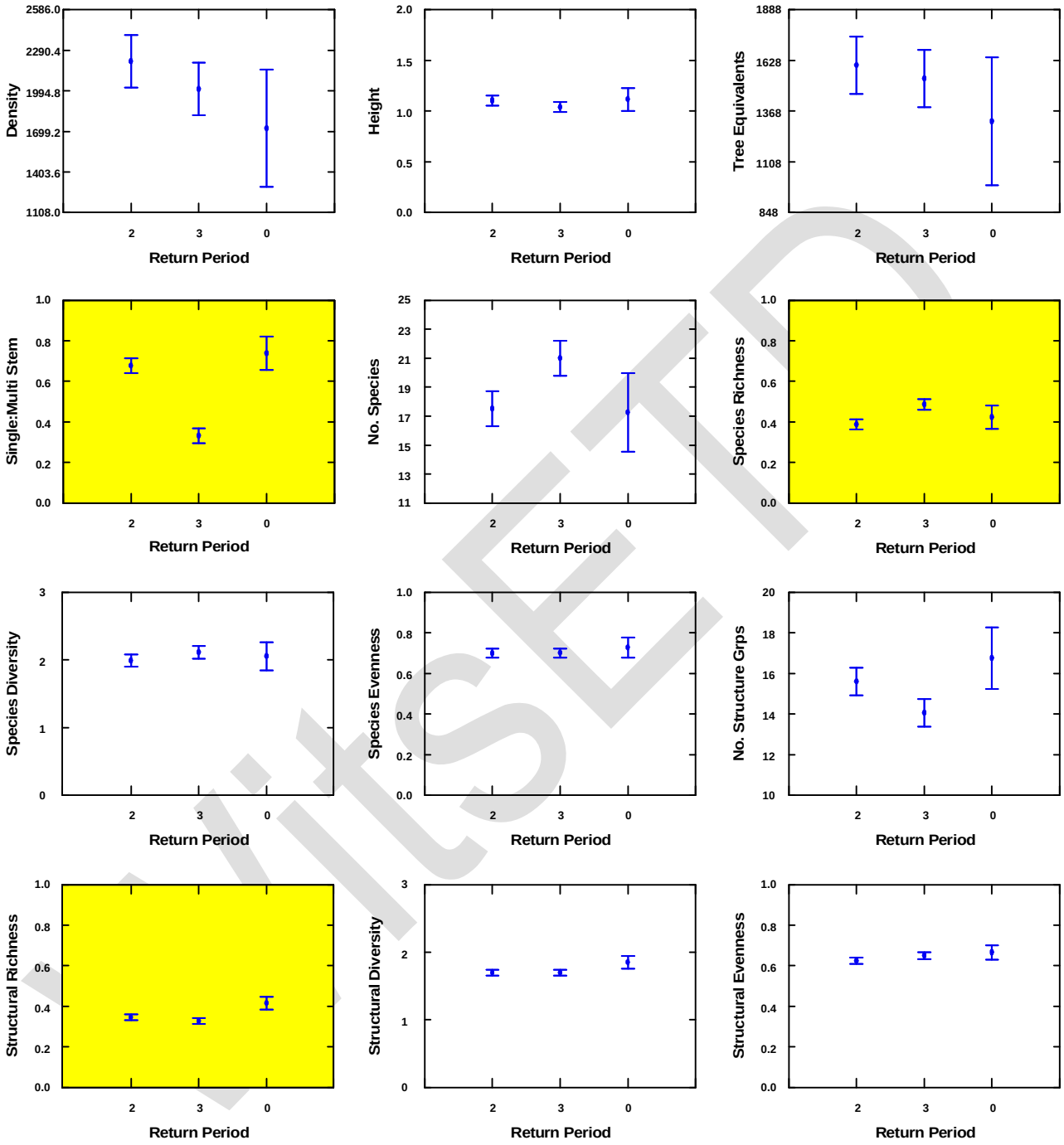


Figure 6-11: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots to be burnt at different frequencies using the No-August-Annual data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

VITSEP

6.2.2.3.4 Differences in the single-stem to multi-stem index between plots burnt at different frequencies

6.2.2.3.4.1 ANOVA and ANCOVA analyses on the single-stem to multi-stem index using the No-August-Annual data grouping

In 1954, the single-stem to multi-stem index was highest on the control treatments (0.738) and lowest on the triennial treatments (0.332) (Table 13-4). The single-stem to multi-stem index was significantly different between the treatments burnt at different frequencies in 1954 ($p < 0.001$) (Table 6-5). Tukey Studentized *post hoc* analyses show that the single-stem to multi-stem index was significantly lower on the triennial treatments than on the on the biennial ($p < 0.001$) and control ($p < 0.001$) treatments in 1954 (Table 14-4). In 1996, the single-stem to multi-stem index was highest on the control treatments (0.539) and lowest on the biennial treatments (0.303) (Table 13-5). The single-stem to multi-stem index was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$) (Table 6-5). Tukey Studentized *post hoc* analyses show that the single-stem to multi-stem index on the control treatments was significantly higher than on the biennial (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$) and triennial (ANOVA: $p = 0.003$, ANCOVA: $p = 0.041$) treatments in 1996 (Table 14-5, and Table 14-6). Between 1954 and 1996, the single-stem to multi-stem index decreased on the control and biennial treatments and increased slightly on the triennial treatments.

6.2.2.3.4.2 ANOVA and ANCOVA analyses on the single-stem to multi-stem index using the August-Control data grouping

In 1954, the single-stem to multi-stem index was highest on the control treatments (0.738) and lowest on the triennial treatments (0.408) (Table 13-6). The single-stem to multi-stem index was significantly different between the treatments burnt at different frequencies in 1954 ($p = 0.031$) (Table 6-6). Tukey Studentized *post hoc* analyses show that the single-stem to multi-stem index on the triennial treatments was significantly lower than on the annual ($p = 0.061$) and control treatments ($p = 0.037$) in 1954 (Table 14-7). In 1996, the single-stem to multi-stem index was highest on the control treatments (0.539) and lowest on the annual treatments (0.126) (Table 13-7). The single-stem to multi-stem index was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: $p < 0.001$, ANCOVA: $p = 0.001$) (Table 6-6). Tukey Studentized *post hoc* analyses show that the single-stem to multi-stem index was significantly higher on the control treatments than on the annual (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$), biennial (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$), and triennial (ANOVA: $p = 0.005$, ANCOVA: $p = 0.073$) treatments in 1996 (Table 14-8, and Table 14-9). Between 1954 and 1996, the single-stem to multi-stem index decreased on all the frequency treatments. The most marked decreases were on the annual and biennial treatments (0.708 to 0.126 and 0.662 to 0.155 respectively).

6.2.2.3.4.3 Summary of the general relationship between the single-stem to multi-stem index and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the mean single-stem to multi-stem index and fire frequency on the Pretoriuskop EBPs was similar in both the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1954, the single-stem to multi-stem index was highest on the control treatments and lowest on the triennial treatments, the annual treatments had the second highest single-stem to multi-stem index and the biennial treatments had the second lowest. In 1996, the single-stem to multi-stem index was highest on the control treatments and lowest on the annual treatments, the triennial treatments had the second highest single-stem to multi-stem index and the biennial treatments had the lowest. Over time, generally there was a decrease in the single-stem to multi-stem index on all the fire frequency treatments. Generally, as the inter-fire period increases from 1 year to beyond 3 years the single-stem to multi-stem index increases. Therefore as the period between fires increases the number of single-stem individuals relative to multi-stem individuals increases.

WISETD

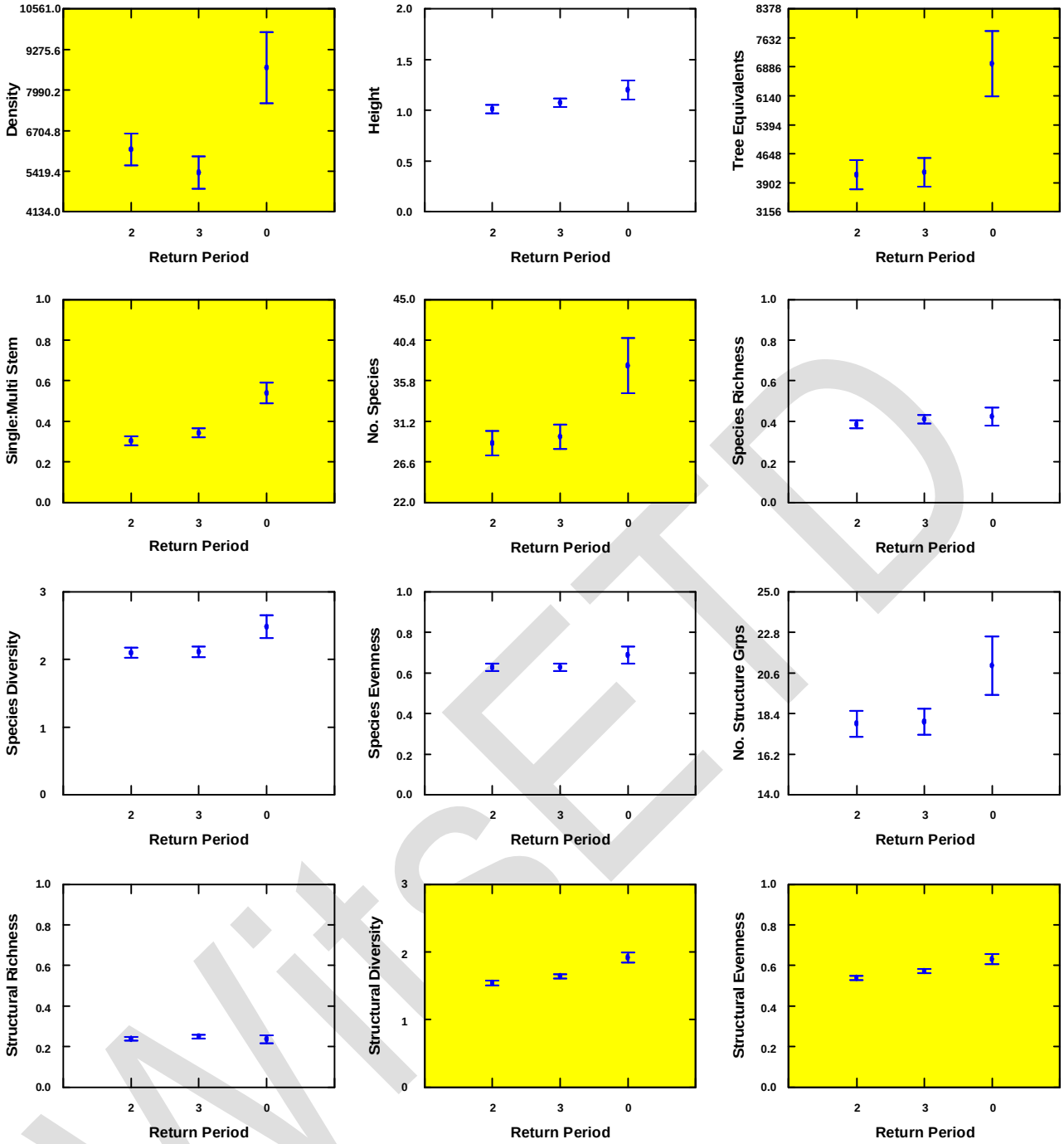


Figure 6-12: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for the treatment effects between plots burnt at different frequencies using the No-August-Annual data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.3.5 Differences in the number of species between plots burnt at different frequencies

6.2.2.3.5.1 ANOVA and ANCOVA analyses on the number of species using the No-August-Annual data grouping

In 1954, the number of species was not significantly different between the treatments burnt at different frequencies (Table 6-5). The mean number of species was highest on the triennial treatments (21.0) and the lowest on the control treatments in 1954 (17.3) (Table 13-4). In 1996, the mean number of species was highest on the control treatments (37.5) and lowest on the biennial treatments (28.7) (Table 13-5). The number of species was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: p = 0.043, ANCOVA: p = 0.016) (Table 6-5). Tukey Studentized *post hoc* analyses show that

number of species was significantly higher on the control treatments than on the biennial (ANOVA: p = 0.035, ANCOVA: p = 0.022) and triennial (ANOVA: p = 0.059, ANCOVA: 0.014) treatments in 1996 (Table 14-5, and Table 14-6). The number of species increased on all the fire frequency treatments between 1954 and 1996.

6.2.2.3.5.2 ANOVA and ANCOVA analyses on the number of species using the August-Control data grouping

In 1954, the number of species was not significantly different between the treatments burnt at different frequencies (Table 6-6). The mean number of species was highest on the annual treatments (18.0) and lowest on the biennial treatments (16.3) (Table 13-6). In 1996, the mean number of species was highest on the control treatments (37.5) and lowest on the biennial (26.3) and triennial treatments (26.3) (Table 13-7). The mean number of species was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: p = 0.030, ANCOVA: p = 0.037) (Table 6-6). Tukey Studentized *post hoc* analyses show that the number of species on the control treatments was significantly higher than the annual (ANOVA: p = 0.085, ANCOVA: p = 0.084), biennial (ANOVA: p = 0.048, ANCOVA: p = 0.060), and triennial (ANOVA: p = 0.048, ANCOVA: 0.060) treatments in 1996 (Table 14-8, and Table 14-9). The number of species increased on all the fire frequency treatments between 1954 and 1996.

6.2.2.3.5.3 Summary of the general relationship between the number of species and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954, the relationship between the number of species and fire frequency on the Pretoriuskop EBPs was not similar in both the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1996 however, the relationship between the number of species and fire frequency was similar in both the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1996, the number of species was highest on the control treatments and lowest on the biennial treatments, the triennial treatment had the second highest number of species and the annual treatment had the second lowest. Over time, the number of species increased on all the fire frequency treatments. Generally, as the inter-fire period increases from 1 year to 2 years the number of species decreases, then as the inter-fire period increases from 2 years to beyond 3 years, the number of species increases.

6.2.2.3.6 Differences in species richness between plots burnt at different frequencies

6.2.2.3.6.1 ANOVA and ANCOVA analyses on the species richness using the No-August-Annual data grouping

In 1954, the species richness was highest on the triennial treatments (0.486) and lowest on the biennial treatments (0.388) (Table 13-4). The species richness was significantly different between the treatments burnt at different frequencies in 1954(p = 0.030) (Table 6-5). Tukey Studentized *post hoc* analyses show that the species richness on the triennial treatments was significantly higher than on the biennial treatments (p = 0.023) (Table 14-4). In 1996, the species richness was not significantly different between the treatments burnt at different frequencies (Table 6-5). The species richness was highest on the control treatments (0.424) and lowest on the biennial treatments (0.384) in 1996 (Table 13-5). Between 1954 and 1996, species richness decreased on the triennial treatments and slightly on the biennial treatments, and increased slightly on the control treatments.

6.2.2.3.6.2 ANOVA and ANCOVA analyses on the species richness using the August-Control data grouping

In 1954, the species richness was not significantly different between the treatments burnt at different frequencies (Table 6-6). The species richness was highest on the control treatments (0.423) and lowest on the biennial treatments (0.329) (Table 13-6). In 1996, the number of species was not significantly different between the treatments burnt at different frequencies (Table 6-6). The species richness was highest on the control treatments (0.424) and lowest on the annual treatments (0.358) (Table 13-6). Between 1954 and

WISER

1996, the species richness increased on the biennial and triennial treatments and slightly on the control treatments, and decreased on the annual treatments.

6.2.2.3.6.3 Summary of the general relationship between the species richness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the species richness and fire frequency on the Pretoriuskop EBPs was not similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). There is no clear trend in species richness on the fire frequency treatments. Generally, the species richness appears to increase as the inter-fire period increases, however this trend is tenuous.

6.2.2.3.7 Differences in species diversity between plots burnt at different frequencies

6.2.2.3.7.1 ANOVA and ANCOVA analyses on the species diversity using the No-August-Annual data grouping

The species diversity was not significantly different between the treatments burnt at different frequencies in 1954 (Table 6-5). The species diversity was highest on the triennial treatments (2.113) and lowest on the biennial treatments (1.988) in 1954 (Table 13-4). In 1996, the species diversity was highest on the control treatments (2.482) and lowest on the biennial treatments (2.098) (Table 13-5). The species diversity was significantly different between the treatments burnt at different frequencies in 1996 (ANCOVA: $p = 0.063$) (Table 6-5). Tukey Studentized *post hoc* analyses show that the species diversity is significantly higher on the control treatments than on the biennial (ANCOVA: $p = 0.087$) and triennial (ANCOVA: $p = 0.052$) treatments in 1996 (Table 14-5, and Table 14-6). Between 1954 and 1996, species diversity decreased slightly on the triennial treatments, and increased on the control and biennial treatments.

6.2.2.3.7.2 ANOVA and ANCOVA analyses on the species diversity using the August-Control data grouping

The species diversity was not significantly different between the treatments burnt at different frequencies in 1954 (Table 6-6). The species diversity was highest on the control treatments (2.054) and was lowest on the biennial treatments (1.740) in 1954 (Table 13-6). In 1996, the species diversity was highest on the control treatments (2.482) and lowest on the biennial treatments (1.892) (Table 13-7). The species diversity was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: $p = 0.067$, ANCOVA: $p = 0.088$) (Table 6-6). Tukey Studentized *post hoc* analyses show that the species diversity is significantly higher on the control treatments than the biennial (ANOVA: $p = 0.080$) and triennial (ANOVA: $p = 0.096$, ANCOVA: 0.091) treatments in 1996 (Table 14-8, and Table 14-9). Between 1954 and 1996, the species diversity increased slightly on the triennial treatments, and increased on the annual, biennial, and triennial treatments.

6.2.2.3.7.3 Summary of the general relationship between the species diversity and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the species diversity and fire frequency on the Pretoriuskop EBPs was not similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). Over time, the species diversity has increased on all the fire frequency treatments with the exception of the triennial treatments, which have remained the same. Generally, as the inter-fire period increases from 1 year to 2 years the species diversity decreases, the species diversity then remains constant between inter-fire periods of 2 years and 3 years, and then the species diversity increases as the inter-fire period increases beyond 3 years.

WISER

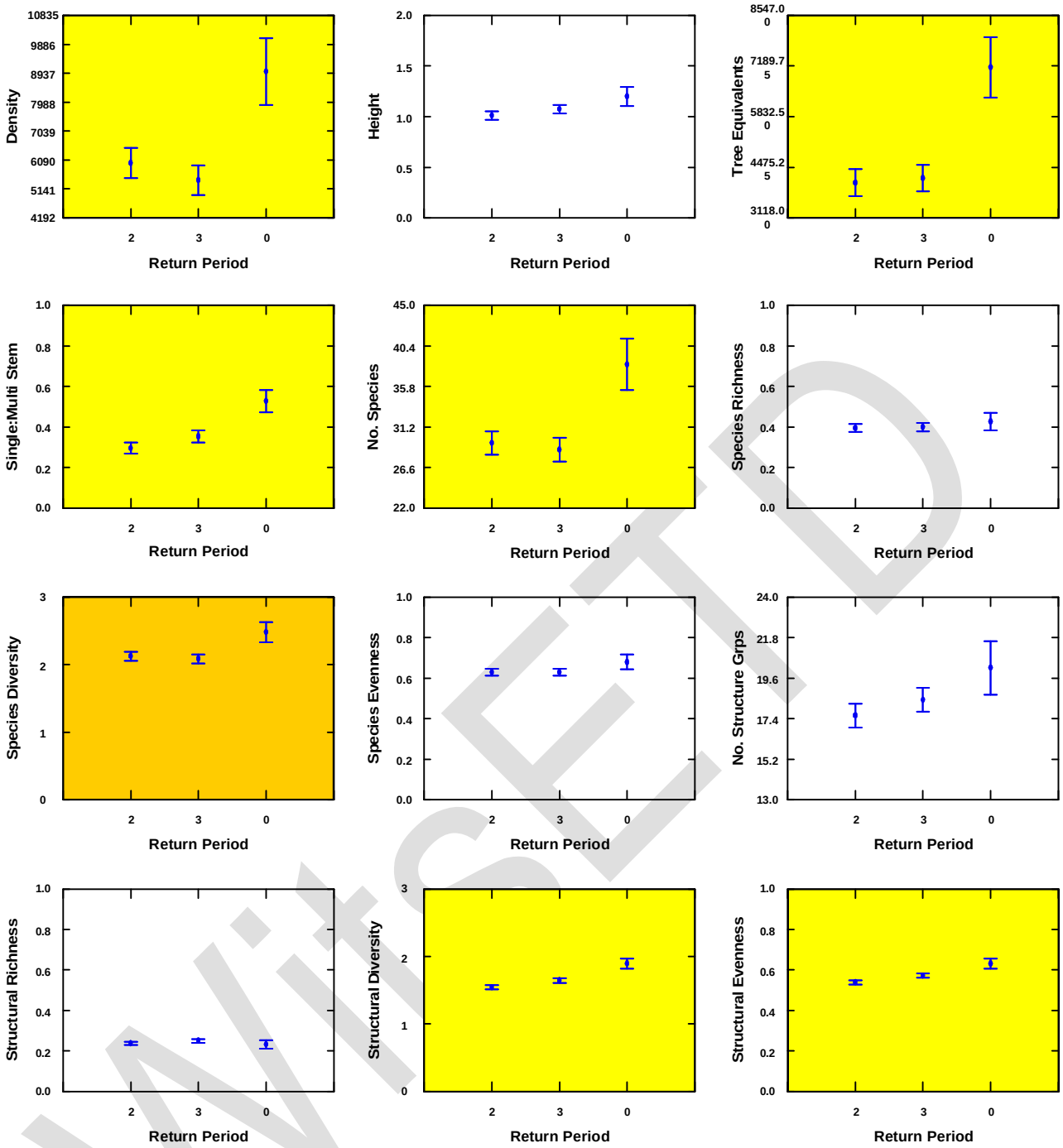


Figure 6-13: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for the treatment effects between plots burnt at different frequencies taking into account the state of the plots before the treatments began. The No-August-Annual data grouping was used in these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.3.8 Differences in species evenness between plots burnt at different frequencies

6.2.2.3.8.1 ANOVA and ANCOVA analyses on the species evenness using the No-August-Annual data grouping

The species evenness was not significantly different between the treatments burnt at different frequencies in 1954 (Table 6-5). The species evenness was highest on the control treatments (0.727) and lowest on the biennial treatments (0.698) in 1954 (Table 13-4). In 1996, the species evenness was highest on the control treatments (0.688) and lowest on the biennial treatments (0.627) (Table 13-5). The species evenness was

WISE D

not significantly different between the treatments burnt at different frequencies in 1996 (Table 6-5). Between 1954 and 1996, the species evenness decreased on all the treatments burnt at different frequencies.

6.2.2.3.8.2 ANOVA and ANCOVA analyses on the species evenness using the August-Control data grouping

The species evenness was not significantly different between the treatments burnt at different frequencies in 1954 (Table 6-6). The species evenness was highest on the control treatments (0.727) and was lowest on the biennial treatments (0.623) in 1954 (Table 13-6). In 1996, the species evenness was highest on the control treatments (0.688) and lowest on the biennial treatments (0.579) (Table 13-7). The species evenness was not significantly different between the treatments burnt at different frequencies in 1996 (Table 6-6). Between 1954 and 1996, the species evenness decreased on all the treatments burnt at different frequencies.

6.2.2.3.8.3 Summary of the general relationship between the species evenness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the species evenness and fire frequency on the Pretoriuskop EBPs was similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1954, the species evenness was highest on the control treatments and lowest on the biennial treatments, the triennial treatments had the second highest species evenness, and the annual treatments had the lowest. In 1996, the species evenness was highest on the control treatments and lowest on the biennial treatments, the triennial treatments had the second highest species evenness and the annual treatments had the second lowest. Over time, the species evenness has decreased on all the fire frequency treatments. Generally, as the inter-fire period increases from 1 year to 2 years, the species evenness decreases, and then as the inter-fire period increases from 2 years to 3 years and up to 42 years the species evenness increases.

6.2.2.3.9 Differences in the number of structural groups between plots burnt at different frequencies

6.2.2.3.9.1 ANOVA and ANCOVA analyses on the number of structural groups using the No-August-Annual data grouping

The number of structural groups was not significantly different between the treatments burnt at different frequencies in 1954 (Table 6-5). The mean number of structural groups was highest on the control treatments (16.8) and lowest on the triennial treatments (14.1) in 1954 (Table 13-4). In 1996, the mean number of structural groups was highest on the control treatments (21.0) and lowest on the biennial treatments (17.850) (Table 13-5). The number of structural groups was not significantly different between the treatments burnt at different frequencies in 1996 (Table 6-5). Between 1954 and 1996, the number of structural groups increased on all the treatments burnt at different frequencies.

6.2.2.3.9.2 ANOVA and ANCOVA analyses on the number of structural groups using the August-Control data grouping

In 1954, the mean number of structural groups was highest on the annual treatments (18.3) and was lowest on the triennial treatments (11.5) (Table 13-6). The number of structural groups was significantly different between the treatments burnt at different frequencies in 1954 ($p = 0.021$) (Table 6-6). Tukey Studentized *post hoc* analyses show that the number of structural groups on the triennial treatments was significantly lower than on the control (0.073), annual (0.019), and biennial (0.091) treatments (Table 14-7). In 1996, the mean number of structural groups was highest on the control treatments (21.0) and lowest on the triennial treatments (16.500) (Table 13-7). The number of structural groups was significantly different between the treatments burnt at different frequencies in 1996 (ANCOVA: $p = 0.069$) (Table 6-6). Tukey Studentized *post hoc* analyses show that the number of structural groups was significantly higher on the control treatments than the annual treatments (ANCOVA: $p = 0.059$) (Table 14-9). Between 1954 and 1996, the number of structural groups increased on the control, biennial, and triennial treatments, and decreased on the annual treatments.

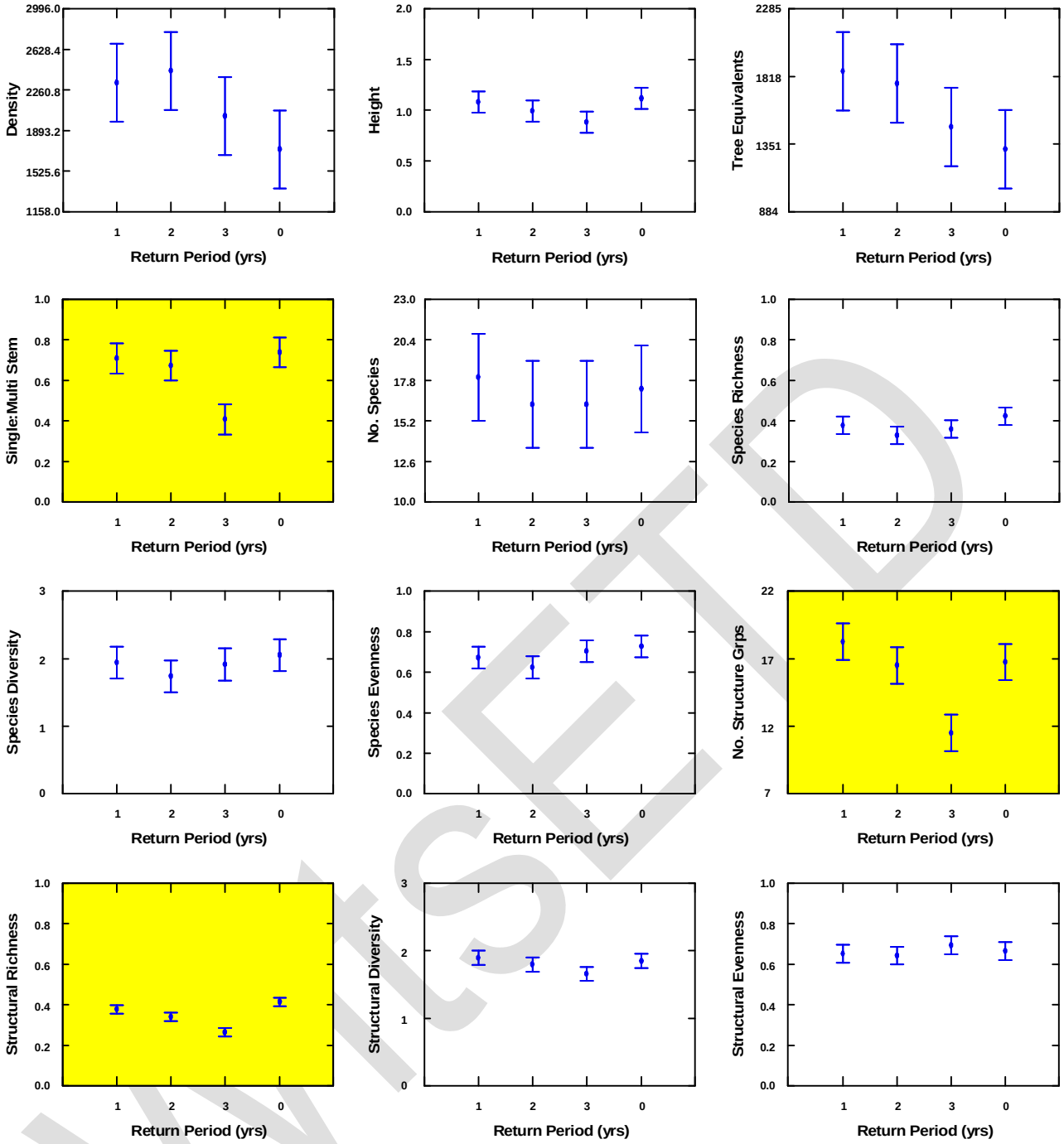


Figure 6-14: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots to be burnt at different frequencies using the August-Control data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.3.9.3 Summary of the general relationship between the number of structural groups and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the number of structural groups and fire frequency on the Pretoriuskop EBPs was similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1954, the number of structural groups was highest on the annual treatments and lowest on the triennia treatments, the control treatment had the second highest number of structural groups and the biennial treatments the lowest. In 1996, the control treatments had the highest number of structural groups and the triennial treatments had the lowest, the biennial treatment had the second highest number of

WISETD

structural groups and the annual had the second lowest. Generally, as the inter-fire period increases from 1 year to beyond 3 years the number of structural groups increases.

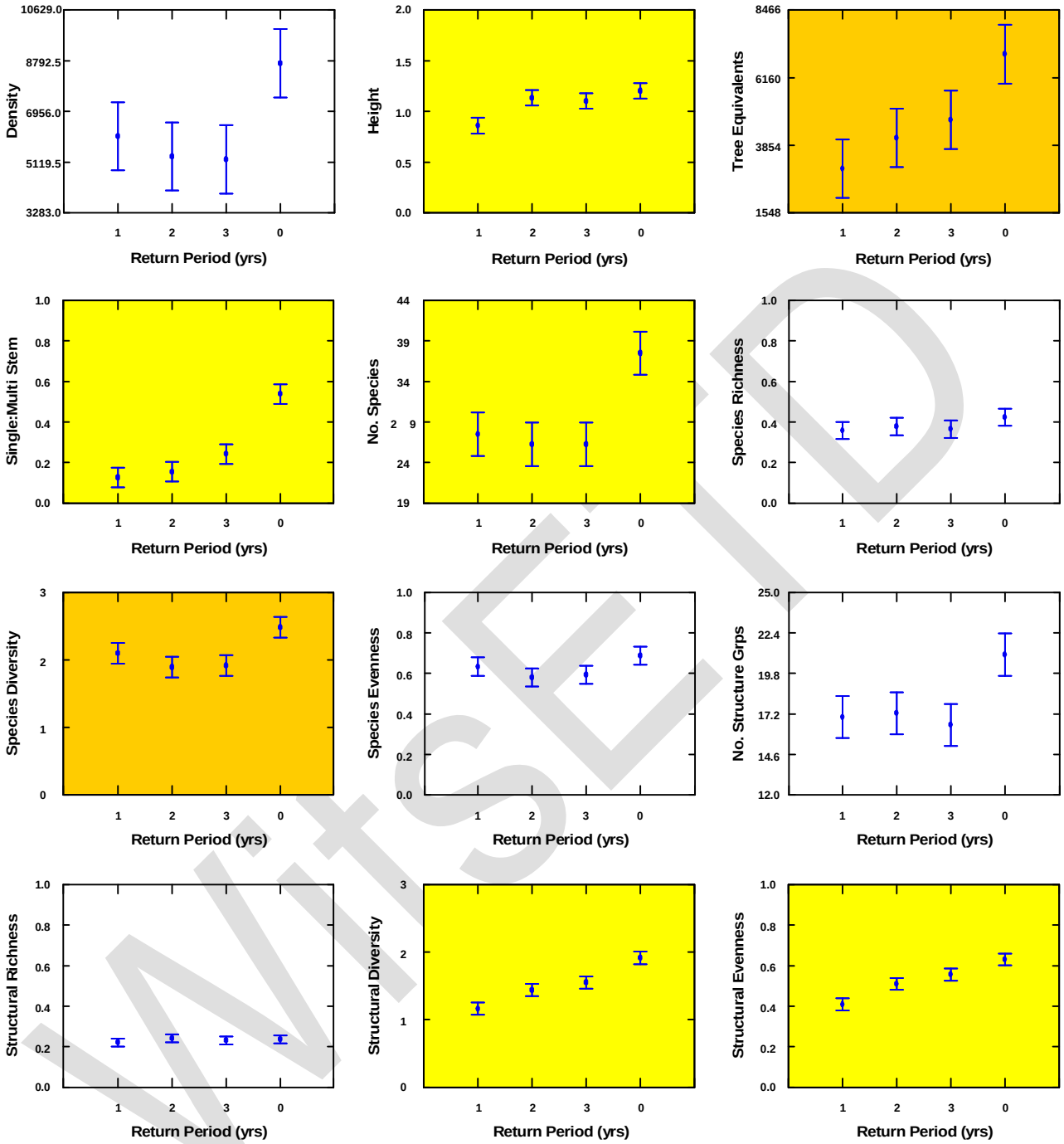


Figure 6-15: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for the treatment effects between plots burnt at different frequencies using the August-Control data grouping. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.3.10 Differences in structural richness between plots burnt at different frequencies

6.2.2.3.10.1 ANOVA and ANCOVA analyses on the structural richness using the No-August-Annual data grouping

In 1954, the mean structural richness was highest on the control treatments (0.451) and lowest on the triennial treatments (0.327) (Table 13-4). The structural richness was significantly different between the treatments burnt at different frequencies in 1954 (p = 0.049) (Table 6-5). Tukey Studentized *post hoc*

analyses show the structural richness on the control treatments was significantly higher than on the triennial treatments (p = 0.039) (Table 14-4). In 1996, the mean structural richness was highest on the triennial treatments (0.249) and lowest on the control treatments (0.237) (Table 13-5). The structural richness was not significantly different between the treatments burnt at different frequencies in 1996 (Table 6-5). Between 1954 and 1996, the structural richness decreased on all the treatments burnt at different frequencies.

6.2.2.3.10.2 ANOVA and ANCOVA analyses on the structural richness using the August-Control data grouping

In 1954, the mean structural richness was highest on the control treatments (0.415) and was lowest on the triennial treatments (0.265) (Table 13-6). The structural richness was significantly different between the treatments burnt at different frequencies in 1954 (p = 0.002) (Table 6-6). Tukey Studentized *post hoc* analyses show that the structural richness on the triennial treatments was significantly lower than on the control (0.001) and annual (0.012) treatments (Table 14-7). In 1996, the mean structural richness was highest on the biennial treatments (0.242) and lowest on the annual treatments (0.221) (Table 13-7). The structural richness was not significantly different between the treatments burnt at different frequencies in 1996 (Table 6-6). Between 1954 and 1996, the structural richness decreased on all the treatments burnt at different frequencies.

6.2.2.3.10.3 Summary of the general relationship between the structural richness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the structural richness and fire frequency on the Pretoriuskop EBPs was not similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). Over time, the structural richness has decreased on all the frequency treatments. There is no clear trend in structural richness on the fire frequency treatments. Generally, the structural richness appears to increase as the inter-fire period increases from 1 year to 3 years, and then as the inter-fire period increases beyond 3 years up to 42 years, the structural richness decreases. However, this trend is weak.

6.2.2.3.11 Differences in structural diversity between plots burnt at different frequencies

6.2.2.3.11.1 ANOVA and ANCOVA analyses on the structural diversity using the No-August-Annual data grouping

In 1954, the structural diversity was not significantly different between the treatments burnt at different frequencies (Table 6-5). The mean structural diversity was highest on the control treatments (1.850) and lowest on the biennial treatments (1.697) in 1954 (Table 13-4). In 1996, the mean structural diversity was highest on the control treatments (1.918) and lowest on the biennial treatments (1.540) (Table 13-5). The structural diversity was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: p < 0.001, ANCOVA: p = 0.001) (Table 6-5). Tukey Studentized *post hoc* analyses show that the structural diversity was significantly higher on the control treatments than on the biennial (ANOVA: p = 0.001, ANCOVA: p = 0.001) and triennial (ANOVA: p = 0.005, ANCOVA: p = 0.014) treatments in 1996 (Table 14-8, and Table 14-9). The *post hoc* analyses also show that the structural diversity was significantly higher on the triennial treatments than on the biennial treatments in 1996 (ANOVA: p = 0.098, ANCOVA: p = 0.094) (Table 14-8, and Table 14-9). Between 1954 and 1996, the structural diversity increased on the control treatments and decreased on the biennial and triennial treatments.

6.2.2.3.11.2 ANOVA and ANCOVA analyses on the structural diversity using the August-Control data grouping

In 1954, the mean structural diversity was highest on the annual treatments (1.897) and was lowest on the triennial treatments (1.658) (Table 13-6). The structural diversity was not significantly different between the treatments burnt at different frequencies in 1954 (Table 6-6). In 1996, the mean structural diversity was highest on the control treatments (1.918) and lowest on the annual treatments (1.162) (Table 13-7). The structural diversity was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: p = 0.001, ANCOVA: p = 0.001) (Table 6-6). Tukey Studentized *post hoc* analyses show that the

structural diversity on the control treatments was significantly higher than the annual (ANOVA: $p < 0.001$, ANCOVA: $p = 0.001$), biennial (ANOVA $p = 0.014$, ANCOVA: $p = 0.019$), and triennial (ANOVA: $p = 0.065$) treatments in 1996 (Table 14-8, and Table 14-9). The *post hoc* analyses also show that the structural diversity was significantly higher on the triennial treatments than on the annual treatments in 1996 (ANOVA: $p = 0.048$, ANCOVA: $p = 0.037$) (Table 14-8, and Table 14-9). Between 1954 and 1996, the structural diversity increased on the control treatment, and decreased on the annual, biennial, and triennial treatments.

6.2.2.3.11.3 Summary of the general relationship between the structural diversity and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954 and 1996, the relationship between the structural diversity and fire frequency on the Pretoriuskop EBPs was similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1954, the structural diversity was highest on the annual treatments and lowest on the triennial treatments, the control treatments had the second highest structural diversity and the biennial had the second lowest. In 1996, the structural diversity was highest on the control treatments and lowest on the annual treatments, the triennial treatments had the second highest structural diversity and the biennial treatments had the second lowest. Over time, the structural diversity increased on the control treatments and decreased on the annual, biennial, and triennial treatments. Generally, as the inter-fire period increases from 1 year to beyond 3 years the structural diversity increases.

6.2.2.3.12 Differences in structural evenness between plots burnt at different frequencies

6.2.2.3.12.1 ANOVA and ANCOVA analyses on the structural evenness using the No-August-Annual data grouping

In 1954, the structural evenness was not significantly different between the treatments burnt at different frequencies (Table 6-5). The mean structural evenness was highest on the control treatments (0.666) and lowest on the biennial treatments (0.624) in 1954 (Table 13-4). In 1996, the mean structural evenness was highest on the control treatments (0.631) and lowest on the biennial treatments (0.539) (Table 13-5). The structural evenness was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: $p = 0.003$, ANCOVA: $p = 0.004$) (Table 6-5). Tukey Studentized *post hoc* analyses show that the structural evenness was significantly higher on the control treatments than on the biennial (ANOVA: $p = 0.003$, ANCOVA: $p = 0.005$) and triennial (ANOVA: $p = 0.080$, ANCOVA: $p = 0.086$) treatments in 1996 (Table 14-8, and Table 14-9). The *post hoc* analyses also show that the structural evenness was significantly higher on the triennial treatments than on the biennial treatments in 1996 (ANOVA: $p = 0.088$) (Table 14-8, and Table 14-9). Between 1954 and 1996, the structural evenness decreased on all the treatments burnt at different frequencies.

6.2.2.3.12.2 ANOVA and ANCOVA analyses on the structural evenness using the August-Control data grouping

In 1954, the mean structural evenness was highest on the triennial treatments (0.694) and was lowest on the biennial treatments (0.643) (Table 13-6). The structural evenness was not significantly different between the treatments burnt at different frequencies in 1954 (Table 6-6). In 1996, the mean structural evenness was highest on the control treatments (0.631) and lowest on the annual treatments (0.409) (Table 13-7). The structural evenness was significantly different between the treatments burnt at different frequencies in 1996 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.003$) (Table 6-6). Tukey Studentized *post hoc* analyses show that the structural evenness on the control treatments was significantly higher than the annual (ANOVA: $p = 0.001$, ANCOVA: $p = 0.002$) and biennial (ANOVA $p = 0{,}056$, ANCOVA: $p = 0.078$) treatments in 1996 (Table 14-8, and Table 14-9). The *post hoc* analyses also show that the structural evenness was significantly higher on the triennial treatments than on the annual treatments in 1996 (ANOVA: $p = 0.019$, ANCOVA: $p = 0.033$) (Table 14-8, and Table 14-9). Between 1954 and 1996, the structural evenness decreased on all the treatments burnt at different frequencies.

WISER

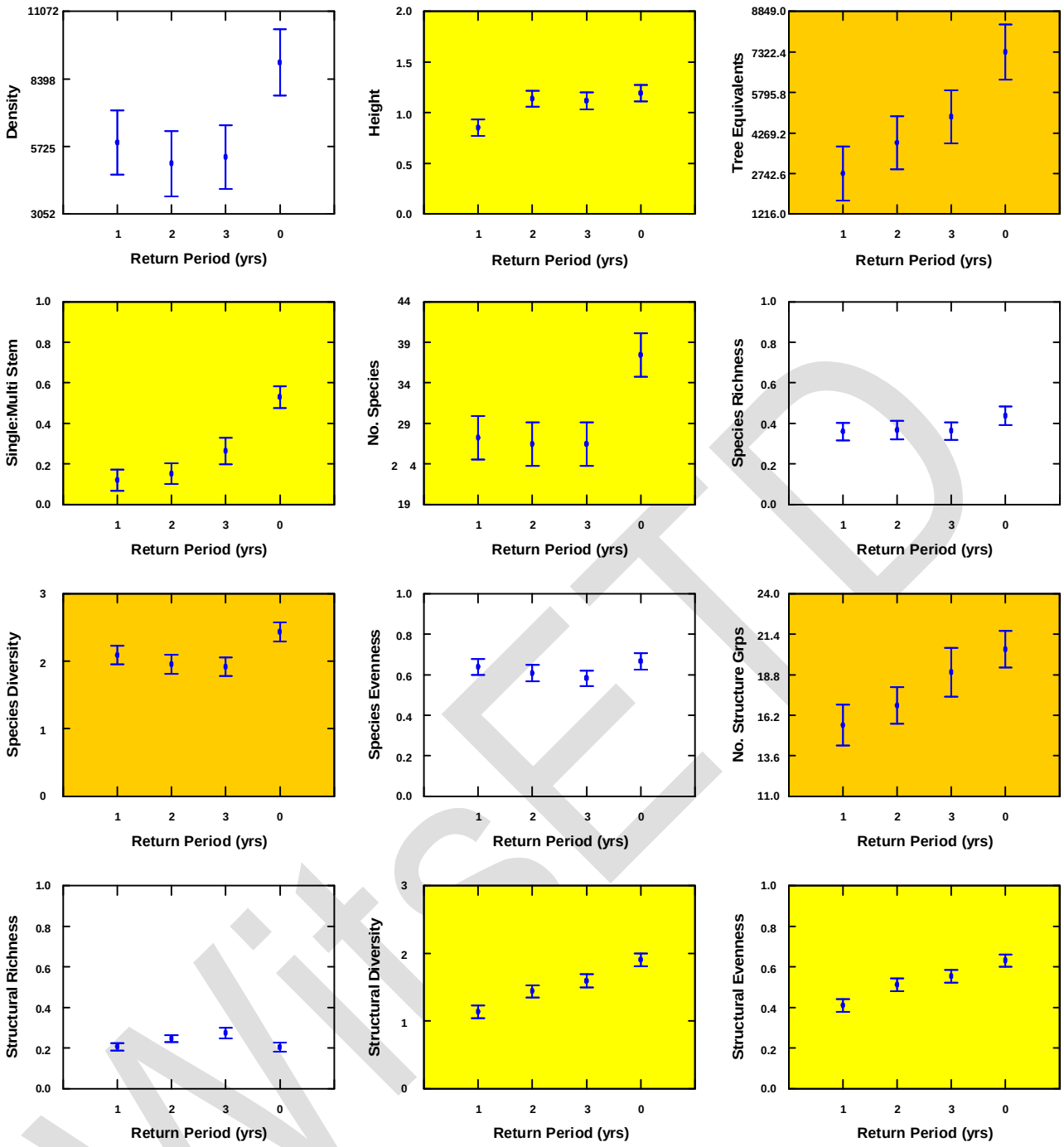


Figure 6-16: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for the treatment effects between plots burnt at different frequencies taking into account the state of the plots before the treatments began. The August-Control data grouping was used in these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.3.12.3 Summary of the general relationship between the structural evenness and fire frequency based on the No-August-Annual and August-Control ANOVA and ANCOVA analyses

In 1954, the relationship between the structural evenness and fire frequency on the Pretoriuskop EBPs was not similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1996, the relationship between the structural evenness and fire frequency on the Pretoriuskop EBPs was similar in the No-August-Annual and August-Control analyses (Figure 6-11 to Figure 6-16). In 1996, the structural evenness was highest on the control treatments and lowest on the annual treatments, the triennial treatments had the second highest structural evenness and the biennial treatments had the second lowest.

WITSETD

Over time, the structural evenness decreased on the treatments burnt at different frequencies. Generally, as inter-fire period increases from 1 year to beyond 3 years the structural evenness increases.

6.2.2.4 Testing for differences in the woody vegetation density, structure and composition between the Pretoriuskop EBPs burnt at different times of the year (February, April, August, October, and December)

The results of the Analysis of Variance and Analysis of Covariance testing for differences in woody vegetation between the fire timing treatments (February, April, August, October and December) on the Pretoriuskop EBPs are presented in Table 6-7 (p. 91) (Figure 6-17 (p. 93), Figure 6-18 (p. 95), and Figure 6-19 (p. 97)). Results of *post hoc* analyses performed where significant differences were found between the fire timing treatments are presented in Table 14-10 (p. 245), Table 14-11 (p. 246), and Table 14-12 (p. 248). Summaries of the 1954 and 1996 data used in these analyses are presented in Appendix 5 in Table 13-8 (p. 229) and Table 13-9 (p. 230) respectively.

Table 6-7: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the timing effects of the fire treatments (the August annual treatments were not included in these analyses).

						Taxonomic diversity				Structural diversity			
Year	Statistic	Density	Mean height	Tree equivalents	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
1954 (ANOVA)	df	5	5	5	5	5	5	5	5	5	5	5	5
	df error	38	38	38	38	38	38	38	38	38	38	38	38
	F-ratio	0.705	1.038	0.615	0.900	0.926	2.133	1.484	1.189	0.731	3.274	1.507	0.970
	p value	0.624	0.410	0.689	0.491	0.475	0.082	0.218	0.333	0.604	0.015	0.210	0.448
1996 (ANOVA)	df	5	5	5	5	5	5	5	5	5	5	5	5
	df error	38	38	38	38	38	38	38	38	38	38	38	38
	F-ratio	1.648	2.767	2.031	2.941	11.798	0.840	2.426	1.711	1.863	0.170	4.329	3.989
	p value	0.171	0.032	0.096	0.024	0.001	0.530	0.053	0.156	0.124	0.972	0.003	0.005
1996:1954 (ANCOVA)	df	5	5	5	5	5	5	5	5	5	5	5	5
	df error	37	37	37	37	37	37	37	37	37	37	37	37
	F-ratio	1.845	2.974	2.500	3.906	11.436	1.163	3.705	1.814	2.170	0.214	3.973	3.898
	p value	0.128	0.024	0.048	0.006	0.001	0.346	0.008	0.134	0.079	0.954	0.006	0.006

Note: The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.4.1 Differences in woody plant density between plots burnt at different times of the year

In 1954 and 1996, the woody plant density was not significantly different between the treatments burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest density (plants/Ha) in 1954 was February (2473.8), August (2228.5), April (2057.5), December (1979.4), October (1803.9), and Control (1721.5) (Table 13-8). In 1996, the rank order of the fire timing treatments from highest to lowest density was Control (8696.0), February (6765.3), December (5716.8), April (5703.1), August (5267.0), and October (5248.9) (Table 13-9). Between 1954 and 1996, the woody plant density increased on all fire treatments.

The intensity of fires varies from cool to extremely hot at different times of the year. Treatments with more intense fires (August and October) have lower woody plant densities than treatments with less intense fires

(February and December). This may be because some individuals cannot survive the more intense fires in August and October while they are able to survive the less intense fires in February and December. Furthermore, the carbohydrate storage phenology of woody plants is also a determinant in their post-fire survival, because woody plants are less likely to recover from fire damage when their carbohydrate reserves are depleted. Carbohydrate reserves are highest at the end of summer in February and April and lowest at the end of winter and the onset of spring in August and October. Therefore, some individuals may not survive fires in August and October because their carbohydrate reserves are low, and they do not have the energy reserves to recover from being burnt.

6.2.2.4.2 Differences in woody plant height between plots burnt at different times of the year

In 1954, the woody plant height was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from tallest to shortest height (m) in 1954 was February (1.184), Control (1.116), December (1.089), October (1.078), April (1.067), and August (0.938) (Table 13-8). In 1996, the rank order of the timing treatments from tallest to shortest height was Control (1.202), October (1.157), August (1.117), December (1.057), April (0.978), and February (0.907) (Table 13-9). The woody plant height was significantly different between the treatments burnt at different times of the year in 1996 (ANOVA: p = 0.032, ANCOVA: p = 0.024) (Table 6-7). Tukey Studentized post hoc analyses show that the woody plant height on the February treatments was significantly shorter than the Control (ANOVA: p = 0.087, ANCOVA: 0.073) and October (ANOVA: p = 0.068, ANCOVA: 0.051) treatments (Table 14-11, and Table 14-12). Between 1954 and 1996, woody plant height decreased on the February, April, and December treatments, and increased on the August, October, and Control treatments.

The August and October treatments have taller plant heights than the February and April treatments. The August and October treatments are also expected to have more intense fires than the February and April treatments.

6.2.2.4.3 Differences in the number of tree equivalents between plots burnt at different times of the year

In 1954, the number of tree equivalents was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest number of tree equivalents (tree equivalents/Ha) in 1954 was February (1851.5), August (1618.9), April (1541.1), December (1489.3), October (1344.6), and Control (1315.3) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest number of tree equivalents was Control (6963.3), August (4406.8), April (4249.3), February (4191.1), October (3992.6), and December (3868.3) (Table 13-9). The number of tree equivalents was significantly different between the treatments burnt at different times of the year in 1996 (ANOVA: p = 0.096, ANCOVA: p = 0.048) (Table 6-7). Tukey Studentized post hoc analyses show that the number of tree equivalents was significantly higher on the Control treatments than on the February (ANCOVA: p = 0.038), April (ANCOVA: p = 0.070), August (ANCOVA: p = 0.087), October (ANOVA: p = 0.079, ANCOVA: p = 0.056), and December (ANOVA: p = 0.060, ANCOVA: p = 0.032) treatments in 1996 (Table 14-11, and Table 14-12). Between 1954 and 1996, the number of tree equivalents increased on all the treatments burnt at different times of the year.

6.2.2.4.4 Differences in the single-stem to multi-stem index between plots burnt at different times of the year

In 1954, the single-stem to multi-stem index was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest single-stem to multi-stem index in 1954 was Control (0.738), December (0.550), August (0.540), April (0.522), October (0.463), and February (0.446) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest single-stem to multi-stem index was Control (0.539), February (0.383), December (0.380), April (0.364), October (0.288), and August (0.199) (Table 13-9). The single-stem to multi-stem index was significantly different between the treatments burnt at different times of the year in 1996 (ANOVA: p = 0.024, ANCOVA: p = 0.006) (Table 6-7). Tukey Studentized post hoc analyses show that the single-stem to

multi-stem index was significantly higher on the Control treatments than on the February (ANOVA: p = 0.031, ANCOVA: p = 0.036), April (ANOVA: p = 0.011, ANCOVA: p = 0.012), August (ANOVA: p = 0.001, ANCOVA: p = 0.001), October (ANOVA: p = 0.001, ANCOVA: p < 0.001), and December (ANOVA: p = 0.026, ANCOVA: p = 0.028) treatments in 1996 (Table 14-11, and Table 14-12). The single-stem to multi-stem index was also significantly lower on the August treatments than on the February (ANOVA: p = 0.001, ANCOVA: p = 0.001), April (ANOVA: p = 0.002, ANCOVA: p = 0.003), and December (ANOVA: p = 0.001, ANCOVA: p = 0.001) treatments in 1996. Between 1954 and 1996, the single-stem to multi-stem index decreased on all the treatments burnt at different times of the year.

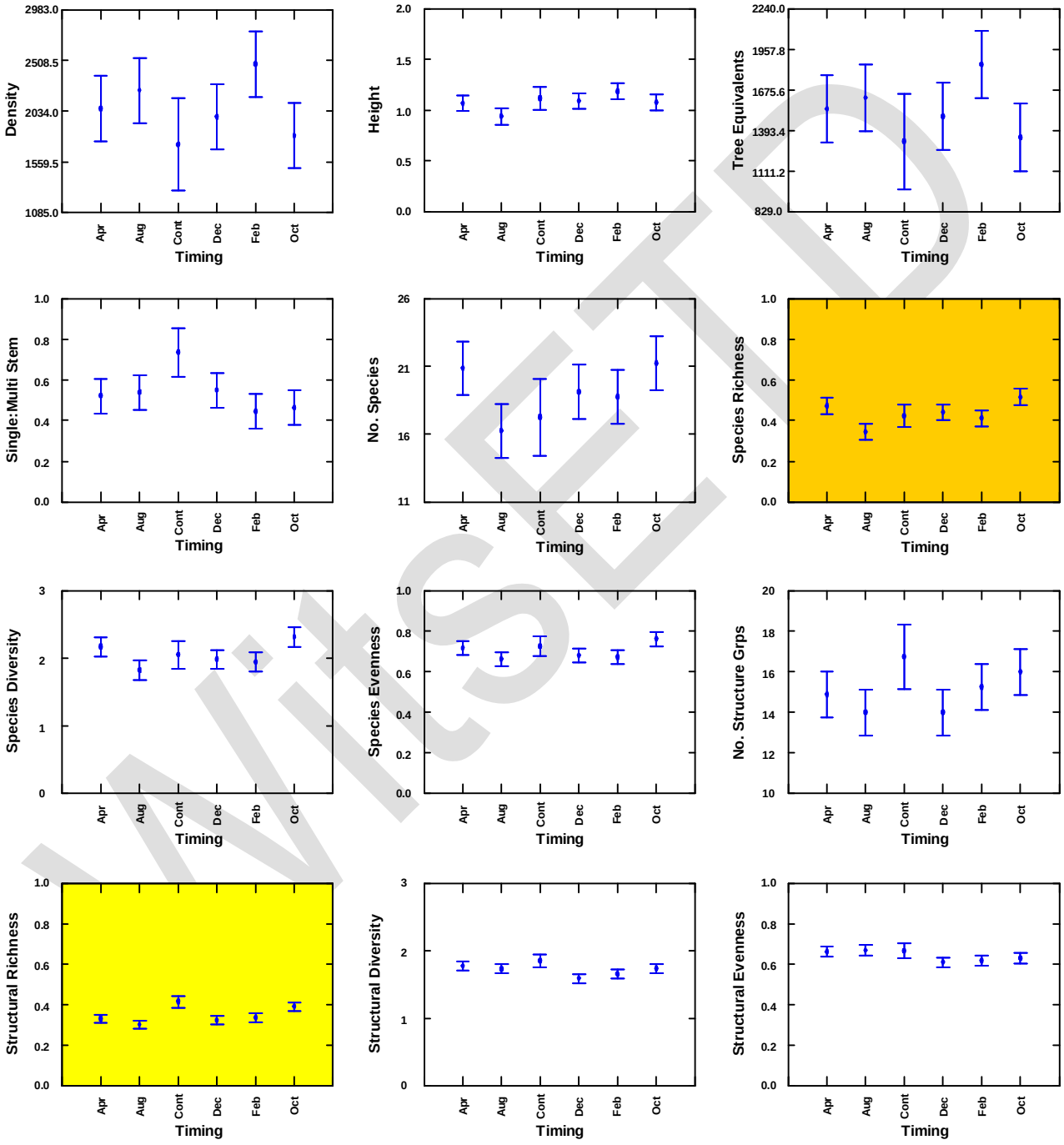


Figure 6-17: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots to be burnt at different times of the year. The August annual treatments were excluded from these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

WISE D

Generally, treatments that burn more intensely (August and October) tend to have more multi-stem individuals relative to single-stem individuals than treatments that burn less intensely (February and December).

6.2.2.4.5 Differences in the number of species between plots burnt at different times of the year

In 1954, the number of species was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest number of species in 1954 was October (21.250), April (20.875), December (19.125), February (18.750), Control (17.250), and August (16.250) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest number of species was Control (37.500), December (32.375), February (31.250), April (29.375), August (26.250), and October (26.125) (Table 13-9). The number of species was significantly different between the treatments burnt at different times of the year in 1996 (ANOVA: p = 0.001, ANCOVA: p = 0 001) (Table 6-7). Tukey Studentized post hoc analyses show that the number of species was significantly higher on the Control treatment than on the April (ANCOVA: p = 0.067), August (ANOVA: p = 0.040, ANCOVA: p = 0.029), and October (ANOVA: p = 0.036, ANCOVA: p = 0.005) treatments in 1996 (Table 14-11, and Table 14-12). Between 1954 and 1996, the number of species increased on all the treatments burnt at different times of the year.

Generally, treatments that burn less intensely (February and December) have higher number of species than treatments that burn more intensely (August and October). This may be because some species can survive the less intense fires in February and December while they are not able to survive the more intense August and October fires. Furthermore, some species may not be able to survive fires in August and October because these fire events occur at the end of the dry season when carbohydrate reserves have been depleted, and these species do not have enough energy reserves to recover from being burnt.

6.2.2.4.6 Differences in species richness between plots burnt at different times of the year

In 1954, the rank order of the fire timing treatments from highest to lowest species richness in 1954 was October (0.516), April (0.472), December (0.441), Control (0.423), February (0.411), and August (0.344) (Table 13-8). In 1954, the species richness was significantly different between the treatments to be burnt at different times of the year (p = 0.082) (Table 6-7). Tukey Studentized post hoc analyses show that the species richness was significantly higher on the treatments to be burnt in October than on the treatments to be burnt in August (p = 0.044) in 1954 (Table 14-11, and Table 14-12). In 1996, the rank order of the timing treatments from highest to lowest species richness was December (0.448), Control (0.424), February (0.402), April (0.391), October (0.373), and August (0.372) (Table 13-9). The species richness was not significantly different between the treatments burnt at different times of the year in 1996 (Table 6-7). Between 1954 and 1996, the species richness decreased on all the treatments burnt at different times of the year. As explained above (p. 66) this decrease in species richness may be an artefact of the calculation of species richness, which is the number of species observed relative to the sample size.

Generally, treatments that burn less intensely (February and December) have higher species richness than treatments that burn more intensely (August and October). However, the species richness between the treatments burnt at different times does not vary much (ranging from 0.372 to 0.448).

6.2.2.4.7 Differences in species diversity between plots burnt at different times of the year

In 1954, the species diversity was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest species diversity in 1954 was October (2.317), April (2.173), Control (2.054), December (1.988), February (1.947), and August (1.827) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest species diversity was Control (2.482), February (2.271), December (2.213), October (2.137), April (1.991) and August (1.904), (Table 13-9). The species diversity was significantly different between the treatments burnt at different times of the year in 1996 (ANOVA: p = 0.053, ANCOVA: p = 0.008) (Table 6-7). Tukey Studentized post hoc analyses show that the species diversity was significantly higher on the Control

treatments than on the April (ANCOVA: p = 0.027), August (ANOVA: p = 0.061, ANCOVA: p = 0.075), and October (ANCOVA: p = 0.092) treatments in 1996 (Table 14-11, and Table 14-12). Post hoc analyses also show that the February treatments had significantly higher species diversity than the April treatments in 1996 (ANCOVA: p = 0.088). Between 1954 and 1996, the species diversity increased on the February, August, December, Control treatments, and decreased on the April and October treatments.

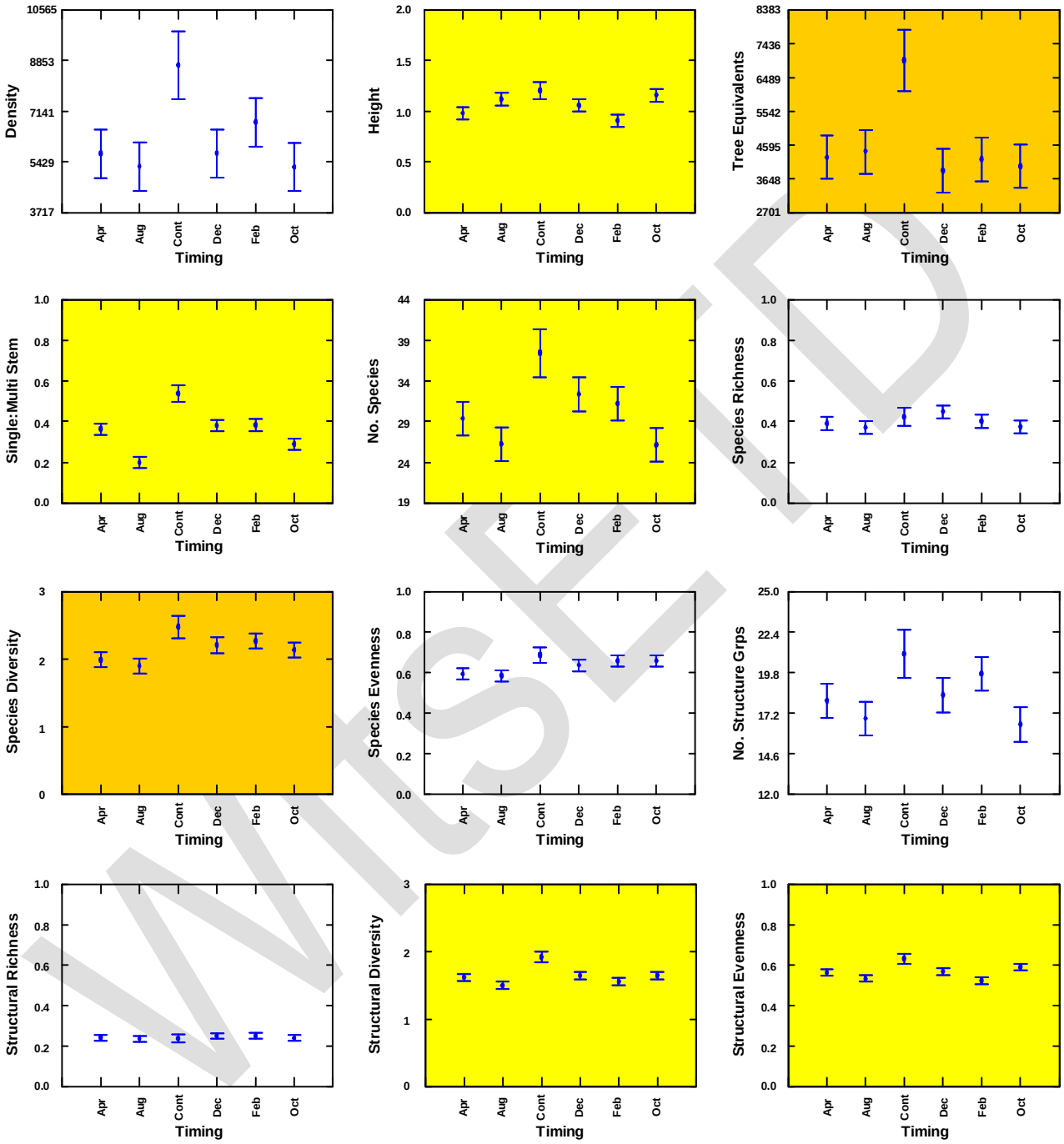


Figure 6-18: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing for the treatment effects between plots burnt at different times of the year. The August annual treatments were excluded from these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

The April, August, and October treatments had the lowest species diversity. Some species may not be able to survive fires in August and October because fires at this time of the year are very intense and most often cause total top kill of saplings and shrubs. Furthermore, August and October fires occur at a time when many

species carbohydrate reserves are depleted and these species are unable to recover from fire damage. This may explain why the species diversity was low on the August and October treatments. The April treatments appear anomalous because fires are less intense in April than they are in August and October, nor are species carbohydrate reserves depleted in April, and yet the species diversity on the April treatments was low. However, Shannon's species diversity is a measure of both the number of species and the relative abundances of the species present. The April treatments did not have the lowest number of species or species richness, however they did have the second lowest species evenness. Species evenness is a measure of how evenly proportioned species abundances are. The species diversity is low on the April treatments because the abundances of the species present are not evenly proportioned.

6.2.2.4.8 Differences in species evenness between plots burnt at different times of the year

In 1954 and 1996, the species evenness was not significantly different between the treatments burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest species evenness in 1954 was October (0.763), Control (0.727), April (0.717), December (0.681), February (0.673), and August (0.663) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest species evenness was Control (0.688), February (0.660), October (0.659), December (0.636), April (0.594), and August (0.586) (Table 13-9). Between 1954 and 1996, the species evenness decreased on all treatments burnt at different frequencies.

6.2.2.4.9 Differences in the number of structural groups between plots burnt at different times of the year

In 1954, the number of structural groups was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest mean number of structural groups in 1954 was Control (16.750), October (16.000), February (15.250), April (14.875), August (14.000), and December (14.000) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest mean number of structural groups was Control (21.000), February (19.750), December (18.375), April (18.000), August (16.875), and October (16.500) (Table 13-9). In 1996, the number of structural groups was significantly different between the treatments burnt at different times of the year (ANCOVA: $p = 0.079$) (Table 6-7). However, Tukey Studentized post hoc analyses do not show any significant differences in the number of structural groups (Table 14-12). Between 1954 and 1996, the number of structural groups increased on all treatments burnt at different frequencies.

Generally, treatments that burn less intensely (February and December) have a higher number of structural groups than treatments that burn more intensely (August and October). The structural classification comprises single-stem and multi-stem basal size classes and height classes, and the February and December treatments had more single stem individuals relative to multi-stem individuals than the August and October treatments. This partly explains why the February and December treatments have a higher number of structural groups than the August and October treatments. Furthermore, top kill of woody plants is higher on the treatments that burn more intensely (August and October) than on plots that burn less intensely (February and December). The result is that proportionately more woody plants are burnt back and coppice from the base on the August and October treatments than on the February and December treatments.

6.2.2.4.10 Differences in structural richness between plots burnt at different times of the year

In 1954, the rank order of the fire timing treatments from highest to lowest structural richness in 1954 was Control (0.415), October (0.391), February (0.336), December (0.322), April (0.330), and August (0.303) (Table 13-8). In 1954, the structural richness was significantly different between the treatments to be burnt at different times of the year ($p = 0.015$) (Table 6-7). Tukey Studentized post hoc analyses show that the structural richness was significantly lower on the August treatment than on the Control (0.039) and October (0.051) treatments in 1954 (Table 14-10). In 1996, the rank order of the timing treatments from highest to lowest structural richness was February (0.251), December (0.250), April (0.241), October (0.239), Control (0.237), and August (0.237) (Table 13-9). In 1996, the structural richness was not significantly different

between the treatments burnt at different times of the year (Table 6-7). Between 1954 and 1996, the structural richness decreased on all treatments burnt at different frequencies.

Generally, the structural richness in 1996 (ranging from 0.237 to 0.251) was very similar between the treatments that were burnt at different times of the year between 1954 and 1996.

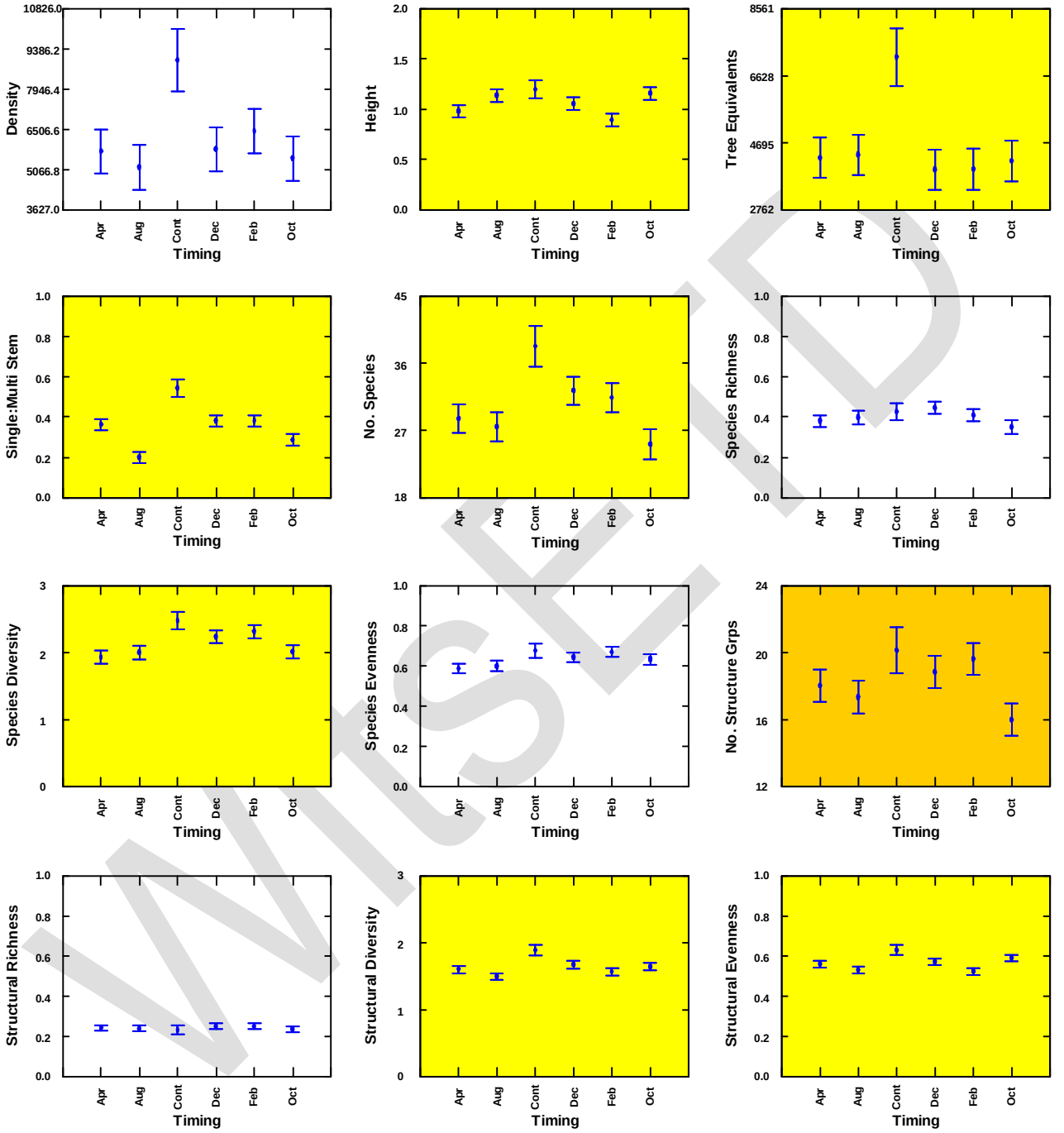


Figure 6-19: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing for the treatment effects between plots burnt at different times of the year taking into account the state of the plots before the treatments began The August annual treatments were excluded from these analyses. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

WISER

6.2.2.4.11 Differences in structural diversity between plots burnt at different times of the year

In 1954, the structural diversity was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest structural diversity in 1954 was Control (1.850), April (1.774), October (1.735), August (1.728), February (1.654), and December (1.591) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest structural diversity was Control (1.918), October (1.645), December (1.644), April (1.615), February (1.555), and August (1.496) (Table 13-9). In 1996, the structural diversity was significantly different between the treatments burnt at different times of the year (ANOVA: p = 0.003, ANCOVA: p = 0.006) (Table 6-7). Tukey Studentized post hoc analyses show structural diversity was significantly higher on the Control treatments than on the February (ANOVA: p = 0.006, ANCOVA: p = 0.023), April (ANOVA: p = 0.032, ANCOVA: p = 0.044), August (ANOVA: p = 0.001, ANCOVA: p = 0.002), October (ANOVA: p = 0.068), and December (ANOVA: p = 0.066) treatments in 1996 (Table 14-11, and Table 14-12). Between 1954 and 1996, the structural diversity decreased on the February, April, and August treatments and increased on the December and Control treatments.

6.2.2.4.12 Differences in structural evenness between plots burnt at different times of the year

In 1954, the structural evenness was not significantly different between the treatments to be burnt at different times of the year (Table 6-7). The rank order of the fire timing treatments from highest to lowest structural evenness in 1954 was August (0.669), Control (0.666), April (0.661), October (0.629), February (0.618), and December (0.609) (Table 13-8). In 1996, the rank order of the timing treatments from highest to lowest structural evenness was Control (0.631), October (0.589), December (0.568), April (0.563), August (0.533), and February (0.522) (Table 13-9). In 1996, the structural evenness was significantly different between the treatments burnt at different times of the year (ANOVA: p = 0.005, ANCOVA: p = 0.006) (Table 6-7). Tukey Studentized post hoc analyses show structural evenness was significantly higher on the Control treatments than on the February (ANOVA: p = 0.007, ANCOVA: p = 0.012) and August (ANOVA: p = 0.019, ANCOVA: p = 0.020) treatments in 1996 (Table 14-11, and Table 14-12). Post hoc analyses also show that the structural evenness on the October treatment was significantly higher than on the February treatment (ANCOVA: p = 0.086). Between 1954 and 1996, the structural evenness increased on all the treatments burnt at different times of the year.

6.2.2.5 Testing for differences in the woody vegetation density, structure and composition between the Pretoriuskop EBPs burnt at different frequencies and at different times of the year (i.e. between the EBP treatments)

The results of the Analyses of Variance and Analyses of Covariance analyses testing for differences in the woody vegetation between the fire treatments on the Pretoriuskop EBPs are presented in Table 6-8 (p. 100), Figure 6-21 (p. 103), Figure 6-22 (p. 107), and Figure 6-23 (p. 111). Results of the post hoc analyses performed where significant differences were found between the fire treatments are presented in Table 14-13 (p. 250), Table 14-14 (p. 251), and Table 14-15 (p. 253). Summaries of the 1954 and 1996 data used in these analyses are presented in Appendix 5 in Table 13-10 (p. 231), and Table 13-11 (p. 233) respectively. Descriptions of the treatment codes are presented in Table 3-1 (p. 15).

The mean and standard error of the means from the ANOVA and ANCOVA analyses on the 1996 data are similar when there was little covariance in the data between the EBP treatments in 1954 and 1996 (Figure 6-22 and Figure 6-23). At times, the standard error of the means from the ANOVA and ANCOVA analyses on the 1996 data are not similar showing that there was covariance in the data between the EBP treatments in 1954 and 1996 (Figure 6-22 and Figure 6-23). For example, the rank order from tallest to shortest mean treatment plant height was similar between the ANOVA and ANCOVA analyses on the 1996 data, and the rank order from most dense to least dense treatment was not similar between the ANOVA and ANCOVA analyses on the 1996.

WITS ETD

6.2.2.5.1 Differences in woody plant density between plots burnt at different frequencies and at different times of the year

In 1954 and 1996, the woody plant density was not significantly different between the different EBP treatments in the Pretoriuskop region (Table 6-8). The treatment with the highest woody plant density (plants/Ha) in 1954, was Feb3 (2540.750) and the Oct3 (1317.000) treatment had the lowest woody plant density (Figure 6-21 and Table 13-10). In 1996, the Con0 treatment had the highest woody plant density (8696.000) and the Dec3 treatment had the lowest woody plant density (4912.750) (Figure 6-22and Table 13-11). Between 1954 and 1996, the woody plant density increased on all the Pretoriuskop EBP treatments.

The rank order of the treatments based on the density of the woody vegetation per treatment was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results from the ANOVA and ANCOVA analyses on the density of the woody vegetation in 1996 differed in the relative placement of the Aug3 and Oct3 treatments. In the ANOVA analysis, the Aug3 treatment had a higher density than the Aug2 treatment and the Oct3 treatment had a higher density than the Oct2 treatment (Figure 6-22). In the ANCOVA analysis, which accounts for the covariance between the 1954 and 1996 data, the Aug2 treatment had a higher density than the Aug3 treatment, and the Oct2 treatment had a higher density than the Oct3 treatment (Figure 6-23). Looking at the ANCOVA analyses, the density on the Biennial treatments was lower than on the Triennial treatments at the same time of the year on the April, August, and October treatments. The density on the Biennial treatments was higher than the Triennial treatments at the same time of the year for the February and December treatments (Figure 6-23). The Feb2 (7937.500) and Dec2 (6520.750) treatments had the second and third highest woody plant density in 1996 (Figure 6-22 and Table 13-11).

Generally, there is a large difference in the density of the woody vegetation (plants/Ha) between the biennial and triennial treatments burnt during the wet season and towards the end of the wet season in February (2344.500), April (904.750), and December (1608.000). The difference in the woody vegetation density between treatments burnt during and towards the end of the dry season in August (99.500) and October (495.250) is smaller.

6.2.2.5.2 Differences in the mean woody plant height between plots burnt at different frequencies and at different times of the year

In 1954, the mean woody plant height was not significantly different between the EBP treatments in the Pretoriuskop region (Table 6-8). The mean woody plant height was highest on the Feb2 treatment (1.279m) and lowest on the Aug3 treatment (0.882m) in 1954 (Table 13-10). In 1996, the treatment (1.202m) had the highest mean woody plant height and the Feb2 treatment (0.846m) had the lowest mean woody plant height (Table 13-11). The mean woody plant height was significantly different between the EBP treatments in 1996 (ANOVA: $p = 0.015$, ANCOVA: $p = 0.015$) (Table 6-8). Tukey Studentized post hoc analyses do not show where the differences lie (Table 14-14 and Table 14-15). Between 1954 and 1996, the mean woody plant height decreased on the Apr2, Apr3, Aug1, Dec2, Feb2, and Feb3 treatments, and increased on the Aug2, Aug3, Control, Dec3, Oct2, and Oct3 treatments.

In 1996, the mean woody plant height on the Biennial treatments was lower than on the Triennial treatments at the same time of the year on the February, October, and December treatments (Figure 6-22 and Figure 6-23). The mean woody plant height on the Biennial treatments was higher than the Triennial treatments at the same time of the year for the April and August treatments.

6.2.2.5.3 Differences in the number of tree equivalents between plots burnt at different frequencies and at different times of the year

In 1954 and 1996, the number of tree equivalents was not significantly different between the EBP treatments in the Pretoriuskop region (Table 6-8). The number of tree equivalents (tree equivalents/Ha) was highest on the Feb3 treatment (1982.500) and lowest on the Oct3 treatment (1068.500) in 1954 (Figure 6-21 and Table 13-10). In 1996, the number of tree equivalents was highest on the Con0 treatment (6963.250) and lowest

WISETP

on the Aug1 treatment (3051.500) (Figure 6-22, Figure 6-23 and Table 13-11). Between 1954 and 1996, the number of tree equivalents increased on all the Pretoriuskop EBP treatments.

Table 6-8: Results of the ANOVA and ANCOVA analyses on the vegetation indices calculated to test the combined effects of timing and frequency of the fire treatments.

						Taxonomic diversity				Structural diversity			
Year	Statistic	Density	Mean height	Tree equivalents	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
1954 (ANOVA)	df	11	11	11	11	11	11	11	11	11	11	11	11
	df error	36	36	36	36	36	36	36	36	36	36	36	36
	F-ratio	0.812	0.895	0.833	5.212	1.056	2.851	0.916	1.161	1.701	2.691	1.363	0.746
	p value	0.628	0.554	0.609	0.001	0.422	0.009	0.536	0.347	0.113	0.012	0.232	0.688
1996 (ANOVA)	df	11	11	11	11	11	11	11	11	11	11	11	11
	df error	36	36	36	36	36	36	36	36	36	36	36	36
	F-ratio	1.081	2.594	1.160	9.003	2.207	0.756	1.340	0.860	1.026	0.812	5.916	7.021
	p value	0.403	0.015	0.348	0.001	0.036	0.679	0.243	0.585	0.445	0.628	0.001	0.001
1996:1954 (ANCOVA)	df	11	11	11	11	11	11	11	11	11	11	11	11
	df error	35	35	35	35	35	35	35	35	35	35	35	35
	F-ratio	1.386	2.603	1.645	8.974	2.570	0.750	2.138	1.521	1.839	1.021	6.604	6.915
	p value	0.223	0.015	0.129	0.001	0.017	0.685	0.043	0.168	0.084	0.449	0.001	0.001

Note: The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

The rank order of the treatments based the mean number of tree equivalents per treatment was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results from the ANOVA and ANCOVA analyses on the number of tree equivalents in 1996 differed in the relative placement of the Dec3 and Oct3 treatments. In the ANOVA analysis, the Dec3 treatment had a higher number of tree equivalents than the Dec2 treatment, and the Oct3 treatment had a lower number of tree equivalents than the Feb2 treatment (Figure 6-22). In the ANCOVA analysis, which accounts for the covariance between the 1954 and 1996 data, the Dec3 treatment had a lower number of tree equivalents than the Dec2 treatment, and the Oct3 treatment had a higher number of tree equivalents than the Feb2 treatment (Figure 6-23). Looking at the ANCOVA analyses, the number of tree equivalents on the Biennial treatments was lower than on the Triennial treatments at the same time of the year on the April, August, and October treatments in 1996. The number of tree equivalents on the Biennial treatments was higher than the Triennial treatments at the same time of the year for the February and December treatments in 1996.

6.2.2.5.4 Differences in the single-stem to multi-stem index between plots burnt at different frequencies and at different times of the year

In 1954, the single-stem to multi-stem index was highest on the Dec2 treatment (0.774) lowest on the Feb3 treatment (0.289) (Figure 6-21 and Table 13-10). The single-stem to multi-stem index was significantly different between the Pretoriuskop EBP treatments in 1954 (p = 0.001) (Table 6-8). Tukey Studentized post hoc analyses show the Apr2 treatment had a significantly higher single-stem to multi-stem index than the Feb3 (p = 0.049) and Oct3 (p = 0.057) treatments in 1954 (Table 14-13). The Aug1 treatment had a significantly higher single-stem to multi-stem index than the Dec3 (p = 0.095), Feb3 (p = 0.046), and Oct3 (p = 0.053) treatments in 1954. The single-stem to multi-stem index on the Aug2 was significantly higher than on the Feb3 treatment (p = 0.093) in 1954. The single-stem to multi-stem index on the Con0 treatment was

WITS ETD

significantly higher than on the Apr3 (p = 0.068), Dec3 (p = 0.053), Feb3 (p = 0.024), and Oct3 (p = 0.029) treatments in 1954. The Dec2 treatment had a significantly higher single-stem to multi-stem index than the Apr3 (p = 0.033), Dec3 (p = 0.025), Feb3 (p = 0.011), and the Oct3 (p = 0.013) treatments in 1954. In 1996, the single-stem to multi-stem index was highest on the Con0 treatment (0.539) and lowest on the Aug1 treatment (0.126) (Figure 6-22, Figure 6-23 and Table 13-11). The single-stem to multi-stem index was significantly different between treatments in 1996 (ANOVA: p = 0.036, ANCOVA: p = 0.017) (Table 6-8). Tukey Studentized post hoc analyses show that in 1996 the Aug1 treatment had a significantly lower single-stem to multi-stem index than the Apr2 (ANOVA: p = 0.003, ANCOVA: p = 0.003), Apr3 (ANOVA: p = 0.007, ANCOVA: p = 0.010), Dec2 (ANOVA: p = 0.003, ANCOVA: p = 0.004), Dec3 (ANOVA: p = 0.001, ANCOVA: p = 0.008), Feb2 (ANOVA: p = 0.020, ANCOVA: p = 0.017), and Feb3 (ANOVA: p = 0.001, ANCOVA: p = 0.001) treatments (Table 14-14 and Table 14-15). The Aug2 treatment had a significantly lower single-stem to multi-stem index than the Apr2 (ANOVA: p = 0.013, ANCOVA: p = 0.016), Apr3 (ANOVA: p = 0.027, ANCOVA: p = 0.029), Dec2 (ANOVA: p = 0.012, ANCOVA: p = 0.020), Dec3 (ANOVA: p = 0.006, ANCOVA: p = 0.008), Feb2 (ANOVA: p = 0.071, ANCOVA: p = 0.064), and Feb3 (ANOVA: p = 0.001, ANCOVA: p = 0.001) treatments in 1996. The Aug3 treatment had a significantly lower single-stem to multi-stem index than the Feb3 treatment (ANOVA: p = 0.050, ANCOVA: p = 0.043) in 1996. The Con0 treatment had a significantly higher single-stem to multi-stem index than the Apr3 (ANOVA: p = 0.066), Aug1 (ANOVA: p = 0.001, ANCOVA: p = 0.001), Aug2 (ANOVA: p = 0.001, ANCOVA: p = 0.001), Aug3 (ANOVA: p = 0.001, ANCOVA: p = 0.003), Feb2 (ANOVA: p = 0.025, ANCOVA: p = 0.046), Oct2 (ANOVA: p = 0.002, ANCOVA: p = 0.003), and Oct3 (ANOVA: p = 0.003, ANCOVA: p = 0.063) treatments in 1996. Between 1954 and 1996, the single-stem to multi-stem index decreased on the Apr2, Aug1, Aug2, Aug3, Con0, Dec2, Feb2, Oct2, and Oct3 treatments and increased on the Apr3, Dec3, and Feb3 treatments.

The rank order of the treatments based the single-stem to multi-stem index per treatment was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results from the ANOVA and ANCOVA analyses on the single-stem to multi-stem index in 1996 differed in the relative placement of the Apr3 treatment. In the ANOVA analyses, the Apr3 treatment had a lower single-stem to multi-stem index than the Apr2 treatment (Figure 6-22). In the ANCOVA analyses, the Apr3 treatment had a higher single-stem to multi-stem index than the Apr2 treatment (Figure 6-23). Looking at the ANCOVA analyses, the single-stem to multi-stem index was lower on the biennial treatments than on the triennial treatments at the same time of the year for all the treatments.

Generally, regarding the frequency of the treatments, the more frequent the fires the less single-stem individuals relative to multi-stem individuals there tend to be (i.e. the single-stem to multi-stem index decreases). Regarding the timing of the treatments, the August treatments have the lowest number of single-stem individuals relative to multi-stem individuals followed by the October treatments having the second lowest single-stem to multi-stem index. The February, April, and December treatments have similar number of single-stem individuals relative to multi-stem individuals and the Control treatment has the highest number of single-stem individuals relative to multi-stem individuals.

6.2.2.5.5 Differences in the number of species between plots burnt at different frequencies and at different times of the year

In 1954, the number of species was not significantly different between the EBP treatments in the Pretoriuskop region (Table 6-8). In 1954, the Apr3 treatment (24.500) had the highest mean number of species and the Aug3, Aug2, and Dec2 treatments (16.250) had the lowest mean number of species (Figure 6-21 and Table 13-10). In 1996, the Con0 treatment (37.500) had the highest mean number of species and the Apr2 treatment (24.500) had the lowest mean number of species (Figure 6-22 and Table 13-11). The number of species was significantly different between treatments in 1996 (ANOVA: p = 0.036, ANCOVA: p = 0.017) (Table 6-8). Tukey Studentized post hoc analyses show that Con0 treatment had a significantly higher number of species than the Apr2 (ANOVA: p = 0.080, ANCOVA: p = 0.045), Oct2 (ANCOVA: p = 0.075), and Oct3 (ANCOVA: p = 0.034) treatments (Table 14-14 and Table 14-15). Between 1954 and 1996, the number of species increased on all the Pretoriuskop EBP treatments.

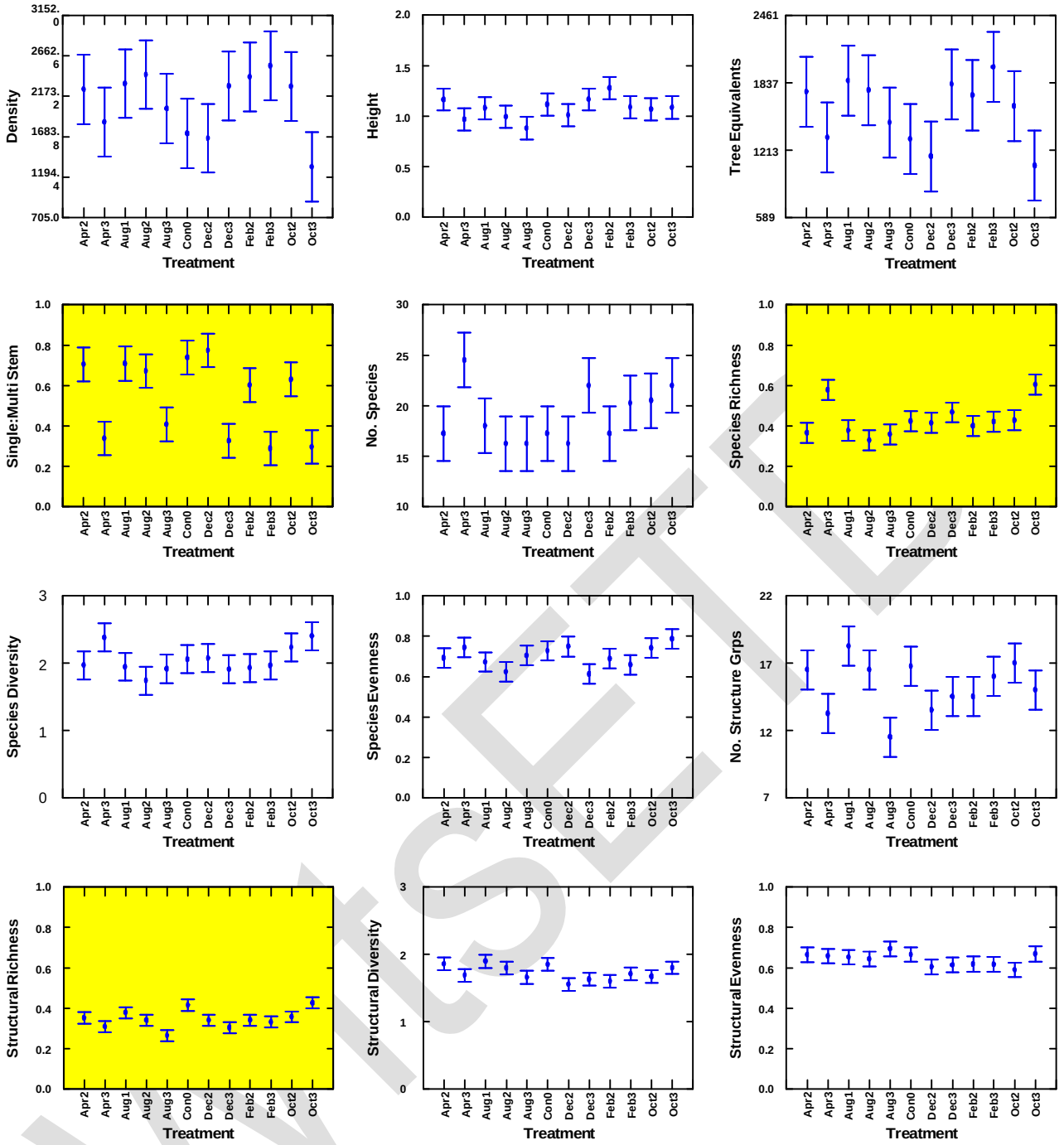


Figure 6-20: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954 data testing for pre-treatment differences between the plots assigned the different treatments. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

The rank order of the treatments based on the number of species was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results from the ANOVA and ANCOVA analyses on the number of species in 1996 differed in the relative placement of the Apr3 and Oct3 treatments. In the ANOVA analysis, the Apr3 treatment had the second highest number of species and the Oct3 treatment had the second lowest number of species (Figure 6-22). In the ANCOVA analysis, the Apr3 treatment had the fourth highest number of species and the Oct3 treatment had the lowest number of species (Figure 6-23). Looking at the ANCOVA analysis, the number of species on the biennial treatments was higher than the triennial treatments at the same time of the year for the February, October, and December treatments in 1996. The number of species on the august annual and biennial treatments was the

WISE

same, and the number of species on the April biennial treatment was lower than the April triennial treatment in 1996.

Generally, regarding the timing of the treatments, the dry season treatments in August and October have the lower number of species than the wet season treatments in February and December. The April treatment is unusual because the Apr3 treatment is grouped with the wet season treatments and the Apr2 treatment is grouped with the dry season treatments. Regarding the frequency of the treatments, biennial treatments tend to have a higher number of species than triennial treatments excepting for the April treatments. The no burn (Con0) treatment had the highest number of species.

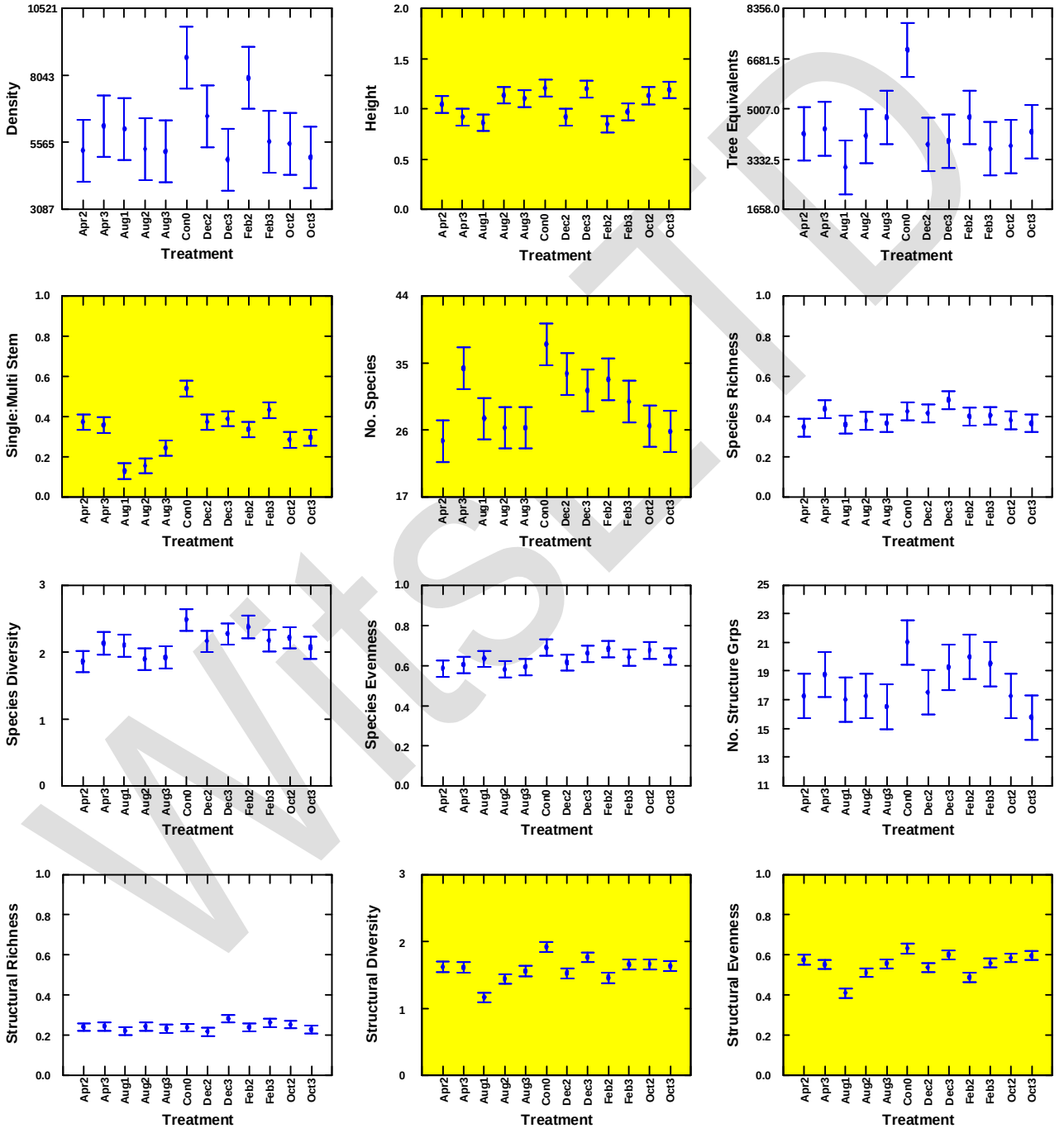


Figure 6-21: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1996 data testing the effect of the different treatments assigned to plots. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

WfSD

6.2.2.5.6 Differences in species richness between plots burnt at different frequencies and at different times of the year

In 1954, the species richness was highest on the Oct3 treatment (0.605) and lowest on the Aug2 treatment (0.329) (Table 13-10). The species richness was significantly different between the Pretoriuskop EBP treatments in 1954 (p = 0.009) (Table 6-8). Tukey Studentized post hoc analyses show that the species richness on the Apr3 treatment was significantly higher than on the Aug2 treatment (p = 0.043) in 1954 (Table 14-13). Post hoc analyses also show that the Oct3 treatment had a significantly higher species richness than the Apr2 (p = 0.062), Aug1 (p = 0.091), Aug2 (p = 0.016), and Aug3 (p = 0.049) treatments in 1954. In 1996, the species richness was not significantly different between the Pretoriuskop EBP treatments (Table 6-8). In 1996, the Dec3 treatment (0.481) had the highest species richness and the Apr2 treatment (0.346) had the lowest species richness (Table 13-11). Between 1954 and 1996, the species richness decreased on the Apr2, Apr3, Aug1, Feb2, Feb3, Oct2, and Oct3 treatments and increased on the Aug2, Aug3, Con0, Dec2, and Dec3 treatments.

The rank order of the treatments based on the species richness was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results of the ANOVA and ANCOVA analyses on the species richness in 1996 differed in the relative placement of the Apr3 and Oct3 treatments. In the ANOVA analysis, the Apr3 treatment had the second highest species richness and the Oct3 treatment had the third lowest species richness (Figure 6-22). In the ANCOVA analysis, the Apr3 treatment had the seventh highest species richness and the Oct3 treatment had the lowest species richness (Figure 6-23). Looking at the ANCOVA analysis, the species richness on the biennial treatments was higher than the triennial treatments at the same time of the year for the dry season treatments in August and October in 1996. The species richness in 1996, on the biennial treatments was lower than the triennial treatments at the same time of the year for the wet season treatments in April and December, and the species richness on the February biennial and triennial treatments was similar.

Generally, fires burnt biennially in the dry season tend to have higher species richness than fires burnt triennially in the dry season. Fires burnt biennially in the wet season tend to have lower species richness than fires burnt triennially in the dry season. The no burn (Con0) treatment had the third highest species richness after the Apr3 and Dec3 treatments.

6.2.2.5.7 Differences in species diversity between plots burnt at different frequencies and at different times of the year

In 1954, the species diversity was not significantly different between the Pretoriuskop EBP treatments (Table 6-8). The Oct3 treatment (2.402) had the highest species diversity in 1954, and the Aug2 treatment (1.740) had the lowest species diversity (Table 13-10). In 1996, the Con0 treatment (2.482) had the highest species diversity and the Apr2 treatment (1.855) had the lowest species diversity (Table 13-11). The species diversity was significantly different between the EBP treatments in the Pretoriuskop region (ANCOVA: p = 0.043) (Table 6-8). Tukey Studentized post hoc analyses do not show where the significant differences lie (Table 14-15). Between 1954 and 1996, the species diversity decreased on the Apr2, Apr3, Oct2, and 0ct3 treatments, and increased on the Aug1, Aug2, Aug3, Con0, Dec2, Dec3, Feb2, and Feb3 treatments.

The rank order of the treatments based on species diversity was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results of the ANOVA and ANCOVA analyses on the species diversity in 1996 differed in the relative placement of the Apr3, Aug2, Oct2, and Oct3 treatments. In the ANOVA analysis, the species diversity on the Apr3 treatment was higher than the Aug1 treatment, the species diversity on the Aug2 treatment was lower than the Aug3 treatment, the species diversity on the Oct2 treatment was higher than the Feb3 treatment, and the Oct3 treatment had the fourth lowest species diversity. In the ANCOVA analysis, the species diversity on the Apr3 treatment was lower than the Aug1 treatment, the species diversity on the Aug2 treatment was higher than the Aug3 treatment, the species diversity on the Oct2 treatment was lower than the Feb3 treatment, and the Oct3 treatment had the lowest species diversity. Looking at the ANCOVA analysis, the species diversity on the biennial

treatments is higher than on the triennial treatments at the same time of the year on the February, August, and October treatments in 1996. The species diversity in 1996, on the biennial treatments was lower than on the triennial treatments at the same time of the year on the April and December treatments.

Generally, treatments burnt in the wet season (February and December) tend to have higher species diversity than treatments burnt in the dry season (August and October). The April treatments tend to have the lowest species diversity and the no burn (Con0) treatments have the highest species diversity.

6.2.2.5.8 Differences in species evenness between plots burnt at different frequencies and at different times of the year

In 1954 and 1996, the species evenness was not significantly different between the Pretoriuskop EBP treatments (Table 6-8). The Oct3 treatment (0.786) had the highest species evenness in 1954, and the Dec3 treatment (0.613) had the lowest species evenness (Table 13-10). In 1996, the Con0 treatment (0.688) had the highest species evenness and the Aug2 treatment (0.579) had the second lowest species evenness (Table 13-11). Between 1954 and 1996, the species evenness decreased on the Apr2, Apr3, Aug1, Aug2, Aug3, Con0, Dec2, Feb2, Feb3, Oct2, and Oct3 treatment, and the species evenness increased on the Dec3 treatment.

The rank order of the treatments based on the species evenness was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results of the ANOVA and ANCOVA analyses on the species evenness in the 1996 differed in the relative placement of the Apr3, Aug2, Dec2, Dec3, Feb2, and Feb3 treatments. In the ANOVA analysis on the species evenness, the Apr3 treatment was higher than the Apr2 treatment, the Aug2 treatment was lower than the Aug3 treatment, the Dec2 treatment was higher than the Aug3 treatment, the Dec3 treatment was lower than on the Dec2 treatment, the Feb2 treatment was the same as the Oct2 treatment, and the Feb3 treatment was lower than the Oct2 treatment. In the ANCOVA analysis on the species evenness, the Apr3 treatment was lower than the Apr2 treatment, the Aug2 treatment was higher than the Aug3 treatment, the Dec2 treatment was the same as the Aug3 treatment, the Dec3 treatment was higher than on the Dec2 treatment, the Feb2 treatment was higher than the Oct2 treatment, and the Feb3 treatment was the same as Oct2 treatment. Looking at the ANCOVA analysis, the species evenness in 1996 on the biennial treatments is higher than the triennial treatments at the same time of the year on the February, April, August, and October treatments. The species evenness in 1996 was lower on the biennial treatment in December than the triennial treatment in December.

6.2.2.5.9 Differences in the number of structural groups between plots burnt at different frequencies and at different times of the year

In 1954, the number of structural groups was not significantly different between the Pretoriuskop EBP treatments (Table 6-8). The Aug1 treatment (18.250) had the highest mean number of structural groups in 1954, and the Aug3 treatment (11.500) had the lowest mean number of structural groups (Table 13-10). In 1996, the Con0 treatment (21.000) had the highest mean number of structural groups, and the Oct3 treatment (15.750) had lowest mean number of structural groups (Table 13-11). The number of structural groups was significantly different between the Pretoriuskop EBP treatment in 1996 (ANCOVA: $p = 0.084$) (Table 6-8). Tukey Studentized post hoc analyses do not show where the significant differences lie (Table 14-15). Between 1954 and 1996, the number of structural groups increased on the Apr2, Apr3, Aug2, Aug3, Con0, Dec2, Dec3, Feb2, Feb3, Oct2, and Oct3 treatments and decreased on the Aug1 treatment.

The rank order of the treatments based on the number of structural groups was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results of the ANOVA and ANCOVA analyses on the number of structural groups in 1996 differed in the relative placement of the Apr3, Aug1, Aug3, Feb2, and Oct3 treatments. In the ANOVA analysis on the number of structural groups, the Apr3 treatment had the fifth highest number of structural groups, the Aug1 treatment had the third lowest number of structural groups, the Aug3 treatment was lower than the Aug2 treatment, the Feb2 treatment was lower than the Con0 treatment, and the Oct3 treatment had the lowest number of structural groups. In the

ANCOVA analysis on the number of structural groups, the Apr3 treatment had the third highest number of structural groups, the Aug1 treatment had the lowest number of structural groups, the Aug3 treatment was higher than the Aug2 treatment, the Feb2 treatment was higher than the Con0 treatment, and the Oct3 treatment had the second lowest number of structural groups. Looking at the ANCOVA analysis, the biennial treatment had lower number of structural groups in 1996 than the triennial treatments at the same time of the year on the April, August, and December treatments. The number of structural groups in 1996 was higher on the biennial treatments than on the triennial treatments at the same time of the year on the October and December treatments.

Generally, the treatments burnt in the dry season (August and October) tend to have a lower number of structural groups than treatments burnt in the wet season (February and December). The no burn (Con0) treatment had the highest number of structural groups in 1996.

6.2.2.5.10 Differences in structural richness between plots burnt at different frequencies and at different times of the year

In 1954, the structural richness was highest on the Oct3 treatment (0.426) and lowest on the Aug3 treatment (0.265) (Table 13-10 and Figure 6-21). The structural richness was significantly different between the Pretoriuskop EBP treatments in 1954 ($p = 0.012$) (Table 6-8). Tukey Studentized post hoc analyses show that the Aug3 treatment had a significantly lower structural richness than the Con0 (0.020) and Oct3 (0.009) treatments (Table 14-13). In 1996, the structural richness was not significantly different between the Pretoriuskop EBP treatments (Table 6-8). The Dec3 treatment (0.282) had the highest structural richness in 1996 and the Dec2 treatment (0.218) had the lowest (Table 13-11 and Figure 6-22). Between 1954 and 1996, the structural richness decreased on all Pretoriuskop EBP treatments.

