

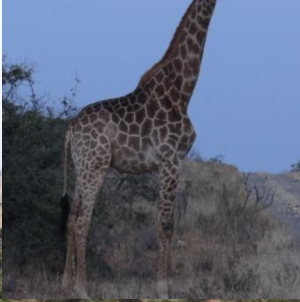
**A PALAEORECONSTRUCTION OF LATE HOLOCENE FIRE
HISTORY AND VEGETATION DYNAMICS FROM A SAVANNA
ECOSYSTEM AT MAPUNGUBWE NATIONAL PARK,
LIMPOPO VALLEY, SOUTH AFRICA**

by

Nonkululeko Mantombi Nomalanga Ngoloyi

Submitted in fulfilment of the academic requirements
for the degree of Master of Science in the Discipline of Geography
School Agricultural, Earth and Environmental Sciences
University of KwaZulu-Natal
Pietermaritzburg

June 2016



ABSTRACT

Palaeoenvironmental studies facilitate the understanding of palaeoclimatic trends that have been difficult to understand within the African context. Multi-proxy climatic reconstructions are spatially and temporally limited in southern Africa due to the shortage of continuous, chronological and high-resolution sequences and the scarcity of suitable terrestrial archives such as wetlands, peatlands and lakes; alternative archives such as swamps, isolated pans and springs have been used in savanna ecosystems. Due to the ecological importance of savannas, there is a need to understand long-term ecosystem processes in these environments, particularly in southern African savannas where there is a lack of records representing the late Holocene, Mapungubwe National Park (MNP) located in the lower Limpopo Valley represents one such site. Situated within the savanna biome and characterised by *Colophospermum mopane* Bushveld; the UNESCO World Heritage Site (inscribed in 2003) is of biodiversity, cultural and archaeological significance. A palaeoreconstruction of MNP was conducted using a multi-proxy fossil based approach. Pollen, charcoal analysis and radiocarbon dating were applied to determine past vegetation change and fire history. Two sites were analysed to infer palaeoenvironmental dynamics at MNP, Croc Pan (CP) and Leokwe Rock Pool (LRP). The AMS radiocarbon dating indicated that the sediments represented young sediments falling within the very late Holocene epoch, with the CP and LRP sequences dating back to ca.1700 cal. AD and ca. 1900 cal. AD, respectively. However; chronological uncertainties were acknowledged due to the limitations of dating young records. Analyses show that the ca. 1700-1865 cal. AD period in the MNP record was broadly contemporaneous with the Little Ice Age (LIA; ca. 1500-1800 AD); declines in arid woodland savanna taxa and Cyperaceae indicated cool, dry conditions; approaching ca. 1800 cal. AD warm wet conditions persisted. The charcoal signal indicated a high frequency of regional fire activity. Between ca. 1865-1945 cal. AD, the charcoal record continued to reflect a regional fire signal; declines in aquatic, riparian and warm savanna taxa at the beginning of this period implied reduced moisture availability however, peaks in Cyperaceae suggested incidents of increased local moisture and changes in local hydrological conditions. The reduction in Cyperaceae and pteridophytes between ca. 1945-1960 cal. AD reflected drying conditions whilst reduced microscopic and macroscopic charcoal suggested inconsistent local and regional fire activity. Between ca. 1960-1985 cal. AD, a transition from warm, dry conditions indicated by increases in Euphorbiaceae undiff. and warm savanna woodland elements to warm, wetter local conditions marked by sharp peak in Cyperaceae was observed. The influx of macroscopic charcoal during this period is suggestive of more frequent local fire activity. Evidence of warm woodland vegetation such

as Combretaceae undiff., Capparaceae undiff. and Fabaceae undiff. accompanied by the inconsistent occurrence of Cyperaceae allude to warm temperature and variable moisture conditions from 1985 to present. The regular increase of macroscopic charcoal is suggestive of an increased frequency of local fires, coincidentally, this period of the record overlaps with the known fire regime for MNP. The increase in macroscopic charcoal towards the end of the Mapungubwe record can also be associated with human activity. The pollen records for MNP reflects that the region has generally been characterised by warmer temperatures and drier conditions during the late Holocene; the vegetation dynamics of MNP have not been directly influenced by fire activity as the record generally indicates regional fire activity. These results show similar trends to other savanna ecosystems in the Limpopo Valley, excluding sites with grassland traits. Pollen and charcoal signals from the MNP records have improved the understanding of tree-grass coexistence and the impact of fire on the dynamics of the savanna ecosystem in the Limpopo Valley. This record has therefore contributed to a greater understanding of late Holocene vegetation change and the fire history of the greater Limpopo Valley.

PREFACE

The candidate conducted this research within the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, between March 2013-June 2016, under the supervision of Prof. T.R Hill and Dr. J.M Finch.

The research presented represents the original work of the author and has not otherwise been submitted in any form of degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.