The rank order of the treatments based on the structural richness was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results of the ANOVA and ANCOVA analyses on the structural richness in 1996 differed in the relative placement of the Aug3 treatment. In the ANOVA analysis, the structural richness on the Aug3 treatment was lower than on the Aug2 treatment. In the ANCOVA analysis, the structural richness on the Aug3 treatment was higher than on the Aug2 treatment. Looking at the ANCOVA analysis, the biennial treatments had higher structural richness than the triennial treatments at the same time of the year on the October treatments (Figure 6-23). The structural richness was lower on the biennial treatments in 1996 than on the triennial treatments at the same time of the year on the February, April, August, and December treatments. The no burn (Con0) treatment had the fifth lowest structural richness in 1996.

Pattern in the structural richness between the different treatments is subtle, generally looking at the ANCOVA analysis the structural richness increases as the inter-fire period increases from 1 year to 3 years at the same time of the year. However, this trend does not continue as the inter-fire period increases beyond 3 years, because the structural richness decreases at some point between 3 years and 42 years.

6.2.2.5.11 Differences in structural diversity between plots burnt at different frequencies and at different times of the year

In 1954, the structural diversity between the Pretoriuskop EBP treatments was not significantly different (Table 6-8). The structural diversity was highest on the Aug1 treatment (1.897) and lowest on the Dec2 treatment (1.554) in 1954 (Table 13-10 and Figure 6-21). In 1996, the structural diversity was highest on the Con0 treatment (1.918) and lowest on the Aug1 treatment (1.162) (Table 13-11 and Figure 6-22). The structural diversity was significantly different between the Pretoriuskop treatments in 1996 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$) (Table 6-8). Tukey Studentized post hoc analyses show that the structural diversity on the Aug1 treatment was significantly lower than on the Apr2 (ANOVA: $p = 0.007$, ANCOVA: $p = 0.004$), Apr3 (ANOVA: $p = 0.009$, ANCOVA: $p = 0.002$), Aug3 (ANOVA: $p = 0.037$, ANCOVA: $p = 0.009$), Dec2 (ANOVA: $p = 0.066$, ANCOVA: $p = 0.015$), Dec3 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$), Feb2 (ANCOVA: $p = 0.007$), Feb3 (ANOVA: $p = 0.003$, ANCOVA: $p = 0.001$), Oct2 (ANOVA: $p = 0.003$, ANCOVA:

p = 0.001), and Oct3 (ANOVA: p = 0.005, ANCOVA: p = 0.002) treatments in 1996 (Table 14-14 and Table 14-15). Post hoc analyses show that the structural diversity on the Con0 treatment was significantly higher than the Aug1 (ANOVA: p = 0.001, ANCOVA: p = 0.001), Aug2 (ANOVA: p = 0.004, ANCOVA: p = 0.004), Aug3 (ANOVA: p = 0.063), Dec2 (ANOVA: p = 0.035), and Feb2 (ANOVA: p = 0.006, ANCOVA: p = 0.031) treatments in 1996. Post hoc analyses also show that the structural diversity on the Dec3 treatment was significantly higher than on the Aug2 treatment in 1996 (ANCOVA: p = 0.057). Between 1954 and 1996, the structural diversity decreased on the Apr2, Apr3, Aug1, Aug2, Aug3, Dec2, Feb2, Feb3, Oct2, and Oct3 treatments and increased on the Con0 and Dec3 treatments.

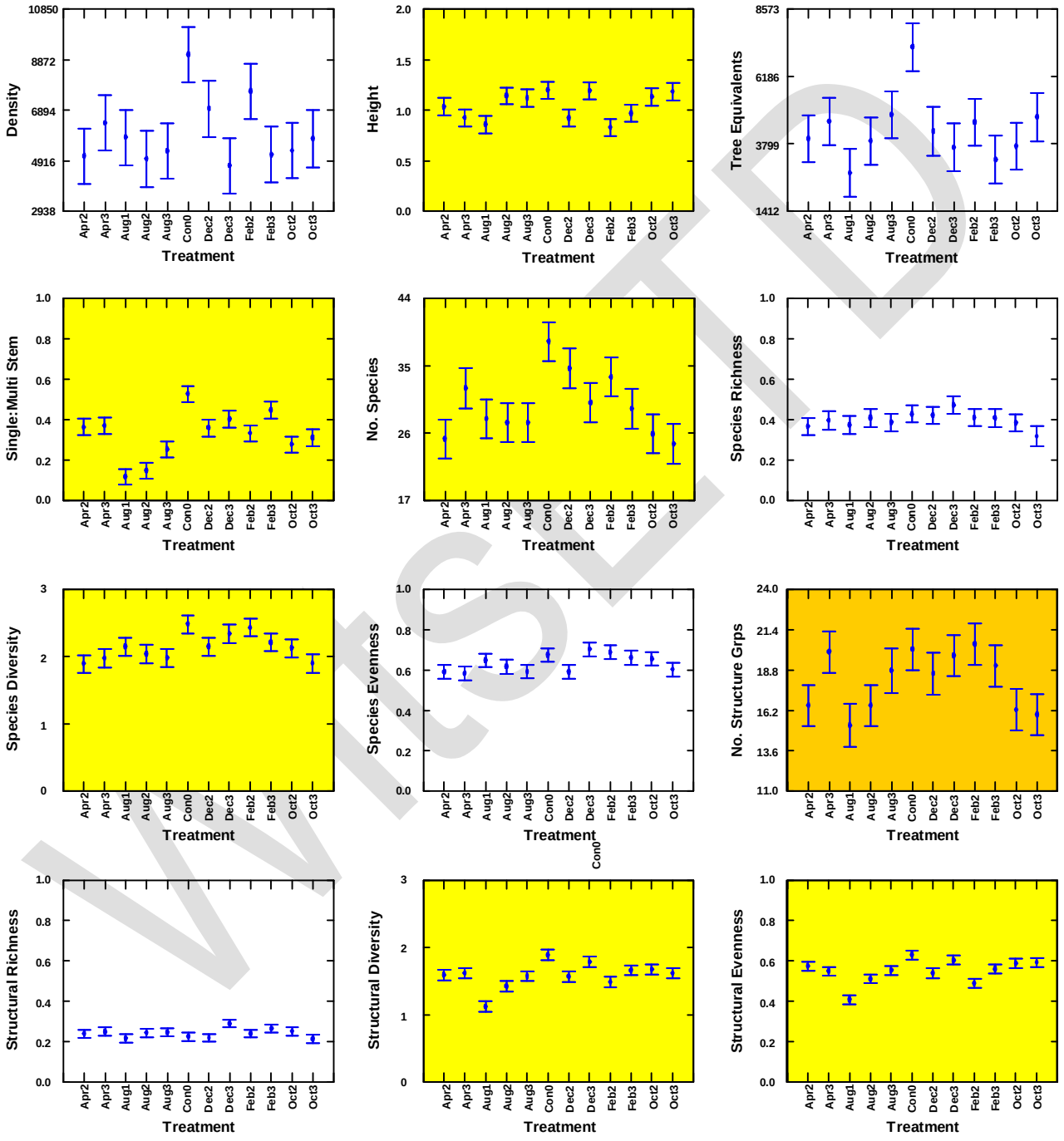


Figure 6-22: The least squares means and standard errors of the vegetation indices from the ANCOVA analyses on the 1996 data (with the 1954 data as covariates) testing the effect of the different treatments assigned to plots taking into account the state of the plots before the treatments began. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

WISE D

The rank order of the treatments based on the structural diversity was not the same for the ANOVA and ANCOVA analyses on the 1996 data (Figure 6-22 and Figure 6-23). The results of the ANOVA and ANCOVA analyses on the structural diversity in 1996 differ in the relative placement of the Apr3 and Oct2 treatments. In the ANOVA analysis, the structural diversity on the Apr3 treatment was lower than on the Apr2 treatment, and the structural diversity on the Oct2 treatment was lower than on the Feb3 treatment. In the ANCOVA analysis, the structural diversity on the Apr3 treatment was higher than on the Apr2 treatment, and the structural diversity on the Oct2 treatment was higher than on the Feb3 treatment. Looking at the ANCOVA analysis, the biennial treatments tend to have lower structural diversities than the triennial treatments at the same time of the year on the February, April, August and December treatments in 1996. The biennial October treatment had a higher structural diversity than the triennial October treatment in 1996. Generally regarding to the fire frequency, the structural diversity increases as the inter-fire period increases from 1 year to 3 years, and beyond 3 years at the same time of the year. Regarding the fire timing, the structural diversity is lowest on treatments burnt in August, December biennially, and February biennially, the structural diversity is highest on the treatments not burnt and those burnt in December triennially.

6.2.2.5.12 Differences in structural evenness between plots burnt at different frequencies and at different times of the year

In 1954, the structural evenness between the Pretoriuskop EBP treatments was not significantly different (Table 6-8). The structural evenness was highest on the Aug3 treatment (0.694) and was lowest on the Oct2 treatment (0.590) in 1954 (Table 13-10 and Figure 6-21). In 1996, the structural evenness was highest on the Con0 treatment (0.631) and lowest on the Aug1 treatment (0.409) (Table 13-11 and Figure 6-22). The structural evenness was significantly different between the Pretoriuskop EBP treatment in 1996 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$) (Table 6-8). Tukey Studentized post hoc analyses show that the structural evenness was significantly higher on the Con0 treatment than on the Aug1 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$), Aug2 (ANOVA: $p = 0.021$, ANCOVA: $p = 0.027$), and Feb2 (ANOVA: $p = 0.003$, ANCOVA: $p = 0.005$) treatments in 1996 (Table 14-14 and Table 14-15). Post hoc analyses show that the structural evenness was significantly lower on the Aug1 treatment than on the Apr2 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$), Apr3 (ANOVA: $p = 0.004$anc 0.005), Aug3 (ANOVA: $p = 0.002$, ANCOVA: $p = 0.004$), Dec2 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.012$), Dec3 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$), Feb3 (ANOVA: $p = 0.002$, ANCOVA: $p = 0.002$), Oct2 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$), and Oct3 (ANOVA: $p = 0.001$, ANCOVA: $p = 0.001$) treatment in 1996. Post hoc analyses also show that the Feb2 treatment had a significantly lower structural evenness than the Dec3 (ANOVA: $p = 0.039$, ANCOVA: $p = 0.040$) and Oct3 (ANOVA: $p = 0.062$, ANCOVA: $p = 0.096$) treatments in 1996. Between 1954 and 1996, the structural evenness decreased on all the Pretoriuskop EBP treatments.

The biennial treatments had a lower structural evenness than the triennial treatments at the same time of the year on the February, August, October and December treatments in 1996. The April biennial treatment had a higher structural evenness than the April triennial treatment in 1996.

Generally regarding to the fire frequency, the structural evenness increases as inter-fire period increases from 1 year to 3 years and beyond 3 years at the same time of the year. Regarding the fire timing, the structural evenness is lowest on treatments burnt in August, December biennially, and February biennially, and the structural evenness is highest on the treatments not burnt and those burnt in December triennially.

6.2.2.6 Testing for differences in the woody vegetation density, structure and composition on the Pretoriuskop EBP Control (no burn) plots between 1954, 1959 and 1996

The results from the Analyses of Variance used to test differences in the woody vegetation between the surveys on the Control treatments in 1954, 1959, and 1996 of the Pretoriuskop EBPs are presented in Table 6-9 (p. 109) and Figure 6-22 (p. 107). The results of the post hoc analyses performed where significant differences were found between the surveys are presented in Table 14-16 (p. 255), and summaries of the data used in these analyses are presented in Appendix 5 in Table 13-12 (p. 235).

WISER

6.2.2.6.1 Differences in woody plant density on the Control treatment between 1954, 1959, and 1996

The density of the woody vegetation (plants/Ha) was lowest in 1954 (1721.5), second highest in 1959 (2396.5), and highest in 1996 (8696.0) (Table 13-12 and Figure 6-22). There was a significant difference in the woody plant density on the Control treatment between 1954, 1959, and 1996 (p = 0.006) (Table 6-9). Tukey Studentized post hoc analyses show that the woody plant density was significantly higher in 1996 than in 1959 (p = 0.015) and 1954 (0.008) (Table 14-16).

The general trend is that as the post fire period increased, the woody plant density increased. The rate of increase in woody plant density (plants/Ha/year) between 1954 and 1959 was 135.0, the rate of increase in density between 1959 and 1996 was 170.3, and the overall rate of increase between 1954 and 1996 was 166.1.

6.2.2.6.2 Differences in the mean woody plant height on the Control treatment between 1954, 1959, and 1996

The mean woody plant height was lowest in 1959 (0.792m), second highest in 1954 (1.116m), and highest in 1996 (1.202m) (Table 13-12 and Figure 6-22). There was a significant difference in the mean woody plant height on the Control treatment between 1954, 1959, and 1996 (p = 0.008) (Table 6-9). Tukey Studentized post hoc analyses show that the mean woody plant height was significantly lower in 1959 than in 1954 (0.030) and 1996 (0.009) (Table 14-16).

The mean woody plant height decreased initially as the inter-fire period increased between 1954 and 1959, and then the mean woody plant height increased as the inter-fire period increased between 1959 and 1996. This result is consistent with the findings on the August treatments in which the mean woody plant height decreased as the inter-fire period increased from 1 year to 3 years, and then the mean woody plant height increased as the inter-fire period increased from 3 years to 42 years.

Table 6-9: Results of the ANOVA analyses on the vegetation indices calculated to test the effects of not burning between 1954 and 1996.

					Taxonomic diversity				Structural diversity			
Statistic	Density	Mean height	Tree equivalents	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
df	2	2	2	2	2	2	2	2	2	2	2	2
df error	9	9	9	9	9	9	9	9	9	9	9	9
F-ratio	9.602	8.644	18.29	5.12	12.562	0.044	2.282	0.292	3.237	6.066	0.372	0.272
p value	0.006	0.008	0.001	0.033	0.002	0.958	0.158	0.754	0.087	0.021	0.7	0.768

Note: The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

6.2.2.6.3 Differences in the number of tree equivalents on the Control treatment between 1954, 1959, and 1996

The number of tree equivalents (tree equivalents/Ha) was lowest in 1954 (1315.3), second highest in 1959 (1650.3), and highest in 1996 (6963.3) (Table 13-12 and Figure 6-22). There was a significant difference in the number of tree equivalents on the Control treatment between 1954, 1959, and 1996 (p = 0.001) (Table 6-9). Tukey Studentized post hoc analyses show that the number of tree equivalents was significantly higher in 1996 than in 1959 (p = 0.002) and 1954 (p = 0.001) (Table 14-16).

Generally, as the inter-fire period increased, the number of tree equivalents increased. The rate of increase in the number of tree equivalents (tree equivalents/Ha/year) between 1954 and 1959 was 67.0 and the rate of increase in tree equivalents between 1959 and 1996 was 143.6, which was almost double the rate of increase from 1954 to 1959. The overall rate of increase of number of tree equivalents between 1954 and 1996 was 134.5.

6.2.2.6.4 Differences in the single-stem to multi-stem index on the Control treatment between 1954, 1959, and 1996

The single-stem to multi-stem index was lowest in 1996 (0.539), second highest in 1959 (0.548), and highest in 1954 (0.738) (Table 13-12 and Figure 6-22). There was a significant difference in the single-stem to multi-stem index on the Control treatment between 1954, 1959, and 1996 ($p = 0.002$) (Table 6-9). Tukey Studentized post hoc analyses show that the single-stem to multi-stem index was significantly higher in 1954 than in 1959 ($p = 0.057$) and 1996 ($p = 0.047$) (Table 14-16).

Generally, as the inter-fire period increased, the single-stem to multi-stem index decreased. That is the number of single-stem individuals relative to multi-stem individuals decreased at first rapidly and then less so as the inter-fire period increased.

6.2.2.6.5 Differences in the number of species on the Control treatment between 1954, 1959, and 1996

The mean number of species was lowest in 1954 (17.3), second highest in 1959 (20.0), and highest in 1996 (37.5) (Table 13-12and Figure 6-22). There was a significantly difference in the number of species on the Control treatment between 1954, 1959, and 1996 ($p = 0.033$) (Table 6-9). Tukey Studentized post hoc analyses show that the number of species was significantly higher in 1996 than in 1959 ($p = 0.003$) and 1954 ($p = 0.008$) (Table 14-16).

Generally, as the inter-fire period increased, the number of species increased. The rate of increase in number of species (number of species/year) between 1954 and 1959 was 0.55, the rate of increase in number of species between 1959 and 1996 was 0.47, and the overall rate of increase in number of species between 1954 and 1996 was 0.48.

6.2.2.6.6 Differences in species richness on the Control treatment between 1954, 1959, and 1996

Species richness was lowest in 1959 (0.410), second highest in 1954 (0.423), and highest in 1996 (0.424) (Table 13-12and Figure 6-22). There was no significant difference in the species richness on the Control treatment between 1954, 1959, and 1996 (Table 6-9).

6.2.2.6.7 Differences in species diversity on the Control treatment between 1954, 1959, and 1996

Species diversity was lowest in 1954 (2.054), second highest in 1959 (2.058), and highest in 1996 (2.482) (Table 13-12and Figure 6-22). There was no significant difference in species diversity on the Control treatment between 1954, 1959 and 1996 (Table 6-9).

Generally, as the inter-fire period increased the species diversity increased. The rate of increase in species diversity on the Control treatment between 1954 and 1959 was 0.001, the rate of increase in species diversity between 1959 and 1996 was 0.011, and the overall rate of increase in species diversity between 1954 and 1996 was 0.010.

6.2.2.6.8 Differences in species evenness on the Control treatment between 1954, 1959, and 1996

Species evenness was lowest in 1996 (0.688), second highest in 1959 (0.696), and highest in 1954 (0.727) (Table 13-12and Figure 6-22). There was no significant difference in the species evenness on the Control treatment between 1954, 1959, and 1996 (Table 6-9). Generally, as the inter-fire period increased the species evenness decreased.

WITS ETD

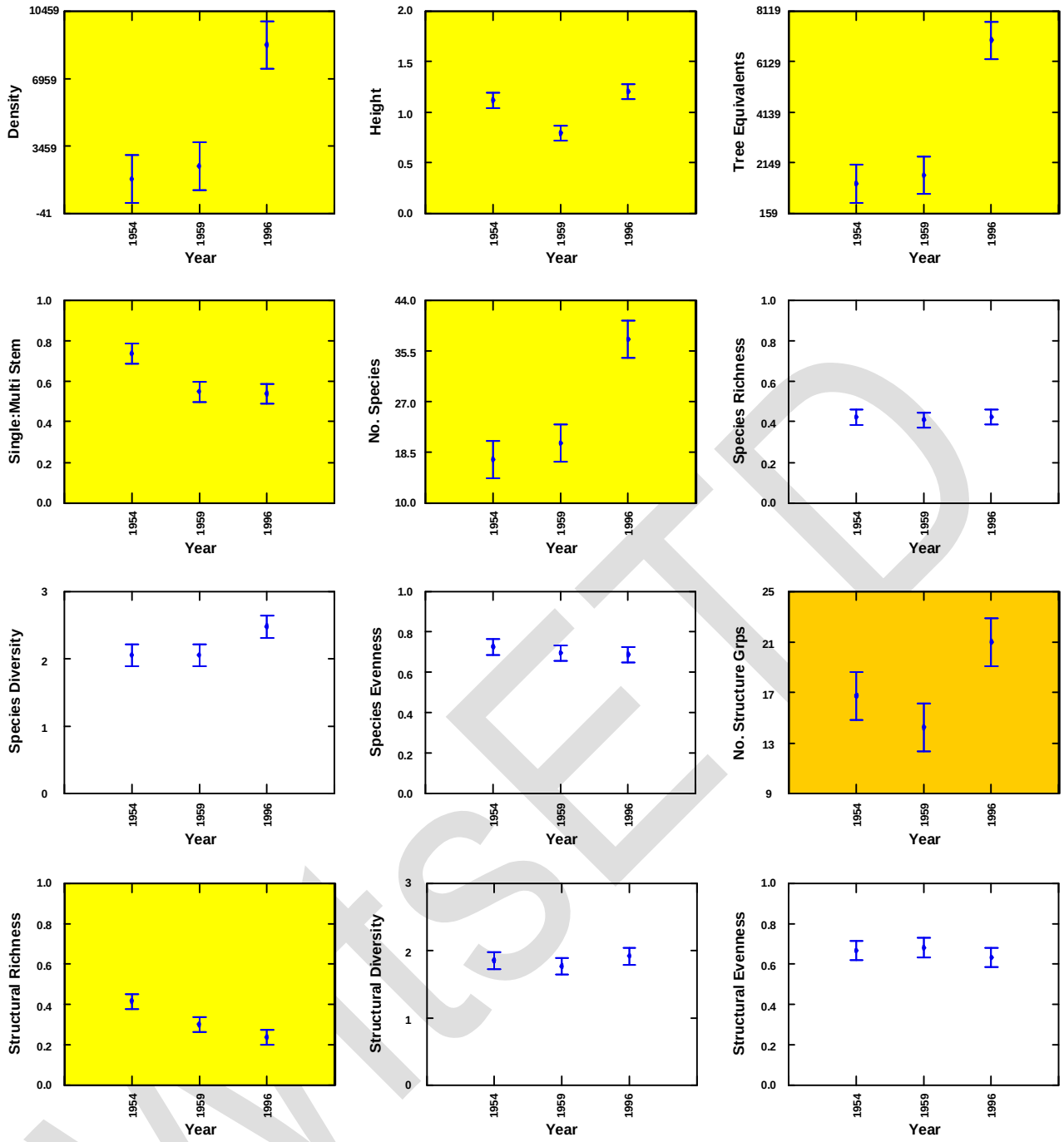


Figure 6-23: The least squares means and standard errors of the vegetation indices from the ANOVA analyses on the 1954, 1959, and 1996 control plot data testing for the effects of not burning. The colour coding shows the level of the test significance (yellow: α=0.05, and orange: α = 0.10).

WISER

6.2.2.6.9 Differences in the number of structural groups on the Control treatment between 1954, 1959, and 1996

The number of structural groups was lowest in 1959 (14.3), second highest in 1954 (16.8), and highest in 1996 (21.0) (Table 13-12and Figure 6-22). There was a significant difference in the number of structural groups on the Control treatment between 1954, 1959, and 1996 (p = 0.087) (Table 6-9). Tukey Studentized post hoc analyses show that the number of structural groups was significantly higher in 1996 than in 1959 (p = 0.077) (Table 14-16).

Generally, with the increase in inter-fire period between 1954 and 1959 the number of structural groups decreased at a rate of 0.5 structures per year. The as the inter-fire period increased between 1959 and 1996

the number of structural groups increased at a rate of 0.18 structures per year. The overall rate of increase in the number of structural groups between 1954 and 1996 was 0.10 structures per year.

6.2.2.6.10 Differences in structural richness on the Control treatment between 1954, 1959, and 1996

The structural richness was lowest in 1996 (0.237), second highest in 1959 (0.300), and highest in 1954 (0.415) (Table 13-12and Figure 6-22). There was a significant difference in the structural richness on the Control treatment between 1954, 1959, and 1996 ($p = 0.021$) (Table 6-9). Tukey Studentized post hoc analyses show that the structural richness was significantly lower in 1996 than in 1954 ($p = 0.018$) (Table 14-16). Generally, as the inter-fire period increased the structural richness decreased.

6.2.2.6.11 Differences in structural diversity on the Control treatment between 1954, 1959, and 1996

The structural diversity was lowest in 1959 (1.765), second highest in 1954 (1.850), and highest in 1996 (1.918) (Table 13-12and Figure 6-22). There was no significant difference in the structural diversity on the Control treatment between 1954, 1959, and 1996 (Table 6-9).

6.2.2.6.12 Differences in structural evenness on the Control treatment between 1954, 1959, and 1996

The structural evenness was lowest in 1996 (0.631), second highest in 1954 (0.666), and highest in 1959 (0.680) (Table 13-12and Figure 6-22). There was no significant difference in structural evenness on the Control treatment between 1954, 1959, and 1996 (Table 6-9).

WitsETD

6.2.3 Analyses of species composition and structure composition on the Pretoriuskop EBPs using Horn's index of similarity

The hierarchical cluster trees derived from the Pearson-Ward cluster analyses are presented in Figure 6-24 (p. 114), Figure 6-26 (p. 117), Figure 6-28 (p. 120), and Figure 6-30 (p. 123). The distances at which the plot clusters were grouped are shown by two vertical dashed lines on the cluster trees. The distance at which 10 to 12 plot clusters are formed is referred to as "distance 1", and the plot clusters are referred to as the "cluster group 1". The distance at which four clusters are formed is referred to as "distance 2" and the plot clusters are referred to as the "cluster group 2". In the cluster tree figures, the plot clusters in the cluster group 1 are denoted by clear boxes, and each cluster is identified by a number on the left hand side. The plot clusters in cluster group 2 are denoted by coloured boxes, and each cluster is identified by a letter on the left hand side.

Each Pearson-Ward cluster tree has a corresponding map showing the layout of the Pretoriuskop EBPs with the plots colour coded according to the cluster grouping at distance 2 in Figure 6-25 (p. 115), Figure 6-27 (p. 118), Figure 6-29 (p. 121), and Figure 6-31 (p. 124). The colours of the Pretoriuskop EBPs (red, green, , and yellow) on the maps correspond to the colours used for the clusters at distance 2 on the Pearson-Ward cluster trees.

6.2.3.1 Pearson-Ward cluster analysis on the similarity of species between EBPs in 1954

In 1954, the first cluster grouping at distance 1 showed that cluster 11 comprised only Numbi replicate plots (Figure 6-24). Looking at Figure 6-25, the Oct2, Dec2, and Dec3 plots in cluster 11 were adjacent to one another, and the Aug3, Aug2, and Apr2 plots in cluster 11 were adjacent to one another (Figure 6-25). Cluster 3 comprised mainly Fayi replicate plots, and all the plots in cluster 3 were adjacent to one another. Cluster 4 comprised mainly Kambeni plots, and all the plots in cluster 4 were adjacent to one another on this replicate. Cluster 10 comprised mainly Shabeni replicate plots. The Shabeni Control, Dec2, and Oct2 plots in cluster 10 were adjacent to one another, and that the Shabeni Apr3 and Dec3 plots in cluster 10 were adjacent to one another.

In 1954, the second cluster grouping up the hierarchy at distance 2 showed that the plots on the Fayi replicate were found in both clusters A and B, the plots on the Numbi and Shabeni replicates were found in clusters C and D, and the plots on the Kambeni replicate were found in clusters A, B, C, and D (Figure 6-24). The Pearson-Ward cluster tree showed that species composition of the plots in clusters A and B were most similar. The map of the EBPs with the SADF vegetation classification showed that the plots in clusters A and B were found in the closed *Terminalia sericea* - *Combretum* woodlands of the Pretoriuskop region (Figure 6-25). The cluster tree showed that the species composition of the plots in cluster C was similar to that of the plots in clusters A and B, and looking at the layout of the plots, the plots in cluster C were found in the open *Terminalia sericea* - *Combretum* woodlands of the Pretoriuskop region. The cluster tree also showed that the species composition of plots in cluster D was least similar to that of clusters A, B and C. Looking at the layout of the plots in Pretoriuskop, the plots in cluster D were found in the open *Terminalia sericea* - *Combretum* woodlands of the Pretoriuskop region.

In 1954, the species composition was similar between plots that were in close proximity for example occurring adjacent to one another or in the same replicate. Furthermore, species composition was also similar between plots that occurred in the same vegetation type for example the open or closed *Terminalia sericea* - *Combretum* woodlands. For example, the dominant vegetation type on the Fayi replicate was *Terminalia sericea* - *Combretum* closed woodland, the dominant vegetation type on the Numbi and Shabeni replicates was *Terminalia sericea* - *Combretum* open woodland, and that of the Kambeni replicate was a transition between the open and closed *Terminalia sericea* - *Combretum* woodlands (Figure 6-25)..

WitsETD

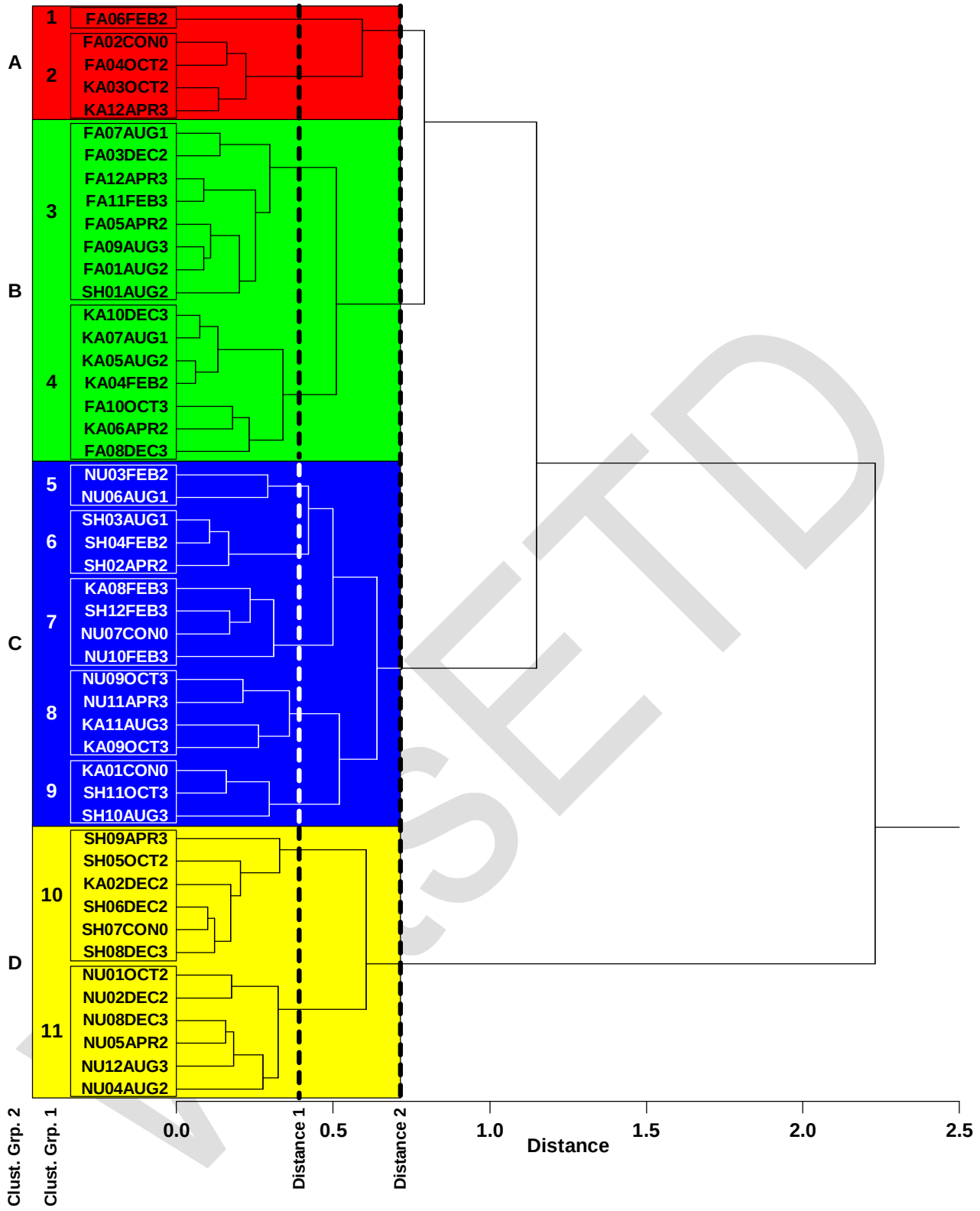


Figure 6-24: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in species between Pretoriuskop EBPs in 1954. The codes for the treatment plots are defined in Table 10-1 (p. 214).

VETTED

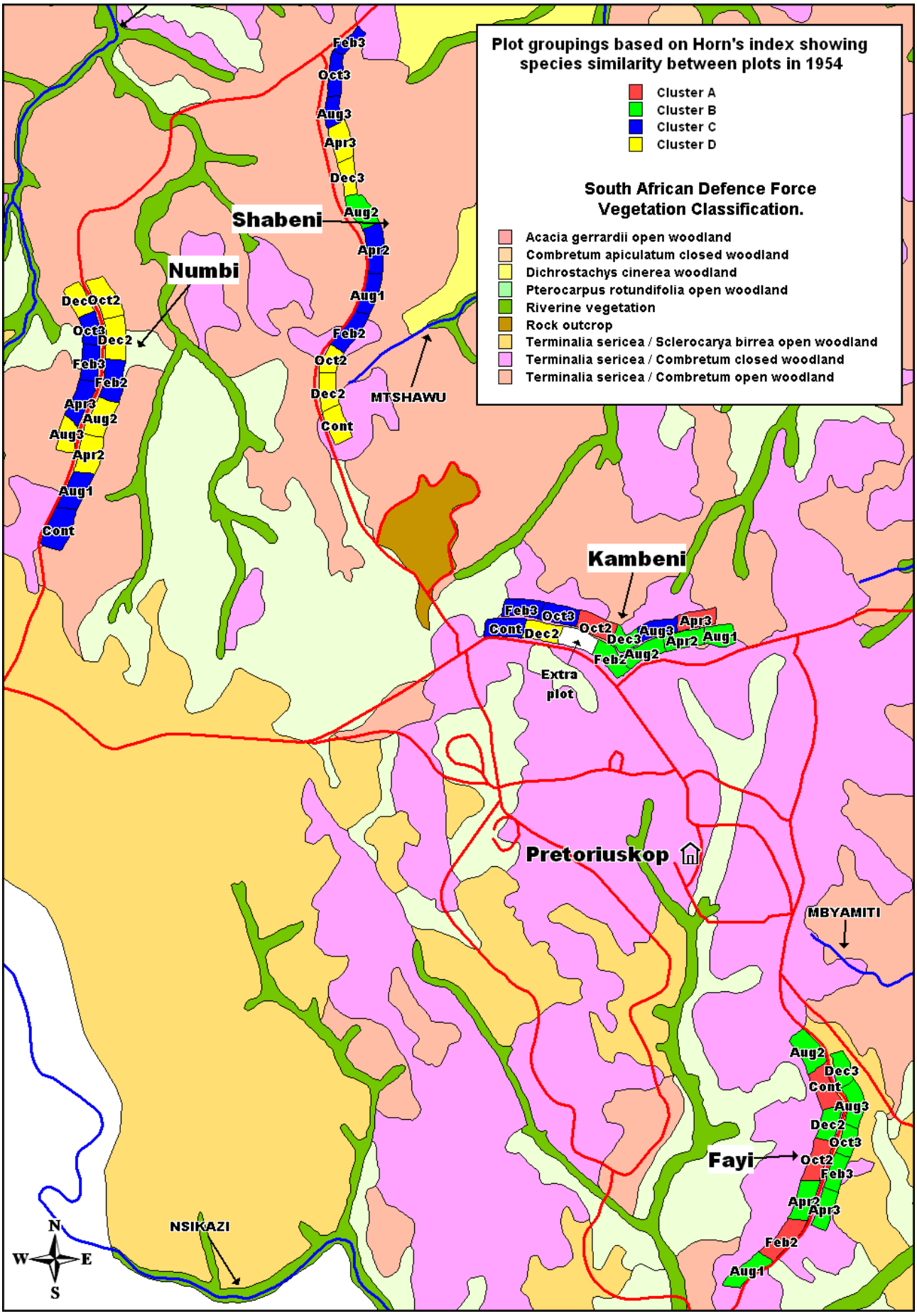


Figure 6-25: Map showing the clustering of the Pretoriuskop EBPs at distance 2 from the Pearson-Ward cluster analysis on Horn's indices of similarity in species between plots in 1954 shown in Figure 6-24.

6.2.3.2 Pearson-Ward cluster analysis on the similarity of species between EBPs in 1996

In 1996, the first cluster grouping at distance 1 showed that cluster 1 comprised only Shabeni replicate plots (Figure 6-26). The map of the Pretoriuskop EBPs showed that the Apr2 and Aug2 plots of cluster 1 were adjacent to one another, and the Apr3 and Feb3 plots were not (Figure 6-27). Cluster 3 comprised only Numbi replicate plots, and the map showed that the Feb3, Oct2, Oct3, and Dec2 plots of cluster 3 were adjacent to one another while Apr2 was not. Cluster 8 comprised two Numbi replicate plots, Feb2 and Apr3, which were adjacent to one another on the replicate. Cluster 7 comprised mainly Kambeni replicate plots, and the map showed that the Feb2, Apr2, Apr3, Aug1, Aug2, Oct2, and Dec3 plots of cluster 7 were adjacent to one another while Feb3 was not. The Fayi plots Feb3, Apr2, Apr3, Aug2, Aug3, and Oct3 were grouped together in cluster 7 and the map showed that they were all adjacent to one another excepting the Aug2 plot. Cluster 10 comprised the Control plots for all the replicates and the Dec3 plot from the Fayi replicate.

In 1996, the second cluster grouping up the hierarchy at distance 2 showed that most plots on the Fayi and Kambeni replicates were found in cluster C, and most plots on the Numbi and Shabeni replicates were found in clusters A and B (Figure 6-26, Figure 6-27). The control plots on all the replicates were found in cluster D along with the Dec3 plot from the Fayi replicate.

Generally, the plots that were not burnt between 1954 and 1996 had species compositions that were more similar to one another than with the plots that were burnt between 1954 and 1996. However, as was the case in 1954 the species composition on plots that were burnt between 1954 and 1996 was similar between plots that were in close proximity for example occurring adjacent to one another or in the same replicate. Furthermore, species composition was also similar between plots that occurred in the same vegetation type for example the open or closed *Terminalia sericea* - *Combretum* woodlands.

In a number of cases, plots that were clustered together at distance 1 in 1954 were clustered together in 1996. In other words, there were plots that were similar in species composition in 1954 that were similar in species composition in 1996 regardless of the fire treatment applied. Five of the Fayi plots in cluster 3 in 1954 were clustered together in cluster 6 in 1996. Five of the Kambeni plots in cluster 4 in 1954 were clustered together in cluster 7 in 1996. Three of the Numbi plots in cluster 11 in 1954 were clustered together in cluster 3 in 1996. Three of the four plots clustered together in cluster 2 in 1954 were clustered together in cluster 7 in 1996. There was no clear pattern regarding the fire treatment effects on the similarity of species between the Pretoriuskop EBPs because, many of the plots remained similar in species composition between 1954 and 1996.

WITS ETD

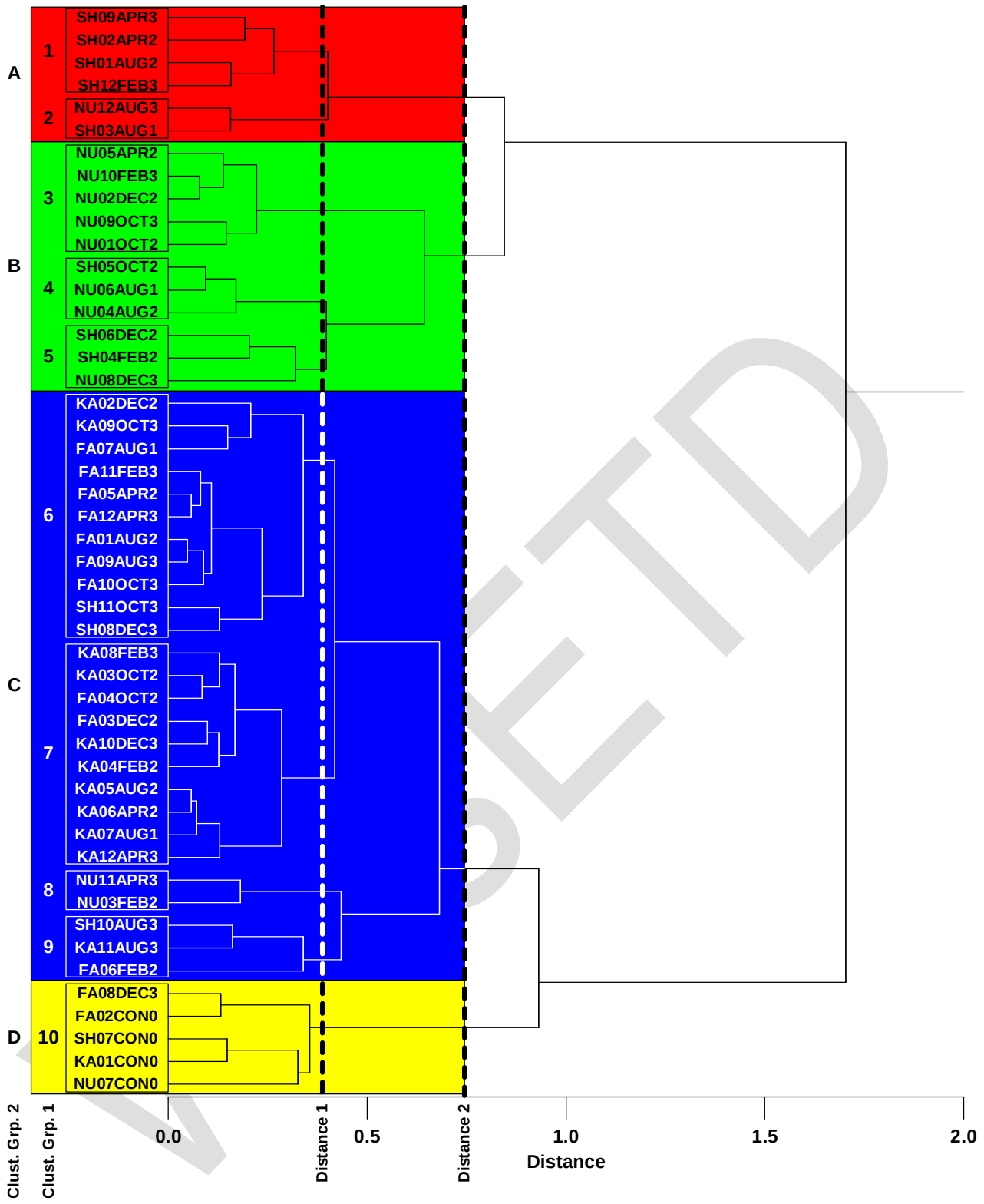


Figure 6-26: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in species between Pretoriuskop EBPs in 1996. The codes for the treatment plots are defined in Table 10-1 (p. 214)

WETD

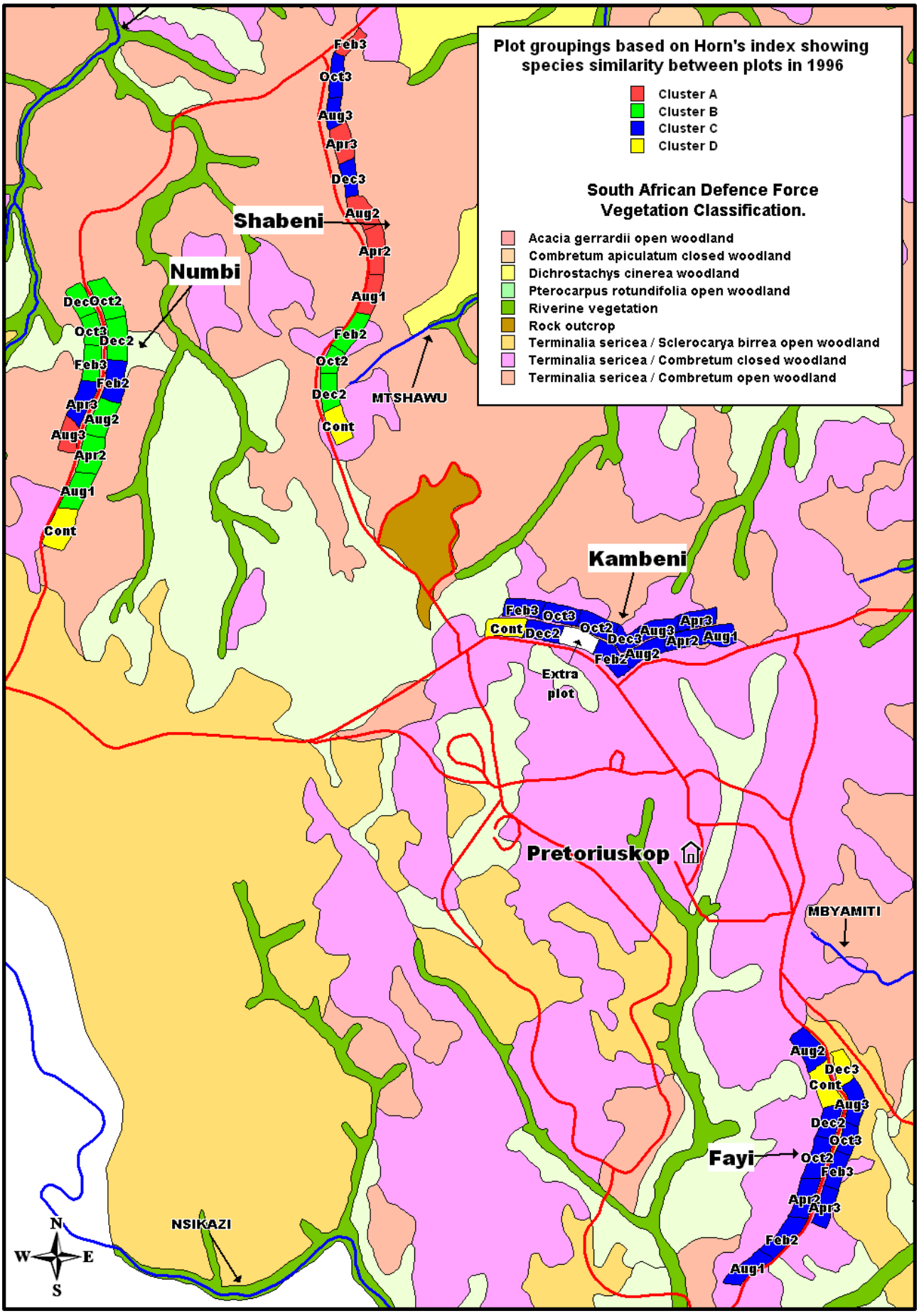


Figure 6-27: Map showing the clustering of the Pretoriuskop EBPs from a Pearson-Ward cluster analysis on Horn's indices of similarity in species between plots in 1996 shown in Figure 6-26.

6.2.3.3 Pearson-Ward cluster analysis on the similarity of structure between EBPs in 1954

In 1954, the first cluster grouping (distance 1) showed that cluster 2 comprised only Fayi replicate plots (Figure 6-28). The map of the Pretoriuskop EBPs showed that the plots in cluster 2 were adjacent to one another on the Fayi replicate (Figure 6-29). Cluster 7 comprised mainly Shabeni replicate plots, and the map showed that almost all the plots in cluster 7 were adjacent to one another on the Shabeni replicate. Cluster 8 comprised mainly Numbi replicate plots, and the map showed that the Control, Apr2, Aug1, and Aug2 plots were adjacent to one another, and the Oct2 and Dec2 plots were adjacent to one another. Cluster 9 comprised mainly Fayi replicate plots and the map showed that the Fayi plots in cluster 9 were adjacent to one another.

In 1954, the second cluster grouping (distance 2) showed that cluster A comprised 4 Kambeni plots, 2 Fayi plots, 1 Shabeni plot, and 1 Numbi plot (Figure 6-28, Figure 6-29). Cluster B comprised six Shabeni plots, five Kambeni plots, four Numbi plots, and three Fayi plots. Cluster C comprised four Shabeni plots, one Numbi plot, and one Kambeni plot. Cluster D comprised seven Fayi plots, six Numbi plots, two Kambeni plots, and one Shabeni plot.

Generally, the woody vegetation structure was similar on adjacent plots or plots that occur in close proximity. Plots from the four replicates were found in all the distance 2 clusters. This suggests that the woody vegetation structure on the plots was not affected by the vegetation type in which the plot occurred. Cluster D comprised seven Fayi plots and six Numbi plots. The vegetation on the locations of the original Fayi and Numbi replicates was burnt in 1953 just before the experiment was set up in 1954. Post fire age may be an important factor contributing to the structure of the woody vegetation of these plots, and may explain why the structure on most of the plots on the original Fayi and Numbi replicates was similar.

WitsETD

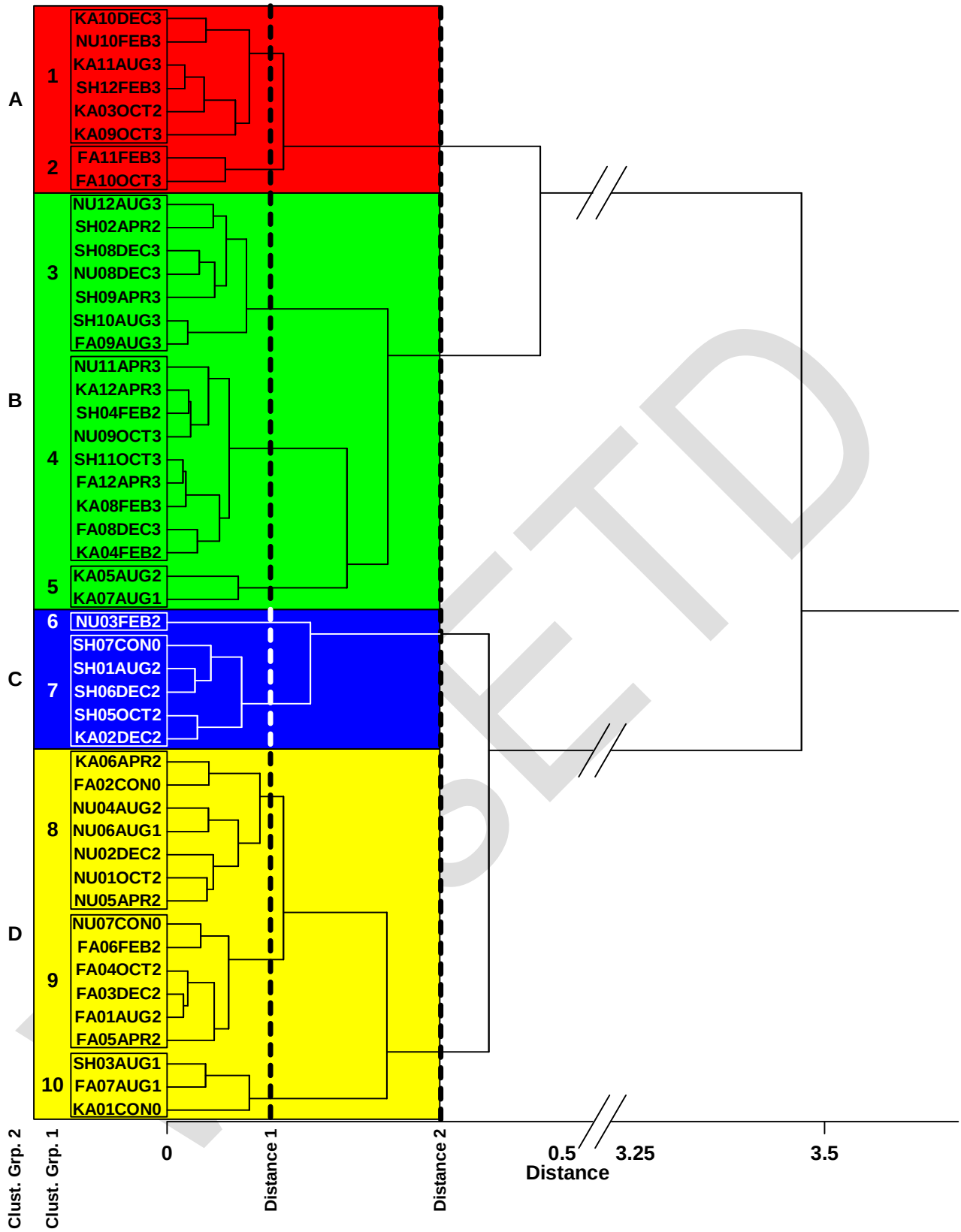


Figure 6-28: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between Pretoriuskop EBPs in 1954. The codes for the treatment plots are defined in Table 10-1 (p. 214)

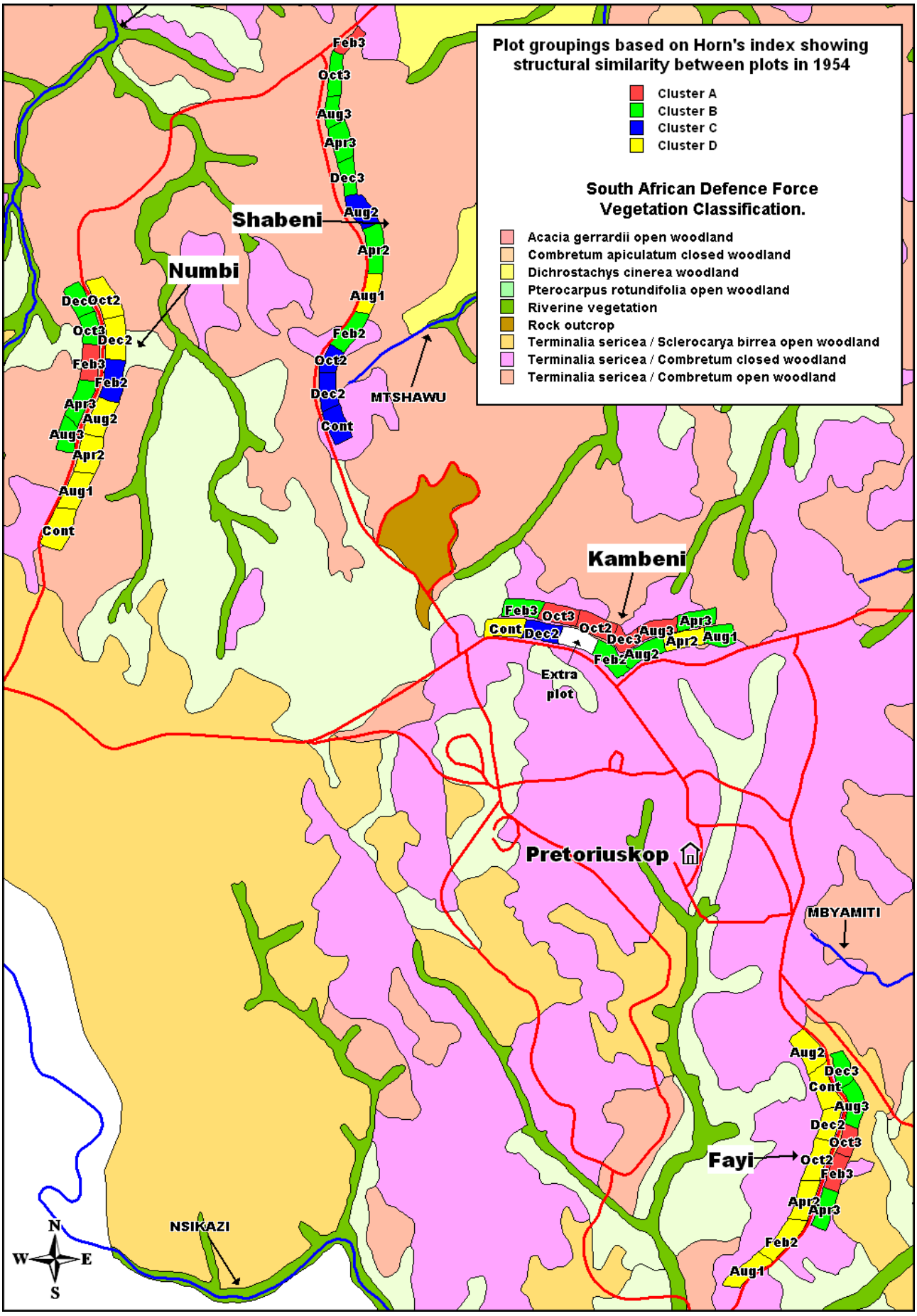


Figure 6-29: Map showing the clustering of the Pretoriuskop EBPs from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between plots in 1954 shown in Figure 6-28.

6.2.3.4 Pearson-Ward cluster analysis on the similarity of structure between EBPs in 1996

In 1996, the first cluster grouping (distance 1) showed that cluster 1 comprised mainly April fire treatment plots from the Kambeni and Numbi replicates (Figure 6-30). The map of the Pretoriuskop EBPs showed that the April treatment plots in cluster 1 on the Kambeni replicate were adjacent to one another (Figure 6-31). Cluster 2 comprised mainly February, April, and December treatment plots from the Fayi, Kambeni, Numbi, and Shabeni replicates. The map showed that some of the plots in cluster 2 were adjacent to one another, for example the Fayi April treatments, and the Kambeni Feb2 and Dec3 treatments. Cluster 3 comprised only the control treatments on the Kambeni and Shabeni replicates. Cluster 5 comprised mainly February, April, and December treatment plots from the Fayi, Kambeni, and Shabeni replicates. The map showed that the Kambeni Feb2 and Dec2 plots in cluster 5 were adjacent to one another. Cluster 8 comprised mainly August and October treatment plots from the Fayi, Numbi, and Shabeni replicates. The map showed that the Numbi Oct2, Oct3, and Dec2 plots of cluster 8 were adjacent to one another. Cluster 9 comprised two August treatment plots from the Fayi and Kambeni replicates. Cluster 10 comprised only August and October treatment plots from the Kambeni and Shabeni replicates. The map showed that the Kambeni Oct2 and Oct3 treatments of cluster 10 were adjacent to one another, and the Shabeni Aug3 and Oct3 treatments of cluster 10 were adjacent to one another. Cluster 12 comprised three August annual treatments from the Fayi, Numbi, and Shabeni replicates.

In 1996, the second cluster grouping (distance 2) showed that cluster A comprised mainly February, April, December and Control treatment plots that were from the Fayi, Kambeni, Numbi, and Shabeni replicates (Figure 6-30, Figure 6-31). Cluster B had two main groupings the first comprised mainly February, April and December treatments from the Fayi, Kambeni, and Shabeni replicates and the second comprised mainly August and October treatments from the Fayi, Numbi, and Shabeni replicates. Cluster C comprised August and October treatments from the Fayi, Kambeni, and Shabeni replicates. Cluster D comprised Aug1 treatments from the Fayi, Kambeni, Numbi, and Shabeni replicates and the Aug2 treatment from the Fayi replicate.

Generally, the structure of the woody vegetation on plots that was burnt annually in August between 1954 and 1996 was different to the plots that were burnt biennially, triennially or not burnt at all between 1954 and 1996. Plots that were burnt in February, April, and December had similar woody vegetation structure, and plots burnt in August and October had similar woody vegetation structure. The structure of the woody vegetation on plots that were not burnt between 1954 and 1996 was similar to plots that were burnt in February, April, and December.

WISER

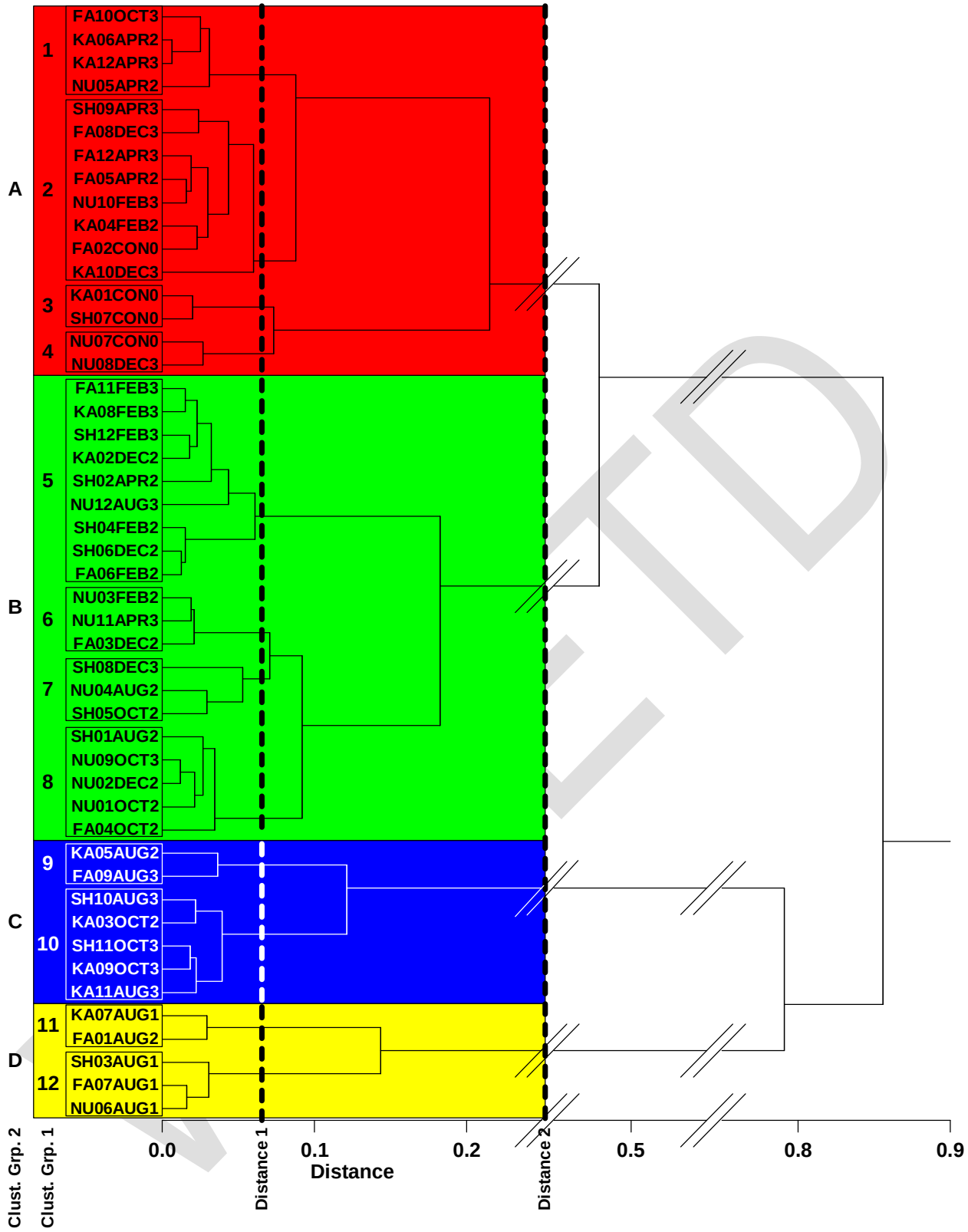


Figure 6-30: Hierarchical cluster tree from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between Pretoriuskop EBPs in 1996. The codes for the treatment plots are defined in Table 10-1 (p. 214)

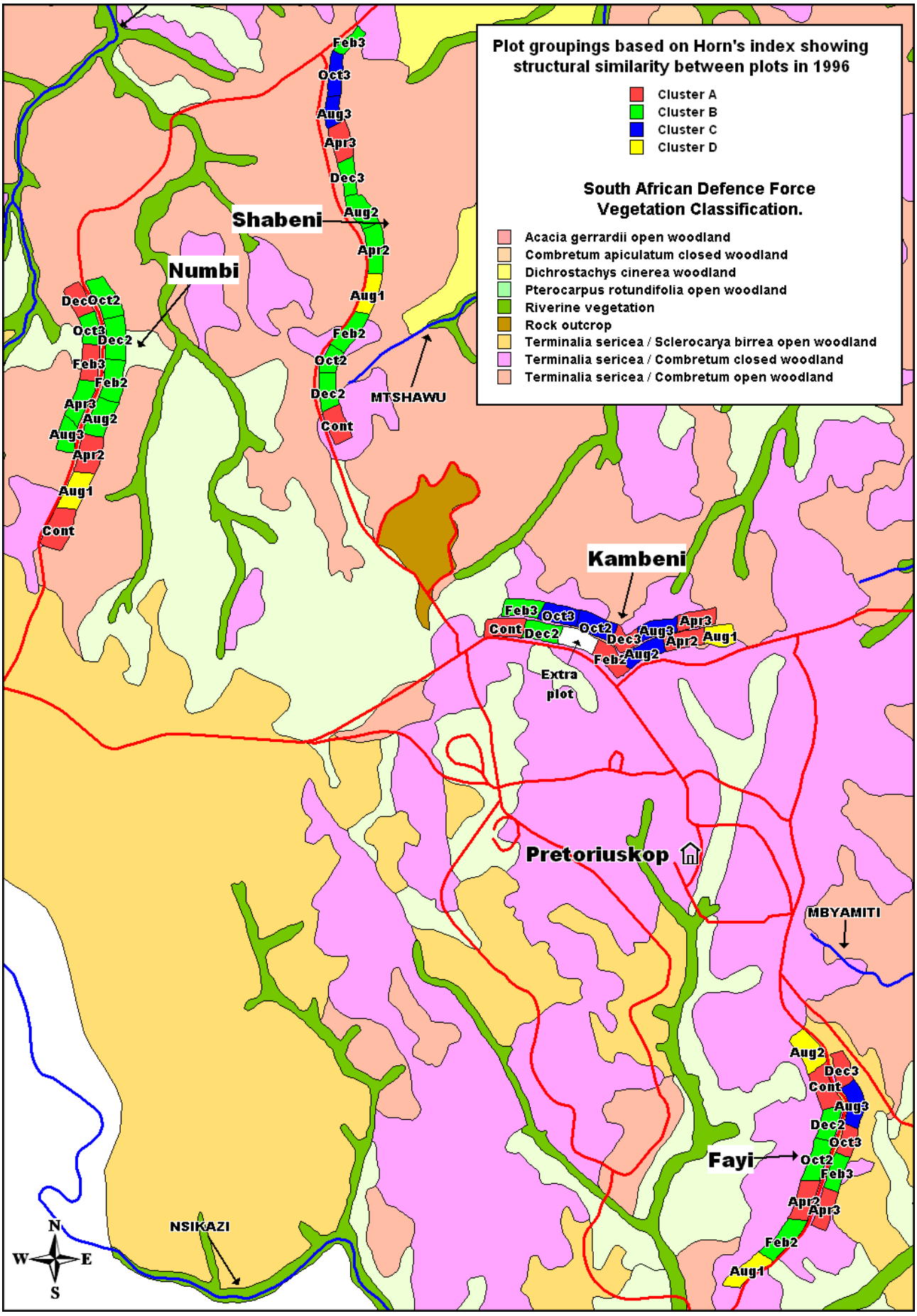


Figure 6-31: Map showing the clustering of the Pretoriuskop EBPs from a Pearson-Ward cluster analysis on Horn's indices of similarity in structure between plots in 1996 shown in Figure 6-30.

6.3 RESULTS FROM THE MULTIVARIATE ANALYSIS EXPLORING THE EFFECTS OF FIRE ON THE COMPOSITION AND STRUCTURE OF THE WOODY VEGETATION OF THE PRETORIUSKOP EXPERIMENTAL BURN PLOTS

In this section, the results from the Correspondence Analyses (CA's) on the 1954 and 1996 survey data are presented in two sections, the first section being the results of the CA's on the species by plot data and the second section being the results of the CA's on the structure by plot data.

For each CA two interpretations of the variation in weighted eigenvectors are presented. In the first interpretation, a traditional bi-plot graph of the first two eigenvectors was used to identify visually groupings in variation along the first two eigenvectors from the CA. In the second interpretation, a step-wise Gamma-Ward cluster analysis was used to identify groupings in variation along the first four eigenvectors from the CA. Many of the general patterns and relationships were similar between the two interpretations, and these general patterns are presented in a separate summary for each CA.

6.3.1 Results from the Correspondence Analysis on the 1954 species by plot data

The results from the CA performed on the 1954 species by plot data are presented in Table 6-10 (p. 125), Figure 6-32 (p. 129), Figure 6-33 (p. 130), Figure 6-34 (p. 131), and Figure 6-35 (p. 132). Table 6-10 shows the Eigenvalues for the first four ordination axes of the CA. Figure 6-32 is a hierarchical cluster tree showing the cluster groups from the step-wise Gamma-Ward cluster analysis on the first four ordination axes. Figure 6-33 is a bi-plot of the first two, weighted eigenvector plot score axes with the data points colour coded to the level 2 cluster colours in Figure 6-32. Figure 6-34 is a bi-plot of the first two, weighted eigenvector species score axes to the data points colour coded with the level 2 cluster colours in Figure 6-32. Figure 6-35 is a map showing the layout of the Pretoriuskop EBP experiment with the plots colour coded to the level 2 cluster colours in Figure 6-32. The weighted eigenvector plot scores for the first four ordination axes, the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973) are presented in Appendix 7 Table 15-1 (p. 256). The weighted eigenvector species scores for the first four ordination axes, the species weights, and the effective number of occurrences of the species (N2 diversity of species) are presented in Appendix 7 Table 15-2 (p. 257).

Table 6-10: Eigenvalues for the first four ordination axes of a Correspondence Analysis (CA) on the species by plot data collected in 1954.

	Axis 1	Axis 2	Axis 3	Axis 4	Total
Eigenvalue	0.3176	0.2264	0.1716	0.1449	2.0086
% Variation	15.8	11.3	8.5	7.2	42.8

The Eigenvalues, for the first four axes of the CA on the 1954 data were 0.318, 0.226, 0.172, and 0.145 (Table 6-10). The first four eigenvectors accounted for 15.8%, 11.3%, 8.5%, and 7.2% of the variation in the species by plot data respectively in 1954, and 42.8% of the total variation in the species by plot data in 1954 (Table 6-10).

6.3.1.1 Bi-plots of the first two weighted species and plot eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1954

There were four main groups of species and plots on the bi-plot graphs of the first two weighted eigenvectors from the Correspondence Analysis on the species by plot data in 1954 (Figure 6-33 and Figure 6-34). Group 1 comprised species and plots with x-axis eigenvector values greater than 0.5. Group 2 comprised species and plots with x-axis eigenvector values less than 0.5 and y-axis eigenvector values greater than 0.7. Group 3 comprised species and plots with x-axis eigenvector values less than 0.5 and y-axis eigenvector values between 0.7 and -0.24. Group 4 comprised species and plots with x-axis eigenvector values less than 0.5

and y-axis eigenvector values less than -0.24. The plots in groups 2, 3 and 4 were related to one another by their physical location in the Pretoriuskop landscape.

The plots in Group 1 were the Shabeni Apr3, Fayi Feb2, and Kambeni Aug3 plots (Figure 6-33). These plots occurred in both the open and closed *Terminalia sericea* - *Combretum* woodlands of Pretoriuskop (Figure 6-35). The species in Group 1 were *Acacia exuvialis*, *Acacia gerrardii*, *Combretum hereroense*, *Ormocarpum trichocarpum*, and *Ozoroa sphaerocarpa* (Figure 6-34). *Acacia gerrardii* occurred on all the plots in Group 1. *Acacia gerrardii* was also found in higher densities on the Group 1 plots than other Pretoriuskop EBPs in 1954 (i.e. > 300 plants/Ha). Half the occurrences of *Combretum hereroense* and *Ozoroa sphaerocarpa* on the Pretoriuskop EBPs occurred on the Group 1 plots in 1954. *Acacia exuvialis* was found only on the Group 1 plots in 1954, and it occurred on the Shabeni Apr3 plot.

Group 2 comprised the Kambeni Dec2 plot, the Numbi Oct2, Dec2, Aug2, Apr2, Aug1, Dec3, and Aug3 plots and the Shabeni Oct2, Dec2, Con0, and Dec3 plots (Figure 6-33). These plots occurred in the *Terminalia sericea* - *Combretum* open woodlands of Pretoriuskop (Figure 6-35). The species in Group 2 were *Annona senegalensis*, *Bridelia mollis*, *Bauhinia galpinii*, *Clerodendrum* species, *Combretum collinum*, *Commiphora mollis*, *Lannea discolor*, *Lonchocarpus capassa*, *Olea europaea*, *Papilionacea*, *Parinari curatellifolia*, *Pterocarpus angolensis*, *Senna petersiana*, *Turraea nilotica*, and *Vangueria infausta* (Figure 6-34). *Annona senegalensis* and *Senna petersiana* occurred on all the plots in Group 2 however, they were also found on many other Pretoriuskop EBPs in 1954. *Lonchocarpus capassa* was found on eleven of the twelve Group 2 plots however, it was also found on many other Pretoriuskop EBPs in 1954. Fifty percent of the occurrences of *Bridelia mollis*, *Lannea discolor*, and *Papilionacea*, fifty-seven percent of the occurrences of *Turraea nilotica*, and sixty-three percent of the occurrences of *Pterocarpus angolensis* occurred on the Group 2 plots in 1954. *Clerodendrum* species, *Olea europaea*, and *Commiphora mollis* were found only on Group 2 plots. *Clerodendrum* species was found on the Shabeni Oct2 plot, *Commiphora mollis* was found on the Numbi Oct2 and Dec3 plots, and the Shabeni Dec3 plot, and *Olea europaea* was found on the Numbi Dec3 plot.

Group 3 comprised the Kambeni Feb3 and Apr3 treatments, the Numbi Feb2, Con0, Oct3, Feb3, and Apr3 treatments, and the Shabeni Apr2, Aug1, Feb2, Aug3, Oct3, and Feb3 treatments (Figure 6-33). These plots occurred in the *Terminalia sericea* - *Combretum* open woodlands of Pretoriuskop (Figure 6-35). The species in Group 3 were *Acacia sieberiana*, *Albizia versicolor*, *Catunaregam spinosa*, *Chaetachme aristata*, *Combretum apiculatum*, *Combretum molle*, *Diospyros mespiliformis*, *Dombeya rotundifolia*, *Euclea divinorum*, *Flacourtia indica*, *Grewia monticola*, *Lannea edulis*, *Maytenus heterophylla*, *Maytenus senegalensis*, *Pappea capensis*, *Pavetta schumanniana*, *Pseudarthria hookeri*, *Pterocarpus rotundifolius*, *Rhus pyroides*, *Rhus transvaalensis*, *Schotia brachypetala*, *Sclerocarya birrea*, *Strychnos madagascariensis*, *Syzygium cordatum*, *Vernonia colorata*, and an unidentified species (Figure 6-34). *Sclerocarya birrea* occurred on all the plots in Group 3 however, it was also found on many other Pretoriuskop EBPs in 1954. *Maytenus senegalensis* was found on eleven of the thirteen Group 3 plots and *Strychnos madagascariensis* was found on twelve of the thirteen Group 3 plots however, they were also found on many other plots in 1954. Sixty-seven percent of the occurrences of *Albizia versicolor*, *Catunaregam spinosa*, and *Combretum apiculatum*, and seventy-five percent of the occurrences of an unidentified species on the Pretoriuskop EBPs in 1954 occurred on the Group 3 plots. *Acacia sieberiana*, *Pseudarthria hookeri*, *Pterocarpus rotundifolius*, *Schotia brachypetala*, *Syzygium cordatum*, and *Vernonia colorata* were found only on Group 3 plots. *Acacia sieberiana* was found on the Kambeni Apr3 plot. *Pseudarthria hookeri* was found on the Numbi Oct3 plot. *Pterocarpus rotundifolius* was found on the Numbi Oct3 and Apr3 plots. *Schotia brachypetala* was found on the Numbi Oct3 plot. *Syzygium cordatum* was found on the Kambeni Feb3 plot. *Vernonia colorata* was found on the Kambeni Feb3 and Numbi Feb3 plots.

Group 4 comprised the Fayi Aug2, Con0, Dec2, Oct2, Apr2, Aug1, Dec3, Aug3, Oct3, Feb3, and Apr3 treatments, the Kambeni Con0, Oct2, Feb2, Aug2, Apr2, Aug1, Oct3, and Dec3 treatments, and the Shabeni Aug2 treatment (Figure 6-33). These plots occurred in the *Terminalia sericea* - *Combretum* closed woodlands of Pretoriuskop (Figure 6-35). The species in Group 4 were *Antidesma venosum*, *Cassine transvaalensis*, *Dalbergia melanoxylon*, *Dichrostachys cinerea*, *Diospyros lycioides*, *Ehretia obtusifolia*,

Euclea natalensis, *Ficus stuhlmannii*, *Grewia flavescens*, *Lannea schweinfurthii*, *Mundulea sericea*, *Ochna natalitia*, *Peltophorum africanum*, *Phyllanthus reticulatus*, *Piliostigma thonningii*, *Securinega virosa*, *Strychnos spinosa*, *Terminalia sericea*, *Trichilia emetica*, *Ximenia caffra*, *Zanthoxylum capense*, and *Ziziphus mucronata* (Figure 6-34). *Dichrostachys cinerea* and *Terminalia sericea* occurred on all the plots in Group 4 however, they were also found on all other Pretoriuskop EBPs in 1954. *Mundulea sericea* was found on fifteen of the twenty Group 4 plots and *Ziziphus mucronata* was found on eighteen of the twenty Group 4 plots, and they were found mainly on the plots in Group 4 in 1954. More than half of the occurrences of *Ochna natalitia*, *Zanthoxylum capense*, *Antidesma venosum*, *Grewia flavescens*, *Ehretia obtusifolia*, *Mundulea sericea*, *Piliostigma thonningii*, *Ziziphus mucronata*, and *Trichilia emetica* on the Pretoriuskop EBPs in 1954 occurred on the Group 4 plots. *Cassine transvaalensis*, *Ficus stuhlmannii*, *Lannea schweinfurthii*, and *Strychnos spinosa* were found only on the Group 4 plots. *Cassine transvaalensis* was found on the Fayi Oct2 plot. *Ficus stuhlmannii* was found on the Fayi Oct3 plot. *Lannea schweinfurthii* was found on the Shabeni Aug2 plot. *Strychnos spinosa* was found on the Fayi Dec3 and Kambeni Oct3 plots.

6.3.1.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1954

The step-wise Ward-Gamma cluster analysis was used to summarise the variation of plots and species along the first four eigenvectors of the Correspondence Analysis on the 1954 data. There were four main clusters of plots and species at level 2 of the step-wise Ward-Gamma cluster analysis (Figure 6-32). These clusters differed from the two dimensional grouping of plots and species along the first two eigenvectors described above (Figure 6-33 and Figure 6-34).

Cluster 1 comprised Fayi Aug2, Con0, Dec2, Apr2, Feb2, Aug1, Dec3, Oct3, and Apr3 treatments, the Kambeni Oct2, Feb2, Aug2, Apr2, Aug1, Aug3, and Apr3 treatments, and the Shabeni Apr3 treatment (Figure 6-32). A map of the Pretoriuskop EBPs showed that the Kambeni Feb2, Apr2, Apr3, Aug1, Aug2, and Aug3 plots were adjacent to one another, the Fayi Feb2, Apr2, Apr3, and Aug1 plots were adjacent to one another, and the Fayi Aug2, Oct3, Dec2, Dec3, and Con0 plots were adjacent to one another (Figure 6-35). The plots in cluster 1 occurred in the *Terminalia sericea* - *Combretum* closed woodlands of Pretoriuskop (Figure 6-35). These plots were associated with *Dichrostachys cinerea*, *Ehretia obtusifolia*, *Maytenus senegalensis*, *Mundulea sericea*, *Sclerocarya birrea*, *Strychnos madagascariensis*, and *Ziziphus mucronata*, which occurred on more than seventy percent of the plots in cluster 1 (Figure 6-32). Most of these species occurred on many other Pretoriuskop EBPs excepting *Ehretia obtusifolia* and *Ziziphus mucronata*, which occurred mainly on the plots in cluster 1. Some species were found only on the plots in cluster 1 for example, *Acacia exuvialis*, *Acacia sieberiana*, and *Ficus stuhlmannii* occurred on the Shabeni Apr3, Kambeni Apr3, and Fayi Oct3 plots respectively. More than seventy percent of the occurrences of *Phyllanthus reticulatus* on the Pretoriuskop EBPs occurred on the plots in cluster 1. *Phyllanthus reticulatus* occurred on the Fayi Aug2, Dec2, Feb2, and Aug1 plots, and the Kambeni Oct2, Aug1, Aug3, and Apr3 plots.

Cluster 2 comprised Fayi Oct2, Aug3, and Feb3 treatments, the Kambeni Con0, Oct3, and Dec3 treatments, and the Shabeni Aug2, Aug1, and Oct3 treatments (Figure 6-32). A map of the Pretoriuskop EBPs showed that the Fayi Oct2 and Feb3 plots were adjacent to one another (Figure 6-35). The plots in cluster 2 occurred in the open and closed *Terminalia sericea* - *Combretum* woodlands of Pretoriuskop (Figure 6-35). The only species found on more than seventy percent of the cluster 2 plots was *Terminalia sericea*, which however this was found on all the Pretoriuskop EBPs (Figure 6-32). Some species were found only on the plots in cluster 2, for example, *Cassine transvaalensis* and *Lannea schweinfurthii*, which were only found on the Fayi Oct2 and Shabeni Aug2 plots respectively. More than seventy percent of the occurrences of *Trichilia emetica* on the Pretoriuskop EBPs occurred on the cluster 2 plots. *Trichilia emetica* occurred on the Fayi Oct2 plot, and Kambeni Oct3 and Dec3 plots.

Cluster 3 comprised the Kambeni Dec2 plot, the Numbi Dec2 and Aug1 plots, and the Shabeni Apr2, Feb2, Oct2, Dec2, Con0, Dec3, and Aug3 plots (Figure 6-32). A map of the Pretoriuskop EBPs showed that the Shabeni Feb2, Oct2, Dec2, and Con0 plots were adjacent to one another (Figure 6-35). The plots in cluster 3

occur mainly on the *Terminalia sericea* - *Combretum* open woodlands of the Pretoriuskop region (Figure 6-35). These plots were associated with *Maytenus heterophylla*, *Lonchocarpus capassa*, *Pavetta schumanniana*, and *Senna petersiana*, which occurred on more than seventy percent of the plots in cluster 3 (Figure 6-32). These species also occurred on many other Pretoriuskop EBPs. *Clerodendrum* species was found only on the plots in cluster 3 and it occurred on Shabeni Oct2 plot.

Cluster 4 comprised the Kambeni Feb3 plot, the Numbi Oct2, Feb2, Aug2, Apr2, Con0, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Feb3 plot (Figure 6-32). A map of the Pretoriuskop EBPs showed that the Numbi Feb2, Feb3, Apr2, Apr3, Aug2, Aug3, Oct2, Oct3, and Dec3 plots were adjacent to one another (Figure 6-35). The plots in cluster 4 occur mainly on the *Terminalia sericea* - *Combretum* open woodlands of the Pretoriuskop region (Figure 6-35). These plots were associated with *Combretum collinum*, *Grewia monticola*, *Parinari curatellifolia*, and *Annona senegalensis*, which occurred on more than seventy percent of the plots in cluster 4 (Figure 6-32). Most of these species occurred on many other Pretoriuskop EBPs excepting *Parinari curatellifolia*, which occurred mainly on the plots in cluster 4. Some species were found only on the plots in cluster 4 however, they did not occur on many plots. For example, *Bauhinia galpinii*, which occurred on the Numbi Aug2, Con0, and Apr3, plots. *Catunaregam spinosa*, which occurred on the Numbi Dec3, Oct3, and Apr3 plots. *Olea europaea*, which occurred on the Numbi Dec3 plot. *Pseudarthria hookeri*, which occurred on the Numbi Oct3 plot. *Pterocarpus rotundifolius*, which occurred on the Numbi Oct3 and Apr3 plots. *Schotia brachypetala*, which occurred on the Numbi Oct3 plot. *Syzygium cordatum*, which occurred on the Kambeni Feb3 plot. *Vernonia colorata*, which occurred on the Kambeni Feb3 and Numbi Feb3 plots. More than seventy percent of the occurrences of *Parinari curatellifolia* and *Lannea discolor* on the Pretoriuskop EBPs occurred on the cluster 4 plots. *Parinari curatellifolia* occurred on the Numbi Aug2 and Dec3 plots, and the Shabeni Feb3 plot. *Lannea discolor* occurred on the Kambeni Feb3 plot, the Numbi Aug2, Apr2, Con0, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Feb3 plot.

6.3.1.3 Summary of the results from the CA's on the 1954 species by plot data

In 1954, as with the results from Horn's similarity index, similarity in species composition between plots was mainly because of proximity. Most often plots that were close to one another in space were more likely to be similar in species composition than plots that were further apart. Furthermore, the EBP replicates were located in two main vegetation types in the Pretoriuskop landscape, namely open and closed *Terminalia sericea* - *Combretum* woodlands. The Numbi and Shabeni replicates are located in areas that are dominated by open *Terminalia sericea* - *Combretum* woodlands, and the Kambeni and Fayi replicates are located in areas that are dominated by closed *Terminalia sericea* - *Combretum* woodlands. In 1954, plots on the Numbi and Shabeni replicates in the open *Terminalia sericea* - *Combretum* woodlands were more likely to be similar in species composition than with plots on the Kambeni and Fayi replicates, which were located in the closed *Terminalia sericea* - *Combretum* woodlands.

In 1954, the Numbi and Shabeni replicates in the open *Terminalia sericea* \ *Combretum* woodlands were associated with *Annona senegalensis*, *Senna petersiana*, *Lonchocarpus capassa*, *Bridelia mollis*, *Lannea discolor*, *Papilionacea*, *Turraea nilotica*, *Pterocarpus angolensis*, *Clerodendrum* species, *Olea europaea*, *Commiphora mollis*, *Maytenus heterophylla*, *Pavetta schumanniana*, *Combretum collinum*, *Grewia monticola*, *Bauhinia galpinii*, *Catunaregam spinosa*, *Pseudarthria hookeri*, *Pterocarpus rotundifolius*, *Schotia brachypetala*, *Syzygium cordatum*, and *Vernonia colorata*. Many of the species occurring on the Numbi and Shabeni replicates were found also on the Kambeni and Fayi replicates. In 1954, the Kambeni and Fayi replicates in the closed *Terminalia sericea* \ *Combretum* woodlands were associated with *Ochna natalitia*, *Zanthoxylum capense*, *Antidesma venosum*, *Grewia flavescens*, *Ehretia obtusifolia*, *Mundulea sericea*, *Piliostigma thonningii*, *Ziziphus mucronata*, *Trichilia emetica*, Cassine *transvaalensis*, *Ficus stuhlmannii*, *Lannea schweinfurthii*, *Strychnos spinosa*, *Maytenus senegalensis*, *Sclerocarya birrea*, *Strychnos madagascariensis*, *Acacia exuvialis*, *Acacia sieberiana*, *Ficus stuhlmannii*, and *Phyllanthus reticulatus*. Unlike the Numbi and Shabeni replicates, many of the species occurring on the Kambeni and Fayi replicates were found mainly on the Kambeni and Fayi replicates.

WITS ETD

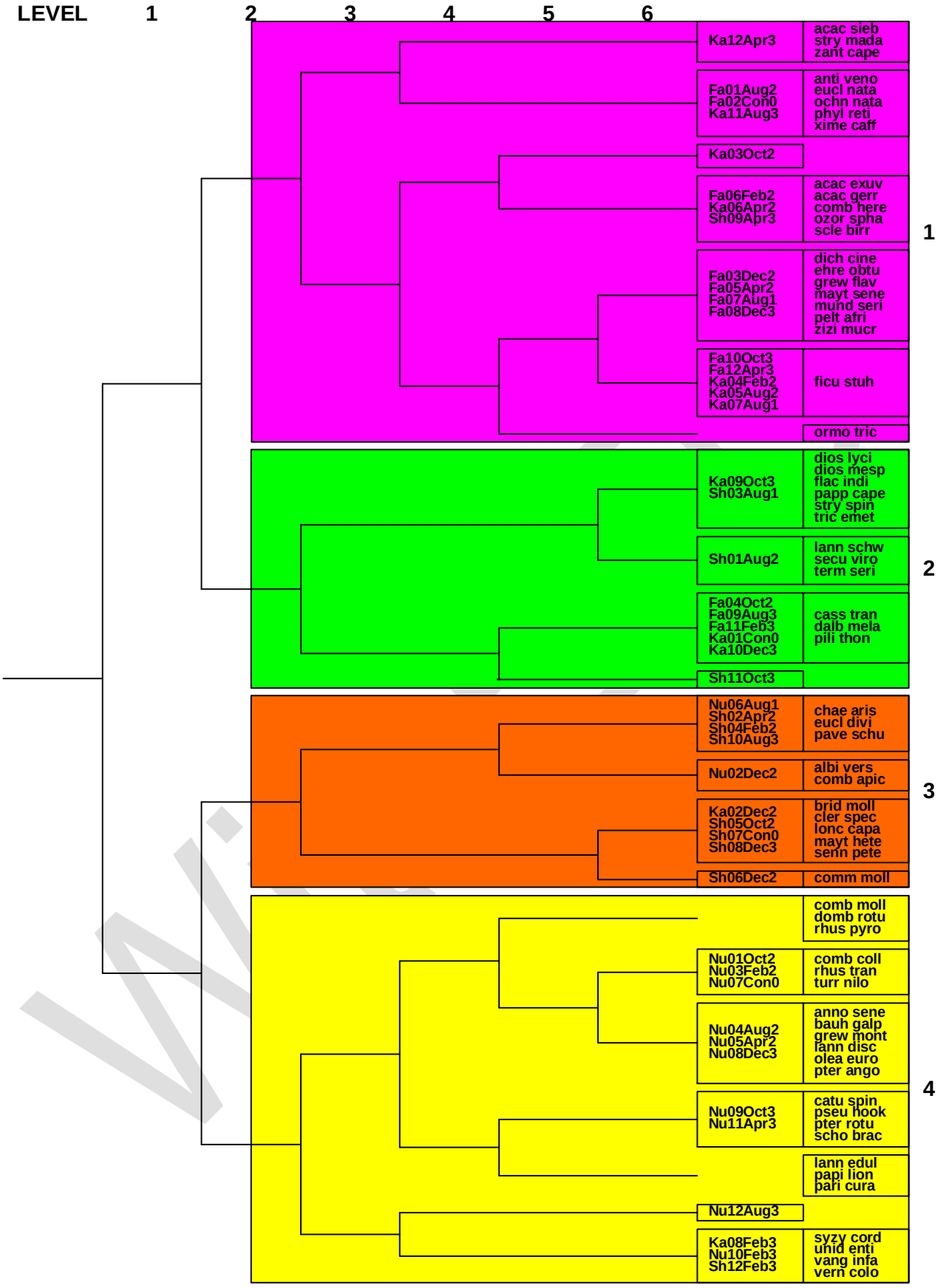


Figure 6-32: Classification of treatment plots and species using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1954 species by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the species are defined in Table 9-1 (p. 210).

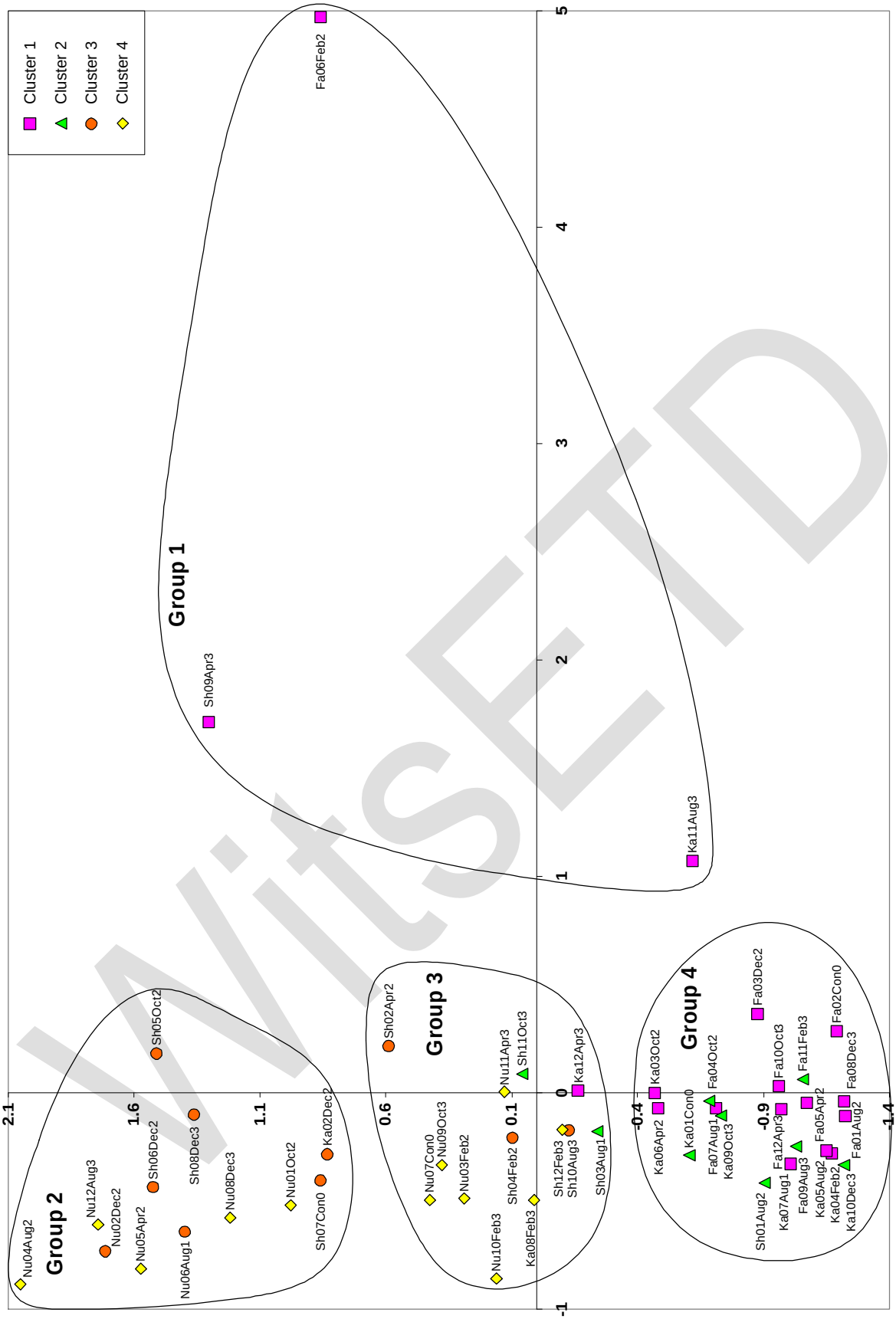


Figure 6-33: Bi-plot of the first two ordination axes from the CA on the 1954 species by plot data showing variation in species composition between treatment plots. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-32). The codes for the treatments are defined in Table 10-1 (p. 214).

WitsETD

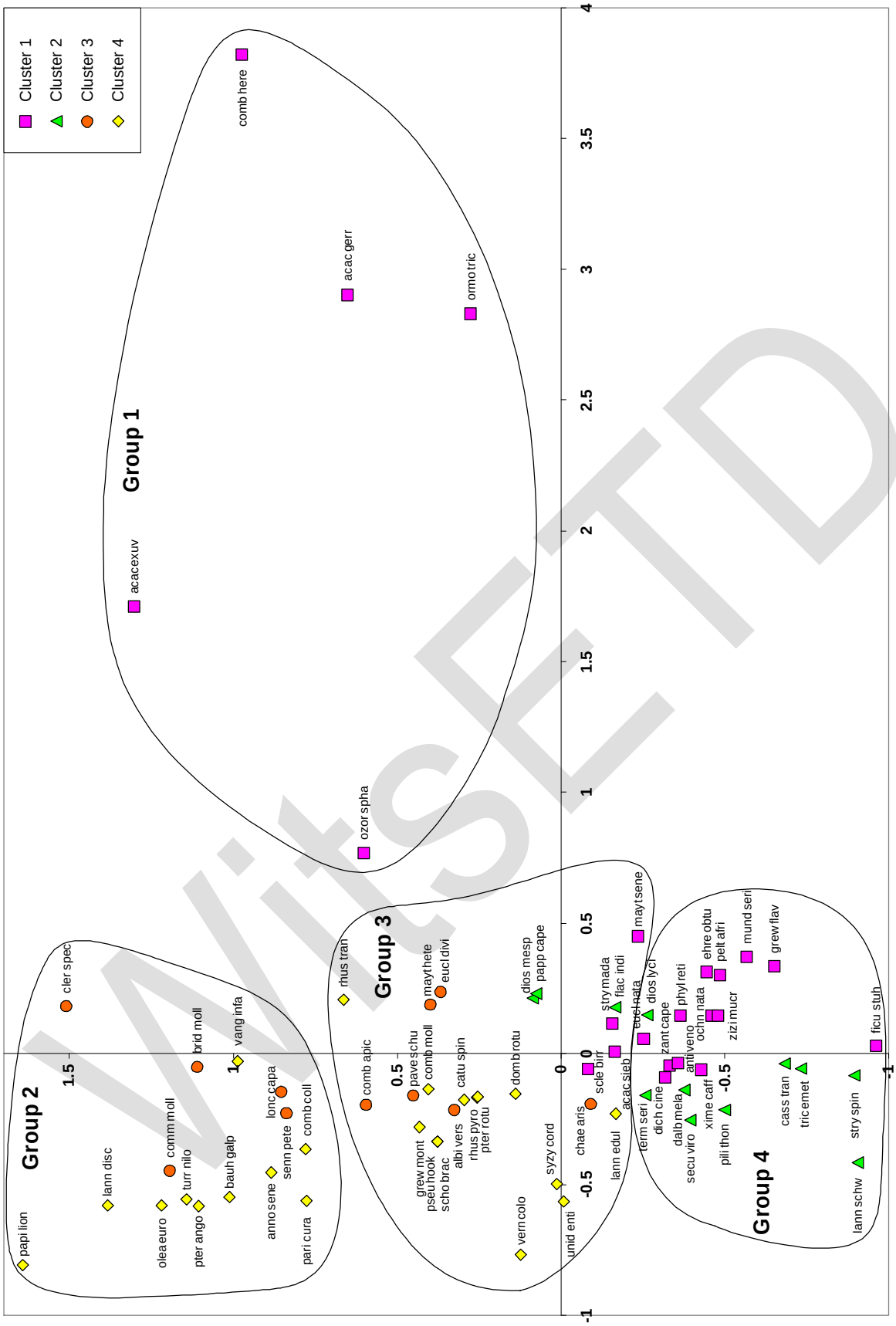


Figure 6-34: Bi-plot of the first two ordination axes from the CA on the 1954 species by plot data showing variation in location (plots) between species. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-32). The codes for the species are defined in Table 9-1 (p. 210).

WitSETD

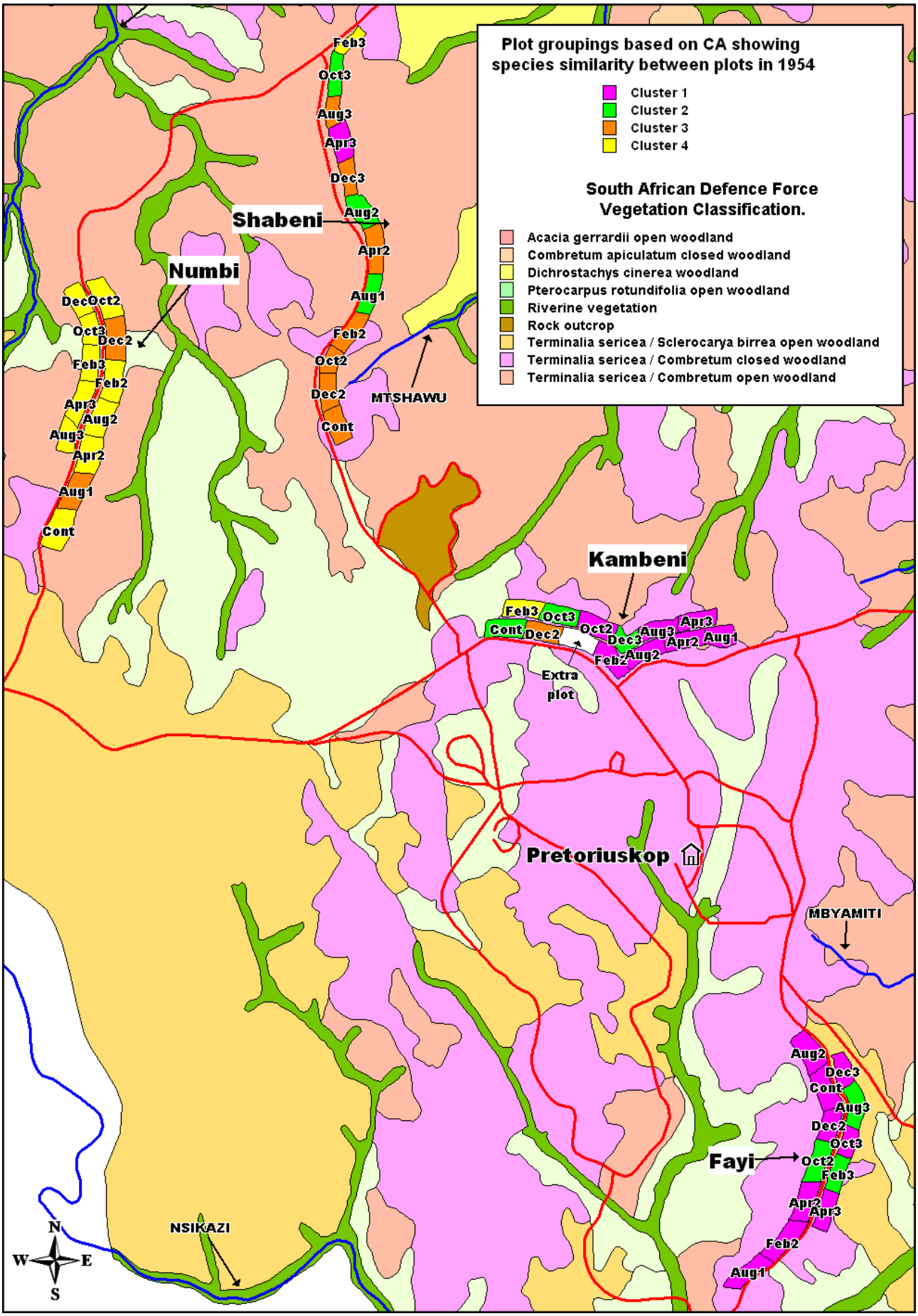


Figure 6-35: Map showing the level 2 clusters from the step-wise Gamma-Ward cluster analysis on the first four ordination axes of the CA on the 1954 species by plot data (Figure 6-32). The codes for the treatments are defined in Table 3-1 (p. 15).

6.3.2 Results from the Correspondence Analysis on the 1996 species by plot data

The results from the CA performed on the 1996 species by plot data are presented in Table 6-11 (p. 133), Figure 6-36 (p. 138), Figure 6-37 (p. 139), Figure 6-38 (p. 140), and Figure 6-39 (p. 141). Table 6-11 shows the Eigenvalues for the first four ordination axes of the CA. Figure 6-36 is a hierarchical cluster tree showing the cluster groups from the step-wise Gamma-Ward cluster analysis on the first four ordination axes. Figure 6-37 is a bi-plot of the first two, weighted eigenvector plots score axes with the data points colour coded to the level 2 cluster colours in Figure 6-36. Figure 6-38 is a bi-plot graph of the first two, weighted eigenvector species score axes with the data points colour coded to the level 2 cluster colours in Figure 6-36. Figure 6-39 is a map showing the layout of the Pretoriuskop EBP experiment with the plots colour coded to the level 2 cluster colours in Figure 6-36. The weighted eigenvector plot scores for the first four ordination axes, the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973) are presented in Appendix 7, Table 15-3 (p. 259). The weighted eigenvector species scores for the first four ordination axes, the species weights, and the effective number of occurrences of the species (N2 diversity of species) are presented in Appendix 7, Table 15-4 (p. 260).

Table 6-11: Eigenvalues for the first four ordination axes of a Correspondence Analysis (CA) on the species by plot data collected in 1996

	Axis 1	Axis 2	Axis 3	Axis 4	Total
Eigenvalue	0.3282	0.2283	0.2015	0.1349	1.8750
% Variation	17.5	12.2	10.7	7.2	47.6

The Eigenvalues, for the first four axes of the CA on the 1996 data were 0.328, 0.228, 0.202, and 0.135 (Table 6-11). The first four eigenvectors accounted for 17.5%, 12.2%, 10.7%, and 7.2% of the variation in the species by plot data respectively in 1996, and 47.6% of the total variation in the species by plot data in 1996 (Table 6-11).

6.3.2.1 Bi-plots of the first two weighted species and plot eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996

There were four main groups of plots and species on the bi-plot graphs of the first two weighted eigenvectors from the Correspondence Analysis on the 1996 data (Figure 6-33 and Figure 6-34). Group 1 comprised species and plots with x-axis eigenvector values greater than 0.35. Group 2 comprised species and plots with x-axis eigenvector values less than 0.35 and y-axis eigenvector values greater than 0.5. Group 3 comprised species and plots with x-axis eigenvector values less than 0.35 and y-axis eigenvector values between 0.5 and -0.5. Group 4 comprised species and plots with x-axis eigenvector values less than 0.35 and y-axis eigenvector values less than -0.5. The plots in Group 1 were not burnt between 1954 and 1996, the plots in Group 2 were related to one another in 1954 (see Group 1 in 1954), and the plots in Group 4 were related to one another by the physical location of the plots and species in the Pretoriuskop region.

The plots in Group 1 were the Fayi Con0 and Dec3 plots, the Kambeni Con0 plot, the Numbi Con0 plot, and the Shabeni Con0 plot (Figure 6-37). Most of the plots in Group 1 were not burnt between 1954 and 1996. The species in Group 1 were *Acacia swazica*, *Bauhinia galpinii*, *Canthium* species, *Cassine aethiopica*, *Combretum mossambicense*, *Commiphora neglecta*, *Croton gratissimus*, *Diospyros lycioides*, *Diospyros whyteana*, *Euclea natalensis*, *Grewia flavescens*, *Heteropyxis natalensis*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Ochna natalitia*, *Olea europaea*, *Peltophorum africanum*, *Psydrax locuples*, *Putterlickia pyracantha*, *Tarenna supra-axillaris*, and *Zanthoxylum capense* (Figure 6-38). *Euclea natalensis*, *Grewia flavescens*, *Ochna natalitia*, and *Peltophorum africanum* occurred on all the plots in Group 1 however, they were also found on many other Pretoriuskop EBPs in 1996. However, *Euclea natalensis* was found in higher densities on the control plots than on any other Pretoriuskop EBP (> 500 plants/Ha). *Diospyros lycioides* was found on four of the five Group 1 plots, however it was also found on many other Pretoriuskop EBPs in 1954. Fifty percent of the occurrences of *Putterlickia pyracantha*, sixty percent of the occurrences of *Olea*

WITS ETD

europaea, and sixty-seven percent of the occurrences of *Commiphora neglecta* on the Pretoriuskop EBPs in 1996 occurred on the Group 1 plots. *Acacia swazica*, *Canthium* species, *Combretum mossambicense*, *Croton gratissimus*, *Diospyros whyteana*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Psydrax locuples*, and *Tarenna supra-axillaris* were found only on Group 1 plots. *Acacia swazica* was found on the Numbi Con0 plot. *Canthium* species was found on the Control plots of the Kambeni, Numbi, and Shabeni replicates. *Combretum mossambicense* was found on the Numbi Con0 plot. *Croton gratissimus* was found on the Kambeni Con0 plot. *Diospyros whyteana* was found on the Numbi Con0 plot. *Hyperacanthus amoenus* was found on the Numbi Con0 and Shabeni Con0 plots. *Kraussia floribunda* was found on the Kambeni Con0 and Numbi Con0 plots. *Psydrax locuples* was found on the Shabeni Con0 plot. *Tarenna supra-axillaris* was found on the Shabeni Con0 plot.

Group 2 comprised the Fayi Feb2, the Kambeni Aug3, and the Shabeni Apr2, Apr3, and Aug3 plots (Figure 6-37). The Shabeni Apr3, Fayi Feb2, and Kambeni Aug3 plots were grouped together in Group 1 in the CA on the 1954 data. The species in Group 2 were *Acacia exuvialis*, *Acacia gerrardii*, *Cassine transvaalensis*, *Combretum hereroense*, *Combretum imberbe*, *Ehretia obtusifolia*, *Euclea divinorum*, *Lannea edulis*, *Ormocarpum trichocarpum*, *Rhus leptodictya*, and *Rhus pentheri* (Figure 6-38). *Ehretia obtusifolia* occurred on all the plots in Group 2 however, it was also found on many other Pretoriuskop EBPs in 1996. *Acacia gerrardii* and *Ormocarpum trichocarpum* were found on four of the five Group 2 plots on 1996. Both *Acacia gerrardii* and *Ormocarpum trichocarpum* were associated with the Group 1 plots in 1954. *Acacia exuvialis* and *Combretum imberbe* were found only on Group 2 plots. *Acacia exuvialis* was found on the Shabeni Apr3 plot, and *Combretum imberbe* was found on the Shabeni Aug3 plot. In 1954, *Acacia exuvialis* was also only found on the Shabeni Apr3 plot.

Group 3 comprised the Fayi Aug2, Dec2, Oct2, Apr2, Aug1, Aug3, Oct3, Feb3, and Apr3 plots, the Kambeni Dec2, Oct2, Feb2, Aug2, Apr2, Aug1, Feb3, Oct3, Dec3, and Apr3 plots, the Numbi Feb2 and Apr2 plots, and the Shabeni Aug2, Dec2, Dec3, Oct3, and Feb3 plots (Figure 6-37). The species in Group 3 were *Acacia sieberiana*, *Acacia xanthophloea*, *Albizia harveyi*, *Antidesma venosum*, *Combretum apiculatum*, *Combretum collinum*, *Combretum molle*, *Dalbergia melanoxylon*, *Dichrostachys cinerea*, *Diospyros mespiliformis*, *Dombeya rotundifolia*, *Ficus sycomorus*, *Flacourtia indica*, *Gardenia volkensii*, *Grewia hexamita*, *Grewia monticola*, *Kigelia africana*, *Lannea schweinfurthii*, *Lonchocarpus capassa*, *Markhamia zanzibarica*, *Maytenus heterophylla*, *Maytenus senegalensis*, *Mundulea sericea*, *Ozoroa sphaerocarpa*, *Pappea capensis*, *Parinari curatellifolia*, *Phyllanthus reticulatus*, *Piliostigma thonningii*, *Pterocarpus angolensis*, *Pterocarpus rotundifolius*, *Rhus pyroides*, *Rhus transvaalensis*, *Schotia brachypetala*, *Sclerocarya birrea*, *Securinega virosa*, *Senna petersiana*, *Spirostachys africana*, *Strychnos madagascariensis*, *Syzygium guineense*, *Terminalia sericea*, *Trichilia emetica*, *Vangueria infausta*, *Ximenia caffra*, and *Ziziphus mucronata* (Figure 6-38). *Dalbergia melanoxylon*, *Dichrostachys cinerea*, *Maytenus senegalensis*, *Strychnos madagascariensis*, and *Terminalia sericea* occurred on all the plots in Group 3, and they were all mainly found on the plots in Group 3 in 1996. *Securinega virosa* was found on nineteen of the twenty-six Group 3 plots in 1996 and was found mainly on the Group 3 plots. *Diospyros mespiliformis* and *Ziziphus mucronata* were found on twenty of the twenty-six Group 3 plots in 1996 and were found mainly on the Group 3 plots. *Senna petersiana* was found on twenty-two of the twenty-six Group 3 plots in 1996 and was found mainly on the Group 3 plots. *Maytenus heterophylla* was found on twenty-three of the twenty-six Group 3 plots in 1996 and was found mainly on the Group 3 plots. *Sclerocarya birrea* was found on twenty-five of the twenty-six Group 3 plots in 1996 and was found mainly on the Group 3 plots. Between fifty and sixty percent of the occurrences of *Grewia hexamita*, *Kigelia africana*, *Pterocarpus rotundifolius*, *Trichilia emetica*, *Parinari curatellifolia*, *Antidesma venosum*, *Rhus transvaalensis*, *Maytenus heterophylla*, *Flacourtia indica*, *Diospyros mespiliformis*, *Sclerocarya birrea*, *Piliostigma thonningii*, *Phyllanthus reticulatus*, *Senna petersiana*, *Dichrostachys cinerea*, *Maytenus senegalensis*, *Terminalia sericea*, *Pappea capensis*, *Strychnos madagascariensis*, *Ximenia caffra*, *Dalbergia melanoxylon*, and *Securinega virosa* on the Pretoriuskop EBPs in 1996 occurred on the Group 3 plots. Between sixty and seventy percent of the occurrences of *Gardenia volkensii* and *Ziziphus mucronata* on the Pretoriuskop EBPs in 1996 occurred on the Group 3 plots. Between seventy and eighty percent of the occurrences of *Acacia sieberiana*, *Mundulea sericea*, *Ozoroa sphaerocarpa* on the Pretoriuskop EBPs in 1996 occurred on the Group 3 plots. *Acacia xanthophloea*,

WITS ETD

Albizia harveyi, *Ficus sycomorus*, *Lannea schweinfurthii*, *Markhamia zanzibarica*, *Syzygium guineense*, *Vangueria infausta* were found only on Group 3 plots. *Acacia xanthophloea* was found on the Kambeni Dec3 plot. *Albizia harveyi* was found on the Kambeni Apr3 plot. *Ficus sycomorus* was found on the Fayi Aug2 plot. *Lannea schweinfurthii* was found on the Kambeni Feb3 plot and Shabeni Dec2 plot. *Markhamia zanzibarica* was found on the Shabeni Dec2 plot. *Syzygium guineense* was found on the Fayi Aug1 plot. *Vangueria infausta* was found on the Fayi Aug1 plot, the Kambeni Aug1, Feb3, and Dec3 plots, and the Shabeni Aug2 and Dec2 plots.

Group 4 comprised the Numbi Oct2, Dec2, Aug2, Aug1, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, the Shabeni Aug1, Feb2, and Oct2 plots (Figure 6-37). These plots occurred in the *Terminalia sericea* - *Combretum* open woodlands of Pretoriuskop (Figure 6-39). The species in Group 4 were *Acacia caffra*, *Albizia versicolor*, *Annona senegalensis*, *Berchemia zeyheri*, *Catunaregam spinosa*, *Faurea saligna*, *Hippobromus pauciflorus*, *Lannea discolor*, *Pavetta schumanniana*, *Strychnos spinosa*, *Syzygium cordatum*, *Turraea nilotica* (Figure 6-38). *Catunaregam spinosa*, *Pavetta schumanniana*, and *Turraea nilotica* occurred on all the plots in Group 4 however, they were also found on many other Pretoriuskop EBPs in 1996. *Annona senegalensis* was found on ten of the twelve Group 4 plots however, it was also found on many other Pretoriuskop plots on 1996. *Albizia versicolor* was found on eleven of the twelve Group 4 plots, and it was found mainly on the Group 4 plots on 1996. Fifty percent of the occurrences of *Hippobromus pauciflorus* and *Albizia versicolor* on the Pretoriuskop EBPs in 1996 were on the Group 4 plots. Sixty-seven percent of the occurrences of *Strychnos spinosa* on the Pretoriuskop EBPs in 1996 were on the Group 4 plots. *Acacia caffra*, *Berchemia zeyheri*, *Faurea saligna*, *Lannea discolor*, and *Syzygium cordatum* were found only on the Group 4 plots. *Acacia caffra* was found on the Numbi Oct3 and Apr3 plots. *Berchemia zeyheri* was found on the Numbi Apr3 plot. *Faurea saligna* was found on the Numbi Aug1 plot. *Lannea discolor* was found on the Numbi Oct2, Aug2, Dec3, Feb3, and Apr3 plots. *Syzygium cordatum* the Numbi Oct2 and Aug1 plots, the Shabeni Aug1 plot.

6.3.2.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996

The step-wise Ward-Gamma cluster analysis was used to summarise the variation of plots and species along the first four eigenvectors of the Correspondence Analysis on the 1996 species by plot data. There were four main clusters of plots and species at level 2 of the step-wise Ward-Gamma cluster analysis (Figure 6-36). These clusters differed from the two dimensional grouping of plots and species along the first two eigenvectors described above (Figure 6-37 and Figure 6-38).

Cluster 1 was similar to Group 1 in 1996, the plots in Group 1 and Cluster 1 were the same, but there were more species in Cluster 1 than in Group 1 in 1996. Cluster 1 comprised the Fayi Con0 and Dec3 plots, the Kambeni Con0 plot, the Numbi Con0 plot, and the Shabeni Con0 plot (Figure 6-36). Cluster 1 contained all the plots that were not burnt between 1954 and 1996. The species in Cluster 1 were *Acacia swazica*, *Antidesma venosum*, *Bauhinia galpinii*, *Canthium* species, *Cassine aethiopica*, *Combretum mossambicense*, *Commiphora neglecta*, *Croton gratissimus*, *Dalbergia melanoxylon*, *Diospyros lycioides*, *Diospyros mespiliformis*, *Diospyros whyteana*, *Euclea natalensis*, *Grewia flavescens*, *Heteropyxis natalensis*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Ochna natalitia*, *Olea europaea*, *Peltophorum africanum*, *Phyllanthus reticulatus*, *Psydrax locuples*, *Putterlickia pyracantha*, *Rhus transvaalensis*, *Securinega virosa*, *Spirostachys africana*, *Tarenna supra-axillaris*, and *Zanthoxylum capense* (Figure 6-36). *Dalbergia melanoxylon*, *Diospyros mespiliformis*, *Euclea natalensis*, *Grewia flavescens*, *Ochna natalitia*, *Peltophorum africanum*, and *Securinega virosa* occurred on all the plots in Cluster 1 however, they were also found on many other Pretoriuskop EBPs in 1996. *Antidesma venosum*, *Diospyros lycioides*, *Phyllanthus reticulatus*, and *Rhus transvaalensis* were found on four of the five Cluster 1 plots in 1996 however, they were also found on many other Pretoriuskop plots in 1996. Fifty percent of the occurrences of *Putterlickia pyracantha* and *Spirostachys africana* on the Pretoriuskop EBPs in 1996 were on the Cluster 1 plots. Between sixty and seventy percent of the occurrences of *Commiphora neglecta* and *Olea europaea* on the Pretoriuskop EBPs in 1996 were on the Cluster 1 plots. *Acacia swazica*, *Canthium* species, *Combretum mossambicense*, *Croton*

gratissimus, *Diospyros whyteana*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Psydrax locuples*, and *Tarenna supra-axillaris* were found only on the Cluster 1 plots in 1996. *Acacia swazica* was found on the Numbi Con0 plot. *Canthium* species was found on the Kambeni Con0 plot, the Numbi Con0 plot, and the Shabeni Con0 plot. *Combretum mossambicense* was found on the Numbi Con0 plot. *Croton gratissimus* was found on the Kambeni Con0 plot. *Diospyros whyteana* was found on the Numbi Con0 plot. *Hyperacanthus amoenus* was found on the Numbi Con0 plot and the Shabeni Con0 plot. *Kraussia floribunda* was found on the Kambeni Con0 plot and the Numbi Con0 plot. *Psydrax locuples* was found on the Shabeni Con0 plot. Finally, *Tarenna supra-axillaris* was found on the Shabeni Con0 plot.

Cluster 2 was similar to Group 4 in 1996, the plots in Group 4 and Cluster 2 were the same, but there were more species in Cluster 2 than in Group 4 in 1996. Cluster 2 comprised the Numbi Oct2, Dec2, Aug2, Aug1, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Aug1, Feb2, and Oct2 plots (Figure 6-36). Most of the plots in Cluster 2 were on the Numbi replicate (Figure 6-39). These plots occurred in the *Terminalia sericea* - *Combretum* open woodlands of Pretoriuskop (Figure 6-39). The Numbi Oct2, Dec2, Aug2, Dec3, Oct3, Feb3, Apr3, and Aug3 plots were adjacent to one another, and the Shabeni Aug1, Feb2, and Oct2 plots were adjacent to one another (Figure 6-39). The species in Cluster 2 were *Acacia caffra*, *Albizia versicolor*, *Annona senegalensis*, *Berchemia zeyheri*, *Catunaregam spinosa*, *Dombeya rotundifolia*, *Faurea saligna*, *Flacourtia indica*, *Hippobromus pauciflorus*, *Lannea discolor*, *Parinari curatellifolia*, *Pavetta schumanniana*, *Pterocarpus rotundifolius*, *Schotia brachypetala*, *Strychnos spinosa*, *Syzygium cordatum*, and *Turraea nilotica* (Figure 6-36). *Catunaregam spinosa*, *Pavetta schumanniana*, and *Turraea nilotica* occurred on all the plots on Cluster 2 however, they were also found on many Pretoriuskop EBPs in 1996. *Annona senegalensis* was found on ten of the twelve Cluster 2 plots however, it was also found on many other Pretoriuskop plots in 1996. *Albizia versicolor* was found on eleven of the twelve Cluster 2 plots, and it was found mainly on the Cluster 2 plots on 1996. Fifty percent of the occurrences of *Albizia versicolor*, *Hippobromus pauciflorus*, *Pterocarpus rotundifolius*, and *Schotia brachypetala* on the Pretoriuskop EBPs in 1996 were on the Cluster 2 plots. Sixty-seven percent of the occurrences of *Strychnos spinosa* on the Pretoriuskop EBPs in 1996 were on the Cluster 2 plots. *Acacia caffra*, *Berchemia zeyheri*, *Faurea saligna*, *Lannea discolor*, and *Syzygium cordatum* occurred only on the Cluster 2 plots. *Acacia caffra* was found on the Numbi Oct3 and Apr3 plots. *Berchemia zeyheri* was found on the Numbi Apr3 plot. *Faurea saligna* was found on the Numbi Aug1 plot. *Lannea discolor* was found on the Numbi Oct2, Aug2, Dec3, Feb3, and Apr3 plots. *Syzygium cordatum* the Numbi Oct2 and Aug1 plots, the Shabeni Aug1 plot.

Cluster 3 comprised many Group 3 plots and species in 1996. Cluster 3 comprised the Fayi Aug2, Dec2, Apr2, Aug1, Aug3, Oct3, Feb3, and Apr3 plots, the Kambeni Dec2, Oct2, Feb2, Aug2, Apr2, Aug1, Feb3, Oct3, Dec3, Aug3, and Apr3 plots, and the Shabeni Dec3 and Oct3 plots (Figure 6-36). Most of the plots in Cluster 3 occurred on the *Terminalia sericea* - *Combretum* closed woodlands of Pretoriuskop (Figure 6-39). The Fayi Dec2, Apr2, Aug3, Oct3, Feb3, and Apr3 plots were adjacent to one another and the Kambeni Dec2, Oct2, Feb2, Aug2, Apr2, Aug1, Feb3, Oct3, Dec3, Aug3, and Apr3 plots were adjacent to one another (Figure 6-36). The species in Cluster 3 were *Acacia xanthophloea*, *Albizia harveyi*, *Dichrostachys cinerea*, *Ficus sycomorus*, *Gardenia volkensii*, *Grewia hexamita*, *Kigelia africana*, *Maytenus senegalensis*, *Rhus leptodictya*, *Rhus pyroides*, *Strychnos madagascariensis*, *Syzygium guineense*, *Terminalia sericea*, *Ximenia caffra*, and *Ziziphus mucronata* (Figure 6-36). *Dichrostachys cinerea*, *Maytenus senegalensis*, *Strychnos madagascariensis*, and *Terminalia sericea* occurred on all the Cluster 3 plots however, they were also found on many other Pretoriuskop EBPs in 1996. *Ximenia caffra* occurred on fifteen of the twenty-one Cluster 3 plots in 1996. *Ziziphus mucronata* occurred on sixteen of the twenty-one Cluster 3 plots in 1996. Between fifty and sixty percent of the occurrences of *Grewia hexamita*, *Kigelia africana*, and *Ziziphus mucronata* on the Pretoriuskop EBPs in 1996 were on the Cluster 3 plots. Sixty-seven percent of the occurrences of *Rhus leptodictya* on the Pretoriuskop EBPs in 1996 were on Cluster 3 plots. *Acacia xanthophloea*, *Albizia harveyi*, *Ficus sycomorus*, *Syzygium guineense*, and *Gardenia volkensii* were found only on the Cluster 3 plots in 1996. *Acacia xanthophloea* was found on the Kambeni Dec3 plot. *Albizia harveyi* was found on the Kambeni Apr3 plot. *Ficus sycomorus* was found on the Fayi Aug2 plot. *Syzygium guineense* was found on the Fayi Aug1 plot. *Gardenia volkensii* was found on the Fayi Dec2 plot and the Kambeni Feb2 and Aug3 plots in 1996.

Cluster 4 comprised the Fayi Oct2 and Feb2 plots, the Numbi Feb2 and Apr2 plots, and the Shabeni Aug2, Apr2, Dec2, Apr3, Aug3, and Feb3 plots (Figure 6-36). These plots occurred mainly in the *Terminalia sericea* - *Combretum* open woodlands of Pretoriuskop (Figure 6-39). The Shabeni Aug2 and Apr2 plots were adjacent to one another and the Shabeni Apr3 and Aug3 plots were adjacent to one another (Figure 6-39). The species in Cluster 4 were *Acacia exuvialis*, *Acacia gerrardii*, *Acacia sieberiana*, *Cassine transvaalensis*, *Combretum apiculatum*, *Combretum collinum*, *Combretum hereroense*, *Combretum imberbe*, *Combretum molle*, *Ehretia obtusifolia*, *Euclea divinorum*, *Grewia monticola*, *Lannea edulis*, *Lannea schweinfurthii*, *Lonchocarpus capassa*, *Markhamia zanzibarica*, *Maytenus heterophylla*, *Mundulea sericea*, *Ormocarpum trichocarpum*, *Ozoroa sphaerocarpa*, *Pappea capensis*, *Piliostigma thonningii*, *Pterocarpus angolensis*, *Rhus pentheri*, *Sclerocarya birrea*, *Senna petersiana*, *Trichilia emetica*, and *Vangueria infausta* (Figure 6-36). *Maytenus heterophylla* occurred on all the plots in Cluster 4 however, it was also found on many other Pretoriuskop EBPs in 1996. *Acacia gerrardii*, *Ehretia obtusifolia*, and *Grewia monticola* were found on seven of the ten Cluster 4 plots in 1996. *Lonchocarpus capassa* was found on eight on the ten Cluster 4 plots in 1996. *Sclerocarya birrea* and *Senna petersiana* were found on nine of the ten Cluster 4 plots in 1996. Fifty percent of the occurrences of *Lannea schweinfurthii* on the Pretoriuskop EBPs in 1996 were on the Cluster 4 plots. *Acacia exuvialis*, *Combretum imberbe*, and *Markhamia zanzibarica* were found only on the Cluster 4 plots in 1996. *Acacia exuvialis* was found on the Shabeni Apr3 plot. *Combretum imberbe* was found on the Shabeni Aug3 plot. *Markhamia zanzibarica* was found on the Shabeni Dec2 plot.

6.3.2.3 Summary of the results from the CA's on the 1996 species by plot data

In 1996, similarity in species composition between plots was mainly due to location and proximity of the plots to one another instead of the treatment applied to the plots. Plots that occurred in the open *Terminalia sericea* - *Combretum* woodlands (Numbi and Shabeni) were more likely to have similar species compositions in comparison with plots that occurred in the closed *Terminalia sericea* - *Combretum* woodlands (Fayi and Kambeni). Furthermore, plots that were adjacent to one another were more likely to have similar species compositions than plots that were further apart. Some plots that were similar to one another in species composition in 1996 were also similar to one another in 1954 regardless of the treatment that had been applied to the plots.

In 1996, the Numbi and Shabeni plots in the open *Terminalia sericea* - *Combretum* woodlands were associated with *Catunaregam spinosa*, *Pavetta schumanniana*, *Turraea nilotica*, *Annona senegalensis*, *Albizia versicolor*, *Hippobromus pauciflorus*, *Albizia versicolor*, *Strychnos spinosa*, *Acacia caffra*, *Berchemia zeyheri*, *Faurea saligna*, *Lannea discolor*, *Syzygium cordatum*, *Pterocarpus rotundifolius*, *Schotia brachypetala*, *Maytenus heterophylla*, *Acacia gerrardii*, *Ehretia obtusifolia*, *Grewia monticola*, *Lonchocarpus capassa*, *Sclerocarya birrea*, *Senna petersiana*, *Lannea schweinfurthii*, *Acacia exuvialis*, *Combretum imberbe*, and *Markhamia zanzibarica*. As in 1954 many of the species occurring on the Numbi and Shabeni replicates were also found on the Kambeni and Fayi replicates. In 1996, the Fayi and Kambeni plots in the closed *Terminalia sericea* - *Combretum* woodlands were mainly associated with *Maytenus senegalensis*, *Strychnos madagascariensis*, *Ximenia caffra*, *Ziziphus mucronata*, *Grewia hexamita*, *Kigelia africana*, *Rhus leptodictya*, *Acacia xanthophloea*, *Albizia harveyi*, *Ficus sycomorus*, *Syzygium guineense*, and *Gardenia volkensii*. The species composition on the control plots was an exception to this. The plots that were not burnt between 1954 and 1996 had species compositions that were more similar to one another than with any of the other plots in Pretoriuskop. The species associated with the control plots were *Euclea natalensis*, *Diospyros lycioides*, *Putterlickia pyracantha*, *Olea europaea*, *Commiphora neglecta*, *Acacia swazica*, *Canthium* species, *Combretum mossambicense*, *Croton gratissimus*, *Diospyros whyteana*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Psydrax locuples*, *Tarenna supra-axillaris*, *Dalbergia melanoxylon*, *Grewia flavescens*, *Ochna natalitia*, *Peltophorum africanum*, *Securinega virosa*, *Antidesma venosum*, *Phyllanthus reticulatus*, *Rhus transvaalensis*, and *Spirostachys africana*. The density of *Euclea natalensis* on the control plots was high (> 500 plants/Ha).

WITS ETD

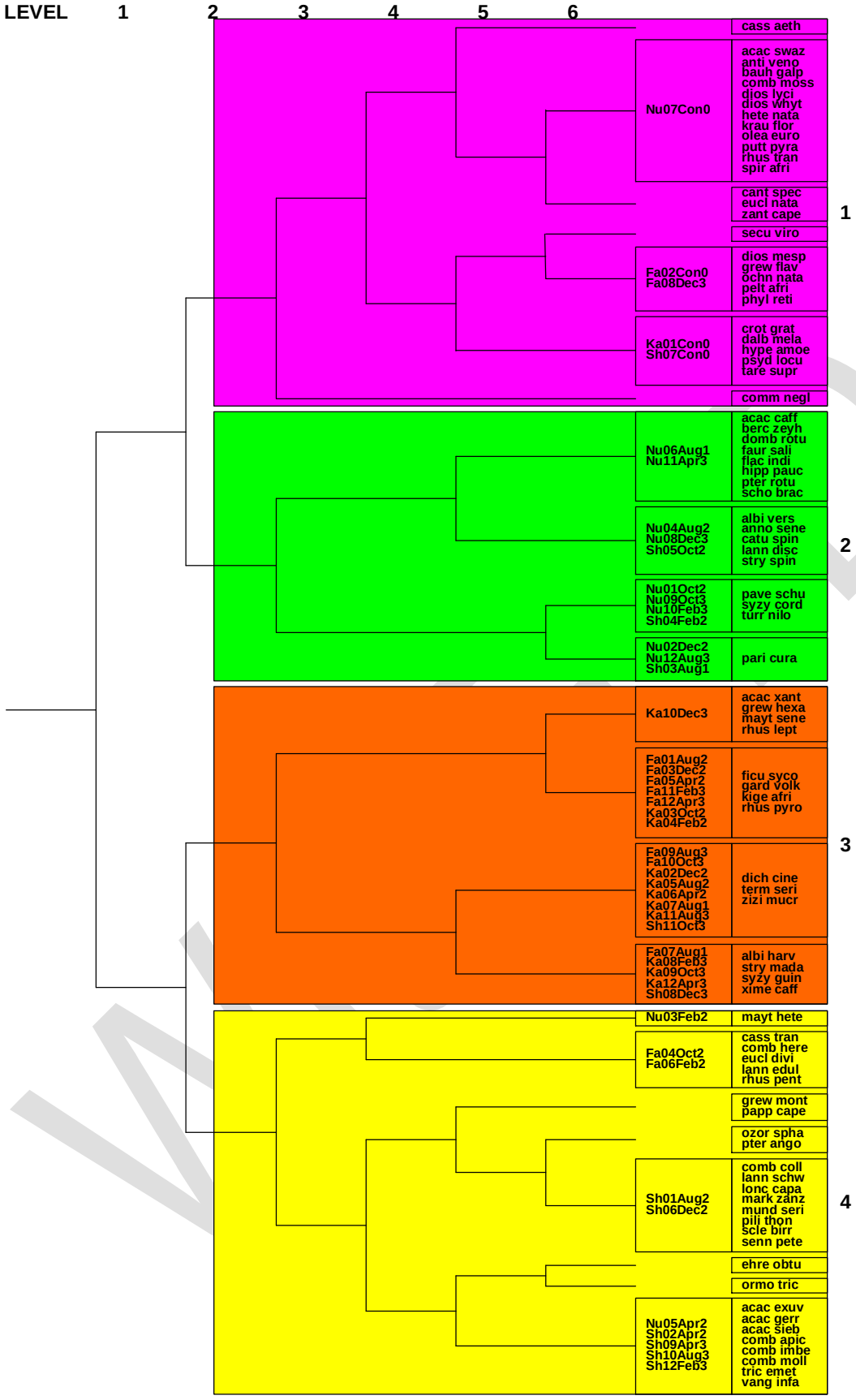


Figure 6-36: Classification of treatment plots and species using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 species by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the species are defined in Table 9-1 (p. 210).

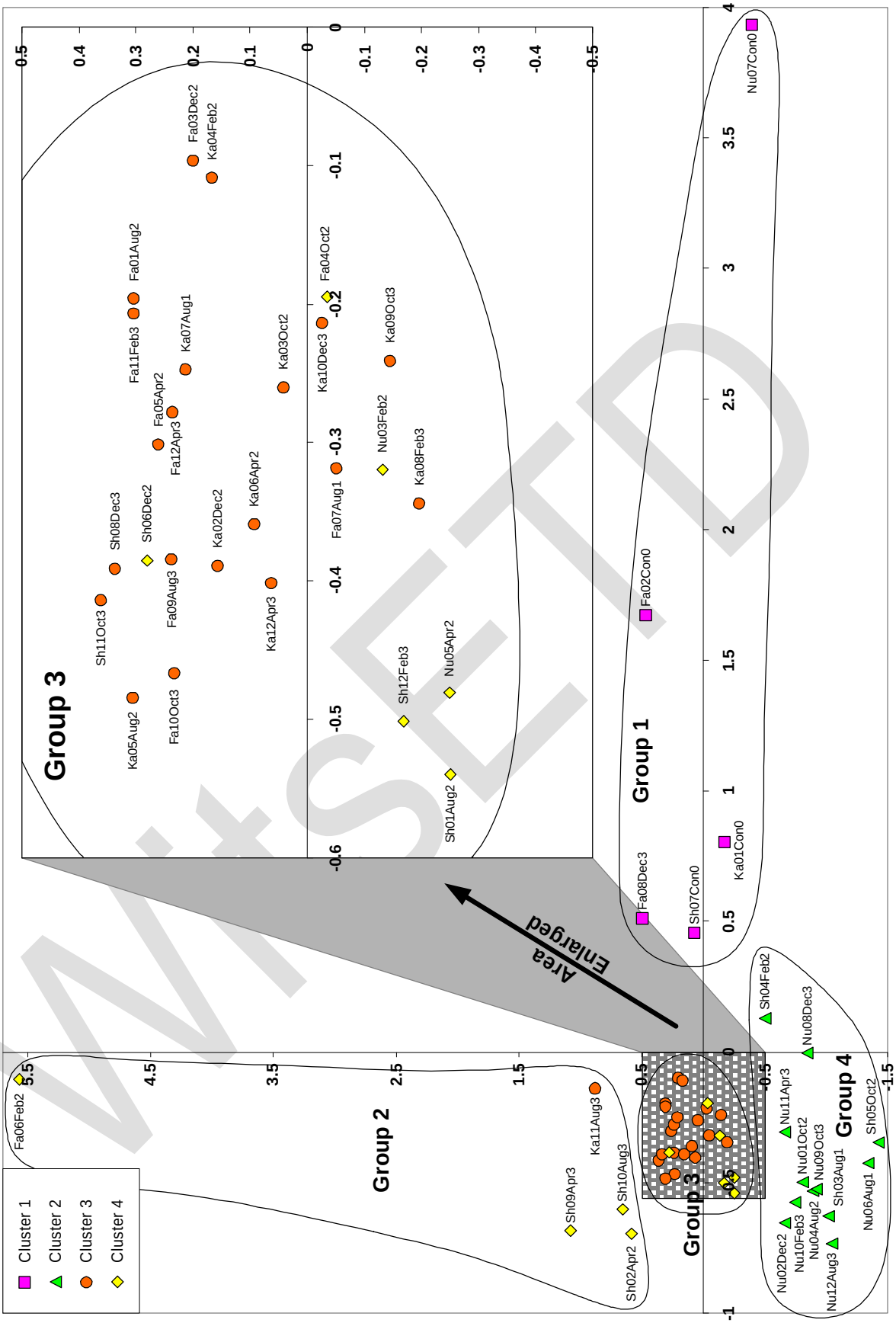


Figure 6-37: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in species composition between treatment plots. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-36). The codes for the treatment plots are defined in Table 10-1 (p. 214).

WitSETD

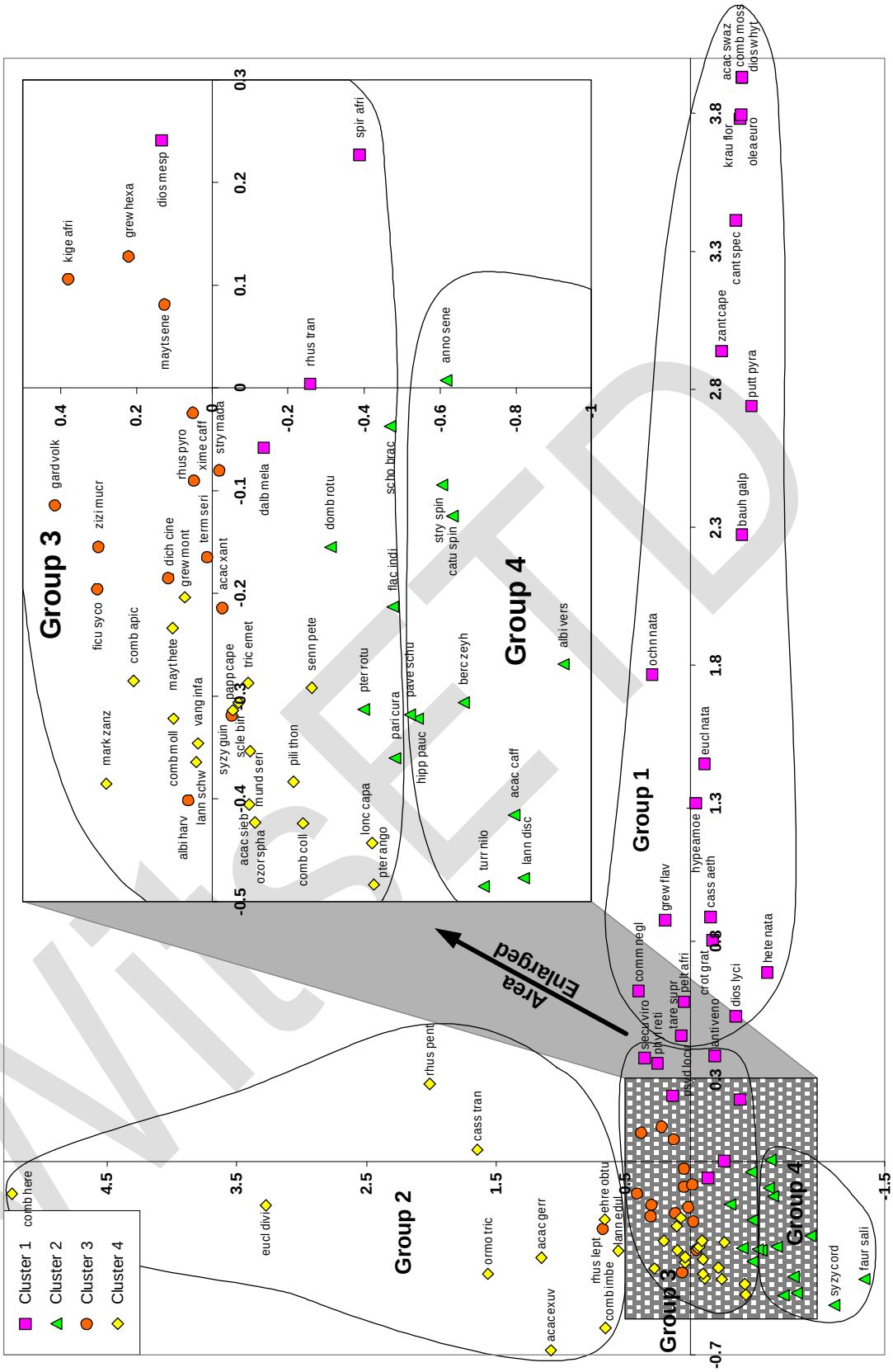


Figure 6-38: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in location (plots) between species. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-36). The codes for the species are defined in Table 9-1 (p. 210).

WITS ETD

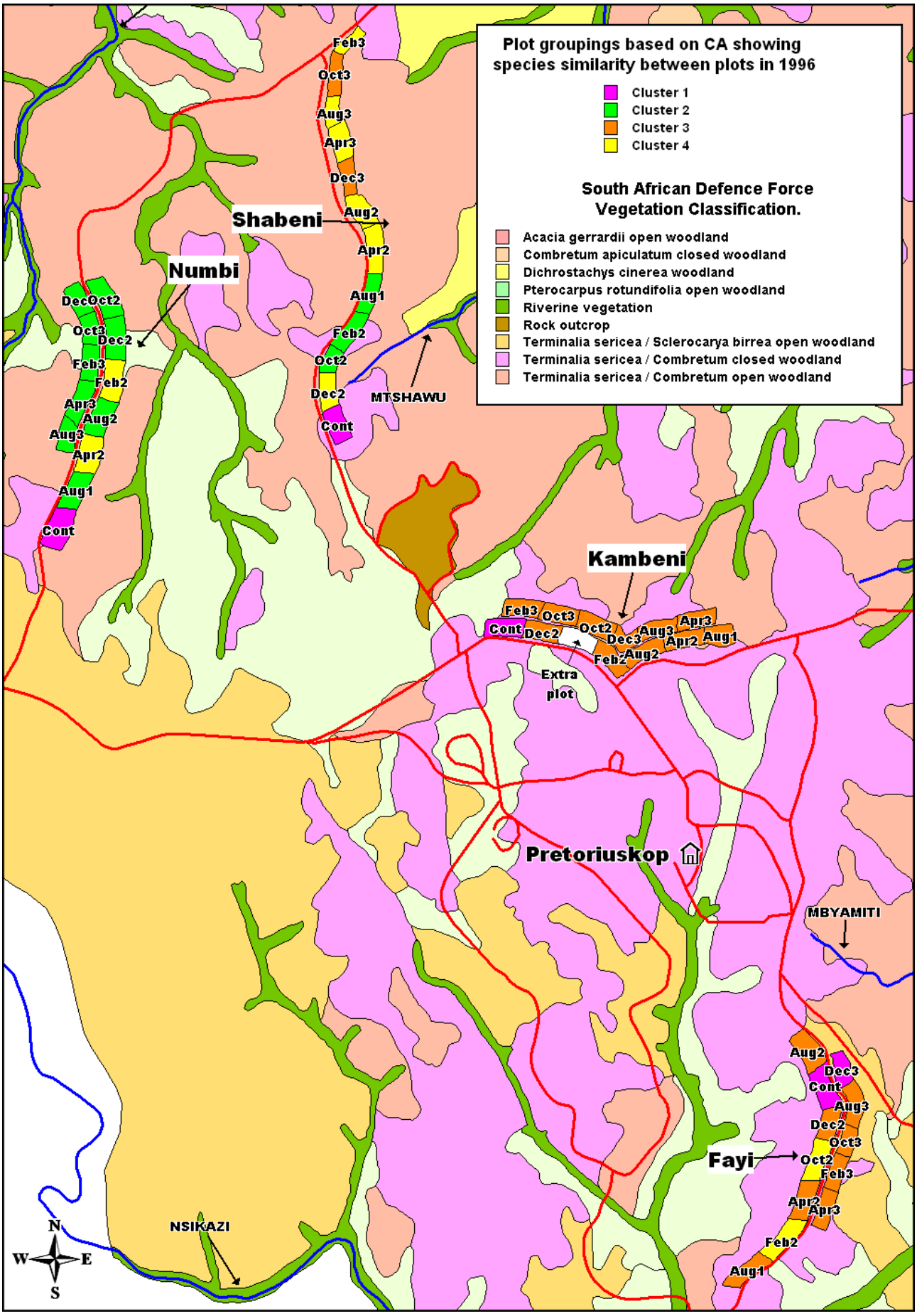


Figure 6-39: Map showing the level 2 groupings of a classification of treatment plots using a stepwise cluster analysis on the first four ordination axes of a CA on the 1996 species by plot data (Figure 6-36). The codes for the treatments are defined in Table 3-1 (p. 15).

6.3.3 Results from the Correspondence Analysis on the 1996 species by plot data with the first eight axes of the CA on the 1954 survey data as covariables

The results from the CA performed on the 1996 species by plot data with the 1954 covariables are presented in Table 6-12 (p. 142), Figure 6-40 (p. 147), Figure 6-41 (p. 148), Figure 6-42 (p. 149), and Figure 6-43 (p. 150). Table 6-12 shows the Eigenvalues for the first four ordination axes of the CA. Figure 6-40 is a hierarchical cluster tree showing the cluster groups from the step-wise Gamma-Ward cluster analysis on the first four ordination axes. Figure 6-41 is a bi-plot of the first two, weighted eigenvector plots score axes with the data points colour coded to the level 2 cluster colours in Figure 6-40. Figure 6-42 is a bi-plot of the first two, weighted eigenvector species score axes with the data points colour coded to the level 2 cluster colours in Figure 6-40. Figure 6-43 is a map showing the layout of the Pretoriuskop EBP experiment with the plots colour coded to the level 2 cluster colours in Figure 6-40. The weighted eigenvector plot scores for the first four ordination axes, the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973) are presented in Table 15-5 (p. 262). The weighted eigenvector species scores for the first four ordination axes, the species weights, and the effective number of occurrences of the species (N2 diversity of species) are presented in Table 15-6 (p. 263).

Table 6-12: Eigenvalues for the first four ordination axes of a Correspondence Analysis (CA) on the species by plot data collected in 1996 with the first eight ordination axes of the 1954 CA as covariables.

	Axis 1	Axis 2	Axis 3	Axis 4	Total
Eigenvalue	0.2896	0.1232	0.1036	0.0883	1.2420
% Variation	23.3	9.9	8.3	7.1	48.7

The Eigenvalues, for the first four axes of the CA on the 1996 data with the 1954 covariables were 0.290, 0.123, 0.104, and 0.088 (Table 6-12). The first four eigenvectors accounted for 23.3%, 9.9%, 8.3%, and 7.1% of the variation in the species by plot data respectively in 1996, and 48.7% of the total variation in the species by plot data in 1996 (Table 6-10).

6.3.3.1 Bi-plots of the first two weighted species and plot eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996 accounting for the relationship between the species and plots in 1954

There were five main groups of plots and species on the bi-plots of the first two weighted eigenvectors from the Correspondence Analysis on the 1996 data with the 1954 covariables (Figure 6-41 and Figure 6-42). Group 1 comprised species and plots with x-axis eigenvector values greater than 0.35. Group 2 comprised species and plots with x-axis eigenvector values less than -0.7. Group 3 comprised plots and species with x-axis eigenvector values between 0.35 and -0.7, and y-axis eigenvector values greater than 0.1. Group 4 comprised plots and species with x-axis eigenvector values between 0.35 and -0.7, and y-axis eigenvector values between 0.1 and -0.45. Group 5 comprised plots and species with x-axis eigenvector values between 0.35 and -0.7, and y-axis eigenvector values less than -0.45.

Group 1 comprised the Fayi Con0 and Dec3 plots, the Kambeni Con0 plot, the Numbi Con0 plot, and the Shabeni Feb2 and Con0 plots (Figure 6-41). Most of the plots in Group 1 were not burnt between 1954 and 1996. The species in Group 1 were *Acacia swazica*, *Antidesma venosum*, *Bauhinia galpinii*, *Canthium* sp., *Cassine aethiopica*, *Combretum mossambicense*, *Commiphora neglecta*, *Croton gratissimus*, *Diospyros lycioides*, *Diospyros whyteana*, *Euclea natalensis*, *Grewia flavescens*, *Heteropyxis natalensis*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Ochna natalitia*, *Olea europaea*, *Peltophorum africanum*, *Psydrax locuples*, *Putterlickia pyracantha*, *Rhus pentheri*, *Securinega virosa*, *Tarenna supra-axillaris*, and *Zanthoxylum capense* (Figure 6-42). Most of the species and plots that were in Group 1 from the CA on the 1996 data using covariables were also in Group 1 from the CA on the 1996 data without covariables. *Euclea natalensis*, *Grewia flavescens*, *Ochna natalitia*, *Peltophorum africanum*, and *Securinega virosa* occurred on

WITSETD

all the plots in Group 1 however, they were also found on many other Pretoriuskop EBPs in 1996. *Euclea natalensis* was found in higher densities on the control plots than on any other Pretoriuskop EBP (> 500 plants/Ha). *Antidesma venosum*, *Diospyros lycioides*, and *Rhus pentheri* was found on five of the six Group 1 plots however, they also were found on many other Pretoriuskop EBPs. Fifty percent of the occurrences of *Putterlickia pyracantha*, sixty percent of the occurrences of *Olea europaea*, and sixty-seven percent of the occurrences of *Commiphora neglecta* on the Pretoriuskop EBPs occurred on the Group 1 plots. *Acacia swazica*, *Canthium* species, *Combretum mossambicense*, *Croton gratissimus*, *Diospyros whyteana*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Psydrax locuples*, and *Tarenna supra-axillaris* were found only on Group 1 plots. *Acacia swazica* was found on the Numbi Con0 plot. *Canthium* species was found on the Control plots of the Kambeni, Numbi, and Shabeni replicates. *Combretum mossambicense* was found on the Numbi Con0 plot. *Croton gratissimus* was found on the Kambeni Con0 plot. *Diospyros whyteana* was found on the Numbi Con0 plot. *Hyperacanthus amoenus* was found on the Numbi Con0 and Shabeni Con0 plots. *Kraussia floribunda* was found on the Kambeni Con0 and Numbi Con0 plot. *Psydrax locuples* was found on the Shabeni Con0 plot. Finally, *Tarenna supra-axillaris* was found on the Shabeni Con0 plot.

Group 2 comprised the Numbi Oct2, Dec2, and Aug1 plots, and the Shabeni Aug2 plot (Figure 6-41). These plots occurred in the *Terminalia sericea* - *Combretum* open woodlands of Pretoriuskop (Figure 6-43). The species in Group 2 were *Faurea saligna* and *Syzygium cordatum* (Figure 6-42). Neither of the species on Group 2 occurred on all the Group 2 plots. Most of the plots and species in Group 2 from the CA on the 1996 data using covariables were in Group 4 of the CA on the 1996 data without covariables. Sixty-seven percent of the occurrences of Syzygium cordatum on the Pretoriuskop EBPs were on the Group 2 plots. *Faurea saligna* was found only on the Numbi Aug1 plot.

Group 3 comprised the Fayi Dec2 and Oct2 plots, the Kambeni Oct2, Feb3, and Dec3 plots, the Numbi Feb2, Feb3, and Apr3 plots, and the Shabeni Oct2 plot (Figure 6-41). The species in Group 3 were *Acacia caffra*, *Acacia xanthophloea*, *Albizia versicolor*, *Berchemia zeyheri*, *Cassine transvaalensis*, *Catunaregam spinosa*, *Dalbergia melanoxylon*, *Flacourtia indica*, *Grewia hexamita*, *Hippobromus pauciflorus*, *Kigelia africana*, *Lannea discolor*, *Lannea edulis*, *Lannea schweinfurthii*, *Maytenus heterophylla*, *Maytenus senegalensis*, *Mundulea sericea*, *Ozoroa sphaerocarpa*, *Pappea capensis*, *Pterocarpus rotundifolius*, *Rhus leptodictya*, *Schotia brachypetala*, and *Strychnos spinosa* (Figure 6-42). *Dalbergia melanoxylon* and *Maytenus senegalensis* occurred on all the plots in Group 3 however, they were also found in many other Pretoriuskop EBPs. *Catunaregam spinosa* and *Maytenus heterophylla* were found on eight of the nine Group 3 plots however, they were also found on many other Pretoriuskop EBPs. Fifty percent of the occurrences of *Acacia caffra*, *Grewia hexamita*, *Hippobromus pauciflorus*, *Lannea schweinfurthii*, and *Schotia brachypetala* on the Pretoriuskop EBPs were on the Group 3 plots. *Acacia xanthophloea*, *Berchemia zeyheri*, and *Pterocarpus rotundifolius* were found only on Group 3 plots. *Acacia xanthophloea* was found on the Kambeni Dec3 plot. *Berchemia zeyheri* was found on the Numbi Apr3 plot. *Pterocarpus rotundifolius* was found on the Numbi Feb2 and Apr3 plots.

Group 4 comprised the Fayi Aug2, Apr2, Feb2, Aug1, Aug3, Oct3, Feb3, and Apr3 plots, the Kambeni Feb2, Aug2, Apr2, and Aug1 plots, the Numbi Aug2 and Dec3 plots, and the Shabeni Aug1, Dec2, and Dec3 plots (Figure 6-41). The species in Group 4 were *Annona senegalensis*, *Combretum apiculatum*, *Combretum collinum*, *Combretum hereroense*, *Combretum molle*, *Dichrostachys cinerea*, *Diospyros mespiliformis*, *Dombeya rotundifolia*, *Ehretia obtusifolia*, *Euclea divinorum*, *Ficus sycomorus*, *Gardenia volkensii*, *Grewia monticola*, *Lonchocarpus capassa*, *Markhamia zanzibarica*, *Pavetta schumanniana*, *Phyllanthus reticulatus*, *Rhus pyroides*, *Rhus transvaalensis*, *Sclerocarya birrea*, *Senna petersiana*, *Spirostachys africana*, *Strychnos madagascariensis*, *Syzygium guineense*, *Terminalia sericea*, *Trichilia emetica*, *Turraea nilotica*, *Vangueria infausta*, *Ximenia caffra*, and *Ziziphus mucronata* (Figure 6-42). *Dichrostachys cinerea*, *Sclerocarya birrea*, *Strychnos madagascariensis*, and *Terminalia sericea* occurred on all plots in Group 4 however, they were also found on many other Pretoriuskop EBPs. *Diospyros mespiliformis* and *Ximenia caffra* were found on twelve of the seventeen Group 4 plots however, they were found on many other Pretoriuskop EBPs. *Phyllanthus reticulatus* and *Ziziphus mucronata* occurred on thirteen of the seventeen Group 4 plots, however they were found on many other Pretoriuskop EBPs. *Ehretia obtusifolia* and *Senna petersiana* were

found on fourteen of the seventeen Group 4 plots however, they were found on many other Pretoriuskop EBPs. *Pavetta schumanniana* was found on fifteen of the seventeen Group 4 plots however, it was also found on many other Pretoriuskop EBPs. Fifty percent of the occurrence of *Euclea divinorum*, *Spirostachys africana*, *Trichilia emetica*, and *Vangueria infausta* on the Pretoriuskop EBPs occurred on the Group 4 plots. *Ficus sycomorus*, *Markhamia zanzibarica*, and *Syzygium guineense* were found only on Group 4 plots. *Ficus sycomorus* was found on the Fayi Aug2 plot. *Markhamia zanzibarica* was found on the Shabeni Dec2 plot. *Syzygium guineense* was found on the Fayi Aug1 plot.

Group 5 comprised the Kambeni Dec2, Oct3, Aug3, and Apr3 plots, the Numbi Apr2, Oct3, and Aug3 plots, and the Shabeni Apr2, Apr3, Aug3, Oct3, and Feb3 plots (Figure 6-41). The species in Group 5 were *Acacia exuvialis*, *Acacia gerrardii*, *Acacia sieberiana*, *Albizia harveyi*, *Combretum imberbe*, *Ormocarpum trichocarpum*, *Parinari curatellifolia*, *Piliostigma thonningii*, and *Pterocarpus angolensis* (Figure 6-42). None of the species in Group 5 occurred on all the Group 5 plots. *Acacia exuvialis*, *Albizia harveyi*, and *Combretum imberbe* were found only on Group 5 plots. *Acacia exuvialis* was found on the Shabeni Apr3 plot. *Albizia harveyi* was found on the Kambeni Apr3 plot. *Combretum imberbe* was found on the Shabeni Aug3 plot.

6.3.3.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the species and plots in Pretoriuskop in 1996 accounting for the relationship between the species and plots in 1954

The step-wise Ward-Gamma cluster analysis was used to summarise the variation of plots and species along the first four eigenvectors of the Correspondence Analysis on the 1996 species by plot data using the first eight axes from the CA on the 1954 data as covariables. There were four main clusters of plots and species at level 2 of the step-wise Ward-Gamma cluster analysis (Figure 6-36). These clusters differed from the two dimensional grouping of plots and species along the first two eigenvectors described above (Figure 6-37 and Figure 6-38).

Cluster 1 comprised the Kambeni Feb3 plot, the Numbi Feb3 plot, and the Shabeni Oct2 plot (Figure 6-40). The species in Cluster 1 were *Acacia caffra*, *Albizia versicolor*, *Cassine transvaalensis*, *Combretum hereroense*, *Dalbergia melanoxylon*, *Euclea divinorum*, *Grewia hexamita*, *Kigelia africana*, *Maytenus senegalensis*, *Pavetta schumanniana*, *Strychnos madagascariensis*, and *Strychnos spinosa* (Table 15-5). *Dalbergia melanoxylon*, *Maytenus senegalensis*, *Pavetta schumanniana*, and *Strychnos madagascariensis* occurred on all the Cluster 1 plots however, they were also found on many other Pretoriuskop EBPs in 1996. The species in Cluster 1 were not found predominantly on the Cluster 1 plots, furthermore some species in Cluster 1 were not found on any of the Cluster 1 plots namely, *Acacia caffra*, *Cassine transvaalensis*, *Euclea divinorum*, *Grewia hexamita*, and *Kigelia africana*.

Cluster 2 comprised the Fayi Aug2, Dec2, Oct2, Apr2, Aug3, Oct3, Feb3, and Apr3 plots, the Kambeni Oct2, Aug2, Apr2, Aug1, and Dec3 plots, the Numbi Oct2, Feb2, Aug2, Aug1, and Apr3 plots, and the Shabeni Aug2 and Aug1 plots (Figure 6-40). The Fayi Dec2, Oct2, Apr2, Aug3, Oct3, Feb3, and Apr3 plots were adjacent to one another, the Kambeni Oct2, Aug2, Apr2, Aug1, and Dec3 plots were adjacent to one another, and the Numbi Feb2, Aug2, and Apr3 plots were adjacent to one another in 1996 (Figure 6-43). The species in Cluster 2 were *Acacia xanthophloea*, *Berchemia zeyheri*, *Catunaregam spinosa*, *Combretum collinum*, *Dichrostachys cinerea*, *Ehretia obtusifolia*, *Faurea saligna*, *Ficus sycomorus*, *Flacourtia indica*, *Hippobromus pauciflorus*, *Lannea discolor*, *Lannea edulis*, *Lannea schweinfurthii*, *Lonchocarpus capassa*, *Maytenus heterophylla*, *Mundulea sericea*, *Ozoroa sphaerocarpa*, *Pappea capensis*, *Pterocarpus rotundifolius*, *Rhus leptodictya*, *Schotia brachypetala*, *Sclerocarya birrea*, *Syzygium cordatum*, *Terminalia sericea*, *Turraea nilotica*, and *Vangueria infausta* (Figure 6-40). *Dichrostachys cinerea*, *Sclerocarya birrea*, and *Terminalia sericea* occurred on all the Cluster 2 plots however, they were also found on many other Pretoriuskop EBPs in 1996. *Ehretia obtusifolia* occurred on seventeen of the twenty Cluster 2 plots, *Maytenus heterophylla* occurred on eighteen of the twenty Cluster 2 plots, and *Catunaregam spinosa* occurred on nineteen of the twenty Cluster 2 plots however, they were also found on many other

Pretoriuskop EBPs. Fifty percent of the occurrences of *Ozoroa sphaerocarpa*, *Schotia brachypetala*, and *Vangueria infausta* on the Pretoriuskop EBPs were on the Cluster 2 plots. Between sixty and seventy percent of the occurrences of *Lannea discolor*, *Lannea edulis*, and *Rhus leptodictya* on the Pretoriuskop EBPs were on the Cluster 2 plots. Eighty-three percent of the occurrences of and *Hippobromus pauciflorus* on the Pretoriuskop EBPs were on the Cluster 2 plots. *Acacia xanthophloea*, *Berchemia zeyheri*, *Faurea saligna*, *Ficus sycomorus*, *Pterocarpus rotundifolius*, and *Syzygium cordatum* were found only on the Cluster 2 plots. *Acacia xanthophloea* was found on the Kambeni Dec3 plot. *Berchemia zeyheri* was found on the Numbi Apr3 plot. *Faurea saligna* was found on the Numbi Aug1 plot. *Ficus sycomorus* was found on the Fayi Aug2 plot. *Pterocarpus rotundifolius* was found on the Numbi Feb2 and Apr3 plots. *Syzygium cordatum* was found on the Numbi Oct2 and Aug1 plots, and the Shabeni Aug1 plot.

Cluster 3 comprised the Fayi Con0, Feb2, Aug1, and Dec3 plots, the Kambeni Con0, Dec2, and Feb2 plots, the Numbi Dec2, Con0, Dec3, and Oct3 plots, and the Shabeni Feb2, Con0, and Dec3 plots (Figure 6-40). The Fayi Con0 and Dec3 plots were adjacent to one another, the Fayi Feb2 and Aug1 plots were adjacent to one another, the Kambeni Con0 and Dec2 plots were adjacent to one another, and the Numbi Dec2, Dec3, and Oct3 plots were adjacent to one another (Figure 6-43). All the plots that were not burnt between 1954 and 1996 were in Cluster 3. The species in Cluster 3 were *Acacia swazica*, *Annona senegalensis*, *Antidesma venosum*, *Bauhinia galpinii*, *Canthium* species, *Cassine aethiopica*, *Combretum apiculatum*, *Combretum mossambicense*, *Commiphora neglecta*, *Croton gratissimus*, *Diospyros lycioides*, *Diospyros mespiliformis*, *Diospyros whyteana*, *Dombeya rotundifolia*, *Euclea natalensis*, *Grewia flavescens*, *Grewia monticola*, *Heteropyxis natalensis*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Ochna natalitia*, *Olea europaea*, *Peltophorum africanum*, *Phyllanthus reticulatus*, *Psydrax locuples*, *Pterocarpus angolensis*, *Putterlickia pyracantha*, *Rhus pentheri*, *Rhus pyroides*, *Rhus transvaalensis*, *Securinega virosa*, *Spirostachys africana*, *Syzygium guineense*, *Tarenna supra-axillaris*, and *Zanthoxylum capense* (Figure 6-40). *Euclea natalensis* occurred on all the Cluster 3 plots however, it was also found on many other Pretoriuskop EBPs in 1996. *Antidesma venosum*, *Diospyros lycioides*, and *Phyllanthus reticulatus* were found on ten of the fourteen Cluster 3 plots. *Grewia flavescens*, *Grewia monticola*, *Ochna natalitia*, *Peltophorum africanum*, and *Rhus pyroides* were found on eleven of the fourteen Cluster 3 plots. *Diospyros mespiliformis*, *Rhus transvaalensis*, and *Securinega virosa* were found on twelve of the fourteen Cluster 3 plots. However, all of these species were also found on many of the other Pretoriuskop EBPs. Between fifty and sixty percent of the occurrences of *Putterlickia pyracantha*, and *Rhus pentheri* on the Pretoriuskop EBPs occurred on the Cluster 3 plots. Sixty-seven percent of the occurrences of *Commiphora neglecta* on the Pretoriuskop EBPs occurred on the Cluster 3 plots. Seventy-five percent of the occurrences of *Heteropyxis natalensis* on the Pretoriuskop EBPs occurred on the Cluster 3 plots, Eighty percent of the occurrences of *Olea europaea* on the Pretoriuskop EBPs occurred on the Cluster 3 plots. *Acacia swazica*, *Canthium* species, *Combretum mossambicense*, *Croton gratissimus*, *Diospyros whyteana*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Psydrax locuples*, *Spirostachys africana*, *Syzygium guineense*, and *Tarenna supra-axillaris* were found only on Cluster 3 plots. *Acacia swazica* was found on the Numbi Con0 plot. *Canthium* species was found on the Control plots of the Kambeni, Numbi, and Shabeni replicates. *Combretum mossambicense* was found on the Numbi Con0 plot. *Croton gratissimus* was found on the Kambeni Con0 plot. *Diospyros whyteana* was found on the Numbi Con0 plot. *Hyperacanthus amoenus* was found on the Numbi Con0 and Shabeni Con0 plots. *Kraussia floribunda* was found on the Kambeni Con0 and Numbi Con0 plots. *Psydrax locuples* was found on the Shabeni Con0 plot. *Spirostachys africana* was found on the Numbi Dec3 plot, and the Shabeni Con0 plot. *Syzygium guineense* was found on the Fayi Aug1 plot. *Tarenna supra-axillaris* was found on the Shabeni Con0 plot. Most of these species were associated with the plots that were not burnt between 1954 and 1996. The control plots may be fire refuges for these fire sensitive species. The occurrence of these species on the control plots may be dependant on local fire refuges such as rock outcrops and large termite mounds on which the species survive and reproduce.

Cluster 4 comprised the Kambeni Oct3, Aug3, and Apr3 plots, the Numbi Apr2 and Aug3 plots, and the Shabeni Apr2, Dec2, Apr3, Aug3, Oct3, and Feb3 plots (Figure 6-40). These occurred mainly in the open *Terminalia sericea* - *Combretum* woodlands of Pretoriuskop (Figure 6-43). The species in Cluster 4 were *Acacia exuvialis*, *Acacia gerrardii*, *Acacia sieberiana*, *Albizia harveyi*, *Combretum imberbe*, *Combretum*

molle, *Gardenia volkensii*, *Markhamia zanzibarica*, *Ormocarpum trichocarpum*, *Parinari curatellifolia*, *Piliostigma thonningii*, *Senna petersiana*, *Trichilia emetica*, *Ximenia caffra*, and *Ziziphus mucronata* (Figure 6-40). No species occurred on all the Cluster 4 plots in 1996. *Combretum molle* occurred on eight of the eleven Cluster 4 plots and *Senna petersiana* occurred on nine of the eleven Cluster 4 plots however, they were both found on other Pretoriuskop EBPs in 1996. *Acacia exuvialis*, *Albizia harveyi*, *Combretum imberbe*, and *Markhamia zanzibarica* were found only on the Cluster 4 plots. *Acacia exuvialis* was found on the Shabeni Apr3 plot. *Albizia harveyi* was found on the Kambeni Apr3 plot. *Combretum imberbe* was found on the Shabeni Aug3 plot. *Markhamia zanzibarica* was found on the Shabeni Dec2 plot.

6.3.3.3 Summary of the results from the CA's on the 1996 species by plot data with covariables

In this analysis, some of the initial variation in species composition between the Pretoriuskop EBPs was accounted for. Location was still found to be a factor determining similarity in species composition between plots, but it was not as strong a factor as in the previous analyses. Proximity was also found still to be a strong factor determining similarity in species composition.

The control plots once again an exception to this. However, it was found that the many of the February and December Biennial and Triennial treatments had species compositions that were similar to those of the plots that were not burnt. The species associated with the control plots and many of the December and February Biennial and Triennial plots were *Euclea natalensis*, *Antidesma venosum*, *Diospyros lycioides*, *Phyllanthus reticulatus*, *Grewia flavescens*, *Grewia monticola*, *Ochna natalitia*, *Peltophorum africanum*, *Rhus pyroides*, *Diospyros mespiliformis*, *Rhus transvaalensis*, and *Securinega virosa*. However, these species were also found on many of the other Pretoriuskop EBPs. Other species associated with these plots were *Putterlickia pyracantha*, *Rhus pentheri*, *Commiphora neglecta*, *Heteropyxis natalensis*, and *Olea europaea*.

WitsETD

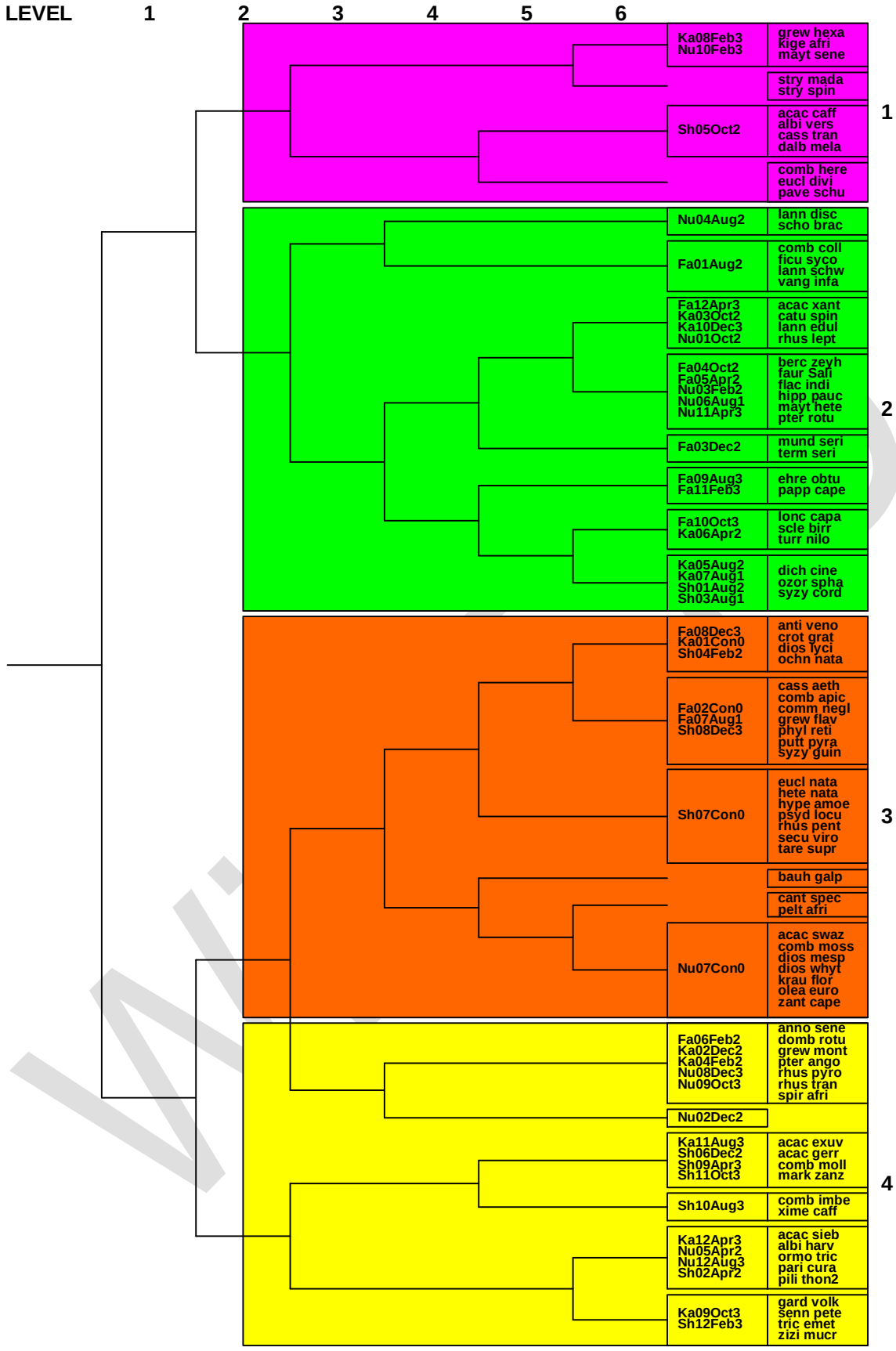


Figure 6-40: Classification of treatment plots and species using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 species by plot data with the first eight ordination axes of the 1954 species by plot CA as covariables. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the species are defined in Table 9-1 (p. 210).

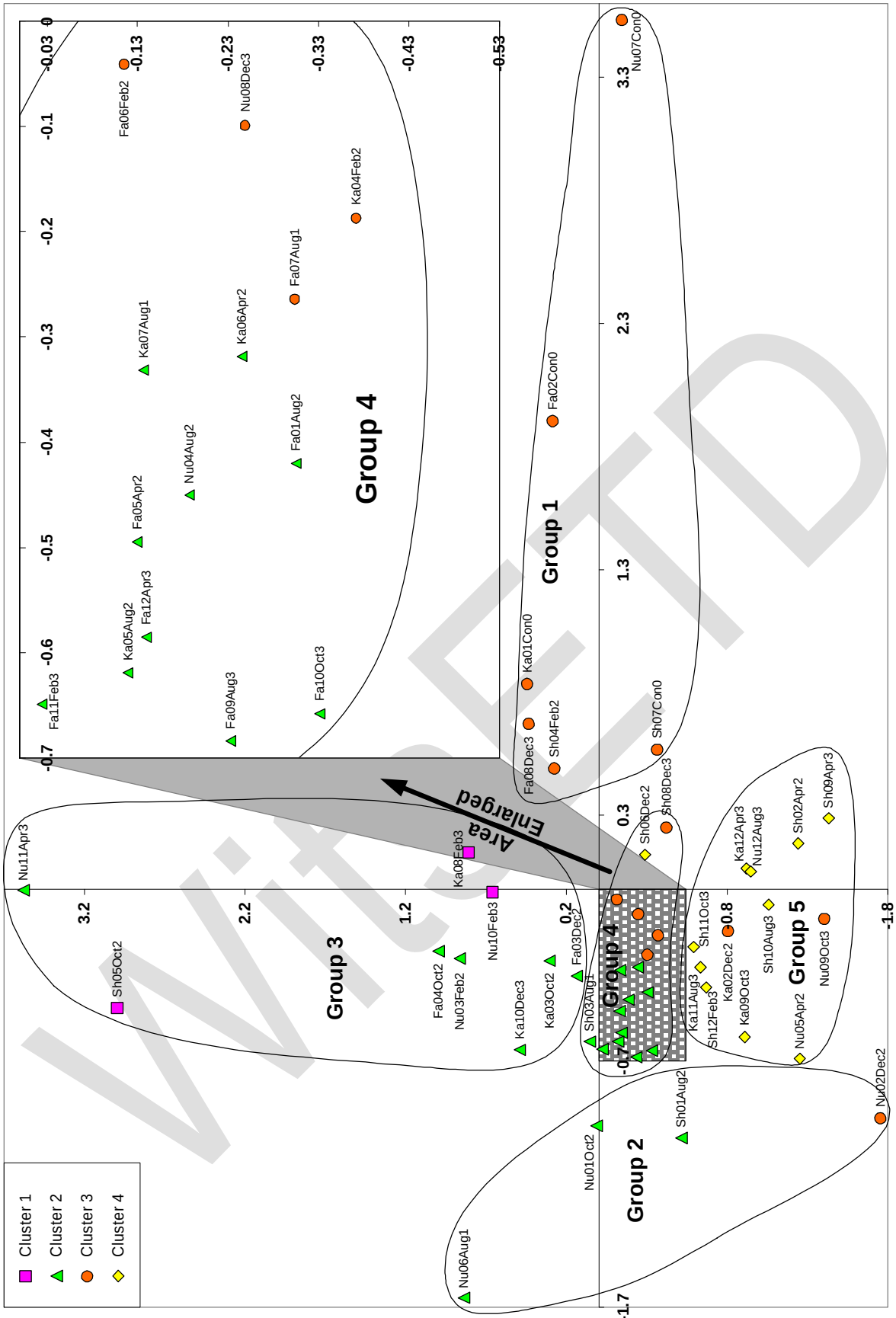


Figure 6-41: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in species composition between treatment plots with the first eight ordination axes of the 1954 species by plot CA as covariables. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-40). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Witsetd

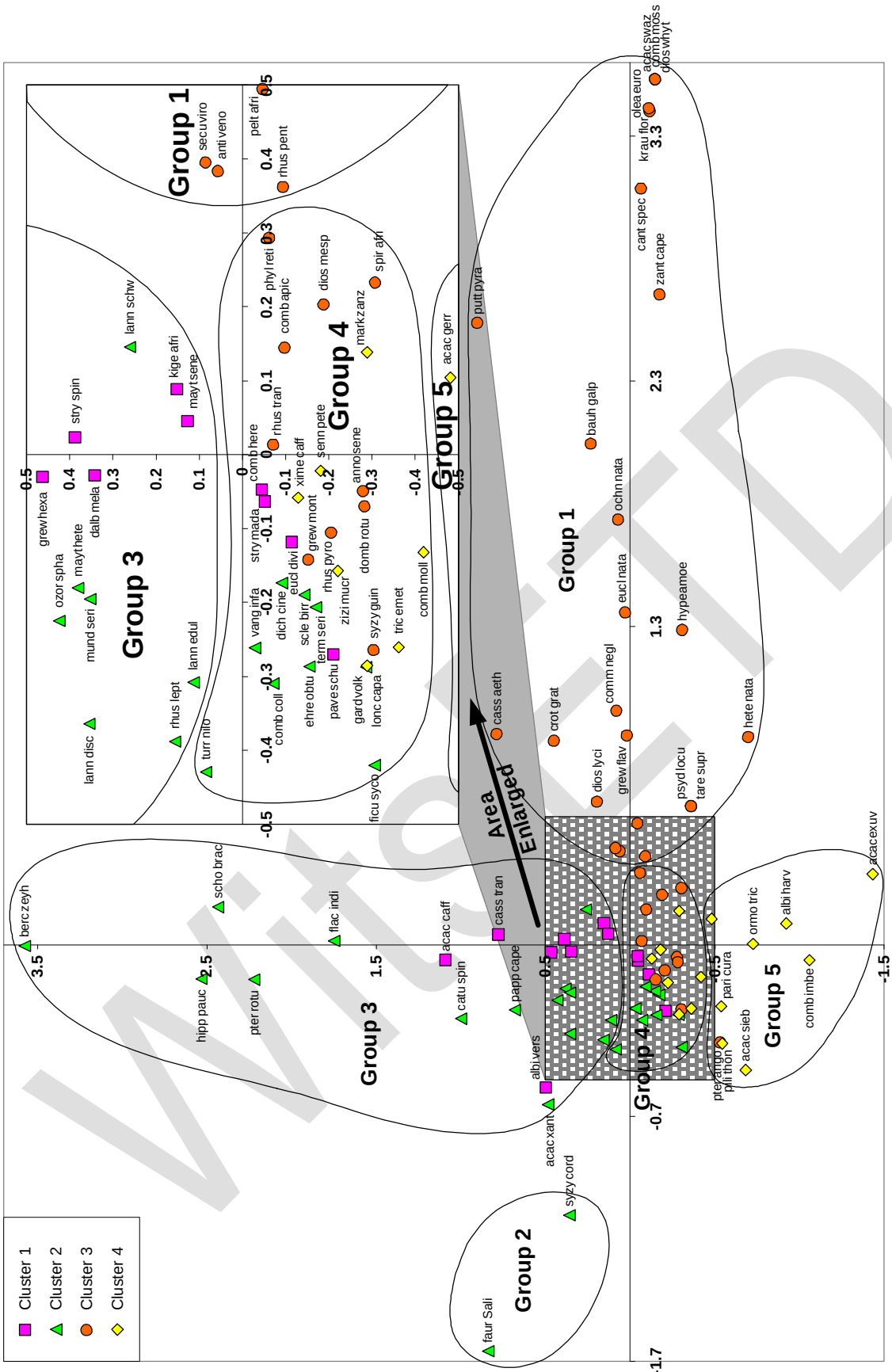


Figure 6-42: Bi-plot of the first two ordination axes from the CA on the 1996 species by plot data showing variation in location (plots) between species with the first eight ordination axes of the 1954 species by plot CA as covariables. The groups are the result of a visual assessment of the grouping of species and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-40). The codes for the species are defined in Table 9-1 (p. 210).

Visited

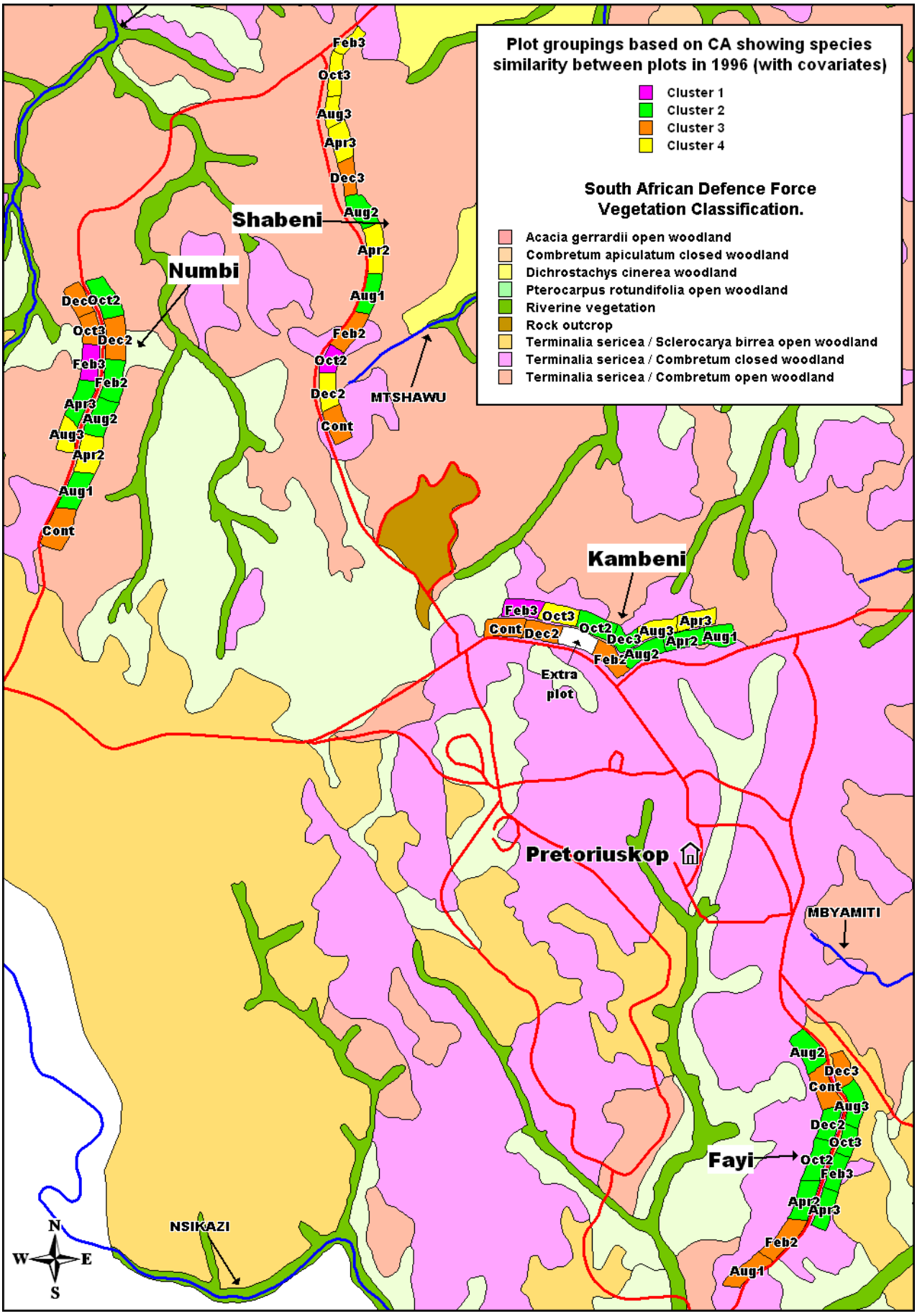


Figure 6-43: Map showing the level 2 groupings of a classification of treatment plots using a stepwise cluster analysis on the first four ordination axes of a CA on the 1996 species by plot data with the first eight ordination axes of the 1954 species by plot CA as covariables (Figure 6-40). The codes for the treatments are defined in Table 3-1 (p. 15).

6.3.4 Results from the Correspondence Analysis on the 1954 structure by plot data

The results from the CA performed on the 1954 structure by plot data are presented in Table 6-13 (p. 151), Figure 6-44 (p. 155), Figure 6-45 (p. 156), Figure 6-46 (p. 157), and Figure 6-47 (p. 158). Table 6-13 shows the Eigenvalues for the first four ordination axes of the CA. Figure 6-44 is a hierarchical cluster tree showing the cluster groups from the step-wise Gamma-Ward cluster analysis on the first four ordination axes. Figure 6-45 is a bi-plot of the first two, weighted eigenvector plot score axes with the data points colour coded to the level 2 cluster colours in Figure 6-44. Figure 6-46 is a bi-plot of the first two, weighted eigenvector structure score axes with the data points colour coded to the level 2 cluster colours in Figure 6-44. Figure 6-47 is a map showing the layout of the Pretoriuskop EBP experiment with the plots colour coded to the level 2 cluster colours in Figure 6-44. The weighted eigenvector plot scores for the first four ordination axes, the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973) are presented in Table 15-7 (p. 265). The weighted eigenvector structure scores for the first four ordination axes, the structure weights, and the effective number of occurrences of the structures (N2 diversity of structures) are presented in Table 15-8 (p. 266).

Table 6-13: Eigenvalues for the first four ordination axes of a Correspondence Analysis on the structure by plot data collected in 1954

	Axis 1	Axis 2	Axis 3	Axis 4	Total
Eigenvalue	0.2492	0.0445	0.0311	0.0191	0.455
% Variation	54.8	9.8	6.8	4.2	75.6

The Eigenvalues, for the first four axes of the CA on the 1954 data were 0.249, 0.045, 0.031, and 0.019 (Table 6-13). The first four eigenvectors accounted for 54.8%, 9.8%, 6.8%, and 4.2% of the variation in the structure by plot data respectively in 1954, and 75.6% of the total variation in the structure by plot data in 1954 (Table 6-13).

6.3.4.1 Bi-plots of the first two weighted structure and plot eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1954

There were two main groups of plots and structures on the bi-plots of the first two weighted eigenvectors from the Correspondence Analysis on the 1954 data (Figure 6-45 and Figure 6-46). Group 1 comprised structure groups and plots with x-axis eigenvector values greater than zero, and Group 2 comprised structure groups and plots with x-axis eigenvector values less than zero.

Group 1 comprised the Fayi Dec3, Aug3, Oct3, Feb3, and Apr3 plots, the Kambeni Oct2, Feb2, Aug2, Feb3, Oct3, Dec3, Aug3, and Apr3 plots, the Numbi Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Apr2, Feb2, Dec3, Apr3, Aug3, Oct3, and Feb3 plots (Figure 6-45). The structures in Group 1 were single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, and multi-stem individuals 0-1m high with basal diameters 0-30cm and 30-91cm, 1-3m high with basal diameters 0-30cm, 30-91cm, and greater than 91cm, 3-5m high with basal diameters 0-30cm, and taller than 5m with basal diameters 0-30cm (Figure 6-46). Multi-stem individuals 0-1m high with basal diameters 0-30cm, and 1-3m high with basal diameters 0-30cm and 30-91cm occurred on all Group 1 plots in 1954, and these structure groups were found mainly on the Group 1 plots in 1954. Multi-stem individuals 0-1m high with basal diameters 0-30cm, and 1-3m high with basal diameters 0-30cm, occurred on all Group 1 plots and they were found mainly on Group 1 plots in 1954. Multi-stem individuals 1-3m high with basal diameters greater than 91cm were found on eighteen of the twenty-five Group 1 plots and they occurred mainly on the Group 1 plots. Multi-stem individuals 1-3m high with basal diameters 30-91cm, and 3-5m high with basal diameters 0-30cm, were found on twenty of the twenty-five Group 1 plots in 1954. Multi-stem individuals 1-3m high with basal diameters 30-91cm, were found on many other Pretoriuskop EBPs, and multi-stem individuals 3-5m high with basal diameters 0-30cm, were found mainly on the Group 1 plots on 1954. Between fifty and sixty percent of the occurrences of single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, and multi-stem individuals 0-1m high

VISITED

with basal diameters 0-30cm, and 1-3m high with basal diameters 0-30cm and greater than 91cm, on the Pretoriuskop EBPs were on the Group 1 plots in 1954. Eighty percent of the occurrences of multi-stem individuals 3-5m high with basal diameters 0-30cm, on the Pretoriuskop EBPs were in the Group 1 plots. Multi-stem individuals taller than 5m with basal diameters 0-30cm, occurred only on the Group 1 plots and were found on the Kambeni Dec3 and Aug3 plots, the Numbi Feb3 plot, and the Shabeni Feb2 plot.

Group 2 comprised the Fayi Aug2, Con0, Dec2, Oct2, Apr2, Feb2, and Aug1 plots, the Kambeni Con0, Dec2, Apr2, and Aug1 plots, the Numbi Oct2, Dec2, Feb2, Aug2, Apr2, Aug1, and Con0 plots, and the Shabeni Aug2, Aug1, Oct2, Dec2, and Con0 plots (Figure 6-45). The single stem structures in Group 2 were 0-1m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, and greater than 17.8cm, 1-3m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, 3-5m high with basal diameters 2.5-7.6cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, and taller than 5m with basal diameters 0.0-2.5cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm (Figure 6-46). The multi-stem structures in Group 2 were 0-1m high with basal diameters greater than 91cm, and 3-5m high with basal diameters 30-91cm and greater than 91cm (Figure 6-46). Single-stem individuals 0-1m high with basal diameters 0.0-2.5cm, 1-3m high with basal diameters 0.0-2.5cm and 2.5-7.6cm, and taller than 5m with basal diameters greater than 17.8cm, occurred on all the Group 2 plots. Single-stem individuals taller than 5m with basal diameters greater than 17.8cm, were found mainly on the Group 2 plots however the rest were found on many other Pretoriuskop EBPs in 1954. Single-stem individuals 3-5m high with basal diameters greater than 17.8cm were found on seventeen of the twenty-three Group 2 plots and occurred mainly on the Group 2 plots in 1954. Single-stem individuals 0-1m high with basal diameters 2.5-7.6cm, and 3-5m high with basal diameters 7.6-12.7cm, were found on nineteen of the twenty-three Group 2 plots and occurred mainly on the Group 2 plots. Single-stem individuals 3-5m high with basal diameters 12.7-17.8cm, occurred on twenty of the twenty-three Group 2 plots and were found mainly on the Group 2 plots in 1954. Single-stem individuals 1-3m high with basal diameters 7.6-12.7cm, were found on twenty-one of the twenty-three Group 2 plots and occurred mainly on the Group 2 plots. Between fifty and sixty percent of the occurrences of single-stem individuals 0-1m high with basal diameters 2.5-7.6cm and greater than 17.8cm, 1-3m high with basal diameters 7.6-12.7cm and 12.7-17.8cm, 3-5m high with basal diameters 7.6-12.7cm and 12.7-17.8cm, and taller than 5m with basal diameters greater than 17.8cm, on the Pretoriuskop EBPs in 1954 occurred on the Group 2 plots. Between fifty and sixty percent of the occurrences of multi-stem individuals 0-1m high with basal diameters greater than 91cm, on the Pretoriuskop EBPs in 1954 occurred on the Group 2 plots. Between sixty and seventy percent of the occurrences of single-stem individuals 3-5m high with basal diameters greater than 17.8cm, and taller than 5m with basal diameters 7.6-12.7cm and 12.7-17.8cm, and multi-stem individuals 3-5m high with basal diameters 30-91cm and greater than 91cm, on the Pretoriuskop EBPs in 1954 occurred on the Group 2 plots. Seventy-nine percent of the occurrences of single-stem individuals 0-1m high with basal diameters 7.6-12.7cm, on the Pretoriuskop EBPs were on the Group 2 plots. Between eighty and ninety percent of the occurrences of single-stem individuals 1-3m high with basal diameters greater than 17.8cm, and 3-5m high with basal diameters 2.5-7.6cm, on the Pretoriuskop EBPs in 1954 were on the Group 2 plots. Single-stem individuals taller than 5m with basal diameters between 0.0-2.5cm occurred only on the Group 2 plots and they were found on the Fayi Feb2 plot.

6.3.4.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1954

The step-wise Ward-Gamma cluster analysis was used to summarise the variation of plots and structures along the first four eigenvectors of the Correspondence Analysis on the 1954 structure by plot data. There were four main clusters of plots and structures at level 2 of the step-wise Ward-Gamma cluster analysis (Figure 6-32). These clusters differed from the two dimensional grouping of plots and structures along the first two eigenvectors described above (Figure 6-33 and Figure 6-34).

Cluster 1 comprised the Fayi Aug2, Con0, Dec2, Oct2, and Feb2 plots, the Kambeni Dec2, Aug2, Apr2, and Aug1 plots, and the Numbi Oct2, Dec2, Aug2, Apr2, Aug1, and Con0 plots (Figure 6-44). The Fayi Aug2, Con0, Dec2, and Oct2 plots were adjacent to one another, the Kambeni Aug2, Apr2, and Aug1 plots were

adjacent to one another, the Numbi Oct2 and Dec2 plots were adjacent to one another, and the Numbi Aug2, Apr2, Aug1, and Con0 plots were adjacent to one another (Figure 6-35). The plots on Cluster 1 were very similar to those in Cluster D of the Pearson-Ward Cluster analysis on the structural similarity in 1954 (Figure 6-28 p. 120). The plots in Cluster 1 occur on the Fayi and Numbi replicates in the areas, which were burnt in 1953 just before the experiment was set up in 1954. Post fire age of the vegetation may be an important factor contributing to the structure of the woody vegetation of these plots, and may explain why the structure on these plots was similar. The single-stem structures in Cluster 1 were 0-1m high with basal diameters 0.0-2.5cm, 7.6-12.7cm, and greater than 17.8cm, 1-3m high with basal diameters 0.0-2.5cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, 3-5m high with basal diameters 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, and taller than 5m with basal diameters 0.0-2.5cm, 12.7-17.8cm, and greater than 17.8cm (Figure 6-44). The multi-stem structures in Cluster 1 were 0-1m high with basal diameters 30-91cm, 1-3m high with basal diameters 30-91cm, and 3-5m high with basal diameters 30-91cm and greater than 91cm (Figure 6-44). Single-stem individuals 0-1m high with basal diameters 0.0-2.5cm, and 1-3m high with basal diameters 0.0-2.5cm and 7.6-12.7cm, occurred on all Cluster 1 plots however, they were found on many Pretoriuskop EBPs in 1954. Single-stem individuals 3-5m high with basal diameters 7.6-12.7cm, were found on thirteen of the fifteen Cluster 1 plots however, they occurred on many other Pretoriuskop EBPs. Single-stem individuals 3-5m high with basal diameters 12.7-17.8cm, and taller than 5m with basal diameters greater than 17.8cm, and multi-stem individuals 1-3m high with basal diameters 30-91cm, were found on fourteen of the fifteen Cluster 1 plots however, they occurred on many other Pretoriuskop EBPs in 1954. Fifty-seven percent of the occurrences of single-stem individuals 0-1m high with basal diameters 7.6-12.7cm, on the Pretoriuskop EBPs in 1954 were on the Cluster 1 plots. Sixty-four percent of the occurrences of multi-stem individuals 3-5m high with basal diameters 30-91cm, on the Pretoriuskop EBPs was on the Cluster 1 plots in 1954. Eighty percent of the occurrences of multi-stem individuals 3-5m high with basal diameters greater than 91cm, on the Pretoriuskop EBPs were on the Cluster 1 plots in 1954. Single-stem individuals taller than 5m with basal diameters 0.0-2.5cm were found only on the Cluster 1 plots, and they occurred on the Fayi Feb2 plot.

Cluster 2 comprised the Numbi Feb2 and Dec3 plots, and the Shabeni Aug2, Oct2, Dec2, Con0, and Apr3 plots (Figure 6-44). The Shabeni Oct2, Dec2, and Con0 plots were adjacent to one another (Figure 6-35). The plots in Cluster 2 were very similar to those in Cluster C of the Pearson-Ward Cluster analysis on the structural similarity in 1954 (Figure 6-28). The structure group in Cluster 2 was the multi-stem individuals 0-1m high with basal diameters greater than 91cm (Figure 6-44). This structure group occurred on four out of seven Cluster 2 plots however, it also occurred on many other Pretoriuskop EBPs in 1954.

Cluster 3 comprised the Fayi Apr2, Aug1, Dec3, and Oct3 plots, the Kambeni Con0 plot, and the Shabeni Aug1 plot (Figure 6-44). Many of the plots in Cluster 3 were those plots in Cluster D of the Pearson-Ward Cluster analysis on the structural similarity in 1954 that were not in Cluster 1 (Figure 6-28). The structures in Cluster 3 were single-stem individuals 0-1m high with basal diameters 2.5-7.6cm, 1-3m high with basal diameters 2.5-7.6cm, 3-5m high with basal diameters 2.5-7.6cm, and taller than 5m with basal diameters 7.6-12.7cm, and multi-stem individuals 1-3m high with basal diameters greater than 91cm (Figure 6-44). single-Stem individuals 0-1m high with basal diameters 2.5-7.6cm, and 1-3m high with basal diameters 2.5-7.6cm, were found on all the Cluster 3 plots however, they also occurred on many other Pretoriuskop EBPs in 1954. Fifty percent of the occurrences of single-stem individuals 3-5m high with basal diameters 2.5-7.6cm, on the Pretoriuskop EBPs was on the Cluster 3 plots in 1954.

Cluster 4 comprised the Fayi Aug3, Feb3, and Apr3 plots, the Kambeni Oct2, Feb2, Feb3, Oct3, Dec3, Aug3, and Apr3 plots, the Numbi Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Apr2, Feb2, Dec3, Aug3, Oct3, and Feb3 plots (Figure 6-44). The Fayi Feb3 and Apr3 were adjacent to one another, the Kambeni Oct2, Feb2, Feb3, Oct3, Dec3, Aug3, and Apr3 plots were adjacent to one another, the Numbi Oct3, Feb3, Apr3, and Aug3 plots were adjacent to one another, and Shabeni Aug3, Oct3, and Feb3 plots were adjacent to one another (Figure 6-35). Many of the plots in Cluster 4 were clustered together in Cluster B from the Pearson-Ward Cluster analysis on the structural similarity in 1954 (Figure 6-28). The structures in Cluster 4 were single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, and multi-stem individuals 0-1m

WISER

high with basal diameters 0-30cm, 1-3m high with basal diameters 0-30cm, 3-5m high with basal diameters 0-30cm, and taller than 5m with basal diameters 0-30cm (Figure 6-44). Multi-stem individuals 0-1m high with basal diameters 0-30cm, and 1-3m high with basal diameters 0-30cm, were found on all the Cluster 4 plots however, they also occurred on many other Pretoriuskop EBPs in 1954. Multi-stem individuals 3-5m high with basal diameters 0-30cm were found on seventeen of the twenty Cluster 4 plots and they occurred mainly on the Cluster 4 plots in 1954. Fifty percent of the occurrences of single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, on the Pretoriuskop EBPs in 1954 were on the Cluster 4 plots. Sixty-eight percent of the occurrences of multi-stem individuals 3-5m high with basal diameters 0-30cm, on the Pretoriuskop EBPs were on the Cluster 4 plots in 1954. Multi-stem individuals taller than 5m with basal diameters 0-30cm, occurred only on the Cluster 4 plots and was found on the Kambeni Dec3 and Aug3 plots, the Numbi Feb3 plot, and the Shabeni Feb2 plot.

6.3.4.3 Summary of the results from the CA's on the 1954 structure by plot data

In 1954, similarity in the structural composition between plots was linked to the proximity of plots to one another. However, no strong patterns emerged regarding similarity in structural composition between plots and the location of the plots in the open and closed *Terminalia sericea* - *Combretum* woodlands of the Pretoriuskop region.

Generally, the structure of the woody vegetation on the control plots, the Annual plots, and the Biennial plots was more similar to one another than to the Triennial plots. The reason for this is that the EBPs in the Pretoriuskop region were established and surveyed in two distinct phases (Table 3-1 p.15 and Table 11-1 p.215). The control plots, the Annual plots, and the Biennial plots were established and surveyed in 1954 while the Triennial plots were established in 1956 and they were surveyed in 1957 and 1958 (Table 3-1 p.15 and Table 11-1 p.215). The establishment of the EBPs in two phases resulted in the baseline vegetation of the plots established in 1956 having been exposed to slightly different fire regimes than the plots that were established in 1954. It is believed that a difference in the time since the last fire event between the two phases is what is responsible for the differences in the structure of the woody vegetation between the two phases.

WitsETD

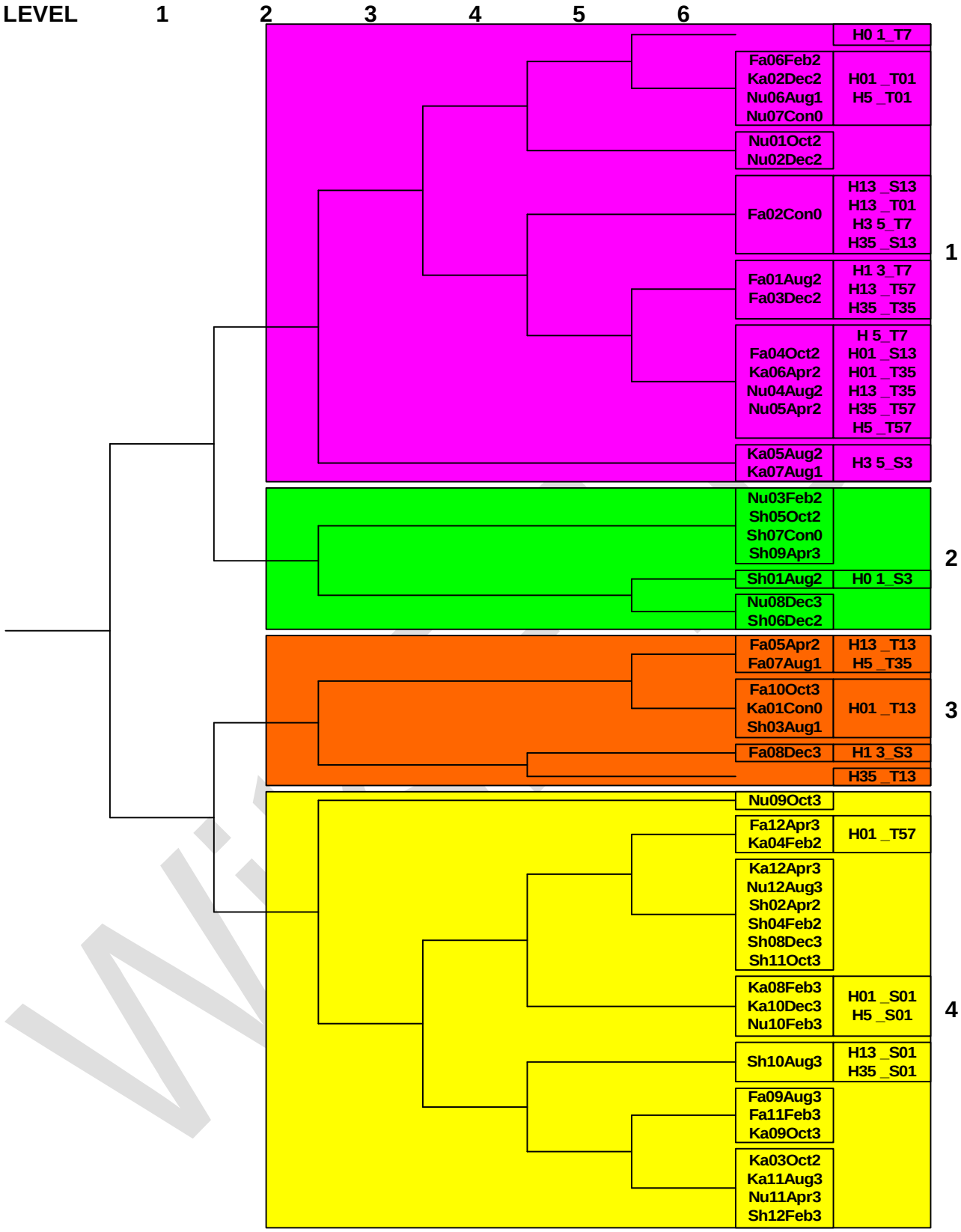


Figure 6-44: Classification of treatment plots and structures using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1954 structure by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the structure groups are defined in Table 5-3 (p. 34).

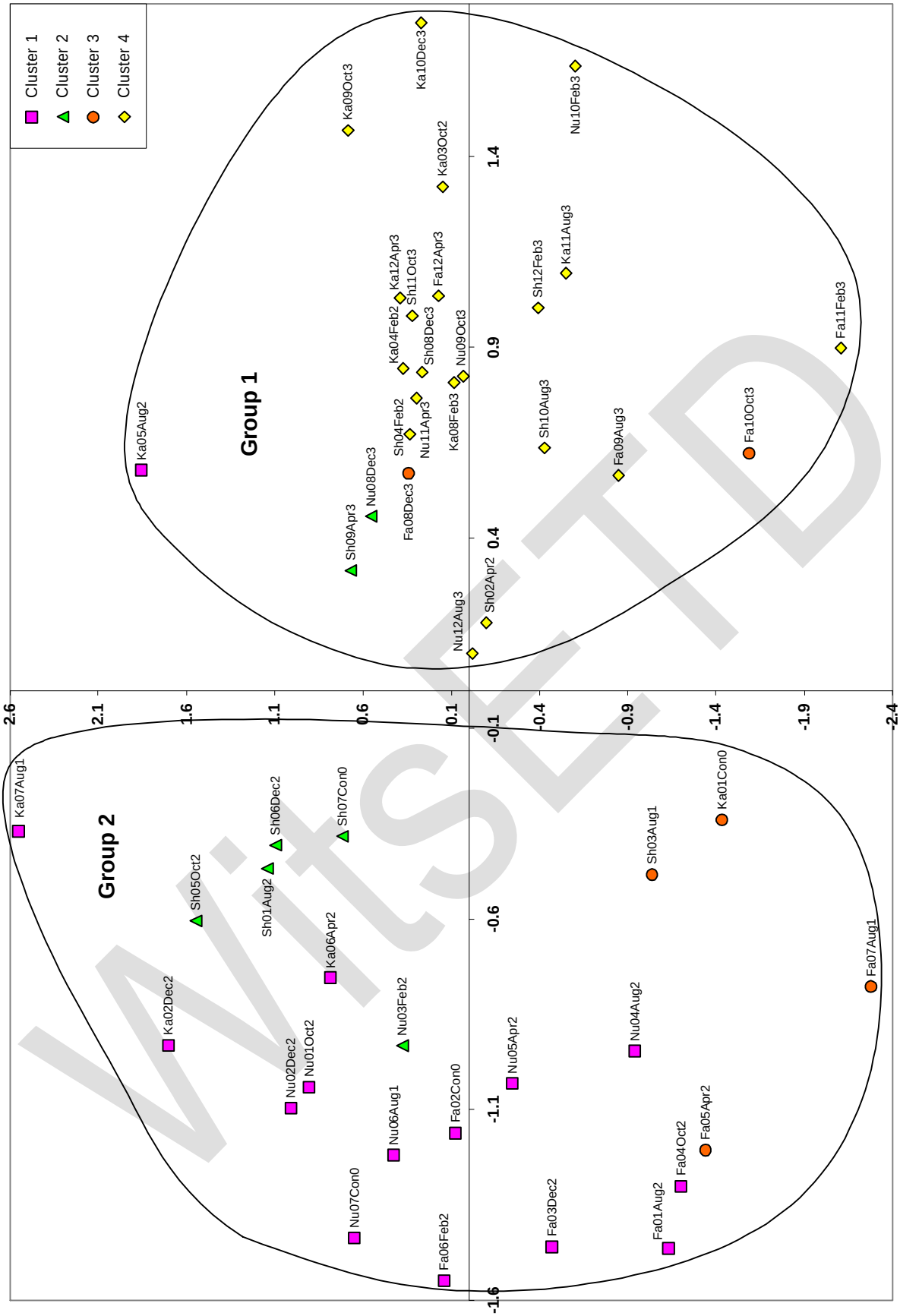


Figure 6-45: Bi-plot of the first two ordination axes from the CA on the 1954 structure by plot data showing variation in structural composition between treatment plots. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-44). The codes for the treatment plots are defined in Table 10-1 (p. 214).

WiSE TD

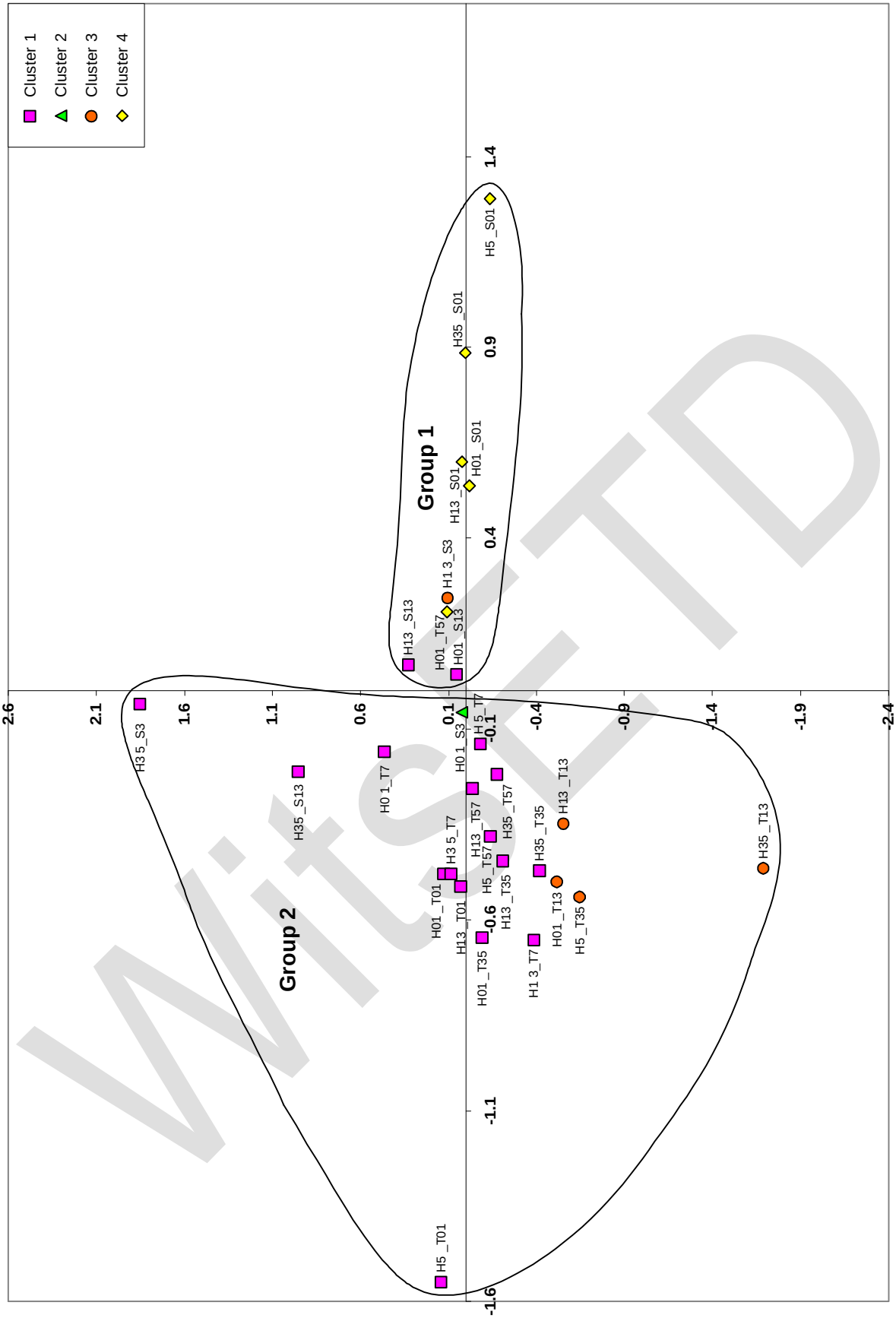


Figure 6-46: Bi-plot of the first two ordination axes from the CA on the 1954 structure by plot data showing variation in location (plots) between structures. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-44). The codes for the structure groups are defined in Table 5-3 (p. 34).