.....
N.M.N Ngoloyi (Candidate)

Date: 14 June 2016

.....
Prof T.R Hill (Supervisor)

Date:

.....
Dr. J. M Finch (Supervisor)

Date:

ACKNOWLEDGEMENTS

I would like to give the most heartfelt thanks to my supervisors **Prof. Trevor Hill** and **Dr. Jemma Finch** for initiating my interest in palaeoenvironmental research; thank you for considering me for this project and for your time, guidance and support.

To **Dr. Jemma Finch**, thank you for your patience, understanding and encouragement throughout this journey; you truly helped me persevere and for that I am truly grateful.

I extend my gratitude to **Dr. Jemma Finch, Kate Strachan, Jared Lodder, Luke Bodmann** and **Patience Gandiwa** for assisting me with my field work. Thank you to Patience for helping me to understand my study site and offering me guidance for my thesis.

To **Camelot Radloff** and **Bradley Hempson**, thank you for assisting me with my macroscopic charcoal processing.

To **Brice Gijbertsen**, thank you for your assistance with GIS, I truly appreciate it.

This research was funded by the **National Research Foundation (NRF)**; I would like to express my gratitude to the **NRF** for supporting the costs of the study. I would also like to thank **SANParks** for providing me with a permit to access **Mapungubwe National Park** to conduct my research and also for providing me with game guards who assisted us in finding suitable sites and always ensured our safety.

Special thanks go to my friends **Nokuphila Buthelezi, Victor Bangamwabo** and **Charles Otunga**, thank you for your support, for constantly checking up on me, encouraging me to reach the finish line and for your assistance with GIS.

To my dearest friends **Ndoni Mcunu** and **Jan Sanroma**, thank you for always lending an ear and reminding me that you are just a phone call away and that I am never alone. Thank you so much **Ndoni** for sharing this journey with me.

Lastly, to my phenomenal mom **Nomlilo Claudia Ngoloyi** your love and support has seen me through this journey. I am so grateful to God for giving me such a cool and intelligent mom like you, every phone call with you has given me the strength to continue. Thank you for constantly reminding me of my abilities and my purpose when times were difficult, I love you very much.

TABLE OF CONTENTS

ABSTRACT.....	i
PREFACE.....	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS.....	v
LIST OF FIGURES	viii
LIST OF TABLES.....	x
LIST OF PLATES.....	xi
LIST OF APPENDICES	xii
CHAPTER ONE: INTRODUCTION	13
1.1. Introduction.....	13
1.2. Research aim and objectives.....	16
1.3. Thesis summary	16
1.4. Conclusion.....	17
CHAPTER TWO: LITERATURE REVIEW.....	18
2.1. Introduction.....	18
2.2. Drivers of climate change	18
2.3. Drivers of vegetation change in southern African savannas.....	20
2.4. Holocene palaeoenvironments of southern Africa	26
2.4.1. Mid Holocene (include age range definition – and for following sections)	26
2.4.2. Late Holocene	31
2.5. Conclusion.....	35
CHAPTER THREE: THEORETICAL METHODOLOGY	37
3.1. Introduction.....	37
3.2. Pollen analysis.....	37
3.2.1. General principles of pollen analysis	38
3.2.2. Key concepts	39
3.2.3. Pollen preservation	41
3.2.4. Field methods	42
3.2.5. Laboratory methods	44
3.3. Charcoal analysis	47
3.3.1. Key concepts	49

3.3.2. Laboratory methods	51
3.3.3. Counting and identification	54
3.4. Dating methods	54
3.4.1. Chronology.....	54
3.4.2. Radiocarbon dating and age-depth modelling	55
3.5. Data presentation	58
3.6. Data Interpretation.....	58
3.7. Conclusion.....	61
CHAPTER FOUR: STUDY AREA	62
4.1. Introduction.....	62
4.2. Site description	62
4.2.1. Geology	63
4.2.2. Climate.....	64
4.2.3. Vegetation.....	66
4.2.4. Human history.....	68
4.2.5. Croc Pan and Leokwe Rock Pool.....	70
4.3. Conclusion.....	72
CHAPTER FIVE: METHODS	73
5.1. Introduction.....	73
5.2. Field methodology	73
5.3. Laboratory methodology	74
5.3.1. Troels-Smith analysis.....	74
5.3.2. Sub-sampling	74
5.3.3. Chronology.....	75
5.3.4. Pollen analysis	75
5.3.5. Microscopic charcoal: pollen slide technique	77
5.3.6. Macroscopic charcoal: wet sieving technique	77
5.4. Data presentation and analysis.....	77
5.5. Conclusion.....	78
CHAPTER SIX: RESULTS.....	79
6.1. Introduction.....	79
6.2. Troels-Smith stratigraphy and chronology.....	79
6.3. Chronology and age-depth models.....	81
6.4. Zonation	83
6.5. Pollen and charcoal analysis	85