WitsETD

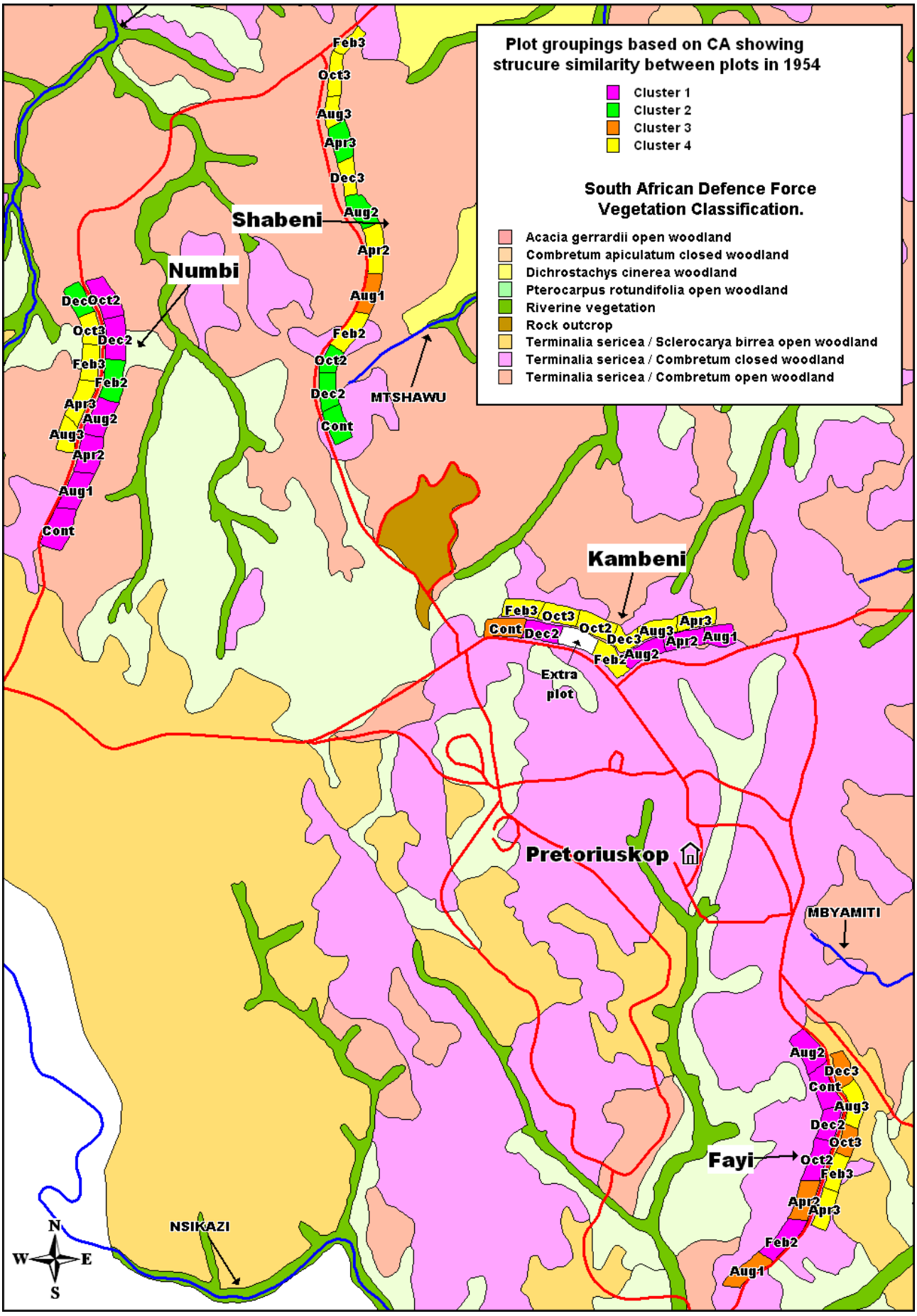


Figure 6-47: Map showing the level 2 clusters from the step-wise Gamma-Ward cluster analysis on the first four ordination axes of the CA on the 1954 structure by plot data (Figure 6-44). The codes for the treatments are defined in Table 3-1 (p. 15).

6.3.5 Results from the Correspondence Analysis on the 1996 structure by plot data

The results from the CA performed on the 1996 structure by plot data are presented in Table 6-14 (p. 159), Figure 6-48 (p. 163), Figure 6-49 (p. 164), Figure 6-50 (p. 165), and Figure 6-51 (p. 166). Table 6-14 shows the Eigenvalues for the first four ordination axes of the CA. Figure 6-48 is a hierarchical cluster tree showing the cluster groups from the step-wise Gamma-Ward cluster analysis on the first four ordination axes. Figure 6-49 is a bi-plot of the first two, weighted eigenvector plot score axes with the data points colour coded to the level 2 cluster colours in Figure 6-48. Figure 6-50 is a bi-plot of the first two, weighted eigenvector structure score axes with the data points colour coded to the level 2 cluster colours in Figure 6-48. Figure 6-51 is a map showing the layout of the Pretoriuskop EBP experiment with the plots colour coded to the level 2 cluster colours in Figure 6-48. The weighted eigenvector plot scores for the first four ordination axes, the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973) are presented in Table 15-9 (p. 267). The weighted eigenvector structure scores for the first four ordination axes, the structure weights, and the effective number of occurrences of the structures (N2 diversity of structures) are presented in Table 15-10 (p. 268).

Table 6-14: Eigenvalues for the first four ordination axes of a Correspondence Analysis on the structure by plot data collected in 1996

	Axis 1	Axis 2	Axis 3	Axis 4	Total
Eigenvalue	0.0951	0.0794	0.0244	0.0146	0.2750
% Variation	34.6	28.9	8.9	5.3	77.6

The Eigenvalues, for the first four axes of the CA on the 1996 data were 0.095, 0.079, 0.024, and 0.015 (Table 6-14). The first four eigenvectors accounted for 34.6%, 28.9%, 8.9%, and 5.3% of the variation in the structure by plot data respectively in 1954, and 77.6% of the total variation in the structure by plot data in 1996 (Table 6-14).

6.3.5.1 Bi-plots of the first two weighted structure and plot eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996

There were three main groups of plots and structures on the bi-plots of the first two weighted eigenvectors from the Correspondence Analysis on the 1996 data (Figure 6-49 and Figure 6-50). Group 1 comprised structure groups and plots with y-axis eigenvector values greater than 1.1. Group 2 comprised structure groups and plots with y-axis eigenvector values less than 1.1 and x-axis eigenvector values greater than -0.7. Group 3 comprised structure groups and plots with y-axis eigenvector values less than 1.1 and x-axis eigenvector values less than -0.7.

Group 1 comprised the Fayi Aug3 plot, the Kambeni Oct2, Aug2, Oct3, and Aug3 plots, and the Shabeni Aug3 and Oct3 plots (Figure 6-49). The Kambeni Oct2 and Oct3 plots were adjacent to one another, the Kambeni Aug2 and Aug3 plots were adjacent to one another and the Shabeni Aug3 and Oct3 plots were adjacent to one another (Figure 6-51). No structure groups were associated predominantly with the plots Group 1.

Group 2 comprised the Fayi Con0, Dec2, Oct2, Apr2, Feb2, Dec3, Oct3, Feb3, and Apr3 plots, the Kambeni Con0, Dec2, Feb2, Apr2, Feb3, Dec3, and Apr3 plots, the Numbi Oct2, Dec2, Feb2, Apr2, Con0, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Aug2, Apr2, Feb2, Dec2, Con0, Dec3, Apr3, and Feb3 plots (Figure 6-49). The Fayi Con0, Dec2, Oct2, Apr2, Feb2, Dec3, Oct3, Feb3, and Apr3 plots were adjacent to one another (Figure 6-51). The Kambeni Con0, Dec2, and Feb3 plots were adjacent to one another, the Kambeni Feb2 and Dec3 plots were adjacent to one another, and the Kambeni Apr2, and Apr3 plots were adjacent to one another. The Numbi Oct2, Dec2, Feb2, Apr2, Dec3, Oct3, Feb3, Apr3, and Aug3 plots were adjacent to one another. The Shabeni Aug2, Apr2, Dec3, and Apr3 plots were adjacent to one another, and the Shabeni Dec2 and Con0 plots were adjacent to one another. The single-stem structures in

WISETD

Group 2 were single-stem individuals 0-1m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, and 12.7-17.8cm, 1-3m high with basal diameters greater than 17.8cm, 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, and 12.7-17.8cm, 3-5m high with basal diameters greater than 17.8cm, 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, and 12.7-17.8cm, and taller than 5m with basal diameters greater than 17.8cm, 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, and 12.7-17.8cm (Figure 6-50). The multi-stem structures in Group 2 were 0-1m high with basal diameters 0-30cm, 1-3m high with basal diameters greater than 91cm, 0-30cm, and 30-91cm, 3-5m high with basal diameters greater than 91cm, 0-30cm, and 30-91cm, and taller than 5m with basal diameters 0-30cm and 30-91cm (Figure 6-50). Single-stem individuals 0-1m high with basal diameters 0.0-2.5cm, and 1-3m high with basal diameters 0.0-2.5cm and 2.5-7.6cm, and multi-stem individuals 0-1m high with basal diameters 0-30cm, and 1-3m high with basal diameters 0-30cm and 30-91cm, occurred on all the Group 2 plots. These structures also occurred mainly on the Group 2 plots. Single-stem individuals 3-5m high with basal diameters greater than 17.8cm were found on twenty-four of the thirty-four Group 2 plots in 1996, and they occurred mainly on the Group 2 plots. Single-stem individuals 3-5m high with basal diameters 7.6-12.7cm, and multi-stem individuals 1-3m high with basal diameters greater than 91cm were found on twenty-five of the thirty-four Group 2 plots, and they occurred mainly on the Group 2 plots. Single-stem individuals 3-5m high with basal diameters 12.7-17.8cm, were found on twenty-seven of the thirty-four Group 2 plots in 1996, and they occurred mainly on the Group 2 plots. Multi-stem individuals 3-5m high with basal diameters 30-91cm, were found on twenty-eight of the thirty-four Group 2 plots, and they occurred mainly on the Group 2 plots. Single-stem individuals 1-3m high with basal diameters 7.6-12.7cm, were found on thirty of the thirty-four Group 2 plots, and they occurred mainly on the Group 2 plots. Single-stem individuals taller than 5m with basal diameters greater than 17.8cm, and multi-stem individuals 3-5m high with basal diameters 0-30cm, were found on thirty-two of the thirty-four Group 2 plots, and they were found mainly on the Group 2 plots. Single-stem individuals 0-1m high with basal diameters 2.5-7.6cm, were found on thirty-three of the thirty-four Group 2 plots, and they were found mainly on the Group 2 plots. Sixty to seventy percent of the occurrences of multi-stem individuals 1-3m high with basal diameters greater than 91cm, 3-5m high with basal diameters 30-91cm, and taller than 5m with basal diameters 30-91cm, on the Pretoriuskop EBPs occurred on the Group 2 plots. Seventy to eighty percent of the occurrences of single-stem individuals 0-1m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, and 7.6-12.7cm, 1-3m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, and 7.6-12.7cm, 3-5m high with basal diameters 7.6-12.7cm and greater than 17.8cm, and taller than 5m with basal diameters 12.7-17.8cm and 17.8cm, on the Pretoriuskop EBPs in 1996 were on the Group 2 plots. Seventy to eighty percent of the occurrences of multi-stem individuals 0-1m high with basal diameters 0-30 cm, 1-3m high with basal diameters 0-30 cm and 30-91cm, 3-5m high with basal diameters 0-30 cm and taller than 5m with basal diameters 0-30 cm, on the Pretoriuskop EBPs in 1996 were on the Group 2 plots. Eighty to ninety percent of the occurrences of single-stem individuals 1-3m high with basal diameters 12.7-17.8cm, 3-5m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, and 12.7-17.8cm, and taller than 5m with basal diameters 0.0-2.5cm, on the Pretoriuskop EBPs in 1996 were on the Group 2 plots. Eighty to ninety percent of multi-stem individuals 3-5m high with basal diameters greater than 91cm, on the Pretoriuskop EBPs in 1996 were on the Group 2 plots. Ninety-four percent of the occurrences of single-stem individuals 1-3m high with basal diameters greater than 17.8cm, on the Pretoriuskop EBPs in were on the Group 2 plots. Single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, and taller than 5m with basal diameters 2.5-7.6cm and 7.6-12.7cm, were found only on the Group 2 plots in 1996. Single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, were found on the Kambeni Dec3 plot. Single-stem individuals taller than 5m with basal diameters between 2.5 and 7.6cm were found on the Fayi Dec3 plot and the Numbi Dec3 plot in 1996. Single-stem individuals taller than 5m with basal diameters 7.6-12.7cm, were found on the Fayi Apr2 and Feb3 plots, the Kambeni Feb2 and Dec3 plots, the Numbi Con0 and Feb3 plots, and the Shabeni Aug2 and Con0 plots in 1996.

Group 3 comprised the Fayi Aug2 and Aug1 plots, the Kambeni Aug1 plot, the Numbi Aug2 and Aug1 plots, and the Shabeni Aug1 and Oct2 plots (Figure 6-49). All the August Annual treatments were in Group 3, along with some August Biennial treatments. The structures in Group 3 were single-stem individuals 0-1m high with basal diameters greater than 17.8cm, and multi-stem individuals 0-1m high with basal diameters greater than 91cm and 30-91cm, and taller than 5m with basal diameters greater than 91cm (Figure 6-50). Multi-stem individuals 0-1m high with basal diameters 30-91cm and greater than 91cm occurred on all the

WITHDRAWN

plots in Group 3 however, they were also found on many other Pretoriuskop EBPs in 1996. Fifty percent of the occurrences of multi-stem individuals taller than 5m with basal diameters greater than 91cm, on the Pretoriuskop EBPs in 1996 were on the Group 2 plots. There were no structures in Group 3 that occurred only on the Group 3 plots.

6.3.5.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996

The step-wise Ward-Gamma cluster analysis was used to summarise the variation of plots and structures along the first four eigenvectors of the Correspondence Analysis on the 1996 structure by plot data. There were four main clusters of plots and structures at level 2 of the step-wise Ward-Gamma cluster analysis (Figure 6-48). These clusters differed from the two dimensional grouping of plots and structures along the first two eigenvectors described above (Figure 6-49 and Figure 6-50).

Cluster 1 comprised the Fayi Aug2, Aug1, and Aug3 plots, the Kambeni Aug2, Aug1, and Aug3 plots, the Numbi Feb2, Aug2, and Aug1 plots, and the Shabeni Aug2, Aug1, Oct2, and Dec3 plots (Figure 6-48). Cluster 1 comprised all the plots that were burnt annually and biennially in August, and many of the plots that were burnt triennially in August. The single-stem structures in Cluster 1 were 0-1m high with basal diameters greater than 17.8cm and taller than 5m with basal diameters greater than 17.8cm and 12.7-17.8cm (Figure 6-48). The multi-stem structures in Cluster 1 were 0-1m high with basal diameters greater than 91cm, 0-30cm, and 30-91cm, 1-3m high with basal diameters 30-91cm, 3-5m high with basal diameters 0-30cm and 30-91cm, and taller than 5m with basal diameters greater than 91cm and 30-91cm (Figure 6-48). Multi-stem individuals 0-1m high with basal diameters 0-30cm, and 1-3m high with basal diameters 30-91cm, occurred on all the Cluster 1 plots however, they occurred on many other Pretoriuskop EBPs in 1996. Multi-stem individuals 3-5m high with basal diameters 30-91cm, occurred on eleven of the thirteen Cluster 1 plots however, they occurred on many other Pretoriuskop EBPs. Single-stem individuals taller than 5m with basal diameters greater than 17.8cm, and multi-stem individuals 0-1m high with basal diameters 30-91cm, and 3-5m high with basal diameters 0-30cm, occurred on twelve of the thirteen Cluster 1 plots however, they occurred on many other Pretoriuskop EBPs in 1996. Fifty percent of the occurrences of single-stem individuals 0-1m high with basal diameters greater than 17.8cm, and multi-stem individuals taller than 5m with basal diameters greater than 91cm, on the Pretoriuskop EBPs occurred on the Cluster 1 plots in 1996. There were no structures in Cluster 1 that occurred only on the Cluster 1 plots.

Cluster 2 comprised the Fayi Oct2, Oct3, and Apr3 plots, the Kambeni Oct2, Feb2, Apr2, Oct3, and Apr3 plots, the Numbi Oct2, Dec2, and Apr2 plots, and the Shabeni Aug3 and Oct3 plots (Figure 6-48). Many of the October Annual and Biennial treatments were found in Cluster 2. The structures in Cluster 2 were multi-stem individuals 1-3m high with basal diameters greater than 91cm and 0-30cm, and taller than 5m with basal diameters 0-30cm (Figure 6-48). Multi-stem individuals 1-3m high with basal diameters 0-30cm, occurred on all Cluster 2 plots however, they were found on many other Pretoriuskop EBPs in 1996. Multi-stem individuals 1-3m high with basal diameters greater than 91cm were found on ten of the thirteen Cluster 2 plots however, they occurred on many Pretoriuskop EBPs in 1996. There were no structures in Cluster 2 that occurred only on the Cluster 2 plots.

Cluster 3 comprised the Fayi Dec2 plot, the Kambeni Con0 and Dec3 plots, and the Shabeni Con0 plot (Figure 6-48). Two of the four Control (no burn) treatments were in Cluster 3 along with two December treatments. In terms of fire timing, the December treatments had the least intense fires (see Table 3-7 p. 22). The structures in Cluster 3 were single-stem individuals 0-1m high with basal diameters 7.6-12.7cm and 12.7-17.8cm, and 3-5m high with basal diameters 2.5-7.6cm (Figure 6-48). Single-stem individuals 3-5m high with basal diameters 2.5-7.6cm, occurred on all the plots in Cluster 3 however, they were also found on many other Pretoriuskop EBPs in 1996. Single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, were found only on the Kambeni Dec3 plot, which occurred on Cluster 3 in 1996.

Cluster 4 comprised the Fayi Con0, Apr2, Feb2, Dec3, and Feb3 plots, the Kambeni Dec2 and Feb3 plots, the Numbi Con0, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Apr2, Feb2, Dec2, Apr3, and Feb3 plots (Figure 6-48). The Fayi Con0 and Dec3 plots were adjacent to one another and the Fayi Apr2 and Feb2 plots were adjacent to one another (Figure 6-51). The Kambeni Dec2 and Feb3 plots were adjacent to one another. Numbi Dec3, Oct3, Feb3, Apr3, and Aug3 plots were adjacent to one another. The single-stem structures in Cluster 4 were 0-1m high with basal diameters 0.0-2.5cm and 2.5-7.6cm, 1-3m high with basal diameters greater than 17.8cm, 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, and 12.7-17.8cm, 3-5m high with basal diameters greater than 17.8cm, 0.0-2.5cm, 7.6-12.7cm, and 12.7-17.8cm, and taller than 5m with basal diameters 0.0-2.5cm, 2.5-7.6cm, and 7.6-12.7cm (Figure 6-48). The multi-stem structures in Cluster 4 were 3-5m high with basal diameters greater than 91cm (Figure 6-48). Single-stem individuals 0-1m high with basal diameters 0.0-2.5cm, and 1-3m high with basal diameters 0.0-2.5cm and 2.5-7.6cm, occurred on all Cluster 4 plots however, they were also found on many other EBPs. Single-stem individuals 3-5m high with basal diameters 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, were found on thirteen of the eighteen Cluster 4 plots however, they were also found on many other Pretoriuskop EBPs. Single-stem individuals 1-3m high with basal diameters 7.6-12.7cm, were found on sixteen of the eighteen Cluster 4 plots however, they were also found on many other Pretoriuskop EBPs in 1996. Single-stem individuals 0-1m high with basal diameters 2.5-7.6cm, were found on seventeen of the eighteen Cluster 4 plots however, they were also found on many other Pretoriuskop EBPs. Fifty percent of the occurrences of single-stem individuals taller than 5m with basal diameters 7.6-12.7cm, and multi-stem individuals 3-5m high with basal diameters greater than 91cm, on the Pretoriuskop EBPs occurred on the Cluster 4 plots in 1996. Between sixty and seventy percent of the occurrences of single-stem individuals 1-3m high with basal diameters 12.7-17.8cm, and taller than 5m with basal diameters 0.0-2.5cm, on the Pretoriuskop EBPs in 1996, occurred on the Cluster 4 plots. Eighty percent of the occurrences of single-stem individuals 3-5m high with basal diameters 0.0-2.5cm, on the Pretoriuskop EBPs occurred on the Cluster 4 plots. Single-stem individuals taller than 5m with basal diameters 2.5-7.6cm, were found only on Cluster 4 plots, and occurred on the Fayi Dec3 plot, and the Numbi Dec3 plot in 1996.

6.3.5.3 Summary of the results from the CA's on the 1996 structure by plot data

In 1996, the predominant pattern that emerged regarding the structural composition of the Pretoriuskop EBPs was that the structural composition of the woody vegetation on plots that were not burnt or that were burnt in December, February and April was more similar to one another than to plots that were burnt in October and August.

The plots that were burnt in August and October were associated with multi-stem individuals of all coppice diameters 0-1m tall and 3-5m tall. The plots burnt in December, February, and April, and those not burnt at all were associated with both single and multi-stem individuals of all heights and basal diameters. In some cases, the structural composition of plots burnt in April was similar to plots that were burnt in August and April, and these plots had multi-stem individuals 1-3m high in common.

WISE

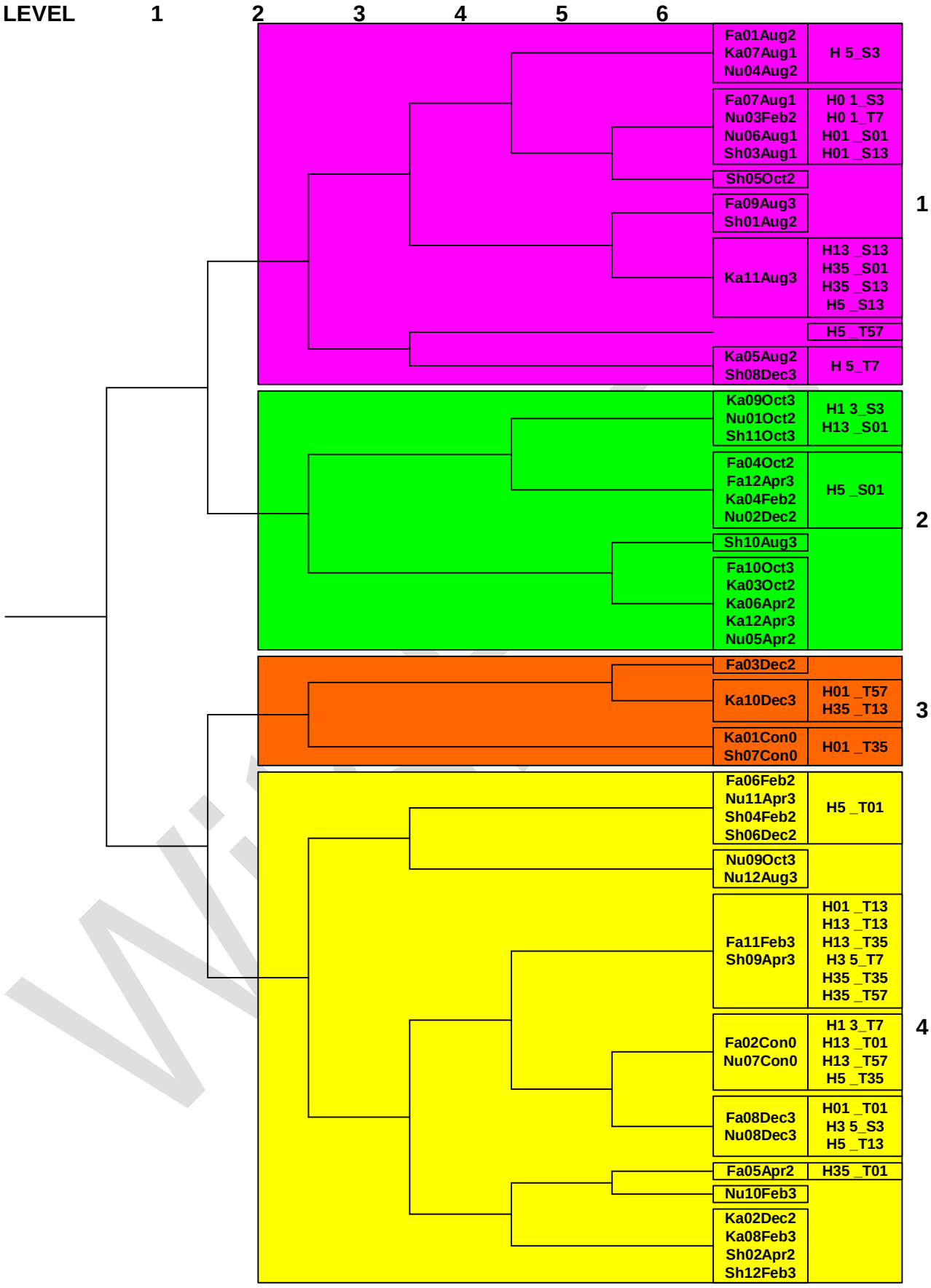


Figure 6-48: Classification of treatment plots and structures using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 structure by plot data. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the structure groups are defined in Table 5-3 (p. 34).

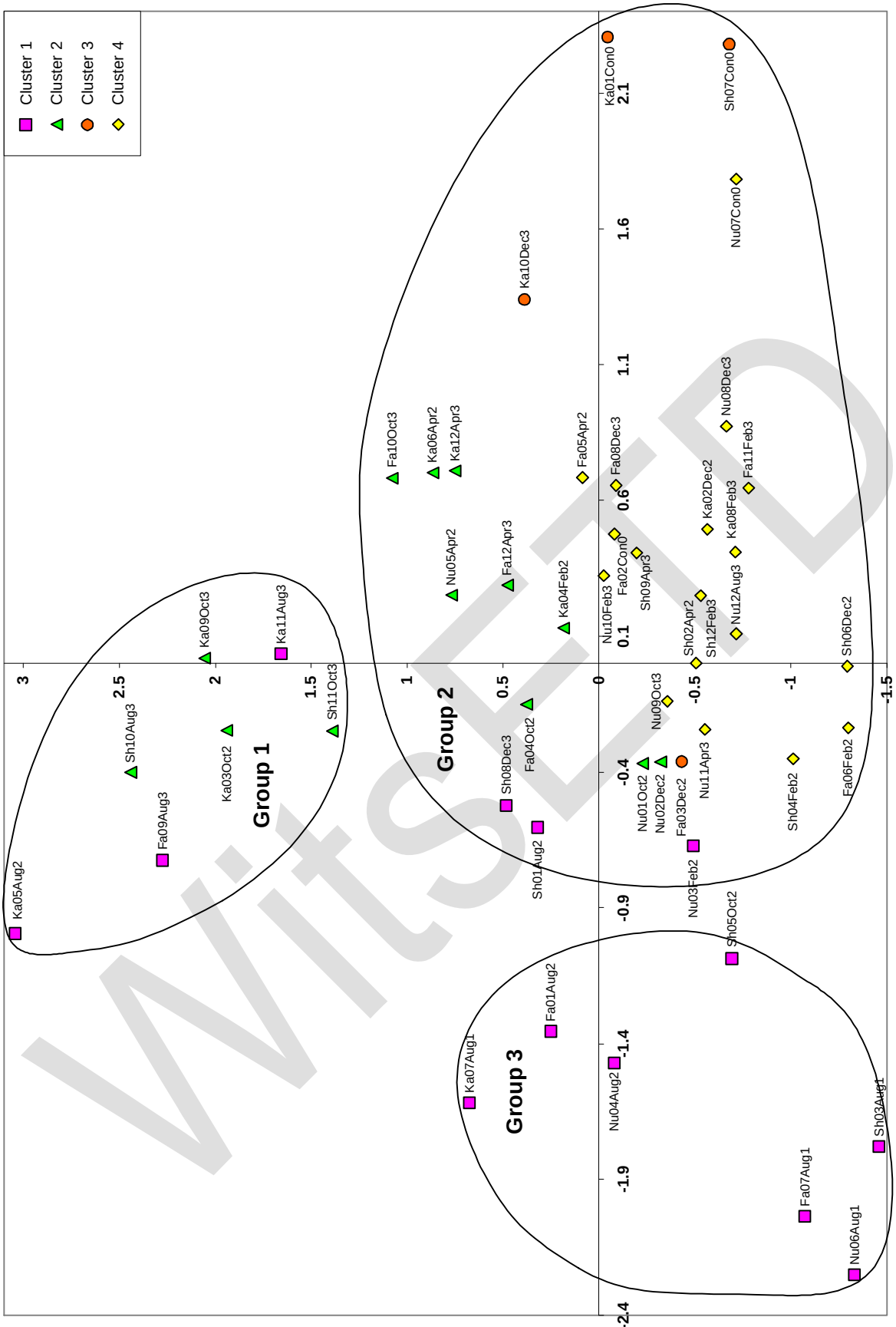


Figure 6-49: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in structural composition between treatment plots. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-48). The codes for the treatment plots are defined in Table 10-1 (p. 214).

WitsETD

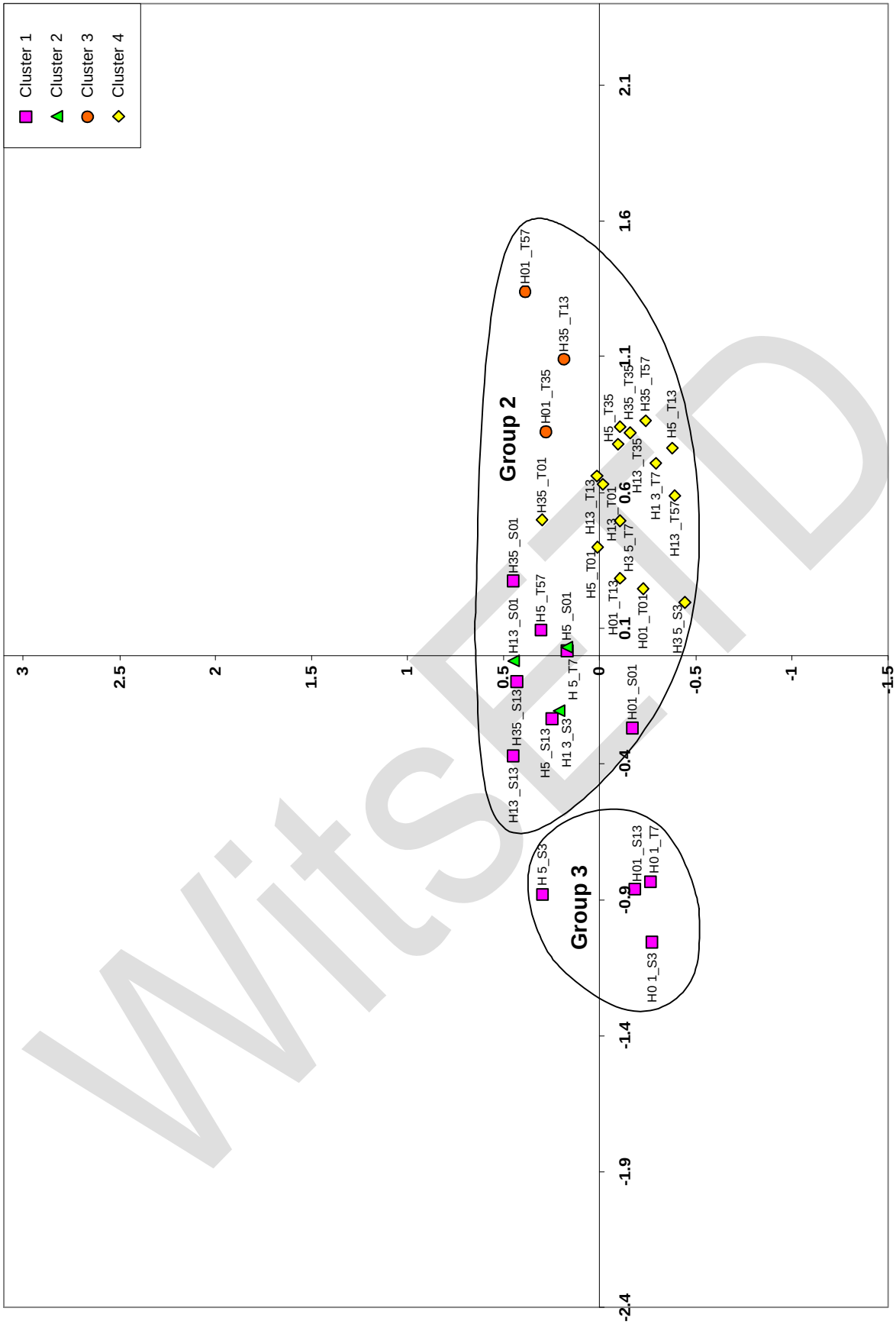


Figure 6-50: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in location (plots) between structures. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-48). The codes for the structure groups are defined in Table 5-3 (p. 34).

WitsETD

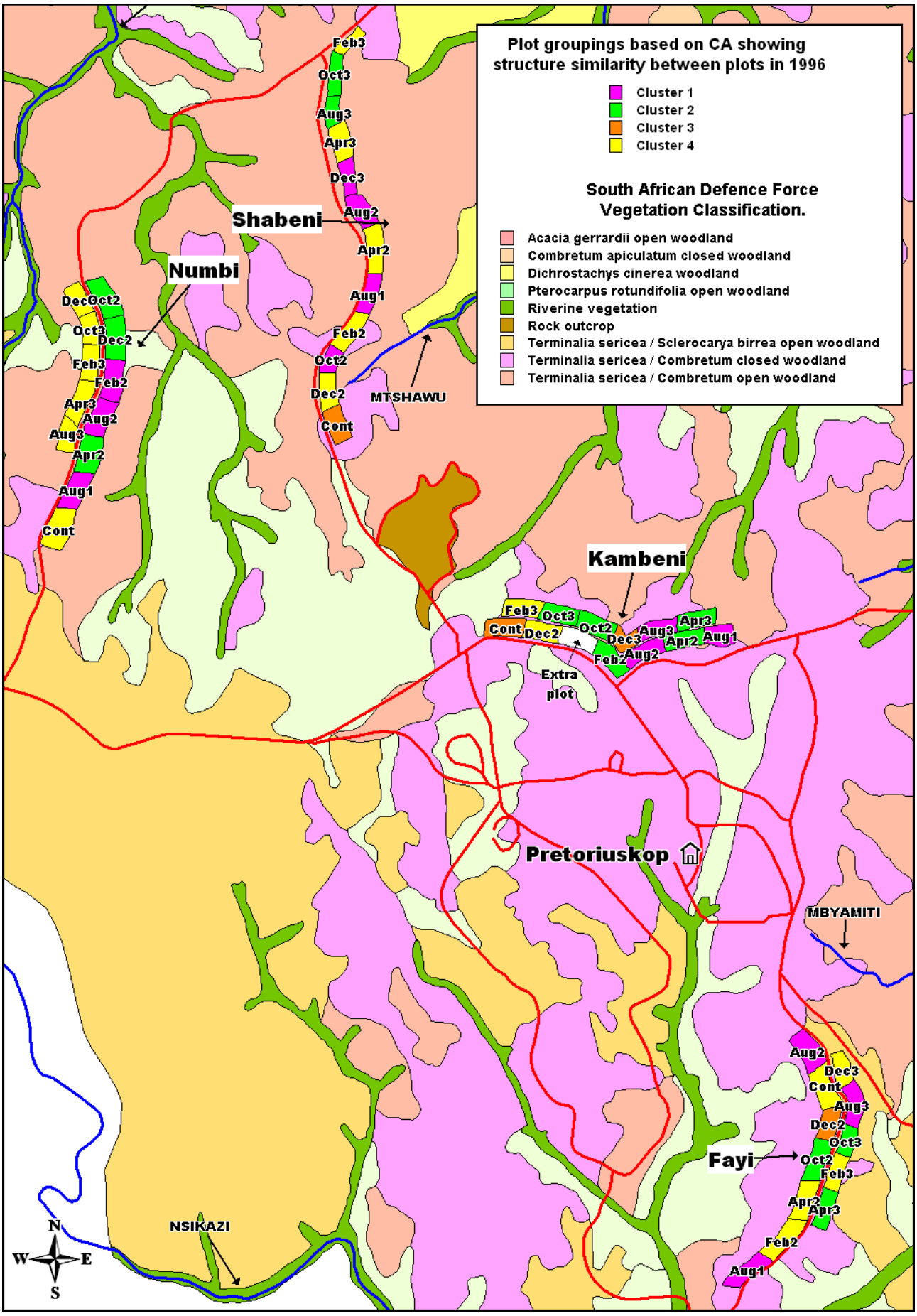


Figure 6-51: Map showing the level 2 clusters from the step-wise Gamma-Ward cluster analysis on the first four ordination axes of the CA on the 1954 structure by plot data (Figure 6-48). The codes for the treatments are defined in Table 3-1 (p. 15).

6.3.6 Results from the Correspondence Analysis on the 1996 structure by plot data with the first eight axes of the CA on the 1954 survey data as covariables

The results from the CA performed on the 1996 structure by plot data with the 1954 covariables are presented in Table 6-15 (p. 167), Figure 6-52 (p. 171), Figure 6-53 (p. 172), Figure 6-54 (p. 173), and Figure 6-55 (p. 174). Table 6-15 shows the Eigenvalues for the first four ordination axes of the CA. Figure 6-52 is a hierarchical cluster tree showing the cluster groups from the step-wise Gamma-Ward cluster analysis on the first four ordination axes. Figure 6-53 is a bi-plot of the first two, weighted eigenvector plot score axes with the data points colour coded to the level 2 cluster colours in Figure 6-52. Figure 6-54 is a bi-plot of the first two, weighted eigenvector structure score axes with the data points colour coded to the level 2 cluster colours in Figure 6-52. Figure 6-55 is a map showing the layout of the Pretoriuskop EBP experiment with the plots colour coded to the level 2 cluster colours in Figure 6-52. The weighted eigenvector plot scores for the first four ordination axes, the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973) are presented in Table 15-11 (p. 269). The weighted eigenvector structure scores for the first four ordination axes, the structure weights, and the effective number of occurrences of the structures (N2 diversity of structures) are presented in Table 15-12 (p. 270).

Table 6-15: Eigenvalues for the first four ordination axes of a Correspondence Analysis on the structure data collected in 1996 with the first four ordination axes of the 1954 Correspondence analysis as covariables.

	Axis 1	Axis 2	Axis 3	Axis 4	Total
Eigenvalue	0.0715	0.0440	0.0157	0.0106	0.2750
% Variation	26.0	16.0	5.7	3.9	51.6

The Eigenvalues, for the first four axes of the CA on the 1996 data with the 1954 covariables were 0.072, 0.044, 0.016, and 0.011 (Table 6-15). The first four eigenvectors accounted for 26.0%, 16.0%, 5.7%, and 3.9% of the variation in the structure by plot data respectively in 1996, and 51.6% of the total variation in the structure by plot data in 1996 (Table 6-15).

6.3.6.1 Bi-plots of the first two weighted structure and plot eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996 accounting for the relationship between the structures and plots in 1954

There were four main groups of plots and structures on the bi-plots of the first two weighted eigenvectors from the Correspondence Analysis on the 1996 data with the 1954 covariables (Figure 6-53 and Figure 6-54). Group 1 comprised structure groups and plots with x-axis eigenvector values greater than 1.5. Group 2 comprised structure groups and plots with x-axis eigenvector values between 1.5 and -1.5, and y-axis eigenvector values greater than 1.2. Group 3 comprised structure groups and plots with x-axis eigenvector values between 1.5 and -1.5, and y-axis eigenvector values less than 1.2. Group 4 comprised structure groups and plots with x-axis eigenvector values less than -1.5. The structures are spread along the first eigenvector axis and concentrated along the second eigenvector axis in the structure bi-plot (Figure 6-54). This resulted in a number of outlying plot groupings not having any associated structures, for example Group 1, Group 2, and Group 4.

Group 1 comprised the Fayi Apr2 and Feb3 plots, the Numbi Con0 plot, and the Shabeni Con0 plot (Figure 6-53). Two of the four Control (no burn) plots in the Pretoriuskop region were in Group 1. No structure groups were associated predominantly with the plots Group 1.

Group 2 comprised the Fayi Aug3 plot, the Kambeni Oct2, Oct3, and Aug3 plots, and the Shabeni Aug3 and Oct3 plots (Figure 6-53). The Kambeni Oct2 and Oct3 plots were adjacent to one another and the Shabeni Aug3 and Oct3 plots were adjacent to one another (Figure 6-55). Three of the four August Triennial treatments were in Group 2. No structure groups were associated predominantly with the plots Group 2.

Group 3 comprised the Fayi Aug2, Con0, Dec2, Oct2, Feb2, Dec3, Oct3, and Apr3 plots, the Kambeni Con0, Dec2, Feb2, Aug2, Apr2, Aug1, Feb3, Dec3, and Apr3 plots, the Numbi Oct2, Dec2, Feb2, Aug2, Apr2, Dec3, Oct3, Feb3, Apr3, and Aug3 plots, and the Shabeni Aug2, Apr2, Feb2, Oct2, Dec2, Dec3, Apr3, and Feb3 plots (Figure 6-53). Group 3 comprised thirty-five of the forty-eight Pretoriuskop EBPs, and all the structures present in 1996 were in Group 3. The single-stem structures in Group 3 were 0-1m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, 1-3m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, 3-5m high with basal diameters 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm, and taller than 5m with basal diameters 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, 12.7-17.8cm, and greater than 17.8cm (Figure 6-54). The multi-stem structures in Group 3 were 0-1m high with basal diameters 0-30cm, 30-91cm, and greater than 91cm, 1-3m high with basal diameters 0-30cm, 30-91cm, and greater than 91cm, 3-5m high with basal diameters 0-30cm, 30-91cm, and greater than 91cm, and taller than 5m with basal diameters 0-30cm, 30-91cm, and greater than 91cm (Figure 6-54). Single-stem individuals 0-1m high with basal diameters 0.0-2.5cm, and 1-3m high with basal diameters 2.5-7.6cm, and multi-stem individuals 0-1m high with basal diameters 0-30cm, and 1-3m high with basal diameters 0-30cm and 30-91cm, occurred on all the Group 3 plots and they were found mainly on the Group 3 plots. A

Group 4 comprised the Fayi Aug1 plot, the Numbi Aug1 plot, and the Shabeni Aug1 plot (Figure 6-53). Three of the four August Annual treatments on the Pretoriuskop EBPs were in Group 4. No structure groups were associated predominantly with the plots Group 4.

6.3.6.2 Step-wise Ward-Gamma cluster analysis of the first four weighted eigenvectors showing the relationship between the structures and plots in Pretoriuskop in 1996 accounting for the relationship between the structures and plots in 1954

The step-wise Ward-Gamma cluster analysis was used to summarise the variation of plots and structures along the first four eigenvectors of the Correspondence Analysis on the 1996 structure by plot data using the first eight axes from the CA on the 1954 data as covariables. There were four main clusters of plots and structures at level 2 of the step-wise Ward-Gamma cluster analysis (Figure 6-48). These clusters differed from the two dimensional grouping of plots and structures along the first two eigenvectors described above (Figure 6-49 and Figure 6-50).

Cluster 1 comprised the Fayi Aug2, Dec2, Aug1, and Aug3 plots, the Kambeni Oct2, Oct3, and Aug3 plots, the Numbi Oct2, Feb2, Aug2, and Aug1 plots, and the Shabeni Aug2, Aug1, Oct2, Dec3, Aug3, and Oct3 plots (Figure 6-52). Nine of the twelve August Annual, Biennial, and Triennial treatment plots were in Cluster 1, and five of the eight October Biennial and Triennial treatment plot were in cluster 1. The Fayi Dec2 and Aug3 plots were adjacent to one another (Figure 6-55). The Kambeni Oct2 and Oct3 were adjacent to one another. The Numbi Feb2 and Aug2 plots were adjacent to one another. The Shabeni Aug2 and Dec3 plots were adjacent to one another and the Shabeni Aug3 and Oct3 plots were adjacent to one another. The single-stem structures in Cluster 1 were 0-1m high with basal diameters greater than 17.8cm and taller than 5m with basal diameters greater than 17.8cm (Figure 6-52). The multi-stem structures in Cluster 1 were 0-1m high with basal diameters greater than 91cm, 0-30cm, and 30-91cm, 1-3m high with basal diameters greater than 91cm, 0-30cm, and 30-91cm, 3-5m high with basal diameters 0-30cm and 30-91cm, and taller than 5m with basal diameters greater than 91cm, 0-30cm, and 30-91cm (Figure 6-52). Multi-stem individuals 0-1m high with basal diameters 0-30cm, and 1-3m high with basal diameters 0-30cm and 30-91cm, occurred on all the Cluster 1 plots however, they were found on many other Pretoriuskop EBPs in 1996. Multi-stem individuals 1-3m high with basal diameters greater than 91cm were found on fourteen of the seventeen Cluster 1 plots however, they were found on many other Pretoriuskop EBPs. Multi-stem individuals 3-5m high with basal diameters between 30 and 91cm were found on fifteen of the seventeen Cluster 1 plots however, they were found on many other Pretoriuskop EBPs in 1996. Single-stem individuals taller than 5m with basal diameters greater than 17.8cm, and multi-stem individuals 0-1m high with basal diameters 30-91cm, and 3-5m high with basal diameters 0-30cm, were found on sixteen of the seventeen Cluster 1 plots however, they were found on many other Pretoriuskop EBPs in 1996. Fifty percent of the occurrences of

single-stem individuals 0-1m high with basal diameters greater than 17.8cm, on the Pretoriuskop EBPs in 1996 were on the Cluster 1 plots. Multi-stem individuals taller than 5m with basal diameters greater than 91cm, were found only on Cluster 1 plots and they occurred on the Kambeni Oct3 plot, and the Shabeni Aug1 plot.

Cluster 2 comprised the Fayi Oct2 and Oct3 plots, the Kambeni Aug2, Apr2, and Apr3 plots, the Numbi Dec2 and Apr2 plots, and the Shabeni Apr2 plot (Figure 6-52). Five of the eight April Biennial and Triennial treatments were in Cluster 2. The Kambeni Aug2, Apr2, and Apr3 plots were adjacent to one another, and the Fayi Oct2 and Oct3 plots were adjacent to one another (Figure 6-55). There were no structures in Cluster 2 (Figure 6-52).

Cluster 3 comprised the Fayi Apr3 plot, the Kambeni Aug1 and Dec3 plots, the Numbi Apr3 plot, and the Shabeni Apr3 plot (Figure 6-52). Three of the four April Triennial treatments were in Cluster 3. The structures in Cluster 3 were single-stem individuals 0-1m high with basal diameters 7.6-12.7cm and 12.7-17.8cm, 3-5m high with basal diameters 2.5-7.6cm, and taller than 5m with basal diameters 0.0-2.5cm (Figure 6-52). Single-stem individuals 0-1m high with basal diameters 12.7-17.8cm, were found only on Cluster 3 plots, and they occurred on the Kambeni Dec3 plot.

Cluster 4 comprised the Fayi Con0, Apr2, Feb2, Dec3, and Feb3 plots, the Kambeni Con0, Dec2, Feb2, and Feb3 plots, the Numbi Con0, Dec3, Oct3, Feb3, and Aug3 plots, and the Shabeni Feb2, Dec2, Con0, and Feb3 plots (Figure 6-52). All the Control (no burn) treatments in the Pretoriuskop EBPs were in Cluster 4. Seven of the eight February Biennial and Triennial Pretoriuskop EBP treatments were in Cluster 4, and half the December Biennial and Triennial treatments were in Cluster 4. The Fayi Con0 and Dec3 plots were adjacent to one another, and the Fayi Apr2, Feb2, and Feb3 plots were adjacent to one another (Figure 6-55). The Kambeni Con0, Dec2, and Feb3 plots were adjacent to one another. The Numbi Dec3, Oct3, and Feb3 plots were adjacent to one another. The Shabeni Dec2 and Con0 plots were adjacent to one another. The single-stem structures on Cluster 3 were 0-1m high with basal diameters 0.0-2.5cm and 2.5-7.6cm, 1-3m high with basal diameters greater than 17.8cm, 0.0-2.5cm, 2.5-7.6cm, 7.6-12.7cm, and 12.7-17.8cm, 3-5m high with basal diameters greater than 17.8cm, 0.0-2.5cm, 7.6-12.7cm, and 12.7-17.8cm, and taller than 5m with basal diameters 2.5-7.6cm, 7.6-12.7cm, and 12.7-17.8cm (Figure 6-52). The multi-stem structures on Cluster 3 were 3-5m high with basal diameters greater than 91cm (Figure 6-52). Single-stem individuals 0-1m high with basal diameters 0.0-2.5cm and 2.5-7.6cm, and 1-3m high with basal diameters 0.0-2.5cm and 2.5-7.6cm, occurred on all Cluster 4 plots however, they were found on many other Pretoriuskop EBPs. Single-stem individuals 3-5m high with basal diameters 12.7-17.8cm, were found on thirteen of the eighteen Cluster 4 plots however, they were found on many other Pretoriuskop EBPs. Single-stem individuals 3-5m high with basal diameters 7.6-12.7cm and greater than 17.8cm were found on fourteen of the eighteen Cluster 4 plots however, they were found on many other Pretoriuskop EBPs in 1996. Single-stem individuals 1-3m high with basal diameters 7.6-12.7cm, were found on seventeen of the eighteen Cluster 4 plots however, they were found on many other Pretoriuskop EBPs. Sixty to seventy percent of the occurrences of single-stem individuals 1-3m high with basal diameters 12.7-17.8cm and greater than 17.8cm, and 3-5m high with basal diameters 0.0-2.5cm, on the Pretoriuskop EBPs were on the Cluster 4 plots in 1996. Seventy-five percent of the occurrences of single-stem individuals taller than 5m with basal diameters 7.6-12.7cm, and multi-stem individuals 3-5m high with basal diameters greater than 91cm, on the Pretoriuskop EBPs were on the Cluster 4 plots. Single-stem individuals taller than 5m with basal diameters 2.5-7.6cm, occurred only on the Cluster 4 plots and was found on the Fayi Dec3 plot and the Numbi Dec3 plot.

6.3.6.3 Summary of the results from the CA's on the 1996 structure by plot data with covariables

The findings from the CA on the 1996 with covariables were similar to the findings from the CA on the 1996 data without covariables. The main pattern to emerge from the analysis on the structural composition of the Pretoriuskop EBPs was that the structural composition of the woody vegetation on plots that were not burnt or that were burnt in December, February and April was more similar to one another than to plots that were

burnt in October and August. The structural compositions of the August Annual plots were more similar to one another than the structural composition of the other plots. As with the CA on the 1996 data without covariables, the structural composition of some of the April treatments was also found to be similar to that of some of the August and October treatments.

WitsETD

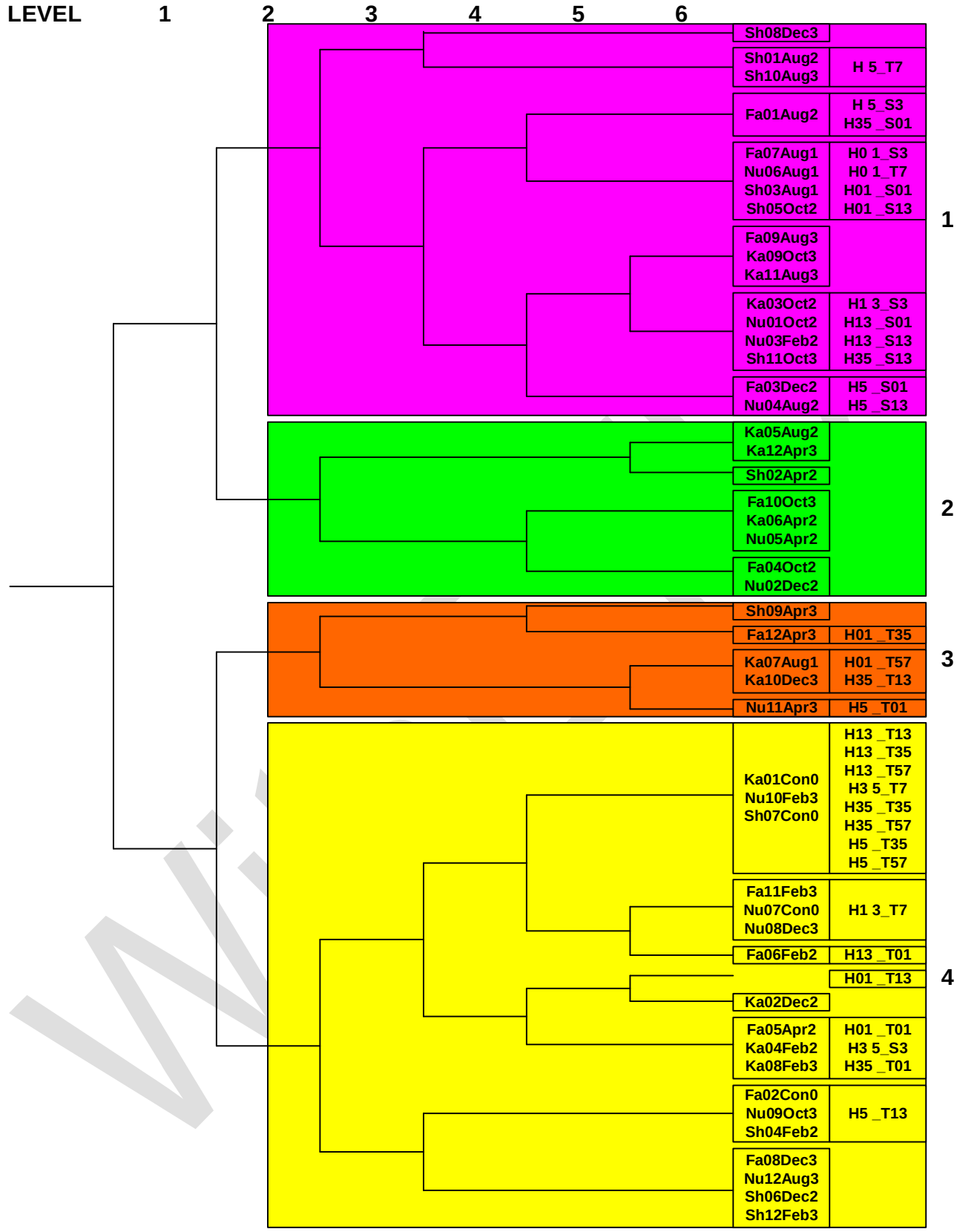


Figure 6-52: Classification of treatment plots and structures using a step-wise Gamma-Ward cluster analysis on the first four ordination axes from the CA on the 1996 structure by plot data with the first eight ordination axes of the 1954 structure by plot CA as covariables. The codes for the treatment plots are defined in Table 10-1 (p. 214) and the codes for the structure groups are defined in Table 5-3 (p. 34).

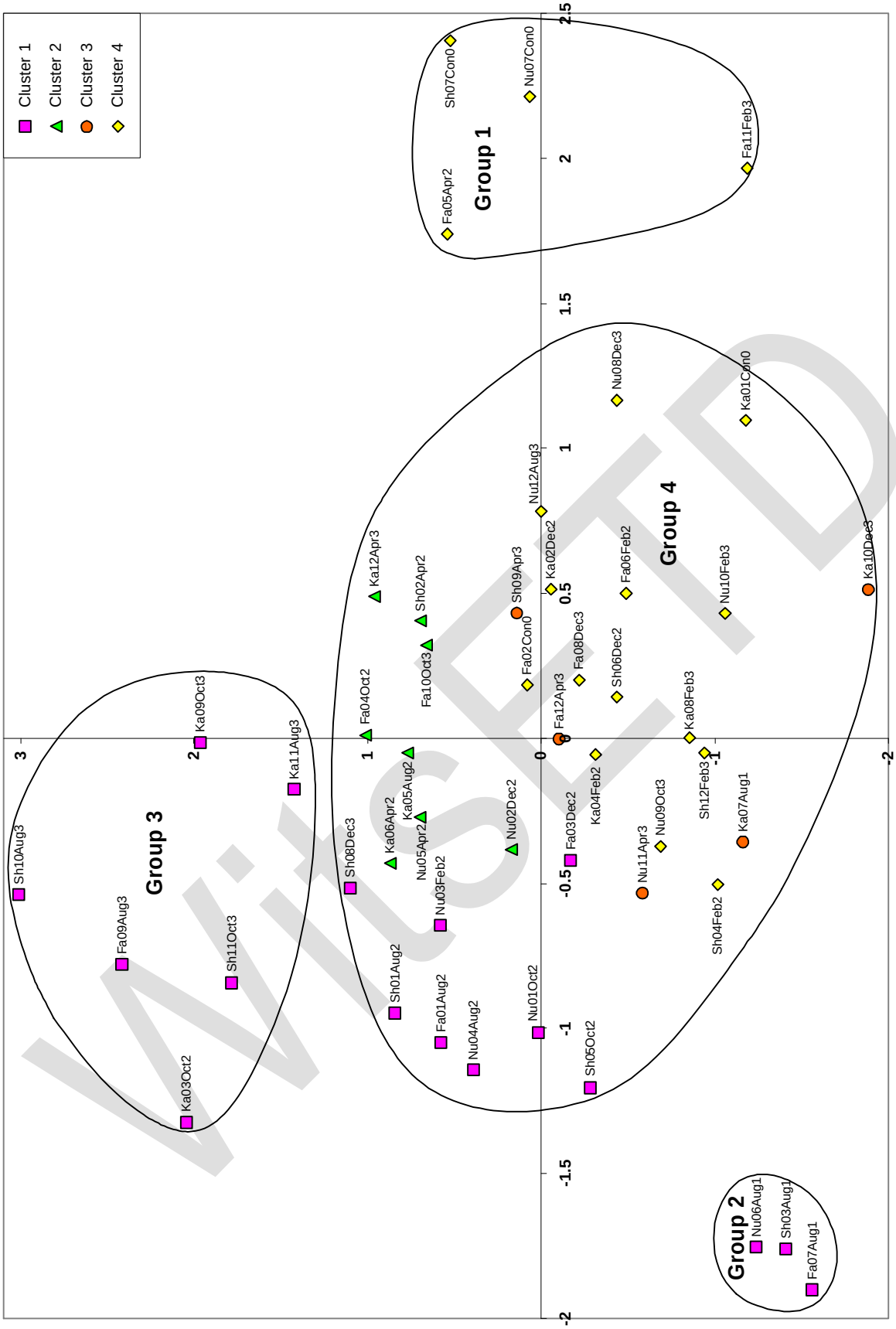


Figure 6-53: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in structural composition between treatment plots with the first eight ordination axes of the 1954 structure by plot CA as covariables. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-52). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Visited

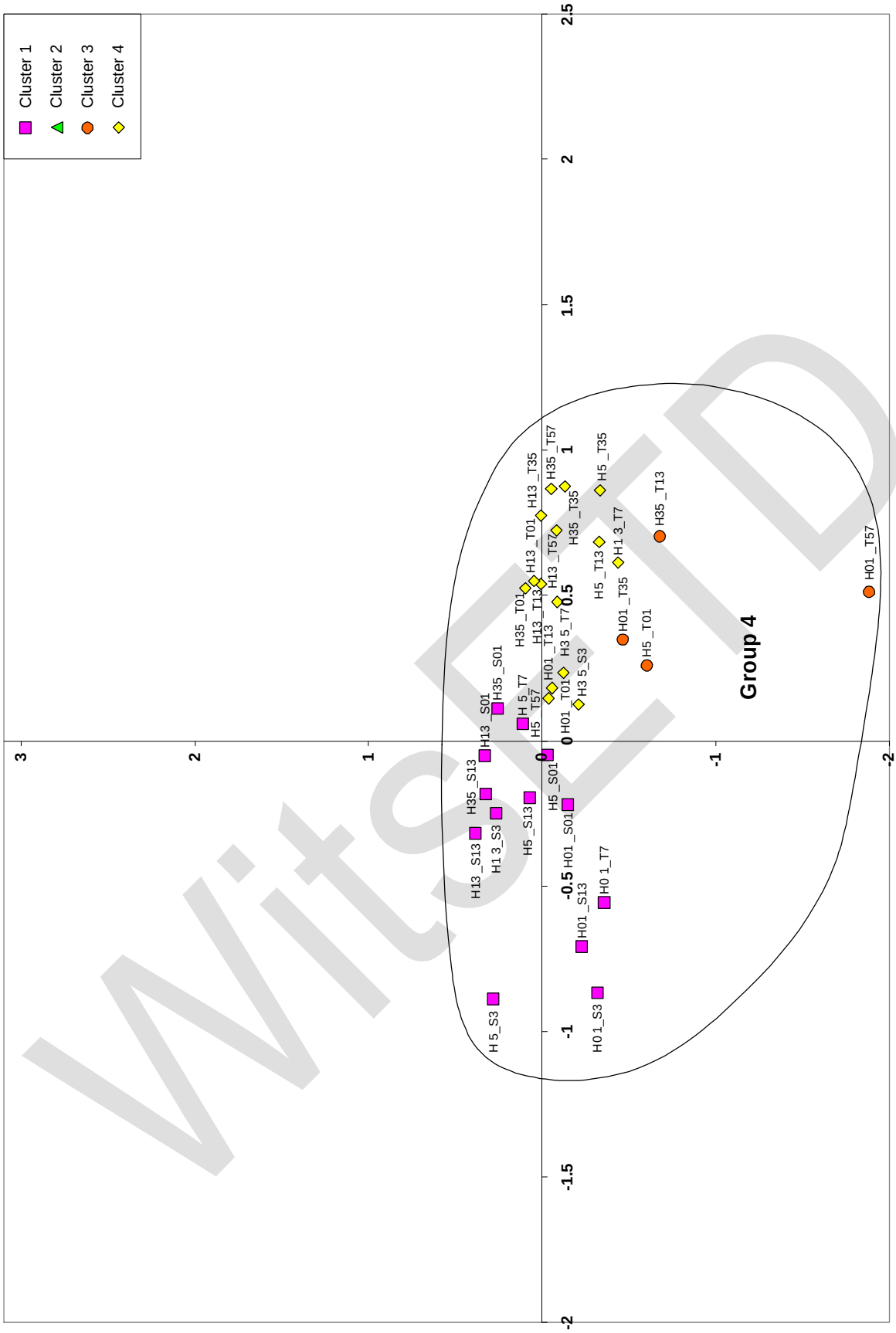


Figure 6-54: Bi-plot of the first two ordination axes from the CA on the 1996 structure by plot data showing variation in location (plots) between structures with the first eight ordination axes of the 1954 structure by plot CA as covariables. The groups are the result of a visual assessment of the grouping of structures and plots along the first two eigenvectors, and the graph points are colour coded to the level 2 clusters from the stepwise Gamma-Ward cluster analysis on the first four eigenvectors (Figure 6-52). The codes for the structure groups are defined in Table 5-3 (p. 34).

WitsETD

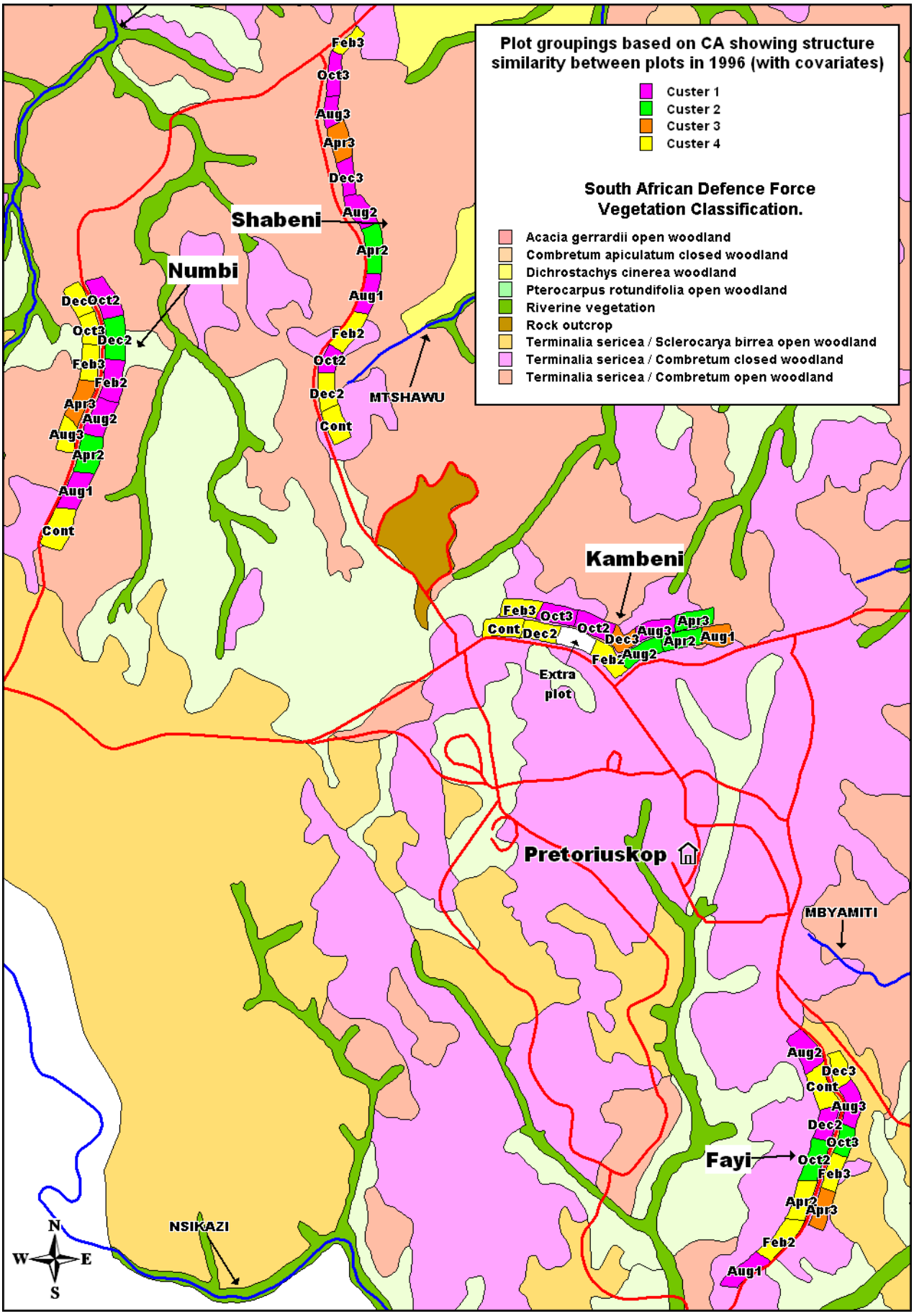


Figure 6-55: Map showing the level 2 groupings of a classification of treatment plots using a stepwise cluster analysis on the first four ordination axes of a CA on the 1996 structure by plot data with the first eight ordination axes of the 1954 structure by plot CA as covariables (Figure 6-52). The codes for the treatments are defined in Table 3-1 (p. 15).

7 DISCUSSION

7.1 SIMILARITIES AND DIFFERENCES IN THE WOODY VEGETATION BETWEEN THE PRETORIUSKOP EBP REPLICATES

The four EBP replicates in the Pretoriuskop region are located in two distinct vegetation types, namely the open and the closed *Terminalia sericea* \ *Combretum* woodlands of Pretoriuskop (Figure 3-3 p. 18). The Numbi and Shabeni replicates are located in the open *Terminalia sericea* \ *Combretum* woodlands in the north-eastern part of the Pretoriuskop region (Figure 3-3). The Kambeni and Fayi replicates are located in the closed *Terminalia sericea* \ *Combretum* woodlands in the south-western part of the Pretoriuskop region (Figure 3-3). The location of the replicates has an influence on the structure and composition of the woody vegetation on the replicates. The Kambeni replicate is located near a transition between the open and the closed *Terminalia sericea* \ *Combretum* woodlands in the central part of the Pretoriuskop region, and some of the characteristics of the open *Terminalia sericea* \ *Combretum* woodlands are manifest on the Kambeni replicate.

In 1954 and in 1996 the number of species, species richness, species diversity, and species evenness of the woody vegetation was higher on the Numbi and Shabeni replicates occurring in the open *Terminalia sericea* \ *Combretum* woodlands than on the Kambeni and Fayi replicates occurring in the closed *Terminalia sericea* \ *Combretum* woodlands. The species composition of many of the plots on the Numbi and Shabeni replicates was more similar than the species composition on the plots of the Kambeni and Fayi replicates. In 1954, the species composition on some of the Kambeni plots was similar to the species composition of some Numbi and Shabeni replicate plots. However, in 1996 the species composition on most of the Kambeni plots was similar to the species composition of the Fayi plots. This may suggest that the transition between the open and closed *Terminalia sericea* \ *Combretum* woodlands migrated slightly northwards between 1954 and 1996, because the Kambeni replicate plots are dominated by closed *Terminalia sericea* \ *Combretum* woodland vegetation characteristics in 1996. It was found that plots that were adjacent to one another were more likely to have similar species compositions than plots that were further apart. Furthermore, the species composition of many plots in 1954 was found to be an important determinant of the species composition of the plots in 1996 regardless of treatment. It was found that there were plots that were similar to one another in species composition in 1996 that had been similar to one another in species composition in 1954, and this was regardless of the fire treatment applied to the plots between 1954 and 1996.

Generally, the density, height, number of tree equivalents, number of structural groups, structural richness, structural diversity, and structural evenness of the woody vegetation on the Pretoriuskop replicates were similar in 1954 and 1996. In 1954, it was found that the establishment of the plots in two distinct phases had an impact on the baseline structure of the woody vegetation. The structural composition of most plots that were established and surveyed in 1954 was more similar to one another than with plots that were established and surveyed between 1956 and 1958. However, there was no clear pattern regarding location of the replicates and the structural composition of the vegetation on the replicates.

The main differences in the woody vegetation between the Pretoriuskop replicates were slightly different species abundances and compositions in the open and closed *Terminalia sericea* \ *Combretum* woodlands. All other woody vegetation characteristics were similar between the replicates in 1954 and 1996, even though there were large changes in the density of the woody vegetation between 1954 and 1996.

7.2 THE EFFECT OF FIRE FREQUENCY ON THE WOODY VEGETATION OF THE PRETORIUSKOP SOURVELD

Change in the density of the woody vegetation as the inter-fire period increases in the Pretoriuskop region is approximately J shaped (Figure 7-1). There is an initial decrease in the woody plant density as the inter-fire

WISER

period increases from 1 year to 3 years, thereafter the density of the woody vegetation increases as the inter-fire period increases beyond 3 years. Change in the number of tree equivalents as the inter-fire period increases is however, not J shaped, and is approximately logarithmic (Figure 7-1). This indicates that the initial decrease in the density of the woody vegetation is caused by a decrease in the density of very short individuals.

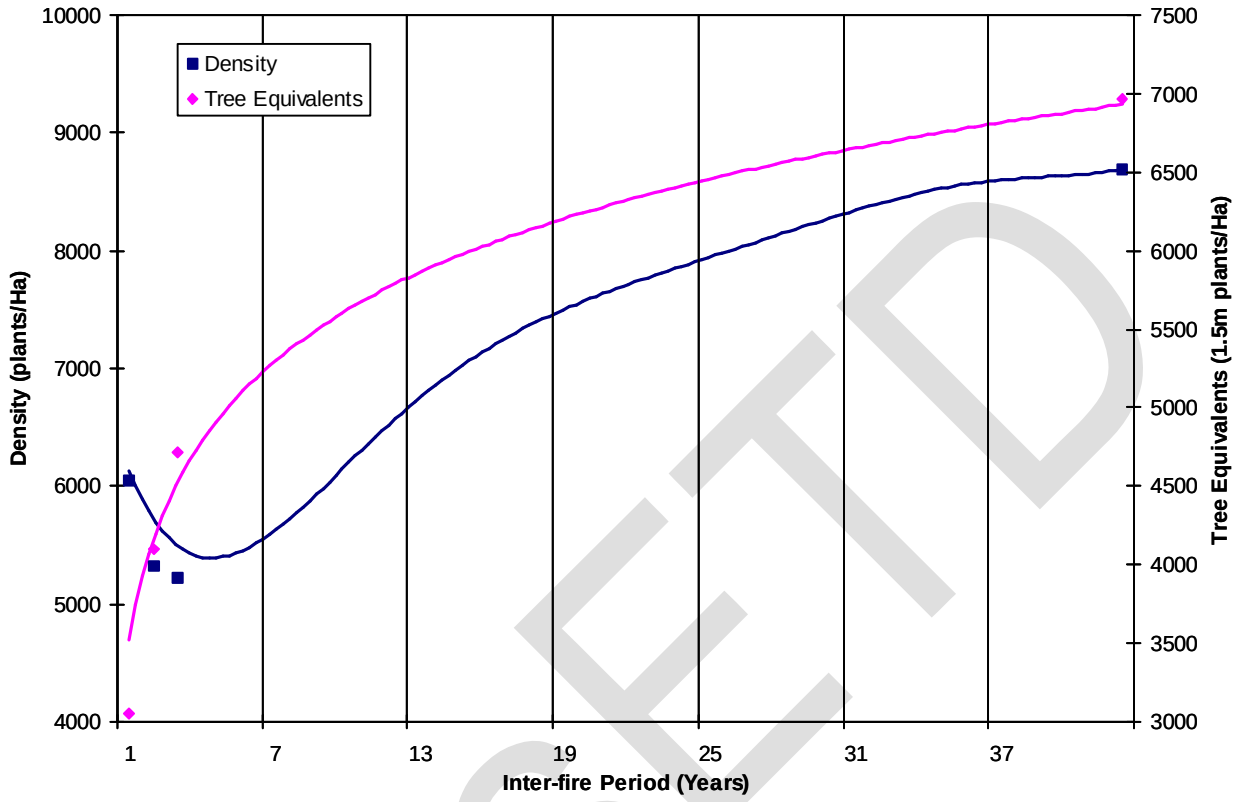


Figure 7-1: Model of the change in the density (plants/Ha) and the number of tree equivalents (tree equivalents/Ha) of the woody vegetation in the Pretoriuskop region as the period between fires increases.

Figure 7-2 shows that the density of individuals 0-1m tall (understorey individuals) decreases as the inter-fire period increases from 1 year to 3 years, and the density of individuals 1-3m tall (overstorey individuals) increases as the inter-fire period increases from 1 year to 3 years. The decrease in the density of the understorey woody vegetation is proportionately greater than the increase in density of the overstorey woody vegetation. This indicates that as the inter-fire period increases from 1 year to 3 years a large proportion of the understorey plants disappear. Many of the understorey individuals at an inter-fire period of 1 year and 3 years are stunted fire tolerant individuals that sprout in response to fire damage. These individuals most often have a resilience response to fire events because they experience 100% mortality of their above ground parts (topkill), and they then sprout from meristematic tissues below ground that have not been damaged by fire.

The dominant understorey species that are common between 1 and 3 years inter-fire periods are *Catunaregam spinosa*, *Dichrostachys cinerea*, *Maytenus senegalensis*, *Pavetta schumanniana*, *Senna petersiana*, *Strychnos madagascariensis*, *Terminalia sericea*, and *Turraea nilotica* (Figure 7-4 and Figure 7-5). The understorey species that dominate when the vegetation is burnt annually but not triennially are *Albizia versicolor*, *Annona senegalensis*, *Euclea natalensis*, and *Lonchocarpus capassa* (Figure 7-4). The understorey species that dominate when the vegetation is burnt triennially but not annually are *Acacia gerrardii*, *Combretum hereroense*, *Diospyros lycioides*, and *Hippobromus pauciflorus* (Figure 7-5). After the

WitsETD

initial decrease in the density of the woody understorey community, the density begins to increase between inter-fire periods of 3 to 5 years. This is seen in Figure 7-3 where a resurvey of the control plots in 1959 after 5 years of fire exclusion showed that the density of the woody understorey community had increased since the baseline survey in 1954. Some species no longer dominate the understorey community when fire has been excluded from the vegetation for over 40 years, for example *Acacia gerrardii*, *Albizia versicolor*, *Combretum hereroense*, *Hippobromus pauciflorus*, *Lonchocarpus capassa*, *Pavetta schumanniana*, *Senna petersiana*, and *Turraea nilotica* (Figure 7-4, Figure 7-5 and Figure 7-6). While these species are certainly fire tolerant, they may not be shade tolerant and therefore do not thrive well as seedlings or saplings, when in the absence of fire the overstorey becomes more wooded. Furthermore, these species may not survive well when the grass and herbaceous layer is not periodically removed by fire and becomes overgrown and moribund.

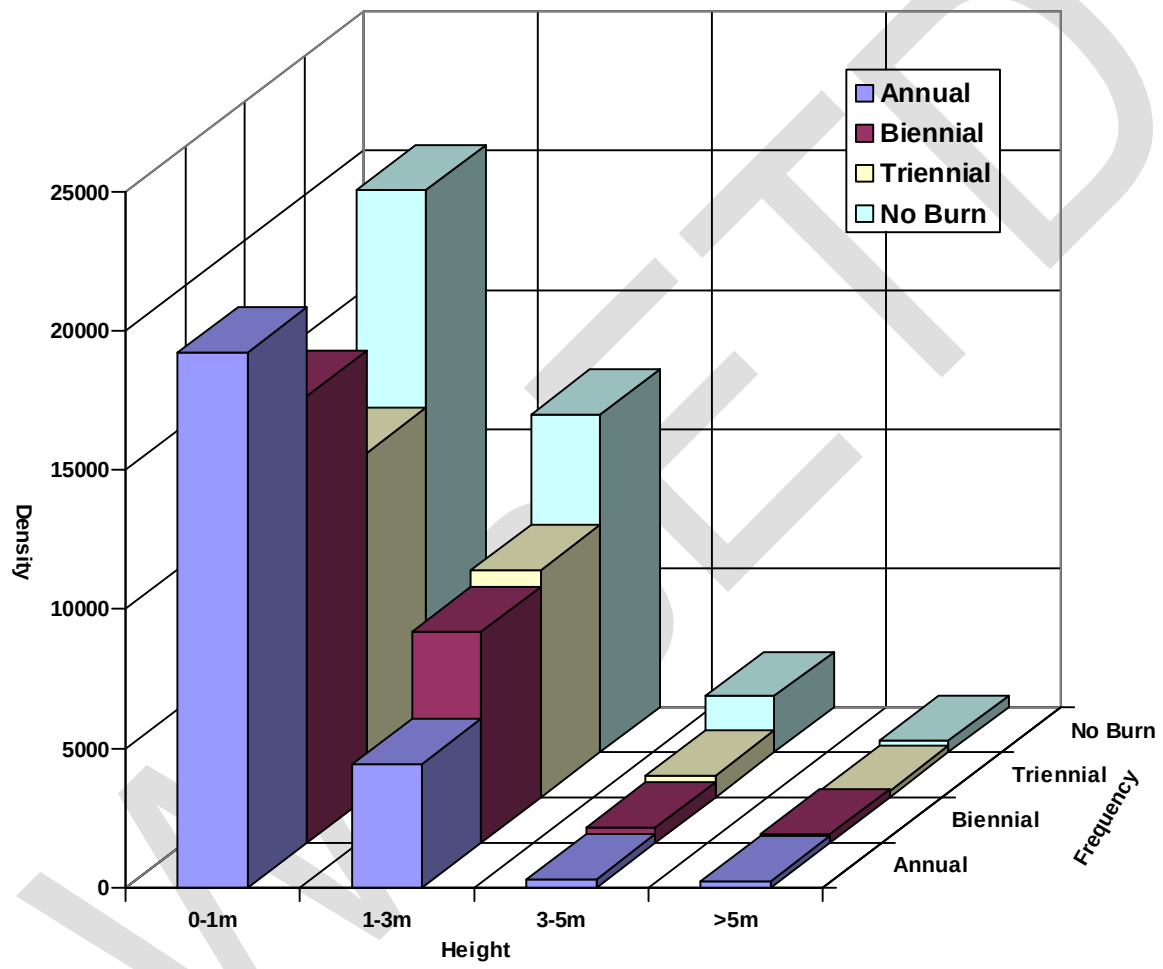


Figure 7-2: The density (plants/Ha) of the woody vegetation at different height classes of vegetation burnt at different fire frequencies.

Figure 7-2 shows that the density of the understorey and overstorey communities increases significantly as the inter-fire period approaches over 40 years. The understorey community of vegetation where fire has been excluded comprises fire sensitive, fire intolerant, and fire tolerant species. Some understorey species that dominate when fire has been excluded are also dominant in vegetation that has been burnt with high or medium frequencies, namely *Catunaregam spinosa*, *Dichrostachys cinerea*, *Diospyros lycioides*, *Maytenus senegalensis*, *Strychnos madagascariensis*, and *Terminalia sericea* (Figure 7-4, Figure 7-5 and Figure 7-6). Some understorey species only dominate when fire has been excluded, such as *Canthium* species, *Dalbergia melanoxylon*, *Diospyros whyteana*, *Ochna natalitia*, *Olea europaea*, *Parinari curatellifolia*,

Putterlickia pyracantha, and *Zanthoxylum capense* (Figure 7-4, Figure 7-5 and Figure 7-6). Some of these species are fire sensitive or fire intolerant, and furthermore these species are almost certainly shade tolerant and survive well when the grass and herbaceous layer become overgrown and moribund.

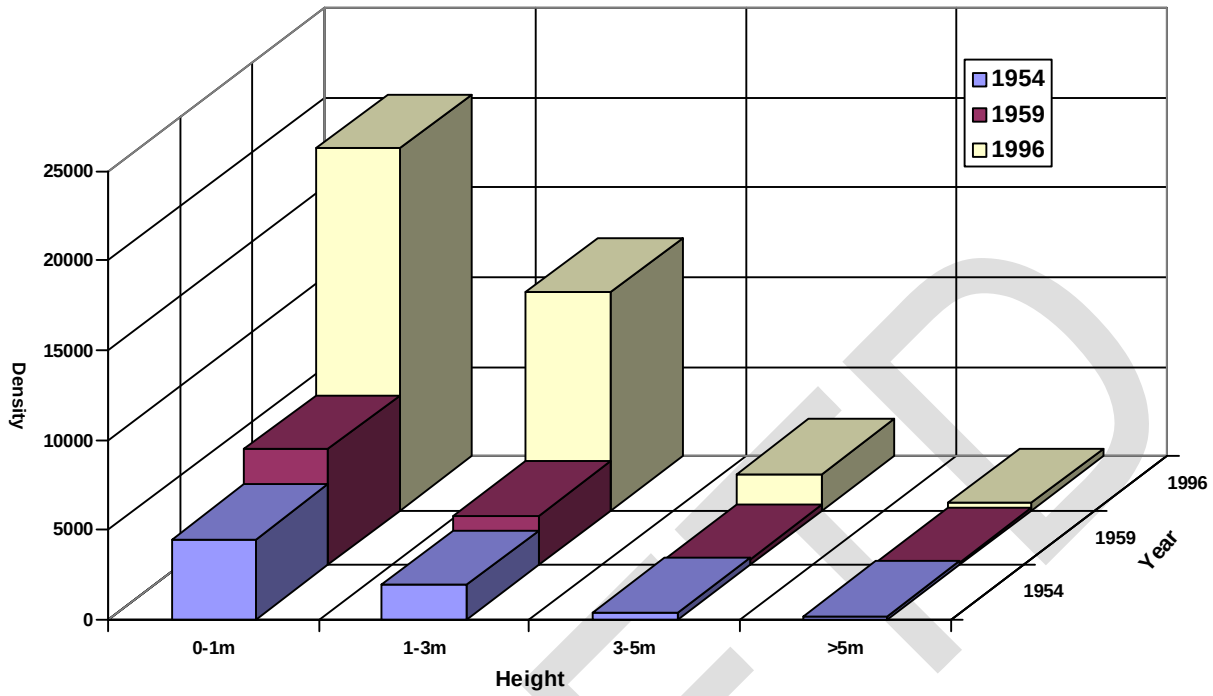


Figure 7-3: The density (plants/Ha) of the woody vegetation at different heights on the control plots at three different years (1954, 1959, and 1996).

As the period between fires increases in the Pretoriuskop region the number of species, species diversity, and species evenness increases. Factors such as the initial species composition of a site and proximity to other sites were found to exercise a great influence on the species composition of a site. However, some generalisations can be made regarding the effects of fire frequency on the species composition of the woody vegetation of the Pretoriuskop region. Species tolerant of high frequency fires are *Albizia versicolor*, *Catunaregam spinosa*, *Lonchocarpus capassa*, *Pavetta schumanniana*, *Senna petersiana*, *Strychnos madagascariensis*, and *Turraea nilotica* (Figure 7-7). *Catunaregam spinosa*, *Senna petersiana*, *Strychnos madagascariensis*, and *Turraea nilotica* are found in areas burnt less frequently. However, they are most abundant in areas burnt frequently where they occur in densities that exceed 600, 200, 240, and 190 plants/Ha respectively. Most individuals of these species are 0-1m tall in areas that are burnt frequently. Species tolerant of medium frequency fires are *Acacia gerrardii*, *Combretum hereroense*, *Diospyros lycioides*, *Hippobromus pauciflorus*, *Maytenus senegalensis*, and *Terminalia sericea* (Figure 7-7). *Terminalia sericea* occurs most abundantly in areas that are burnt less frequently with densities that exceed 320 plants/Ha.

Fire sensitive and fire intolerant species are *Acacia swazica*, *Bauhinia galpinii*, *Combretum mossambicense*, *Commiphora neglecta*, *Croton gratissimus*, *Dalbergia melanoxylon*, *Diospyros lycioides*, *Diospyros whyteana*, *Euclea natalensis*, *Hyperacanthus amoenus*, *Kraussia floribunda*, *Ochna natalitia*, *Olea europaea*, *Psydrax locuples*, *Putterlickia pyracantha*, *Tarenna supra-axillaris*, and *Zanthoxylum capense* (Figure 7-7). Species like *Catunaregam spinosa*, *Dichrostachys cinerea*, *Senna petersiana*, and *Terminalia sericea* decrease in density as the inter-fire period increases beyond medium frequency fires.

WISE

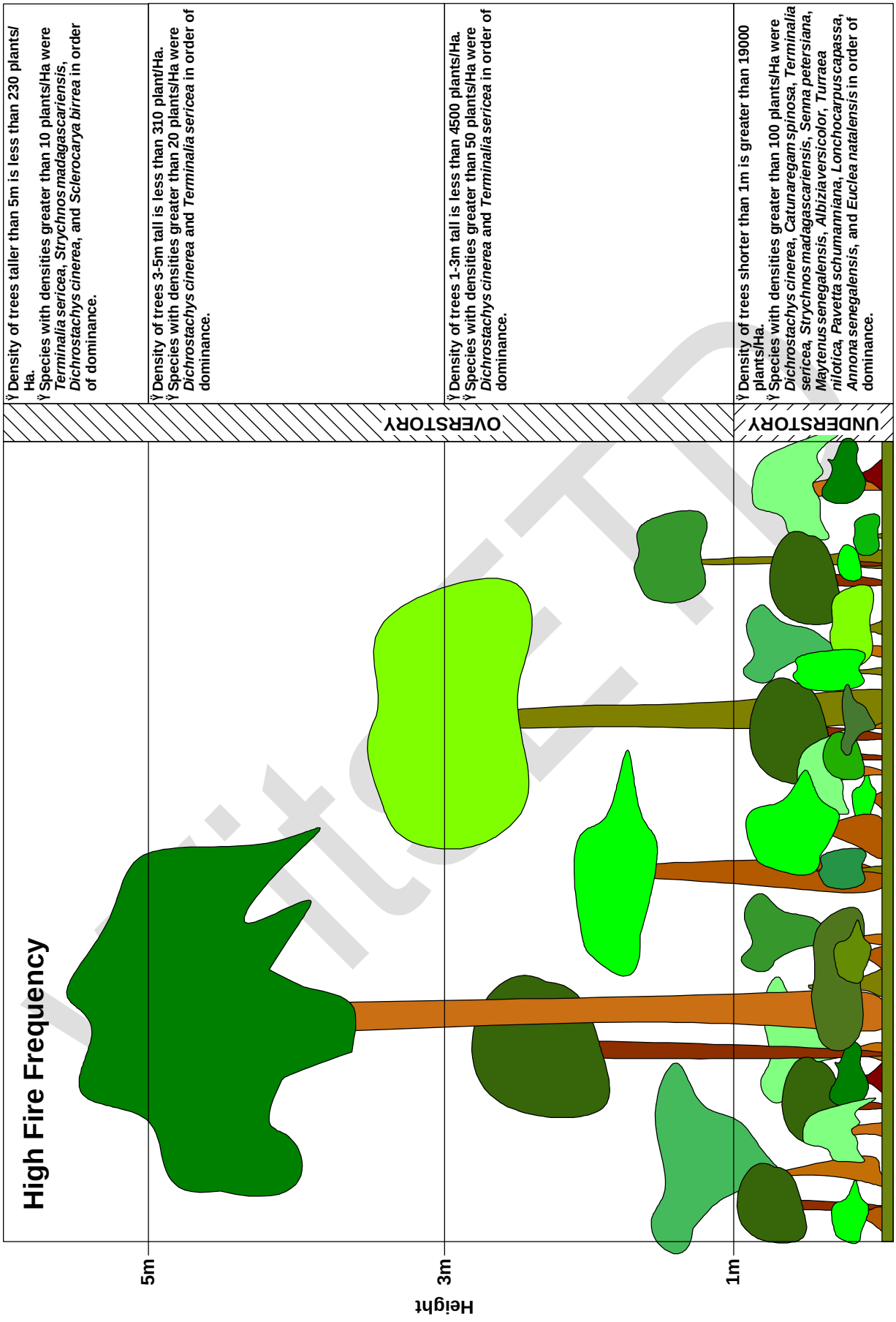


Figure 7-4: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being subjected to high frequency (Annual) fires.

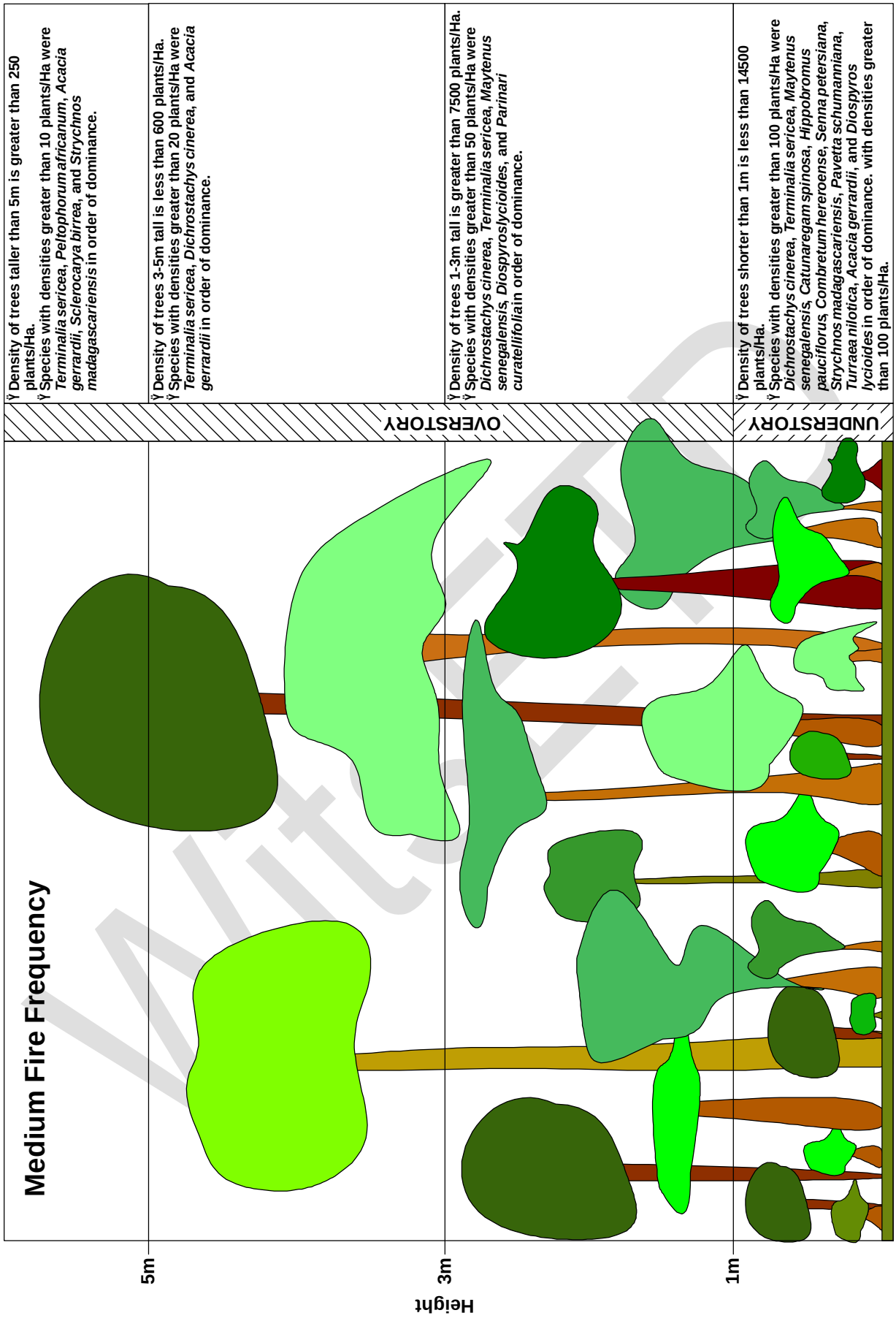


Figure 7-5: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being subjected to medium frequency (Biennial and Triennial) fires.

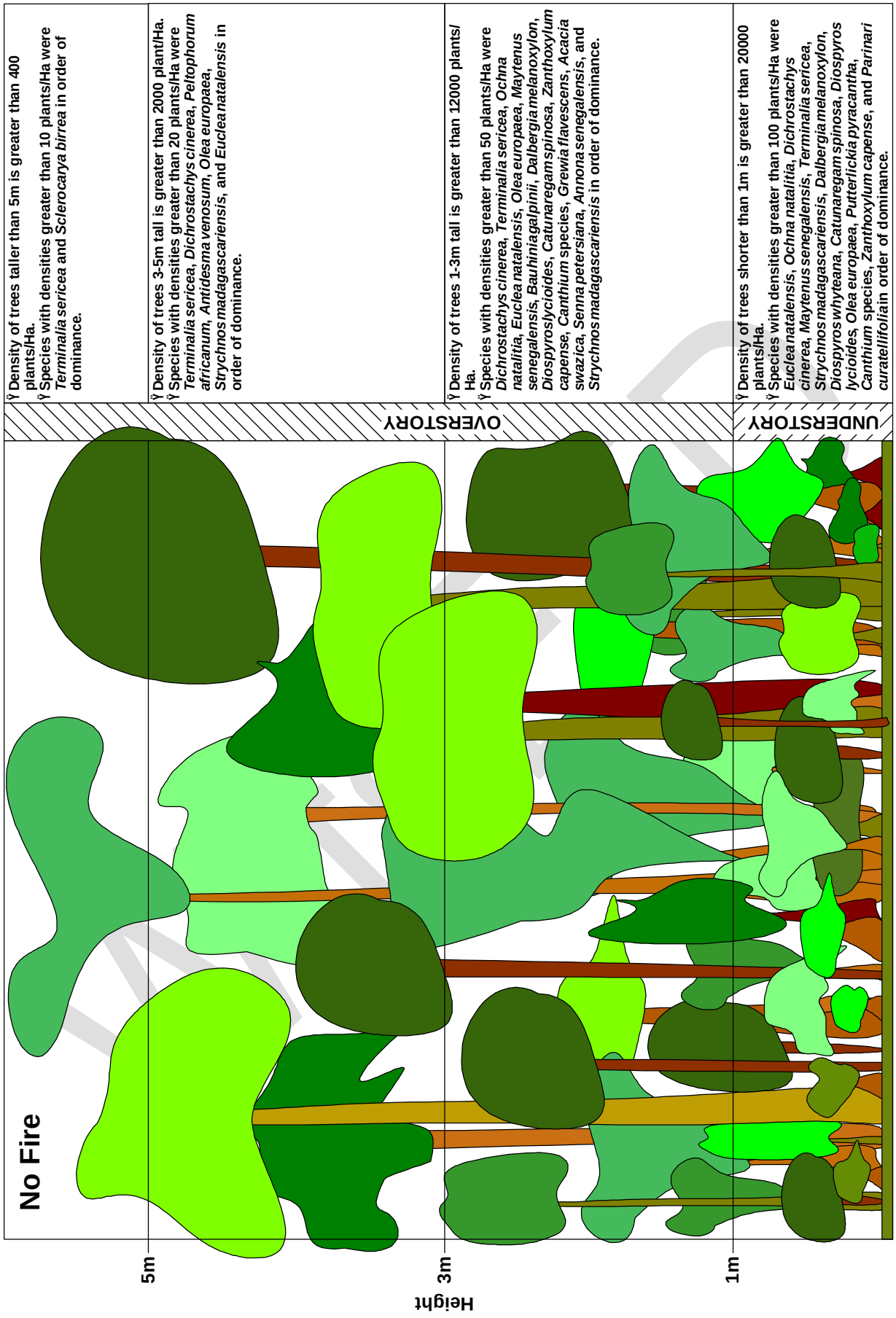


Figure 7-6: Conceptual model showing the vegetation density, height structure, and composition of the Pretoriuskop vegetation after being protected from fire for 42 years.

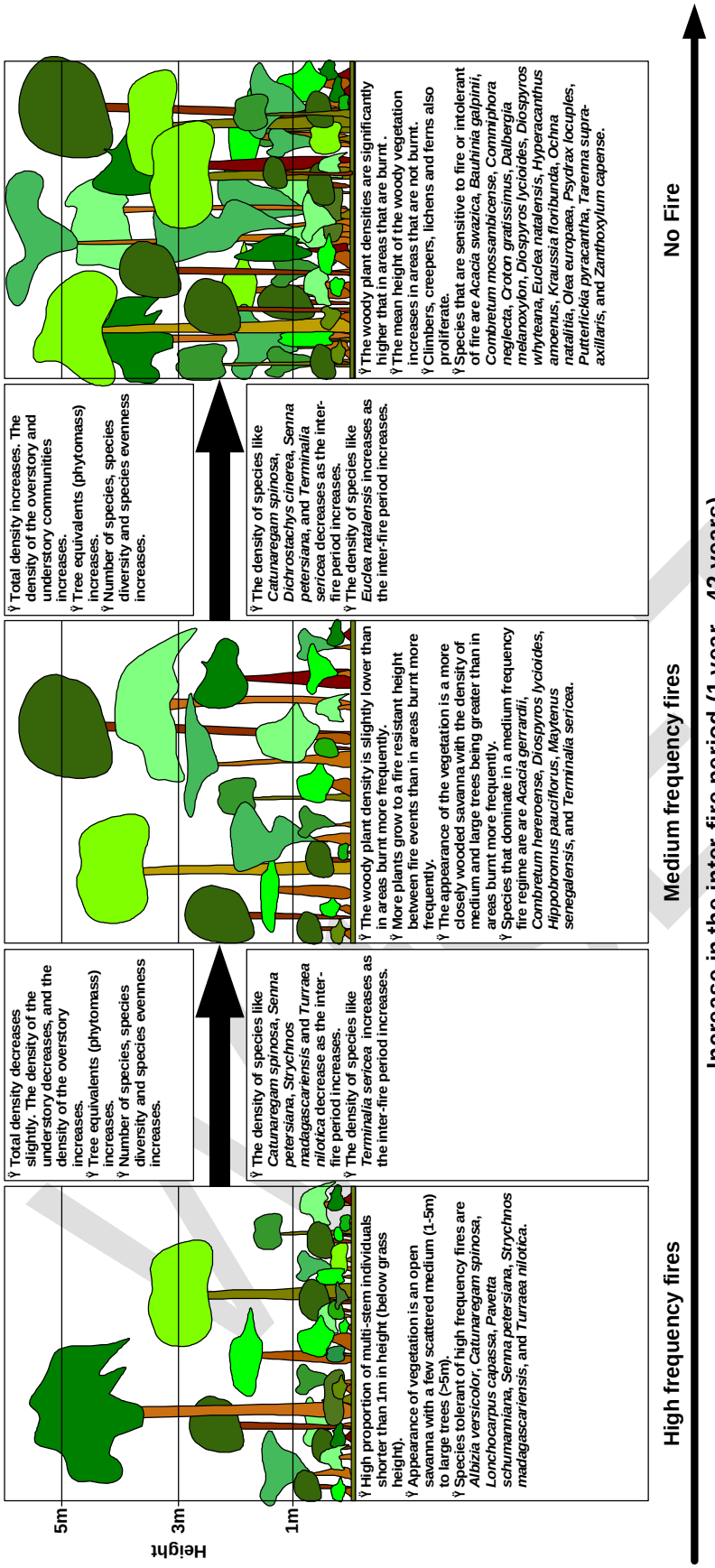


Figure 7-7: Conceptual model showing the changes in the woody vegetation of the Pretoriuskop region as the fire frequency decreases from high frequency fires to fire exclusion.

Some fire sensitive species do occur in areas that have been burnt but they are most abundant in areas that have not been burnt. Furthermore, when these species are found in areas that are burnt they are most often found on termitaria or rocky ground, which act as fire refuges. *Euclea natalensis* is most abundant in areas where fire has been excluded, where its densities exceed 500 plants/Ha. Areas where fire is naturally excluded like rocky outcrops and large termitaria are fire refuges for fire sensitive species and fire intolerant species within the Pretoriuskop landscape. However, the occurrence of fire sensitive and fire intolerant species in areas where fire has been excluded is dependant on the proximity of other fire refuges where these species survive and reproduce. For this reason, fire can be excluded from an area that has no local fire refugia, and many of the above fire sensitive and fire intolerant species will not appear for many years if at all.

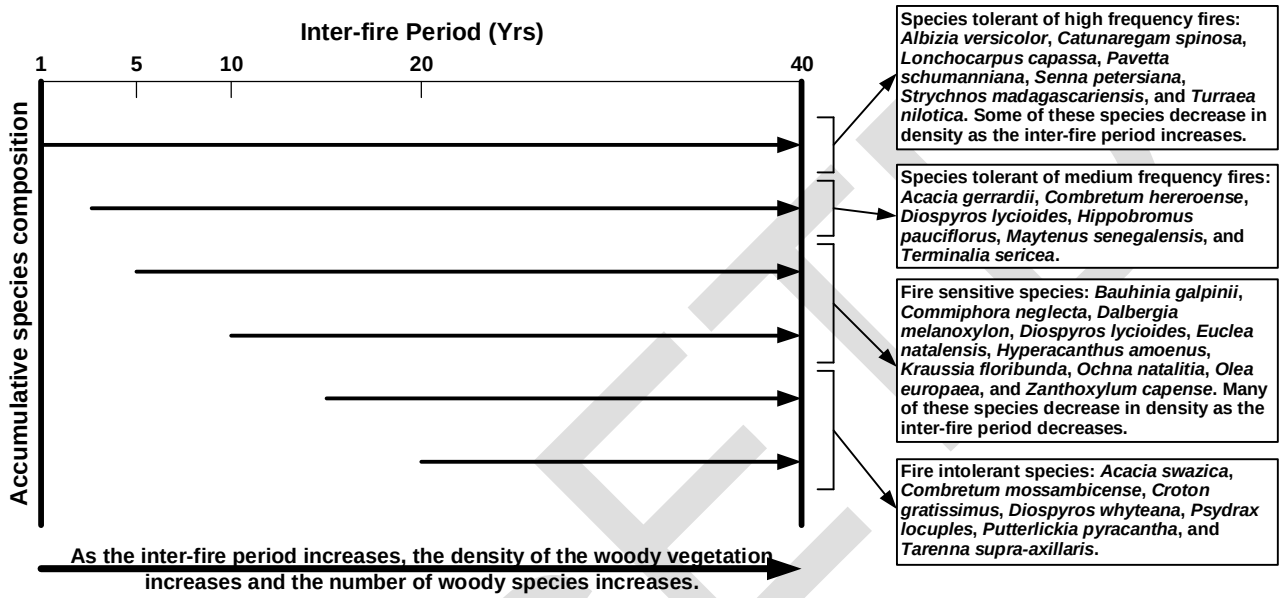


Figure 7-8: The typical accumulative floristic succession of the woody vegetation in the Pretoriuskop region as the inter-fire period increases.

The exclusion of fire in the Pretoriuskop region does not result in typical relay floristic succession in the woody vegetation where fire tolerant species are replaced by fire sensitive species, which in turn are replaced by fire intolerant species. Floristic succession in the Pretoriuskop region when fire is excluded is accumulative (Figure 7-8).

Table 7-1: The average density of woody vegetation (plants/Ha) on the Control EBPs (fire excluded) in the Pretoriuskop region 1954, 1959, 1969, and 1996. The densities of the woody vegetation in 1954, 1959, and 1996 were from belt transect surveys of the Pretoriuskop EBPs. The density of the woody vegetation in 1969 was from a quadrate middle-point survey of the Pretoriuskop EBPs (Van Wyk 1971).

Treatment	1954	1959	1969	1996
Con0	1722	2397	3506	8696

As the inter-fire period increases from high frequency fires to medium frequency fires, species that are tolerant of high frequency fires coexist with species that are tolerant of medium frequency fires. As the inter-fire period increases from medium frequency fires to low frequency fires, species that are tolerant of high and medium frequency fires coexist with species that are fire sensitive and are tolerant of low frequency fires. Finally, as the inter-fire period increases beyond 40 years fire tolerant, fire sensitive, and fire intolerant species coexist. The net result of the accumulative floristic succession in the woody vegetation is that the

density of the woody vegetation increases (Table 7-1). Furthermore, the number of woody species increases when fire is excluded from the woody vegetation in the Pretoriuskop region.

Generally, as the inter-fire period increases the number of structural groups, structural diversity, and structural evenness increases. Factors such as the initial structural composition and vegetation type (i.e. open or closed *Terminalia sericea* \ *Combretum* woodlands) did not have a great influence on the structural composition of the woody vegetation of a site. Occasionally the structural composition of the woody vegetation was found to be similar at adjacent sites. However, post fire age was found to be an important factor that affects the structural composition of the woody vegetation in the Pretoriuskop region.

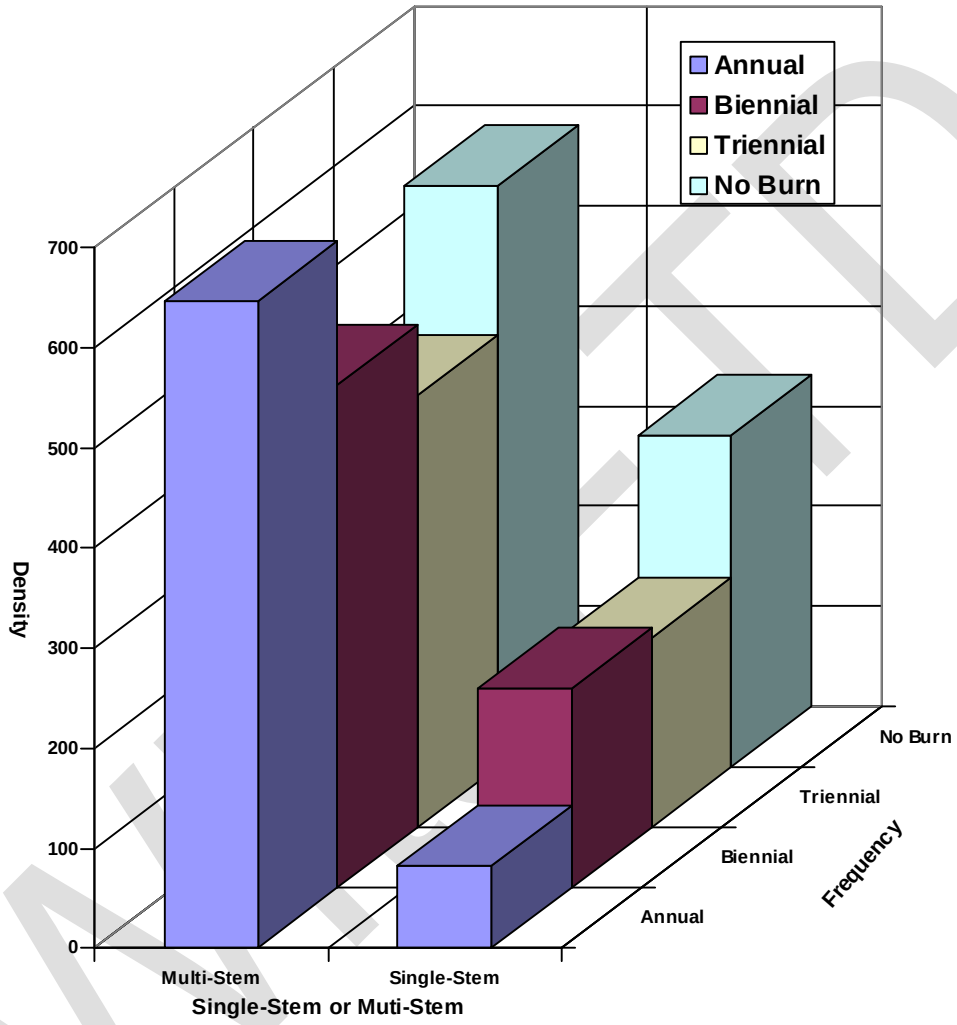


Figure 7-9: The density (plants/Ha) of single-stem and multi-stem woody plants in vegetation burnt at different fire frequencies.

It was found that as the period since the last fire event increases the single-stem to multi-stem index increases. Figure 7-9, Figure 7-10, and Figure 7-11 show that as the inter-fire period increases from 1 year to 3 years, the density of multi-stem plants decreases, and the density of single-stem plants increases. The density of multi-stem plants and single-stem plants increases as the inter-fire period increases beyond 3 years (Figure 7-9, Figure 7-10, Figure 7-11 and Figure 7-12). However, the single-stem to multi-stem index increases as the inter-fire period increases beyond 3 years, which indicates that the ratio of single-stem to multi-stem individuals decreases as the inter-fire period increases.

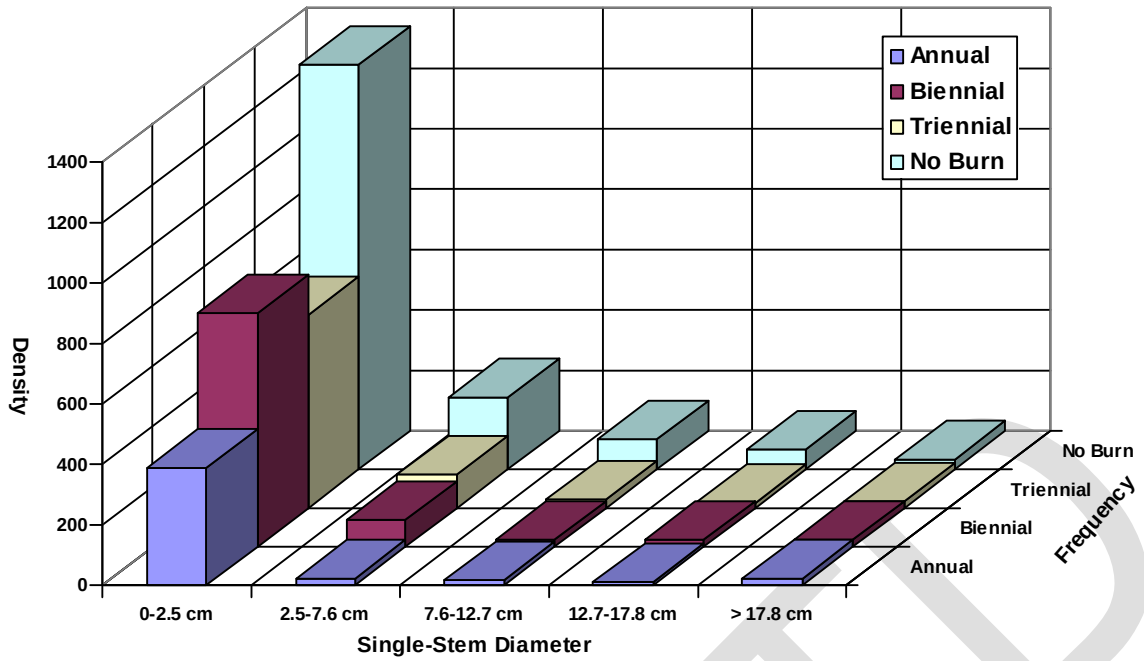


Figure 7-10: The density (plants/Ha) of different diameter classes of single-stem woody plants in vegetation burnt at different fire frequencies.

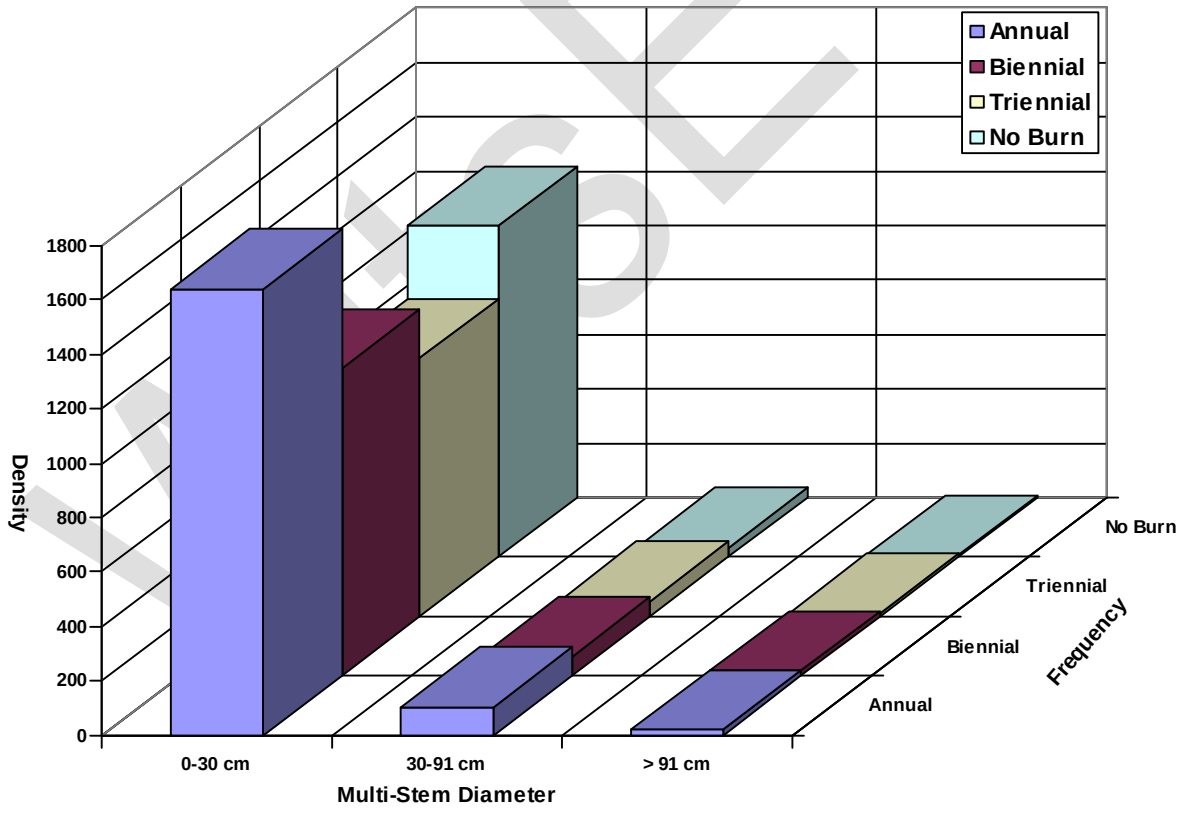


Figure 7-11: The density (plants/Ha) of different diameter classes of multi-stem woody plants in vegetation burnt at different fire frequencies.

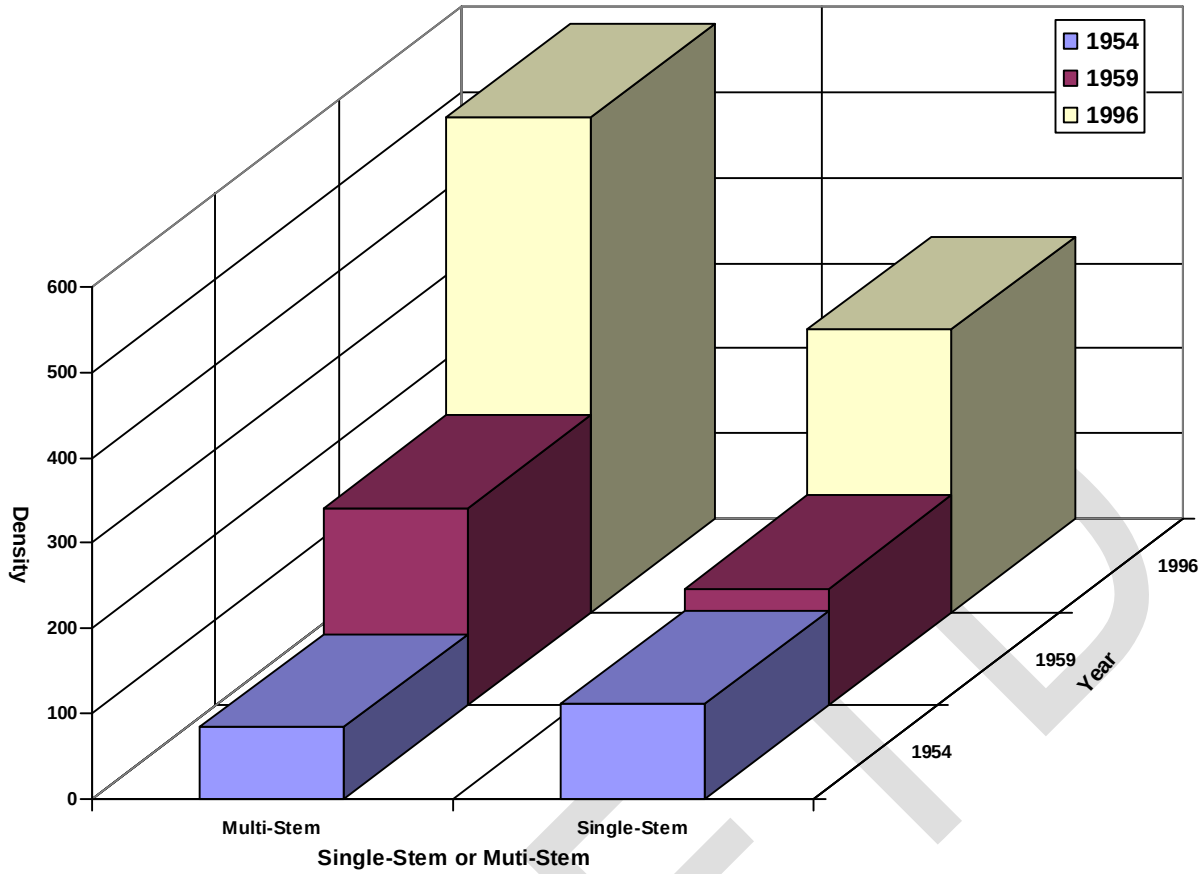


Figure 7-12: The density (plants/Ha) of single-stem and multi-stem woody plants on the control plots at three different years (1954, 1959, and 1996).

The increase in the density of single-stem plants in the 0-2.5 cm and 2.5-7.6 cm classes accounts for most of the increase in single-stem plants as the inter-fire period increases from 1 year to beyond 3 years (Figure 7-10). The decrease in density of multi-stem plants in the 0-30 cm class accounts for most of the decrease in multi-stem plants as the inter-fire period increases from 1 year to 3 years (Figure 7-11). The increase in density of multi-stem plants in the 0-30 cm class also accounts for most of the increase in multi-stem plants as the inter-fire period increases beyond 3 years (Figure 7-11). In contrast, the density of multi-stem plants in the 30-91 cm class decreases as the inter-fire period increases form 1 year to beyond 3 years.

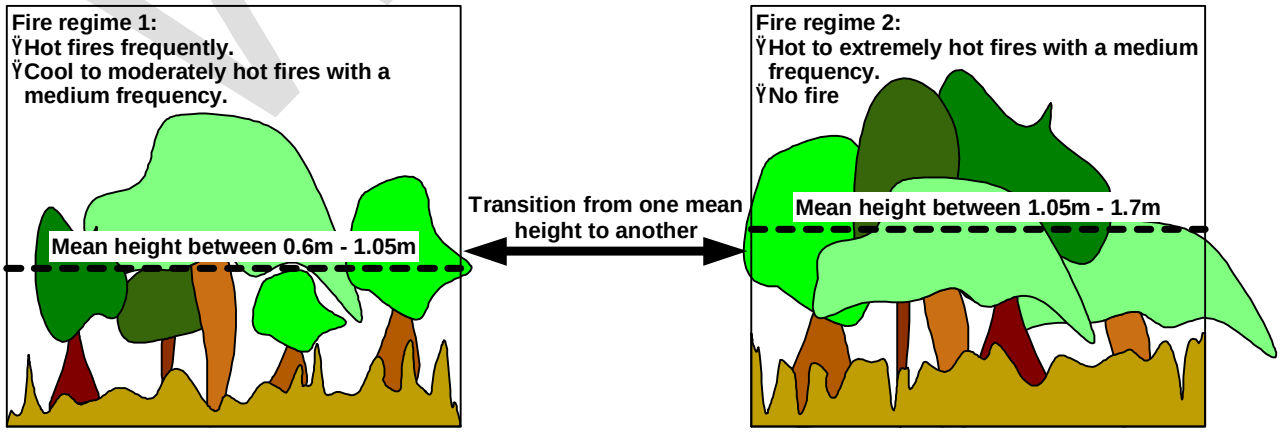


Figure 7-13: Model showing the combined effect of fire frequency and fire intensity on the height structure of the woody vegetation on the Pretoriuskop EBPs.

In Pretoriuskop, the mean height of the woody vegetation increases as the inter-fire period increases. It was found that vegetation burnt with hot fires frequently or cool to moderately hot fires with a medium frequency (fire regime 1) had a shorter mean plant height than vegetation burnt with hot to extremely hot fires with a medium frequency or where fire had been excluded (fire regime 2) (Figure 7-13 and Figure 7-14). The density of woody plants 0-1m tall is greater when the vegetation is exposed to fire regime 1 than when the vegetation is exposed to fire regime 2. Conversely, the density of woody plants 1-3 m tall is greater when the vegetation is exposed to fire regime 2 than when the vegetation is exposed to fire regime 1. This is why the average difference between the woody plant density and number of tree equivalents in the vegetation burnt with fire regime 1 was almost double the average difference in vegetation burnt with fire regime 2.

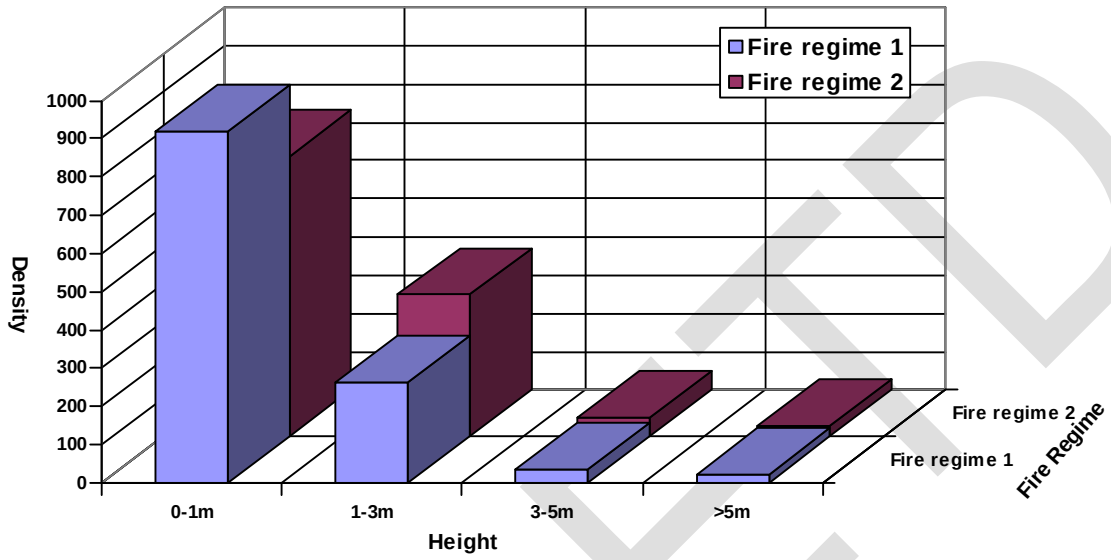


Figure 7-14: The density (plants/Ha) of the woody vegetation at different height classes burnt under two fire regimes, Fire regime 1 denotes hot fires burnt frequently or cool to moderately hot fires burnt with a medium frequency. Fire regime 2 denotes where fire has been excluded, or hot to extremely hot fires burnt with a medium frequency.

The findings from the Morale fire experiment in Botswana are different to those in Pretoriuskop. The Morale Fire experiment was established in 1958 at the Pasture Research Station at Morale in Botswana (Sweet 1982). The Morale is in an arid savanna, which is dominated by *Acacia nigrescens* and *Combretum apiculatum*. The annual average rainfall at Morale is approximately 450mm occurring predominantly between October and March.

Table 7-2: Results from analyses performed on the density (plants/Ha) of the woody vegetation in 1981 on the Morale Fire experimental plots burnt at different frequencies between 1958 and 1981 (Sweet 1982).

	Annual	Biennial	Triennial	Quadrennial	Pentennial	No burn	Density	N
Annual	1.000						1210	1
Biennial		1.000					1240	1
Triennial	0.001	0.001	1.000				1870	1
Quadrennial	0.001	0.001		1.000			1960	1
Pentennial	0.001	0.001	0.001	0.001	1.000		2180	1
No burn			0.001	0.001	0.001	1.000	1280	1

Note: The methods of analyses used by Sweet (1982) were not specified.

WITS ETD

The Morale fire experiment comprised six plots of 1.2 Ha each to which six fire treatments were applied. The treatments were no burn and five burn treatments at different return periods during the dry season, namely annual, biennial, triennial, quadrennial, and pentennial. The mean annual grass (fuel) production (dry mass) at Morale is between 1676 and 1740 Kg/Ha/year, and the cumulative fuel load on the plots burnt pentennially was estimated at approximately 5876 Kg/Ha/year (Sweet 1982). In 1981, a survey of the woody vegetation on each of the plots was conducted which provided a 23 year period over which the effects of the treatments were assessed (Table 7-2) (Sweet 1982).

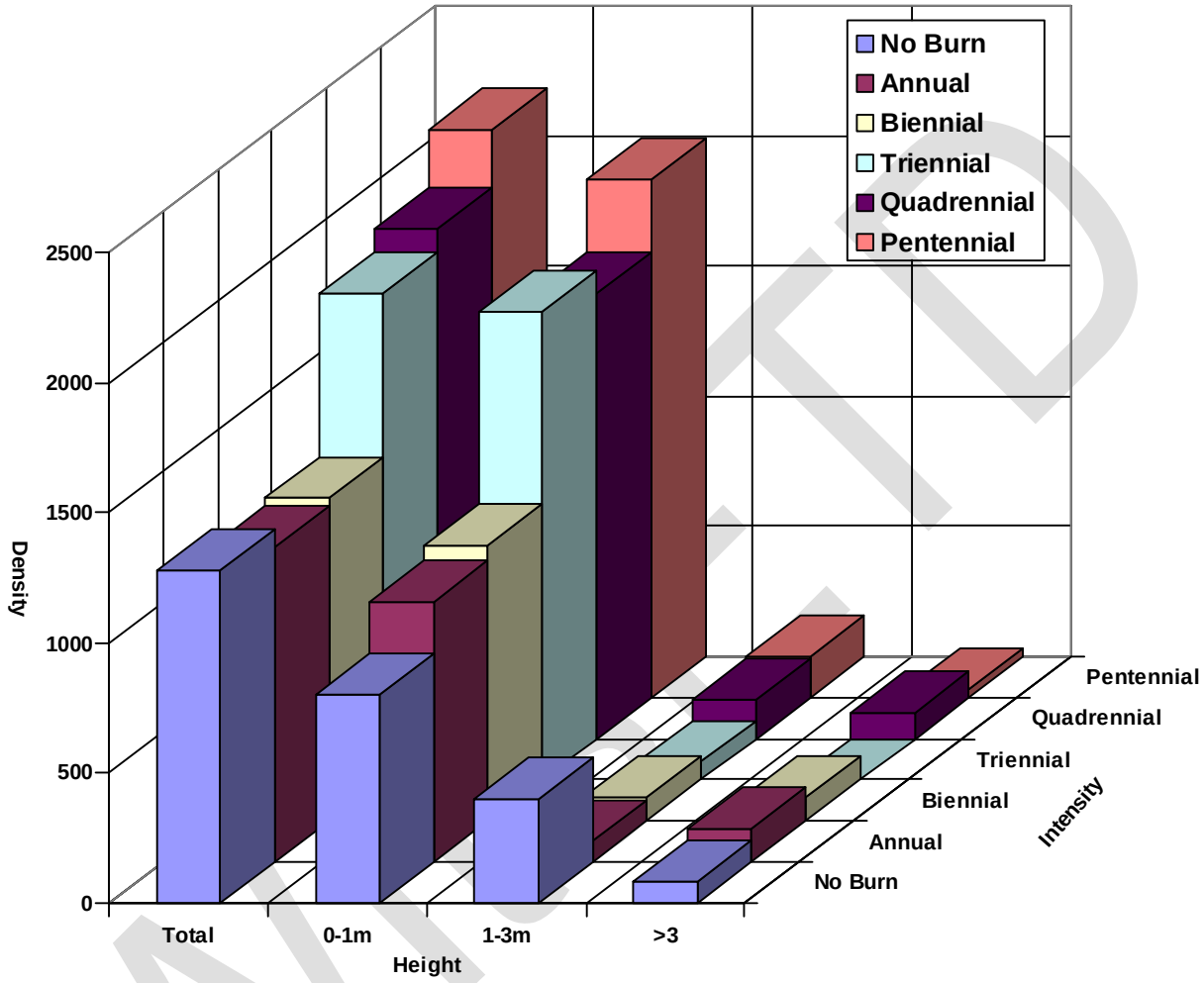


Figure 7-15: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Morale Fire experimental plots in 1981 (Sweet 1982).

At Morale, Sweet (1982) found that as the inter-fire period increased from 1 year to 5 years the density of the woody vegetation increased significantly, without any initial decrease as was found in Pretoriuskop (Table 7-2). Furthermore, at Morale as the inter-fire period increased beyond 5 years and approached 20 years, the density of the woody vegetation decreased significantly (Table 7-2). However, at Pretoriuskop the density of the woody vegetation increased significantly as the inter-fire period increased beyond 3 years (Figure 7-2 and Figure 7-3). Sweet (1982) concluded that the growth of woody plant seedlings and coppicing individuals shorter than 1m tall was suppressed by frequent fire, which resulted in the density of the woody vegetation being low when burnt annually and biennially (Figure 7-15). Sweet (1982) also concluded that the exclusion of fire resulted in the escape of individuals less than 1m tall from the grass layer being restricted, which explained why the density of the woody vegetation was low when fire was excluded (Figure 7-15). The findings at Morale are in contrast with the findings in Pretoriuskop where the exclusion of fire results in an

increase in the density of the woody vegetation. In Pretoriuskop, the exclusion of fire results in seedlings and coppicing individuals escaping the grass layer and savanna woodlands are the result.

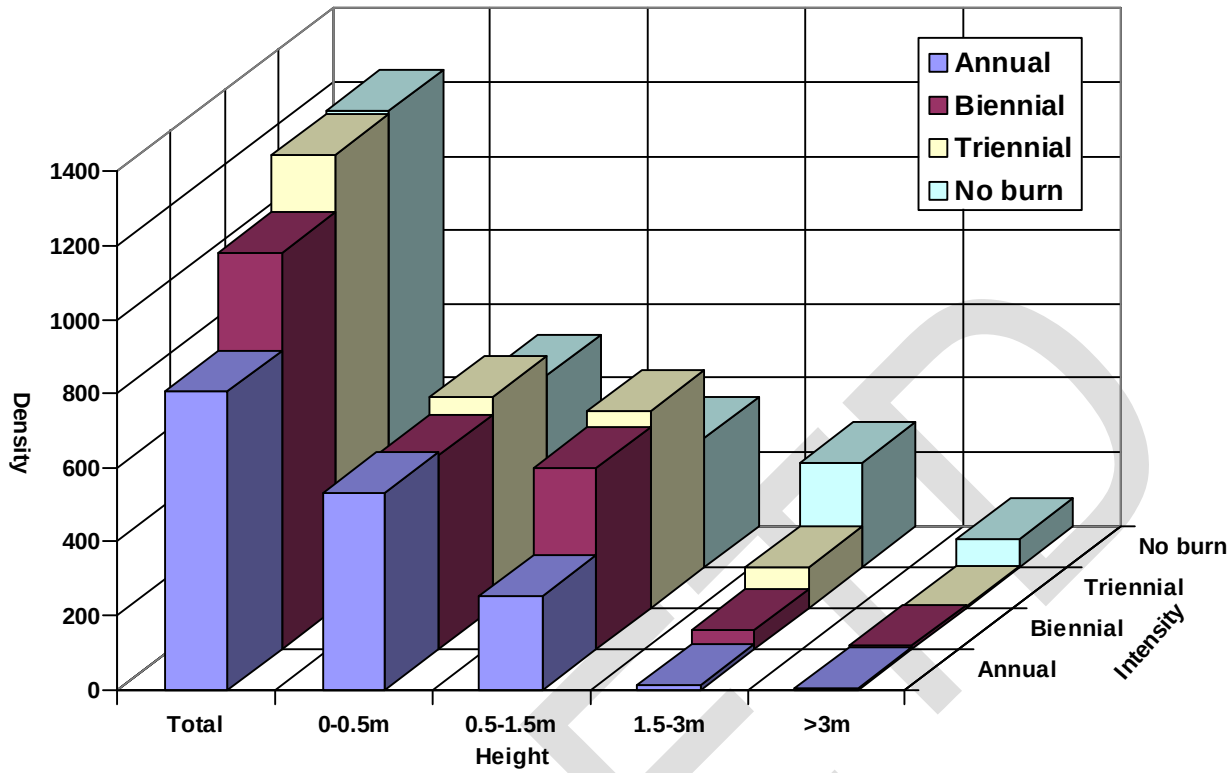


Figure 7-16: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Satara EBPs in 1971 (Gertenbach and Potgieter 1975).

The findings in Pretoriuskop are also different from the findings on the EBPs in the Satara region of the KNP. The Satara region is more arid than Pretoriuskop and experiences on average 548 mm of rainfall annually (Gertenbach 1983). In 1975, it was found that as the inter-fire period increased from 1 year to 3 years the density of the woody vegetation increased without an initial decrease (Figure 7-16). However, as the inter-fire period increased beyond 3 years the density of the woody vegetation did not increase. Figure 7-16 shows that the density of woody individuals 0-1.5m tall decreases as the inter-fire period increases beyond 3 years, and the density of woody individuals > 1.5m tall increases as the inter-fire period increases beyond 3 years. During 1980, two treatments were added to the EBPs in the Satara region, namely the October 4-year and 6-year treatments (Annual report 1980). In 2000, two separate studies on the Satara EBPs found that as the inter-fire period increased from 1 year to 4 year the density of the woody vegetation increased without any initial decrease (Gertenbach and Potgieter 1975, Enslin *et al.* 2000, Shackleton and Scholes 2000). The density of the woody vegetation then decreased as the inter-fire period increased beyond 4 years (Gertenbach and Potgieter 1975, Enslin *et al.* 2000, Shackleton and Scholes 2000). The findings on the Satara EBPs in 1975 and 2000 are similar to those at the Morale fire experiment where the exclusion of fire results in a decrease in the density of the woody vegetation.

The difference in vegetation response to the exclusion of fire in Morale and Satara as opposed to Pretoriuskop is believed to be because Morale and Satara are semi-arid savannas and Pretoriuskop is a mesic savanna. This point is reinforced by findings in the mesic savannas of the northern Accra Plains in Ghana (Carson and Abbiw, 1990). The northern Accra Plains experience on average 1170 mm of rainfall annually. It was found that the exclusion of fire over a 29-year period resulted in forest vegetation displacing the savanna vegetation.

WITSETD

It appears that the exclusion of fire in moist savannas that receive more than 600 mm of rain annually results in the woody vegetation becoming denser to various degrees ranging from savanna woodlands to forests. The exclusion of fire in arid to semi-arid savannas that receive less than 600 mm of rain annually does not result in the woody vegetation becoming denser. However, the biomass of the woody vegetation does increase when fire is suppressed in arid and semi-arid savannas.

WitsETD

7.3 THE EFFECT OF FIRE TIMING ON THE WOODY VEGETATION OF THE PRETORIUSKOP SOURVELD

The density of the woody vegetation in the Pretoriuskop region is lower when burnt by the hot to extremely hot fires in August and October than when burnt by the very cool to moderately hot fires in February and December. There are a number of reasons why the density of the woody vegetation is higher in vegetation that is burnt in December and February as opposed to August and October.

Generally, topkill of the woody vegetation in the KNP is higher when burnt by more intense fires than less intense fires (Trollope and Tainton 1986, Trollope 1999b). The intensity of fires in August and October is higher than in December and February, and therefore topkill of trees and shrubs is higher in August and October than in December and February. In many savanna woody species topkill does not equate to mortality however, other factors such as seasonal non-structural carbohydrate (starch) phenology combined with topkill, as discussed below, may well equate with mortality.

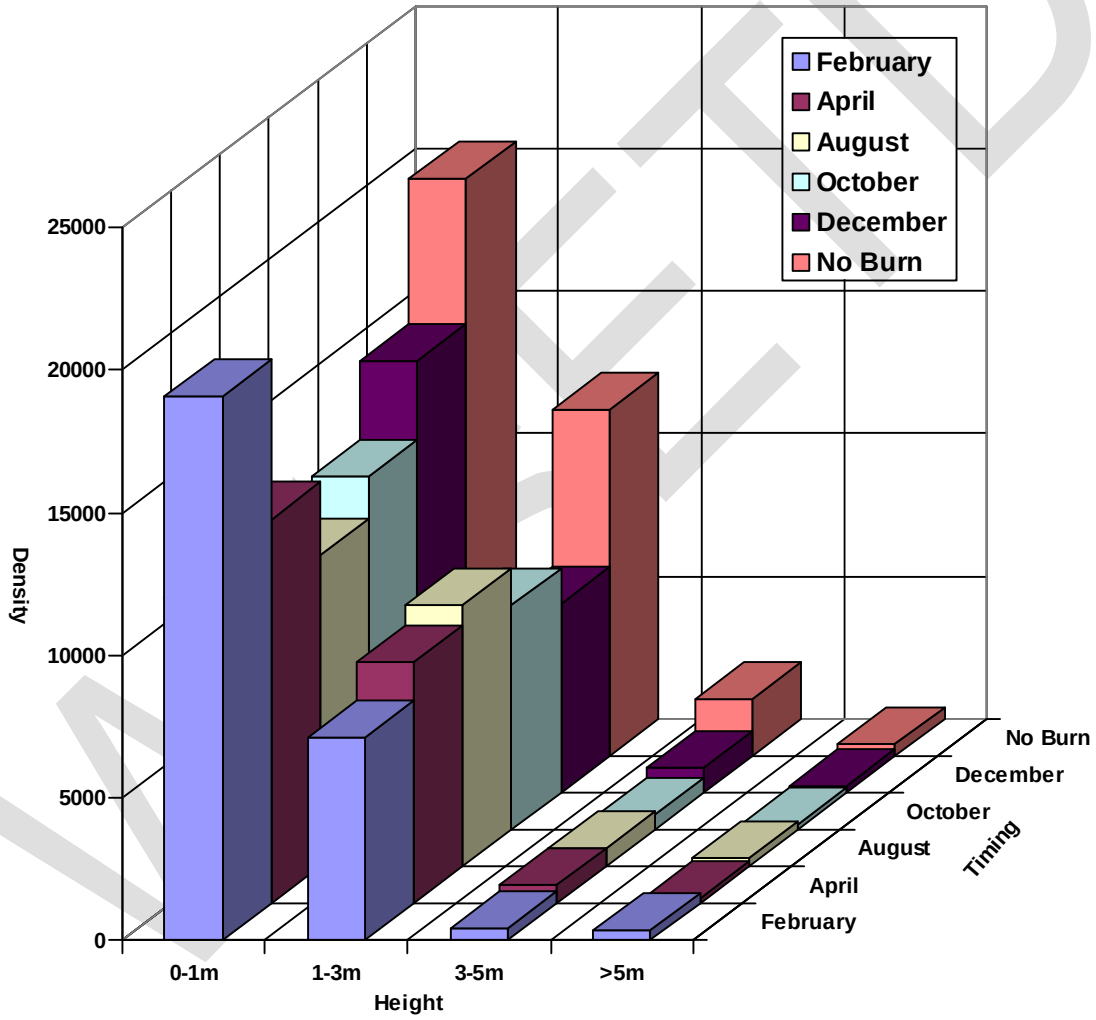


Figure 7-17: The density (plants/Ha) of the woody vegetation burnt at different times of the year at different height classes. Note: The August Annual treatment data was excluded.

However, short bushes (0-1m tall) are most prone to significant topkill regardless of the intensity of a fire (Trollope and Tainton 1986). So why is the density of the understorey vegetation so much higher in areas burnt in December and February than in areas burnt in August and October (Figure 7-17)? Buffalo grass (*Panicum maximum*) that grows under the large trees in the Pretoriuskop region is green in the summer

months between December and February. The green *Panicum maximum* prevents fire from burning under the large trees and effectively protects seedlings, juvenile trees, and shrubs from fire. The areas under large trees effectively become fire refuges and nurseries of seedlings, juvenile trees, and shrubs. The growth of the juvenile trees and shrubs is suppressed by the *Panicum maximum* growing under the trees and the juvenile trees and shrubs remain stunted under the large trees because of the shading effect the overstorey trees. The result is a high density of seedlings and stunted juveniles between 0-1m high (understorey trees) in vegetation burnt during the summer months of December and February as opposed to the winter months of August and October (Figure 7-17). The dominant understorey species that are common in vegetation burnt in summer and in winter in Pretoriuskop are *Catunaregam spinosa*, *Dichrostachys cinerea*, *Maytenus senegalensis*, *Pavetta schumanniana*, *Senna petersiana*, *Strychnos madagascariensis*, *Terminalia sericea*, and *Turraea nilotica*. The understorey species that dominate when the vegetation is burnt in summer are *Canthium* species, *Dalbergia melanoxylon*, *Diospyros whyteana*, *Olea europaea*, *Parinari curatellifolia*, *Putterlickia pyracantha*, and *Zanthoxylum capense*. The understorey species that dominate when the vegetation is burnt in winter are *Lonchocarpus capassa* and *Parinari curatellifolia*. Although, the density of understorey woody vegetation is highest in vegetation burnt in the summer months, the density of the overstorey woody vegetation (1m – 3m) is higher in vegetation burnt during the winter months (Figure 7-17). This is why the average height of the woody vegetation is higher in vegetation burnt in August and October, than in vegetation burnt in February and April, and why the number of tree equivalents (phytomass) is lower in vegetation burnt in December and February in comparison with August and October.

Finally, the levels of non-structural carbohydrate reserves of the woody plants have a direct effect on the heat resistance and the sprouting capacity of woody plants in response to fire damage (West 1965, Hoffmann *et al.* 2000). The levels of non-structural carbohydrate reserves of plants are lowest toward the end of the dry season and the beginning of the new growth season between August and October when they have been depleted (West 1965). While the levels of non-structural carbohydrate reserves are highest in the middle of the growing season between December and February (West 1965). Between August and October, woody plants in Pretoriuskop are most susceptible to fatal damage by fire because they are most susceptible to heat damage and less able to sprout from undamaged meristematic tissues. While between December and February the woody plants in Pretoriuskop are least susceptible to fatal damage by fire as they have excess non-structural carbohydrate reserves, which enable them to sprout from undamaged meristematic tissues.

Ignoring areas in which fire has been excluded, Figure 7-18 shows that the density of the understorey woody vegetation tends to be higher when burnt by very cool, to cool fires than when burnt by hot to extremely hot fires. Furthermore, the density of overstorey vegetation (1-3m) tends to be highest in areas burnt by extremely hot fires and lowest in areas burnt by very cool fires (Figure 7-18). However, it is difficult to separate the intensity effects from the timing effects of fire because the hot to extremely hot fires occur in August and October, while the very cool, to cool fires occur in December and February (Table 3-7 p. 22).

In Pretoriuskop, the number of species and species diversity of the woody vegetation is higher in vegetation that is burnt in December and February in comparison with vegetation burnt in August and October. In 1963, Ramsay and Innes reviewed six fire experiments in West Africa and concluded, “late dry-season (fierce) burns are particularly destructive to trees and shrubs of all except the most fire-resistant species” (Ramsay and Innes 1963). In Pretoriuskop, some species may not be adapted to surviving the late dry season fires in August and October because they are very intense and furthermore the starch stores of the plants are depleted, which may explain why the number of species and species diversity is lower in areas burnt in August and October.

The species composition of the woody vegetation in areas burnt in December and February is more similar than with areas that have been burnt in August and October. Furthermore, the species composition of the woody vegetation in areas where fire has been excluded is more similar to the species composition of woody vegetation burnt in December and February than in areas that have been burnt in August and October. The species associated with woody vegetation burnt in December and February and where fire has been

excluded are *Euclea natalensis*, *Antidesma venosum*, *Diospyros lycioides*, *Phyllanthus reticulatus*, *Grewia flavescens*, *Grewia monticola*, *Ochna natalitia*, *Peltophorum africanum*, *Rhus pyroides*, *Diospyros mespiliformis*, *Rhus transvaalensis*, *Securinega virosa*, *Putterlickia pyracantha*, *Rhus pentheri*, *Commiphora neglecta*, *Heteropyxis natalensis*, and *Olea europaea*.

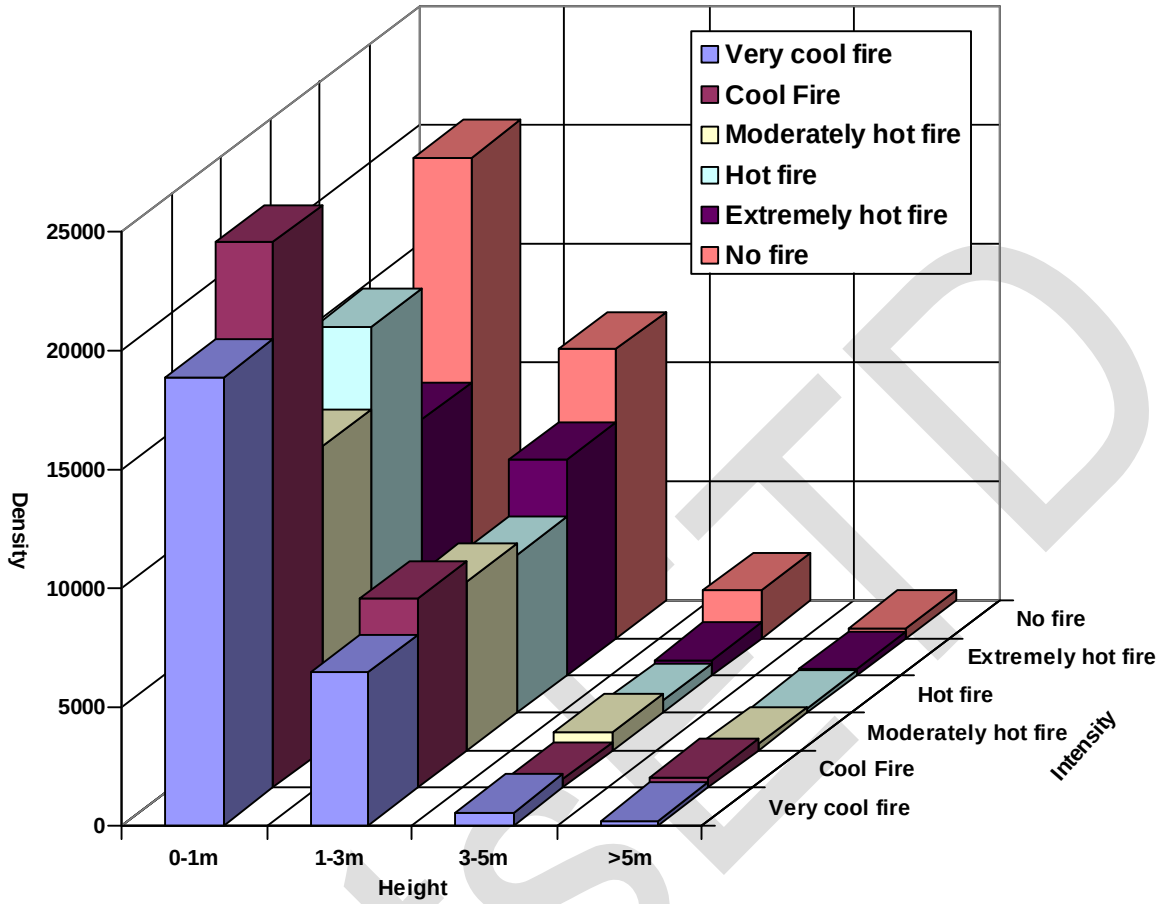


Figure 7-18: The density (plants/Ha) of the woody vegetation burnt with different fire intensities. The fire intensity classes used are those defined in "The intensity of fires on the Pretoriuskop EBP treatments" p. 19.

Structurally, the mean height of woody vegetation is shorter in areas burnt in February and December than in areas burnt in August and December and where fire has been excluded. The woody vegetation has more multi-stem individuals relative to single-stem individuals in vegetation burnt in August and October than in vegetation burnt in December and February or where fire has been excluded. Furthermore, the structural composition of areas burnt in December and February and where fire has been excluded is more similar than with areas burnt in August and October. Generally, the structure of the woody vegetation in areas burnt in August and October is dominated by multi-stem individuals with basal diameters ranging from almost zero to greater than 3 m that are 0-1m tall or 3-5m tall. The structure of the woody vegetation in areas not burnt or areas burnt in December, February, and April is dominated by both single-stem and multi-stem individuals of all heights and basal diameters.

The woody vegetation in Pretoriuskop responds differently to fires occurring in December and February than to fires occurring in August and October. However, the woody vegetation of Pretoriuskop has a mixed response to fires occurring in April. The woody vegetation response to fires in April is sometimes similar to the response to fires in December and February. For example, the mean height of the woody vegetation and number of single-stem individuals relative to multi-stem individuals of the woody vegetation in areas burnt in April is similar to areas burnt in December and February. The structure of the woody vegetation in areas

burnt in April is generally similar to the structure of the woody vegetation burnt in December and February. The woody vegetation response to fires in April is sometimes similar to the response to fires in August and October. For example, the tree equivalents, number of species, and species diversity of woody vegetation burnt in April is similar to areas burnt in August and October. The structure of the woody vegetation in areas burnt in April is occasionally similar to the structure of woody vegetation burnt in August, especially regarding the high densities of multi-stem individuals 1-3m tall. The woody vegetation response to fires in April is sometimes at some point between the response of the woody vegetation to December and February fires and to August and October fires. For example, the density of woody vegetation burnt in April is between that of areas burnt in December and February and areas burnt in August and October.

There are a number of reasons for this. Fires in April are more intense than fires in December and February but less intense than fires in August and October, and topkill of woody vegetation in April is expected to be higher than in February and December (Table 3-7 p. 22). Furthermore, the density of the understorey woody vegetation is lower in April than in December and February (Figure 7-17), this is because the vegetation burnt in April does not recover fully before the dry season, and the woody vegetation 0-1m tall is often browsed heavily during the winter months. However, the levels of stored non-structural carbohydrates in woody plants are not depleted in April because it is the end of the growing season. This results in a lower probability of topkill related mortality in April than in August and October. These factors contribute to the mixed response of the woody vegetation in Pretoriuskop to fires in April.

The findings of the Olokemeji Fire experiment in Nigeria are similar to those in Pretoriuskop. The Olokemeji Fire experiment was established near Ibadan in south-western Nigeria in 1923 is located in a mesic savanna with a mean annual rainfall of about 1320 mm (West 1965, Fuwape 1991). The experiment comprised three treatment plots each 42.6 X 39.6 m in size. Three fire treatments were applied to the plots, namely a control in which fire was excluded and annual fires in the early dry season (December) and the late dry season (March) (Fuwape 1991). These treatments are similar to the control treatment, the April treatment (early dry season), and the August (late dry season) treatment in the EBP experiment.

Table 7-3: Data from five vegetation surveys on the Olokemeji Fire experiment plots showing the density of woody plant (plants/Ha) on plots that were burnt annually at different times of the year (Fuwape 1991).

Year	March burn (Late dry season)	December burn (Early dry season)	No burn Control
1929	2181	2259	2259
1935	445	1304	2330
1957	581	966	2567
1976	788	1399	2703
1988	640	1429	3302

In the Olokemeji Fire experiment, the density of the woody vegetation was highest on the fire-protected plot at each of the surveys between 1929 and 1988 (Table 7-3). The density of the woody vegetation increased steadily between 1929 and 1988 on the fire-protected plot at a rate of between 7 and 50 plants/Ha/year. The density of the woody vegetation on the late dry season treatment decreased dramatically between 1929 and 1935 at a rate of 289 plants/Ha/year. The density of the woody vegetation then fluctuated between 445 and 788 plants/Ha between 1935 and 1988 (Table 7-3). The density of the woody vegetation on the early dry season treatment also decreased between 1929 and 1935 at a rate of 159 plants/Ha/year. The density of the woody vegetation then fluctuated between 966 and 1429 plants/Ha between 1935 and 1988 (Table 7-3). These results are similar to the findings on the Pretoriuskop EBPs where the density of the woody vegetation was lower on the late dry season treatments in August than the early dry season treatments in April. Furthermore, the fire-protected plots on the Pretoriuskop EBPs also had the highest woody plant density.

WITS ETD

The findings of the Kainji Fire experiment in Nigeria are similar to those of the Olokemeji Fire experiment in Nigeria and the EBPs in Pretoriuskop. The Kainji Fire experiment was established in 1971 in the Kainji Park in a landscape dominated by *Terminalia macroptera*, and it is located in a mesic savanna with an average annual rainfall of about 1070 mm (Fuwape 1991). The experiment comprised three treatment plots each 50 X 20 m in size. Three fire treatments similar to the Olokemeji Fire experiment were applied to the experimental plots, namely annual burns in the early dry season (December) and late dry season (March), and a control from which fire was excluded (Fuwape 1991). These treatments are similar to the April (early dry season), August (late dry season), and no burn treatments in the EBP experiment.

Table 7-4: Data from two vegetation surveys on the Kainji Fire experiment plots showing the density of woody plant (plants/Ha) on plots that were burnt annually at different times of the year (Fuwape 1991).

Year	March burn (Late dry season)	December burn (Early dry season)	No burn Control
1973	130	200	120
1976	110	210	170

In the Kainji Fire experiments the density of the woody vegetation decreased on the late dry season treatment, it increased slightly on the early dry season treatment, and it increased markedly on the fire-protected treatment (Table 7-4). Although the period over which the treatments were applied to the vegetation is much shorter than for the Olokemeji Fire experiment and the Pretoriuskop EBPs the trends are certainly similar.

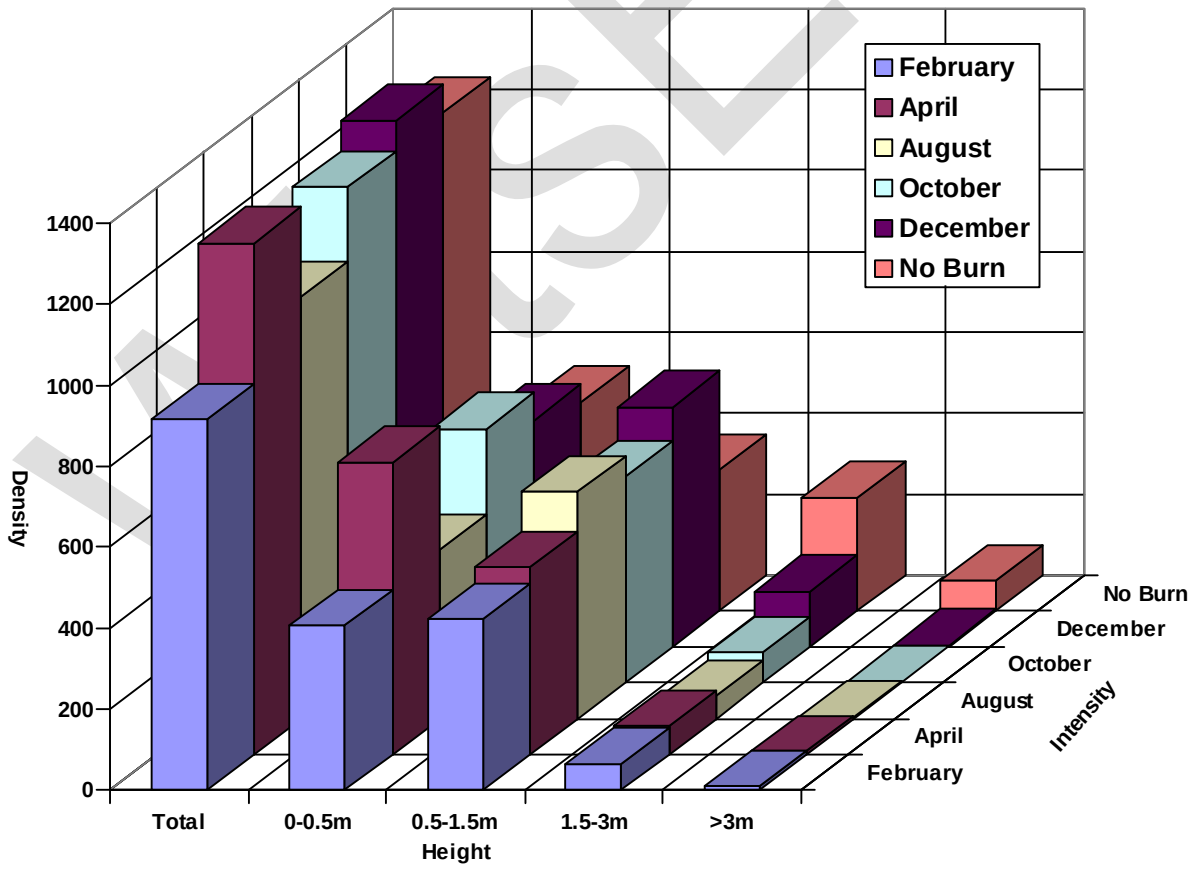


Figure 7-19: The density (plants/Ha) of the woody vegetation burnt at different fire frequencies at different height classes on the Satara EBPs in 1971 (Gertenbach and Potgieter 1975). Note: The August Annual treatment data was excluded

WITHDRAWN

The findings regarding the effects of early dry season fires and late dry season fires on the density of the woody vegetation in the Satara EBPs of the KNP are similar to those of the Olokemeji and Kainji fire experiments and the Pretoriuskop EBPs. The density of woody vegetation in areas burnt in the early dry season (April) is higher than in areas burnt in the late dry season (August) (Figure 7-19) (Enslin *et al.* 2000). However, regarding differences in the density of the woody vegetation burnt at other times of the year the patterns are very different. In Pretoriuskop, the density of the woody vegetation was highest when burnt in December and February however, in Satara the density of the woody vegetation was highest when burnt in April, October, and December (Figure 7-19). Furthermore in Pretoriuskop the density of the woody vegetation was lowest when burnt in August and October fires however, in Satara the density of the woody vegetation was lowest when burnt in February and April (Figure 7-19).

Many studies compare the effects of early dry season fires on woody vegetation in comparison with late dry season fires. These results have then been compared between different vegetation types with the aim to establish pattern especially regarding the use of fire to maintain or decrease the density of woody vegetation. However, the results from the Pretoriuskop and Satara EBPs in the KNP suggest that from an ecosystem perspective the timing of fires may affect the woody vegetation differently in different areas even when the affects at certain times appear similar.

WitsETD

7.4 CHANGES IN THE WOODY VEGETATION OF THE PRETORIUSKOP REGION BETWEEN 1954 AND 1996

The density of the woody vegetation (plants/Ha) in Pretoriuskop increased slightly (14.55%) between 1954 and 1969 (Table 7-5). However, the density of the woody vegetation in Pretoriuskop increased significantly (160.79%) between 1969 and 1996 (Table 7-5). The rate of increase in the woody plant density between 1954 and 1969 was 14.9 plants/Ha/year, and the rate of increase between 1969 and 1996 was 136.8 plants/Ha/year. Furthermore, the number of tree equivalents per hectare (phytomass) increased significantly between 1954 and 1996 from 1571.7 in 1954 to 4285.9 in 1996. This increase in the number of tree equivalents (phytomass) of the woody vegetation between 1954 and 1996 was a result of the increase in the woody plant density and not an increase in the height structure of the woody vegetation between 1954 and 1996.

Table 7-5: The average density of woody vegetation (plants/Ha) on the twelve Pretoriuskop EBP treatments in 1954, 1969, and 1996. The densities of the woody vegetation in 1954, and 1996 were calculated from the belt transect surveys of the Pretoriuskop EBPs. The densities of the woody vegetation in 1969 were calculated from the quadrate middle-point survey of the Pretoriuskop EBPs in 1969 (Van Wyk 1971).

Treatment	1954	1969	1996	% change from 1954 to 1969	% change from 1969 to 1996	% change from 1954 to 1996
Apr2	2255.25	2064.14	5250.75	-8.47	154.38	132.82
Apr3	1859.75	2022.11	6155.50	8.73	204.41	230.99
Aug1	2326.00	2306.98	6054.00	-0.82	162.42	160.28
Aug2	2433.50	2417.89	5316.75	-0.64	119.89	118.48
Aug3	2023.50	2005.77	5217.25	-0.88	160.11	157.83
Con0	1721.50	3506.00	8696.00	103.66	148.03	405.14
Dec2	1663.25	1984.75	6520.75	19.33	228.54	292.05
Dec3	2295.50	1897.19	4912.75	-17.35	158.95	114.02
Feb2	2406.75	2903.57	7937.50	20.64	173.37	229.8
Feb3	2540.75	2459.92	5593.00	-3.18	127.37	120.13
Oct2	2290.75	2175.05	5496.50	-5.05	152.71	139.94
Oct3	1317.00	2089.83	5001.25	58.68	139.31	279.75
Average	2094.46	2319.43	6012.67	14.55	160.79	198.44

A factor contributing to the dramatic increase in the density of the woody vegetation of Pretoriuskop between 1954 and 1996, especially between 1969 and 1996, is believed to be the increase in the concentration of atmospheric CO_2 that has occurred between the 1950s and the turn of the millennium (Figure 7-20). In 1958 the concentration of atmospheric CO_2 was approximately 314.78 parts per million by volume (ppmv), and in 2003 the concentration of atmospheric CO_2 was approximately 375.57 ppmv (Appendix 8 Table 16-1 p.271) (Keeling and Whorf 2004). Using the Sheffield Dynamic Global Vegetation Model, Bond *et al.* (2003) predict that the increase in the concentration of atmospheric CO_2 from pre-industrial levels (approximately 180 ppmv) to their current levels (approximately 370 ppmv) will cause mesic savannas to become woodier. It appears that this has occurred in the mesic savannas of the Pretoriuskop region over the past half a century. What is interesting is that the density of the woody vegetation on the Pretoriuskop EBPs did not increase that much between 1954 and 1969 (Table 7-5 and Figure 7-20). However, it did increase dramatically between 1969 and 1996 (Table 7-5 and Figure 7-20). The increase in the density of the woody vegetation between 1969 and 1996 in comparison with 1954 and 1969 is disproportionately greater than the period between 1969 and 1996 (28 years) in comparison with 1954 and 1969 (15 years). Furthermore, the density of the woody vegetation on some of the treatments in 1969 was almost the same or lower than in 1954 (i.e. August Annual, Biennial, and Triennial treatments, the Biennial April and October treatments, and Triennial February and December treatments) (Table 7-5). While, the density of the woody vegetation increased on all treatments between 1969 and 1996 (Table 7-5). The reason for the disproportionate increase in the woody vegetation between 1969 and 1996 in comparison with 1954 and 1969 is believed to be that the KNP

experienced a number of drought years between 1960 and 1970 (Gertenbach 1980a, Van Wilgen et al. 2000). Between 1961 and 1971, the mean annual rainfall in KNP was 457.5mm, while between 1971 and 1981 the mean annual rainfall was 638.7mm (Van Wilgen *et al.* 2000). Furthermore, the concentration of atmospheric CO_2 increased approximately 2.9% between 1954 and 1969 (Figure 7-20) (Keeling and Whorf 2004). However, the concentration of atmospheric CO_2 increased approximately 16.0% between 1969 and 1996 (Figure 7-20) (Keeling and Whorf 2004). The greater increase in the concentration of atmospheric CO_2 between 1969 and 1996 as opposed to between 1954 and 1969 is also believed to be the reason why the density of the woody vegetation increased more between 1969 and 1996 than between 1954 and 1969.

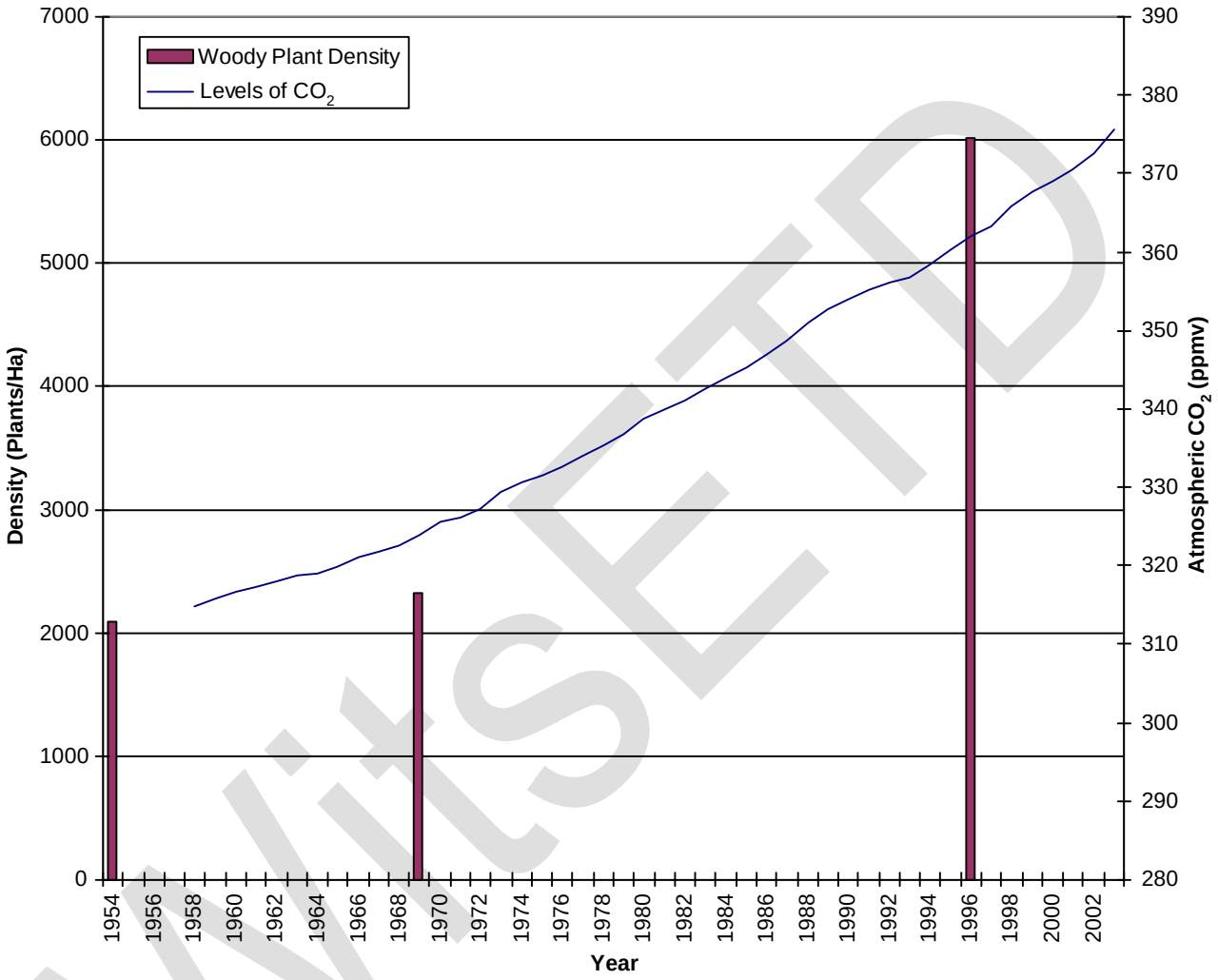


Figure 7-20: The mean density of woody vegetation (plants/Ha) on the Pretoriuskop EBPs in 1954, 1969, and 1996, and the atmospheric CO_2 concentration (ppmv) between 1958 and 2003 taken as the average annual atmospheric CO_2 concentration at 10 Scripps Institution of Oceanography (SIO) air sampling sites (Keeling and Whorf 2004). The annual average atmospheric CO_2 concentration for each SIO site is presented in Appendix 8 Table 16-1 (p.271).

Generally, the number of species and species diversity increased from 1954 to 1996, while the species evenness decreased between 1954 and 1996. Some species were dominant in 1954 and in 1996 regardless of the changes in the density of the woody vegetation that occurred, namely *Dichrostachys cinerea*, *Diospyros lycioides*, *Maytenus senegalensis*, *Pavetta schumanniana*, *Sclerocarya birrea*, *Senna petersiana*, *Strychnos madagascariensis*, *Terminalia sericea*, and *Turraea nilotica*. In 1954, *Acacia gerrardii*, *Annona senegalensis*, *Combretum molle*, *Lonchocarpus capassa*, *Mundulea sericea*, and *Parinari curatellifolia* were found to be dominant but were not dominant in 1996. In 1996, *Catunaregam spinosa*, *Euclea natalensis*, *Ochna natalitia*, and *Dalbergia melanoxylon* were found to be dominant but were not dominant in 1954. The

height structure of the woody vegetation between 1954 and 1996 was similar. However, the number of single-stem individuals relative to multi-stem individuals decreased between 1954 and 1996. Generally, the structural richness, structural diversity, and the structural evenness of the woody vegetation decreased between 1954 and 1996.

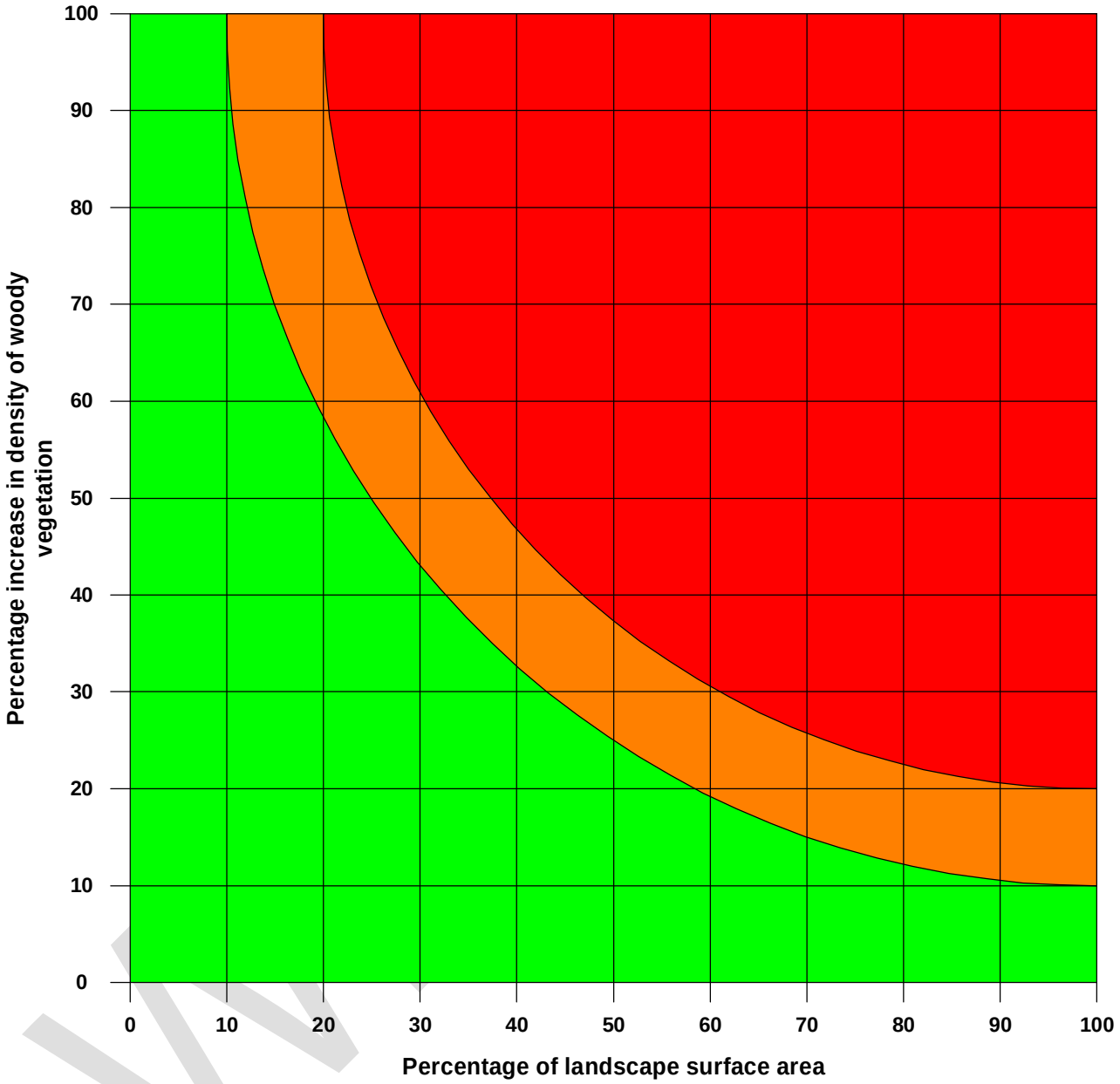


Figure 7-21: Graph showing the upper limits of the Thresholds of Potential Concern for the density (plants/Ha) of the woody vegetation within a landscape in the KNP (Provided by N Zambatis KNP Scientific Services). The colours green, orange, and red indicate the level of concern that expressed regarding the magnitude of change, namely green is ok, orange is caution, and red is potential concern.

KNP management have incorporated Thresholds for Potential Concern (TPC) into their biodiversity monitoring system. TPCs are used to identify limits in biodiversity indicators, which when exceeded signal a potential concern for the management in the KNP. Figure 7-21 models the non-linear upper limits of the TPCs related to the density of the woody vegetation. This TPC defines the upper limit of acceptable change in woody vegetation density depending on the spatial extent of that change. Looking at the green area in Figure 7-21, in any landscape in the KNP an increase in woody plant density of up to 100% is acceptable if

the area in which that amount of change occurred covered less that 10% of the area of that landscape. Furthermore, for an entire landscape an increase of only 20% in the density of woody plants would be accepted before there would be cause for concern.

The point from which change in the density of the woody vegetation is measured is the earliest recorded data regarding the density of the woody vegetation in an area. In the Pretoriuskop landscape, the surveys on the EBPs in 1954 and 1996 provide data at two points in time 42 years apart. This data gives a window into the changes that have occurred in the woody vegetation over the past half a century. In Pretoriuskop, the density of the woody vegetation increased by almost 200% between 1954 and 1996. In terms of the suggested TPCs regarding the density of the woody vegetation at the landscape level, this increase in woody plant density by almost 200% would appear to raise a flag. However, the increase in woody plant density since the mid 1950s is driven by factors that are outside of the control of KNP management.

Herein lays the heart of the issue. Should the KNP management respond to this TPC red flag by making every attempt to stem the densification of the Pretoriuskop woody vegetation or should the densification process be allowed to proceed unchecked because it is driven by factors, such as atmospheric CO_2 levels, which are outside of the control of the KNP management? These are important considerations, not the least because if KNP management decided to stem the densification process then they would most certainly have to review their current approach to prescribed burning in the Pretoriuskop region. Trollope (1983) has shown that the densification of savanna ecosystems can be successfully stemmed and even reversed with the judicious use of fire at the right time and frequency. The current patch mosaic burning approach to fire management is not believed to be structured nor rigorous enough to stem the densification of the woody vegetation in the Pretoriuskop region. Furthermore, it is expected that if current patch mosaic prescribed burning approach is not adjusted, the current application of fire could result in the densification of the woody vegetation in the Pretoriuskop region being accelerated as the atmospheric CO_2 levels increase globally.

WitsETD

8 REFERENCES

8.1 PUBLISHED JOURNAL ARTICLES AND BOOKS

Acocks JPH, 1953. Veld types of South Africa. Memoirs of Botanical Surveys of South Africa 28: 1-192.

Albini FA, 1993. Dynamics and modelling of vegetation fires: observations. In eds. Crutzen PJ and JG Goldhammer, Fire in the environment: ecological, atmospheric, and climatic importance of vegetation fires. John Wiley & Sons, New York.

Bartlett HH, 1956. Fire in relation to primitive agriculture and grazing in the tropics - annotated bibliography. Annual Arbour, University of Michigan, Department of Botany, volume II. (In West 1965).

Begon M, Harper JL, and CR Townsend, 1986. Ecology: Individuals, Populations, and Communities. Blackwell Scientific Publications, Oxford.

Biggs HC and ALF Potgieter, 1999. Overview of the fire management policy of the Kruger National Park. Koedoe 42(1): 101-110.

Biggs R, Biggs HC, Dunne TT, Govender N, and ALF Potgieter, 2003. Experimental burn plot trial in the Kruger National Park: history, experimental design, and suggestions for data analysis. Koedoe 46 (1): 1-15.

Bhattacharya NC, Biswas PK, Bhattacharya S, Sionit N, and BR Strain, 1985. Growth and yield response of sweet potato to atmospheric CO2 enrichment. Crop Science 25: 975-981.

Bond WJ and JJ Midgley, 1995. Kill thy neighbour: an individualistic argument for the evolution of flammability. Oikos 73: 79-85.

Bond WJ and BW Van Wilgen, 1996. Fire and plants. Chapman and Hall, London.

Bond WJ, 1997. Fire. In eds. Cowling RM, Richardson DM and SM Pierce, Vegetation of Southern Africa. Cambridge University Press, Cambridge.

Bond WJ and GF Midgley, 2000. A proposed CO_2-controlled mechanism of woody plant invasion in grasslands and savannas. Global Change Biology 6(8): 865-869.

Bond WJ, Woodward FI, and GF Midgley, 2002. Does elevated CO_2 play a role in bush encroachment? Natural Forests and Savanna Woodlands Symposium III, May 2002.

Bond WJ, Midgley GF, and FI Woodward, 2003. The importance of low atmospheric CO_2 and fire in promoting the spread of grasslands and savannas. Global Change Biology 9(7): 973-982.

Bond WJ, Woodward FI, and GF Midgley, 2005. The global distribution of ecosystems in a world without fire. New Phytologist 165 (2), 525-538 (doi: 10.1111/j.1469-8137.2004.01252.x).

Bourliere L and M Hadley, 1970. The ecology of tropical savannas. Annual Review of Ecology and Systematics 1: 125-152.

Brain CK and A Sillen, 1988. Evidence from the Swartkrans cave for the earliest use of fire. Nature 336: 464-466.

WiSETD

Brockett BH, Biggs HC, and BW Van Wilgen, 2001. A patch mosaic burning system for conservation areas in southern African savannas. International Journal of Wildland Fire 10: 169-183.

Brower JE and JH Zar, 1977. Field and laboratory methods for general ecology. Wm. C. Brown Publishers, Iowa.

Brynard AM, 1964. The influence of veld burning on the vegetation and game of the Kruger National Park. In ed. Davis DHS, Ecological studies in Southern Africa. Dr W Junk Publishers, The Hague.

Brynard AM, 1971. Controlled burning in the Kruger National Park - History and development of a veld burning policy. Proceedings of the 11th Annual Tall Timbers Fire and Ecology Conference. Tall Timbers Research Station, Florida.

Burbridge AB, 1938. Uncontrolled grass and forest fires and their prevention. Bulletin 1081 of the Department of Agriculture of South Rhodesia. (In West 1965).

Campbell RS, 1960. Use of fire in grassland management. FAO Workshop Party. Pasture and fodder development in tropical Americas. Maracay, Venezuela. (In West 1965).

Cangelosi VE, Taylor PH and PF Rice, 1983. Basic statistics. A real world approach. West Publishing Company, St. Paul.

Carruthers J, 1995. The Kruger National Park: A social and political history. University of Natal Press, Pietermaritzburg.

Carson WP and DK Abbiw, 1990. The vegetation of a fire protected site in the northern Accra Plains, Ghana. African Journal of Ecology 28:143-146.

Cerling TE, Harris JM, MacFadden BJ, Leakey MG, Quade J, Eisemann V, and JR Ehleringer, 1997. Global vegetation change through the Miocene-Pliocene boundary. Nature 389:153-158.

Cottam G and JT Curtis, 1956. The use of distance measures in phytosociological sampling. Ecology 37: 451-460.

Davidson RL, Brynard AM, Gillard P, Lecatsas G and J Leigh, 1961. Veld burning: a calibration of the belt transect method in Combretum woodland in the Kruger National Park. Koedoe 4: 31-41.

Enslin BW, Potgieter ALF, Biggs HC, and R Biggs, 2000. Long term effects of fire frequency and season on the woody vegetation dynamics of the *Sclerocarya birrea*/*Acacia nigrescens* savanna of the Kruger National Park. Koedoe 43(1): 27-37.

Ehleringer JR, Cerling TE, and BR Helliker, 1997. C4 photosynthesis, atmospheric CO2, and climate. Oecologia 112:285-299.

Fuwape JA 1991. The influence of fire on savanna rangeland in Nigeria. Proceedings IV International Rangeland Congress, Montpellier, France.

Garner RD and ETF Witkowski, 1997. Variations in seed size and shape in relation to depth of burial in the soil and pre-dispersal predation in *Acacia nilotica*, *A. tortilis*, and *Dichrostachys cinerea*. South African Journal of Botany 63: 371-377.

Gertenbach WPD and ALF Potgieter, 1979 a. Veldbrandnavorsing in die struikmopanieveld van die Nasionale Krugerwildtuin. Koedoe 22: 1-28.

WITSETD

Gertenbach WPD, 1980a. Rainfall patterns in the Kruger National Park. Koedoe 23: 35-43.

Gertenbach WPD, 1983. Landscapes of the Kruger National Park. Koedoe 26: 9-121.

Goldhammer JG, 1997. Overview of fire and smoke management issues and options in tropical vegetation. In eds. Haron Abu Hassan, Dahlan Taha, Mohd Puat Dahalan, and Amran Mahmud, Transboundary Pollution and the Sustainability of Tropical Forests: Towards Wise Forest Fire Management - The Proceedings of the AIFM International Conference. Ampang Press, Kuala Lumpur.

Gordon AD, 1987. A review of hierarchical classification. Journal of Review of the Statistical Society 150: 119 -137.

Higgins SI, Bond WJ, and WSW Trollope, 2000. Fire, resprouting and variability: a recipe for grass-tree coexistence in savanna. Journal of Ecology 88: 213 – 229.

Hill MO, 1973. Diversity and evenness: a unifying notion and its consequences. Ecology 54: 427-432.

Hoffmann WA, Bazzaz Fayi, Chatterton NJ, Harrison PA and Jackson RB, 2000. Elevated CO2 enhances resprouting of a tropical savanna tree. Oecologia 123: 312 – 317.

Holling CS and Meffe GK, 1996. Communal and control and pathology of natural resource management. Conservation Biology 10: 328-337.

Huntley BJ 1982. Southern African savannas. In eds. Huntley BJ and BH Walker. Ecology of tropical savannas. Springer - Verlag, Berlin.

Huston MA, 1994. Biological diversity. Cambridge University Press.

Jackson DA, Somers KM and HH Harvey, 1989. Similarity coefficients: Measures of co-occurrence and association or simply measures of occurrence? The American Naturalist 133(3): 436 – 453.

Kayll AJ, 1974. Use of fire in land management. In eds. Kozlowski TT and CE Ahlgren, Fire and ecosystems. Academic Press, New York.

Komarek EV, 1968. Lightning and lightning fires as ecological forces. In: Proceedings of the eighth Annual Tall Timbers Fire and Ecology Conference. Tall Timbers Research Station, Florida.

Komarek EV, 1971. Lighting and fire ecology in Africa. Proceedings of the 11th Annual Tall Timbers Fire and Ecology Conference. Tall Timbers Research Station, Florida.

Kruger FJ, 1984. Effects of fire on vegetation structure and dynamics. In eds. P de V Booysen and NM Tainton, Ecological effects of fire in Southern African ecosystems. Springer-Verlag, Berlin.

Ligavha M, Stock WD, and WJ Bond, 1999. The physiology of sprouting and its ecological implications in savanna woodland dynamics. Natural Forests and Savanna Woodlands Symposium II, September 1999.

Ludewig F, Sonnewald U, Kauder F, Heineke D, Geiger M, Stitt M, Muller-Rober BT, Gillissen B, Kuhn C and Frommer WB, 1998. The role of transient starch in acclimation to elevated atmospheric CO2. Federation of European Biochemical Societies (FEBS) Letters 429: 147-151.

Malanson GP, 1987, Diversity, stability, and resilience: Effects of fire regime. In ed. Trabaud L, The role of fire in ecological systems. SBP Academic Publishing, Netherlands.

WISETD

Mbalo BA and ETF Witkowski, 1997. Tolerance to soil temperatures experienced during and after the passage of fire in seeds of *Acacia karroo*, *A. tortilis*, and *Chromolaena odorata*. South African Journal of Botany 63: 421-425.

Mentis MT and AW Bailey, 1990. Changing perceptions of fire management in savanna parks. Journal of the Grassland Society of South Africa 7(2): 81-85.

Miglietta F, Magliulo V, Bindi M, Cerio L, Vaccari FP, Loduca V and A Peressotti, 1998. Free Air CO2 Enrichment of potato (Solanum tuberosum L.): development, growth, and yield. Global Change Biology 4: 163-172.

Miyanishi K and Kellman M, 1986. The role of root nutrient reserves in re-growth of two savanna shrubs. Canadian Journal of Botany 64: 1244–1248.

Munnick MC, Verster E, and TH Van Rooyen, 1990. Spatial pattern and variability of the soil and hillslope properties in a granitic landscape, 1. Pretoriuskop area. South African Journal of Soil 7(2): 121-130.

Mutch RW, 1970. Wildland fires and ecosystems - a hypothesis. Ecology 51: 1046- 1051.

Pielou EC, 1975. Ecological diversity. John Wiley and Sons, New York.

Palgrave KC, 1991. Trees of Southern Africa. Struik Publishers, Cape Town.

Ramsay JM and RR Innes, 1963. Some quantitative observations on the effects of fire in Guinea Savanna vegetation of Northern Ghana over a period of eleven years. Sols Africa 8(1): 41-85. (In West 1965).

Rosenthal R and RL Rosnow, 1991. Essentials of behavioural research: Methods and data analysis. McGraw-Hill, New York.

Scheiner SM, 2001. Theories, Hypotheses, and Statistics. In eds. Scheiner SM and J Gurevitch, Design and analysis of ecological experiments. Oxford University Press, Oxford.

Scholes RJ and BH Walker, 1993. An African savanna: Synthesis of the Nylsvley study. Cambridge University Press.

Scholes RJ, 1997. Savanna. In eds. Cowling RM, Richardson DM and SM Pierce, Vegetation of Southern Africa. Cambridge University Press, Cambridge.

Scholes RJ and SR Archer, 1997. Tree-grass interactions in savannas. Annual Review of Ecology and Systematics 28: 517-544.

SCOPE 1978. South African programme for the SCOPE mid-term project on the ecological effects of fire. September 1978.

Scott JD, 1947. Veld management in South Africa. Bulletin 278 of the Union of South Africa's Department of Agriculture. (In West 1965).

Shackleton CM, Cawe SG, and CJ Geldenhuys, 1999. Review of the definitions and classifications of South African indigenous forests and woodlands. Report to the Department of Water Affairs and Forestry. Report No. ENV-P-C 99007, CSIR, Environmentek, Pretoria.

Shackleton CM and RJ Scholes, 2000. Impact of fire frequency on woody community structure and soil nutrients in the Kruger National Park. Koedoe 43(1): 75-81.

WiSETD

Sousa WP, 1984. The role of disturbance in natural communities. Annual Review of .Ecological Systems 15: 353-391.

Southwood TRE and PA Henderson, 2000. Ecological methods. Blackwell Science, Oxford.

Stalmans M, 2002. Vegetation, fire, and herbivore interrelationships in the Songimvelo Game Reserve: A landscape ecological approach towards analyzing pattern and change. PhD thesis, University of the Witwatersrand, Johannesburg.

Stokes CS, 1942. Sanctuary. Cape Union Times.

Sweet RJ 1982. Bush control with fire in *Acacia nigrescens* / *Combretum apiculatum* savanna in Botswana. Proceedings of the Grassland Society of South Africa 17: 25-28.

Ter Braak CJF, 1988. Canoco – A FORTRAN program for canonical ordination by [partial] [detrended] [canonical] correspondence analysis, principal components analysis and redundancy analysis (version 2.1) – Technical report: LWA-88-02. Group Landbouwwiskunde.

Tidmarsh CE and CM Havenga, 1955. The wheel-point method of survey and measurement of semi-open grasslands and Karroo vegetation in South Africa. Botanical Survey Memoirs 29.

Trabaud L and J Lepart, 1980. Diversity and stability in Garrigue ecosystems after fire. Vegetatio 43: 49-57.

Trollope WSW 1980. Controlling bush encroachment with fire in the savanna areas of South Africa. Proceedings of the Grassland Society of South Africa 15: 173-177.

Trollope WSW, 1983. Control of bush encroachment in the arid savannas of south-eastern Africa. PhD, University of Natal, Pietermaritzburg.

Trollope WSW, 1984. Fire in savanna. Eds. Booysen PV and NM Tainton, Ecological effects of fire in South African systems. Ecological Studies 48

Trollope WSW and ALF Potgieter, 1985. Fire behaviour in the Kruger National Park. Journal of the Grassland Society of Southern Africa 2 (2): 17-22.

Trollope WSW and NM Tainton, 1986. Effect of fire intensity on the grass and bush components of the eastern Cape thornveld. Journal of the Grassland Society of South Africa 3(2): 37-42.

Trollope WSW, Trollope LA, and OJH Bosch, 1990. Veld and pasture management terminology in southern Africa. Journal of the Grassland Society of South Africa 7(1): 52-61.

Trollope WSW, Everson CS, and NM Tainton, 1991. Effect and use of fire in the grassland and savanna areas of South Africa. In ed. Tainton NM, Veld and pasture management in South Africa. Shuter and Shooter, Pietermaritzburg.

Trollope WSW, Trollope LA, Potgieter ALF, and N Zambatis, 1994. SAFARI 92 – Characterisation of biomass and fire behaviour in the small experimental burns in the Kruger National Park. Journal of Geophysical Research 101 (D19): 23531-23539.

Trollope WSW, Biggs HC, Potgieter ALF, and N Zambatis, 1995. A structured vs. a wilderness approach to burning in the Kruger National Park in South Africa. V International Rangeland Congress, Salt Lake City.

WISETD

Trollope WSW, 1999a. Veld Burning. Fire Behaviour. Ed. Tainton NM. Veld management in South Africa. University of Natal Press, Pietermaritzburg.

Trollope WSW, 1999b. Effects and use of fire in southern African savannas. Natural Forests and Savanna Woodlands Symposium II, September 1999.

Trollope WSW, Potgieter ALF, Biggs HC, Govender N., Van Wilgen B, Kruger J, and BH Brockett, 2003. An integrated fire management system for the Kruger National Park in South Africa. Proceedings Third International Wildland Fire Conference, Sydney, Australia.

Van Der Schijff HP, 1958. Inleidende verslag oor veldbrandnavorsing in die Nasionale Krugerwildtuin. Koedoe 1: 60-93.

Van Wilgen BW and RJ Scholes, 1997. The vegetation and fire regimes of southern hemisphere Africa. In eds. Van Wilgen BW, Andreae MO, Goldhammer JG and JA Lindesay, Fire in southern African savannas: Ecological and atmospheric perspectives. Witwatersrand University Press.

Van Wilgen BW, HC Biggs and ALF Potgieter, 1998. Fire management in the Kruger National Park, with suggestions on the detection of thresholds of potential concern. Koedoe 41: 69-87.

Van Wilgen BW, Andreae MO, Goldhammer JG, and JA Lindesay, 1997. Fire in southern African savannas. Witwatersrand University Press. Johannesburg.

Van Wilgen BW, Biggs HC, O'Regan SP, and N Mare, 2000. A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996. South African Journal of Science 96: 167-178.

Van Wilgen BW, Govender N, Biggs HC, Ntsala D, and XN Fund, In Press. Response of savanna fire regimes to changing fire management policies in a large African national park. Conservation Biology.

Van Wyk P, 1971. Veld burning in the Kruger National Park, An interim report of some aspects of research. Proceedings of the 11th Annual Tall Timbers Fire and Ecology Conference. Tall Timbers Research Station, Florida.

Venter FJ and WPD Gertenbach, 1986. A cursory review of the climate and vegetation of the Kruger National Park. Koedoe 29: 139-148.

Vogl RJ, 1974. Effects of fire on grasslands. In eds. Kozlowski TT and CE Ahlgren, Fire and ecosystems. Academic Press, New York.

Walker BH and I Noy-Meir, 1982. Aspects of stability and resilience in savanna ecosystems. In eds. Huntley BJ and BH Walker. Ecology of tropical savannas. Springer - Verlag, Berlin.

Walter H, 1971. Ecology of tropical and subtropical vegetation. Olivar and Boyd, Edinburgh.

Ward JH, 1963. Hierarchical grouping to optimise an objective function. Journal of the American Statistical Association 58: 236.

West O, 1965. Fire in vegetation and its use in pasture management with special reference to tropical and subtropical Africa. Mimeographed Publication No. 1 of Commonwealth Bureau of Pastures and Field Crops. Commonwealth Agricultural Bureaux. Hurley, Berkshire.

West O, 1969. Fire, its effect on the ecology of vegetation in Rhodesia and its application in grazing management. Rhodesia Science News 3: 321-326.

WISETD

West O, 1971. Fire, man, and wildlife as interacting factors limiting the development of vegetation in Rhodesia. Proceedings of the 11th Annual Tall Timbers Fire and Ecology Conference. Tall Timbers Research Station, Florida.

Whelan RJ, 1995. The ecology of fire. Cambridge University Press.

Wilson BG and ETF Witkowski, 2003. Seed banks, bark thickness, and change in age and size structure (1978–1999) of the African savanna tree, *Burkea africana*. Plant Ecology 167: 151–162.

Witkowski ETF and TG O'Connor, 1996. Topo-edaphic, floristic and physiognomic gradients of woody plants in a semi-arid African savanna woodland. Vegetatio 124: 9-23.

Woods D, Potgieter A, Landmann T, and N Govender, 2002. Fire policy, experiments and experience in the Kruger National Park, South Africa. Paper presented at the Southern African Fire Network (SAFNet) Conference - 29 July 2002. Gaborone, Botswana.

8.2 DIGITAL AND INTERNET REFERENCES

Anonymous, 2004. About CDIAC (Carbon Dioxide Information Analysis Center). Carbon Dioxide Information Analysis Center (cdiac.esd.ornl.gov).
URL: http://cdiac.esd.ornl.gov/about/intro.html

Braack LEO, 1997. A revision of parts of the management plan for the Kruger National Park. Volume VIII: Policy proposals regarding issues relating to biodiversity maintenance, maintenance of wilderness qualities, and provision of human benefits. Scientific Services Management Plan. South African National Parks, Skukuza.
URL: http://www.parks-sa.co.za.

Govender N, 2003. Fire management in the Kruger National Park. Arid Lands Newsletter - Fire Ecology I (54). November-December 2003.
URL: http://ag.arizona.edu/OALS/ALN/ALNHome.html.

Idso SB, Idso KE, and CD Idso, 2000a. Growth response to CO_2 (tubers) – Summary. Centre for the Study of Carbon Dioxide and Global Climate Change (www.co2science.org).
URL: http://www.co2science.org/subject/t/summaries/tubers.htm.

Idso SB, Idso KE, and CD Idso, 2000b. Growth response to CO_2 (starch) – Summary. Centre for the Study of Carbon Dioxide and Global Climate Change (www.co2science.org).
URL: http://www.co2science.org/subject/s/summaries/starch.htm.

Idso SB, Idso KE, and CD Idso, 2002a. Stomatal conductance (Trees) - Summary. Centre for the Study of Carbon Dioxide and Global Climate Change (www.co2science.org).
URL: http://www.co2science.org/subject/s/summaries/stomataltrees.htm.

Idso SB, Idso KE, and CD Idso, 2002b. Water use efficiency (Trees) - Summary. Centre for the Study of Carbon Dioxide and Global Climate Change (www.co2science.org).
URL: http://www.co2science.org/subject/w/summaries/wateruse trees.htm.

Idso SB, Idso KE, and CD Idso, 2003. Trees (Range Expansions) - Summary. Centre for the Study of Carbon Dioxide and Global Climate Change (www.co2science.org).
URL: http://www.co2science.org/subject/r/summaries/rangeexptrees.htm.

WISETD

Keeling CD and TP Whorf, 2004. Atmospheric CO2 records from sites in the Scripps Institution of Oceanography (SIO) air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee., U.S.A.
URL: http://cdiac.esd.ornl.gov/trends/co2/sio-keel.htm

StatSoft 1999. Electronic Statistics Textbook. Tulsa, OK. StatSoft Inc.
URL: http://www.statsoft.com/textbook/stathome.html.

Systat 1998. SYSTAT Version 9 for Windows Help Files. Copyright © SPSS Inc.

Van Wilgen BW, 2002. Changing paradigms in conservation: Lessons from six decades of fire management in a large African national park. Australasian Fire Authorities Council (AFAC) Annual Conference.
URL: http://www.ausfire.com/afac_conference/documents/vanwilgen.doc (This document no longer available online).

8.3 UNPUBLISHED RESEARCH REPORTS: SOUTH AFRICAN NATIONAL PARKS BOARD OF TRUSTIES:

Brynard AM, Davidson RL, Gillard P, Lecatsas G, and J Leigh, 1960. Calibration of the belt transect method in Combretum woodland in the Kruger National Park. Unpublished report, Annexure C of the Annual Report of the Kruger National Park: April 1959 – March 1960.

Gertenbach WPD and ALF Potgieter, 1975. Veldbrandnavorsing in die knoppiesdoring-maroelaveld van die sentrale distrik Nasionale Krugerwildtuin. Unpublished report, Kruger National Park.

Gertenbach WPD and ALF Potgieter, 1979 b. Veldbrandnavorsing in die struikmopanieveld van die Nasionale Krugerwildtuin. Unpublished report, Kruger National Park.

Gertenbach WPD, 1980a. Veldbrandprogram van die Nasionale Krugerwildtuin. Unpublished report, Kruger National Park.

Potgieter ALF, 1997. A proposed amended fire management policy for the Kruger National Park. Unpublished report, Kruger National Park.

Sarnak NI, Shapiro S, and AM Starfield, 1977. Analysis of burning experiment data from the Kruger National Park. Unpublished report, Kruger National Park. (Annotated copy with comments)

Scott JD, 1972. Visit to the Kruger National Park by JD Scott DSc, Professor of Pasture Science, University of Natal. Unpublished report, Kruger National Park.

Trollope WSW and ALF Potgieter, 1983. Characteristics of fire behaviour in the Kruger National Park. Unpublished report, Kruger National Park.

Trollope WSW, Potgieter ALF and Zambatis, 1990. Characterization of fire behaviour in the Kruger National Park. Unpublished report. Kruger National Park.

Trollope WSW, Potgieter ALF, Biggs HC, and LA Trollope, 1998. Report on the experimental burning plots (EBP) trial in the major vegetation types of the Kruger National Park. Unpublished Kruger National Park Research Department Report No 9/98, 1998.

Van Wyk, P 1975. Memorandum: Veldbrand in die Krugerwildtuin. Unpublished report, Kruger National Park.

WISETD

Von Broembsen HH, 1963. Report on two visits to the Kruger National Park. Unpublished report, Annexure B of the Annual Report of the Kruger National Park: November 1963 – October 1964.

8.4 UNPUBLISHED ANNUAL REPORTS: SOUTH AFRICAN NATIONAL PARKS BOARD OF TRUSTIES:

1951, 1953, 1954, 1955, 1956, 1957, 1959, 1960, 1962, 1963, 1964, 1965, 1966, 1967, 1971, 1972, 1973, 1976, 1980, 1989, 1990.

8.5 UNPUBLISHED CORRESPONDENCE AND COMMENTS: SOUTH AFRICAN NATIONAL PARKS BOARD OF TRUSTIES

Anonymous 1977. Comments and correspondence attached to the Research Report submitted by Sarnak *et al.* 1977.

8.6 UNPUBLISHED MINUTES OF MEETINGS: SOUTH AFRICAN NATIONAL PARKS BOARD OF TRUSTIES

Minutes 1962. Agenda and minutes of a meeting of the National Parks Board of Trustees, 26th November 1962. Unpublished, Pretoria.

8.7 PERSONAL COMMUNICATION

Potgieter A, 1998. SANP coordinator. Kruger National Park, Scientific Services.

WitsETD

9 APPENDIX 1: WOODY PLANT SPECIES LISTS FOR THE THREE SURVEYS (1954, 1959 AND 1996) CONDUCTED ON THE PRETORIUSKOP EXPERIMENTAL BURN PLOTS

Table 9-1: List of all woody species found on the Pretoriuskop EBPs in the 1954, 1959, and 1996 surveys with the species nomenclature according to Palgrave (1991). The list shows the species codes used when displaying species data in tables and figures through out this document.

Family	Species name	Species code
Anacardiaceae	*Lannea discolor* (Sond.) Engl.	lann disc
	Lannea edulis var. *edulis*	lann edul
	Lannea schweinfurthii (Engl.) Engl. var. *stuhlmannii* (Engl.) Kokwaro	lann schw
	Ozoroa sphaerocarpa R. & A. Fernandes	ozor spha
	Rhus leptodictya Diels	rhus lept
	Rhus pentheri Zahlbr.	rhus pent
	Rhus pyroides Burch.	rhus pyro
	Rhus transvaalensis Engl.	rhus tran
	Sclerocarya birrea (A. Rich.) Hochst. var. *caffra* (Sond.) Kokwaro	scle birr
Annonaceae	*Annona senegalensis* subsp. *senegalensis* Pers.	anno sene
Asteraceae	*Vernonia colorata* (Willd.) Drake	vern colo
Bignoniaceae	*Kigelia africana* (Lam.) Benth.	kige afri
	Markhamia zanzibarica (Bojes ex DC.) K. Schum.	mark zanz
Boraginaceae	*Ehretia obtusifolia* Hochst. ex DC.	ehre obtu
Burseraceae	*Commiphora mollis* (Oliver) Engl.	comm moll
	Commiphora neglecta Veldoorn	comm negl
Caesalpinioideae	*Bauhinia galpinii* N.E. Brown	bauh galp
	Peltophorum africanum Sond.	pelt afri
	Piliostigma thonningii (K. Schum.) Milne-Redh.	pili thon
	Schotia brachypetala Sond.	scho brac
	Senna petersiana (Bolle) Lock	senn pete
Celastraceae	*Cassine aethiopica* Thunb.	cass aeth
	Cassine transvaalensis (Burtt Davy) Codd	cass tran
	Maytenus heterophylla (Eckl. & Zeyh) N.K.B. Robson	mayt hete
	Maytenus senegalensis (Lam.) Exell	mayt sene
	Putterlickia pyracantha (L.) Szyszyl	putt pyra
Combretaceae	*Combretum apiculatum* Sonder. subsp. *apiculatum*	comb apic
	Combretum collinum Fresen.	comb coll
	Combretum hereroense Schinz	comb here
	Combretum imberbe Wawra	comb imbe
	Combretum molle R.Br. ex G. Don	comb moll
	Combretum mossambicense (Klotzsch) Engl.	comb moss
	Terminalia sericea Burch. ex DC.	term seri
Ebenaceae	*Diospyros lycioides* Desf.	dios lyci
	Diospyros mespiliformis Hochst. ex A. DC.	dios mesp
	Diospyros whyteana (Hiern) F. White	dios whyt
	Euclea divinorum Hiern	eucl divi
	Euclea natalensis A. DC. subsp. *natalensis*	eucl nata
Euphorbiaceae	*Antidesma venosum* E. Mey. ex Tul.	anti veno
	Bridelia mollis Hutch.	brid moll
	Croton gratissimus Burch. var. *gratissimus*	crot grat
	Phyllanthus reticulatus Poir.	phyl reti
	Securinega virosa (Roxb. Ex Willd) Pax & K. Hoffm.	secu viro
	Spirostachys africana Sond.	spir afri
Flacourtiaceae	*Flacourtia indica* (N. L. Burm.) Merr.	flac indi
Leguminosae	*Pseudarthria hookeri* Wight & Arn. var. *hookeri*	pseu hook
Loganiaceae	*Strychnos madagascariensis* Poir.	stry mada
	Strychnos spinosa Lam.	stry spin
Meliaceae	*Trichilia emetica* Vahl.	tric emet
	Turraea nilotica Kotschy & Peyr	turr nilo
Mimosoideae	*Acacia caffra* (Thunb.) Willd.	acac caff
	Acacia gerrardii Benth. var. *gerrardii*	acac gerr

WISER

Family	Species name	Species code
	Acacia xanthophloea Benth.	acac xant
	Acacia exuvialis Veldoorn	acac exuv
	Acacia sieberiana DC. var. *woodii* (Burt Davy) Keay & Brenan	acac sieb
	Acacia swazica Burtt Davy	acac swaz
	Albizia harveyi Fourn.	albi harv
	Albizia versicolor Welw. ex Oliver	albi vers
	Dichrostachys cinerea (L.) Wright ex Arn.	dich cine
Moraceae	*Ficus stuhlmannii* Warb.	ficu stuh
	Ficus sycomorus L. subsp. sycomorus	ficu syco
Myrtaceae	*Heteropyxis natalensis* Harv.	hete nata
	Syzygium cordatum Hochst.	syzy cord
	Syzygium guineense (Willd.) DC.	syzy guin
Ochnaceae	*Ochna natalitia* (Meisn.) Walp.	ochn nata
Olacaceae	*Olea europaea* L. subsp. *africana* (Mill.) P.S. Green	olea euro
	Ximenia caffra Sond. var. *caffra*	xime caff
Papilionoideae	*Dalbergia melanoxylon* Guillemin & Perrottet	dalb mela
	Lonchocarpus capassa Rolfe	lonc capa
	Mundulea sericea (Willd.) A. Chev.	mund seri
	Ormocarpum trichocarpum (Taub.) Engl.	ormo tric
	Papilionacea	papi lion
	Pterocarpus angolensis DC.	pter ango
	Pterocarpus rotundifolius (Sond.) Druce subsp. *rotundifolius*	pter rotu
Proteaceae	*Faurea saligna* Harv.	faur sali
Rhamnaceae	*Berchemia zeyheri* (Sonder) Grubov	berc zeyh
	Ziziphus mucronata Willd. subsp. *mucronata*	zizi mucr
Rosaceae	*Parinari curatellifolia* Planch. ex Benth.	pari cura
Rubiaceae	*Canthium* sp.	cant spec
	Catunaregam spinosa (Thunb.) Tirvengadum subsp. *spinosa*	catu spin
	Gardenia volkensii K. Schum. subsp. *spatulifolia*	gard volk
	Hyperacanthus amoenus (Sims) Bridson	hype amoe
	Kraussia floribunda Harv.	krau flor
	Pavetta schumanniana F. Hoffm. ex K. Schum.	pave schu
	Psydrax locuples (K. Schum.) Bridson	psyd locu
	Tarenna supra-axillaris (Hemsl.) Brem.	tare supr
	Vangueria infausta Burch.	vang infa
Rutaceae	*Zanthoxylum capense* (Thunb.) Harv.	zant cape
Sapindaceae	*Hippobromus pauciflorus* (L.f.) Randlk.	hipp pauc
	Pappea capensis Eckl. & Zeyh.	papp cape
Sterculiaceae	*Dombeya rotundifolia* (Hochst.) Planchon	domb rotu
Tiliaceae	*Grewia flavescens* Juss. var. *flavescens*	grew flav
	Grewia hexamita Burret	grew hexa
	Grewia monticola Sond.	grew mont
Ulmaceae	*Chaetachme aristata* Planchon	chae aris
Unidentified	Unidentified	unid enti
Verbenaceae	*Clerodendrum* sp.	cler spec

WISER

Table 9-2: List showing the woody species found on the Pretoriuskop EBPs in the three surveys conducted in 1954, 1959, and 1996. This list links the species code defined in Table 9-1 to the species name used at the time of each of the surveys.

Species code	1954 species name	1959 species name	1996 species name
acac caff			*Acacia caffra*
acac exuv			*Acacia exuvialis*
acac gerr	*Acacia gerrardii*		*Acacia gerrardii*
acac sieb	*Acacia* sp. *Acacia woodii*		*Acacia sieberiana*
acac swaz		*Acacia ataxacantha*	*Acacia swazica*
acac xant			*Acacia xanthophloea*
albi harv			*Albizia harveyi*
albi vers	*Albizia versicolor*		*Albizia versicolor*
anno sene	*Annona chrysophylla*	*Annona chrysophylla*	*Annona senegalensis*
anti veno	*Antidesma venosum*	*Antidesma venosum*	*Antidesma venosum*
berc zeyh			*Berchemia zeyheri*
brid moll	*Bridelia mollis*	*Bridelia mollis*	
bauh galp	*Bauhinia galpinii*	*Bauhinia galpinii*	*Bauhinia galpinii*
cant spec			*Canthium* sp.
cass aeth			*Cassine aethiopica*
cass tran	*Pseudocassine transvaalensis*		*Cassine transvaalensis*
catu spin	*Randia* sp. *Randia vestita*	*Randia* sp.	*Catunaregam spinosa*
chae aris	*Chaetachme aristata*		
cler spec	*Clerodendrum* sp.		
comb apic	*Combretum apiculatum* *Combretum* sp.		*Combretum apiculatum*
comb coll	*Combretum suluense* *Combretum zeyheri*		*Combretum collinum*
comb here	*Combretum transvaalensis*		*Combretum hereroense*
comb imbe			*Combretum imberbe*
comb moll	*Combretum gueinzii*	*Combretum gueinzii*	*Combretum molle*
comb moss			*Combretum mossambiquensis*
comm moll	*Commiphora mollis* *Commiphora* sp.		
comm negl			*Commiphora neglecta*
crot grat			*Croton gratissimus*
dalb mela	*Dalbergia melanoxylon* *Dalbergia* sp.	*Dalbergia melanoxylon*	*Dalbergia melanoxylon*
dich cine	*Dichrostachys glomerata* *Dichrostachys nyassana*	*Dichrostachys nyassana*	*Dichrostachys cinerea*
dios lyci	*Rhus villosa* *Royena lucida* *Royena schlechteri* *Royena sericea* *Royena* sp.	*Royena schlechteri*	*Diospyros lycioides*
dios mesp	*Diospyros mespiliformis*	*Diospyros mespiliformis*	*Diospyros mespiliformis*
dios whyt			*Diospyros whyteana*
domb rotu	*Dombeya rotundifolia*	*Dombeya rotundifolia*	*Dombeya rotundifolia*
ehre obtu	*Ehretia amoena* *Ehretia rigida* *Ehretia* sp.	*Ehretia amoena* *Ehretia* sp.	*Ehretia obtusifolia*
eucl divi	*Euclea divinorum* *Euclea* sp.	*Euclea divinorum*	*Euclea divinorum*
eucl nata	*Euclea multiflora*	*Euclea multiflora*	*Euclea natalensis*
faur sali			*Faurea saligna*
ficu stuh	*Ficus stuhlmannii*		
ficu syco			*Ficus sycomorus*
flac indi	*Flacourtia hirtiuscula*	*Flacourtia hirtiuscula*	*Flacourtia indica*
gard volk			*Gardenia volkensii*
grew flav	*Grewia flavescens*	*Grewia flavescens*	*Grewia flavescens*
grew hexa			*Grewia hexamita*
grew mont	*Grewia monticola*		*Grewia monticola*

WITS ETD

Species code	1954 species name	1959 species name	1996 species name
hete nata			*Heteropyxis natalensis*
hipp pauc			*Hippobromus pauciflorus*
hype amoe			*Hyperacanthus amoenus*
kige afri			*Kigelia africana*
krau flor		*Kraussia schlechteri*	*Kraussia floribunda*
lann schw	*Lannea* sp.		*Lannea schweinfurthii*
lann disc	*Lannea discolor*		*Lannea discolor*
lann edul	*Lannea edulis*	*Lannea edulis*	*Lannea edulis*
lonc capa	*Lonchocarpus capassa*	*Lonchocarpus capassa*	*Lonchocarpus capassa*
mark zanz			*Markhamia zanzibarica*
mayt hete	*Gymnosporia buxifolia*	Gymnosporia buxifolia	*Maytenus heterophylla*
mayt sene	*Gymnosporia senegalensis*	*Gymnosporia senegalensis*	*Maytenus senegalensis*
mund seri	*Mundulea sericea*	*Mundulea sericea*	*Mundulea sericea*
ochn nata	*Ochna natalitia* *Ochna* sp.	*Ochna natalitia*	*Ochna natalitia*
olea euro	*Olea africana*		*Olea europaea*
ormo tric	*Ormocarpum trichocarpum*	*Ormocarpum trichocarpum*	*Ormocarpum trichocarpum*
ozor spha	*Heeria reticulata*		*Ozoroa sphaerocarpa*
papi lion	Papilionacea		
papp cape	*Pappea capensis*		*Pappea capensis*
pari cura	*Parinari mobola*	*Parinari mobola*	*Parinari curatellifolia*
pave schu	*Pavetta schumanniana* *Pavetta* sp.	*Pavetta schumanniana*	*Pavetta schumanniana*
pelt afri	*Peltophorum africanum*	*Peltophorum africanum*	*Peltophorum africanum*
phyl reti	*Phyllanthus reticulatus* *Phyllanthus tuberosa*	*Phyllanthus* sp.	*Phyllanthus reticulatus*
pili thon	*Piliostigma thonningii*	*Piliostigma thonningii*	*Piliostigma thonningii*
pseu hook	*Pseudarthria hookeri*	*Pseudarthria hookeri*	
pter ango	*Pterocarpus angolensis*	*Pterocarpus angolensis*	*Pterocarpus angolensis*
pter rotu	*Pterocarpus rotundifolius*		*Pterocarpus rotundifolius*
putt pyra			*Putterlickia pyracantha*
rhus lept			*Rhus leptodictya*
rhus pent			*Rhus pentheri*
rhus pyro	*Rhus gueinzii* *Rhus pyroides* *Rhus* sp.	*Rhus pyroides*	*Rhus pyroides*
rhus tran	*Rhus transvaalensis*	*Rhus transvaalensis*	*Rhus transvaalensis*
scho brac	*Schotia brachypetala*		*Schotia brachypetala*
scle birr	*Sclerocarya caffra*	*Sclerocarya caffra*	*Sclerocarya birrea*
secu viro	*Flueggea virosa*		*Securinega virosa*
senn pete	*Cassia petersiana*	*Cassia petersiana*	*Senna petersiana*
spir afri			*Spirostachys africana*
stry mada	*Strychnos innocua* *Strychnos* sp.	*Strychnos innocua*	*Strychnos madagascariensis*
stry spin	*Strychnos spinosa*		*Strychnos spinosa*
syzy cord	*Syzygium cordatum*		*Syzygium cordatum*
syzy guin			*Syzygium guineense*
tare supr			*Tarenna supra-axillaris*
term seri	*Terminalia sericea*	*Terminalia sericea*	*Terminalia sericea*
tric emet	*Trichilia emetica*		*Trichilia emetica*
turr nilo	*Turraea* sp.		*Turraea nilotica*
unid enti	Ongeidentifiseerd		
vang infa	*Vangueria infausta*	*Vangueria infausta*	*Vangueria infausta*
veno colo	*Vernonia* sp.		
xime caff	*Ximenia caffra* *Ximenia* sp.	*Ximenia caffra*	*Ximenia caffra*
zant cape	*Fagara capensis*	*Fagara capensis*	*Zanthoxylum capense*
zizi mucr	*Ziziphus mucronata*	*Ziziphus mucronata*	*Ziziphus mucronata*

WITS ETD

10 APPENDIX 2: LIST OF THE PRETORIUSKOP EXPERIMENTAL BURN PLOTS AND TREATMENTS

Table 10-1: List of the Pretoriuskop Experimental Burn Plots, the treatment assigned to the plot in 1954 and 1956, and the plot code used when displaying plot data in tables and figures through out this document. A description of the treatment codes are presented in Table 3-1 (p. 15).

Replicate	Plot Number	Treatment Code	Plot Code
Fayi	1	Aug2	Fa01Aug2
	2	Cont	Fa02Con0
	3	Dec2	Fa03Dec2
	4	Oct2	Fa04Oct2
	5	Apr2	Fa05Apr2
	6	Feb2	Fa06Feb2
	7	Aug1	Fa07Aug1
	8	Dec3	Fa08Dec3
	9	Aug3	Fa09Aug3
	10	Oct3	Fa10Oct3
	11	Feb3	Fa11Feb3
	12	Apr3	Fa12Apr3
Kambeni	1	Cont	Ka01Con0
	2	Dec2	Ka02Dec2
	3	Oct2	Ka03Oct2
	4	Feb2	Ka04Feb2
	5	Aug2	Ka05Aug2
	6	Apr2	Ka06Apr2
	7	Aug1	Ka07Aug1
	8	Feb3	Ka08Feb3
	9	Oct3	Ka09Oct3
	10	Dec3	Ka10Dec3
	11	Aug3	Ka11Aug3
	12	Apr3	Ka12Apr3
Numbi	1	Oct2	Nu01Oct2
	2	Dec2	Nu02Dec2
	3	Feb2	Nu03Feb2
	4	Aug2	Nu04Aug2
	5	Apr2	Nu05Apr2
	6	Aug1	Nu06Aug1
	7	Cont	Nu07Con0
	8	Dec3	Nu08Dec3
	9	Oct3	Nu09Oct3
	10	Feb3	Nu10Feb3
	11	Apr3	Nu11Apr3
	12	Aug3	Nu12Aug3
Shabeni	1	Aug2	Sh01Aug2
	2	Apr2	Sh02Apr2
	3	Aug1	Sh03Aug1
	4	Feb2	Sh04Feb2
	5	Oct2	Sh05Oct2
	6	Dec2	Sh06Dec2
	7	Cont	Sh07Con0
	8	Dec3	Sh08Dec3
	9	Apr3	Sh09Apr3
	10	Aug3	Sh10Aug3
	11	Oct3	Sh11Oct3
	12	Feb3	Sh12Feb3

WITS ETD

11 APPENDIX 3: METADATA FOR THE SURVEYS OF THE WOODY VEGETATION OF THE PRETORIUSKOP EBPS IN 1954, 1959 AND 1996

The survey information in Table 11-1 comprises:

- The year the survey was done (**Year**). For the baseline survey, 1954 was the year even though the surveys were conducted between 1954 and 1958. For the final survey, 1996 was the year even though the surveys were conducted during 1996 and 1997.
- The treatment plot information:
  - The name of the replicate on which the plot occurs (**Replicate**). See Figure 3-3 (p. 18) for the layout of the Pretoriuskop replicates
  - The plot number (**Plot**).
  - The treatment applied to the plot (**Treatment Code**). See Table 3-1 (p. 15) for a definition of the treatment codes.
- The survey transect information:
  - The transect indicator (A or B) (**Transect**). This denotes which diagonal of the plot that was surveyed.
  - The date the transect was surveyed (**Date**). Many of the 1954 survey dates had the same date. These dates are believed to be the date the data was captured into a summarised format and not the date the actual survey was done. A more likely date for the 1954 surveys is believed to be approximately a month before the first application of the treatments on each plot.
  - The direction of the survey transect across the diagonal of the plot (**Direction**).
  - The length of the transect (m) (**Length**). In the 1996 surveys some of the transect lengths are less than 300m. The reasons for the lengths being less than 300m are given in the comments. In some cases, the reason for the length being shorter than 300m was believed to have been valid for the 1954 and 1959 surveys. These survey lengths were then adjusted accordingly, which is why some of the transect lengths in 1954 and 1959 are less than 310m.
  - The width of the transect (m) (**Width**).
  - The area of the transect (m^2) (**Area**).
  - General comments (**Comments**).

Table 11-1: A list showing the information for each of the survey transects that was used to survey the woody vegetation of the Pretoriuskop EBPs in 1954, 1959, and 1996.

Year	Replicate	Plot	Treatment Code	Transect	Date	Direction	Length (m)	Width (m)	Area (m^2)	Comments
1954	Fayi	1	Aug2	A	09 Apr 54		305	1.524	464.82	
1954	Fayi	1	Aug2	B	09 Apr 54		305	1.524	464.82	
1954	Fayi	2	Cont	A	09 Apr 54		305	1.524	464.82	
1954	Fayi	2	Cont	B	09 Apr 54		305	1.524	464.82	
1954	Fayi	3	Dec2	A	09 Apr 54		305	1.524	464.82	
1954	Fayi	3	Dec2	B	09 Apr 54		301	1.524	458.724	Into road (4m)
1954	Fayi	4	Oct2	A	09 Apr 54		305	1.524	464.82	
1954	Fayi	4	Oct2	B	09 Apr 54		305	1.524	464.82	
1954	Fayi	5	Apr2	A	09 Apr 54		305	1.524	464.82	
1954	Fayi	5	Apr2	B	09 Apr 54		305	1.524	464.82	
1954	Fayi	6	Feb2	A	09 Apr 54		305	1.524	464.82	

WISER

Year	Replicate	Plot	Treatment Code	Transect	Date	Direction	Length (m)	Width (m)	Area (m^2)	Comments
1954	Fayi	6	Feb2	B	09 Apr 54		305	1.524	464.82	
1954	Fayi	7	Aug1	A	09 Apr 54		305	1.524	464.82	
1954	Fayi	7	Aug1	B	09 Apr 54		305	1.524	464.82	
1954	Fayi	8	Dec3	A	24 Jun 54		305	1.524	464.82	
1954	Fayi	8	Dec3	B	24 Jun 54		305	1.524	464.82	
1954	Fayi	9	Aug3	A	28 Jul 58		305	1.524	464.82	
1954	Fayi	9	Aug3	B	28 Jul 58		305	1.524	464.82	
1954	Fayi	10	Oct3	A	07 Oct 58		295	1.524	449.58	Into road (10m)
1954	Fayi	10	Oct3	B	07 Oct 58		305	1.524	464.82	
1954	Fayi	11	Feb3	A	21 Nov 57		305	1.524	464.82	
1954	Fayi	11	Feb3	B	21 Nov 57		305	1.524	464.82	
1954	Fayi	12	Apr3	A	26 Mar 58		305	1.524	464.82	
1954	Fayi	12	Apr3	B	26 Mar 58		305	1.524	464.82	
1954	Kambeni	1	Cont	A	08 Apr 54		305	1.524	464.82	
1954	Kambeni	1	Cont	B	08 Apr 54		305	1.524	464.82	
1954	Kambeni	2	Dec2	A	08 Apr 54		305	1.524	464.82	
1954	Kambeni	2	Dec2	B	08 Apr 54		299	1.524	455.676	Telephone road through plot (6m)
1954	Kambeni	3	Oct2	A	16 Nov 54		305	1.524	464.82	
1954	Kambeni	3	Oct2	B	16 Nov 54		305	1.524	464.82	
1954	Kambeni	4	Feb2	A	08 Apr 54		305	1.524	464.82	Not sure of the survey date.
1954	Kambeni	4	Feb2	B	08 Apr 54		305	1.524	464.82	Not sure of the survey date.
1954	Kambeni	5	Aug2	A	08 Apr 54		305	1.524	464.82	
1954	Kambeni	5	Aug2	B	08 Apr 54		305	1.524	464.82	
1954	Kambeni	6	Apr2	A	08 Apr 54		305	1.524	464.82	
1954	Kambeni	6	Apr2	B	08 Apr 54		275	1.524	419.1	Rock outcrop (30m)
1954	Kambeni	7	Aug1	A	08 Apr 54		305	1.524	464.82	
1954	Kambeni	7	Aug1	B	08 Apr 54		305	1.524	464.82	
1954	Kambeni	8	Feb3	A	21 Nov 57		305	1.524	464.82	
1954	Kambeni	8	Feb3	B	21 Nov 57		305	1.524	464.82	
1954	Kambeni	9	Oct3	A	07 Oct 58		305	1.524	464.82	
1954	Kambeni	9	Oct3	B	07 Oct 58		297	1.524	452.628	Road through plot (7.6m)
1954	Kambeni	10	Dec3	A	26 Nov 58		288	1.524	438.912	Into road (17m)
1954	Kambeni	10	Dec3	B	26 Nov 58		305	1.524	464.82	
1954	Kambeni	11	Aug3	A	28 Jul 58		305	1.524	464.82	
1954	Kambeni	11	Aug3	B	28 Jul 58		305	1.524	464.82	
1954	Kambeni	12	Apr3	A	26 Mar 58		305	1.524	464.82	
1954	Kambeni	12	Apr3	B	26 Mar 58		292	1.524	445.008	Into road (12.8m)
1954	Numbi	1	Oct2	A	07 Apr 54		305	1.524	464.82	
1954	Numbi	1	Oct2	B	07 Apr 54		305	1.524	464.82	
1954	Numbi	2	Dec2	A	07 Apr 54		305	1.524	464.82	
1954	Numbi	2	Dec2	B	07 Apr 54		305	1.524	464.82	
1954	Numbi	3	Feb2	A	07 Apr 54		305	1.524	464.82	
1954	Numbi	3	Feb2	B	07 Apr 54		305	1.524	464.82	
1954	Numbi	4	Aug2	A	07 Apr 54		305	1.524	464.82	
1954	Numbi	4	Aug2	B	07 Apr 54		305	1.524	464.82	
1954	Numbi	5	Apr2	A	07 Apr 54		305	1.524	464.82	
1954	Numbi	5	Apr2	B	07 Apr 54		305	1.524	464.82	
1954	Numbi	6	Aug1	A	07 Apr 54		305	1.524	464.82	
1954	Numbi	6	Aug1	B	07 Apr 54		305	1.524	464.82	
1954	Numbi	7	Cont	A	07 Apr 54		305	1.524	464.82	
1954	Numbi	7	Cont	B	07 Apr 54		305	1.524	464.82	
1954	Numbi	8	Dec3	A	26 Nov 58		305	1.524	464.82	

WITS ETD

Year	Replicate	Plot	Treatment Code	Transect	Date	Direction	Length (m)	Width (m)	Area (m^2)	Comments
1954	Numbi	8	Dec3	B	26 Nov 58		305	1.524	464.82	
1954	Numbi	9	Oct3	A	07 Oct 58		305	1.524	464.82	
1954	Numbi	9	Oct3	B	07 Oct 58		305	1.524	464.82	
1954	Numbi	10	Feb3	A	22 Nov 57		305	1.524	464.82	
1954	Numbi	10	Feb3	B	22 Nov 57		305	1.524	464.82	
1954	Numbi	11	Apr3	A	27 Mar 58		305	1.524	464.82	
1954	Numbi	11	Apr3	B	27 Mar 58		305	1.524	464.82	
1954	Numbi	12	Aug3	A	31 Jul 58		305	1.524	464.82	
1954	Numbi	12	Aug3	B	31 Jul 58		281	1.524	428.244	Into road (24m)
1954	Shabeni	1	Aug2	A	09 Apr 54		305	1.524	464.82	Not sure of the survey date.
1954	Shabeni	1	Aug2	B	09 Apr 54		305	1.524	464.82	Not sure of the survey date.
1954	Shabeni	2	Apr2	A	09 Apr 54		305	1.524	464.82	
1954	Shabeni	2	Apr2	B	09 Apr 54		305	1.524	464.82	
1954	Shabeni	3	Aug1	A	09 Apr 54		305	1.524	464.82	
1954	Shabeni	3	Aug1	B	09 Apr 54		305	1.524	464.82	
1954	Shabeni	4	Feb2	A	15 Apr 54		305	1.524	464.82	
1954	Shabeni	4	Feb2	B	15 Apr 54		305	1.524	464.82	
1954	Shabeni	5	Oct2	A	15 Apr 54		305	1.524	464.82	
1954	Shabeni	5	Oct2	B	15 Apr 54		284	1.524	432.816	Into road (13 m)
1954	Shabeni	6	Dec2	A	15 Apr 54		305	1.524	464.82	
1954	Shabeni	6	Dec2	B	15 Apr 54		305	1.524	464.82	
1954	Shabeni	7	Cont	A	15 Apr 54		305	1.524	464.82	
1954	Shabeni	7	Cont	B	15 Apr 54		305	1.524	464.82	
1954	Shabeni	8	Dec3	A	26 Nov 58		305	1.524	464.82	
1954	Shabeni	8	Dec3	B	26 Nov 58		305	1.524	464.82	
1954	Shabeni	9	Apr3	A	27 Mar 58		305	1.524	464.82	
1954	Shabeni	9	Apr3	B	27 Mar 58		305	1.524	464.82	
1954	Shabeni	10	Aug3	A	28 Jul 58		305	1.524	464.82	
1954	Shabeni	10	Aug3	B	28 Jul 58		305	1.524	464.82	
1954	Shabeni	11	Oct3	A	08 Oct 58		305	1.524	464.82	
1954	Shabeni	11	Oct3	B	08 Oct 58		305	1.524	464.82	
1954	Shabeni	12	Feb3	A	21 Nov 57		305	1.524	464.82	
1954	Shabeni	12	Feb3	B	21 Nov 57		299	1.524	455.676	Into road (6m)
1959	Fayi	2	Cont	A	10 Mar 59		305	1.524	464.82	
1959	Fayi	2	Cont	B	10 Mar 59		305	1.524	464.82	
1959	Kambeni	1	Cont	A	10 Mar 59		305	1.524	464.82	
1959	Kambeni	1	Cont	B	10 Mar 59		305	1.524	464.82	
1959	Numbi	7	Cont	A	13 Mar 59		305	1.524	464.82	
1959	Numbi	7	Cont	B	13 Mar 59		305	1.524	464.82	
1959	Shabeni	7	Cont	A	13 Mar 59		305	1.524	464.82	
1959	Shabeni	7	Cont	B	13 Mar 59		305	1.524	464.82	
1996	Fayi	1	Aug2	A	31 Jul 96	SSW	300	2	600	
1996	Fayi	1	Aug2	B	06 Aug 96	NW	300	2	600	
1996	Fayi	2	Cont	A	22 Sep 97	SW	300	2	600	
1996	Fayi	2	Cont	B	23 Sep 97	NW	300	2	600	
1996	Fayi	3	Dec2	A	04 Dec 96	SE	300	2	600	
1996	Fayi	3	Dec2	B	04 Dec 96	NE	296	2	592	Into road (4m)
1996	Fayi	4	Oct2	A	05 Sep 96	SW	300	2	600	
1996	Fayi	4	Oct2	B	05 Sep 96	SE	300	2	600	
1996	Fayi	5	Apr2	A	27 May 97	SW	300	2	600	
1996	Fayi	5	Apr2	B	28 May 97	NW	300	2	600	
1996	Fayi	6	Feb2	A	11 Dec 96	NW	300	2	600	

WiSER

Year	Replicate	Plot	Treatment Code	Transect	Date	Direction	Length (m)	Width (m)	Area (m^2)	Comments
1996	Fayi	6	Feb2	B	12 Dec 96	NE	300	2	600	
1996	Fayi	7	Aug1	A	06 Aug 96	N	300	2	600	
1996	Fayi	7	Aug1	B	07 Aug 96	SW	300	2	600	
1996	Fayi	8	Dec3	A	29 Aug 97	SW	300	2	600	
1996	Fayi	8	Dec3	B	09 Sep 97	NW	300	2	600	
1996	Fayi	9	Aug3	A	21 Aug 97	SW	300	2	600	
1996	Fayi	9	Aug3	B	22 Aug 97	NW	300	2	600	
1996	Fayi	10	Oct3	A	24 Sep 97	SW	290	2	580	Into road (10m)
1996	Fayi	10	Oct3	B	24 Sep 97	NW	300	2	600	
1996	Fayi	11	Feb3	A	29 Jan 97	NE	300	2	600	
1996	Fayi	11	Feb3	B	30 Jan 97	SE	300	2	600	
1996	Fayi	12	Apr3	A	26 May 97	NE	300	2	600	
1996	Fayi	12	Apr3	B	27 May 97	SE	300	2	600	
1996	Kambeni	1	Cont	A	19 Sep 97	SW	300	2	600	
1996	Kambeni	1	Cont	B	19 Sep 97	NW	300	2	600	
1996	Kambeni	2	Dec2	A	09 Dec 96	SE	300	2	600	
1996	Kambeni	2	Dec2	B	09 Dec 96	NE	294	2	588	Telephone road through plot (6m)
1996	Kambeni	3	Oct2	A	29 Aug 96	NW	300	2	600	
1996	Kambeni	3	Oct2	B	03 Sep 96	SW	300	2	600	
1996	Kambeni	4	Feb2	A	17 Dec 96	ENE	300	2	600	
1996	Kambeni	4	Feb2	B	22 Jan 97	NW	300	2	600	
1996	Kambeni	5	Aug2	A	19 Jul 96	WNW	300	2	600	
1996	Kambeni	5	Aug2	B	23 Jul 96	SW	300	2	600	
1996	Kambeni	6	Apr2	A	21 May 97	WSW	300	2	600	Excavations for road in segment A6 (30m)
1996	Kambeni	6	Apr2	B	22 May 97	NE	270	2	540	Rock outcrop through segments B2 (11.4m), B3 (17.2m), B4 (1.5m)
1996	Kambeni	7	Aug1	A	14 Aug 96	NW	300	2	600	
1996	Kambeni	7	Aug1	B	14 Aug 96	NE	300	2	600	
1996	Kambeni	8	Feb3	A	23 Jan 97	SE	300	2	600	
1996	Kambeni	8	Feb3	B	24 Jan 97	NE	300	2	600	
1996	Kambeni	9	Oct3	A	26 Aug 97	NW	300	2	600	
1996	Kambeni	9	Oct3	B	27 Aug 97	NE	292	2	584	Road through plot (7.6m)
1996	Kambeni	10	Dec3	A	25 Aug 97	NE	283	2	566	Into road (17m)
1996	Kambeni	10	Dec3	B	26 Aug 97	NW	300	2	600	
1996	Kambeni	11	Aug3	A	20 Aug 97	WNW	300	2	600	
1996	Kambeni	11	Aug3	B	20 Aug 97	NE	300	2	600	
1996	Kambeni	12	Apr3	A	22 May 97	WNW	300	2	600	
1996	Kambeni	12	Apr3	B	23 May 97	SW	287	2	574	Into road (12.8m)
1996	Numbi	1	Oct2	A	27 Aug 96	NNE	300	2	600	
1996	Numbi	1	Oct2	B	27 Aug 96	NW	300	2	600	
1996	Numbi	2	Dec2	A	26 Nov 96	SE	300	2	600	
1996	Numbi	2	Dec2	B	26 Nov 96	NE	300	2	600	
1996	Numbi	3	Feb2	A	23 Jun 97	SSE	300	2	600	
1996	Numbi	3	Feb2	B	24 Jun 97	NE	300	2	600	
1996	Numbi	4	Aug2	A	26 Aug 96	SSE	300	2	600	
1996	Numbi	4	Aug2	B	26 Aug 96	SW	300	2	600	
1996	Numbi	5	Apr2	A	04 Jun 97	NE	300	2	600	
1996	Numbi	5	Apr2	B	05 Jun 97	SE	300	2	600	
1996	Numbi	6	Aug1	A	22 Aug 96	SE	300	2	600	
1996	Numbi	6	Aug1	B	23 Aug 96	SW	300	2	600	

WITS ETD

Year	Replicate	Plot	Treatment Code	Transect	Date	Direction	Length (m)	Width (m)	Area (m^2)	Comments
1996	Numbi	7	Cont	A	11 Sep 97	NE	300	2	600	
1996	Numbi	7	Cont	B	15 Sep 97	SE	300	2	600	
1996	Numbi	8	Dec3	A	12 Jun 97	NW	300	2	600	
1996	Numbi	8	Dec3	B	12 Jun 97	SW	300	2	600	
1996	Numbi	9	Oct3	A	11 Jun 97	NW	300	2	600	
1996	Numbi	9	Oct3	B	11 Jun 97	SW	300	2	600	
1996	Numbi	10	Feb3	A	28 Jan 97	SW	300	2	600	
1996	Numbi	10	Feb3	B	29 Jan 97	NW	300	2	600	
1996	Numbi	11	Apr3	A	03 Jun 97	NW	300	2	600	
1996	Numbi	11	Apr3	B	04 Jun 97	NE	300	2	600	
1996	Numbi	12	Aug3	A	10 Jun 97	NW	300	2	600	
1996	Numbi	12	Aug3	B	10 Jun 97	SW	276	2	552	Into road (24m)
1996	Shabeni	1	Aug2	A	15 Aug 96	SSW	300	2	600	
1996	Shabeni	1	Aug2	B	19 Aug 96	SE	300	2	600	
1996	Shabeni	2	Apr2	A	29 May 97	NE	300	2	600	
1996	Shabeni	2	Apr2	B	29 May 97	SE	300	2	600	
1996	Shabeni	3	Aug1	A	19 Aug 96		300	2	600	
1996	Shabeni	3	Aug1	B	21 Aug 96		300	2	600	
1996	Shabeni	4	Feb2	A	11 Feb 97	NE	300	2	600	
1996	Shabeni	4	Feb2	B	24 Jun 97	SE	300	2	600	Surveyed from 24 Jun 97 to 18 Aug 97 (segments 2 - 6 were surveyed after the fire treatment)
1996	Shabeni	5	Oct2	A	03 Sep 96	NE	300	2	600	
1996	Shabeni	5	Oct2	B	04 Sep 96	SE	279	2	558	Into road (13 m)
1996	Shabeni	6	Dec2	A	27 Nov 96	NE	300	2	600	
1996	Shabeni	6	Dec2	B	28 Nov 96	NW	300	2	600	
1996	Shabeni	7	Cont	A	18 Sep 97	NNE	300	2	600	
1996	Shabeni	7	Cont	B	18 Sep 97	SE	300	2	600	
1996	Shabeni	8	Dec3	A	27 Jun 97	SE	300	2	600	
1996	Shabeni	8	Dec3	B	28 Aug 97	NE	300	2	600	
1996	Shabeni	9	Apr3	A	02 Jun 97	SE	300	2	600	
1996	Shabeni	9	Apr3	B	03 Jun 97	NE	300	2	600	
1996	Shabeni	10	Aug3	A	19 Aug 97	NE	300	2	600	
1996	Shabeni	10	Aug3	B	19 Aug 97	SE	300	2	600	
1996	Shabeni	11	Oct3	A	28 Aug 97	SE	300	2	600	
1996	Shabeni	11	Oct3	B	28 Aug 97	NE	300	2	600	
1996	Shabeni	12	Feb3	A	27 Jan 97	EEN	300	2	600	
1996	Shabeni	12	Feb3	B	28 Jan 97	SSW	294	2	588	Into road (6m)

WITS ETD

12 APPENDIX 4: VEGETATION INDICES CALCULATED TO SUMMARISE THE STRUCTURE AND COMPOSITION OF THE WOODY VEGETATION ON THE PRETORIUSKOP EXPERIMENTAL BURN PLOTS

Table 12-1: Summary of the vegetation indices calculated from the data collected in the 1954 baseline survey.

						Taxonomic diversity				Structural diversity			
Replicate	Treatment	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single-stem to Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Fayi	Aug2	2381	1.277	1830	0.900	18	0.369	1.830	0.633	17	0.348	1.707	0.602
	Con0	1661	1.208	1229	0.805	19	0.466	2.239	0.760	16	0.393	1.816	0.655
	Dec2	2936	1.072	2318	0.900	22	0.406	2.319	0.750	17	0.314	1.719	0.607
	Oct2	2262	1.237	1869	0.866	22	0.463	2.322	0.751	18	0.379	1.848	0.639
	Apr2	2348	1.179	1984	0.825	16	0.330	1.778	0.641	19	0.392	1.974	0.670
	Feb2	3166	1.071	1939	0.922	19	0.338	2.068	0.702	17	0.302	1.313	0.463
	Aug1	2690	1.222	2501	0.752	15	0.289	1.878	0.694	21	0.405	2.151	0.707
	Dec3	1972	1.668	1752	0.388	20	0.450	1.610	0.537	18	0.405	2.044	0.707
	Aug3	1982	0.921	1536	0.429	13	0.292	1.503	0.586	11	0.247	1.728	0.721
	Oct3	833	1.192	823	0.395	18	0.624	2.080	0.720	14	0.485	2.037	0.772
	Feb3	3832	0.939	3079	0.343	18	0.291	1.601	0.554	18	0.291	1.791	0.619
	Apr3	2004	0.909	1616	0.301	19	0.424	1.900	0.645	16	0.358	1.790	0.645
Kambeni	Con0	830	1.370	849	0.624	12	0.417	1.839	0.740	13	0.451	2.200	0.858
	Dec2	990	0.906	562	0.759	15	0.477	2.144	0.792	11	0.350	1.421	0.592
	Oct2	2188	1.254	1668	0.207	21	0.449	2.155	0.708	17	0.364	1.667	0.588
	Feb2	1412	0.953	1114	0.336	12	0.319	1.160	0.467	12	0.319	1.679	0.676
	Aug2	1561	1.047	1370	0.366	9	0.228	1.157	0.527	15	0.380	1.989	0.734
	Apr2	1503	1.147	1252	0.714	15	0.387	1.740	0.643	14	0.361	1.882	0.713
	Aug1	2336	0.914	1840	0.580	14	0.290	1.326	0.502	18	0.372	1.929	0.667
	Feb3	1413	0.993	1096	0.343	16	0.426	2.042	0.737	15	0.399	1.797	0.664
	Oct3	1333	0.923	1014	0.148	22	0.603	2.532	0.819	18	0.494	1.715	0.593
	Dec3	2931	0.932	2705	0.132	16	0.296	1.256	0.453	17	0.314	1.481	0.523
	Aug3	3337	0.867	2597	0.281	26	0.450	2.322	0.713	17	0.294	1.769	0.624
	Apr3	2320	0.914	1651	0.284	24	0.498	2.346	0.738	13	0.270	1.578	0.615
Numbi	Oct2	2141	0.991	1496	0.790	16	0.346	2.004	0.723	18	0.389	1.668	0.577
	Dec2	1658	1.224	1113	0.812	13	0.319	2.047	0.798	16	0.393	1.622	0.585
	Feb2	401	1.639	398	0.783	11	0.549	1.946	0.812	9	0.451	1.642	0.747
	Aug2	2617	1.024	1761	0.765	24	0.469	2.682	0.844	16	0.313	1.869	0.674
	Apr2	2348	1.398	1998	0.785	17	0.351	2.129	0.752	18	0.372	1.933	0.669
	Aug1	2220	0.909	1329	0.830	21	0.446	2.244	0.737	16	0.340	1.561	0.563
	Con0	1897	0.773	1361	0.880	17	0.390	1.987	0.701	19	0.436	1.582	0.537
	Dec3	2177	1.159	1514	0.437	27	0.579	2.537	0.770	13	0.279	1.605	0.626
	Oct3	2067	1.274	1624	0.330	33	0.726	2.880	0.824	16	0.352	1.817	0.655
	Feb3	2809	1.326	2176	0.165	19	0.358	1.919	0.652	14	0.264	1.448	0.549
	Apr3	1650	1.050	1150	0.321	31	0.763	2.828	0.823	14	0.345	1.837	0.696
	Aug3	1880	0.834	1061	0.523	17	0.392	2.247	0.793	8	0.184	1.476	0.710

WITS

Table 12-1 continued.

						Taxonomic diversity				Structural diversity			
Replicate	Treatment	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single-stem to Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Shabeni	Aug2	3175	0.629	2113	0.658	14	0.248	1.293	0.490	18	0.319	1.626	0.563
	Apr2	2822	0.934	1776	0.496	21	0.395	2.225	0.731	15	0.282	1.641	0.606
	Aug1	2058	1.277	1749	0.671	22	0.485	2.326	0.753	18	0.397	1.948	0.674
	Feb2	4648	1.452	3431	0.368	27	0.396	2.544	0.772	20	0.293	1.764	0.589
	Oct2	2572	0.795	1450	0.657	23	0.454	2.449	0.781	15	0.296	1.500	0.554
	Dec2	1069	0.842	627	0.626	15	0.459	1.772	0.654	10	0.306	1.456	0.632
	Con0	2498	1.113	1822	0.643	21	0.420	2.151	0.707	19	0.380	1.803	0.612
	Dec3	2102	0.908	1323	0.349	25	0.545	2.223	0.691	10	0.218	1.380	0.599
	Apr3	1465	1.000	902	0.449	24	0.627	2.435	0.766	10	0.261	1.556	0.676
	Aug3	895	0.905	683	0.397	9	0.301	1.587	0.722	10	0.334	1.659	0.720
	Oct3	1035	0.958	813	0.313	15	0.466	2.115	0.781	12	0.373	1.629	0.656
	Feb3	2109	1.095	1579	0.304	28	0.610	2.299	0.690	17	0.370	1.799	0.635

Table 12-2: Summary of the vegetation indices calculated from the data collected in the 1959 survey on the No burn plots.

						Taxonomic diversity				Structural diversity			
Replicate	Treatment	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Fayi	Con0	2263	0.802	1986	0.529	21	0.441	2.144	0.704	22	0.463	2.183	0.706
Kambeni	Con0	1129	0.783	738	0.573	12	0.357	1.856	0.747	9	0.268	1.656	0.754
Numbi	Con0	3350	0.800	1853	0.479	28	0.484	2.655	0.797	11	0.190	1.466	0.611
Shabeni	Con0	2844	0.785	2024	0.610	19	0.356	1.577	0.536	15	0.281	1.755	0.648

WISER

Table 12-3: Summary of the vegetation indices calculated from the data collected in the 1996 survey.

						Taxonomic diversity				Structural diversity			
Replicate	Treatment	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Fayi	Aug2	6805	1.25	4958	0.133	22	0.267	1.605	0.519	21	0.255	1.516	0.498
	Con0	9565	1.185	7137	0.384	30	0.307	2.109	0.62	22	0.225	1.729	0.559
	Dec2	7739	0.981	4962	0.29	35	0.398	2.12	0.596	21	0.239	1.541	0.506
	Oct2	6406	1.101	5084	0.318	29	0.362	2.137	0.635	19	0.237	1.789	0.607
	Apr2	6484	1.347	5235	0.414	26	0.323	1.825	0.56	23	0.286	1.778	0.567
	Feb2	6291	0.759	3200	0.388	30	0.378	2.595	0.763	23	0.29	1.447	0.462
	Aug1	5698	0.891	2602	0.12	27	0.358	1.963	0.596	17	0.225	1.127	0.398
	Dec3	6707	1.491	4981	0.405	35	0.427	2.14	0.602	23	0.281	1.854	0.591
	Aug3	6018	1.196	5932	0.129	27	0.348	1.632	0.495	16	0.206	1.545	0.557
	Oct3	4133	0.93	3950	0.348	14	0.218	1.606	0.609	15	0.233	1.735	0.641
	Feb3	6371	0.959	3974	0.463	31	0.388	1.848	0.538	22	0.276	1.699	0.55
	Apr3	6555	0.912	5179	0.338	31	0.383	1.908	0.556	21	0.259	1.7	0.558
Kambeni	Con0	4983	1.244	4653	0.572	32	0.453	2.64	0.762	19	0.269	2.055	0.698
	Dec2	5958	0.93	3586	0.445	28	0.363	1.755	0.527	14	0.181	1.497	0.567
	Oct2	2655	1.236	2602	0.223	21	0.408	1.868	0.614	15	0.291	1.768	0.653
	Feb2	10409	0.832	7918	0.344	30	0.294	1.938	0.57	22	0.216	1.645	0.532
	Aug2	5548	1.282	6016	0.065	28	0.376	1.481	0.444	19	0.255	1.282	0.435
	Apr2	6469	1.007	5672	0.364	30	0.373	1.729	0.508	19	0.236	1.693	0.575
	Aug1	6515	1.019	4795	0.098	29	0.359	1.848	0.549	19	0.235	1.433	0.487
	Feb3	6208	0.888	3857	0.452	27	0.343	2.127	0.645	18	0.228	1.618	0.56
	Oct3	5893	1.574	5814	0.219	27	0.352	2.011	0.61	15	0.195	1.599	0.59
	Dec3	7157	1.33	6739	0.432	27	0.319	1.772	0.538	24	0.284	1.96	0.617
	Aug3	7381	1.114	7359	0.235	35	0.407	2.229	0.627	21	0.244	1.73	0.568
	Apr3	6196	0.881	5113	0.373	30	0.381	1.952	0.574	16	0.203	1.638	0.591
Numbi	Oct2	3917	1.256	2670	0.332	30	0.479	2.624	0.771	20	0.32	1.716	0.573
	Dec2	5201	0.867	3413	0.331	31	0.43	2.085	0.607	18	0.25	1.619	0.56
	Feb2	3401	0.879	1835	0.245	34	0.583	2.37	0.672	16	0.274	1.328	0.479
	Aug2	5951	0.818	3158	0.151	26	0.337	2.238	0.687	14	0.181	1.319	0.5
	Apr2	5500	0.858	4192	0.323	23	0.31	1.895	0.604	15	0.202	1.553	0.573
	Aug1	7381	0.64	2711	0.095	26	0.303	2.164	0.664	15	0.175	0.912	0.337
	Con0	14163	1.209	10323	0.587	44	0.37	2.725	0.72	22	0.185	1.807	0.585
	Dec3	3489	0.901	2255	0.482	35	0.593	2.849	0.801	16	0.271	1.694	0.611
	Oct3	6788	1.044	4366	0.362	37	0.449	2.618	0.725	19	0.231	1.593	0.541
	Feb3	5803	0.9	4460	0.385	30	0.394	2.26	0.665	21	0.276	1.75	0.575
	Apr3	7465	0.834	4012	0.331	47	0.544	2.646	0.687	19	0.22	1.441	0.489
	Aug3	3889	0.892	2032	0.429	19	0.305	2.082	0.707	12	0.192	1.322	0.532
Shabeni	Aug2	2963	1.183	2268	0.27	29	0.533	2.244	0.667	15	0.275	1.643	0.607
	Apr2	2550	0.954	1551	0.385	19	0.376	1.972	0.67	12	0.238	1.461	0.588
	Aug1	4622	0.886	2098	0.193	28	0.412	2.415	0.725	17	0.25	1.178	0.416
	Feb2	11649	0.914	5922	0.363	37	0.343	2.595	0.719	19	0.176	1.399	0.475
	Oct2	9008	0.922	4661	0.257	26	0.274	2.215	0.68	15	0.158	1.362	0.503
	Dec2	7185	0.882	3285	0.424	40	0.472	2.664	0.722	17	0.201	1.447	0.511
	Con0	6073	1.17	5740	0.613	44	0.565	2.453	0.648	21	0.269	2.081	0.683
	Dec3	2298	1.072	1725	0.232	28	0.584	2.322	0.697	14	0.292	1.542	0.584
	Apr3	4406	1.035	3040	0.384	29	0.437	2.006	0.596	19	0.286	1.657	0.563
	Aug3	3581	1.2	3531	0.179	24	0.401	1.722	0.542	17	0.284	1.612	0.569
	Oct3	3191	1.195	2794	0.247	25	0.443	2.022	0.628	14	0.248	1.599	0.606
	Feb3	3990	1.122	2363	0.426	31	0.491	2.437	0.71	17	0.269	1.551	0.547

WITHDRAWN

13 APPENDIX 5: DESCRIPTIVE STATISTICAL SUMMARY OF THE DATA USED IN THE ANOVA AND ANCOVA ANALYSES

Table 13-1: Summary of data collected on the Pretoriuskop EBPs in 1954 and 1996. This data was used to test for changes in the woody vegetation structure and composition on the Pretoriuskop EBPs between 1954 and 1996.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
1954	N	48	48	48	48	48	48	48	48	48	48	48	48
	Min	401	0.629	398	0.132	9	0.228	1.157	0.453	8	0.184	1.313	0.463
	Max	4648	1.668	3431	0.922	33	0.763	2.880	0.844	21	0.494	2.200	0.858
	Mean	2094.458	1.076	1571.729	0.541	18.979	0.431	2.042	0.700	15.271	0.347	1.726	0.641
	SD	817.070	0.217	637.720	0.237	5.444	0.119	0.413	0.099	3.167	0.065	0.199	0.071
1996	N	48	48	48	48	48	48	48	48	48	48	48	48
	Min	2298	0.640	1551	0.065	14	0.218	1.481	0.444	12	0.158	0.912	0.337
	Max	14163	1.574	10323	0.613	47	0.593	2.849	0.801	24	0.320	2.081	0.698
	Mean	6012.667	1.041	4285.896	0.324	29.646	0.396	2.135	0.633	18.083	0.241	1.582	0.549
	SD	2309.038	0.196	1816.365	0.129	6.323	0.086	0.340	0.081	3.134	0.039	0.223	0.069

WitsETD

Table 13-2: Summary of data collected on the Pretoriuskop replicates (Fayi, Kambeni, Numbi, and Shabeni) in 1954. This data was used to test for differences between the EBP replicates in the Pretoriuskop region in 1954.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Fayi	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	833	0.901	872	0.301	13	0.289	1.503	0.537	11	0.247	1.313	0.463
	Max	3832	1.743	3179	0.922	22	0.624	2.322	0.760	21	0.485	2.151	0.772
	Mean	2338.917	1.160	1893.167	0.652	18.250	0.395	1.927	0.665	16.833	0.360	1.826	0.651
	SD	768.851	0.228	600.314	0.254	2.633	0.099	0.281	0.077	2.517	0.064	0.218	0.078
Kambeni	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	830	0.872	545	0.132	9	0.228	1.157	0.453	11	0.270	1.421	0.523
	Max	3337	1.476	2819	0.759	26	0.603	2.532	0.819	18	0.494	2.200	0.858
	Mean	1846.167	1.041	1521.000	0.398	16.833	0.403	1.835	0.653	15.000	0.364	1.759	0.654
	SD	773.712	0.216	683.800	0.217	5.254	0.105	0.499	0.131	2.412	0.064	0.220	0.087
Numbi	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	401	0.737	444	0.165	11	0.319	1.919	0.652	8	0.184	1.448	0.537
	Max	2809	2.133	2264	0.880	33	0.763	2.880	0.844	19	0.451	1.933	0.747
	Mean	1988.750	1.215	1449.500	0.618	20.500	0.474	2.287	0.769	14.750	0.343	1.672	0.632
	SD	609.033	0.432	500.376	0.248	6.922	0.150	0.353	0.058	3.415	0.075	0.157	0.069
Shabeni	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	895	0.603	629	0.304	9	0.248	1.293	0.490	10	0.218	1.380	0.554
	Max	4648	1.721	3520	0.671	28	0.627	2.544	0.781	20	0.397	1.948	0.720
	Mean	2204.000	1.045	1555.583	0.494	20.333	0.451	2.118	0.711	14.500	0.319	1.647	0.626
	SD	1064.933	0.317	799.236	0.148	5.836	0.112	0.378	0.081	3.920	0.054	0.162	0.049

WitsETD

Table 13-3: Summary of data collected on the Pretoriuskop replicates (Fayi, Kambeni, Numbi, and Shabeni) in 1996. This data was used to test for differences between the EBP replicates in the Pretoriuskop region in 1996.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Fayi	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	4133	0.759	2602	0.120	14	0.218	1.605	0.495	15	0.206	1.127	0.398
	Max	9565	1.491	7137	0.463	35	0.427	2.595	0.763	23	0.290	1.854	0.641
	Mean	6564.333	1.084	4766.167	0.311	28.083	0.346	1.957	0.591	20.250	0.251	1.622	0.541
	SD	1263.696	0.215	1206.902	0.120	5.744	0.059	0.287	0.069	2.832	0.027	0.200	0.066
Kambeni	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	2655	0.832	2602	0.065	21	0.294	1.481	0.444	14	0.181	1.282	0.435
	Max	10409	1.574	7918	0.572	35	0.453	2.640	0.762	24	0.291	2.055	0.698
	Mean	6281.000	1.111	5343.667	0.318	28.667	0.369	1.946	0.581	18.417	0.237	1.660	0.573
	SD	1777.262	0.225	1568.564	0.152	3.367	0.042	0.293	0.080	3.029	0.034	0.211	0.069
Numbi	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	3401	0.640	1835	0.095	19	0.303	1.895	0.604	12	0.175	0.912	0.337
	Max	14163	1.256	10323	0.587	47	0.593	2.849	0.801	22	0.320	1.807	0.611
	Mean	6079.000	0.925	3785.583	0.338	31.833	0.425	2.380	0.693	17.250	0.231	1.504	0.530
	SD	2923.552	0.170	2254.297	0.134	8.189	0.107	0.304	0.058	3.049	0.047	0.254	0.073
Shabeni	N	12	12	12	12	12	12	12	12	12	12	12	12
	Min	2298	0.882	1551	0.179	19	0.274	1.722	0.542	12	0.158	1.178	0.416
	Max	11649	1.200	5922	0.613	44	0.584	2.664	0.725	21	0.292	2.081	0.683
	Mean	5126.333	1.045	3248.167	0.331	30.000	0.444	2.256	0.667	16.417	0.246	1.544	0.554
	SD	2864.546	0.128	1475.657	0.125	7.097	0.091	0.281	0.056	2.539	0.045	0.218	0.070

WitsETD

Table 13-4: Summary of data collected on the Pretoriuskop EBPs to be burnt at different frequencies in 1954 excluding the August annual treatment. This data was used to test for pre-treatment differences between the plots to be burnt at different frequencies in 1954.

						Taxonomic diversity				Structural diversity			
Frequency	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
None	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	830	0.773	849	0.624	12	0.390	1.839	0.701	13	0.380	1.582	0.537
	Max	2498	1.370	1822	0.880	21	0.466	2.239	0.760	19	0.451	2.200	0.858
	Mean	1721.500	1.116	1315.250	0.738	17.250	0.423	2.054	0.727	16.750	0.415	1.850	0.666
	SD	690.938	0.252	401.546	0.125	3.862	0.032	0.178	0.028	2.872	0.034	0.256	0.137
Biennial	N	20	20	20	20	20	20	20	20	20	20	20	20
	Min	401	0.629	398	0.207	9	0.228	1.157	0.467	9	0.282	1.313	0.463
	Max	4648	1.639	3431	0.922	27	0.549	2.682	0.844	20	0.451	1.989	0.747
	Mean	2209.900	1.104	1603.450	0.677	17.500	0.388	1.988	0.698	15.600	0.346	1.696	0.624
	SD	945.569	0.240	683.961	0.212	4.763	0.081	0.423	0.106	3.033	0.044	0.185	0.068
Triennial	N	20	20	20	20	20	20	20	20	20	20	20	20
	Min	833	0.834	683	0.132	9	0.291	1.256	0.453	8	0.184	1.380	0.523
	Max	3832	1.668	3079	0.523	33	0.763	2.880	0.824	18	0.494	2.044	0.772
	Mean	2007.300	1.038	1534.700	0.332	21.000	0.486	2.113	0.701	14.050	0.327	1.697	0.650
	SD	779.754	0.202	665.139	0.100	6.181	0.144	0.442	0.103	3.103	0.081	0.181	0.061

Table 13-5: Summary of data collected on the Pretoriuskop EBPs burnt at different frequencies in 1996 excluding the August annual treatment. This data was used to test for the treatment effects on the plots burnt at different frequencies between 1954 and 1996.

						Taxonomic diversity				Structural diversity			
Frequency	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
None	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4983	1.170	4653	0.384	30	0.307	2.109	0.620	19	0.185	1.729	0.559
	Max	14163	1.244	10323	0.613	44	0.565	2.725	0.762	22	0.269	2.081	0.698
	Mean	8696.000	1.202	6963.250	0.539	37.500	0.424	2.482	0.688	21.000	0.237	1.918	0.631
	SD	4135.607	0.032	2459.790	0.105	7.550	0.112	0.273	0.065	1.414	0.041	0.176	0.070
Biennial	N	20	20	20	20	20	20	20	20	20	20	20	20
	Min	2550	0.759	1551	0.065	19	0.267	1.481	0.444	12	0.158	1.282	0.435
	Max	11649	1.347	7918	0.445	40	0.583	2.664	0.771	23	0.320	1.789	0.653
	Mean	6104.450	1.013	4109.400	0.303	28.700	0.384	2.098	0.627	17.850	0.238	1.540	0.539
	SD	2411.223	0.182	1629.767	0.101	5.283	0.083	0.349	0.088	3.249	0.045	0.161	0.057
Triennial	N	20	20	20	20	20	20	20	20	20	20	20	20
	Min	2298	0.834	1725	0.129	14	0.218	1.606	0.495	12	0.192	1.322	0.489
	Max	7465	1.574	7359	0.482	47	0.593	2.849	0.801	24	0.292	1.960	0.641
	Mean	5375.950	1.074	4173.800	0.342	29.450	0.410	2.109	0.628	17.950	0.249	1.642	0.572
	SD	1582.418	0.208	1564.979	0.102	6.840	0.092	0.340	0.078	3.300	0.033	0.138	0.034

WISER

Table 13-6: Summary of data collected on the No burn, August annual, August biennial, and August triennial treatments. This data was used to test for pre-treatment differences between the plots to be burnt at different frequencies in 1954.

						Taxonomic diversity				Structural diversity			
Fire Frequency (yr)	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
None	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	830	0.773	849	0.624	12	0.390	1.839	0.701	13	0.380	1.582	0.537
	Max	2498	1.370	1822	0.880	21	0.466	2.239	0.760	19	0.451	2.200	0.858
	Mean	1721.500	1.116	1315.250	0.738	17.250	0.423	2.054	0.727	16.750	0.415	1.850	0.666
	SD	690.938	0.252	401.546	0.125	3.862	0.032	0.178	0.028	2.872	0.034	0.256	0.137
Annual	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2058	0.909	1329	0.580	14	0.289	1.326	0.502	16	0.340	1.561	0.563
	Max	2690	1.277	2501	0.830	22	0.485	2.326	0.753	21	0.405	2.151	0.707
	Mean	2326.000	1.081	1854.750	0.708	18.000	0.377	1.944	0.671	18.250	0.378	1.897	0.653
	SD	268.114	0.196	484.924	0.107	4.082	0.103	0.456	0.115	2.062	0.029	0.246	0.062
Biennial	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	1561	0.629	1370	0.366	9	0.228	1.157	0.490	15	0.313	1.626	0.563
	Max	3175	1.277	2113	0.900	24	0.469	2.682	0.844	18	0.380	1.989	0.734
	Mean	2433.500	0.994	1768.500	0.672	16.250	0.329	1.740	0.623	16.500	0.340	1.798	0.643
	SD	670.201	0.269	306.225	0.227	6.344	0.112	0.692	0.159	1.291	0.030	0.162	0.076
Triennial	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	895	0.834	683	0.281	9	0.292	1.503	0.586	8	0.184	1.476	0.624
	Max	3337	0.921	2597	0.523	26	0.450	2.322	0.793	17	0.334	1.769	0.721
	Mean	2023.500	0.882	1469.250	0.408	16.250	0.359	1.915	0.703	11.500	0.265	1.658	0.694
	SD	1003.512	0.039	828.881	0.100	7.274	0.076	0.429	0.086	3.873	0.064	0.130	0.047

WitsETD

Table 13-7: Summary of data collected on the No burn, August annual, August biennial, and August triennial treatments. This data was used to test for the treatment effects on the plots burnt at different frequencies between 1954 and 1996.

						Taxonomic diversity				Structural diversity			
Fire Frequency (yr)	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
None	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4983	1.170	4653	0.384	30	0.307	2.109	0.620	19	0.185	1.729	0.559
	Max	14163	1.244	10323	0.613	44	0.565	2.725	0.762	22	0.269	2.081	0.698
	Mean	8696.000	1.202	6963.250	0.539	37.500	0.424	2.482	0.688	21.000	0.237	1.918	0.631
	SD	4135.607	0.032	2459.790	0.105	7.550	0.112	0.273	0.065	1.414	0.041	0.176	0.070
Annual	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4622	0.640	2098	0.095	26	0.303	1.848	0.549	15	0.175	0.912	0.337
	Max	7381	1.019	4795	0.193	29	0.412	2.415	0.725	19	0.250	1.433	0.487
	Mean	6054.000	0.859	3051.500	0.126	27.500	0.358	2.097	0.633	17.000	0.221	1.162	0.409
	SD	1176.267	0.159	1192.608	0.045	1.291	0.045	0.249	0.077	1.633	0.033	0.214	0.062
Biennial	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2963	0.818	2268	0.065	22	0.267	1.481	0.444	14	0.181	1.282	0.435
	Max	6805	1.282	6016	0.270	29	0.533	2.244	0.687	21	0.275	1.643	0.607
	Mean	5316.750	1.133	4100.000	0.155	26.250	0.378	1.892	0.579	17.250	0.242	1.440	0.510
	SD	1654.366	0.214	1698.117	0.085	3.096	0.113	0.406	0.117	3.304	0.041	0.170	0.071
Triennial	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	3581	0.892	2032	0.129	19	0.305	1.632	0.495	12	0.192	1.322	0.532
	Max	7381	1.200	7359	0.429	35	0.407	2.229	0.707	21	0.284	1.730	0.569
	Mean	5217.250	1.100	4713.500	0.243	26.250	0.365	1.916	0.593	16.500	0.232	1.552	0.557
	SD	1804.123	0.145	2385.523	0.131	6.702	0.048	0.285	0.094	3.697	0.041	0.171	0.017

WitsETD

Table 13-8: Summary of data collected on the Pretoriuskop EBPs burnt at different times of the year excluding the August annual treatment. This data was used to test for pre-treatment differences between the plots to be burnt at different times of the year in 1954.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
February	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	401	0.939	398	0.165	11	0.291	1.160	0.467	9	0.264	1.313	0.463
	Max	4648	1.639	3431	0.922	28	0.610	2.544	0.812	20	0.451	1.799	0.747
	Mean	2473.750	1.184	1851.500	0.446	18.750	0.411	1.947	0.673	15.250	0.336	1.654	0.618
	SD	1406.396	0.259	1029.295	0.261	6.182	0.113	0.421	0.114	3.536	0.064	0.182	0.086
April	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	1465	0.909	902	0.284	15	0.330	1.740	0.641	10	0.261	1.556	0.606
	Max	2822	1.398	1998	0.825	31	0.763	2.828	0.823	19	0.392	1.974	0.713
	Mean	2057.500	1.067	1541.125	0.522	20.875	0.472	2.173	0.717	14.875	0.330	1.774	0.661
	SD	485.444	0.169	400.494	0.223	5.330	0.151	0.368	0.068	2.850	0.051	0.163	0.037
August	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	895	0.629	683	0.281	9	0.228	1.157	0.490	8	0.184	1.476	0.563
	Max	3337	1.277	2597	0.900	26	0.469	2.682	0.844	18	0.380	1.989	0.734
	Mean	2228.500	0.938	1618.875	0.540	16.250	0.344	1.827	0.663	14.000	0.303	1.728	0.669
	SD	819.827	0.188	600.185	0.215	6.319	0.090	0.541	0.126	3.780	0.062	0.155	0.064
October	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	833	0.795	813	0.148	15	0.346	2.004	0.708	12	0.296	1.500	0.554
	Max	2572	1.274	1869	0.866	33	0.726	2.880	0.824	18	0.494	2.037	0.772
	Mean	1803.875	1.078	1344.625	0.463	21.250	0.516	2.317	0.763	16.000	0.391	1.735	0.629
	SD	642.075	0.183	406.314	0.272	5.600	0.123	0.293	0.045	2.204	0.067	0.163	0.069
December	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	990	0.842	562	0.132	13	0.296	1.256	0.453	10	0.218	1.380	0.523
	Max	2936	1.668	2705	0.900	27	0.579	2.537	0.798	18	0.405	2.044	0.707
	Mean	1979.375	1.089	1489.250	0.550	19.125	0.441	1.988	0.681	14.000	0.322	1.591	0.609
	SD	735.410	0.270	756.590	0.266	5.167	0.099	0.417	0.126	3.381	0.061	0.216	0.052
Control	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	830	0.773	849	0.624	12	0.390	1.839	0.701	13	0.380	1.582	0.537
	Max	2498	1.370	1822	0.880	21	0.466	2.239	0.760	19	0.451	2.200	0.858
	Mean	1721.500	1.116	1315.250	0.738	17.250	0.423	2.054	0.727	16.750	0.415	1.850	0.666
	SD	690.938	0.252	401.546	0.125	3.862	0.032	0.178	0.028	2.872	0.034	0.256	0.137

WISER

Table 13-9: Summary of data collected on the Pretoriuskop EBPs burnt at different times of the year excluding the August annual treatment. This data was used to test for the treatment effects on the plots burnt at different times of the year between 1954 and 1996.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
February	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	3401	0.759	1835	0.245	27	0.294	1.848	0.538	16	0.176	1.328	0.462
	Max	11649	1.122	7918	0.463	37	0.583	2.595	0.763	23	0.290	1.750	0.575
	Mean	6765.250	0.907	4191.125	0.383	31.250	0.402	2.271	0.660	19.750	0.251	1.555	0.522
	SD	2872.652	0.106	1963.681	0.070	3.012	0.093	0.282	0.076	2.605	0.040	0.150	0.044
April	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	2550	0.834	1551	0.323	19	0.310	1.729	0.508	12	0.202	1.441	0.489
	Max	7465	1.347	5672	0.414	47	0.544	2.646	0.687	23	0.286	1.778	0.591
	Mean	5703.125	0.978	4249.250	0.364	29.375	0.391	1.991	0.594	18.000	0.241	1.615	0.563
	SD	1555.412	0.165	1384.033	0.031	8.228	0.073	0.279	0.060	3.505	0.033	0.120	0.032
August	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	2963	0.818	2032	0.065	19	0.267	1.481	0.444	12	0.181	1.282	0.435
	Max	7381	1.282	7359	0.429	35	0.533	2.244	0.707	21	0.284	1.730	0.607
	Mean	5267.000	1.117	4406.750	0.199	26.250	0.372	1.904	0.586	16.875	0.237	1.496	0.533
	SD	1603.352	0.170	1944.800	0.113	4.833	0.081	0.325	0.098	3.271	0.039	0.169	0.054
October	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	2655	0.922	2602	0.219	14	0.218	1.606	0.609	14	0.158	1.362	0.503
	Max	9008	1.574	5814	0.362	37	0.479	2.624	0.771	20	0.320	1.789	0.653
	Mean	5248.875	1.157	3992.625	0.288	26.125	0.373	2.137	0.659	16.500	0.239	1.645	0.589
	SD	2145.955	0.212	1208.088	0.058	6.728	0.091	0.350	0.061	2.390	0.050	0.139	0.050
December	N	8	8	8	8	8	8	8	8	8	8	8	8
	Min	2298	0.867	1725	0.232	27	0.319	1.755	0.527	14	0.181	1.447	0.506
	Max	7739	1.491	6739	0.482	40	0.593	2.849	0.801	24	0.292	1.960	0.617
	Mean	5716.750	1.057	3868.250	0.380	32.375	0.448	2.213	0.636	18.375	0.250	1.644	0.568
	SD	1937.417	0.232	1625.638	0.086	4.596	0.098	0.388	0.095	3.889	0.041	0.181	0.042
Control	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4983	1.170	4653	0.384	30	0.307	2.109	0.620	19	0.185	1.729	0.559
	Max	14163	1.244	10323	0.613	44	0.565	2.725	0.762	22	0.269	2.081	0.698
	Mean	8696.000	1.202	6963.250	0.539	37.500	0.424	2.482	0.688	21.000	0.237	1.918	0.631
	SD	4135.607	0.032	2459.790	0.105	7.550	0.112	0.273	0.065	1.414	0.041	0.176	0.070

WISER

Table 13-10: Summary of data used to test for pre-treatment differences between the plots to be burnt with different fire treatments in 1954.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Apr2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	1503	0.934	1252	0.496	15	0.330	1.740	0.641	14	0.282	1.641	0.606
	Max	2822	1.398	1998	0.825	21	0.395	2.225	0.752	19	0.392	1.974	0.713
	Mean	2255.250	1.165	1752.500	0.705	17.250	0.366	1.968	0.692	16.500	0.352	1.858	0.665
	SD	549.027	0.190	348.767	0.147	2.630	0.031	0.245	0.058	2.380	0.048	0.149	0.044
Apr3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	1465	0.909	902	0.284	19	0.424	1.900	0.645	10	0.261	1.556	0.615
	Max	2320	1.050	1651	0.449	31	0.763	2.828	0.823	16	0.358	1.837	0.696
	Mean	1859.750	0.968	1329.750	0.339	24.500	0.578	2.377	0.743	13.250	0.308	1.690	0.658
	SD	379.676	0.069	365.340	0.075	4.933	0.149	0.381	0.074	2.500	0.050	0.144	0.035
Aug1	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2058	0.909	1329	0.580	14	0.289	1.326	0.502	16	0.340	1.561	0.563
	Max	2690	1.277	2501	0.830	22	0.485	2.326	0.753	21	0.405	2.151	0.707
	Mean	2326.000	1.081	1854.750	0.708	18.000	0.377	1.944	0.671	18.250	0.378	1.897	0.653
	SD	268.114	0.196	484.924	0.107	4.082	0.103	0.456	0.115	2.062	0.029	0.246	0.062
Aug2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	1561	0.629	1370	0.366	9	0.228	1.157	0.490	15	0.313	1.626	0.563
	Max	3175	1.277	2113	0.900	24	0.469	2.682	0.844	18	0.380	1.989	0.734
	Mean	2433.500	0.994	1768.500	0.672	16.250	0.329	1.740	0.623	16.500	0.340	1.798	0.643
	SD	670.201	0.269	306.225	0.227	6.344	0.112	0.692	0.159	1.291	0.030	0.162	0.076
Aug3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	895	0.834	683	0.281	9	0.292	1.503	0.586	8	0.184	1.476	0.624
	Max	3337	0.921	2597	0.523	26	0.450	2.322	0.793	17	0.334	1.769	0.721
	Mean	2023.500	0.882	1469.250	0.408	16.250	0.359	1.915	0.703	11.500	0.265	1.658	0.694
	SD	1003.512	0.039	828.881	0.100	7.274	0.076	0.429	0.086	3.873	0.064	0.130	0.047
Con0	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	830	0.773	849	0.624	12	0.390	1.839	0.701	13	0.380	1.582	0.537
	Max	2498	1.370	1822	0.880	21	0.466	2.239	0.760	19	0.451	2.200	0.858
	Mean	1721.500	1.116	1315.250	0.738	17.250	0.423	2.054	0.727	16.750	0.415	1.850	0.666
	SD	690.938	0.252	401.546	0.125	3.862	0.032	0.178	0.028	2.872	0.034	0.256	0.137
Dec2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	990	0.842	562	0.626	13	0.319	1.772	0.654	10	0.306	1.421	0.585
	Max	2936	1.224	2318	0.900	22	0.477	2.319	0.798	17	0.393	1.719	0.632
	Mean	1663.250	1.011	1155.000	0.774	16.250	0.415	2.070	0.749	13.500	0.341	1.554	0.604
	SD	899.318	0.172	813.381	0.115	3.948	0.071	0.228	0.066	3.512	0.040	0.141	0.021
Dec3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	1972	0.908	1323	0.132	16	0.296	1.256	0.453	10	0.218	1.380	0.523
	Max	2931	1.668	2705	0.437	27	0.579	2.537	0.770	18	0.405	2.044	0.707
	Mean	2295.500	1.167	1823.500	0.327	22.000	0.467	1.906	0.613	14.500	0.304	1.628	0.614
	SD	432.048	0.353	613.309	0.135	4.967	0.127	0.580	0.144	3.697	0.078	0.293	0.076
Feb2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	401	0.953	398	0.336	11	0.319	1.160	0.467	9	0.293	1.313	0.463
	Max	4648	1.639	3431	0.922	27	0.549	2.544	0.812	20	0.451	1.764	0.747
	Mean	2406.750	1.279	1720.500	0.602	17.250	0.401	1.930	0.688	14.500	0.341	1.599	0.619
	SD	1880.800	0.321	1302.613	0.295	7.411	0.104	0.574	0.154	4.933	0.074	0.198	0.122

WITS

Table 13-10 continued.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density (plants/Ha)	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Feb3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	1413	0.939	1096	0.165	16	0.291	1.601	0.554	14	0.264	1.448	0.549
	Max	3832	1.326	3079	0.343	28	0.610	2.299	0.737	18	0.399	1.799	0.664
	Mean	2540.750	1.088	1982.500	0.289	20.250	0.421	1.965	0.658	16.000	0.331	1.709	0.617
	SD	1032.394	0.171	854.098	0.084	5.315	0.137	0.290	0.078	1.826	0.064	0.174	0.049
Oct2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2141	0.795	1450	0.207	16	0.346	2.004	0.708	15	0.296	1.500	0.554
	Max	2572	1.254	1869	0.866	23	0.463	2.449	0.781	18	0.389	1.848	0.639
	Mean	2290.750	1.069	1620.750	0.630	20.500	0.428	2.232	0.741	17.000	0.357	1.671	0.590
	SD	194.002	0.219	190.244	0.295	3.109	0.055	0.194	0.032	1.414	0.042	0.142	0.036
Oct3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	833	0.923	813	0.148	15	0.466	2.080	0.720	12	0.352	1.629	0.593
	Max	2067	1.274	1624	0.395	33	0.726	2.880	0.824	18	0.494	2.037	0.772
	Mean	1317.000	1.087	1068.500	0.296	22.000	0.605	2.402	0.786	15.000	0.426	1.799	0.669
	SD	540.536	0.173	381.707	0.105	7.874	0.107	0.379	0.048	2.582	0.074	0.176	0.074

WitsETD

Table 13-11: Summary of data used to test for treatment differences between the plots burnt with different fire treatments between 1954 and 1996.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Apr2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2550	0.858	1551	0.323	19	0.310	1.729	0.508	12	0.202	1.461	0.567
	Max	6484	1.347	5672	0.414	30	0.376	1.972	0.670	23	0.286	1.778	0.588
	Mean	5250.750	1.041	4162.500	0.371	24.500	0.346	1.855	0.586	17.250	0.240	1.621	0.576
	SD	1858.424	0.213	1848.391	0.038	4.655	0.034	0.103	0.068	4.787	0.034	0.142	0.009
Apr3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4406	0.834	3040	0.331	29	0.381	1.908	0.556	16	0.203	1.441	0.489
	Max	7465	1.035	5179	0.384	47	0.544	2.646	0.687	21	0.286	1.700	0.591
	Mean	6155.500	0.915	4336	0.356	34.250	0.436	2.128	0.603	18.750	0.242	1.609	0.550
	SD	1282.807	0.086	1016.361	0.026	8.539	0.076	0.348	0.058	2.062	0.038	0.115	0.043
Aug1	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4622	0.640	2098	0.095	26	0.303	1.848	0.549	15	0.175	0.912	0.337
	Max	7381	1.019	4795	0.193	29	0.412	2.415	0.725	19	0.250	1.433	0.487
	Mean	6054.000	0.859	3051.500	0.126	27.500	0.358	2.097	0.633	17.000	0.221	1.162	0.409
	SD	1176.267	0.159	1192.608	0.045	1.291	0.045	0.249	0.077	1.633	0.033	0.214	0.062
Aug2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2963	0.818	2268	0.065	22	0.267	1.481	0.444	14	0.181	1.282	0.435
	Max	6805	1.282	6016	0.270	29	0.533	2.244	0.687	21	0.275	1.643	0.607
	Mean	5316.750	1.133	4100.000	0.155	26.250	0.378	1.892	0.579	17.250	0.242	1.440	0.510
	SD	1654.366	0.214	1698.117	0.085	3.096	0.113	0.406	0.117	3.304	0.041	0.170	0.071
Aug3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	3581	0.892	2032	0.129	19	0.305	1.632	0.495	12	0.192	1.322	0.532
	Max	7381	1.200	7359	0.429	35	0.407	2.229	0.707	21	0.284	1.730	0.569
	Mean	5217.250	1.100	4713.500	0.243	26.250	0.365	1.916	0.593	16.500	0.232	1.552	0.557
	SD	1804.123	0.145	2385.523	0.131	6.702	0.048	0.285	0.094	3.697	0.041	0.171	0.017
Con0	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4983	1.170	4653	0.384	30	0.307	2.109	0.620	19	0.185	1.729	0.559
	Max	14163	1.244	10323	0.613	44	0.565	2.725	0.762	22	0.269	2.081	0.698
	Mean	8696.000	1.202	6963.250	0.539	37.500	0.424	2.482	0.688	21.000	0.237	1.918	0.631
	SD	4135.607	0.032	2459.790	0.105	7.550	0.112	0.273	0.065	1.414	0.041	0.176	0.070
Dec2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	5201	0.867	3285	0.290	28	0.363	1.755	0.527	14	0.181	1.447	0.506
	Max	7739	0.981	4962	0.445	40	0.472	2.664	0.722	21	0.250	1.619	0.567
	Mean	6520.750	0.915	3811.500	0.373	33.500	0.416	2.156	0.613	17.500	0.218	1.526	0.536
	SD	1152.358	0.052	776.854	0.074	5.196	0.046	0.376	0.081	2.887	0.032	0.073	0.032
Dec3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2298	0.901	1725	0.232	27	0.319	1.772	0.538	14	0.271	1.542	0.584
	Max	7157	1.491	6739	0.482	35	0.593	2.849	0.801	24	0.292	1.960	0.617
	Mean	4912.750	1.199	3925.000	0.388	31.250	0.481	2.271	0.659	19.250	0.282	1.762	0.601
	SD	2388.861	0.263	2356.737	0.109	4.349	0.132	0.448	0.115	4.992	0.009	0.183	0.015
Feb2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	3401	0.759	1835	0.245	30	0.294	1.938	0.570	16	0.176	1.328	0.462
	Max	11649	0.914	7918	0.388	37	0.583	2.595	0.763	23	0.290	1.645	0.532
	Mean	7937.500	0.846	4718.750	0.335	32.750	0.400	2.375	0.681	20.000	0.239	1.455	0.487
	SD	3793.606	0.067	2726.758	0.063	3.403	0.127	0.310	0.083	3.162	0.053	0.136	0.031

WITS

Table 13-11 continued.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
Feb3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	3990	0.888	2363	0.385	27	0.343	1.848	0.538	17	0.228	1.551	0.547
	Max	6371	1.122	4460	0.463	31	0.491	2.437	0.710	22	0.276	1.750	0.575
	Mean	5593.000	0.967	3663.500	0.431	29.750	0.404	2.168	0.639	19.500	0.262	1.654	0.558
	SD	1095.022	0.108	905.458	0.035	1.893	0.062	0.248	0.073	2.380	0.023	0.088	0.012
Oct2	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	2655	0.922	2602	0.223	21	0.274	1.868	0.614	15	0.158	1.362	0.503
	Max	9008	1.256	5084	0.332	30	0.479	2.624	0.771	20	0.320	1.789	0.653
	Mean	5496.500	1.129	3754.250	0.283	26.500	0.381	2.211	0.675	17.250	0.251	1.659	0.584
	SD	2812.281	0.154	1303.036	0.052	4.041	0.086	0.313	0.070	2.630	0.071	0.200	0.063
Oct3	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	3191	0.93	2794	0.219	14	0.218	1.606	0.609	14	0.195	1.593	0.541
	Max	6788	1.574	5814	0.362	37	0.449	2.618	0.725	19	0.248	1.735	0.641
	Mean	5001.250	1.186	4231.000	0.294	25.750	0.365	2.064	0.643	15.750	0.227	1.632	0.595
	SD	1634.886	0.28	1247.403	0.072	9.430	0.108	0.417	0.055	2.217	0.022	0.069	0.041

WitsETD

Table 13-12: Summary of data used to test the effects of not burning between 1954, 1959, and 1996.

						Taxonomic diversity				Structural diversity			
Treatment	Statistic	Density	Mean height (m)	Tree equivalents (per Ha)	Single:Multi stem	Number of species	Species Richness	Species diversity	Species evenness	Number of structural groups	Structure richness	Structure diversity	Structure evenness
1954	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	830	0.773	849	0.624	12	0.390	1.839	0.701	13	0.380	1.582	0.537
	Max	2498	1.370	1822	0.880	21	0.466	2.239	0.760	19	0.451	2.200	0.858
	Mean	1721.500	1.116	1315.250	0.738	17.250	0.423	2.054	0.727	16.750	0.415	1.850	0.666
	SD	690.938	0.252	401.546	0.125	3.862	0.032	0.178	0.028	2.872	0.034	0.256	0.137
1959	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	1129	0.783	738	0.479	12	0.356	1.577	0.536	9	0.190	1.466	0.611
	Max	3350	0.802	2024	0.610	28	0.484	2.655	0.797	22	0.463	2.183	0.754
	Mean	2396.500	0.792	1650.250	0.548	20.000	0.410	2.058	0.696	14.250	0.300	1.765	0.680
	SD	954.602	0.010	612.570	0.056	6.583	0.064	0.460	0.113	5.737	0.115	0.304	0.063
1996	N	4	4	4	4	4	4	4	4	4	4	4	4
	Min	4983	1.170	4653	0.384	30	0.307	2.109	0.620	19	0.185	1.729	0.559
	Max	14163	1.244	10323	0.613	44	0.565	2.725	0.762	22	0.269	2.081	0.698
	Mean	8696.000	1.202	6963.250	0.539	37.500	0.424	2.482	0.688	21.000	0.237	1.918	0.631
	SD	4135.607	0.032	2459.790	0.105	7.550	0.112	0.273	0.065	1.414	0.041	0.176	0.070

WitsETD

14 APPENDIX 6: TUKEY STUDENTIZED *POST HOC* ANALYSES ON THE ANOVA AND ANCOVA ANALYSES OF THE VEGETATION INDICES CALCULATED

The coloured cells show the level of the test significance: yellow: α=0.05, and orange: α = 0.10. LS Mean is the least squares mean, SE is the standard error, and N is the number of samples.

Table 14-1: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between the replicates in 1954.

Single:Multi stem	Fayi	Kambeni	Numbi	Shabeni	LS Mean	SE	N
Fayi	1.000				0.652	0.064	12
Kambeni	0.035	1.000			0.398	0.064	12
Numbi	0.982	0.083	1.000		0.618	0.064	12
Shabeni	0.309	0.710	0.520	1.000	0.494	0.064	12

Species diversity	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				1.927	0.111	12
Kambeni	0.936	1.000			1.835	0.111	12
Numbi	0.117	0.031	1.000		2.287	0.111	12
Shabeni	0.623	0.288	0.707	1.000	2.118	0.111	12

Species evenness	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				0.665	0.026	12
Kambeni	0.990	1.000			0.653	0.026	12
Numbi	0.035	0.016	1.000		0.769	0.026	12
Shabeni	0.589	0.405	0.415	1.000	0.711	0.026	12

Structural diversity	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				1.826	0.055	12
Kambeni	0.823	1.000			1.759	0.055	12
Numbi	0.212	0.683	1.000		1.672	0.055	12
Shabeni	0.115	0.486	0.989	1.000	1.647	0.055	12

WiSETD

Table 14-2: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between the replicates in 1996.

Mean height (m)	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				1.084	0.054	12
Kambeni	0.984	1.000			1.111	0.054	12
Numbi	0.181	0.087	1.000		0.925	0.054	12
Shabeni	0.957	0.821	0.414	1.000	1.045	0.054	12

Tree equivalents (per Ha)	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				4766.167	482.537	12
Kambeni	0.832	1.000			5343.667	482.537	12
Numbi	0.484	0.118	1.000		3785.583	482.537	12
Shabeni	0.133	0.018	0.860	1.000	3248.167	482.537	12

Species Richness	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				0.346	0.023	12
Kambeni	0.897	1.000			0.369	0.023	12
Numbi	0.087	0.324	1.000		0.425	0.023	12
Shabeni	0.021	0.107	0.930	1.000	0.444	0.023	12

Species diversity	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				1.957	0.084	12
Kambeni	1.000	1.000			1.946	0.084	12
Numbi	0.005	0.004	1.000		2.38	0.084	12
Shabeni	0.073	0.058	0.725	1.000	2.256	0.084	12

Species evenness	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				0.591	0.019	12
Kambeni	0.982	1.000			0.581	0.019	12
Numbi	0.003	0.001	1.000		0.693	0.019	12
Shabeni	0.036	0.014	0.778	1.000	0.667	0.019	12

Number of structural groups	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				20.25	0.828	12
Kambeni	0.409	1.000			18.417	0.828	12
Numbi	0.064	0.753	1.000		17.25	0.828	12
Shabeni	0.011	0.332	0.892	1.000	16.417	0.828	12

VISITED

Table 14-3: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between the replicates in 1996 using the baseline data (1954) as covariates.

Mean height (m)	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				1.082	0.055	12
Kambeni	0.979	1.000			1.113	0.055	12
Numbi	0.184	0.091	1.000		0.922	0.056	12
Shabeni	0.968	0.825	0.408	1.000	1.046	0.055	12

Tree equivalents (per Ha)	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				4624.197	491.428	12
Kambeni	0.692	1.000			5384.931	480.008	12
Numbi	0.696	0.127	1.000		3862.051	482.596	12
Shabeni	0.219	0.016	0.821	1.000	3272.404	479.309	12

Species Richness	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				0.352	0.023	12
Kambeni	0.907	1.000			0.373	0.023	12
Numbi	0.197	0.522	1.000		0.418	0.023	12
Shabeni	0.040	0.166	0.887	1.000	0.441	0.023	12

Species Richness	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				0.352	0.023	12
Kambeni	0.907	1.000			0.373	0.023	12
Numbi	0.197	0.522	1.000		0.418	0.023	12
Shabeni	0.040	0.166	0.887	1.000	0.441	0.023	12

Species diversity	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				1.986	0.081	12
Kambeni	1.000	1.000			1.998	0.083	12
Numbi	0.041	0.062	1.000		2.317	0.084	12
Shabeni	0.149	0.195	0.894	1.000	2.236	0.081	12

Species evenness	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				0.598	0.019	12
Kambeni	0.991	1.000			0.591	0.019	12
Numbi	0.039	0.023	1.000		0.678	0.020	12
Shabeni	0.079	0.044	0.960	1.000	0.664	0.019	12

Number of structural groups	Fayi	Kambeni	Numbi	Shabeni	Mean	SE	N
Fayi	1.000				19.761	0.814	12
Kambeni	0.688	1.000			18.501	0.789	12
Numbi	0.187	0.763	1.000		17.413	0.791	12
Shabeni	0.048	0.361	0.905	1.000	16.658	0.794	12

WISET

Table 14-4: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots to be burnt at different frequencies in 1954 using the No-August-Annual data grouping.

Single-stem to Multi-stem	None	Biennial	Triennial	Mean	SE	N
None	1.000			0.738	0.082	4
Biennial	0.773	1.000		0.677	0.036	20
Triennial	0.001	0.001	1.000	0.332	0.036	20

Species richness	None	Biennial	Triennial	Mean	SE	N
None	1.000			0.423	0.056	4
Biennial	0.833	1.000		0.388	0.025	20
Triennial	0.572	0.023	1.000	0.486	0.025	20

Structural richness	None	Biennial	Triennial	Mean	SE	N
None	1.000			0.415	0.032	4
Biennial	0.129	1.000		0.346	0.014	20
Triennial	0.039	0.608	1.000	0.327	0.014	20

WitsETD

Table 14-5: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the No-August-Annual data grouping.

Density	None	Biennial	Triennial	Mean	SE	N
None	1.000			8696.000	1129.841	4
Biennial	0.104	1.000		6104.450	505.280	20
Triennial	0.028	0.569	1.000	5375.950	505.280	20

Tree equivalents	None	Biennial	Triennial	Mean	SE	N
None	1.000			6963.250	837.943	4
Biennial	0.009	1.000		4109.400	374.740	20
Triennial	0.011	0.992	1.000	4173.800	374.740	20

Single-stem to Multi-stem	None	Biennial	Triennial	Mean	SE	N
None	1.000			0.539	0.051	4
Biennial	0.001	1.000		0.303	0.023	20
Triennial	0.003	0.449	1.000	0.342	0.023	20

Number of species	None	Biennial	Triennial	Mean	SE	N
None	1.000			37.500	3.114	4
Biennial	0.035	1.000		28.700	1.393	20
Triennial	0.059	0.923	1.000	29.450	1.393	20

Structural diversity	None	Biennial	Triennial	Mean	SE	N
None	1.000			1.918	0.076	4
Biennial	0.001	1.000		1.540	0.034	20
Triennial	0.005	0.098	1.000	1.642	0.034	20

Structural evenness	None	Biennial	Triennial	Mean	SE	N
None	1.000			0.631	0.024	4
Biennial	0.003	1.000		0.539	0.011	20
Triennial	0.080	0.088	1.000	0.572	0.011	20

WITSETD

Table 14-6: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the baseline data (1954) as covariates. The No-August-Annual data grouping was used in these analyses.

Density	None	Biennial	Triennial	Mean	SE	N
None	1.000			8988.070	1094.947	4
Biennial	0.044	1.000		5991.168	488.688	20
Triennial	0.013	0.699	1.000	5430.818	486.386	20

Tree equivalents	None	Biennial	Triennial	Mean	SE	N
None	1.000			7158.578	804.832	4
Biennial	0.003	1.000		4060.769	358.459	20
Triennial	0.005	0.968	1.000	4183.365	357.821	20

Single-stem to Multi-stem	None	Biennial	Triennial	Mean	SE	N
None	1.000			0.527	0.055	4
Biennial	0.001	1.000		0.295	0.027	20
Triennial	0.041	0.441	1.000	0.353	0.030	20

Number of species	None	Biennial	Triennial	Mean	SE	N
None	1.000			38.287	2.937	4
Biennial	0.022	1.000		29.379	1.333	20
Triennial	0.014	0.918	1.000	28.613	1.346	20

Species diversity	None	Biennial	Triennial	Mean	SE	N
None	1.000			2.481	0.150	4
Biennial	0.087	1.000		2.123	0.067	20
Triennial	0.052	0.917	1.000	2.085	0.067	20

Structural diversity	None	Biennial	Triennial	Mean	SE	N
None	1.000			1.893	0.077	4
Biennial	0.001	1.000		1.543	0.034	20
Triennial	0.014	0.094	1.000	1.644	0.034	20

Structural evenness	None	Biennial	Triennial	Mean	SE	N
None	1.000			0.631	0.025	4
Biennial	0.005	1.000		0.539	0.011	20
Triennial	0.086	0.104	1.000	0.572	0.011	20

WiSETD

Table 14-7: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots to be burnt at different frequencies in 1954 using the August-Control data grouping.

Single-stem to Multi-stem	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				0.738	0.074	4
Annual	0.992	1.000			0.708	0.074	4
Biennial	0.922	0.985	1.000		0.672	0.074	4
Triennial	0.037	0.061	0.108	1.000	0.408	0.074	4

Number of structure groups	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				16.750	1.350	4
Annual	0.860	1.000			18.250	1.350	4
Biennial	0.999	0.797	1.000		16.500	1.350	4
Triennial	0.073	0.019	0.091	1.000	11.500	1.350	4

Structural richness	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				0.415	0.021	4
Annual	0.619	1.000			0.378	0.021	4
Biennial	0.107	0.588	1.000		0.340	0.021	4
Triennial	0.001	0.012	0.107	1.000	0.265	0.021	4

WitsETD

Table 14-8: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the August-Control data grouping.

Mean height (m)	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				1.202	0.076	4
Annual	0.035	1.000			0.859	0.076	4
Biennial	0.918	0.103	1.000		1.133	0.076	4
Triennial	0.783	0.168	0.990	1.000	1.100	0.076	4

Tree equivalents	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				6963.250	1001.474	4
Annual	0.071	1.000			3051.500	1001.474	4
Biennial	0.234	0.879	1.000		4100.000	1001.474	4
Triennial	0.420	0.654	0.972	1.000	4713.500	1001.474	4

Single-stem to Multi-stem	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				0.539	0.048	4
Annual	0.001	1.000			0.126	0.048	4
Biennial	0.001	0.975	1.000		0.155	0.048	4
Triennial	0.005	0.366	0.587	1.000	0.243	0.048	4

Number of species	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				37.500	2.659	4
Annual	0.085	1.000			27.500	2.659	4
Biennial	0.048	0.987	1.000		26.250	2.659	4
Triennial	0.048	0.987	1.000	1.000	26.250	2.659	4

Species diversity	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				2.482	0.155	4
Annual	0.339	1.000			2.097	0.155	4
Biennial	0.080	0.785	1.000		1.892	0.155	4
Triennial	0.096	0.840	0.999	1.000	1.916	0.155	4

Structural diversity	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				1.918	0.092	4
Annual	<0.001	1.000			1.162	0.092	4
Biennial	0.014	0.198	1.000		1.440	0.092	4
Triennial	0.065	0.048	0.822	1.000	1.552	0.092	4

Structural evenness	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				0.631	0.030	4
Annual	0.001	1.000			0.409	0.030	4
Biennial	0.056	0.129	1.000		0.510	0.030	4
Triennial	0.326	0.019	0.686	1.000	0.557	0.030	4

WISETD

Table 14-9: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between plots burnt at different frequencies between 1954 and 1996 using the baseline data (1954) as covariates. The August-Control data grouping was used in these analyses.

Mean height (m)	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				1.192	0.082	4
Annual	0.048	1.000			0.852	0.080	4
Biennial	0.960	0.113	1.000		1.136	0.079	4
Triennial	0.922	0.183	0.998	1.000	1.115	0.084	4

Tree equivalents	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				7313.455	1032.018	4
Annual	0.048	1.000			2742.675	1022.199	4
Biennial	0.153	0.842	1.000		3896.534	1002.484	4
Triennial	0.353	0.487	0.901	1.000	4875.585	996.889	4

Single-stem to Multi-stem	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				0.529	0.054	4
Annual	0.001	1.000			0.119	0.052	4
Biennial	0.001	0.970	1.000		0.151	0.051	4
Triennial	0.073	0.435	0.591	1.000	0.263	0.066	4

Number of species	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				37.419	2.674	4
Annual	0.084	1.000			27.225	2.689	4
Biennial	0.060	0.997	1.000		26.428	2.680	4
Triennial	0.060	0.997	1.000	1.000	26.428	2.680	4

Species diversity	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				2.434	0.139	4
Annual	0.334	1.000			2.087	0.137	4
Biennial	0.135	0.899	1.000		1.951	0.140	4
Triennial	0.091	0.815	0.998	1.000	1.916	0.137	4

Number of structure groups	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				20.423	1.180	4
Annual	0.059	1.000			15.557	1.309	4
Biennial	0.181	0.876	1.000		16.817	1.169	4
Triennial	0.893	0.493	0.728	1.000	18.953	1.559	4

Structural diversity	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				1.904	0.092	4
Annual	0.001	1.000			1.136	0.094	4
Biennial	0.019	0.152	1.000		1.441	0.091	4
Triennial	0.167	0.037	0.679	1.000	1.592	0.098	4

Structural evenness	None	Annual	Biennial	Triennial	Mean	SE	N
None	1.000				0.631	0.031	4
Annual	0.002	1.000			0.410	0.031	4
Biennial	0.078	0.147	1.000		0.512	0.031	4
Triennial	0.336	0.033	0.782	1.000	0.554	0.031	4

WISETD

Table 14-10: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots to be burnt at different times of the year in 1954 using the No-August-Annual data grouping.

Species richness	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.472	0.04	8
Aug	0.230	1.000					0.344	0.04	8
Cont	0.980	0.856	1.000				0.423	0.056	4
Dec	0.994	0.521	1.000	1.000			0.441	0.04	8
Feb	0.885	0.838	1.000	0.994	1.000		0.411	0.04	8
Oct	0.969	0.044	0.759	0.769	0.438	1.000	0.516	0.04	8

Structural richness	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.330	0.021	8
Aug	0.937	1.000					0.303	0.021	8
Cont	0.204	0.039	1.000				0.415	0.030	4
Dec	1.000	0.984	0.135	1.000			0.322	0.021	8
Feb	1.000	0.864	0.275	0.997	1.000		0.336	0.021	8
Oct	0.328	0.051	0.986	0.210	0.444	1.000	0.391	0.021	8

WitsETD

Table 14-11: Tukey *post hoc* analyses for the ANOVA analyses testing for differences between plots burnt at different times of the year between 1954 and 1996 using the No-August-Annual data grouping.

Mean height (m)	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.978	0.062	8
Aug	0.615	1.000					1.117	0.062	8
Cont	0.315	0.967	1.000				1.202	0.087	4
Dec	0.945	0.982	0.752	1.000			1.057	0.062	8
Feb	0.962	0.181	0.087	0.530	1.000		0.907	0.062	8
Oct	0.338	0.997	0.998	0.858	0.068	1.000	1.157	0.062	8

Tree equivalents	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						4249.25	611.684	8
Aug	1.000	1.000					4406.75	611.684	8
Cont	0.132	0.177	1.000				6963.25	865.052	4
Dec	0.998	0.989	0.060	1.000			3868.25	611.684	8
Feb	1.000	1.000	0.118	0.999	1.000		4191.125	611.684	8
Oct	1.000	0.997	0.079	1.000	1.000	1.000	3992.625	611.684	8

Single-stem to Multi-stem	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.364	0.028	8
Aug	0.002	1.000					0.199	0.028	8
Cont	0.011	0.001	1.000				0.539	0.040	4
Dec	0.998	0.001	0.026	1.000			0.380	0.028	8
Feb	0.996	0.001	0.031	1.000	1.000		0.383	0.028	8
Oct	0.414	0.236	0.001	0.213	0.185	1.000	0.288	0.028	8

Number of species	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						29.375	2.097	8
Aug	0.896	1.000					26.25	2.097	8
Cont	0.245	0.040	1.000				37.5	2.965	4
Dec	0.911	0.326	0.720	1.000			32.375	2.097	8
Feb	0.988	0.549	0.527	0.999	1.000		31.25	2.097	8
Oct	0.880	1.000	0.036	0.305	0.522	1.000	26.125	2.097	8

Species diversity	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						1.991	0.114	8
Aug	0.994	1.000					1.904	0.114	8
Cont	0.157	0.061	1.000				2.482	0.162	4
Dec	0.743	0.411	0.753	1.000			2.213	0.114	8
Feb	0.521	0.232	0.893	0.999	1.000		2.271	0.114	8
Oct	0.943	0.702	0.516	0.997	0.961	1.000	2.137	0.114	8

Structural diversity	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						1.615	0.055	8
Aug	0.647	1.000					1.496	0.055	8
Cont	0.032	0.001	1.000				1.918	0.078	4
Dec	0.999	0.413	0.066	1.000			1.644	0.055	8
Feb	0.970	0.973	0.006	0.856	1.000		1.555	0.055	8
Oct	0.999	0.406	0.068	1.000	0.850	1.000	1.645	0.055	8

WISETD

Structural evenness	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.563	0.017	8
Aug	0.805	1.000					0.533	0.017	8
Cont	0.197	0.019	1.000				0.631	0.024	4
Dec	1.000	0.675	0.275	1.000			0.568	0.017	8
Feb	0.531	0.997	0.007	0.393	1.000		0.522	0.017	8
Oct	0.874	0.193	0.696	0.948	0.075	1.000	0.589	0.017	8

WitsETD

Table 14-12: Tukey *post hoc* analyses for the ANCOVA analyses testing for differences between plots burnt at different times of the year between 1954 and 1996 using the baseline data (1954) as covariates. The No-August-Annual data grouping was used in these analyses.

Mean height (m)	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.980	0.062	8
Aug	0.508	1.000					1.135	0.064	8
Cont	0.349	0.993	1.000				1.197	0.088	4
Dec	0.953	0.944	0.770	1.000			1.055	0.062	8
Feb	0.918	0.117	0.073	0.449	1.000		0.892	0.063	8
Oct	0.347	1.000	0.999	0.850	0.051	1.000	1.157	0.062	8

Tree equivalents	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						4253.443	585.254	8
Aug	1.000	1.000					4344.073	585.995	8
Cont	0.070	0.087	1.000				7161.710	832.929	4
Dec	0.998	0.995	0.032	1.000			3917.059	585.702	8
Feb	0.999	0.996	0.038	1.000	1.000		3928.375	598.186	8
Oct	1.000	1.000	0.056	1.000	1.000	1.000	4165.820	590.906	8

Single-stem to Multi-stem	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.364	0.028	8
Aug	0.003	1.000					0.199	0.028	8
Cont	0.012	0.001	1.000				0.543	0.042	4
Dec	0.998	0.001	0.028	1.000			0.381	0.028	8
Feb	0.998	0.001	0.036	1.000	1.000		0.381	0.029	8
Oct	0.410	0.272	< 0.001	0.210	0.198	1.000	0.287	0.029	8

Number of species	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						28.569	1.947	8
Aug	0.999	1.000					27.508	1.977	8
Cont	0.067	0.029	1.000				38.311	2.739	4
Dec	0.738	0.507	0.490	1.000			32.350	1.926	8
Feb	0.905	0.720	0.325	0.999	1.000		31.392	1.927	8
Oct	0.807	0.960	0.005	0.117	0.233	1.000	25.151	1.957	8

Species diversity	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						1.937	0.097	8
Aug	0.997	1.000					2.004	0.099	8
Cont	0.027	0.075	1.000				2.481	0.136	4
Dec	0.256	0.523	0.707	1.000			2.242	0.096	8
Feb	0.088	0.223	0.923	0.993	1.000		2.318	0.097	8
Oct	0.991	1.000	0.092	0.612	0.304	1.000	2.018	0.101	8

Number of structure groups	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						18.061	0.954	8
Aug	0.995	1.000					17.362	0.964	8
Cont	0.810	0.576	1.000				20.148	1.371	4
Dec	0.991	0.873	0.973	1.000			18.862	0.964	8
Feb	0.852	0.562	1.000	0.993	1.000		19.628	0.955	8
Oct	0.662	0.922	0.151	0.326	0.106	1.000	16.013	0.964	8

WISETD

Structural diversity	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						1.601	0.054	8
Aug	0.710	1.000					1.492	0.054	8
Cont	0.044	0.002	1.000				1.887	0.078	4
Dec	0.951	0.227	0.269	1.000			1.670	0.056	8
Feb	0.998	0.922	0.023	0.754	1.000		1.567	0.054	8
Oct	0.996	0.394	0.117	0.999	0.931	1.000	1.640	0.054	8

Structural evenness	Apr	Aug	Cont	Dec	Feb	Oct	Mean	SE	N
Apr	1.000						0.561	0.017	8
Aug	0.797	1.000					0.531	0.017	8
Cont	0.208	0.020	1.000				0.629	0.024	4
Dec	0.999	0.597	0.380	1.000			0.571	0.017	8
Feb	0.644	1.000	0.012	0.385	1.000		0.524	0.017	8
Oct	0.837	0.169	0.764	0.964	0.086	1.000	0.590	0.017	8

WitsETD

Table 14-13: Tukey post hoc analyses for the ANOVA analyses testing for differences between plots to be burnt with different fire treatments in 1954.

Single-stem to Multi-stem	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												0.705	0.084	4
Apr3	0.127	1.000											0.339	0.084	4
Aug1	1.000	0.120	1.000										0.708	0.084	4
Aug2	1.000	0.221	1.000	1.000									0.672	0.084	4
Aug3	0.371	1.000	0.355	0.543	1.000								0.408	0.084	4
Con0	1.000	0.068	1.000	1.000	0.231	1.000							0.738	0.084	4
Dec2	1.000	0.033	1.000	0.999	0.127	1.000	1.000						0.774	0.084	4
Dec3	0.101	1.000	0.095	0.181	1.000	0.053	0.025	1.000					0.327	0.084	4
Feb2	0.999	0.549	0.999	1.000	0.883	0.990	0.946	0.481	1.000				0.602	0.084	4
Feb3	0.049	1.000	0.046	0.093	0.997	0.024	0.011	1.000	0.297	1.000			0.289	0.084	4
Oct2	1.000	0.401	1.000	1.000	0.768	0.999	0.985	0.341	1.000	0.194	1.000		0.630	0.084	4
Oct3	0.057	1.000	0.053	0.107	0.998	0.029	0.013	1.000	0.330	1.000	0.219	1.000	0.296	0.084	4

Species richness	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												0.366	0.050	4
Apr3	0.143	1.000											0.578	0.050	4
Aug1	1.000	0.198	1.000										0.377	0.050	4
Aug2	1.000	0.043	1.000	1.000									0.329	0.050	4
Aug3	1.000	0.115	1.000	1.000	1.000								0.359	0.050	4
Con0	0.999	0.556	1.000	0.966	0.998	1.000							0.423	0.050	4
Dec2	1.000	0.481	1.000	0.982	1.000	1.000	1.000						0.415	0.050	4
Dec3	0.945	0.906	0.976	0.704	0.916	1.000	1.000	1.000					0.467	0.050	4
Feb2	1.000	0.355	1.000	0.996	1.000	1.000	1.000	0.998	1.000				0.401	0.050	4
Feb3	1.000	0.536	1.000	0.971	0.999	1.000	1.000	1.000	1.000	1.000			0.421	0.050	4
Oct2	0.999	0.597	1.000	0.954	0.997	1.000	1.000	1.000	1.000	1.000	1.000		0.428	0.050	4
Oct3	0.062	1.000	0.091	0.016	0.049	0.326	0.268	0.720	0.182	0.310	0.361	1.000	0.605	0.050	4

Structural richness	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												0.352	0.027	4
Apr3	0.992	1.000											0.308	0.027	4
Aug1	1.000	0.808	1.000										0.378	0.027	4
Aug2	1.000	0.999	0.997	1.000									0.340	0.027	4
Aug3	0.540	0.992	0.178	0.734	1.000								0.265	0.027	4
Con0	0.887	0.247	0.998	0.734	0.020	1.000							0.415	0.027	4
Dec2	1.000	0.999	0.997	1.000	0.724	0.743	1.000						0.341	0.027	4
Dec3	0.983	1.000	0.745	0.998	0.997	0.200	0.998	1.000					0.304	0.027	4
Feb2	1.000	0.999	0.998	1.000	0.714	0.753	1.000	0.998	1.000				0.341	0.027	4
Feb3	1.000	1.000	0.984	1.000	0.857	0.586	1.000	1.000	1.000	1.000			0.331	0.027	4
Oct2	1.000	0.981	1.000	1.000	0.458	0.930	1.000	0.965	1.000	1.000	1.000		0.357	0.027	4
Oct3	0.749	0.144	0.984	0.556	0.009	1.000	0.566	0.114	0.578	0.409	0.819	1.000	0.426	0.027	4

WFSTD

Table 14-14: Tukey post hoc analyses for the ANOVA analyses testing for differences between plots to be burnt with different fire treatments between 1954 and 1996.

Mean height (m)	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												1.041	0.084	4
Apr3	0.994	1.000											0.915	0.084	4
Aug1	0.918	1.000	1.000										0.859	0.084	4
Aug2	1.000	0.785	0.483	1.000									1.133	0.084	4
Aug3	1.000	0.911	0.664	1.000	1.000								1.100	0.084	4
Con0	0.964	0.418	0.184	1.000	0.999	1.000							1.202	0.084	4
Dec2	0.994	1.000	1.000	0.783	0.910	0.415	1.000						0.915	0.084	4
Dec3	0.970	0.436	0.195	1.000	0.999	1.000	0.434	1.000					1.199	0.084	4
Feb2	0.877	1.000	1.000	0.413	0.591	0.147	1.000	0.156	1.000				0.846	0.084	4
Feb3	1.000	1.000	0.998	0.956	0.991	0.700	1.000	0.719	0.996	1.000			0.967	0.084	4
Oct2	1.000	0.806	0.508	1.000	1.000	1.000	0.804	1.000	0.437	0.963	1.000		1.129	0.084	4
Oct3	0.984	0.505	0.239	1.000	1.000	1.000	0.503	1.000	0.194	0.783	1.000	1.000	1.186	0.084	4

Single-stem to Multi-stem	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												0.371	0.038	4
Apr3	1.000	1.000											0.356	0.038	4
Aug1	0.003	0.007	1.000										0.126	0.038	4
Aug2	0.013	0.027	1.000	1.000									0.155	0.038	4
Aug3	0.443	0.622	0.589	0.885	1.000								0.243	0.038	4
Con0	0.122	0.066	0.001	0.001	0.001	1.000							0.539	0.038	4
Dec2	1.000	1.000	0.003	0.012	0.429	0.128	1.000						0.373	0.038	4
Dec3	1.000	1.000	0.001	0.006	0.275	0.224	1.000	1.000					0.388	0.038	4
Feb2	1.000	1.000	0.020	0.071	0.853	0.025	1.000	0.997	1.000				0.335	0.038	4
Feb3	0.992	0.959	0.001	0.001	0.050	0.698	0.993	1.000	0.816	1.000			0.431	0.038	4
Oct2	0.880	0.962	0.187	0.451	1.000	0.002	0.871	0.724	0.997	0.241	1.000		0.283	0.038	4
Oct3	0.949	0.989	0.121	0.326	0.998	0.003	0.943	0.841	1.000	0.348	1.000	1.000	0.294	0.038	4

Number of species	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												24.500	2.792	4
Apr3	0.389	1.000											34.250	2.792	4
Aug1	1.000	0.852	1.000										27.500	2.792	4
Aug2	1.000	0.674	1.000	1.000									26.250	2.792	4
Aug3	1.000	0.674	1.000	1.000	1.000								26.250	2.792	4
Con0	0.080	0.999	0.353	0.203	0.203	1.000							37.500	2.792	4
Dec2	0.508	1.000	0.925	0.788	0.788	0.996	1.000						33.500	2.792	4
Dec3	0.852	1.000	0.998	0.978	0.978	0.904	1.000	1.000					31.250	2.792	4
Feb2	0.633	1.000	0.969	0.880	0.880	0.985	1.000	1.000	1.000				32.750	2.792	4
Feb3	0.969	0.990	1.000	0.999	0.999	0.714	0.998	1.000	1.000	1.000			29.750	2.792	4
Oct2	1.000	0.714	1.000	1.000	1.000	0.228	0.821	0.985	0.904	0.999	1.000		26.500	2.792	4
Oct3	1.000	0.591	1.000	1.000	1.000	0.158	0.714	0.957	0.821	0.996	1.000	1.000	25.750	2.792	4

Structural diversity	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												1.621	0.076	4
Apr3	1.000	1.000											1.609	0.076	4
Aug1	0.007	0.009	1.000										1.162	0.076	4
Aug2	0.864	0.909	0.331	1.000									1.440	0.076	4
Aug3	1.000	1.000	0.037	0.995	1.000								1.552	0.076	4
Con0	0.242	0.195	0.001	0.004	0.063	1.000							1.918	0.076	4
Dec2	0.999	1.000	0.066	1.000	1.000	0.035	1.000						1.526	0.076	4
Dec3	0.972	0.950	0.001	0.152	0.721	0.946	0.563	1.000					1.762	0.076	4
Feb2	0.918	0.950	0.260	1.000	0.999	0.006	1.000	0.201	1.000				1.455	0.076	4
Feb3	1.000	1.000	0.003	0.695	0.998	0.403	0.986	0.997	0.779	1.000			1.654	0.076	4
Oct2	1.000	1.000	0.003	0.670	0.997	0.427	0.982	0.998	0.757	1.000	1.000		1.659	0.076	4
Oct3	1.000	1.000	0.005	0.817	1.000	0.287	0.997	0.984	0.882	1.000	1.000	1.000	1.632	0.076	4

WITSETD

Structural evenness	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												0.576	0.022	4
Apr3	1.000	1.000											0.550	0.022	4
Aug1	0.001	0.004	1.000										0.409	0.022	4
Aug2	0.637	0.977	0.103	1.000									0.510	0.022	4
Aug3	1.000	1.000	0.002	0.937	1.000								0.557	0.022	4
Con0	0.831	0.337	0.001	0.021	0.456	1.000							0.631	0.022	4
Dec2	0.980	1.000	0.013	0.999	1.000	0.147	1.000						0.536	0.022	4
Dec3	1.000	0.899	0.001	0.194	0.957	0.998	0.661	1.000					0.601	0.022	4
Feb2	0.220	0.692	0.398	1.000	0.560	0.003	0.916	0.039	1.000				0.487	0.022	4
Feb3	1.000	1.000	0.002	0.926	1.000	0.482	1.000	0.965	0.534	1.000			0.558	0.022	4
Oct2	1.000	0.994	0.001	0.468	0.999	0.932	0.927	1.000	0.131	0.999	1.000		0.584	0.022	4
Oct3	1.000	0.956	0.001	0.278	0.986	0.989	0.781	1.000	0.062	0.989	1.000	1.000	0.595	0.022	4

WitsETD

Table 14-15: Tukey post hoc analyses for the ANCOVA analyses testing for differences between plots to be burnt with different fire treatments between 1954 and 1996 using the baseline data (1954) as covariates.

Mean height (m)	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												1.033	0.085	4
Apr3	0.999	1.000											0.926	0.085	4
Aug1	0.942	1.000	1.000										0.858	0.084	4
Aug2	0.999	0.803	0.453	1.000									1.141	0.085	4
Aug3	1.000	0.891	0.597	1.000	1.000								1.119	0.088	4
Con0	0.958	0.521	0.203	1.000	1.000	1.000							1.198	0.084	4
Dec2	0.998	1.000	1.000	0.781	0.878	0.487	1.000						0.921	0.085	4
Dec3	0.971	0.582	0.236	1.000	1.000	1.000	0.544	1.000					1.190	0.085	4
Feb2	0.845	1.000	1.000	0.353	0.515	0.128	1.000	0.141	1.000				0.826	0.088	4
Feb3	1.000	1.000	0.999	0.941	0.979	0.722	1.000	0.768	0.989	1.000			0.966	0.084	4
Oct2	1.000	0.856	0.511	1.000	1.000	1.000	0.835	1.000	0.380	0.962	1.000		1.129	0.084	4
Oct3	0.978	0.589	0.249	1.000	1.000	1.000	0.557	1.000	0.167	0.788	1.000	1.000	1.185	0.084	4

Single-stem to Multi-stem	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												0.361	0.04	4
Apr3	1.000	1.000											0.369	0.041	4
Aug1	0.003	0.010	1.000										0.116	0.040	4
Aug2	0.016	0.029	1.000	1.000									0.146	0.040	4
Aug3	0.768	0.583	0.497	0.802	1.000								0.251	0.040	4
Con0	0.138	0.356	0.001	0.001	0.003	1.000							0.526	0.041	4
Dec2	1.000	1.000	0.004	0.020	0.831	0.123	1.000						0.358	0.042	4
Dec3	1.000	1.000	0.002	0.008	0.247	0.690	1.000	1.000					0.401	0.042	4
Feb2	1.000	1.000	0.017	0.064	0.951	0.046	1.000	0.985	1.000				0.331	0.039	4
Feb3	0.962	0.948	0.001	0.001	0.043	0.982	0.964	0.999	0.717	1.000			0.447	0.043	4
Oct2	0.918	0.907	0.167	0.430	1.000	0.003	0.940	0.623	0.997	0.212	1.000		0.277	0.039	4
Oct3	0.999	0.993	0.126	0.288	0.995	0.063	1.000	0.861	1.000	0.350	1.000	1.000	0.309	0.043	4

Number of species	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												25.209	2.613	4
Apr3	0.828	1.000											31.986	2.744	4
Aug1	1.000	0.994	1.000										27.902	2.603	4
Aug2	1.000	0.987	1.000	1.000									27.369	2.635	4
Aug3	1.000	0.987	1.000	1.000	1.000								27.369	2.635	4
Con0	0.045	0.892	0.222	0.168	0.168	1.000							38.209	2.613	4
Dec2	0.340	1.000	0.795	0.707	0.707	0.997	1.000						34.619	2.635	4
Dec3	0.977	1.000	1.000	1.000	1.000	0.570	0.984	1.000					30.011	2.643	4
Feb2	0.531	1.000	0.927	0.876	0.876	0.975	1.000	0.998	1.000				33.459	2.613	4
Feb3	0.993	1.000	1.000	1.000	1.000	0.418	0.945	1.000	0.990	1.000			29.229	2.606	4
Oct2	1.000	0.883	1.000	1.000	1.000	0.075	0.470	0.991	0.663	0.999	1.000		25.876	2.610	4
Oct3	1.000	0.676	0.999	1.000	1.000	0.034	0.283	0.932	0.441	0.976	1.000	1.000	24.511	2.643	4

Species diversity	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												1.89	0.133	4
Apr3	1.000	1.000											1.971	0.138	4
Aug1	0.966	0.999	1.000										2.144	0.134	4
Aug2	1.000	1.000	1.000	1.000									2.033	0.137	4
Aug3	1.000	1.000	0.999	1.000	1.000								1.976	0.134	4
Con0	0.120	0.297	0.826	0.485	0.293	1.000							2.476	0.133	4
Dec2	0.967	0.999	1.000	1.000	0.999	0.823	1.000						2.143	0.133	4
Dec3	0.458	0.772	0.996	0.901	0.750	1.000	0.996	1.000					2.334	0.134	4
Feb2	0.203	0.464	0.929	0.640	0.435	1.000	0.929	1.000	1.000				2.427	0.134	4
Feb3	0.871	0.985	1.000	0.999	0.985	0.946	1.000	1.000	0.987	1.000			2.204	0.133	4
Oct2	0.984	1.000	1.000	1.000	1.000	0.767	1.000	0.992	0.898	1.000	1.000		2.121	0.135	4
Oct3	1.000	1.000	0.977	1.000	1.000	0.144	0.975	0.533	0.256	0.902	0.986	1.000	1.896	0.139	4

WITSETD

Number of structure groups	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												16.518	1.326	4
Apr3	0.813	1.000											19.953	1.347	4
Aug1	1.000	0.456	1.000										15.226	1.386	4
Aug2	1.000	0.813	1.000	1.000									16.518	1.326	4
Aug3	0.992	1.000	0.871	0.992	1.000								18.745	1.429	4
Con0	0.728	1.000	0.309	0.728	1.000	1.000							20.119	1.332	4
Dec2	0.994	1.000	0.868	0.994	1.000	0.999	1.000						18.555	1.340	4
Dec3	0.858	1.000	0.488	0.858	1.000	1.000	1.000	1.000					19.709	1.318	4
Feb2	0.629	1.000	0.269	0.629	0.999	1.000	0.996	1.000	1.000				20.459	1.318	4
Feb3	0.962	1.000	0.668	0.962	1.000	1.000	1.000	1.000	1.000	1.000			19.066	1.318	4
Oct2	1.000	0.737	1.000	1.000	0.981	0.627	0.985	0.785	0.536	0.923	1.000		16.220	1.338	4
Oct3	1.000	0.590	1.000	1.000	0.939	0.532	0.953	0.663	0.404	0.859	1.000	1.000	15.911	1.314	4

Structural diversity	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												1.588	0.075	4
Apr3	1.000	1.000											1.618	0.074	4
Aug1	0.004	0.002	1.000										1.120	0.077	4
Aug2	0.898	0.770	0.190	1.000									1.422	0.074	4
Aug3	1.000	1.000	0.009	0.957	1.000								1.569	0.074	4
Con0	0.194	0.346	0.001	0.004	0.157	1.000							1.887	0.075	4
Dec2	1.000	1.000	0.015	0.965	1.000	0.191	1.000						1.568	0.077	4
Dec3	0.787	0.888	0.001	0.057	0.629	0.998	0.630	1.000					1.787	0.074	4
Feb2	0.998	0.979	0.077	1.000	1.000	0.031	1.000	0.188	1.000				1.486	0.075	4
Feb3	1.000	1.000	0.001	0.517	0.999	0.582	0.999	0.983	0.880	1.000			1.659	0.073	4
Oct2	1.000	1.000	0.001	0.444	0.997	0.677	0.997	0.993	0.816	1.000	1.000		1.672	0.074	4
Oct3	1.000	1.000	0.002	0.783	1.000	0.302	1.000	0.885	0.986	1.000	1.000	1.000	1.613	0.074	4

Structural evenness	Apr2	Apr3	Aug1	Aug2	Aug3	Con0	Dec2	Dec3	Feb2	Feb3	Oct2	Oct3	Mean	SE	N
Apr2	1.000												0.574	0.023	4
Apr3	1.000	1.000											0.549	0.023	4
Aug1	0.001	0.005	1.000										0.408	0.023	4
Aug2	0.681	0.982	0.104	1.000									0.510	0.023	4
Aug3	1.000	1.000	0.004	0.969	1.000								0.553	0.023	4
Con0	0.837	0.357	0.001	0.027	0.430	1.000							0.629	0.023	4
Dec2	0.994	1.000	0.012	0.999	1.000	0.227	1.000						0.539	0.023	4
Dec3	0.999	0.867	0.001	0.181	0.922	0.999	0.685	1.000					0.603	0.023	4
Feb2	0.292	0.765	0.369	1.000	0.721	0.005	0.907	0.040	1.000				0.489	0.023	4
Feb3	1.000	1.000	0.002	0.910	1.000	0.585	1.000	0.965	0.540	1.000			0.560	0.023	4
Oct2	1.000	0.986	0.001	0.420	0.995	0.978	0.919	1.000	0.123	0.999	1.000		0.588	0.023	4
Oct3	1.000	0.963	0.001	0.323	0.981	0.989	0.879	1.000	0.096	0.996	1.000	1.000	0.592	0.023	4

WISETD

Table 14-16: Tukey post hoc analyses for the ANOVA analyses testing for differences in the plots that were not burnt between 1954, 1959, and 1996.

Density	1954	1959	1996	LS Mean	SE	N
1954	1.000			1721.5	1241.367	4
1959	0.922	1.000		2396.5	1241.367	4
1996	0.008	0.015	1.000	8696	1241.367	4

Mean height (m)	1954	1959	1996	LS Mean	SE	N
1954	1.000			1.116	0.073	4
1959	0.030	1.000		0.792	0.073	4
1996	0.695	0.009	1	1.202	0.073	4

Tree equivalents	1954	1959	1996	LS Mean	SE	N
1954	1.000			1315.25	740.892	4
1959	0.946	1.000		1650.25	740.892	4
1996	0.001	0.002	1.000	6963.25	740.892	4

Single-stem to Multi-stem	1954	1959	1996	LS Mean	SE	N
1954	1.000			0.738	0.050	4
1959	0.057	1.000		0.548	0.050	4
1996	0.047	0.991	1.000	0.539	0.050	4

Number of species	1954	1959	1996	LS Mean	SE	N
1954	1.000			17.25	3.099	4
1959	0.809	1.000		20	3.099	4
1996	0.003	0.008	1.000	37.5	3.099	4

Number of structure groups	1954	1959	1996	LS Mean	SE	N
1954	1.000			16.750	1.897	4
1959	0.635	1.000		14.250	1.897	4
1996	0.301	0.077	1.000	21.000	1.897	4

Structural richness	1954	1959	1996	LS Mean	SE	N
1954	1.000			0.415	0.037	4
1959	0.122	1.000		0.300	0.037	4
1996	0.018	0.470	1.000	0.237	0.037	4

WiSETD

15 APPENDIX 7: THE WEIGHTED EIGENVECTOR SAMPLE SCORES FROM THE FIRST FOUR ORDINATION AXES FROM CORRESPONDENCE ANALYSES (CA) ON THE 1954 AND 1996 SPECIES AND STRUCTURE DATA

Table 15-1: Weighted eigenvector plot scores from the CA on the 1954 species by plot data. The table also shows the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Plot	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
Fa01Aug2	-0.1072	-1.2281	-0.2465	0.0475	2381	4.12
Fa02Con0	0.2851	-1.1915	-0.6005	0.5331	1661	6.33
Fa03Dec2	0.3671	-0.8789	-0.1698	0.3240	2936	6.7
Fa04Oct2	-0.0378	-0.6832	0.3516	-0.0796	2262	6.83
Fa05Apr2	-0.0450	-1.0751	-0.2512	-0.1190	2348	4.05
Fa06Feb2	4.9733	0.8584	0.7310	-0.3985	3166	5.21
Fa07Aug1	-0.0686	-0.7166	-0.5224	-0.1908	2690	4.44
Fa08Dec3	-0.0378	-1.2246	-0.7809	-0.5237	1972	2.65
Fa09Aug3	-0.2486	-1.0310	-0.0914	-0.3771	1982	3.02
Fa10Oct3	0.0314	-0.9620	-0.1479	-0.4126	833	4.76
Fa11Feb3	0.0636	-1.0569	0.1325	-0.1783	3832	3.61
Fa12Apr3	-0.0748	-0.9736	-0.0859	-0.0991	2004	4.23
Ka01Con0	-0.2913	-0.6069	0.3114	-0.4479	830	4.45
Ka02Dec2	-0.2838	0.8324	-1.4618	-1.4272	990	5.97
Ka03Oct2	0.0013	-0.4721	-0.6241	-0.2462	2188	5.86
Ka04Feb2	-0.2778	-1.1725	-0.3348	-0.5786	1412	2.14
Ka05Aug2	-0.2641	-1.1528	-0.4847	-0.7233	1561	2.33
Ka06Apr2	-0.0680	-0.4859	-0.8095	-0.9366	1503	3.21
Ka07Aug1	-0.3293	-1.0109	-0.4849	-0.7089	2336	2.63
Ka08Feb3	-0.4973	0.0124	1.1770	-1.9109	1413	5.71
Ka09Oct3	-0.1056	-0.7307	1.2717	2.3530	1333	8.36
Ka10Dec3	-0.3341	-1.2215	0.0477	-0.4391	2931	2.53
Ka11Aug3	1.0715	-0.6209	0.5216	1.1477	3337	5.97
Ka12Apr3	0.0091	-0.1662	-0.4706	0.0712	2320	6.23
Nu01Oct2	-0.5211	0.9776	-0.4759	-0.1207	2141	4.39
Nu02Dec2	-0.7314	1.7140	-0.8810	0.0713	1658	6.17
Nu03Feb2	-0.4882	0.2881	-0.3855	-0.2170	401	4.94
Nu04Aug2	-0.8851	2.0524	1.9361	1.0904	2617	10.62
Nu05Apr2	-0.8131	1.5742	0.5785	-0.5449	2348	6.42
Nu06Aug1	-0.6431	1.3965	-0.7974	1.9265	2220	6.44
Nu07Con0	-0.4955	0.4234	0.1180	0.2242	1897	4.77
Nu08Dec3	-0.5785	1.2176	-0.0039	-0.2885	2177	8.04
Nu09Oct3	-0.3342	0.3769	1.2099	2.7472	2067	10.6
Nu10Feb3	-0.8600	0.1585	4.1738	-1.9268	2809	4.04
Nu11Apr3	0.0042	0.1300	0.5533	1.4063	1650	10.02
Nu12Aug3	-0.6112	1.7451	-0.1664	-0.8658	1880	6.58
Sh01Aug2	-0.4160	-0.9065	0.2358	-0.2870	3175	2.21
Sh02Apr2	0.2175	0.5864	-0.6783	0.9229	2822	6.7
Sh03Aug1	-0.1796	-0.2398	-0.1765	0.6965	2058	5.98
Sh04Feb2	-0.2071	0.0964	-0.3519	1.8871	4648	8.33
Sh05Oct2	0.1831	1.5084	-1.2568	-0.7298	2572	8.29
Sh06Dec2	-0.4341	1.5220	-1.5311	-1.6049	1069	3.78
Sh07Con0	-0.4025	0.8604	-0.9900	-0.7742	2498	5.77
Sh08Dec3	-0.1002	1.3617	-1.5654	-1.3654	2102	5.57
Sh09Apr3	1.7122	1.3015	-0.2430	-0.8270	1465	7.32
Sh10Aug3	-0.1718	-0.1287	-0.7071	-0.0745	895	3.54
Sh11Oct3	0.0859	0.0592	0.3722	-0.0609	1035	5.53
Sh12Feb3	-0.1736	-0.1020	0.8550	-0.5033	2109	5.48

WISE TD

Table 15-2: Weighted eigenvector species scores from the CA on the 1954 species by plot data. The table shows the species weights and the effective number of occurrences of the species (N2 diversity of species) (Hill 1973). The codes for the species are defined in Table 9-1 (p. 210).

Species	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
acac exuv	1.7120	1.3015	-0.2429	-0.8267	11	1
acac gerr	2.9036	0.6517	0.2836	-0.1073	2221	3.31
acac sieb	0.0092	-0.1662	-0.4702	0.0716	11	1
albi vers	-0.2146	0.3232	-0.4820	0.2557	132	8
anno sene	-0.4557	0.8841	0.2699	0.0340	2038	16.52
anti veno	-0.0354	-0.3582	-0.1083	0.3543	371	14.96
brid moll	-0.0473	1.1078	-1.4069	-1.1736	97	1.25
bauh galp	-0.5489	1.0123	0.9306	0.8099	108	2.79
cass tran	-0.0376	-0.6833	0.3517	-0.0795	11	1
catu spin	-0.1776	0.2962	0.8199	1.9223	216	2.2
chae aris	-0.1894	-0.0934	-0.2436	1.2106	174	2.95
cler spec	0.1828	1.5083	-1.2569	-0.7298	56	1
comb apic	-0.1947	0.5935	-0.4656	-0.0584	33	3
comb coll	-0.3639	0.7799	0.2418	0.5968	669	9.29
comb here	3.8226	0.9727	0.2102	-0.6178	97	1.54
comb moll	-0.1350	0.4047	-0.1066	0.6012	1409	9.27
comm moll	-0.4447	1.1937	-0.5123	-0.5159	44	2.67
dalb mela	-0.1400	-0.3783	-0.0932	-0.1720	284	9.5
dich cine	-0.0893	-0.3208	-0.1876	-0.1632	24229	36.65
dios lyci	0.1473	-0.2641	0.2813	1.1575	1093	7.63
dios mesp	0.2135	0.0857	0.3772	1.1886	530	5.54
domb rotu	-0.1535	0.1385	0.1166	0.4643	197	7.8
ehre obtu	0.3150	-0.4465	-0.0029	0.2118	555	10.94
eucl divi	0.2373	0.3648	0.2155	0.5186	294	10.38
eucl nata	0.0581	-0.2553	-0.1012	0.6179	800	13.52
ficu stuh	0.0316	-0.9623	-0.1480	-0.4127	11	1
flac indi	0.1766	-0.1647	0.6715	1.0663	120	5.82
grew flav	0.3370	-0.6524	-0.2050	0.3323	240	10.64
grew mont	-0.2803	0.4316	0.0312	-0.1157	482	15.66
lann disc	-0.5783	1.3835	0.9782	0.5190	87	2.94
lann edul	-0.2281	-0.1681	0.1974	-0.1996	238	4.28
lann schw	-0.4161	-0.9064	0.2355	-0.2873	32	1
lonc capa	-0.1442	0.8511	-0.4658	-0.3613	1561	10.92
mayt hete	0.1883	0.3967	-0.0365	0.0683	987	21.92
mayt sene	0.4508	-0.2365	-0.0099	0.0966	6357	17.73
mund seri	0.3732	-0.5694	-0.1995	-0.0307	1503	15.7
ochn nata	0.1499	-0.4601	-0.0731	0.7552	725	10
olea euro	-0.5787	1.2177	-0.0040	-0.2888	11	1
ormo tric	2.8321	0.2754	0.3595	-0.2276	758	2.93
ozor spha	0.7692	0.5999	0.3060	-0.6650	22	2
papi lion	-0.8079	1.6422	1.6473	0.8783	173	1.29
papp cape	0.2296	0.0744	0.7382	1.6195	75	2.59
pari cura	-0.5611	0.7773	1.3739	-0.0151	2107	8.03
pave schu	-0.1584	0.4504	-0.2422	0.6317	3358	10.89
pelt afri	0.3013	-0.4861	0.1129	0.1792	575	7.17
phyl reti	0.1493	-0.3673	-0.2045	0.4609	358	8.08
pili thon	-0.2126	-0.5012	0.2589	-0.3948	99	7.36
pseu hook	-0.3345	0.3767	1.2099	2.7472	43	1
pter ango	-0.5817	1.1073	0.1851	-0.4036	249	4.06
pter rotu	-0.1652	0.2534	0.8817	2.0769	22	2
rhus pyro	-0.1670	0.2560	0.2420	0.5945	328	15.62
rhus tran	0.2075	0.6652	0.2897	0.5297	185	4.53
scho brac	-0.3345	0.3767	1.2099	2.7472	32	1
scle birr	-0.0576	-0.0850	-0.1470	-0.2482	2792	32.89
secu viro	-0.2543	-0.3967	1.0647	0.3341	132	7.2
senn pete	-0.2270	0.8355	-0.4850	-0.4534	8123	20.92
stry mada	0.1159	-0.1574	-0.2268	0.2689	2563	19.16
stry spin	-0.0829	-0.8952	0.5878	1.3941	33	1.8
syzy cord	-0.4973	0.0126	1.1769	-1.9110	11	1
term seri	-0.1581	-0.2564	0.1643	-0.0277	26618	29.98
tric emet	-0.0576	-0.7337	0.6740	1.2827	98	2.82

WISFD

Species	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
turr nilo	-0.5573	1.1428	-0.3403	0.8112	1725	6.07
unid enti	-0.5639	-0.0090	2.6903	-1.3702	173	2.38
vang infa	-0.0290	0.9855	1.1251	-0.4254	207	4.24
vern colo	-0.7667	0.1213	3.4031	-1.9226	420	1.62
xime caff	-0.0602	-0.4297	-0.1508	0.0019	587	15.26
zant cape	-0.0431	-0.3330	-0.4346	1.4359	33	1.8
zizi mucr	0.1487	-0.4807	-0.2724	-0.2393	601	16.75
acac exuv	1.7120	1.3015	-0.2429	-0.8267	11	1

WitsETD

Table 15-3: Weighted eigenvector plot scores from the CA on the 1996 species by plot data. The table also shows the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Plot	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
Fa01Aug2	-0.1955	0.3039	-1.1159	-0.3963	6805	3.51
Fa02Con0	1.6728	0.4704	-0.6129	-0.1237	9565	6.1
Fa03Dec2	-0.0961	0.1992	-0.6706	-0.5335	7739	4.62
Fa04Oct2	-0.1949	-0.0350	-0.1941	-0.7490	6406	5.63
Fa05Apr2	-0.3012	0.2603	-1.0343	-0.4654	6484	4.08
Fa06Feb2	-0.1046	5.5640	3.0665	-0.9710	6291	9.36
Fa07Aug1	-0.3181	-0.0509	-0.6110	0.0601	5698	4.8
Fa08Dec3	0.5135	0.4979	-0.7705	-0.5908	6707	5.13
Fa09Aug3	-0.3841	0.2381	-1.0266	-0.2742	6018	3.26
Fa10Oct3	-0.4660	0.2330	-1.0056	-0.4172	4133	3.39
Fa11Feb3	-0.2066	0.3041	-0.9016	-0.2775	6371	4.5
Fa12Apr3	-0.2780	0.2365	-0.8631	-0.5893	6555	4.22
Ka01Con0	0.8062	-0.1723	-0.4506	-0.1361	4983	9.65
Ka02Dec2	-0.3891	0.1568	-0.8222	0.0821	5958	3.03
Ka03Oct2	-0.2601	0.0414	-0.4373	-0.2715	2655	4.19
Ka04Feb2	-0.1083	0.1666	-1.1365	-0.5212	10409	4.26
Ka05Aug2	-0.4841	0.3053	-0.8299	-0.1804	5548	2.44
Ka06Apr2	-0.3589	0.0920	-0.7067	0.0594	6469	3.21
Ka07Aug1	-0.2467	0.2124	-0.6814	-0.1036	6515	3.33
Ka08Feb3	-0.3436	-0.1958	-0.3495	0.3019	6208	5.57
Ka09Oct3	-0.2405	-0.1450	-0.7704	-0.1152	5893	4.43
Ka10Dec3	-0.2135	-0.0272	-0.5568	-0.8544	7157	4.07
Ka11Aug3	-0.1365	0.8762	-0.4757	0.2370	7381	4.93
Ka12Apr3	-0.4012	0.0632	-0.6158	0.9479	6196	3.9
Nu01Oct2	-0.4972	-0.8077	0.7664	-0.2725	3917	9.57
Nu02Dec2	-0.6543	-0.6658	0.1335	0.1799	5201	4.75
Nu03Feb2	-0.3198	-0.1318	0.1723	-0.9023	3401	5.35
Nu04Aug2	-0.5315	-0.8933	1.0503	-0.5958	5951	6.07
Nu05Apr2	-0.4806	-0.2485	-0.4679	-0.1611	5500	4.02
Nu06Aug1	-0.4252	-1.3415	1.9515	-1.3604	7381	5.47
Nu07Con0	3.9319	-0.3967	0.4590	0.4257	14163	9.5
Nu08Dec3	-0.0041	-0.8474	0.6092	-0.2901	3489	11.77
Nu09Oct3	-0.5248	-0.9244	0.6943	-0.1484	6788	8.31
Nu10Feb3	-0.5769	-0.7457	0.2392	-0.3206	5803	5.75
Nu11Apr3	-0.3068	-0.6637	1.7127	-2.0656	7465	7.64
Nu12Aug3	-0.7340	-1.0453	1.4309	3.4831	3889	5.04
Sh01Aug2	-0.5398	-0.2508	0.0911	1.2855	2963	6
Sh02Apr2	-0.6956	0.5881	0.2013	2.1837	2550	4.71
Sh03Aug1	-0.6289	-1.0176	1.4538	2.3238	4622	7.78
Sh04Feb2	0.1308	-0.5047	0.6194	0.4033	11649	10.09
Sh05Oct2	-0.3474	-1.4206	1.9828	-1.1722	9008	5.3
Sh06Dec2	-0.3853	0.2801	1.0877	2.3250	7185	10.05
Sh07Con0	0.4586	0.0687	-0.4785	0.3201	6073	6.78
Sh08Dec3	-0.3909	0.3373	-0.5116	0.9344	2298	6.8
Sh09Apr3	-0.6837	1.0795	0.5846	3.2428	4406	4.15
Sh10Aug3	-0.6011	0.6531	-0.4831	0.6767	3581	2.83
Sh11Oct3	-0.4136	0.3621	-0.6906	0.1964	3191	4.33
Sh12Feb3	-0.5013	-0.1687	-0.2345	1.1251	3990	6.94

WISFD

Table 15-4: Weighted eigenvector species scores from the CA on the 1996 species by plot data. The table shows the species weights and the effective number of occurrences of the species (N2 diversity of species) (Hill 1973). The codes for the species are defined in Table 9-1 (p. 210).

Species	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
acac caff	-0.4157	-0.7941	1.2035	-1.1069	34	2
acac exuv	-0.6837	1.0796	0.5849	3.2428	8	1
acac gerr	-0.3492	1.1488	0.7468	1.4218	2742	5.33
acac sieb	-0.4055	-0.0961	-0.2840	0.4471	100	5.52
acac swaz	3.9319	-0.3966	0.4591	0.4256	83	1
acac xant	-0.2135	-0.0272	-0.5569	-0.8545	9	1
albi harv	-0.4013	0.0633	-0.6158	0.9479	68	1
albi vers	-0.2685	-0.9263	1.1003	-0.5493	1081	6.74
anno sene	0.0074	-0.6167	0.5124	-0.1091	1559	10.77
anti veno	0.3859	-0.1863	-0.0332	-0.0728	893	17.29
berc zeyh	-0.3066	-0.6638	1.7126	-2.0653	8	1
bauh galp	2.2744	-0.3977	0.4809	-0.1028	284	2.38
cant spec	3.4139	-0.3557	0.3097	0.3416	458	1.39
cass aeth	0.8899	-0.1529	0.2144	-0.5197	192	6.49
cass tran	0.0455	1.6432	1.3174	-0.9559	174	5.15
catu spin	-0.1244	-0.6341	0.9560	-0.5486	17264	11.28
comb apic	-0.2854	0.2080	-0.2428	0.5898	207	2.61
comb coll	-0.4240	-0.2388	0.8678	0.9094	1669	4.73
comb here	-0.1167	5.2342	2.9371	-0.9636	1066	1.12
comb imbe	-0.6011	0.6531	-0.4830	0.6768	8	1
comb moll	-0.3219	0.1021	0.0710	0.3809	1623	12.82
comb moss	3.9319	-0.3966	0.4591	0.4256	42	1
comm negl	0.6190	0.3987	0.0454	0.7785	42	2.75
crot grat	0.8060	-0.1725	-0.4506	-0.1360	17	1
dalb mela	-0.0579	-0.1373	-0.1374	-0.1235	4285	16.03
dich cine	-0.1840	0.1158	-0.2368	-0.0121	81817	39.27
dios lyci	0.5293	-0.3532	0.2949	0.2577	3492	10.49
dios mesp	0.2412	0.1338	-0.0509	0.0726	1457	15.6
dios whyt	3.9319	-0.3966	0.4591	0.4256	208	1
domb rotu	-0.1552	-0.3103	0.0885	-0.3291	408	6.59
ehre obtu	-0.2086	0.6643	-0.0537	-0.0658	2199	10.38
eucl divi	-0.1579	3.2773	1.7352	-0.4045	748	2.87
eucl nata	1.4436	-0.1113	-0.0379	0.0808	10283	7.58
faur sali	-0.4252	-1.3416	1.9513	-1.3605	8	1
ficu syco	-0.1955	0.3039	-1.1160	-0.3963	8	1
flac indi	-0.2126	-0.4754	1.0687	-1.1316	801	2.97
gard volk	-0.1137	0.4140	-0.7610	-0.2727	24	3
grew flav	0.8753	0.1909	-0.2459	-0.0036	1192	13.13
grew hexa	0.1286	0.2199	-0.6574	-0.7303	17	1.99
grew mont	-0.2034	0.0728	0.0920	-0.1921	825	19.89
hete nata	0.6882	-0.5966	0.4841	-0.0301	125	2.63
hipp pauc	-0.3222	-0.5413	1.2401	-1.4563	1008	2.08
hype amoe	1.3006	-0.0442	-0.2512	0.3457	33	1.58
kige afri	0.1061	0.3790	-0.9025	-0.5279	16	2
krau flor	3.7812	-0.3858	0.4153	0.3985	166	1.1
lann disc	-0.4768	-0.8199	0.8170	-0.5650	100	3.56
lann edul	-0.3225	0.5558	0.0263	-0.5363	82	6.17
lann schw	-0.3644	0.0422	0.3691	1.3134	16	2
lonc capa	-0.4429	-0.4203	0.5595	0.6909	2759	15.24
mark zanz	-0.3853	0.2802	1.0877	2.3248	8	1
mayt hete	-0.2338	0.1050	0.2293	-0.2791	2249	22.52
mayt sene	0.0816	0.1257	-0.1625	-0.1955	23449	24.74
mund seri	-0.3530	-0.0994	0.1634	0.1923	570	8.42
ochn nata	1.7685	0.2924	0.0023	0.0145	7003	4.85
olea euro	3.7968	-0.3950	0.4483	0.3923	1083	1.08
ormo tric	-0.4066	1.5640	0.5229	0.7648	1133	7.1
ozor spha	-0.4227	-0.1105	-0.0108	-0.0131	33	3.99
papp cape	-0.3142	-0.0540	0.2741	-0.2300	173	7.1
pari cura	-0.3606	-0.4805	0.1076	0.3168	2186	8.88
pave schu	-0.3186	-0.5204	0.5280	0.0034	7684	14.77
pelt afri	0.5806	0.0455	-0.2480	0.0188	1152	9.92

WISFD

Species	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
phyl reti	0.3581	0.2552	-0.4356	-0.1501	1060	13.36
pili thon	-0.3838	-0.2128	-0.1536	0.2389	148	10.59
psyd locu	0.4586	0.0686	-0.4785	0.3202	25	1
pter ango	-0.4832	-0.4264	-0.0812	-0.2322	536	4.76
pter rotu	-0.3132	-0.3978	0.9425	-1.4836	16	2
putt pyra	2.7413	-0.4717	0.8112	-0.2741	267	1.68
rhus lept	-0.2419	0.6746	-0.2923	-0.5672	82	4.46
rhus pent	0.2803	2.0132	0.7733	-0.3225	315	5.84
rhus pyro	-0.0900	0.0493	-0.7051	-0.2547	1126	3.38
rhus tran	0.0045	-0.2587	-0.1233	-0.2192	1212	12.92
scho brac	-0.0372	-0.4677	1.0843	-1.4979	74	2.03
scle birr	-0.3068	-0.0684	-0.0319	0.2685	4303	20.12
secu viro	0.3756	0.3502	-0.0441	-0.1083	1102	14.85
senn pete	-0.2915	-0.2608	0.5171	1.1878	10815	15.72
spir afri	0.2272	-0.3895	0.0654	0.0150	16	2
stry mada	-0.0802	-0.0181	-0.1603	0.0890	12537	22.14
stry spin	-0.0947	-0.6047	0.4523	-0.1733	123	5.33
syzy cord	-0.5213	-1.1087	1.5243	0.3380	42	2.75
syzy guin	-0.3181	-0.0508	-0.6111	0.0601	8	1
tare supr	0.4586	0.0686	-0.4785	0.3202	8	1
term seri	-0.1639	0.0132	-0.3192	-0.1049	59298	34.49
tric emet	-0.2868	-0.0929	-0.1994	0.2994	82	6.17
turr nilo	-0.4857	-0.7163	0.7494	0.1997	4813	13.02
vang infa	-0.3458	0.0386	0.0185	0.7617	58	5.37
xime caff	-0.0234	0.0513	-0.2987	0.0738	620	23.99
zant cape	2.9397	-0.2405	0.2341	0.3800	635	1.76
zizi mucr	-0.1544	0.3005	-0.4657	0.0596	856	17.63

WitsETD

Table 15-5: Weighted eigenvector plot scores from the CA on the 1996 species by plot data with the first eight weighted eigenvector axes of the CA on the 1954 species by plot data as covariables. The table also shows the plot weights and the effective number of species that occur on the plots (N2 species diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Plot	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
Fa01Aug2	-0.4204	-0.3054	-0.1137	-0.5282	6805	3.51
Fa02Con0	1.9062	0.2820	-0.8471	-0.9175	9565	6.1
Fa03Dec2	-0.3525	0.1351	-0.0120	0.1957	7739	4.62
Fa04Oct2	-0.2530	0.9969	-0.0352	-0.1085	6406	5.63
Fa05Apr2	-0.4944	-0.1293	-0.2146	-0.2651	6484	4.08
Fa06Feb2	-0.0403	-0.1151	-1.2094	0.9705	6291	9.36
Fa07Aug1	-0.2634	-0.3037	-0.5374	-0.8962	5698	4.8
Fa08Dec3	0.6732	0.4327	-1.0972	-0.5001	6707	5.13
Fa09Aug3	-0.6842	-0.2326	0.2513	-0.3552	6018	3.26
Fa10Oct3	-0.6576	-0.3315	-0.2024	-0.0686	4133	3.39
Fa11Feb3	-0.6494	-0.0240	0.3325	-0.4243	6371	4.5
Fa12Apr3	-0.5852	-0.1394	-0.3266	-0.2662	6555	4.22
Ka01Con0	0.8338	0.4451	-0.7477	0.4159	4983	9.65
Ka02Dec2	-0.1691	-0.8052	-1.5118	1.1263	5958	3.03
Ka03Oct2	-0.2918	0.3024	0.0399	0.3003	2655	4.19
Ka04Feb2	-0.1865	-0.3724	-0.9011	0.7155	10409	4.26
Ka05Aug2	-0.6188	-0.1194	0.5640	0.2462	5548	2.44
Ka06Apr2	-0.3187	-0.2450	0.0832	0.7685	6469	3.21
Ka07Aug1	-0.3314	-0.1369	0.4878	0.2488	6515	3.33
Ka08Feb3	0.1517	0.8090	0.0148	0.0388	6208	5.57
Ka09Oct3	-0.6011	-0.9091	0.0737	-0.1361	5893	4.43
Ka10Dec3	-0.6532	0.4872	-0.1257	0.0164	7157	4.07
Ka11Aug3	-0.3158	-0.6310	1.5039	-1.4621	7381	4.93
Ka12Apr3	0.0851	-0.9208	0.7449	1.1127	6196	3.9
Nu01Oct2	-0.9635	0.0122	-0.2946	-0.1745	3917	9.57
Nu02Dec2	-0.9311	-1.7536	-0.9905	0.5613	5201	4.75
Nu03Feb2	-0.2815	0.8609	0.5812	0.2497	3401	5.35
Nu04Aug2	-0.4505	-0.1872	-0.1970	-0.7133	5951	6.07
Nu05Apr2	-0.6894	-1.2538	-0.5614	-0.0056	5500	4.02
Nu06Aug1	-1.6589	0.8356	-0.1219	-0.9012	7381	5.47
Nu07Con0	3.5345	-0.1480	0.4628	0.3545	14163	9.5
Nu08Dec3	-0.0989	-0.2491	-1.7850	0.2536	3489	11.77
Nu09Oct3	-0.1185	-1.4038	-2.0340	0.1455	6788	8.31
Nu10Feb3	-0.0098	0.6605	-0.6256	-0.5632	5803	5.75
Nu11Apr3	-0.0047	3.5756	1.5703	0.1875	7465	7.64
Nu12Aug3	0.0703	-0.9440	2.2855	3.5636	3889	5.04
Sh01Aug2	-1.0129	-0.5143	1.8813	1.4237	2963	6
Sh02Apr2	0.1867	-1.2422	1.3161	2.2758	2550	4.71
Sh03Aug1	-0.6205	0.0525	2.8251	2.4766	4622	7.78
Sh04Feb2	0.4927	0.2742	-0.2734	0.0447	11649	10.09
Sh05Oct2	-0.4814	2.9924	-0.9822	0.5800	9008	5.3
Sh06Dec2	0.1393	-0.2882	1.2959	-3.2021	7185	10.05
Sh07Con0	0.5670	-0.3637	-0.7526	0.3245	6073	6.78
Sh08Dec3	0.2514	-0.4238	-0.6467	-1.2590	2298	6.8
Sh09Apr3	0.2884	-1.4326	2.7893	-2.2095	4406	4.15
Sh10Aug3	-0.0638	-1.0564	0.6253	-0.4246	3581	2.83
Sh11Oct3	-0.2344	-0.5913	0.3247	-1.1555	3191	4.33
Sh12Feb3	-0.3997	-0.6666	1.2515	0.6181	3990	6.94

WISFD

Table 15-6: Weighted eigenvector species scores from the CA on the 1996 species by plot data with the first eight weighted eigenvector axes of the CA on the 1954 species by plot data as covariables. The table shows the species weights and the effective number of occurrences of the species (N2 diversity of species) (Hill 1973). The codes for the species are defined in Table 9-1 (p. 210).

Species	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
acac caff	-0.0616	1.0857	-0.2318	0.1665	34	2
acac exuv	0.2883	-1.4321	2.7891	-2.2093	8	1
acac gerr	0.1050	-0.4809	1.2502	-1.5815	2742	5.33
acac sieb	-0.5102	-0.6819	0.2783	0.5177	100	5.52
acac swaz	3.5345	-0.1478	0.4628	0.3546	83	1
acac xant	-0.6531	0.4870	-0.1259	0.0164	9	1
albi harv	0.0851	-0.9211	0.7448	1.1127	68	1
albi vers	-0.5809	0.4966	-0.6945	-0.0774	1081	6.74
anno sene	-0.0484	-0.2789	-0.3632	0.1230	1559	10.77
anti veno	0.3840	0.0564	-0.0957	0.0463	893	17.29
berc zeyh	-0.0050	3.5752	1.5703	0.1871	8	1
bauh galp	2.0482	0.2293	0.4482	0.2286	284	2.38
cant spec	3.0875	-0.0648	0.2645	0.3630	458	1.39
cass aeth	0.8617	0.7870	0.3001	0.0042	192	6.49
cass tran	0.0419	0.7737	-0.2192	0.3145	174	5.15
catu spin	-0.3026	0.9988	-0.0838	-0.0250	17264	11.28
comb apic	0.1457	-0.0980	-0.2740	-0.7540	207	2.61
comb coll	-0.3097	-0.0723	0.6597	-1.3841	1669	4.73
comb here	-0.0459	-0.0445	-1.1234	0.9248	1066	1.12
comb imbe	-0.0640	-1.0560	0.6253	-0.4246	8	1
comb moll	-0.1319	-0.4194	0.4396	-0.4372	1623	12.82
comb moss	3.5345	-0.1478	0.4628	0.3546	42	1
comm negl	0.9562	0.0799	-0.0273	-1.7627	42	2.75
crot grat	0.8338	0.4455	-0.7476	0.4158	17	1
dalb mela	-0.0268	0.3424	-0.1947	0.1874	4285	16.03
dich cine	-0.1727	-0.0900	0.1155	-0.0441	81817	39.27
dios lyci	0.5843	0.1939	-0.2337	0.0226	3492	10.49
dios mesp	0.2041	-0.1893	0.1794	-0.0023	1457	15.6
dios whyt	3.5345	-0.1478	0.4628	0.3546	208	1
domb rotu	-0.0690	-0.2821	-0.7920	-0.0086	408	6.59
ehre obtu	-0.2864	-0.1539	0.4955	-0.2522	2199	10.38
eucl divi	-0.1177	-0.1146	-0.4287	0.0599	748	2.87
eucl nata	1.3560	0.0255	-0.0677	0.0579	10283	7.58
faur sali	-1.6588	0.8355	-0.1220	-0.9012	8	1
ficu syco	-0.4203	-0.3055	-0.1137	-0.5283	8	1
flac indi	0.0144	1.7476	0.5934	0.0586	801	2.97
gard volk	-0.2850	-0.2893	0.1969	-0.1837	24	3
grew flav	0.8562	0.0160	-0.0617	-0.2229	1192	13.13
grew hexa	-0.0289	0.4614	-0.5830	-0.2266	17	1.99
grew mont	-0.1414	-0.1522	-0.3466	-0.0107	825	19.89
hete nata	0.8475	-0.7015	-0.9303	0.1251	125	2.63
hipp pauc	-0.1413	2.5295	1.2764	0.3008	1008	2.08
hype amoe	1.2865	-0.3119	-0.4581	0.3316	33	1.58
kige afri	0.0895	0.1517	-0.6559	-0.3826	16	2
krau flor	3.4043	-0.1192	0.4045	0.3575	166	1.1
lann disc	-0.3638	0.3547	-0.3064	-0.4347	100	3.56
lann edul	-0.3085	0.1127	-0.2170	0.0525	82	6.17
lann schw	0.1455	0.2602	0.6553	-1.5817	16	2
lonc capa	-0.2870	-0.2863	0.2801	0.4049	2759	15.24
mark zanz	0.1393	-0.2881	1.2959	-3.2022	8	1
mayt hete	-0.1805	0.3808	0.2652	0.0474	2249	22.52
mayt sene	0.0464	0.1260	-0.1735	-0.1576	23449	24.74
mund seri	-0.1944	0.3537	0.1008	0.5856	570	8.42
ochn nata	1.7369	0.0706	-0.3053	-0.2009	7003	4.85
olea euro	3.4172	-0.1134	0.4264	0.3533	1083	1.08
ormo tric	0.0026	-0.7238	0.2298	0.4489	1133	7.1
ozor spha	-0.2249	0.4250	1.0240	0.5584	33	3.99
papp cape	-0.2668	0.6806	1.0575	-0.0332	173	7.1
pari cura	-0.2512	-0.5388	0.0226	0.3602	2186	8.88
pave schu	-0.2697	-0.2108	-0.4511	0.0777	7684	14.77

WISFD

Species	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
pelt afri	0.4956	-0.0468	-0.0154	0.1629	1152	9.92
phyl reti	0.2945	-0.0622	-0.2002	-0.3293	1060	13.36
pili thon	-0.4042	-0.5423	-0.1099	-0.0665	148	10.59
psyd locu	0.5672	-0.3645	-0.7528	0.3243	25	1
pter ango	-0.3983	-0.5352	-0.8335	-0.0285	536	4.76
pter rotu	-0.1433	2.2179	1.0758	0.2182	16	2
putt pyra	2.5402	0.8979	0.7739	0.3075	267	1.68
rhus lept	-0.3875	0.1565	-0.3643	0.0231	82	4.46
rhus pent	0.3625	-0.0939	-0.6977	0.1088	315	5.84
rhus pyro	-0.1044	-0.2048	-0.5673	0.4074	1126	3.38
rhus tran	0.0146	-0.0710	-0.5268	0.3206	1212	12.92
scho brac	0.1539	2.4338	0.7752	0.0758	74	2.03
scle birr	-0.1897	-0.1428	0.1312	0.2054	4303	20.12
secu viro	0.3963	0.0845	-0.3816	0.1668	1102	14.85
senn pete	-0.0216	-0.1817	0.9129	0.7606	10815	15.72
spir afri	0.2342	-0.3067	-1.2688	0.2888	16	2
stry mada	-0.0627	-0.0529	-0.0707	-0.4458	12537	22.14
stry spin	0.0247	0.3868	-0.1307	-0.1643	123	5.33
syzy cord	-1.1062	0.3623	1.0382	0.6046	42	2.75
syzy guin	-0.2633	-0.3033	-0.5373	-0.8962	8	1
tare supr	0.5672	-0.3645	-0.7528	0.3243	8	1
term seri	-0.2065	-0.1695	-0.1997	0.0619	59298	34.49
tric emet	-0.2604	-0.3617	0.1958	0.0491	82	6.17
turr nilo	-0.4295	0.0853	0.1317	0.4085	4813	13.02
vang infa	-0.2613	-0.0289	0.6150	-0.8236	58	5.37
xime caff	-0.0581	-0.1287	0.0424	-0.0586	620	23.99
zant cape	2.6549	-0.1735	0.4587	0.2294	635	1.76
zizi mucr	-0.1573	-0.2215	0.1947	0.0156	856	17.63

WitsETD

Table 15-7: Weighted eigenvector plot scores from the CA on the 1954 structure by plot data. The table also shows the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Plot	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
Fa01Aug2	-1.4636	-1.1334	0.2559	-1.0090	2380	3.13
Fa02Con0	-1.1600	0.0741	0.7975	-0.1494	1658	3.51
Fa03Dec2	-1.4590	-0.4693	0.1875	-0.0874	2934	3.03
Fa04Oct2	-1.3008	-1.2027	0.2395	0.4741	2260	3.52
Fa05Apr2	-1.2047	-1.3435	1.5120	-0.8944	2347	3.97
Fa06Feb2	-1.5471	0.1418	-1.3498	-0.7114	3165	2.08
Fa07Aug1	-0.7757	-2.2766	1.0212	-0.3603	2693	5.61
Fa08Dec3	0.5709	0.3380	0.9811	0.1488	1972	5.34
Fa09Aug3	0.5640	-0.8481	-0.3779	-0.5965	1980	4.49
Fa10Oct3	0.6225	-1.5887	0.6778	1.9661	833	5.43
Fa11Feb3	0.8984	-2.1054	0.4228	-1.5144	3832	4.19
Fa12Apr3	1.0354	0.1729	0.1275	-0.3661	2002	4.17
Ka01Con0	-0.3392	-1.4346	2.0477	4.2887	830	7.25
Ka02Dec2	-0.9294	1.7003	-0.9206	0.0670	989	2.47
Ka03Oct2	1.3203	0.1481	0.1896	1.3058	2185	3.47
Ka04Feb2	0.8453	0.3729	0.1181	-1.0656	1411	4.16
Ka05Aug2	0.5786	1.8538	3.6962	-1.5023	1562	5.33
Ka06Apr2	-0.7533	0.7841	0.7994	0.8286	1504	3.98
Ka07Aug1	-0.3689	2.5492	3.3111	-1.5463	2337	4.29
Ka08Feb3	0.8067	0.0828	0.0221	0.2490	1411	4.3
Ka09Oct3	1.4691	0.6858	1.4434	0.8142	1330	3.29
Ka10Dec3	1.7511	0.2683	0.0935	0.4487	2931	3.05
Ka11Aug3	1.0938	-0.5494	0.1611	0.1706	3338	4.1
Ka12Apr3	1.0281	0.3901	-0.4327	0.2403	2320	3.66
Nu01Oct2	-1.0410	0.9041	-0.4090	1.0430	2143	2.77
Nu02Dec2	-1.0957	1.0050	-0.1879	1.1141	1659	2.66
Nu03Feb2	-0.9317	0.3774	-1.1207	-0.0980	399	3.34
Nu04Aug2	-0.9445	-0.9396	0.0226	0.1468	2614	3.84
Nu05Apr2	-1.0299	-0.2457	0.4377	3.5015	2347	3.77
Nu06Aug1	-1.2180	0.4260	-0.6833	-0.4801	2218	2.6
Nu07Con0	-1.4348	0.6461	-0.4104	0.4126	1897	2.4
Nu08Dec3	0.4561	0.5563	-1.0630	-0.2865	2175	3.8
Nu09Oct3	0.8232	0.0318	0.0528	0.8677	2068	4.24
Nu10Feb3	1.6378	-0.6014	-0.6419	-0.0794	2809	3.01
Nu11Apr3	0.7664	0.2970	0.3991	0.7131	1648	4.56
Nu12Aug3	0.0966	-0.0188	-1.4362	-1.1266	1881	3.57
Sh01Aug2	-0.4683	1.1403	-0.8208	-0.9220	3175	3.19
Sh02Apr2	0.1778	-0.0978	-1.1053	-0.8882	2821	3.61
Sh03Aug1	-0.4827	-1.0386	-0.2055	0.0659	2057	4.53
Sh04Feb2	0.6717	0.3363	-0.4862	0.3144	4650	4
Sh05Oct2	-0.6049	1.5454	-0.6919	0.4880	2572	2.79
Sh06Dec2	-0.4064	1.0929	-1.1783	-0.5657	1066	2.97
Sh07Con0	-0.3835	0.7190	-0.4946	-0.1852	2498	3.65
Sh08Dec3	0.8342	0.2664	-1.5045	-0.4439	2099	3.2
Sh09Apr3	0.3135	0.6686	-0.6261	0.3686	1463	3.69
Sh10Aug3	0.6351	-0.4288	-0.2673	-1.0243	895	4.2
Sh11Oct3	0.9822	0.3192	-0.4310	-0.1171	1035	3.74
Sh12Feb3	1.0028	-0.3900	-0.0891	0.7173	2108	4.03

WISFD

Table 15-8: Weighted eigenvector structure scores from the CA on the 1954 structure by plot data. The table shows the structure weights and the effective number of occurrences of the structures (N2 diversity of structures) (Hill 1973). The codes for the structure groups are defined in Table 5-3 (p. 34).

Structure	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
H01_S01	0.5360	-0.0196	-0.0762	-0.0087	25029	30.43
H01_S13	0.0442	0.0492	0.1910	0.4418	709	24.06
H01_S3	-0.0565	0.0215	-0.0984	-0.1285	349	15.2
H01_T01	-0.4785	0.1260	-0.1001	-0.0186	35183	33.88
H01_T13	-0.4990	-0.5174	-0.1129	0.0429	1343	21.79
H01_T35	-0.6466	-0.0935	0.0766	0.0822	165	13.24
H01_T57	0.2073	0.1075	0.0266	-0.1974	209	17.19
H01_T7	-0.1594	0.4617	0.0441	0.0107	251	14.49
H13_S01	0.5985	0.0236	0.0317	-0.0144	16224	29.58
H13_S13	0.0684	0.3276	0.4812	0.2846	2071	30.35
H13_S3	0.2442	0.1013	0.5683	-0.0585	760	22.66
H13_T01	-0.5119	0.0256	0.2112	-0.1936	3954	29.41
H13_T13	-0.3470	-0.5550	0.1343	-0.1294	6300	25.92
H13_T35	-0.4441	-0.2086	0.1703	0.6383	1873	26.02
H13_T57	-0.2555	-0.0362	0.1519	0.0396	239	8.43
H13_T7	-0.6520	-0.3874	1.2179	0.0219	66	4.5
H35_S01	0.8857	0.0056	0.1178	-0.1044	814	16.81
H35_S13	-0.2117	0.9512	1.0088	0.2862	132	10.29
H5_S3	-0.0333	1.8511	2.6464	-1.0163	130	3.3
H35_T13	-0.4636	-1.6894	0.6647	-0.7442	109	5.05
H35_T35	-0.4702	-0.4217	0.2332	0.1632	1278	24.57
H35_T57	-0.2166	-0.1792	0.2395	0.3238	954	27.49
H35_T7	-0.4791	0.0833	0.5229	-0.2819	479	18.81
H5_S01	1.2886	-0.1365	-0.2184	0.2126	44	4
H5_T01	-1.5471	0.1419	-1.3497	-0.7154	11	1
H5_T35	-0.5386	-0.6492	0.1643	-0.0975	143	11.27
H5_T57	-0.3802	-0.1407	-0.0302	0.3531	165	11.84
H5_T7	-0.1384	-0.0843	-0.0161	0.3069	1517	32.52

WitSETD

Table 15-9: Weighted eigenvector plot scores from the CA on the 1996 structure by plot data. The table also shows the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Plot code	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
Fa01Aug2	-1.3514	0.2488	1.7999	-0.1233	6808	2.91
Fa02Con0	0.476	-0.081	0.1822	0.0805	9567	4.11
Fa03Dec2	-0.358	-0.4344	0.5258	0.0501	7743	3.2
Fa04Oct2	-0.151	0.3764	-0.5065	0.7144	6407	4.36
Fa05Apr2	0.6854	0.0872	0.0526	-0.1335	6479	4.32
Fa06Feb2	-0.2363	-1.298	-0.7769	0.0501	6290	2.95
Fa07Aug1	-2.032	-1.074	1.5428	-0.223	5699	1.93
Fa08Dec3	0.6545	-0.0915	0.5357	0.6091	6710	4.43
Fa09Aug3	-0.7225	2.2731	-0.0085	-0.5253	6015	3.14
Fa10Oct3	0.6819	1.0772	-0.1045	0.0737	4135	4.28
Fa11Feb3	0.6467	-0.7801	-0.2676	-0.8046	6372	3.84
Fa12Apr3	0.2884	0.4751	-0.0136	0.7573	6559	4.07
Ka01Con0	2.3077	-0.0462	2.577	-2.0352	4986	5.87
Ka02Dec2	0.4942	-0.5663	-1.2284	0.1264	5958	3.57
Ka03Oct2	-0.2448	1.9363	-0.693	-0.4338	2659	4.14
Ka04Feb2	0.1294	0.1864	-0.739	0.292	10409	3.88
Ka05Aug2	-0.9914	3.0379	-0.0033	-1.1085	5549	2.43
Ka06Apr2	0.7032	0.8666	-0.2193	0.1317	6466	4.2
Ka07Aug1	-1.6155	0.6745	0.9058	-0.6527	6515	2.88
Ka08Feb3	0.4104	-0.7096	-1.0622	-0.134	6206	3.75
Ka09Oct3	0.0196	2.0542	-0.2595	0.3381	5893	3.53
Ka10Dec3	1.3411	0.387	2.5936	4.8397	7154	5.22
Ka11Aug3	0.0362	1.6554	0.2831	0.462	7381	3.93
Ka12Apr3	0.7082	0.75	-0.4115	-0.0731	6195	4.07
Nu01Oct2	-0.3698	-0.2262	-0.6597	-0.245	3914	3.91
Nu02Dec2	-0.3627	-0.3227	-0.4211	0.0489	5200	3.6
Nu03Feb2	-0.6686	-0.4936	0.6385	-0.1032	3399	2.73
Nu04Aug2	-1.4697	-0.0831	0.3411	-0.3756	5951	2.69
Nu05Apr2	0.2515	0.7666	-0.568	-0.0629	5498	3.78
Nu06Aug1	-2.2473	-1.3338	1.6843	-0.1856	7381	1.68
Nu07Con0	1.782	-0.7164	-0.0366	-0.3426	14166	4.45
Nu08Dec3	0.873	-0.6641	-0.5434	-0.1516	3489	4.16
Nu09Oct3	-0.1393	-0.3549	-0.8629	0.1942	6790	3.66
Nu10Feb3	0.3247	-0.0243	-0.2037	-0.09	5799	4.13
Nu11Apr3	-0.2421	-0.5522	-0.5271	0.2105	7464	3.21
Nu12Aug3	0.1074	-0.7145	-2.1277	0.7743	3890	3.12
Sh01Aug2	-0.6016	0.3176	-0.1842	-0.4869	2965	3.76
Sh02Apr2	0.0014	-0.5061	-0.867	-0.1841	2550	3.41
Sh03Aug1	-1.7778	-1.4619	1.3137	-0.0783	4624	2.06
Sh04Feb2	-0.3514	-1.0126	-0.8992	0.4089	11649	3.02
Sh05Oct2	-1.0844	-0.6931	-0.5129	0.0105	9009	2.86
Sh06Dec2	-0.0098	-1.2954	-1.0772	0.2938	7184	3.09
Sh07Con0	2.2809	-0.6805	2.3034	-2.968	6074	5.59
Sh08Dec3	-0.5216	0.479	0.1102	-0.6521	2301	3.47
Sh09Apr3	0.4058	-0.1981	-0.0997	-0.7386	4405	3.93
Sh10Aug3	-0.4	2.4412	-0.8288	-1.0943	3581	3.46
Sh11Oct3	-0.2488	1.3889	-0.9564	0.109	3190	3.81
Sh12Feb3	0.2492	-0.5293	-1.5448	0.2104	3989	3.57

WISFD

Table 15-10: Weighted eigenvector structure scores from the CA on the 1996 structure by plot data. The table shows the structure weights and the effective number of occurrences of the structures (N2 diversity of structures) (Hill 1973). The codes for the structure groups are defined in Table 5-3 (p. 34).

Structure code	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
H01_S01	-0.2659	-0.1729	0.0637	0.0063	110183	38.13
H01_S13	-0.8594	-0.1838	0.3302	-0.1028	2239	21.09
H01_S3	-1.0549	-0.2747	0.3823	-0.1341	334	14.39
H01_T01	0.2461	-0.2259	-0.1762	0.0282	67226	34.11
H01_T13	0.2855	-0.104	-0.0213	-0.1866	1311	30.25
H01_T35	0.8247	0.2793	1.3353	0.2284	91	6.3
H01_T57	1.3412	0.3865	2.5936	4.837	9	1
H01_T7	-0.8293	-0.2669	0.5341	0.0311	73	7.23
H13_S01	-0.0189	0.4489	-0.0429	-0.0152	66335	38.51
H13_S13	-0.3687	0.4499	-0.1525	-0.1449	6275	30.74
H13_S3	-0.2044	0.2122	-0.2768	0.0193	649	24.14
H13_T01	0.6291	-0.0144	0.054	0.0516	9441	20.57
H13_T13	0.6611	0.0146	0.1935	-0.0624	10478	26.62
H13_T35	0.8196	-0.1599	0.4992	-0.6037	1418	15.9
H13_T57	0.5892	-0.3911	0.0323	-0.3747	332	13.95
H13_T7	0.7077	-0.2927	0.5244	0.0499	183	13.29
H35_S01	0.276	0.4475	0.3333	0.3485	3854	25.61
H35_S13	-0.0938	0.4281	0.0342	0.1512	1332	26.82
H35_S3	0.195	-0.4428	-0.1406	-0.0461	91	6.98
H35_T01	0.5001	0.3017	0.1929	-0.1317	49	4.41
H35_T13	1.0929	0.1867	1.4116	1.6891	512	4.94
H35_T35	0.8429	-0.1064	0.6671	-0.443	1218	14.27
H35_T57	0.8648	-0.2401	0.7208	-0.7662	1092	13.63
H35_T7	0.4954	-0.104	0.4296	-0.3543	599	20.34
H5_S01	0.0311	0.1734	0.0239	0.4568	425	14.65
H5_S13	-0.2301	0.2479	-0.0799	0.176	467	19.21
H5_S3	-0.8791	0.2962	0.527	0.1286	16	2
H5_T01	0.3988	0.0114	0.226	1.1181	41	4.99
H5_T13	0.7637	-0.3779	-0.0038	0.2312	16	2
H5_T35	0.7788	-0.0943	0.209	0.0184	200	5.31
H5_T57	0.0938	0.306	0.423	-0.0634	599	13.41
H5_T7	0.0207	0.1662	0.1536	-0.1286	1529	32.76

WitsETD

Table 15-11: Weighted eigenvector plot scores from the CA on the 1996 structure by plot data with the first eight weighted eigenvector axes of the 1954 CA of the structure data as covariables. The table also shows the plot weights and the effective number of structural groups that occur on the plots (N2 structural diversity of plots) (Hill 1973). The codes for the treatment plots are defined in Table 10-1 (p. 214).

Plot code	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
Fa01Aug2	-1.0476	0.5754	1.613	-0.4608	6808	2.91
Fa02Con0	0.1842	0.0809	0.1037	0.212	9567	4.11
Fa03Dec2	-0.4197	-0.1715	-0.2136	0.2296	7743	3.2
Fa04Oct2	0.0114	1.0127	-0.5575	2.2382	6407	4.36
Fa05Apr2	1.7381	0.5422	-0.2599	0.9447	6479	4.32
Fa06Feb2	0.5001	-0.4869	-0.4013	0.2607	6290	2.95
Fa07Aug1	-1.9003	-1.5635	-0.1247	-0.2762	5699	1.93
Fa08Dec3	0.2019	-0.2184	-0.2296	1.6543	6710	4.43
Fa09Aug3	-0.7777	2.4159	0.6147	-0.68	6015	3.14
Fa10Oct3	0.3202	0.6619	-0.5385	0.4088	4135	4.28
Fa11Feb3	1.965	-1.1893	-0.3726	-0.7767	6372	3.84
Fa12Apr3	-0.0003	-0.1048	0.1622	-0.0945	6559	4.07
Ka01Con0	1.0965	-1.1796	0.698	-2.5829	4986	5.87
Ka02Dec2	0.515	-0.0539	-0.5448	-0.2119	5958	3.57
Ka03Oct2	-1.3235	2.0432	-0.0727	-0.0143	2659	4.14
Ka04Feb2	-0.0557	-0.3132	-1.499	-0.2904	10409	3.88
Ka05Aug2	-0.0509	0.771	-0.9935	-1.0955	5549	2.43
Ka06Apr2	-0.43	0.8726	-0.726	-0.1915	6466	4.2
Ka07Aug1	-0.3562	-1.1633	0.402	-0.0843	6515	2.88
Ka08Feb3	0.0025	-0.8531	-1.4196	-0.3247	6206	3.75
Ka09Oct3	-0.0152	1.9625	1.4275	1.1487	5893	3.53
Ka10Dec3	0.5151	-1.884	3.1089	2.9952	7154	5.22
Ka11Aug3	-0.1741	1.4209	1.0281	0.4006	7381	3.93
Ka12Apr3	0.4894	0.9634	0.298	-0.5018	6195	4.07
Nu01Oct2	-1.0139	0.0137	-0.5319	-0.4097	3914	3.91
Nu02Dec2	-0.3846	0.1707	-1.3784	1.2998	5200	3.6
Nu03Feb2	-0.6441	0.5793	-0.2107	-0.0548	3399	2.73
Nu04Aug2	-1.1426	0.3913	-0.0527	0.4935	5951	2.69
Nu05Apr2	-0.2703	0.6991	-1.1438	-0.0014	5498	3.78
Nu06Aug1	-1.7502	-1.2382	1.7324	-0.7878	7381	1.68
Nu07Con0	2.2108	0.0685	0.4601	0.3799	14166	4.45
Nu08Dec3	1.1664	-0.4362	-0.0378	-0.138	3489	4.16
Nu09Oct3	-0.3725	-0.6869	-0.3968	-0.1935	6790	3.66
Nu10Feb3	0.4303	-1.0588	-0.6954	-1.6043	5799	4.13
Nu11Apr3	-0.5317	-0.5829	-0.1148	0.1916	7464	3.21
Nu12Aug3	0.7829	0.0002	-1.9587	1.4716	3890	3.12
Sh01Aug2	-0.9455	0.8431	0.1552	-1.189	2965	3.76
Sh02Apr2	0.4063	0.6961	-0.3039	0.0614	2550	3.41
Sh03Aug1	-1.7586	-1.41	1.0511	-0.7211	4624	2.06
Sh04Feb2	-0.5032	-1.0157	-0.6757	0.0886	11649	3.02
Sh05Oct2	-1.2029	-0.2833	0.5085	-0.2102	9009	2.86
Sh06Dec2	0.1435	-0.438	-0.4824	0.5787	7184	3.09
Sh07Con0	2.4061	0.5236	1.6267	-2.6023	6074	5.59
Sh08Dec3	-0.5148	1.0976	1.3861	-1.318	2301	3.47
Sh09Apr3	0.4329	0.14	0.8194	-1.3276	4405	3.93
Sh10Aug3	-0.5368	3.0119	-0.2314	-0.54	3581	3.46
Sh11Oct3	-0.8414	1.7812	-0.1009	0.0987	3190	3.81
Sh12Feb3	-0.0493	-0.9383	-2.3309	0.2263	3989	3.57

WISFD

Table 15-12: Weighted eigenvector structure scores from the CA on the 1996 data with the first eight weighted eigenvector axes of the 1954 CA of the structure data as covariables. The table shows the structure weights and the effective number of occurrences of the structures (N2 diversity of structures) (Hill 1973). The codes for the structure groups are defined in Table 5-3 (p. 34).

Structure code	Axis 1	Axis 2	Axis 3	Axis 4	Weight	N2
H01_S01	-0.2176	-0.1523	0.0323	-0.0172	110183	38.13
H01_S13	-0.7061	-0.2304	0.2052	-0.1157	2239	21.09
H01_S3	-0.8669	-0.3202	0.2163	-0.1735	334	14.39
H01_T01	0.2335	-0.1209	-0.1454	0.0452	67226	34.11
H01_T13	0.1824	-0.0602	-0.1485	-0.2341	1311	30.25
H01_T35	0.3493	-0.4656	0.767	-0.2604	91	6.3
H01_T57	0.5151	-1.8843	3.1089	2.994	9	1
H01_T7	-0.5545	-0.3593	0.4349	0.1326	73	7.23
H13_S01	-0.0507	0.3299	-0.0092	-0.0039	66335	38.51
H13_S13	-0.3171	0.3806	-0.0289	-0.0025	6275	30.74
H13_S3	-0.2499	0.2643	-0.1891	0.1279	649	24.14
H13_T01	0.5497	0.0469	0.1005	0.1256	9441	20.57
H13_T13	0.5393	0.0074	0.1627	-0.0947	10478	26.62
H13_T35	0.7753	0.0081	0.3048	-0.5024	1418	15.9
H13_T57	0.7234	-0.0812	0.0407	-0.131	332	13.95
H13_T7	0.6127	-0.4405	0.2221	-0.0407	183	13.29
H35_S01	0.1127	0.2535	0.3897	0.2502	3854	25.61
H35_S13	-0.1806	0.3212	0.0928	0.2506	1332	26.82
H35_S3	0.1241	-0.2086	-0.4152	0.101	91	6.98
H35_T01	0.5235	0.0971	-0.016	0.2774	49	4.41
H35_T13	0.7044	-0.6805	1.4495	1.2169	512	4.94
H35_T35	0.8744	-0.1342	0.4158	-0.4302	1218	14.27
H35_T57	0.8679	-0.0528	0.4025	-0.7006	1092	13.63
H35_T7	0.4774	-0.0885	0.2202	-0.3148	599	20.34
H5_S01	-0.0479	-0.0322	-0.0334	0.2624	425	14.65
H5_S13	-0.1935	0.0708	-0.0234	0.1531	467	19.21
H5_S3	-0.8869	0.2765	1.2393	0.2138	16	2
H5_T01	0.2611	-0.6042	0.3921	0.4091	41	4.99
H5_T13	0.6842	-0.3277	-0.1336	0.7624	16	2
H5_T35	0.8618	-0.3331	-0.1225	-0.3844	200	5.31
H5_T57	0.1451	-0.0403	0.0351	-0.2015	599	13.41
H5_T7	0.0588	0.1085	0.0707	-0.1685	1529	32.76

WiSETD

16 APPENDIX 8: ATMOSPHERIC CO_2 RECORDS FROM SITES IN THE SCRIPPS INSTITUTION OF OCEANOGRAPHY (SIO) AIR SAMPLING NETWORK FROM 1958 TO 2003

The data presented in Table 16-1 was compiled from ten SIO sites where atmospheric CO_2 levels have been monitored over the past half a century (Keeling and Whorf 2004). The SIO data is available on the web at the Carbon Dioxide Information Analysis Center (CDIAC) (http://cdiac.esd.ornl.gov), which is considered the primary centre for global-change data and information analysis (Anon. 2004). The data comprises the annual average concentration of atmospheric CO_2 in parts per million by volume (ppmv) as determined using flask samples collected at each of the sites (Keeling and Whorf 2004).

Table 16-1: The mean annual atmospheric CO_2 levels (ppmv) at ten Scripps Institution of Oceanography (SIO) air sampling sites between 1958 and 2003 (Keeling and Whorf 2004).

Year	Alert	American Samoa	Baring Head	Point Barrow	Cape Kumukahi	Christmas Island	Kermadec Islands	La Jolla Pier	Mauna Loa	South Pole	Average
1958										314.78	314.78
1959									316.00	315.64	315.82
1960									316.91	316.45	316.68
1961									317.63	317.08	317.36
1962									318.46	317.62	318.04
1963									319.02	318.35	318.69
1964									319.52	318.68	319.10
1965									320.09	319.42	319.76
1966									321.34	320.72	321.03
1967									322.13	321.32	321.73
1968									323.11	321.91	322.51
1969									324.60	323.12	323.86
1970								326.86	325.65	324.32	325.61
1971								327.49	326.32	325.12	326.31
1972								328.15	327.52	326.00	327.22
1973						329.96		330.20	329.61	327.62	329.35
1974				332.77		330.54		331.49	330.29	328.49	330.72
1975				333.28		331.60		332.14	331.16	329.50	331.54
1976				334.15		332.58		333.16	332.18	330.60	332.53
1977				335.31		334.26		334.79	333.88	332.03	334.05
1978			333.79	336.99		335.68		336.30	335.52	333.69	335.33
1979			335.16	338.42		337.33		338.02	336.89	335.03	336.81
1980			336.85	340.15	339.10	339.17		339.58	338.67	336.98	338.64
1981			338.26	341.39	340.27	340.32		341.08	339.95	338.26	339.93
1982		340.58	339.39	342.51	341.32	341.43		341.88	341.09	339.39	340.95
1983		342.11	340.95	344.07	342.84	343.33	341.39	343.48	342.75	341.17	342.45
1984		343.83	342.19	345.65	344.58	344.73	342.86	345.36	344.44	342.58	344.02
1985		345.28	343.48	346.98	345.91	345.94	344.10	346.51	345.86	343.82	345.32
1986	348.47	346.37	345.10	348.60	347.45	347.18	345.54	347.74	347.14	345.32	346.89
1987	349.94	347.97	346.82	350.05	349.33	349.07	347.57	349.64	348.99	346.99	348.64
1988	352.71	350.11	348.72	352.94	351.67	351.46	349.52	352.35	351.44	348.95	350.99
1989	355.05	351.59	350.37	355.34	353.14	352.95	350.86	353.56	352.94	350.44	352.62

WITSETD

Year	Alert	American Samoa	Baring Head	Point Barrow	Cape Kumukahi	Christmas Island	Kermadec Islands	La Jolla Pier	Mauna Loa	South Pole	Average
1990	355.86	353.02	351.58	356.26	354.87	354.13	352.26	354.86	354.19	351.77	353.88
1991	357.30	354.28	352.84	357.38	356.04	355.32	353.55	356.38	355.62	353.12	355.18
1992	357.91	355.23	354.04	357.88	356.73	356.33	354.71	356.80	356.36	354.24	356.02
1993	358.15	356.11	354.97	358.28	357.53	357.41	355.56	357.66	357.10	355.16	356.79
1994	359.84	357.74	356.44	359.78	359.30	359.15	357.08	359.38	358.86	356.48	358.41
1995	361.83	359.69	357.95	362.09	361.18	361.13	358.89	361.26	360.90	358.35	360.33
1996	363.77	361.23	359.63	364.07	362.9	363.09	360.27	363.02	362.58	359.99	362.06
1997	364.73	362.28	361.13	365.06	364.34	364.15	361.82	364.12	363.84	361.2	363.27
1998	367.27	364.79	363.61	367.36	366.92	366.72	364.23	366.89	366.58	363.7	365.81
1999	369.34	366.99	365.4	369.76	368.44	368.54	366.29	368.75	368.3	365.65	367.75
2000	370.79	368.21	366.61	370.82	370.12	370.05	367.19	369.84	369.47	367.05	369.02
2001	372.11	369.91	368.17	372.38	371.64	371.51	368.78	371.4	371.03	368.34	370.53
2002	374.09	371.94	370.57	374.49	373.39	373.79	371.33	373.28	373.07	370.66	372.66
2003	377.05	374.17		376.99	376.04	375.93		375.98	375.61	372.77	375.57

WitsETD

17 APPENDIX 9: CONFERENCE TALKS, POSTERS, AND PAPERS PUBLISHED

Four talks and one poster were presented at various research conferences on the woody vegetation data collected on the Pretoriuskop EBPs. These papers and posters are presented below in chronological order from the first presentation in January 1998 to the last presentation in February 2003. One peer-reviewed paper was collaborated on regarding the fire history of the KNP between 1941 and 1996. This paper is presented last.

17.1 THE LONG-TERM EFFECT OF FIRE FREQUENCY AND SEASON ON THE TREES AND SHRUBS IN THE SOURVELD SAVANNAS OF THE KRUGER NATIONAL PARK.

This paper was presented as a talk at the South African Association of Botanists (SAAB) Conference. Cape Town, January 1998.

SP O'Regan & ETF Witkowski

Abstract

In the Kruger National Park (KNP), a fire experiment has been running since 1954. The experimental layout was a randomised block design in which twelve treatments were replicated four times each in four of the six major veld types defined in by Van Der Schijff (1958). One of the distinct veld types is the sourveld bushveld of Pretoriuskop in which this study was conducted. Twelve fire treatments comprising a control (no burn), and annual, biennial and triennial burns at different times of the year were applied to 6 hectare plots for 42 years. The trees and shrubs each plot were surveyed using belt transects before the commencement of the experiment. This data serves as a baseline and control to the experiment. All plots were re-surveyed between May 1996 and September 1997. The effects of the different fire frequencies on the structure of the tree and shrub community within the lowveld sourveld will be presented. Furthermore, the significance of these data in interpreting the effects of past fire management policies in the Pretoriuskop region will also be discussed.

Introduction

Savannas are tropical grasslands with scattered trees (Bourliere and Hadley 1970). They are dynamic in their structure and composition, and are affected by fluctuations in rainfall, levels of herbivory, and the fire regime. The role of fire in savannas is generally accepted as being one of mediating the co-existence between trees and grass (Scholes and Walker 1993). In terms of savanna management, though the role of fire has historically been a controversial topic. This is primarily because it has been traditionally viewed and applied as powerful management tool instead of as an ecosystem process.

In the KNP in the early 1950's controversy surrounded the formulation and implementation of a fire management policy (Annual report 1951). In response to the evident lack in understanding the role of fire in the lowveld savannas, the National Parks Board initiated a fire research experiment (Annual report 1953).

An introduction to the KNP fire research experiment

The primary objective of the KNP fire research experiment when it was started was to provide a "scientific" basis for the fire management policies in the Park. Specifically, the aim was to determine the fire regime,

WITS ETD

based on frequency and season of fire occurrence, most appropriate to maintaining the desired vegetation structure within four major veld types defined at the time within the KNP.

The four major veld types in which the experiment was laid out were:

1. The *Terminalia* - *Dichrostachys* sourveld with long grass of Pretoriuskop.
2. The *Combretu*m veld between Skukuza and Pretoriuskop.
3. The Knob-thorn - Marula veld near Satara.
4. The Mopane veld between Shingwedzi and Letaba.

The experimental design

The experimental design was a randomised block design in which 12 treatments were replicated four times within each veld type. The twelve treatments comprised a control and combinations of three frequencies (namely annual, biennial, and triennial burns) burnt at five different times of the year, namely February, April, August, October, and December. The treatments were applied to plots approximately 6ha in size.

For clarity, “block” refers to a replicate of treatment plots, while “plot” refers to the area within each block to which each treatment was applied.

This study was concerned with the plots located in the sourveld savanna of Pretoriuskop.

Aims and Objectives

The aim of this study was to investigate the long-term effects of different fire treatments on the tree and shrub community structure and composition in the Pretoriuskop sourveld savannas of the Kruger National Park (KNP).

The objectives of this study can be divided into two broad categories, working objectives and analytical objectives. The working objectives involve the collection and capturing of data. The analytical objectives involve the analysis, and assimilation of the data.

Study area

Area description

The Pretoriuskop area is located in the south-west of the KNP, and experiences relatively high average annual rainfall of 744mm (Gertenbach 1980a). The terrain is moderately undulating, with the vegetation on the watersheds being open woodland, while the low-lying areas and drainage lines are more densely covered with trees and shrubby vegetation (Gertenbach 1983, Munnick *et al.* 1990). The dominant tree species in this area are *Terminalia sericea* and *Dichrostachys cinerea* subsp. *nyassana* (Gertenbach 1983). The dominant grass species is *Hyperthelia dissoluta* (Gertenbach 1983).

The layout of plots in the Pretoriuskop area

Four blocks of twelve plots were located in the Pretoriuskop sourveld. They were spread out within this veld type, one being placed on the Fayi, loop, another below Kambeni Hill, the third near Shabeni koppie and the last near Numbi Gate (Figure 17-1).

Methods and materials

A number of surveys of the woody vegetation were done on the plots between 1954 and 1996. The data collected in 1954 and in 1996 are presented here.

WITSETD

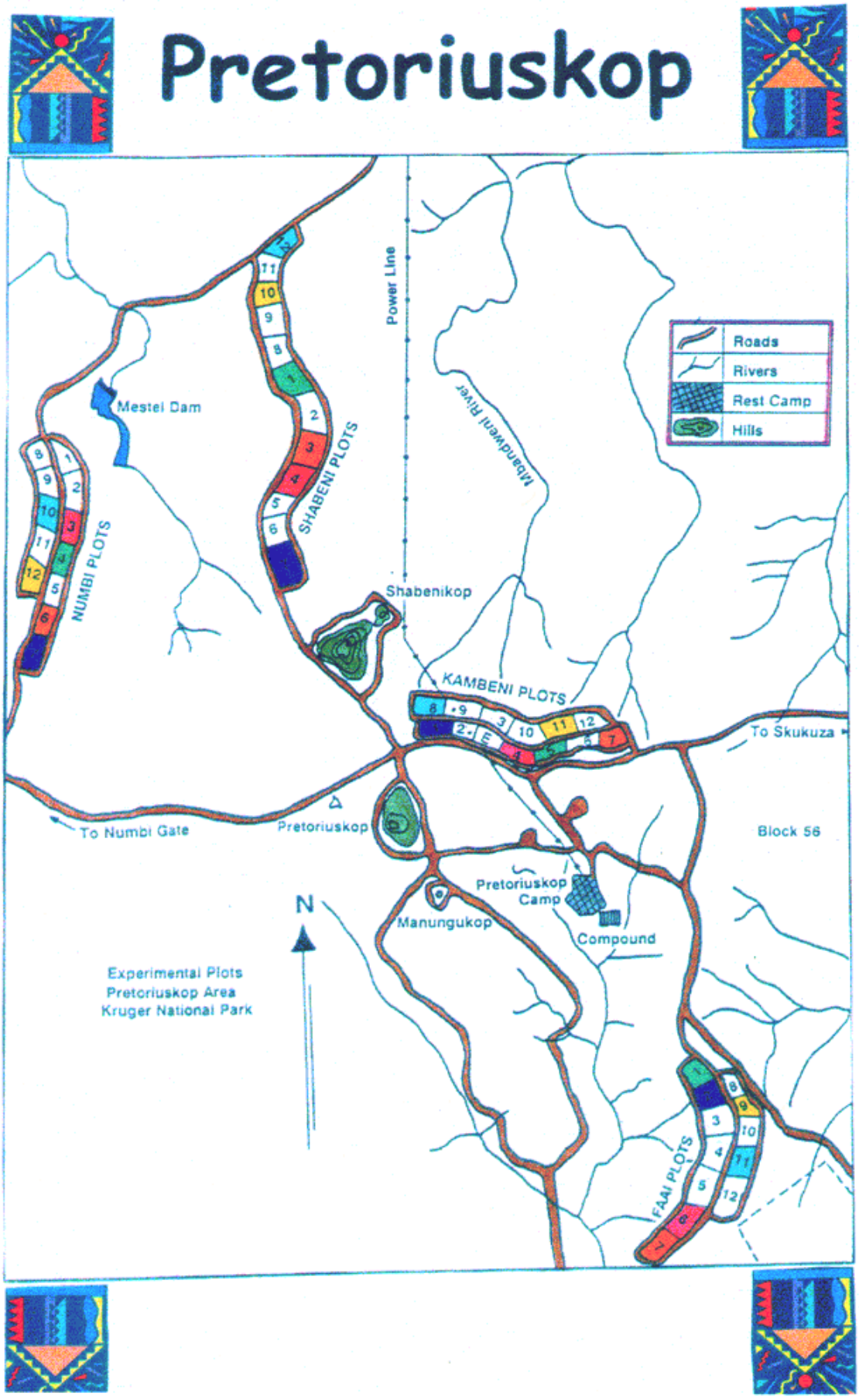


Figure 17-1: Layout of the four blocks of plots in the Pretoriuskop landscape, showing the placement of the six treatments focused on in this presentation.

The 1954 and 1996 surveys were conducted in a similar fashion namely transects were placed along the diagonals of each of the plots. The surveys comprised the measuring the height and coppice or stem diameters for each individual within each transect. However, the height measurements were not recorded in 1954.

These data represent the start and end of a period covering some 42 years of treatment application.

In this presentation six of the twelve treatments are focused on, namely the control, the August annual, biennial, and triennial treatments, and the February biennial and triennial treatments. These treatments comprise four different fire return periods (no fire, annual fires, biennial fires, and triennial fires) at two different times of the year (February and August).

Characteristics of the fire treatments and anecdotal post fire regeneration notes

Generally, the August treatments tend to be clean-burnt intense fires. *Panicum maximum* (Buffalo grass) found under large trees is dry in August and so these fires tend to scorch the trunks and the lower branches of large trees. Topkill of shrubs in August treatments is very high. Grazing, browsing, and trampling of shoots (both herbaceous and woody) is higher after the August treatments than a February treatments, because the first rains usually occur in October, and post fire regeneration and recovery of vegetation is slower than in February.

Generally, the February treatments are less intense than the August burns, they tend to be slow burning and range from patchy to relatively clean, and topkill of shrubs is low but can be high. Buffalo grass (*Panicum maximum*) growing under the large trees is green this time of the year and so the trees and under canopy seedlings are protected from the fires. Regeneration and recovery is relatively quick if rains continue into the autumn. If the rains end early in the wet season the plots are then heavily grazed and browsed through out the dry season and only gain a grass sward in the following wet season.

The frequency of the treatments affects the fire intensity because the longer inter-fire period (i.e. 3 years) the greater the build up of moribund plant material (fuel load). Therefore, treatments with an inter-fire period of 3 years tend to be more intense than treatments with an inter-fire period of 2 years at the same time of the year.

Analyses

Conceptual framework for the analyses

The KNP revised their management mission, vision, and objectives in between 1994 and 1996. The resultant mission or vision was “To maintain biodiversity in all its natural facets and fluxes …” (Braack 1997). Dr. Reed Noss’s (1990) conceptual framework for biodiversity was adopted during this process for defining and monitoring biodiversity. The framework comprised three primary elements being structure, function, and composition at four scales, namely genetic, species (community), habitat (landscape), and region. It is expected that biodiversity will change as species performances (resilience, competitiveness, persistence etc.) respond differently to resource gradients in space and time. Therefore, it is expected that consistent differences in fire regimes will result in differences in biodiversity. This provides a convenient framework with in which the effects of the different treatments on the woody vegetation can be studied, namely the effects of the treatments on the biodiversity of the woody vegetation of the plots at the species and community level (i.e. community structure and composition).

WITS ETD

Indices used to summarise the species and structural characteristics of the woody vegetation on the plots

The data available are height (m), basal diameter (cm), and whether the individual is single-stem or multi-stem for each individual surveyed. Since the heights of the plants were only recorded in 1996, they were not used in these analyses. At the community level (or plot level), we can look at both structural and compositional biodiversity. The structural and compositional components are:

- Density: Is defined as the number of individuals per unit area per plot.
- Physiognomy: Is defined as the number of single stemmed individuals relative to the number of coppicing individuals per plot.
- Diversity: Is defined as the number of individuals per species relative to the total number of individuals. Simpson's Index was used to calculate diversity.
- Composition: Is defined as the occurrence (and abundance) or absence of each species, and the species distribution in time and space. Variation in species composition in space is determined by their presence or absence on a plot. Variation in species composition over time is determined by their presence or absence in a survey (1954 or 1996).

Analyses

Randomised block ANOVA's and ANCOVA's were done on the density, physiognomy and diversity components.

Correspondence Analyses (CA) were done on the composition data, with the four block factors (Fayi, Numbi, Kambeni, and Shabeni) as covariables.

Results and Discussion

The effect of fire on the density of the woody vegetation.

In terms of fire frequency, the density of the woody vegetation on the control plots was significantly higher than on the burnt plots. This is consistent with other research findings regarding "bush encroachment" in savannas, where in the absence of fire, woody plant density tends to increase.

In terms of fire timing, there was no significant difference in the density of the woody vegetation between the August treatments and the February treatments.

Looking at a height class distribution of relative abundances of woody plants between treatments revealed some interesting results regarding the August and February treatments in 1996 (Figure 17-2). Five height classes were defined, namely 0-1m, 1-3m, 3-5m, 5-10m and >10m. There were a large number of woody plants shorter than 1m on the August annual treatments and on the February biennial and triennial treatments. This was expected for the August Annual treatment because frequent intense fires often prevent woody plants from emerging from the herbaceous layer by constantly burning the individuals back, which explains for high number of woody plants that were shorter than 1m on the August Annual treatments. The explanation for the high relative abundance of woody individuals shorter than 1m in the February treatments was not quit as obvious. In February *Panicum maximum*, which is frequently found under large trees, is still green. This provides a safe site for seedlings and saplings, as fire does not often burn into the sward of green grass. The individuals under the tree canopies often persist and remain stunted and so their numbers make up the bulk of the less than 1m height category.

WISETD

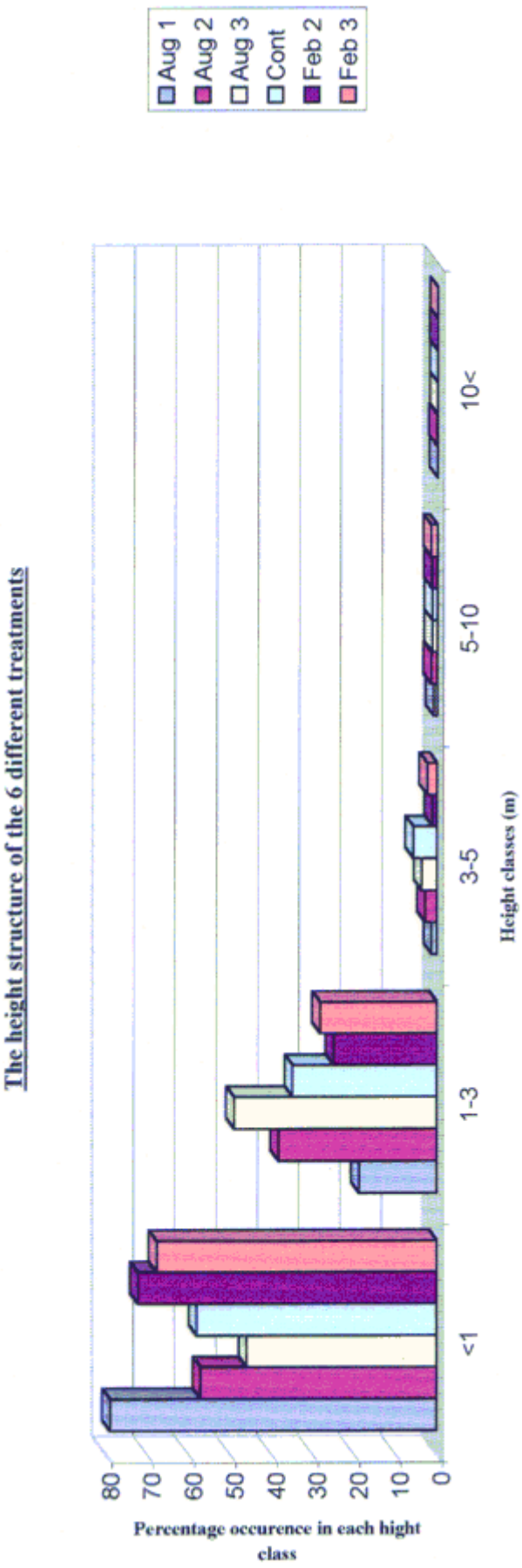


Figure 17-2: Graph showing the relative abundances of woody individuals in each of the five height classes for each of the six treatments.

The effect of fire on the physiognomy of the woody vegetation

There were significantly more single stem individuals on the control plots in comparison to the burnt plots. This was expected since most woody savanna plants have the capacity to sprout either from epicormic buds or from basal coppice buds when damaged. After a fire, plants that are burnt back often sprout from basal coppice buds, and these plants are typically multi-stemmed individuals. In the absence of fire, there is no top kill from fire and only mechanical damage to the plants may cause them to coppice from the base. It is for this reason that there were significantly more single stem individuals on the control plots relative to multi-stem individuals. Many savanna species are by nature multi-stemmed though and so it does not imply that in the absence of fire there will be no multi-stemmed individuals.

There were significantly more single stem individuals relative to multi-stem individuals on the February plots than on the August plots. This was because fires in August tend to be more intense than fires in February resulting in a higher percentage top kill of woody individuals and thus more individuals that sprout from basal coppice buds after the fire.

What is interesting is that the February biennial and triennial treatments are significantly different to the August annual and biennial treatments and not significantly different to the August triennial treatment. This may be a result of the fact that in the first year (and possibly the second year) after a fire individuals that sprouted from basal coppice buds often direct nutrient resources into the growth of many stems. However, it appears that after a certain height is reached resources may then be channelled into the growth of one or two primary stems. The other stems (depending on the species and time since last fire) become moribund and die or they remain reduced. This may explain why the August triennial burns do not have significantly less single stem individuals compared to the February burns.

The effect of fire on the diversity of woody vegetation

It is useful to view the diversity of the woody vegetation in Pretoriuskop within the paradigm of disturbance-mediated co-existence between woody species. Within this paradigm, the intermediate disturbance hypothesis postulates that diversity will be at a maximum at an intermediate frequency of disturbance. Looking at the diversity of the woody vegetation on the plots burnt at different frequencies, there is no significant differences between the Simpson's diversity indices of the plots burnt at different frequencies. This indicates that possibly none of the frequencies at which the plots were burnt can be considered intermediate within the fire disturbance regime of the Pretoriuskop region.

There is a significant difference, though, between the treatments burnt at different times of the year. The control plots have a significantly higher diversity than the burnt plots, and the February treatments have significantly higher diversity than the August plots. In terms of fire intensity, the August burns would generally represent an extreme because of dry climatic conditions and dry fuel. The February burns would generally be less intense, because of moister climatic and fuel conditions. The actual intermediate might be at some other intensity or timing however, the intermediate disturbance hypothesis does help interpreting the data in terms of disturbance gradients.

The control has a significantly higher diversity because more species occur on these plots. This is because fire sensitive species occur on these plots as well as fire tolerant species.

The effect of fire on the composition of the woody vegetation

Correspondence Analyses (CA) were used to determine the effect of fire on the species composition of the plots. The species densities for the 1954 and 1996 data sets were subjected to CA's with the blocks (replicates) as covariates. The Eigenvalues for the first axes of the 1954 and 1996 data sets were 0.3784 and 0.3413, accounting for 25.7% and 24.9% of the variation respectively. Bi-plots of the species-plot scores show that most plots were centrally located with most species being ubiquitously associated with the plots in 1954. Four plots stand out:

WISER

- The Fayi Feb2 treatment was associated with high densities of *Ormocarpum trichocarpum*, *Acacia gerardii*, and *Combretum hereoensis*.
- The Numbi Aug1 and Aug3 treatments were associated with *Turraea nilotica*.
- The Numbi Feb3 treatment was associated with *Pterocarpus angolensis* and *Vernonia* species.

There were no apparent associations between the treatment plots in ordinal space prior to the start of the experiment.

For the 1996 data, variation on the first axis separates the burnt plots from the plots that were not burnt (control plots). The control plots were associated with high densities of *Bauhinia galpinii*, *Olea europaea*, *Zanthoxylum capensis*, *Ochna natalensis*, *Putterlickia pyracantha*, and *Bridelia mollis*. Some of these species were only associated with the control plots, namely, *Bridelia mollis*, *Olea europaea*, *Putterlickia pyracantha*, *Canthium inerme*, and *Kraussia floribunda*. These species are more than likely fire intolerant. The occurrence of fire sensitive or intolerant species on the control plots depends upon the proximity of the nearest fire refuge in which these species are found. Fire refuges are generally large termite hills, rock outcrops, and drainage lines. The control plots acted like natural fire refuges with the exception that they did not have hard, rocky or water logged soil. For this reason, the species associated with the burnt plots were also found in high densities on the control plots.

A long absence of fire can result in changes in the species composition of an area. However at this point it is unclear as to the species compositional changes that may occur because of the prolonged exclusion of fire in the Pretoriuskop region.

Change in density and diversity over time

What is quit interesting is that density on the plots in 1996 is significantly higher than on the plots in 1954. Furthermore, the diversity is also higher on the plots in 1996 than in 1954, though this is not significant ($p = 0.061$). People have often made anecdotal observations about the encroachment of *Dichrostachys cinerea* and other woody species in the Pretoriuskop area. Furthermore, some photographic evidence seems to support these observations.

What might be the driving force behind an increase in the density and diversity of woody species in the Pretoriuskop area? People were still living within the park boundaries in the Pretoriuskop region and practising small scale agricultural up until at least 1925. Furthermore, a KNP Scientific Services field assistant Maxim Signwane remembered his family being remove from the Numbi area when he was a young boy. So some 70 years ago the Pretoriuskop region was still inhabited. These people harvested trees and fruit they practised agriculture and they kept livestock (Baloye pers. com. 1997). This increase in density and diversity may be a direct result of the exclusion of man inhabiting the area.

Conclusion

The two aspects of a fire regime held constant (frequency and timing) in this experiment affect the woody vegetation composition and diversity differentially. A greater understanding of these impacts will enhance our understanding of fire as an ecosystem process. What is important is translating these results to the landscape level. The fire history of the KNP has been recently captured into onto a spatial database. With this data, results from the KNP experiment can be extrapolated to the landscape level and can be tested.

References

Annual report 1951. Unpublished annual Report of the South African National Parks Board of Trusties 1951.

Annual report 1953. Unpublished annual Report of the South African National Parks Board of Trusties 1951.

WITS ETD

Baloye J, 1997. KNP Scientific Services Field Assistant. Kruger National Park, Scientific Services.

Bourliere L and M Hadley, 1970. The ecology of tropical savannas. Annual Review of Ecology and Systematics 1: 125-152.

Braack LEO, 1997. A revision of parts of the management plan for the Kruger National Park. Volume VIII: Policy proposals regarding issues relating to biodiversity maintenance, maintenance of wilderness qualities, and provision of human benefits. Scientific Services Management Plan. South African National Parks, Skukuza.
URL: http://www.parks-sa.co.za.

Gertenbach WPD, 1980. Rainfall patterns in the Kruger National Park. Koedoe 23: 35-43.

Gertenbach WPD, 1983. Landscapes of the Kruger National Park. Koedoe 26: 9-121.

Munnick MC, Verster E, and TH Van Rooyen, 1990. Spatial pattern and variability of the soil and hillslope properties in a granitic landscape, 1. Pretoriuskop area. South African Journal of Soil 7(2): 121-130.

Noss R, 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach. Conservation Biology 4 (4): 355-364.

Scholes RJ and BH Walker, 1993. An African savanna: Synthesis of the Nylsvley study. Cambridge University Press.

Van Der Schijff HP, 1958. Inleidende verslag oor veldbrandnavorsing in die Nasionale Krugerwildtuin. Koedoe 1: 60-93.

WitsETD

17.2 THE ROLE OF THE EXPERIMENTAL BURN PLOTS (EBP) IN VALIDATING WOODY VEGETATION THRESHOLDS FOR POTENTIAL CONCERN (TPC) WITH RESPECT TO THE MONITORING OF MANAGEMENT STRATEGIES IN THE KRUGER NATIONAL PARK (KNP).

This paper was presented as a talk at the Kruger National Park Research Conference. Skukuza, August 1998.

SP O'Regan & ETF Witkowski

Introduction

The management of land for conservation purposes is and has long been a controversial issue. At one end, there are those who advocate intervention - which often benefits a few key species - and on the other end those who advocate non-intervention - called the Wilderness conservation ethic. There are gradients of different approaches between these two extremes. However, irrespective of the management strategy one problem often still remains, which is that of not having enough precise information. Fire management in most conservation areas is no exception to this.

Often a lot of emphasis is placed on trying to assess the so-called "natural" fire regime in an area. The rationale being that in the absence of more precise information about the ecological effects of different fire regimes, the best management can do is to emulate nature.

Along this vein, attempts can be made to estimate historic fire frequencies over various time spans -like pre-human or pre-industrial. However, other equally important components of fire regimes like areas burnt in past fires, fire intensity, season of fire, and type are much more difficult to estimate. Also without the aid of humans, fire regimes almost certainly varied widely over time and that variation in the fire regime itself is likely to have been ecologically important.

Robert Whelan (1995) suggests that a profitable approach to fire research might be to place more emphasis on understanding how organisms, populations, and communities respond to experimentally imposed fire regimes, than on trying to determine the historical fire regimes for an area.

The Kruger National Park (KNP) is in a position in which not only have there been studies into the history of fire in the Lowveld area, but there is also a small-scale fire experiment, which was established in the KNP in 1954. This experiment provides a long-term database that few other wilderness parks, nature reserves, or conservation areas posses.

How can data from this experiment be used for meaningful assessment of management initiatives in the KNP?

With the recent restructuring and reworking of the Mission, Vision, and Objectives of the KNP, the monitoring strategy within the park has also been reshaped. As part of the new approach to monitoring biodiversity, Thresholds of Potential Concern (TPC) have also been set for different ecosystem characteristics within the KNP. TPCs are warning lights indicating changes in monitored biodiversity that should be a cause for concern and warrant some attention.

Each TPC has both spatial and temporal bounds. The TPCs for the density of woody vegetation in the KNP are summarized in Figure 17-3. This is a change over area graph, showing the percentage of acceptable change in woody vegetation density varying with the spatial extent of that change.

WISETD

For example in any one landscape an increase in woody plant density of up to 100 percent would be acceptable, if the area in which that amount of change occurred covered less that 10 percent of the area of that landscape. For an entire landscape, an increase of only 20 percent in the density of woody plants would be accepted before there would be cause for concern.

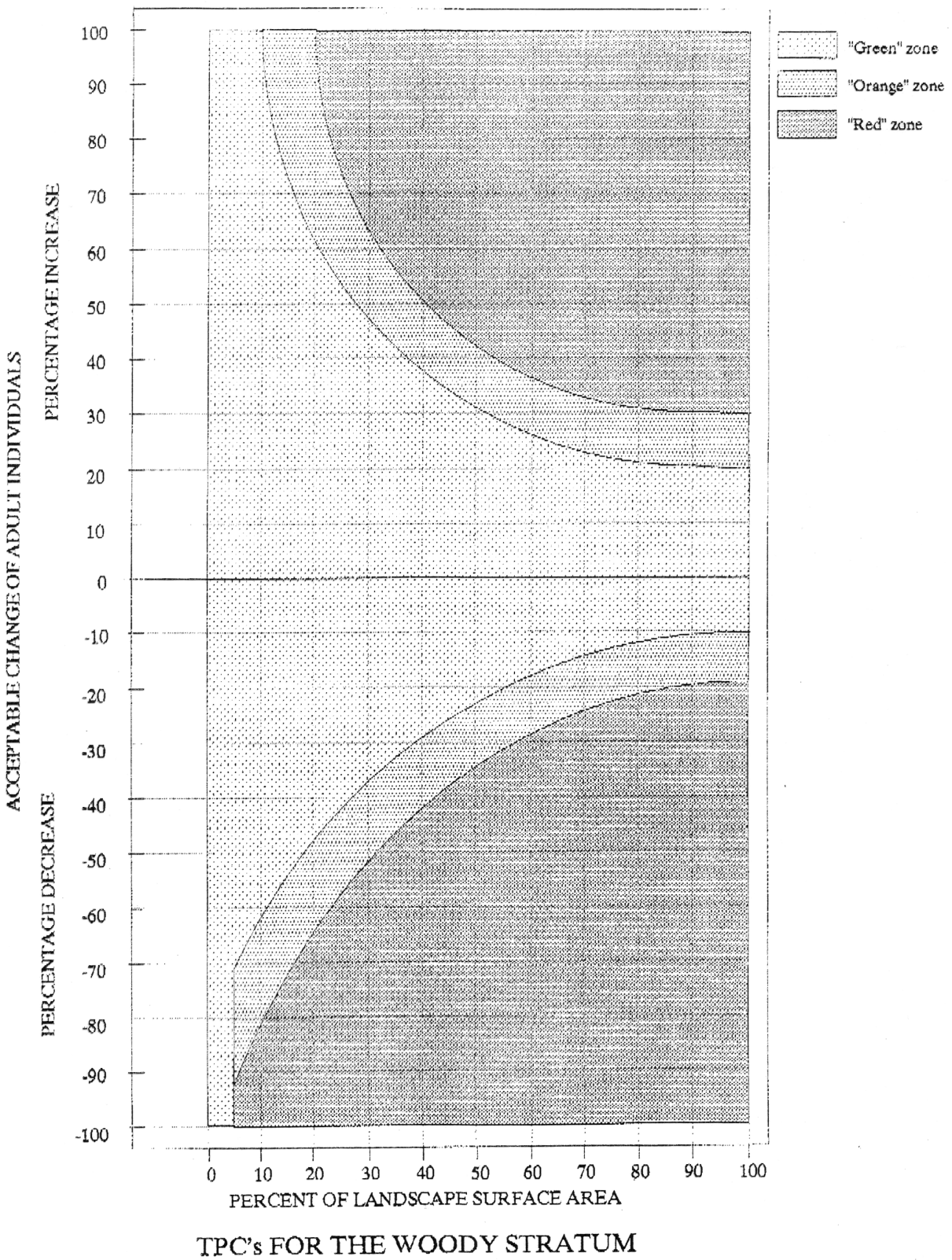


Figure 17-3: Change over area graph modelling the suggested Thresholds of Potential Concern for the density of the woody vegetation in the KNP (Provided by N Zambatis KNP Scientific Services).

The benchmark from which change is measured is any points in time at which accurate measurements have been made that are relevant to any particular TPC. In other words, there should be potential concern if a threshold level of change has been exceeded from any point in the history of quantitative monitoring within the KNP.

The Experimental Burn Plots were set up in 1954. In the Pretoriuskop Sourveld region, forty-eight plots were laid out in four replicates in different parts of the landscape. A baseline vegetation survey was conducted on each plot. The woody vegetation survey's were done with belt transects placed along the diagonals of each plot. In addition, twelve burning treatments were applied to the plots, at three return periods, namely annual, biennial, and triennial burns, and at five different times of the year, with one of the treatments being a control (no burn). A survey similar to the baseline was conducted in 1996. This provides a 42-year period over which woody vegetation change can be analysed.

What changes have there been over this 42-year period?

In almost all cases regardless of the burning treatment applied to a plot the woody plant density has increased since 1954. On only two plots out of 48 has the density decreased and in both cases by only a few percent. The trend since 1954 has been an increase in the density of woody vegetation on the plots in Pretoriuskop Sourveld. The magnitude of this increase in density ranges from 10 percent to over 700 percent since 1954. The average increase in woody plant density on these plots has been over 200 percent, which far exceeds the thresholds of potential concern that have been suggested for the woody vegetation in the KNP.

Can these trends be seen as being applicable to the entire Sourveld landscape?

The median inter-fire period for the whole Pretoriuskop landscape is 2 years, and the inter-fire periods of the different treatments are 1 year, 2 years, and 3 years. The fire return periods of the treatments applied to the EBPs are comparable to the median fire return period of the Pretoriuskop landscape. The timing of the experimental fires is also comparable to those in the rest of the landscape. What is important though is that an increase in density has occurred regardless of the treatments applied to the plots.

Anecdotal observations made by research staff and section rangers seem to support this evidence, and suggest that this increase in woody plant density on the EBPs to some extent reflects what has occurred at the landscape level in the Pretoriuskop Sourveld. Photographic evidence also appears to support these observations.

The Threshold for Potential Concern for an increase or decrease in density of trees and shrubs at the landscape level is 20 percent. Since 1954 the density of woody vegetation in the Pretoriuskop Sourveld has increased, and appears to exceed the suggested TPCs, by at least eight times.

Should there be eight times as much potential for concern then?

Along with the increase in density, there has been an increase in the number of species recorded on the plots, from 68 species in 1954 to 88 in 1996. There was however no significant increase in the species diversity between 1954 and 1996. This is because the species diversity was calculated using Shannon and Simpson's Diversity Indices. These indices calculated species diversity as the number of species relative to the total number of individuals surveyed. In 1996, eighty-eight species were recorded in a survey of over 35000 individuals, and in 1954, sixty-eight species were recorded from over 9000 individuals. Therefore, the calculated species diversity in 1954 is similar to the species diversity calculated for 1996. This is a mathematical issue though; the point being that previously rare and unrecorded species on these plots are now being found in higher numbers and are being recorded.

WISER

What might be the driving force behind this increase in density of the woody species in the Pretoriuskop area?

The Pretoriuskop area was still inhabited by humans less than 75 years ago. People living in the area utilised trees to build houses and animal shelters. In addition, the fruits and seed of many tree species were harvested. Small-scale agriculture was practised both near homestead's and further away in special areas that were well suited for growing certain crops, and livestock was kept. Furthermore, towards the latter half of last century and the beginning of this century, white farmers used the Pretoriuskop area as a winter pasture for sheep and cattle, and the area was burnt almost annually to provide green palatable grass for grazing. The increase in density and numbers of some uncommon species since 1954 may be a direct result of the exclusion any one or all of these human activities from the Pretoriuskop area.

William Bond (1998) suggests that an increase in global CO_2 levels may be another possible reason for the increase in woody plant density in the Pretoriuskop area. Savanna ecosystems appeared in the late Miocene period some 5 to 23 million years ago. The Miocene was a time of warmer global climates than those in the proceeding Oligocene, or the following Pliocene, and atmospheric CO_2 levels dropped below 500ppm during this period. This drop in CO_2 favoured the expansion of C_4 grass dominated ecosystems. There is evidence that global CO_2 levels are increasing and it is predicted that the CO_2 levels will return to above 500ppm by 2050.

How can an increase CO_2 levels favour woody species in fire prone environments?

In savanna ecosystems, many woody species respond vegetatively to fire damage by resprouting. Often individuals remain in a stunted multi-stemmed condition for many years, as they are unable to escape the herbaceous layer between fire events. Individuals caught in this danger zone are classified as either sprouters or Gullivers. These individuals sprout from the base and often form a lignotuber below ground. The difference between sprouters and gullivers is in their strategy for surviving within the danger zone.

Gullivers form obscenely large underground storage organs, and in between fire events, they put all their energy and resources into trying to escape the fire danger zone. Invariably gullivers do not become sexually mature until they have reached a critical height at which point they have escapes the fire danger zone. Sprouters on the other hand have much smaller below ground storage organs, and in between fires, resources are allocated to both growth and reproduction.

It seems that these below ground storage organs are carbohydrate sinks, containing mainly starch. They can almost be seen "large potatoes" supporting the plants through rough times and continual fire damage. The bigger the storage organ the more competitive an individual will be in a fire prone environment.

Under elevated CO_2 conditions, potato plants (*Solanum tuberosum*) and sweet potato plants (*Ipomoea batatas*) produce more and larger tubers than those under CO_2 depleted conditions (Bhattacharya *et al.* 1985, Ludewig *et al.* 1998, Miglietta *at al.* 1998). If elevated CO_2 conditions result in more carbon allocation to below ground storage organs then this may result in an increase in the long-term competitiveness of some woody species. Individuals may be able to persist beyond their previous potential and thus resulting in a larger viable population of fire retarded woody plants than there may have been in the past.

CO2 levels have been increasing since the industrial revolution, however since the 1950's the CO_2 levels have increased at a much more rapid rate.

Can this partially explain for the relatively quick increase in woody plant density since 1954?

In all likely hood both explanations for the increase in density of the trees and shrubs in the Sourveld hold some ground. What is not known though is the relative importance of each. Studies into the potential

magnitude of anthropogenic impacts on the environment have and are still being conducted. Furthermore, the future and prospective continuance of the EBPs appears to lie in their ability to provide data that may be useful for monitoring the effects of global climate change on the vegetation structure in the KNP.

When managing biodiversity in all its natural facets and fluxes it is essential that we understand what these facets and fluxes are. For example, a flux at one spatial or temporal scale may have directionality at another scale.

Long-term databases can be used to provide a context for the management of certain aspects of biodiversity. Management practices are often implemented based on the assumption that certain long-term processes are operating in a community. However, there is often not enough information or data against which we can test for these long-term processes or trends. Furthermore, many organisms have long life spans, and effects of even single disturbance events on their lives are often not evident for many years.

Long-term studies like the EBPs are rare, and are often started with a particular question in mind, that question or purpose, though, does not restrict their applicability in other areas. The relatively controlled nature and well-documented histories inherited with long-term studies are invaluable for assessing current and historical management initiatives.

References

Bhattacharya NC, Biswas PK, Bhattacharya S, Sionit N, and BR Strain, 1985. Growth and yield response of sweet potato to atmospheric CO2 enrichment. Crop Science 25: 975-981.

Bond WJ, 1998. Proceedings of South African Association of Botanists Conference. January 1998. Cape Town.

Ludewig F, Sonnewald U, Kauder F, Heineke D, Geiger M, Stitt M, Muller-Rober BT, Gillissen B, Kuhn C and Frommer WB, 1998. The role of transient starch in acclimation to elevated atmospheric CO2. Federation of European Biochemical Societies (FEBS) Letters 429: 147-151.

Miglietta F, Magliulo V, Bindi M, Cerio L, Vaccari FP, Loduca V and A Peressotti, 1998. Free Air CO2 Enrichment of potato (Solanum tuberosum L.): development, growth, and yield. Global Change Biology 4: 163-172.

Whelan RJ, 1995. The ecology of fire. Cambridge University Press.

WiSETD

17.3 RESPONSES OF THE WOODY VEGETATION, IN THE PRETORIUSKOP SOURVELD SAVANNAS OF THE KRUGER NATIONAL PARK (KNP), TO FIRES BURNT AT DIFFERENT FREQUENCIES.

This paper was presented as a poster at the Grassland Society of Southern Africa (GSSA) Conference. Warm Baths, February 1999.

SP O'Regan & ETF Witkowski

Abstract

Fire plays an important role in the maintenance of both the structure and function of savanna ecosystems. In the early 1950's, controversy surrounded the formulation and implementation of a fire management policy in the Kruger National Park (KNP). This controversy highlighted the lack of understanding of the role fire played in this predominantly arid savanna ecosystem. In 1954, a fire experiment was started in the KNP the aim of the experiment was to provide a scientific basis for fire management policies. The original objective of the experiment was to determine which fire regime would best produce a desirable vegetation structure and composition for different parts of the park.

The experimental layout was a randomised block design in which twelve fire treatments were replicated four times in each of four major vegetation zones that had been defined in the KNP by Van Der Schijff (1958). The twelve treatments were a no burn, an annual August burn, and biennial and triennial burns at five different times of the year, namely February, April, August, October, and December. Prior to the start of the experiment, a baseline vegetation survey was done on each plot. The woody vegetation was surveyed with a belt transect (1.5mX310m) placed along the two diagonals of each plot. Individuals in each transect were identified and classified as either single or multi-stem. In 1996, a similar survey was conducted on the plots in the Pretoriuskop sourveld vegetation zone of the KNP. This provides us with a 42-year period over which the woody vegetation responses to the fire treatments in this area can be analysed. The effects of the different fire frequencies on the structure of the tree and shrub community within the lowveld sourveld will be presented. Furthermore, the significance of these data for interpreting the effects of past fire management policies in this area will also be discussed

Introduction to the KNP fire experiment

The KNP fire experiment is a large field experiment in which twelve fire treatments have been applied to four different vegetation types within the park over the past 45 years. The twelve treatments comprised four fire frequencies or return periods namely annual, biennial, and triennial and no burn. Before starting the experiment, a baseline vegetation survey was conducted on the experimental plots in 1954. In 1996, a similar survey was done on the plots in the Pretoriuskop sourveld. This provided a 42-yr period over which the fire treatment effects on the woody vegetation in the Pretoriuskop area were analysed.

The Pretoriuskop sourveld savannas

The Pretoriuskop sourveld is located in the south-western region of the KNP. It is a mesic savanna experiencing a relatively high annual rainfall of 744mm (Gertenbach 1983, Venter and Gertenbach 1986). It is also a nutrient poor savanna in which the soils on the watersheds are deeply leached (Gertenbach 1983). Post fire grass and herbaceous vegetation recovery tends to be relatively quick and the fire return periods range from annual to triennial burns. The median fire return period in the Pretoriuskop sourveld between 1953 and 1996 was 1.9yrs (Van Wilgen *et al.* 2000)

WISETD

Woody savanna species response to fire

Most woody savanna species respond to fire damage by vegetatively resprouting. If the canopies are burnt severely, individuals will often sprout from the base. These woody individuals often remain stunted, because they compete with grasses and herbs, and they are heavily browsed. These individuals can remain in a stunted multi-stemmed condition for many years if consecutive fires are intense and the intervals between fires are too short to allow them to escape to a fire resistant height.

Many studies have shown that a reduction in fire frequency or intensity in savanna ecosystems results in an increase in the number of woody plants and their height, canopy volume and biomass (Scholes and Walker 1993). The converse has also been found to be true and an increase in fire frequency or intensity has been found to cause reductions of woody plant density, canopy volume, and biomass.

Similar trends have been recorded in the KNP for the woody vegetation of the Pretoriuskop sourveld.

The effect of fire return period on the vegetation structure of the woody vegetation of the Pretoriuskop sourveld

The vegetation structure on the experimental plots can be quantified and analysed in three major categories, namely density, composition, and phenology.

- Density is calculated as the number of individuals per hectare on each plot.
- Composition is the species compliment and abundance on the plots. This is assessed in a number of ways ranging from species richness (Menhinick's) and diversity (Simpson's) indices to Canonical analyses of the species on the experimental plots.
- Phenology describes the physical structure of the woody vegetation. Ratios of the number of single stemmed individuals to the number of multi-stemmed individuals were calculated and further analyses on the height structure of each plot were done.

The effect of fire frequency on the density of the woody vegetation

Woody plant density is significantly higher on the plots that were not burnt than on the plots that were burnt ($p = 0.037$). This is consistent with hypothesis on “bush encroachment” in savannas ecosystems, where in the absence of fire, woody plant density tends to increase.

The mean height of the plants on plots burnt annually is significantly lower than plots burnt triennially and not burnt ($p = 0.021$ and $p = 0.029$ respectively). As the inter-fire period increases, the numbers of individuals that escape to a fire resistant height increases, and these plants no longer remain in a stunted form not escaping the herbaceous and grass layer.

The effect of fire frequency on the physiognomy of the woody vegetation

There are significantly more single stem individuals on the plots that were not burnt than on the plots that were burnt ($p < 0.000$). This is expected since most woody savanna plants sprout in response to fire damage from either epicormic or basal coppice buds depending on the severity of the fire damage to the plants. Plants resprouting from basal coppice buds typically become multi-stemmed individuals. In the absence of fire, there is no top kill from fire and only mechanical damage to the plants may cause them to coppice from the base. It is for this reason that there are significantly more single stem individuals on the control plots relative to multi-stem individuals.

There are also significantly higher numbers of single stem individuals on the plots burnt triennially than on those burnt annually ($p = 0.017$). This is because in the first year (and possibly the second year) after a fire, individuals coppicing from the base often channel resources into the growth of a number of stems. However,

it appears that after a certain height is reached resources are then be channelled into the growth of one or two primary stems. Either the other stems become moribund or they remain reduced depending on the species and time since the last fire event.

The effect of fire frequency on the composition of woody vegetation

Species richness and diversity are significantly higher on plots that were not burnt than on the plots that were burnt. This is because fire intolerant and fire sensitive species occur on these plots as well as fire tolerant species.

Fire sensitive and intolerant species usually occur on or near fire refuges like large termite hills, rocky outcrops, koppies, and drainage lines. The unburned plots are fire refuges, however, unlike natural fire refuges they do not have hard, rocky or water logged soil. For this reason, fire tolerant species associated with the burnt plots also occur on the unburned plots.

A Canonical Analysis was performed on the species by plot densities from the 1996 data set. The first four plot score axes of a Correspondence Analysis on the baseline data (1954) were used as covariates during the analysis, and the ranked treatment return periods were used as environmental variables.

The Eigenvalue for the first axis of the canonical analysis is 0.232 accounting for 16.3% of the variation. The species environmental correlation is 0.871 and is statistically significant (p=0.001 - tested by a 999 permutation Monte Carlo test). The first canonical axis separated the plots burnt at different frequencies. This axis was used to describe differences in species compliment under different fire frequencies in the model below (Figure 17-4).

References

Gertenbach WPD, 1983. Landscapes of the Kruger National Park. Koedoe 26: 9-121.

Scholes RJ and BH Walker, 1993. An African savanna: Synthesis of the Nylsvley study. Cambridge University Press.

Van Wilgen BW, Biggs HC, O'Regan SP, and N Mare, 2000. A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996. South African Journal of Science 96: 167-178.

Venter FJ and WPD Gertenbach, 1986. A cursory review of the climate and vegetation of the Kruger National Park. Koedoe 29: 139-148.

WiSETD

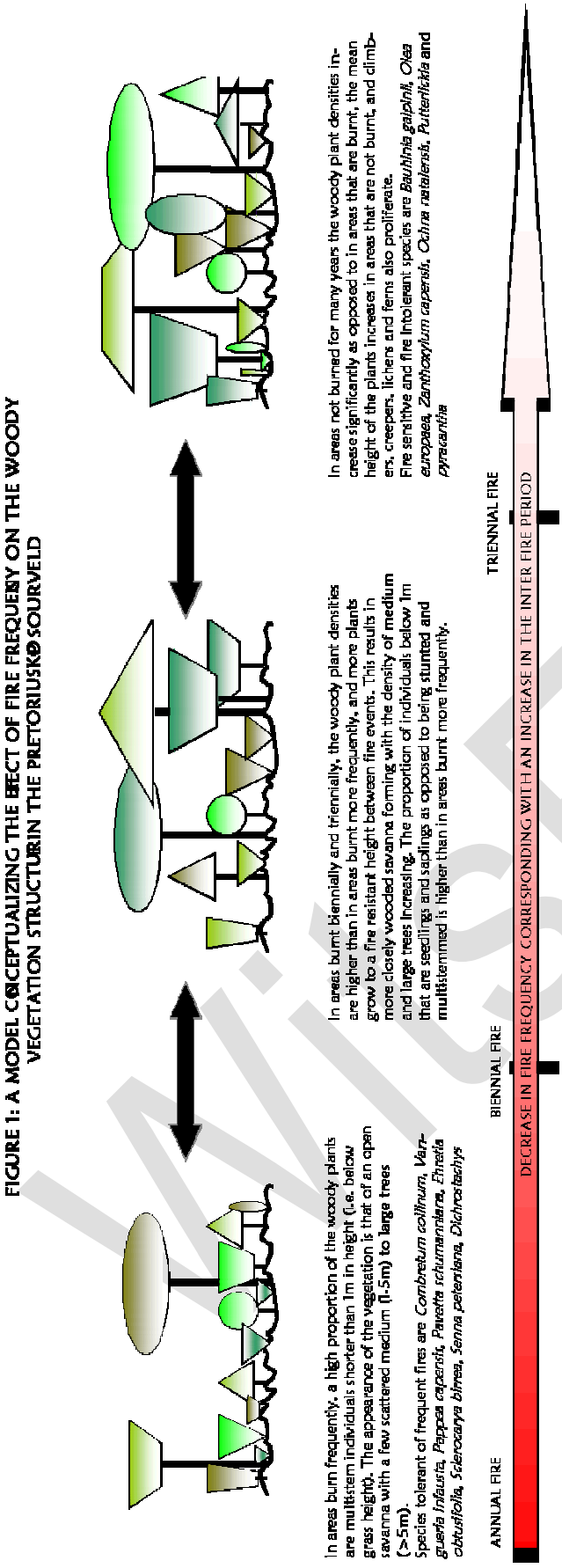


Figure 17-4: Model showing the effect of fire frequency on the structure and composition of the woody vegetation of the Pretoriuskop sourveld.

WISETD

17.4 THE EFFECT OF DIFFERENT FIRE RETURN PERIODS ON THE STRUCTURE AND COMPOSITION OF WOODY VEGETATION IN THE PRETORIUSKOP SOURVELD

This paper was presented as a talk at the Kruger National Park Research Conference. Skukuza, April 2000.

This paper is almost identical to the poster presented at the 1998 GSSA conference in Warm baths.

SP O'Regan & ETF Witkowski

Pretoriuskop is classified as a nutrient poor mesic savanna with an average annual rainfall of about 744ml (Gertenbach 1983, Venter and Gertenbach 1986). The soils on the watersheds of the Pretoriuskop region are deep, sandy, and leached (Gertenbach 1983).

Post fire grass and herbaceous vegetation recovery in the Pretoriuskop landscape tends to be relatively quick and the inter-fire periods range from 1 year to 3 years. The median inter-fire period over the past 50yrs is 1.9yrs (Van Wilgen *et al.* 2000).

Woody savanna species response to fire

Most woody savanna species respond to fire damage by vegetatively resprouting. If the canopies are burnt severely, individuals often sprout from the base. These individuals often become stunted as they compete with grass and herbaceous plants, and are heavily browsed. These individuals can remain in a stunted multi-stemmed condition for many years if consecutive fires are too intense or the intervals are too short to allow them to escape to a fire resistant height.

Many studies have shown that a reduction in fire frequency or intensity in savanna ecosystems results in an increase in the number of woody plants and their height, canopy volume and biomass. The converse has also been found to be true in that an increase in fire frequency or intensity results in reductions of woody plant density, canopy volume, and biomass.

Similar trends have been recorded in the KNP for the woody vegetation of the Pretoriuskop sourveld.

The effect of fire return period on the vegetation structure of the woody vegetation of the Pretoriuskop sourveld

Using the data available, vegetation structure on the experimental plots can be quantified into three main categories, namely density, composition, and phenology.

Density is calculated as the number of individuals per hectare on each plot.

Composition is the species compliment and abundance on the plots. This is assessed in a number of ways ranging from species richness (Menhinick's) and diversity (Simpson's) indices to Canonical analyses of the species on the experimental plots.

Phenology describes the physical structure of the woody vegetation. Ratios of the number of single stemmed individuals to the number of multi-stemmed individuals were calculated and further analyses on the height structure of each plot were done.

WISETD

The effects of fire return period, on the density of the woody vegetation.

Woody plant density is significantly higher on the plots that were not burnt than on the plots that were burnt ($p = 0.012$). This is not surprising, since it is consistent with hypothesis on "bush encroachment" in savannas ecosystems, where in the absence of fire, woody plant density tends to increase.

The densities between the plots that were burnt at different frequencies did not differ significantly. However, plots burnt annually did tend to be denser than the plots burn biennially and triennially.

It is difficult to make any substantial statements regarding the effect of increasing inter-fire period on the density of woody vegetation in the Pretoriuskop sourveld since. This is because the density of the woody vegetation on almost all plots regardless of treatment applied increased between 1954 and 1996.

The effect of fire frequency on the physiognomy of the woody vegetation

There are significantly more single stem individuals on the plots that were not burnt than on the plots that were burnt (0.000). This is expected since most woody savanna plants sprout from either epicormic or basal coppice buds in response to fire damage depending on the severity of the damage to the plants. Plants resprouting from basal coppice buds typically become multi-stemmed individuals. In the absence of fire, there is no top kill from fire and only mechanical damage to the plants may cause them to coppice from the base. It is for this reason that there are significantly more single stem individuals on the control plots relative to multi-stem individuals.

There are also a significantly higher number of single stem individuals on the plots burnt triennially than on those burnt annually ($p = 0.017$). This is because in the first year (and possibly the second year) after fire individuals that coppice from the base often allocate resources into the growth of a number of stems. However, after a certain height is reached resources are then channelled into the growth of one or two primary stems. Either the other stems become moribund or they remain reduced depending on the species and time since last fire.

The effect of increasing the inter-fire period on the height structure of the woody vegetation is also quite evident. The mean height of the plants on plots burnt annually is significantly shorter than plots burnt triennially and not burnt ($p = 0.021$ and $p = 0.029$ respectively). As the inter-fire period increases, the numbers of woody individuals that escape to a fire resistant height increases and they are no longer trapped stunted below the grass height.

The effect of fire frequency on the composition of woody vegetation

Species richness and diversity are significantly higher on the plots not burnt than on the plots that were burnt. This is because fire intolerant and fire sensitive species occur on these plots as well as fire tolerant species.

Fire sensitive and intolerant species usually occur on or near fire refuges like large termite hills, rocky outcrops, koppies, and drainage lines. The unburned plots are fire refuges, however, unlike natural fire refuges they do not have hard, rocky or water logged soil. For this reason, fire tolerant species associated with the burnt plots also occur on the unburned plots.

A canonical analysis was done on the species by plot densities from the 1996 data set. The first four plot score axes of a correspondence analysis on the baseline data (1954) were used as covariates for the analysis, and the ranked treatment return periods were used as environmental variables.

The Eigenvalue for the first axis of the canonical analysis is 0.232 accounting for 16.3% of the variation. The species environmental correlation is 0.871 and is statistically significant ($p=0.001$ - tested by a 999

WISER

permutation Monte Carlo test). The first ordination axis separated the plots burnt at different frequencies. This axis was used primarily to describe changes in species compliment under different fire frequencies.

The linear axis in Figure 17-5 represents an increase in the fire return period. The axis representing inter-fire period does not correspond to once off fire events but rather the mean (or median) inter-fire period over a long time (i.e. 42 yrs), and the timing and intensity of fires at these return periods are not constant.

A high frequency fire regime (i.e. annual) causes a decrease in the density of woody plants, and changes the physical structure of the woody vegetation. Woody plants that are well established often cannot escape the grass and herbaceous layer between fire events, and they are often burnt back at each fire event. These individuals remain in a stunted multi-stemmed form until they can escape the grass layer and reach a fire resistant height, or until they die. Many savanna species, although fire tolerant, cannot persist when the inter-fire periods are too short. However, some species such as *Turraea nilotica* and *Catunaregam spinosa* are tolerant of frequent fires (i.e. Annual fire). Other species tolerant of frequent fires are listed in Figure 17-5.

Areas burnt biennially and triennially have a higher woody plant density than areas burnt more frequently. In areas burnt annually and biennially interval between fires is also long enough for plants to grow to a fire resistant height. Furthermore, the proportion of seedlings relative to stunted multi-stemmed individuals below 1m tall is also higher in areas burnt less frequently. The result is that the vegetation becomes more closely wooded and the density of medium and large trees increases.

This trend continues as the period between successive fires is increased. Areas not burned for many years (the data base time span being 42 years) become woodland savannas. The woody plant density and mean plant height increases significantly in comparison with burnt areas. Fire sensitive species like *Bauhinia galpinii*, *Olea europaea*, *Zanthoxylum capensis*, *Ochna natalensis*, and *Putterlickia pyracantha* are found on these plots and climbers (creepers), ferns and lichen proliferate.

References

Gertenbach WPD, 1983. Landscapes of the Kruger National Park. Koedoe 26: 9-121.

Van Wilgen BW, Biggs HC, O'Regan SP, and N Mare, 2000. A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996. South African Journal of Science 96: 167-178.

Venter FJ and WPD Gertenbach, 1986. A cursory review of the climate and vegetation of the Kruger National Park. Koedoe 29: 139-148.

WitsETD

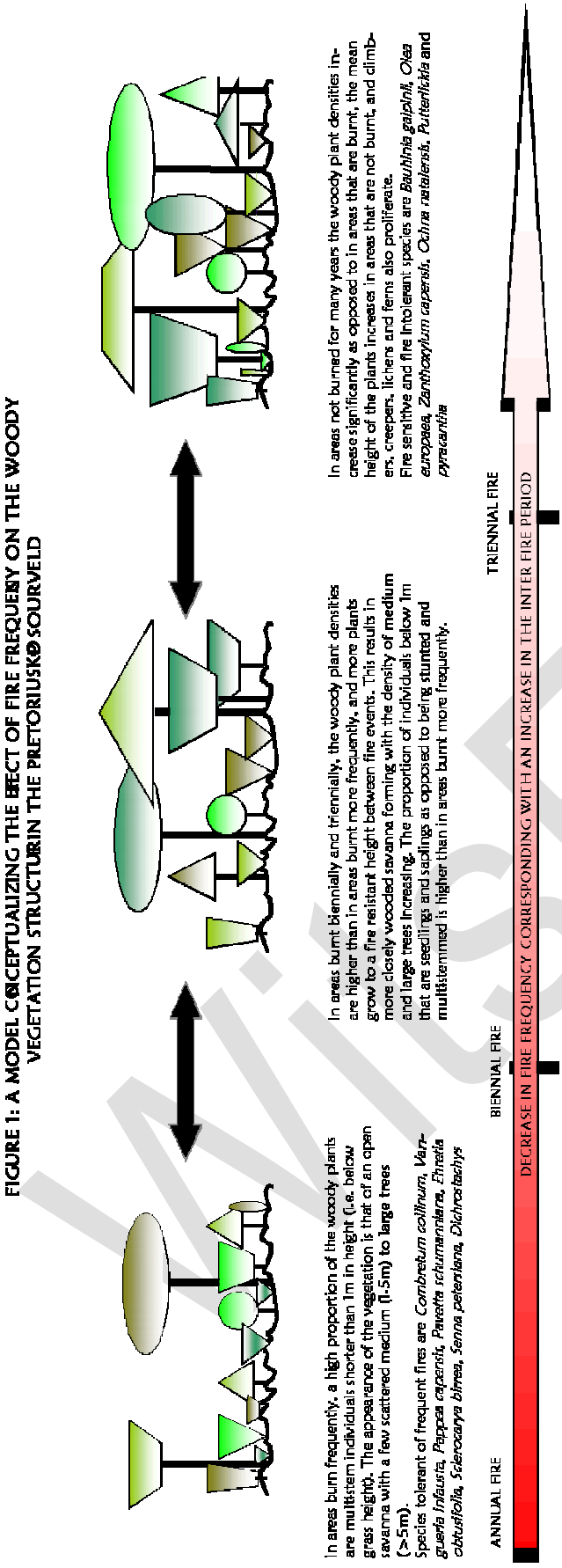


Figure 17-5: Model showing the effect of fire frequency on the structure and composition of the woody vegetation of the Pretoriuskop sourveld.

WISETD

17.5 LONG-TERM EFFECTS OF FIRE ON THE SPECIES AND STRUCTURAL DIVERSITY OF THE TREES AND SHRUBS IN THE SOURVELD BUSHVELD OF THE KRUGER NATIONAL PARK

This paper was presented as a talk at the Kruger National Park Research Conference. Skukuza, April 2003.

SP O'Regan & ETF Witkowski

Introduction

The formulation and implementation of a fire management policy in the Kruger National Park (KNP) in the early 1950's was characterised by controversy and disagreement (Annual report 1951). The controversy highlighted the lack of data and understanding of the role that fire played in this predominantly arid savanna ecosystem. In 1954 in response to this controversy the Experimental Burn Plot experiment was started, the aim of the experiment being to provide a scientific basis for fire management policies within the KNP.

The experimental design of the fire experiment was a pseudo-randomised block design in which 12 fire treatments were replicated four times each, in each of the four major veld types defined in the KNP by Van Der Schijff (1958). The four veld types were, the sourveld of Pretoriuskop, the Combretum veld surrounding Skukuza, the Knob-thorn - Marula veld near Satara, and the Mopane veld between Shingwedzi and Letaba. The twelve treatments were no fire, annual fire in August, and biennial and triennial fires at five different times of the year, namely February, April, August, October, and December.

Four replicates of twelve plots each were laid out in the Pretoriuskop sourveld. The four replicates, named after nearby landmarks, are Numbi, Shabeni, Kambeni, and Fayi. The twelve treatments were randomly assigned to the plots within each replicate. These treatments were applied between fastidiously between 1954 and 1996.

There is an extra plot in the Kambeni replicate. This is because soil was used from this plot to construct the road between Numbi gate and Pretoriuskop rest camp in 1954 (Annual report 1955). The affected treatment (October biennial) was relocated to the second row of the replicate in 1956.

Methods

Data collection

In 1954 a baseline survey on each of the plots was done. The woody vegetation was surveyed by means of two belt transects placed along the diagonals of each plot. In 1996, a similar survey was done on the Pretoriuskop set of plots.

The data recorded in 1996:

- Plants within each line were identified.
- The height was measured.
- Whether the individual was live or dead
- Whether the individual had a single stem or multi stems.
- Stem diameter in centimetres for single stem individuals was measured.
- Base diameter in centimetres (coppice diameter) for multi-stem individuals was measured.

Estimating height for the 1954 data

The heights of the plants were not measured during the 1954 survey; the plant heights were estimated using the 1996 survey data.

Estimating height class

1. Each individual in the 1996 survey was classified into one of eight stem or coppice diameter classes, which were used in the 1954 surveys (Table 17-1).

Table 17-1: The single-stem and multi-stem diameter classes used to classify individuals during the 1954 baseline survey (Van Der Schijff 1958).

Basal stem class	Diameter class (cm)	Diameter class code
Multi	0.00 – 30.48	**S01**
	30.48 – 91.44	**S13**
	> 91.44	**S3**
Single	0.00 – 2.54	**T01**
	2.54 – 7.62	**T13**
	7.62 – 12.7	**T35**
	12.7 – 17.78	**T57**
	> 17.78	**T7**

2. Each individual in the 1996 survey was also classified into one of four height classes (Table 17-2).

Table 17-2: The height classes used to classify individuals in the 1996 survey.

Height class (m)	Height class code
0 – 1	**H01**
1 – 3	**H13**
3 – 5	**H35**
> 5	**H5**

3. Estimating the height class for species common to the 1954, 1959, and 1996 surveys:

The relative number of individuals per height class for each diameter class was calculated from the 1996 data. These ratios were used to estimate the number of individuals in each height class within each diameter class for each species in the 1954 and 1959 data.

4. Estimating the height class for species present in the 1954 and 1959 surveys but not present in 1996:

The height class ratios for each diameter class were calculated for the entire 1996 dataset. These ratios were used to estimate the number of individuals in each height class within each diameter class for those species present in the 1954 and 1959 surveys and not in the 1996 survey.

Estimating height

The mean height for each of the four height classes (0-1 m, 1-3 m, 3-5 m and >5 m) was calculated using the 1996 data. These mean heights were used to estimate the height of each individual in the 1954 and 1959 surveys based on the individuals estimated height class.

Analysis

Diversity is a measure of the variability of composition (Pielou 1975). Composition can be any categorization or grouping used to classify a collection of individuals. Diversity has two distinct components: 1) the number of different groups in a collection, and 2) the relative amount of each group in a collection (Huston 1994).

WiSETD

Two aspects of woody vegetation diversity were investigated, namely taxonomic diversity and structural diversity

Taxonomic diversity

Taxonomic diversity was measured at the species level. The designation of what represented a species unit was taken to be the classification of woody species according to Palgrave (1991).

Structural diversity

The woody individuals in each survey were grouped using two structural classifications, namely the single and multi stem diameter classes (Table 17-1) and the height classes (Table 17-2). The height and diameter classifications were combined into a single structural classification. Therefore the height, diameter, and whether the individual was single-stemmed or multi-stemmed were represented in a single combined structural classification. This structural classification comprised 32 structural groups.

Indices of diversity

The diversity of the woody vegetation on the Pretoriuskop EBPs was measured for each plot using four indices that quantify the different components of diversity. The indices used were:

- The number of species of structural groups.
- Menhinick's species of structural richness index.
- Shannon's species or structural diversity index.
- Shannon's species or structural evenness index.

Number of species or structure groups

The number of groups (s_j) is a count of the number of species or structural groups on plot *j*. This index is used to quantify the first component of diversity.

Menhinick's species or structural richness

Menhinick's index of richness (sm_j) calculates the number of species or structural groups (s_j) relative to the square root of the number of individuals (n_j) on a plot *j* (Brower and Zar 1977).

$$sm_j = \frac{s_j}{\sqrt{n_j}}$$ **Menhinick's richness index.**

This index quantifies the first component of diversity relative to the sample size, and consequently standardises the estimation for different collection sizes.

Shannon's species or structural diversity index

Shannon's index of diversity is a measure of the uncertainty of predicting the identity (class) of an individual chosen randomly from a population (Brower and Zar 1977). It quantifies the combined components of diversity, namely the number of groups and relative abundance of each group in a collection of individuals.

$$H'_j = -\sum p_i \ln p_i$$ **Shannon's diversity index.**

Where H'_j is Shannon's diversity, and p_i is calculated as $p_i = \frac{n_i}{n_j}$, where n_i is the number of individuals in species or structural group *i* and n_j is the number of individuals on plot *j*.

WISETD

Shannon's species or structural evenness index

Shannon's evenness is a measure of the nearness of the calculated diversity index to the maximum possible diversity, where maximum diversity occurs when all species are evenly proportioned (Brower and Zar 1977).

$$J'_j = \frac{H'_j}{H\max'_j}$$ **Shannon's evenness index.**

Where J'_j is Shannon's evenness and H'_j is Shannon's diversity. $H\max'_j$ is calculated as $H\max'_j = \ln s_j$, where s_j is the number of species or structural groups on plot *j*.

Analysis of variance (ANOVA) and analysis of covariance (ANCOVA)

ANOVA and ANCOVA analyses were used to test for the effects of the different treatments on various measures of species and structural diversity calculated.

The size of the tests

The size (α) of the ANOVA, ANCOVA, and Tukey tests was set at 0.10. That is the probability of rejecting a null hypothesis was set at 0.10.

The data groupings testing the treatment effects

The effect of fire frequency on the woody vegetation of the Pretoriuskop sourveld

Two different plot groupings were used to test for the effects of fire frequency on the wood vegetation of the Pretoriuskop sourveld. This was because the experimental design of the Experimental Burn Plot (EBP) experiment was not symmetrical. Five fire treatments were burnt biennially and triennially each in February, April, August, October, and December. However, only one fire treatment was burnt annually in August.

The two plot groups were:

- Frequency (no Aug1): in which the annual August treatments were excluded from the analyses so as not to confound frequency effects with timing effects because there were no annual treatments at any other time of the year.
- Frequency (Aug and Cont): in which only the August annual, biennial, and triennial treatments and the control treatments were used in the analyses.

The effect of fire timing on the woody vegetation of the Pretoriuskop sourveld:

- In the testing the effects of fire timing on the woody vegetation of Pretoriuskop the annual August treatment was excluded. This was so as not to confound the timing effects with frequency effects because there was only one annual treatment in August and at no other time of the year.

The combined effect of fire frequency and timing on the woody vegetation of the Pretoriuskop sourveld:

- This analysis tests each fire treatment as individuals irrespective of the treatment frequency and timing.

The effect of not burning on the woody vegetation of the Pretoriuskop sourveld:

- This analysis tests the effect of not burning on the woody vegetations of the Pretoriuskop sourveld. The data collected on the control plots in the 1954, 1959, and 1996 surveys were used in this analysis.

WITS ETD

Changes in the woody vegetation density, structure, and composition in the Pretoriuskop region since 1954:

This analyses tests for changes in the woody vegetation of the Pretoriuskop sourveld at the landscape level between 1954 and 1996.

The covariates for the ANCOVA's

In the Analyses of Covariance (ANCOVA), the 1954 data were used as the covariates when performing the analyses on the 1996 data.

Post hoc analyses

The Tukey Student's t statistic was used for post hoc comparisons to determine which pairs of means differed significantly in the ANOVA's and ANCOVA's

Horn's index of community similarity

Horn's index of community similarity was calculated to compare the similarity of woody vegetation species diversity and structural diversity between treatment plots.

Horn's index of community similarity is based on Shannon's diversity index. The similarity of two communities is calculated by comparing their combined diversity, with their potential maximum and minimum diversity. Horn's index is 0 when the two communities have no species in common and 1 when the species composition and relative abundances are identical (Brower and Zar 1977).

Cluster analyses of Horn's similarity indices

The Horn's similarity indices were subjected to hierarchical cluster analyses to detect natural groupings in data. The distance was computed using Pearson distance measure, and the cluster-linking algorithm used was Ward's method (Ward 1963).

Mapping cluster groups in space

Using a map of the treatment plots the clusters derived in the cluster analyses were mapped onto the treatment plots. This with a background of a vegetation classification of the Pretoriuskop landscape created by the SADF in the mid 1980's provides an effective means for interpreting the results.

Results

Testing the effects of fire timing in the woody vegetation

(The August annual treatments were excluded from these analyses.)

- The mean height on plots burnt in February is significantly lower than on plots not burnt and plot burnt in October.
- Tree equivalents index is significantly higher on plots not burnt than on plots that were burnt.
- The single stem ratio is significantly higher on plots not burnt than on plots burnt. Furthermore, it is significantly lower on plots burnt in August than on plots burnt in April, December, and February.
- The number of species is significantly higher on plots not burnt than on plots burnt in April, August, and October.
- Species diversity is significantly higher on plots not burnt than on plots burnt in April, August, and October. Furthermore, plots burnt in February have significantly higher species diversity than those burnt in April.
- The post hoc analyses were not able to elucidate any significant differences in the number of structure groups between plots burnt at different times of the year.

WISETD

- Structural diversity is significantly higher on plots not burnt than on plots burnt in April, August, and February.
- Structural evenness is significantly higher on plots not burnt than on those burnt in August and February. Furthermore, plot burnt in October have a significantly higher structural evenness than those burnt in February.

Testing the effects of fire frequency on the woody vegetation (part 1)

(The August annual treatments were excluded from these analyses.)

- Density is significantly lower on the plots burnt biennially and triennially than on those not burnt.
- Tree equivalents indices are significantly higher on plots that are not burnt than on those that are burnt. The general trend is that as the return period between fires increases so the phytomass of the woody vegetation increases.
- The ratio of single stem individuals is significantly higher on the plots not burnt than on the plots that were burnt. The general trend is that the single-stem to multi-stem index increases as the inter-fire period increases.
- The number of species is significantly higher on the plots not burnt than on those that are burnt.
- Species diversity is significantly higher on the plots not burnt than on those that were burnt.
- Structural diversity is significantly higher on the plots not burnt than on the plots that were burnt. Furthermore, the structural diversity on the plots burnt triennially was significantly higher than on those burnt biennially.
- Structural evenness is significantly higher on the plots not burnt than on the plots that were burnt.

Testing the effects of fire frequency on the woody vegetation (part 2)

(Only the Control and August annual, biennial, and triennial treatments included in these analyses)

- Mean height is significantly taller on the plots not burnt than on those burnt annually. The trend indicates that as the inter-fire period between fires increases so the mean height of the woody vegetation increases.

- Tree equivalents increases significantly between the plots burnt annually and those not burnt. The trend indicates that as the inter-fire period between fires increases so the phytomass (tree equivalents) of the woody vegetation increases.

- The ratio of single stem individuals is significantly higher on the plots not burnt than on those burnt. This is expected since many savanna trees and shrubs respond to fire damage by resprouting from the base. However once they have reached a critical height most often one stem dominates and the others die off as resources are channelled into the growth of a single stem. The trend is one of an increasing ratio of single stem individuals as the return period between fires increases.

- The number of species is significantly higher on the plots not burnt than on those burnt. The trend is one of an increase in the number of woody species as the return period between fires increases.

- Species diversity is significantly higher on the plots not burnt than on those burnt triennially. This is an interesting result since the general trend seems to be an initial decrease in species diversity as inter-fire period increases from 1 year to 3 years. The species diversity then increases as inter-fire period increases beyond 3 years.

- There are significantly less structural groups on the plots burnt annually in comparison with those not burnt. The general trend is an increase in structure groups as inter-fire period increases.

WISER

- The plots burnt annually and biennially have a significantly lower structural diversity in comparison with those not burnt. The plots burnt triennially have a significantly higher structural diversity in comparison with those burnt annually.

- The plots burnt annually and biennially have a significantly lower structural evenness in comparison with those not burnt. The plots burnt triennially have a significantly higher structural evenness in comparison with those burnt annually.

- The general trend for structural diversity and evenness is that as the inter-fire period increases the structural diversity and evenness of the woody vegetation increases.

Testing the combined effects of fire timing and frequency

- The post hoc analyses were not able to elucidate any significant differences in the woody vegetation density between plots burnt at different times of the year.
- The number of species is significantly higher on plots not burnt than on those burnt biennially in April, biennially on October and triennially in October.
- The single stem ratio is significantly higher on plots not burnt than on plots burnt annually in August, biennially in August, triennially in August, biennially in February, biennially in October and triennially in October. Plots burnt annually and biennially in August have significantly lower single stem ratios than those burnt biennially and triennially in April, December, and February. Plots burnt triennially in August have a significantly lower single stem ratio than those burnt triennially in February.
- The post hoc analyses were not able to elucidate any significant differences in the species diversity between plots burnt at different times of the year.
- The post hoc analyses were not able to elucidate any significant differences in the number of structure groups between plots burnt at different times of the year.
- Structural diversity is significantly higher on plots not burnt than on those burnt annually in August, biennially in August and biennially in February. Structural diversity on plots burnt annually in August is significantly lower than on those burnt triennially in August, and biennially and triennially in April, December, February, and October. The plots burnt biennially in August have a significantly lower structural diversity than those burnt triennially in December.
- Structural evenness is significantly higher on plots not burnt than on those burnt annually in August, biennially in August and biennially in February. Structural evenness on plots burnt annually in August is significantly lower than on those burnt triennially in August, triennially in February, and biennially and triennially in April, December and October. The plots burnt biennially in February have a significantly lower structural evenness than those burnt triennially in December and those burnt triennially in October.

Testing the effects of the absence of fire on the woody vegetation

- Density increases significantly between 1954 and 1996 and 1959 and 1996.
- Mean height anomalously decreases significantly between 1954 and 1959 and then increases significantly between 1959 and 1996. There is no significant increase in mean height between 1954 and 1996.
- The number of tree equivalents increases significantly between 1954 and 1996, and 1959 and 1996. This indicates an increase in phytomass or woody biomass in the absence of fire.
- The ratio of single stem individuals decreases significantly between 1954 and 1959, and 1954 and 1996. This is not expected since we would expect a significant increase in single stem individuals with an increase in inter-fire period.
- Number of species increases significantly between 1954 and 1996 and 1959 and 1996. However, species richness does not differ significantly between the tree surveys. This is because the sample size on the control plots was 639 in 1954, 890 in 1959, and 4175 in 1996. The Menhinick's richness

WITHDRAWN

quantifies the number of species relative to the sample size, and consequently standardises the estimation.

- The number of structure groups significantly increases between 1959 and 1996. However, there is no significant increase between 1954 and 1996.
- Structural richness decreases significantly between 1954 and 1996. This is a mathematical artefact based in the differences in sample size between 1954 and 1996 since Menhinick's richness index is affected by sample size.
- There are no significant differences in the species and structural diversity and evenness between 1954, 1959, and 1996.

Plots grouped based on horn's index of similarity

Species overlap between plots

- The plots not burnt were grouped together with similar species diversities.
- Some plots whose diversities were similar in 1954 were also found to be similar in 1996:

Structural overlap between

- The plots not burnt were grouped together with similar structural diversities.

References

Annual report 1951. Unpublished annual Report of the South African National Parks Board of Trusties 1951.

Annual report 1955. Unpublished annual Report of the South African National Parks Board of Trusties 1955.

Brower JE and JH Zar, 1977. Field and laboratory methods for general ecology. Wm. C. Brown Publishers, Iowa.

Huston MA, 1994. Biological diversity. Cambridge University Press.

Pielou EC, 1975. Ecological diversity. John Wiley and Sons, New York.

Palgrave KC, 1991. Trees of Southern Africa. Struik Publishers, Cape Town.

Southwood TRE and PA Henderson, 2000. Ecological methods. Blackwell Science, Oxford.

StatSoft 1999. Electronic Statistics Textbook. Tulsa, OK. StatSoft Inc.
URL: http://www.statsoft.com/textbook/stathome.html

Van Der Schijff HP, 1958. Inleidende verslag oor veldbrandnavorsing in die Nasionale Krugerwildtuin. Koedoe 1: 60-93.

Ward JH, 1963. Hierarchical grouping to optimise an objective function. Journal of the American Statistical Association 58: 236.

WiSETD

17.6 THE LONG-TERM EFFECTS OF FIRE FREQUENCY AND SEASON ON THE WOODY VEGETATION IN THE PRETORIUSKOP SOURVELD OF THE KRUGER NATIONAL PARK

This paper was presented as a talk at the Kruger National Park Research Conference. Skukuza, April 2005.

SP O'Regan & ETF Witkowski

This is a summary of the findings from this MSc, in which the effects of fire frequency and season on the woody vegetation in Pretoriuskop were studied using the Experimental Burn Plot framework.

WHAT ARE THE EFFECTS OF THE FREQUENCY OF FIRE ON THE WOODY VEGETATION IN PRETORIUSKOP?

The exclusion of fire in Pretoriuskop generally results in an increase in the density, species diversity, species evenness, structural diversity, and structural evenness of the woody vegetation.

Post fire succession in Pretoriuskop is not relay floristic succession, where fire sensitive woody species replace fire tolerant species as the period between fires increases.

Instead, the post fire floristic succession is accumulative and as the period between fires increases, fire tolerant and fire intolerant woody species coexist.

The increase in the density of the woody vegetation as the period between fires increases is not linear but rather J shaped with an initial decrease in the density as the period between fires increases from 1 year to 3 years. The initial decrease in density is the result of a loss of very short woody individuals, less than 1m tall. In contrast, there is no initial decrease in the number of tree equivalents (which is a measure of phytomass of the woody vegetation) as the period between fires increases.

Under a high frequency fire regime, the woody vegetation in Pretoriuskop is made up of a high proportion of multi-stem individuals shorter than 1m tall, which are below grass height. The appearance of vegetation is an open savanna with a few scattered medium to large trees.

Under a medium frequency fire regime, the woody plant density is slightly lower than in areas burnt more frequently, and more plants grow to fire resistant heights between fire events. The appearance of the vegetation is a more closely wooded savanna with the density of medium and large trees being greater than in areas burnt more frequently.

When fire is excluded in Pretoriuskop, the woody plant density is significantly higher than in areas that have been burnt, and the average height of the woody vegetation is taller than in areas that have been burnt. The appearance of the vegetation is a closed savanna woodland in which climbers, creepers, lichens, and ferns proliferate.

The findings regarding the effect of fire frequency on the density of the woody vegetation in Pretoriuskop are similar to findings from other fire experiments in mesic African savannas. However, they are different from the findings in fire experiments in semi-arid to arid savannas in Africa.

Generally, it seems that the exclusion of fire in moist or mesic savannas (which experience more than 600 mm of rain annually) results in the woody vegetation becoming denser as well as the woody biomass increasing. However, the exclusion of fire in semi-arid to arid savannas (which experience less than 600mm of rain annually) does not necessarily result in the woody vegetation becoming more dense, even though the woody biomass does increase.

WISETD

WHAT ARE THE EFFECTS OF THE TIMING OF FIRE ON THE WOODY VEGETATION IN PRETORIUSKOP?

Generally, under a winter fire regime, in which fires occur between August and October, the woody vegetation is less dense and has a lower species diversity than under a summer fire regime. And, the structure of the woody vegetation under a winter fire regime is generally dominated by multi-stem individuals that are 0-1m tall and 3-5m tall.

Under a summer fire regime, in which fires occur between December and February, the woody vegetation is more dense and has a higher species diversity than under a winter fire regime. And, The structure of the woody vegetation under a summer fire regime is dominated by both single-stem and multi-stem individuals of all heights and basal diameters.

In Pretoriuskop, woody vegetation burnt in the early dry season (i.e. in April) is more dense than woody vegetation burnt in late dry season (i.e. in August). This is consistent with findings in fire experiments else where in Africa where late dry season fires result in a decrease in the density of the woody vegetation.

Generally, the density, species composition, and structural composition of the woody vegetation in areas that have been burnt in summer fires is more similar to areas where fire has been excluded than to areas that have been burnt in winter fires.

WHAT CHANGES HAVE OCCURRED IN THE WOODY VEGETATION OF PRETORIUSKOP BETWEEN THE 1950'S AND THE 1990'S

The density and species diversity of the woody vegetation has increased between 1954 and 1996. With the density of the woody vegetation increasing by almost 200%.

Two main factors are believed to have driven these changes:

1. The exclusion of human habitation of the KNP.

2. The increased atmospheric CO2 levels between 1954 and 1996.

Up until 1926, the human impact on the vegetation in the Pretoriuskop region was significant. As early as 1944, James Stevenson-Hamilton commented in a report to the National Board of trustees that a factor contributing toward bush encroachment in the KNP was that there was no "native population" in the park. The people who had lived in the area before the proclamation of the Nature Reserve had harvested trees and fruit, they practised agriculture, and they kept livestock. And, Stevenson-Hamilton believed that their agricultural practices tended keep the bushveld open to a greater extent than one might expect. Furthermore, up until 1926 Sheep farmers bought their sheep to graze in the Pretoriuskop region annually in the winter. It is reported that they would always burn the old grass in the area to create pastures for gazing.

Regarding atmospheric CO2. As the atmospheric CO2 levels increase the water use efficiency of the many woody plants increases. Furthermore, many woody plants experience increased rates of photosynthesis and a greater production of carbohydrates. So generally, as the atmospheric CO2 levels increase, perennial woody species loose less water while producing more biomass, and it is expected that they will become more dominant relative to annual herbaceous species.

These two factors are believed to be driving the densification of the woody vegetation in Pretoriuskop.

WiSETD

17.7 A FIRE HISTORY OF THE SAVANNA ECOSYSTEMS IN THE KRUGER NATIONAL PARK, SOUTH AFRICA, BETWEEN 1941 AND 1996.

This paper was published in the South African Journal of Science Volume 96 in April 2000.

A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996

B.W. van Wilgen[a], H.C. Biggs[b], S.P. O'Regan[c] and N. Marè[b]

This paper analyses the fire history of the Kruger National Park (1.9 million ha), South Africa, for different periods in the park's history, where fire protection was followed by prescribed burning and then a 'natural' (lightning) fire policy. Fires covering 16.79 million ha occurred between 1941 and 1996 (16% of the area burning each year on average). Of this area, 5.15 million ha was burnt between 1941 and 1957, when limited prescribed burning and protection from fire took place (16% burning each year on average). Between 1957 and 1991, 2213 prescribed burns covering 5.1 million ha (46.3% of the 10.98 million ha burnt during that period) were carried out. Lightning fires affected 2.5 million ha between 1957 and 1996, or 21.6% of the area. The mean fire return period was 4.5 years, with intervals between fires from 1 to 34 years. The distribution around the mean was not symmetrical and the median fire interval was 3.1 years. Some areas burnt more often than others, and mean fire return periods ranged from 2.7 to 7.1 years in the 11 major land systems of the park. Fires occurred in all months, but 59% of them took place from September to November. Prescribed burns were concentrated late in the dry season (September to November). Lightning fires were later, with 84.7% of the area burning between September and January. The implications of the analysis for the management of the park are discussed.

Savannas are tropical grasslands with scattered trees; they occupy about 20% of the land surface of the Earth, and 40% of Africa. These ecosystems are dynamic in their structure and composition, which changes in response to fluctuations in rainfall, levels of herbivory and occasional fires that burn through the grass swards. The role of fire in the maintenance of structure and function in African savannas is probably the oldest issue in savanna ecology[1] and remains contentious. In conservation areas, where early ideas were formed around equilibrium theory, fire was regarded first as something to be avoided, and was later applied at a fixed return period, when it was realized that fire was an integral part of the system. However, with the development of non-equilibrium theories of savanna dynamics, policy and practice in fire management have shifted towards burning under diverse rather than fixed conditions.[2,3]

Fire management in the Kruger National Park has followed a similar trend. After the proclamation of the park in 1926, occasional and limited burning was used until 1948 only to provide green grazing for wildlife. Between 1948 and 1956, prescribed burning was stopped and firebreaks were established to assist in the control of wildfires. This policy was changed in 1957 to a formal system of burning once every three years in spring on fixed management areas (termed 'blocks') ranging in size from 50 to 20 000 ha. In 1975, this policy was amended to allow for longer periods between fires in drier areas, with the season of burn varied between late winter, mid-summer and autumn.[4] In 1992, the policy was again changed to one of allowing natural (lighting-ignited) fires to burn freely, but where prescribed burning would not be carried out, and all other fires of human origin were suppressed. For the sake of analysis, we recognized three periods in this paper. The period prior to 1956 was one of protection from fire, from 1957 to 1991, prescribed burning was actively practised, and from 1992 only lightning fires were permitted to burn.

The shift away from rigid prescribed burning on a fixed cycle was in response to several recent concerns. For example, Trollope and co-workers[5] concluded that a dominance of grass species characteristic of poorly managed pastures and overgrazing was a result of 'excessively frequent burning'. In addition, there was concern over putative trends in woody vegetation structure.[6] It appears (for example, from examining early aerial photographs) that large areas have been homogenized, possibly due to the rigid application of a policy of burning at three-year intervals. Tree densities have declined, greatly for some species, and this decline may be due to an 'unnatural' fire regime (in combination with other factors, such as browsing by ever-increasing numbers of elephants). In a revision of the research objectives for the park, developing an understanding of the attributes of natural fire regimes has been identified as a priority.

The Kruger National Park has a comprehensive set of fire records spanning five decades. These data have only partially been analysed. For example, the records for fires between 1980 and 1993 showed that most (90%) fires were of human origin, while lightning fires affected only 10% of the park. Lightning fires, however, took place in spring and summer (September to February), whereas other fires were predominantly in late winter and spring (June to October).[7] While that analysis is useful, the available records span a much longer period and can also be evaluated spatially to provide information about the historical influences of fire on vegetation patterns and trends in the park.

This study reports on an analysis of fire patterns in the Kruger National Park based on fire records that date back to 1941, to quantify the nature of the fire regime that existed during the period of formal management. This record is probably the longest fire history for any savanna ecosystem in the world, and provides an important benchmark for interpreting the changes in vegetation structure that have taken place.

The study area

The Kruger National Park is situated in the low-lying savannas of the eastern parts of the Northern and Mpumalanga provinces of South Africa, adjacent to Mozambique in the east and Zimbabwe in the north (Fig. 1). The park was established in 1926, and covers 1 948 528 ha. Elevations range from 260 to 839 m

[a]CSIR Division of Water, Environment and Forestry Technology, P.O. Box 320, Stellenbosch, 7599 South Africa. E-mail: bvwilgen@csir.co.za
[b]Scientific Services, Kruger National Park, Private Bag X402, Skukuza, 1350 South Africa E-mail: biggs@parks-sa.co.za; sanhu@parks-sa.co.za
[c]Department of Botany, University of the Witwatersrand, Private Bag 3, WITS, 2050 South Africa. E-mail: seano@gecko.biol.wits.ac.za

above sea level. Mean annual rainfall varies from around 750 mm in the south to approximately 350 mm in the north (Fig. 2), but variations about the mean can be marked from year to year (Fig. 3).[8] The pattern of rainfall over the past century has been characterized by extended wet and dry periods, in which the rainfall tended to be either higher or lower than the long-term mean for between 6 and 12 consecutive years (Table 1).[9] These wet and dry periods have marked effects on the dynamics of the ecosystem, and on the occurrence of fires.

The park is crossed by seven perennial or seasonal rivers (the Crocodile, Sabie, Olifants, Letaba, Shingwidzi, Luvuvhu and Limpopo), which run from west to east. Geologically, the park can be divided into western and eastern halves. In the west, granites and their erosion products dominate, while the eastern sector is predominantly underlain by basalt, but includes the Lebombo Hills (primarily rhyolite formations) running from north to south. Two important areas of sandveld (on recent sands) also occur in the north, around Punda Maria and Pafuri.

Several studies have sought to classify the landscapes and vegetation formations of the park. One such study has divided the park into 35 'landscapes' based on geomorphology and vegetation.[10] Another subdivided the park into 56 'land types' on the basis of soil and vegetation patterns and landform characteristics.[11] These land types were combined into 11 'land systems' on the basis of geological, geomorphological and climatic characteristics. The boundaries of these divisions have been captured on a geographic information system (GIS) and provided a framework for the examination of fire regimes in this study.

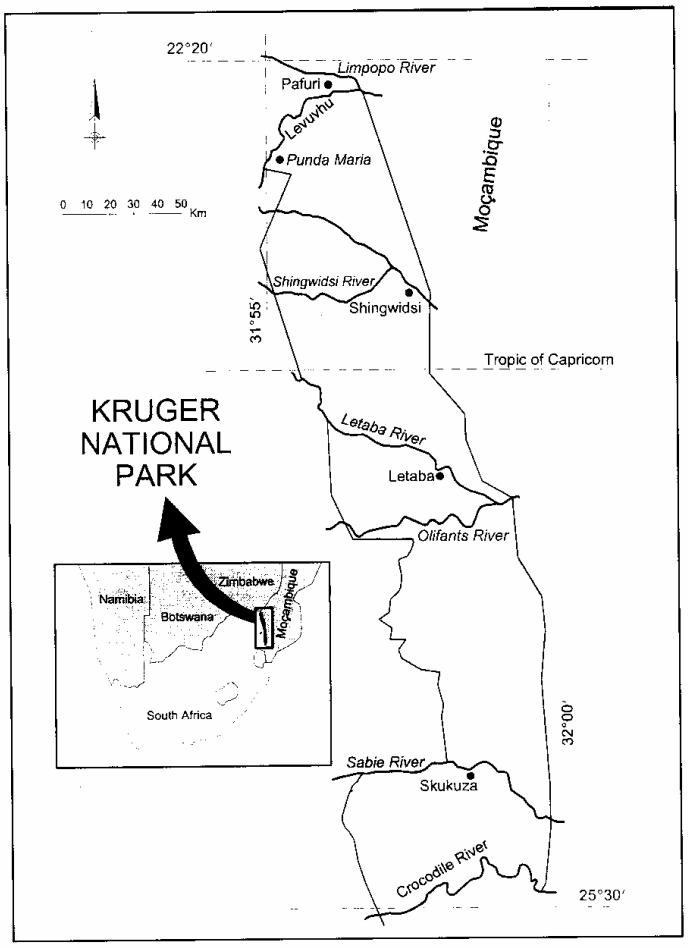


Fig. 1. Map of South Africa showing the location and topographical features of the Kruger National Park.

The flora of the park comprises 1983 species (N. Zambatis, pers. comm.), including over 400 tree and shrub species,[12] and over 220 grasses. Broadly speaking, there are four dominant vegetation types in the park. In the southwest, the low nutrient status of the soils results in a relatively low grazing pressure, and grass fuels accumulate during the growing season; rainfall is also higher, and as a result of these factors fires tend to be relatively frequent in these areas. The area is well wooded, and important tree species include the red bushwillow *(Combretum apiculatum)*, knobthorn *(Acacia nigrescens)*, tamboti *(Spirostachys africana)* and marula *(Sclerocarya birrea)*. In the southeast, on basalt substrates, grasses are more palatable and tend to be heavily grazed. Important tree species include the knobthorn, leadwood *(Combretum imberbe)* and marula. North of the Olifants River, the granite areas in the west are poorly grassed; mopane *(Colophospermum mopane)* and red bushwillow are dominant trees. The northeastern areas on basalt are dominated by multi-stemmed mopane shrubs about 1 to 2 m in height.

The fauna of the park is also diverse, including 147 species of mammals[13] and 492 species of birds.[14] Important herbivores include elephant *(Loxodonta africana)*, buffalo *(Syncerus caffer)*, impala *(Aepyceros melampus)*, zebra *(Equus burchelli)*, wildebeest *(Connochaetes taurinus)*, waterbuck *(Kobus ellipsiprymnus)*, kudu *(Tragelaphus strepsiceros)*, giraffe *(Giraffa camelopardalis)*, white and black rhinoceros *(Ceratotherium simum* and *Diceros bicornis)* and hippopotamus *(Hippopotamus amphibius)*. Herbivory, particularly by grazers, has an important influence on fires through the consumption of grass fuels. In addition, browsing (particularly by elephants) has a strong impact on subsequent tree mortality after fires.

The fire record

Fires in the Kruger National Park were traditionally recorded in ranger's diaries prior to the introduction of a programme of prescribed burning in 1957. When prescribed burning was introduced, the park was subdivided into over 400 management areas, or 'blocks', ranging in size from 50 to 23 800 ha (mean = 4198 ha, Fig. 4). The boundaries of the 453 blocks that existed at

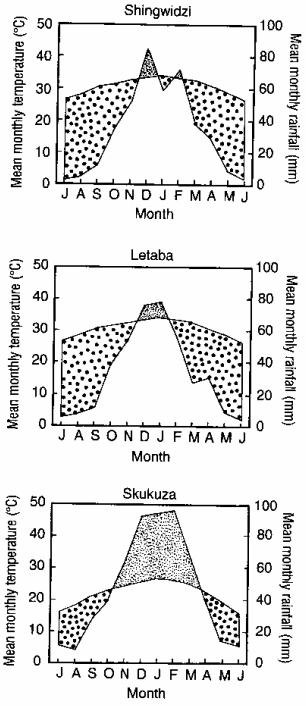


Fig. 2. Climate diagrams for three locations in the Kruger National Park (see Fig. 1 for the localities of stations).

the time of this study were captured on a GIS, and formed the basis of our analysis. The fire records for different periods were in three formats, as follows:

(i) Sketch maps of the distribution of fires for each year from 1941 to 1956, available from a previous analysis of ranger's diaries.[15] These were digitized, and overlaid on the boundaries of existing fire blocks to establish the percentage of the block that was burnt in each year. These fires were recorded at a coarse scale (1:500 000), resulting in partially burnt blocks only providing a crude estimate of percentage burnt.

(ii) The board controlling the park took a decision to institute prescribed burning in fixed blocks on a three-year cycle in 1957.[15] Fire records for each of these blocks, giving the dates and causes of fires, and in some cases an estimate of the percentage of the block that burned, were available from 1957 to 1991. These records were extracted from the management files for each block.

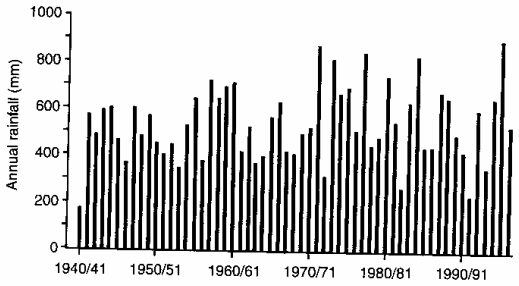


Fig. 3. Total annual rainfall at Skukuza, Kruger National Park, between 1940/41 and 1996/97. Data are for climatic years (1 July to 30 June).

(iii) As from 1992, all prescribed burns were stopped. Natural (lightning) fires were allowed to burn in line with a management policy, although other fires did occur. These fires were mapped (using fire reports and satellite images to establish boundaries on 1:50 000 topographical maps) and added to the database by allocating a date, percentage burnt, and cause of each fire to the existing fire management blocks.

Between 1957 and 1988, numerous adjustments were made to the boundaries of blocks. We established the extent and dates of these changes by comparing older maps to the existing set of blocks. Where necessary, fire records were re-allocated to the existing blocks by assigning the date of the fire and its cause, together with an estimate of the percentage of the existing block that would have burnt in that fire.

The cause of fires was recorded in seven categories: prescribed fires (where the whole block was intentionally burnt); firebreak fires (where the boundaries of the block were ignited under conditions where the fire would not progress very far, with the intention of creating a buffer strip — we refer to these strips as 'firebreaks' throughout); fires caused by lighting; escape fires (where prescribed or firebreak fires unintentionally spread to the block concerned, or where any fires originating outside the park burnt a block inside the park); other fires of human origin (poachers or trans-border migrants being the most common causes); other fires of known cause; and fires of unknown origin.

The fire record consisted of 5512 individual burns between 1957 and 1992, that burnt an area of 10.97 million ha. The total number of fires between 1941 and 1956 is not known (only the annual extent of fires was available), but during this period burnt 5.15 million ha. The period between 1992 and 1996 was initially characterized by a severe drought, and not many fires occurred. However, extensive lightning fires occurred in 1996, following good rains in 1995, burning 359 424 (50.4%) of the 712 055 ha burnt between 1992 and 1996.

Table 1. Cyclical patterns of rainfall from available recording stations in the Kruger National Park, showing the extent and duration of wet and dry periods between 1919/20 and 1992/93.[9] The mean annual rainfall for all stations was 534.2 mm.

Dates	Number of recording stations	Length of period (years)	Type of period	Mean rainfall for period (mm)
1919/20–1924/25	1–2	6	Wet	650.2
1925/26–1935/36	3–7	10	Dry	462.3
1936/37–1942/43	8–11	6	Wet	590.1
1943/44–1952/53	9	9	Dry	510.6
1953/54–1960/61	9–14	7	Wet	586.4
1961/62–1970/71	14–17	9	Dry	457.5
1971/72–1981/82	17–19	10	Wet	638.7
1982/83–1994/94	19–27	12	Dry	450.0
1994/95–1996/97	29–34	2	Wet?	560.7

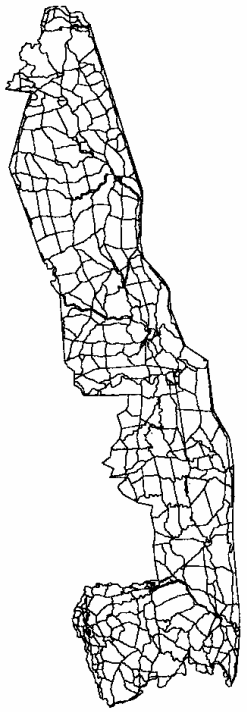


Fig. 4. Distribution of management units ('blocks') which formed the basis for a spatial analysis of fire regimes in the Kruger National Park. See Fig. 1 for scale.

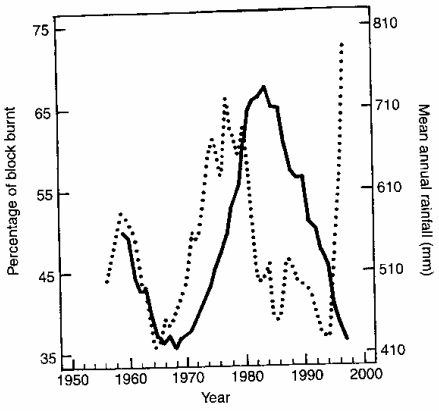


Fig. 5. Trends in percentage burn recorded in fires between 1957 and 1992 (5-year running mean, solid line), and annual rainfall (3-year running mean, dotted line). There is a significant relationship between percentage burn and annual rainfall five years before the fires ($y = 29.95$, $x = 0.034$, where y is the percentage of the block burnt and x is the annual rainfall five years prior to the burn; $r^2 = 0.17$, $P < 0.012$).

Data analysis

Estimation of percentage of block burnt

The 1137 records for individual fires between 1980 to 1993 were complete in terms of estimates of the percentage area of the blocks that burnt.[7] Many (60%) of the fire records from 1957 to 1979 did not have these estimates; however, the cause of fires was consistently recorded. To fill in missing values of percentage burn, we assumed that firebreak burns (743 of the 4375 records between 1957 and 1979) burnt 20% of the block concerned, based on the estimates for fires from this source (firebreak burns were usually ignited to create a fuel-break around the periphery of the block, under conditions that would normally cause the fire to die out at night). Where more than one firebreak burn occurred in a block in the same year, we assumed that the total area of all firebreak burns that year was 20%, and reduced the estimates for individual burns proportionally.

For those records where the percentage area of the block burnt was recorded (73% of the 5512 fires between 1957 and 1992), a clear annual trend was evident. This trend was significantly correlated with annual rainfall five years earlier (Fig. 5). We used this relationship to estimate percentage burn for the fires where this was not recorded, excluding the firebreak burns (where we assumed that 20% of the area of the block was burned). In order to obtain an estimate, we first subtracted the extent of firebreak burns that occurred before the burn in question in the same year from the area of the block. We then used the relationship to estimate the proportion of the remainder of the block that would have burnt. Where more than one non-firebreak burn occurred in a block in the same year, we assumed that the total area of all non-firebreak burns that year was equal to the estimate, and reduced the estimates for individual burns proportionally.

Frequency of fires

Fire frequency was examined in three ways. First, where we wished to test for significant differences in fire return periods between areas of interest, the mean return period was calculated as

$$RP = \frac{\left(\sum i_j a_j\right)}{\left(\sum n_j a_j\right)},$$

where RP is the return period in years, j is the number of blocks in the area of interest, i is the inter-fire period in years, a is the area of block j, and n is the number of inter-fire periods (the number of fires minus 1). Using this method, we were able to test for differences between areas using one-way analysis of variance.

Secondly, where return periods were determined for short intervals, cases arose where only one fire had occurred in some blocks in the period concerned (that is, there was no inter-fire period on record). This precluded the use of the above formula, and we used $RP = y/(b/a)$, where RP is the return period in years, y is the number of years over which fires were recorded, b is the extent of all fires recorded over y years, and a is the area over which fires were recorded. In this case, only one number is produced, and it is not possible to test for the significance of any differences.

Thirdly, we estimated the frequency distribution around the mean by determining the period between successive fires in each block. To do this, we divided each block into 10 equal sub-blocks, and randomly assigned sub-blocks as burnt or not in each year based on the percentage burnt (i.e., if 20% of a block had burnt, two randomly selected sub-blocks were designated as having burnt). A key assumption in doing this was that each subdivision of a block had an equal chance of burning; this assumption was the only way to deal with the data, as the exact location of each fire within blocks with incomplete burns was not known. These data were used to determine the distribution of periods between successive fires in each block. To determine the distribution for the whole area being examined, we totalled the periods for all blocks, weighted by area.

We used maps of the land systems[11] and of rainfall to examine patterns of fire frequency. The rainfall distribution was derived from a national database that models rainfall from existing recording stations and topographical factors at a resolution of one minute by one minute.[16] We also divided the data into different periods in order to determine the effects of climatic periods, and periods of differing management policies, on fire frequency.

Seasonality of fires

Seasonality of fires was examined monthly. The area burnt in each month was totalled for the area, time period, and cause. We used these data to establish whether seasonal differences in the proportion of area burnt varied between the land systems in the park, and between wet or dry periods. We also examined whether fires of different origin (particularly those started by lightning) differed in their seasonal occurrence.

Size of fires and extent of area burnt

The extent of fires was calculated from the area of the management blocks, and the estimates of the percentage of the block that burnt. These were then totalled for different landscapes, rainfall zones or time periods of interest (such as wet and dry climatic cycles, and periods of differing management policy). The estimation of the size of fires was constrained by the fact that fire records were kept for individual management blocks and not for individual fires. Thus, if a fire burnt over more than one block, this was not recorded. However, occurrences of the same fire burning in more than one block prior to 1992 were rare, as fires were almost always confined to a single block by effective backburning from the boundaries. For the fires that occurred after 1992, accurate maps of individual fires were available. We were able, in these cases, to estimate the areas of individual fires from these maps, using the areas of management blocks as a basis.

Fire climate

Climate and weather are important in determining the opportunities for fires to occur and spread, and together with fuel properties will affect their size and intensity. We obtained daily weather data from two representative weather stations in the park (Skukuza and Letaba, see Fig. 1) for the period 1981 to 1997, and used the U.S. National Fire Danger Rating System[17] to calculate daily indices of fire danger. The data used included daily maximum and minimum temperature and relative humidity, cloud cover, rainfall duration and wind speed, and an estimate of the fuel composition and structure (we used fuel model L). Results are expressed in terms of a 'burning index', which can be related to the spread and intensity of a fire under prevailing conditions.

Effect of fuel load on the occurrence of fire

Grass biomass (fuel) estimates were defined from one to four points per management block for approximately two-thirds of the blocks in the park from 1989 onwards. These points were distributed across the whole park and all land systems, and were taken to be representative of fuel loads throughout the block. The single point (or in the case of blocks with multiple sampling points, the mean) biomass per block was determined for each year from 1989 to 1996. The annual occurrence of fire (other than in firebreak burns) in blocks was recorded as a binary variable — burnt or not burnt. The probability of a fire of any size occurring in a block in a given year was then estimated as a function of biomass using logistic regression.[18]

Results

Fire frequency

The mean fire return period for the entire dataset was 4.5 years. However, the distribution around the mean was not symmetrical (Fig. 6), and the median fire interval was 3.1 years. This indicates a skewed distribution in the data, with many short-interval fires, but a few areas experiencing relatively long intervals between fires, thus increasing the mean interval between them. Fires that burnt within one year of a previous fire accounted for 16% of the area burnt over the past 56 years; a further 17% of the area burnt within 2 years of a previous fire, and another 16% within 3 years (Fig. 6). Thus, for more than half a century, about half the area burnt within 3 years of the previous fire. About 80% of the area burnt within 7 years of the previous fire, and a small proportion (about 10%) burnt 10 years or more after the previous fire. As can be expected in a large and diverse area, the spatial distribution of mean fire return periods varied spatially (Fig. 7).

Mean and median fire return periods ranged from 2.7 to 7.1, and 1.8 and 4.6 years, respectively, in the 11 major land systems of the park (Table 2) between 1941 and 1996. The range of intervals between fires for the different land systems was from 1 to between 30 and 40 years. Most land systems had mean fire return periods of between 4 and 5.8 years, and two (the Klipkoppies and Phalaborwa systems) had mean fire return periods of 6 years or more. The median fire return period was generally shorter than the mean, and was much less for the Malelane system (1.8 as opposed to 5.3 years). Few areas (less than 1% of the Malelane land system to 10% of the Klipkoppies land system) managed to escape fire for more than 15 years (Fig. 8).

Rainfall has a marked effect on the production of grass fuels, and therefore on fire return periods. This was evident for areas that receive a mean annual rainfall of over 700 mm (Table 3). Here, the mean return period was 3.5 years, compared with around 5.2 years for areas with annual rainfall between 400 and 700 mm. Fire returns were longer in dry periods (where grass productivity, and hence fuel loads, would have been low) than in wet (Table 4). For the 10 years between 1971 and 1980 (a wet cycle, see Table 1), the mean return period was 4.3 years over the whole of the park. Over a similar period between 1983 and 1992 (a dry cycle), the corresponding period was 9.1 years. Mean fire return periods were similar between 1941 and 1956, prior to prescribed burning, and between 1957 and 1992, when prescribed burning was actively practised (5.9 and 6.2 years, respectively, Table 4). It would appear, therefore, that attempts at protection from fire did little to reduce fire frequencies. With the adoption of a policy of lightning fire, indications are that the

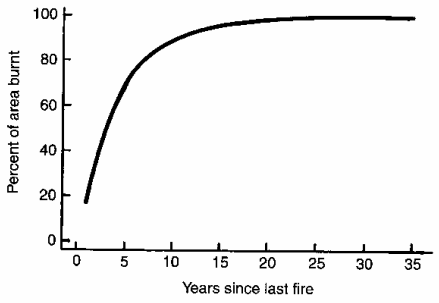


Fig. 6. The cumulative probability of fire in the Kruger National Park, calculated from fire records between 1941 and 1996.

mean fire return periods have become longer. Because this policy has only operated for 5 years, we compared the mean fire return periods between 1992 and 1996 (where prescribed burning was not carried out, and lightning fires were allowed to burn) with a period of equal length and similar rainfall (1981–85). The mean return period under the lightning fire policy was 13.3 years, more than double that in the prescribed burning era (6 years, Table 4). This indicates that, for dry periods at least, the new policy could lead to longer intervals between fires.

Fire season

Fires occurred in all months of the year for the period of analysis (1957 to 1996), but most of the area (80%) burnt in the months from June to November (Fig. 9). September, October and November had the largest proportions of area burnt (23, 21 and 15%, respectively). Firebreak burns were conducted earlier in the year, with most (70% of the area) being carried out between May and July. Prescribed burns, which accounted for 43.7% of the total area burnt (see below), were concentrated late in the dry season, with 66.5% of the prescription-burnt area being burnt in the months of September, October and November. Lightning fires tended to be later in the year, with 84.7% of the area attributed to this cause burning between September and January. Other fires (most of which were of human origin) followed the same seasonal pattern as prescribed burns (80% of the area burning from July to November).

The seasonal distribution of fires was examined for the period when the lightning fire policy was in operation (1992–96). Here, a total of 712 031 ha was burnt in 5 years (Table 4). These fires were

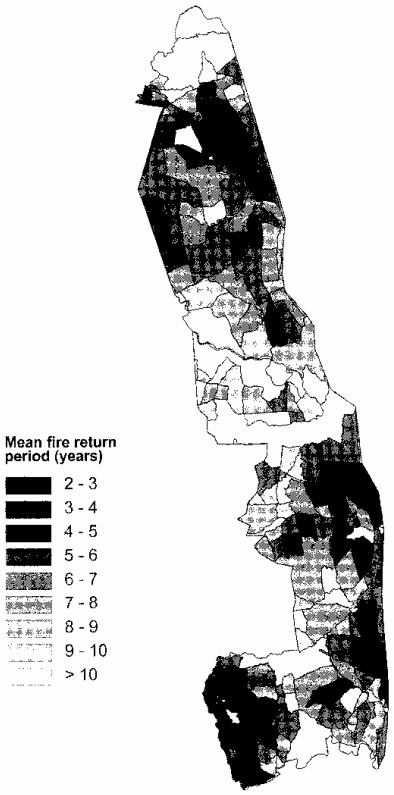


Fig. 7. Map of the Kruger National Park showing mean fire return periods calculated from fire records between 1957 and 1996. See Fig. 1 for scale.

Table 2. Fire return periods in 11 land systems (after Venter[11]) in the Kruger National Park, South Africa, between 1941 and 1996. Means with the same superscript letter do not differ significantly at $P < 0.0005$.

Land system	Salient features	Area (km^2)	Extent of fires between 1941 and 1996 (km^2)	Fire return periods (years)		
				Mean	Median	Range
Malelane	*Combretum apiculatum* bush savanna on granite. Rainfall 600–700 mm/yr	400.3	5415	5.3[ac]	1.8	1–34
Skukuza	*Combretum apiculatum/Terminalia sericea* bush savanna on granite. Rainfall 500–750 mm/yr	3742.6	35 496	4.2[bd]	3.3	1–40
Satara	*Acacia nigrescens/Sclerocarya birrea* tree savanna on basalt and gabbro. Rainfall 500–650 mm/yr	2599.7	27 766	5.0[c]	2.9	1–35
Vutome	*Acacia welwitschii/Euclea divinorum* tree savanna on Karoo sedimentary rocks. Rainfall 500–650 mm/yr	746.6	5767	5.8[c]	3.8	1–39
Sabiepoort	*Combretum apiculatum/Pterocarpus rotundifolius* bush savanna on rhyolite. Rainfall 500–650 mm/yr	855.0	9362	4.1[bd]	2.6	1–34
Phalaborwa	*Colophospermum mopane/Combretum apiculatum* bush savanna on granite. Rainfall 450–600 mm/yr	4981.9	40 521	7.1[e]	3.4	1–32
Letaba	*Colophospermum mopane* bush savanna on basalt and gabbro. Rainfall 450–500 mm/yr	3418.2	29 884	4.4[ad]	2.9	1–33
Bulweni	*Terminalia sericea/Combretum zeyheri* bush savanna on deep recent sands. Rainfall 450–500 mm/yr	395.3	2459	3.7[bdf]	3.3	1–30
Klipkoppies	*Colophospermum mopane/Combretum apiculatum* tree and bush savanna on rhyolite. Rainfall 450–500 mm/yr	482.4	3457	6.1[ce]	4.6	1–32
Nwambiya	*Baphia massaiensis* bush savanna on recent sands. Rainfall < 400 mm/yr	508.1	3884	3.6[bf]	3.4	1–35
Pafuri	*Colophospermum mopane/Burkea africana* tree and bush savanna on volcanic rocks and floodplains. Rainfall 400–650 mm/yr	861.7	3935	2.7[f]	4.5	1–35
Total		18 991.8	167 947	4.5	3.1	1–40

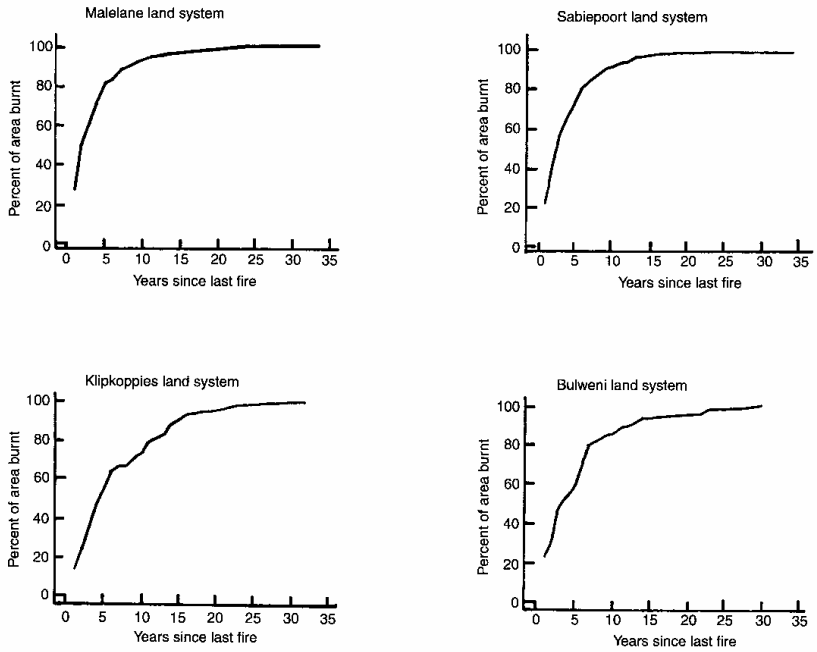


Fig. 8. The cumulative probability of fire in four land systems (see Table 2) in the Kruger National Park, calculated from fire records between 1941 and 1996.

concentrated in the three months from September to November, when 83% of the area was burnt (Fig. 10). We also examined a period of equal duration and similar rainfall (1981–85), when the policy of prescribed burning was in operation. Here, a much greater area was burnt (1.57 million ha), with 82% of the burns occurring over either an earlier or longer period (six months from June to November). The adoption of a lightning fire policy has therefore led to a discernible shift in fire season.

Size of fires and extent of area burnt

Fires covering 16.79 million ha occurred during the 56 years between 1941 and 1996 in the park. Of this area, 5.15 million ha burnt from 1941 to 1956, for which the records are not detailed enough to provide more than an annual total for each year. During the era of prescribed burning, 2213 prescribed burns were carried out, and these affected about 5.1 million ha (46.3% of the 10.92 million ha burnt during that period). There were also

Table 3. Fire return periods for zones of mean annual rainfall in the Kruger National Park. Means with the same superscript letter do not differ significantly at $P < 0.0005$.

Mean annual rainfall zone (mm)	Area (km^2)	Area burnt between 1957 and 1996 (km^2)	Mean fire return period (years)
400–500	6251	37 852	5.0^a
500–600	8663	54 919	5.3^b
600–700	2745	16 976	5.2^{ab}
700–800	314.6	1665	3.5^c
800–900	69.5	1238	3.5^c

Table 4. Mean fire return periods for wet and dry climatic periods, and for periods of varying management policies in the Kruger National Park (18 991.8 km^2).

Period of analysis	Extent of fires (km^2)	Mean fire return period (years)
Wet climatic cycle (1971–1980)	44 149	4.3
Dry climatic cycle (1983–1992)	20 834	9.1
Limited prescribed burning and active fire protection (1941–1956)	51 541	5.9
Active prescribed burning (1957–1992)	109 750	6.2
Active prescribed burning (1981–1985)*	15 733	6.0
Lightning fire policy (1992–1996)	7120	13.3

*This period was chosen for a similar rainfall pattern to the period under which the lightning fire policy had been operative, for comparative purposes.

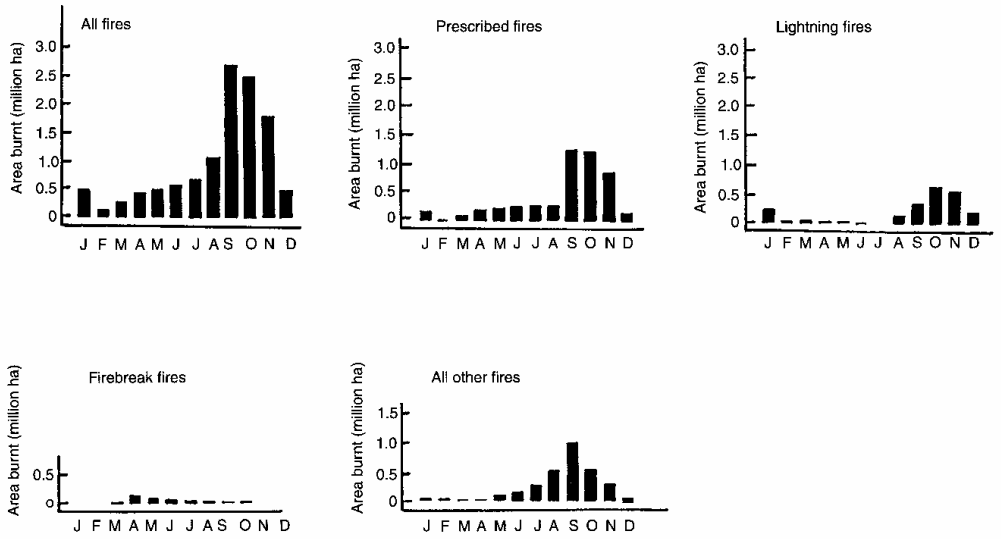


Fig. 9. Monthly distribution of total area burnt by different sources of ignition in the Kruger National Park between 1957 and 1996.

742 firebreak burns during this period, which affected an estimated total of 577 140 ha (see methods). Thus, formal management accounted for only 52% of the area burnt during this period. Lightning fires accounted for 2.5 million ha, or 21.6% of the area burnt between 1957 and 1991. Because these fires tended to occur later in the season, it can be assumed that their extent would have been greater if prescribed burning, which removed fuels that could have burnt in lightning fires, had not taken place. The balance of fires was caused mainly by poachers and refugees or were escape fires from burning operations.

Between 1957 and 1991, most fires were between 2000 and 4000 ha in size (Fig. 11A). Those more extensive than 10 000 ha burnt only 6% of the total area; the largest fire on record for this period was 18 110 ha. The period between 1992 and 1996 was characterized by 102 small fires of <10 000ha, and twelve really large ones (Fig. 11B). The large fires (>10 000 ha) accounted for 73% of the area burnt; four of these fires were greater than 30 000 ha in size (52 811, 75 396, 75 831 and 204 172 ha, respectively). These four fires all occurred in 1996, and were the largest fires recorded in the park's history.

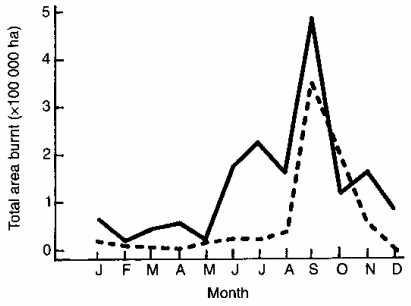


Fig. 10. Monthly distribution of area burnt in all fires under two fire management policies (lightning fires, dashed line, and prescribed burns, solid line) for two periods with similar rainfall (1981–85 for prescribed burning, and 1992–96 for lightning fires).

Fire climate

The mean burning index for each month at both of the stations analysed (Fig. 12) shows that conditions conducive to fires were highest during July, August and September, and lowest from December to March. Skukuza has higher mean burning indices as it experiences higher mean windspeeds than Letaba. Because the burning indices are mean (monthly) conditions, it is more useful to determine when extreme conditions occur, as are the times when large fires can be expected. Daily burning indices of greater than 50 (at Skukuza) and 39 (at Letaba) are in the top 5% of all values recorded at these stations. The occurrence of these conditions shows a far greater seasonal trend (Fig. 12). Such conditions occur frequently from June to October, and hardly ever between December and April (Letaba had higher occurrences in these months, as it is much drier than Skukuza, see Fig. 2).

The conditions that prevailed during the large fires of 1996 are of particular interest. These fires, in the south of the park, burnt between September 25 and October 5 of 1996. On these days, the burning index was always above 27, and exceeded 50 on three of the days. The park's managers contended that these conditions were unusual, and not likely to occur frequently. We determined that these conditions occurred at least once in 7 of the 16 years between 1981 and 1996 (Fig. 13). However, in at least 3 of these years (1989, 1992 and 1994), mean fuel loads (as determined in routine pre-fire surveys) were low (<2500 kg ha^{-1}, ranging from 1132 to 2128 kg ha^{-1}). Higher fuel loads were present in 1990 and 1991 (2740 and 2686 kg h^{-1}, respectively), while in 1996 the mean fuel load was 3653 kg ha^{-1}. Estimates of fuel load were not available for the only other year in the period analysed that had extended periods of severe fire weather (1986, Fig. 13). While this analysis covers only a short period, it appears that conditions of severe fire weather that coincide with fuel loads in excess of 3500 kg ha^{-1} are necessary for extensive (>30 000 ha) fires. The frequency of occurrence of such conditions over the long term is not known, but may be rare.

Effect of fuel load on the occurrence of fire

There was a significant relationship between grass biomass

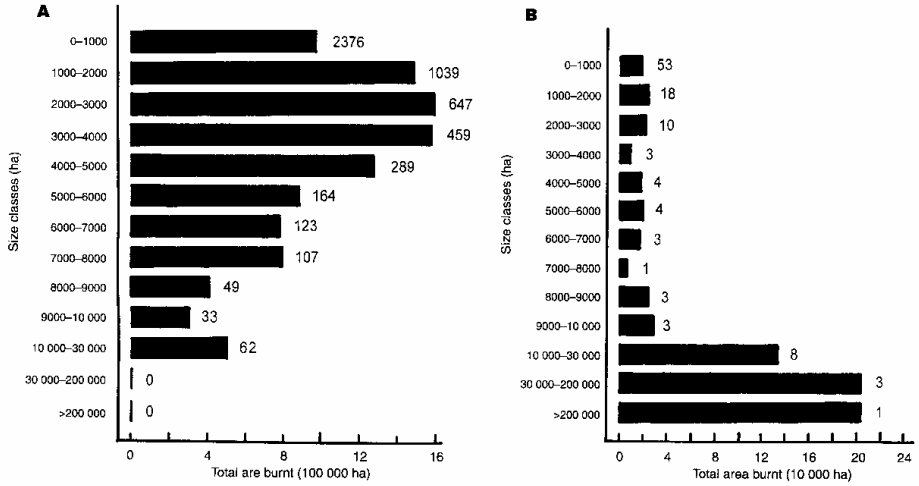
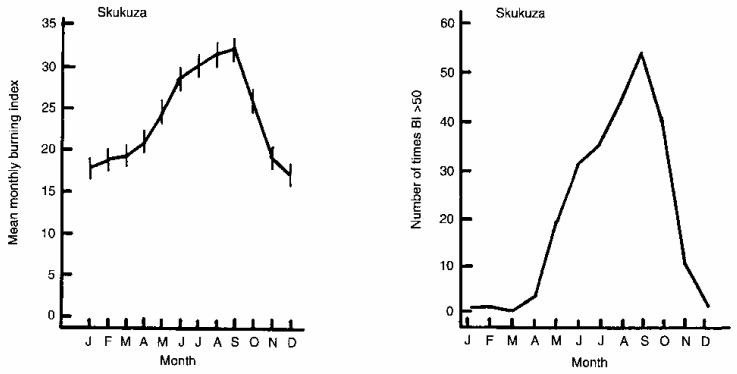


Fig. 11. Distribution of area burnt in fires of different size classes in the Kruger National Park. **A**, fires burnt between 1957 and 1991, when prescribed burning on fixed blocks was conducted; and **B**, fires burnt between 1992 and 1996, under a policy of lightning fires. The number of fires is shown next to the bars. Note the changes of scale for fires >10 000ha.

(fuel), and the probability of a fire occurring in any given block, and this relationship varied between years (Fig. 14, Table 5). The probability of a fire of any size occurring depends on grass biomass. The reason for the relationship differing between years may be due to the severity of fire weather, with the probability of fire increasing in those years where severe fire weather coincides with higher fuel loads. This is indicated in Fig. 14, where the probability of fire was higher in 1996 (a year with severe fire weather) than in 1995 (a year without such weather).



Discussion

The fire history in the Kruger National Park

There are many difficulties associated with constructing a fire history in ecosystems where long-lived trees that bear fire scars and annual rings are absent. As a result, detailed analyses of fire frequencies in such ecosystems tend to be rare. The lack of detailed analyses can lead to erroneous interpretations of fire frequency. This was the case in the Kruger National Park, where perceptions among managers were influenced by the mean fire return periods of around 7 years, based on analysis of data for 1980–1992.[7] Because mean return intervals are normally calculated without considering the shape of the frequency distribution about the

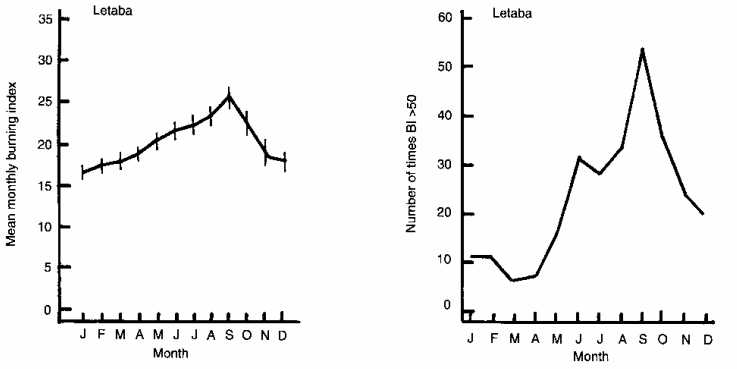


Fig. 12. Annual cycle of mean monthly burning index, and the number of days in each month that the burning index (BI) was in the top 5% of all values recorded, at two stations in the Kruger National Park. Data are for the period 1981–97; bars represent 95% confidence intervals of the mean.

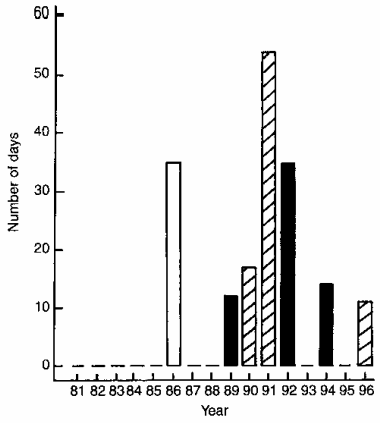


Fig. 13. The occurrence of extended periods (>10 days) of high fire danger (burning index >27 on each day, with at least three days >50) at Skukuza between 1981 and 1996. Shaded bars show years where conditions occurred together with high (> 2500 kg ha^{-1}) fuel loads. Solid bars indicate years when fuel loads were below 2500 kg ha^{-1} (fuel estimates were not available for 1986).

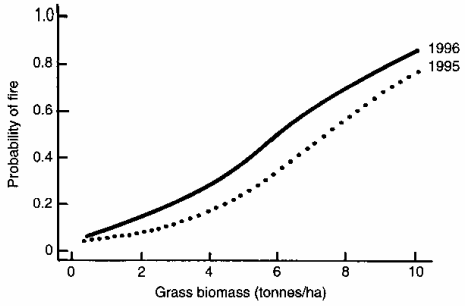


Fig. 14. The relationship between grass biomass (fuel) and the probability of fire in two individual years in the Kruger National Park. Severe fire weather conditions occurred in 1996, but not in 1995. The regression equations were $P(f) = e^Z/(1 + e^Z)$, where $P(f)$ = the probability of fire, e = the base of natural logarithms, and $Z = -3.47 + 0.00047b$ for 1995, and $-2.47 + 0.00051b$ for 1996 (b = grass biomass in kg ha^{-1}).

mean,[19] it was assumed that periods between fires were acceptably long. This study has shown that the return period between fires is much shorter than originally believed, as the median value for fire return period was well below the mean for most land systems. Concerns have recently been raised that the park has been burnt too frequently,[5] resulting in deterioration of the grass sward and in relatively high mortality of trees. Our data support the notion that the park has been burnt frequently. Large areas of the park have been subjected to annual and biennial burns, and this could have important implications for the conservation of vegetation structure and biodiversity.

Fire season is another element of the fire regime that can have important biological effects. This analysis has shown that most fires take place in relatively rain-free winter months, when grasses are dormant and dry. However, there appears to be an important difference in seasonality between fires caused by lightning and other fires. Lightning fires tend to occur later in the year, and even in the period after the start of summer rains. Proponents of a policy of lightning fires (where lightning-ignited fires dominate) argue that the shift in fire season brought about by prescribed burning differs significantly from the regime under which the ecosystem evolved, and that this shift could have undesirable consequences. The effects of changes in fire season on grass species is relatively well understood,[20,21] but the impacts on the balance between grass and woody species is less well understood and may be significant. This is one area where savanna ecologists could profit from an improved understanding of the physiology, reproductive biology and life history characteristics of the most important woody species. The lack of such knowledge has been identified as a conspicuous deficiency in the understanding of savanna dynamics,[22] and will be needed to interpret the response of woody species to shifts in fire season.

Variation between and within land systems

The range of fire return periods varied almost threefold, from 2.7 to 7.1 years. The reasons for this variation are complex and related to the dynamics of the fuel layer and to sources of ignition. Fuel loads in savanna ecosystems are largely dominated by the grass layer; the grass biomass is a function of rainfall, soil fertility and herbivory.[23] Some examples of these interactions are discussed below.

The Malelane land system had the shortest median return period (1.8 years, Table 2). Here, relatively high rainfall and low fertility combine to produce a high biomass of grass. These grasses are seasonally unpalatable, and such areas are known locally as sourveld. Herbivory levels in sourveld are lower, and fire frequencies are consequently higher.[20] The true sourveld areas make up a smaller proportion of the Malelane and Skukuza land systems; these are described by Gertenbach[10] as two landscapes that make up 846 km^2. Median fire return periods for both areas were 1.9 years. In addition to higher fuel loads, the areas are also on the boundary of the park, where additional sources of ignition and firebreak burning affect fire frequency.

The Satara land system has lower rainfall than the Malelane, but is characterized by relatively nutrient-rich, basalt-derived soils. Grasses in this area tend to be palatable throughout the year (a condition known locally as sweetveld), and herbivory levels are high. Despite lower rainfall and higher levels of herbivory, the mean fire return period does not differ significantly from that of the Malelane system. We attribute this to the ability of the fertile soils to produce good crops of grass in years of relatively high rainfall, which in turn support a similar number of fires to the Malelane system.

Table 5. Diagnostics of two logistic regressions giving the relationship between grass biomass and the probability of fire in the Kruger National Park in 1995 and 1996 (see Fig. 14).

Year	Estimates	Standard error of estimates	% deviance explained	Significance (P)
1995	Constant (–3.7)	0.4504	7.006	0.0004
	Biomass coefficient (0.00047)	0.000134		
1996	Constant (–2.47)	0.3539	13.358	<0.0005
	Biomass coefficient (0.00051)	0.000080		

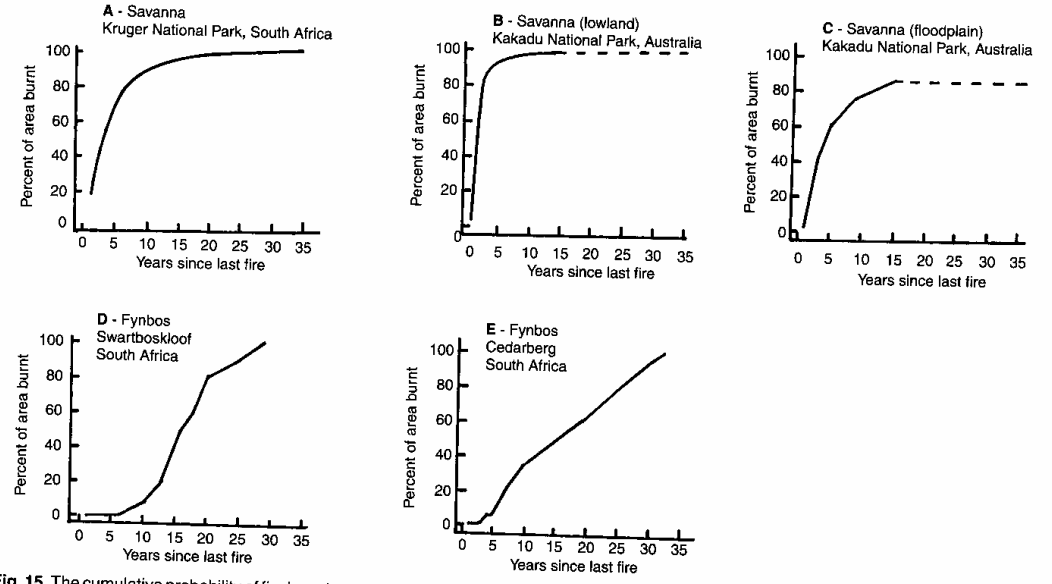


Fig. 15. The cumulative probability of fire in various ecosystems for which detailed fire histories are available. **A**, savannas in the Kruger National Park (this study); **B** and **C**, savannas in the Kakadu National Park, Australia;[25] **D**, fynbos shrublands at Swartboskloof;[27] and **E**, fynbos shrublands in the Cedarberg mountains.[26] Dashed lines indicate extrapolations beyond the available data.

The Phalaborwa (on granite) and Letaba (on basalt) land systems, north of the Olifants River, are dominated by mopane trees and shrubs. This species dominates on both granite and basalt, because of shallow soils underlain by impervious bedrock.[24] On basalts, grass biomass (and thus fuel) is presumably higher after good rains on the relatively fertile soils, which could explain the difference in mean fire return periods (4.4 and 7.1 years) despite similar rainfall.

Variation in mean fire return periods can be as great within land systems as between them. This can be seen in the mosaic of different return periods in adjacent areas (Fig. 7). The fact that these periods vary substantially between blocks with the same underlying geology and vegetation type, and the same climate and weather is probably due to differences in the dynamics of the fuel layer. This is probably a function of differential rates of herbivory. For example, Russell-Smith and co-workers[25] attributed a marked increase in fire frequency to increased herbaceous fuel loads associated with the removal of feral water buffalo in Kakadu National Park in Australia. Herbivory in turn is possibly related to the distribution of artificial water points. There are 611 boreholes and 129 dams in the park, and these have a strong influence on the spatial distribution of grazing pressure. The relationships between the artificial provision of water, herbivory, fire and feedback effects on vegetation dynamics are topics that need to be researched to be able to assess the consequences of ecosystem management in the area.

Comparison with other ecosystems

Detailed accounts of the fire history of savanna ecosystems are rare, but Russell-Smith and his co-workers[25] assembled a 15-year fire history for savanna vegetation types in the Kakadu National Park, northern Australia, from LANDSAT MSS imagery (Fig. 15). Here, fire frequencies were very high in lowland vegetation, with a median return period of less than 2 years. The floodplains at Kakadu, on the other hand, were characterized by less frequent fires, and a median return period of around 4 years. It would appear, therefore, that fire frequencies in the Australian park were similar to those in the Kruger National Park. The Kakadu data were also analysed with respect to fire size; while the median fire size was <300 ha, some very large, late dry season fires (>400 000 ha) did occur. These are typical of uncontrolled, late dry season fires in the vast unpopulated expanses of northern Australia.[25] Such fires have not, until recently, been a feature of the Kruger National Park, as fires were confined to management blocks.

Fire histories are also available for several fynbos (shrubland) ecosystems from the mediterranean-climate areas of the Western Cape, South Africa.[26,27] Here, fire return periods are longer (in the order of 15 years). A further feature of these ecosystems is that the distribution of fire return periods tends to be symmetrical around the mean (Fig. 15), so that median and mean values for fire return periods are similar. This indicates a normal distribution of return periods around the mean, as opposed the savanna systems which have skewed distribution. Fire return periods are also longer than for savanna, probably as a result of the coarser nature of fynbos fuels, coupled with slower build-up rates and less frequent occurrences of weather conditions conducive to large fires. The approach for depicting the distribution of fire return periods provides a useful descriptor of the fire regime in grasslands, savannas, and shrublands such as chaparral, fynbos, or heathlands. This is because fires in these ecosystems tend always to be surface fires burning in grass layers (for savannas and grasslands) or shrub canopies (in shrublands). In coniferous and boreal forests, on the other hand, the approach is less informative. In these ecosystems, fires can burn as low-intensity surface fires, or high-intensity crown fires, and these fires will have fundamentally different effects with the same frequency and return periods.

The management of fire regimes

The current fire management policy in the Kruger National Park allows 'natural' fires to burn freely. Prescribed burning is

not carried out, and fires of human origin are extinguished. However, anthropogenic fires have been a feature of the last 35 000 years or more. Because lightning alone may not ignite sufficient fires to simulate the park in historical times, some consideration must also be given to allowing additional fires to burn. These would make up for fires that would have been started by man in the past, or those that would have entered the park from outside but are not now able to do so. Managers are required to contain fires that are not started by lightning, and it is assumed that the area burnt by non-lightning fires will be sufficient to make up for the additional fires that would have occurred in the past. Because of the uncertainty about the nature of the historical fire regime, managers will have to monitor the occurrence of fires, and base the need to intervene on the patterns of fire that establish themselves. The application of these principles is discussed in another paper.[28] The present analysis provides a benchmark around which rules can be developed to test whether an acceptable fire regime does eventuate. The indications to date are that some significant shifts have already taken place. The overall area that has burnt under the lightning fire policy is smaller, and the fires have been in the form of a few very large conflagrations, and relatively fewer small ones. Mean return periods between fires has increased, and there has been a shift in the occurrence of fire to later in the season. The degree to which these shifts can be accommodated will depend on their actual or predicted impacts. We suggest that managers draw up hypothetical thresholds to the distribution curves for fire frequency and season that can be taken as indicators of potential concern.[28] Fire records can be updated annually, using computer technology,[29,30] and tested against these thresholds. In addition, managers can monitor trends in the plant and animal communities in the park. Any changes in the structure or composition of these populations or communities can be interpreted in terms of the fire regime and its history.

B.v.W. thanks the CSIR Division of Water, Environment and Forestry Technology, and South African National Parks for supporting this work. N. Zambatis and A. Potgieter were responsible for the curation of the fire database on which this paper is based. R. Burgan of the Intermountain Fire Sciences Laboratory, Missoula, Montana, kindly ran the fire danger calculations against a tight deadline. B. Brebnor, A. Potgieter, J. van Wilgen, J. Wrench and N. Zambatis provided valuable assistance at various stages of the project.

Received 13 December 1999. Accepted 20 January 2000.

1. Scholes B.J. and Walker B.H. (1993). *An African Savanna: Synthesis of the Nylsvley Study.* Cambridge University Press, Cambridge.
2. Mentis M.T. and Bailey A.W. (1990). Changing perceptions of fire management in savanna parks. *J. Grassl. Soc. Sthn Afr.* 7, 81–85.
3. Walker B.J. (1989). Diversity and stability in ecosystem conservation. In *Conservation for the Twenty-first Century,* eds D. Western and M.C. Pearl, pp. 121–130. Oxford University Press, New York.
4. Van Wilgen B.W., Everson C.S. and Trollope W.S.W. (1990). Fire management in southern Africa: some examples of current objectives, practices and problems. In *Fire in the Tropical Biota: Ecosystem Processes and Global Challenges,* ed. J.G. Goldammer, pp. 179–209. Springer, Berlin.
5. Trollope W.S.W., Biggs H.C., Potgieter A.L.F. and Zambatis N. (1995). A structured vs a wilderness approach to burning in the Kruger National Park in South Africa. In *Rangelands in a Sustainable Biosphere,* ed. N.E. West, pp. 574–575. Society for Range Management, Denver.
6. Eckhardt, H.C., Van Wilgen, B.W. and Biggs, H.C. (in press). Trends in woody vegetation cover in the Kruger National Park, South Africa, between 1940 and 1998. *Afr. J. Ecol.*
7. Trollope W.S.W. (1993). Fire regime of the Kruger National Park for the period 1980–1992. *Koedoe* 36, 45–52.
8. Tyson P.D. and Dyer T.G.J. (1978). The predicted above-normal rainfall of the seventies and the likelihood of droughts in the eighties. *S. Afr. J. Sci.* 74, 372–377.
9. Zambatis N. (1996). *Pre- and Post-drought Composition and Trends of the Herbaceous Layer of the Kruger National Park (1989–1995).* Scientific Report 2/96, Scientific Services, National Parks Board, Skukuza.
10. Gertenbach W.P.D. (1983). Landscapes of the Kruger National Park. *Koedoe* 26, 9–121.
11. Venter F.J. (1990). A classification of land for management planning in the Kruger National Park. Ph.D. thesis, University of South Africa.
12. Van Wyk P. (1972). *Trees of the Kruger National Park.* Purnell, Cape Town.
13. Zambatis G. and Zambatis N. (1997). *Checklists of the Vertebrate Fauna of the Kruger National Park (excluding avian fauna).* Scientific Report 9/97, National Parks Board, Skukuza.
14. Sinclair I and Whyte I. (1991). *Field Guide to the Birds of the Kruger National Park.* Struik, Cape Town.
15. Joubert S.C.J. (1986). *Masterplan for the Management of the Kruger National Park.* Scientific Services, Kruger National Park, Skukuza.
16. Dent M.C., Lynch S.D. and Schulze R.E. (1989). *Mapping Mean Annual and other Rainfall Statistics over Southern Africa.* ACRU report 27, University of Natal, Pietermaritzburg.
17. Deeming J.E., Burgan R.E. and Cohen J.D. (1978). *The National Fire Danger Rating System–1978.* U.S.D.A. Forest Service, General Technical Report INT-39.
18. Collett D. (1991). *Modelling Binary Data.* Chapman & Hall, London.
19. Bond W.J. and Van Wilgen B.W. (1996). *Plants and Fire.* Chapman & Hall, London.
20. Tainton N.M. and Mentis M.T. (1984). Fire in grassland. In *Ecological Effects of Fire in South African Ecosystems,* eds P. de V. Booysen and N.M. Tainton, pp. 115–148. Springer-Verlag, Berlin.
21. Trollope W.S.W. (1989). Veld burning as a management practice in livestock production. In *Veld Management in the Eastern Cape,* eds J.E. Danckwerts and W.R. Teague, pp. 67–73. Government Printer, Pretoria.
22. Scholes R.J. (1997). Savanna. In *The Vegetation of Southern Africa,* eds R.M. Cowling, D.M. Richardson and S.M. Pierce, pp. 258–277. Cambridge University Press, Cambridge.
23. Van Wilgen B.W. and Scholes R.J. (1997). The vegetation and fire regimes of southern hemisphere Africa. In *Fire in Southern African Savannas: Ecological and Atmospheric Perspectives,* eds B.W. van Wilgen, M.O. Andreae, G.J. Goldammer and J.A. Lindesay, pp. 27–46. Witwatersrand University Press, Johannesburg.
24. Cole M.M. and Le Roux H.D. (1978). The role of geobotany, biogeochemistry and geochemistry in mineral exploration in South West Africa and Botswana — a case history. *Trans. Geol. Soc. S. Afr.* 81, 277–317.
25. Russell-Smith J., Ryan P.G. and Durieu, R. (1997). A LANDSAT MSS-derived fire history of Kakadu National Park, monsoonal northern Australia, 1980–94: seasonal extent, frequency and patchiness. *J. appl. Ecol.* 34, 748–766.
26. Brown P.J., Manders P.T., Kruger F.J., Bands D.P. and Andrag R.H. 1991. Prescribed burning as a conservation management practice: a case history from the Cederberg mountains, Cape Province, South Africa. *Biol. Cons.* 56, 1–18.
27. Van Wilgen B.W. and McDonald D.J. (1992). The Swartboskloof experimental site. In *Fire in South African Mountain Fynbos: Species, Community and Ecosystem Response in Swartboskloof,* eds B.W. van Wilgen, D.M. Richardson, F.J. Kruger and H.J. van Hensbergen, pp. 1–20. Springer-Verlag, Heidelberg.
28. Van Wilgen B.W., Biggs H.C. and Potgieter A.L.F. (1998). Fire management and research in the Kruger National Park, with suggestions on the detection of thresholds of potential concern. *Koedoe* 41, 69–87.
29. Richardson D.M., Van Wilgen B.W., le Maitre D.C., Higgins K.B. and Forsyth G.G. (1994). A computer-based system for fire management in the mountains of the Cape Province, *South Africa. Int. J. Wildl. Fire* 4, 17–32.
30. Van Wilgen B.W., Richardson D.M. and Seydack A. (1994). Managing fynbos for biodiversity: constraints and options in a fire-prone environment. *S. Afr. J. Sci.* 90, 322–329.

NEW PUBLICATION

An Introduction to South Africa's Geological and Mining Heritage

by M.J. Viljoen & W.U. Reimold

A stunningly illustrated introduction in A5 format to some of South Africa's most magnificent and typical geological features. Written for the non-specialist with more than 360 colour photographs and numerous maps, the book also serves as a useful field guide and introductory text for teachers of geography and the Earth Sciences. Particular emphasis is placed on geological processes, as well as descriptions of sites of historical, palaeontological and cultural interest.

Published by Mintek in association with the Geological Society of South Africa. Pp. 187. R110.00

Enquiries should be directed to: Karl Kowar, Information Centre, Mintek [(011) 709-4265; e-mail: info@mintek.co.za].