6.5.1. Croc Pan Pollen	87
6.5.2. Leokwe Rock Pool	92
6.5.3. Croc Pan charcoal.....	97
6.5.4. Leokwe Rock Pool charcoal	100
6.5.5. Summary of palaeoenvironmental trends and cross-correlation analyses	102
CHAPTER SEVEN: DISCUSSION.....	111
7.1. Introduction.....	111
7.2. Mapungubwe National Park Record	111
7.3. Palaeoenvironmental synthesis for Mapungubwe National Park.....	112
7.3.2 Vegetation reconstruction of Mapungubwe National Park	112
7.3.3. Fire History of Mapungubwe National Park	118
7.4. Interpretation of ecologically significant observations.....	121
7.4.1. Baobab dynamics.....	121
7.4.2. Cactaceae.....	122
7.5. Human impacts and disturbances.....	123
7.6. Limitations	125
7.7. Conclusion.....	126
CHAPTER EIGHT: CONCLUSION	127
8.1. Palaeoreconstruction synthesis	127
8.2. Review of research aim and objectives.....	128
8.3. Conclusions.....	130
REFERENCES	132
APPENDICES.....	i

LIST OF FIGURES

Figure 2.1 Map illustrating the study sites referenced within the text.	25
Figure 3.2 Exponential curve illustrating the radiocarbon decay of ^{14}C with time (adapted from Walker, 2005)	55
Figure 4.1 Map showing the location of Mapungubwe National Park and the location of specific study sites, Croc Pan and Leokwe Rock Pool within the Mapungubwe National Park, Limpopo.....	62
Figure 4.2 The vegetation type distribution across the Savanna Biome in the Limpopo Province, South Africa according to Acocks' (1988) classification.....	66
Figure 6.1 Sediment descriptions for each distinctive stratum along the depth of Croc Pan (MAP-CP13-1A) core using Troels-Smith analysis (Kershaw, 1997)	80
Figure 6.2 Sediment descriptions for each distinctive stratum along the Leokwe Rock Pool (MAP-LRP13-4A) core using Troels-Smith analysis (Kershaw, 1997).	81
Figure 6.3 Age Depth Models for Croc Pan (A) and Leokwe Rock Pool (B)	82
Figure 6.4 Zonation diagrams performed by stratigraphically constrained cluster analysis (CONISS) in Psimpoll 4.27.....	84
Figure 6.5 Main pollen diagram plotted against the Troels-Smith stratigraphy, age-depth scale (AD-cm) and calibrated ^{14}C ages (AD) for Croc Pan.	89
Figure 6.6 Pollen Diagram displaying total pollen for Croc Pan against the associated age-depth scale (AD-cm), ^{14}C ages (AD) and Troels-Smith stratigraphy	90
Figure 6.7 Main pollen diagram for Leokwe Rock Pool plotted against the Troels-Smith stratigraphy, age-depth scale (AD-cm) and calibrated ^{14}C ages (AD).	95
Figure 6.8 Pollen Diagram displaying total pollen (%) for Leokwe Rock Pool against the associated age-depth scale (AD-cm), ^{14}C ages (AD), Troels-Smith stratigraphy and CONISS zonation units.	96
Figure 6.9 Charcoal Diagram displaying macroscopic wet sieving charcoal and microscopic pollen slide charcoal at Croc Pan	99

Figure 6.10 Charcoal Diagram displaying macroscopic wet sieving and microscopic pollen slide charcoal at Leokwe Rock Pool.....	101
Figure 6.11 Cross correlation tests for Croc Pan.....	105
Figure 6.12 Cross correlation tests for Leokwe Rock Pool	107
Figure 6.13 Summary diagram showing the trends of pollen concentration, microscopic charcoal concentration and macroscopic charcoal count from 1700 cal. AD (CP) and 1900 cal. AD (LRP).....	110

LIST OF TABLES

Table 2.1 Table listing the study sites referenced within the literature review text	28
Table 3.1 Broad list of environmental indicators according to selected pollen taxa representative of the savanna biome.....	59
Table 4.1 Characteristics and locality of the main sediments types found in the Limpopo River Basin	64
Table 6.1 Radiocarbon results showing the uncalibrated and calibrated ages for Croc Pan and Leokwe Rock Pool	82
Table 6.2 Classification of taxa according to ecological grouping.....	85
Table 6.3 Species list and images of pollen reference material collected.....	86
Table 6.4 Summary of cross correlation trends for Croc Pan (A) and Leokwe Rock Pool (B).....	103
Table 6.5 Correlations between fossil pollen ecological groups and charcoal at Croc Pan and Leokwe Rock Pool	104
Table 7.1 Summary of palaeoenvironmental dynamics at Mapungubwe National Park.....	120

LIST OF PLATES

Plate 3.1 Pollen reference slides for Asteraceae <i>Vernonia fastigata</i> and Fabaceae <i>Acacia nigrescens</i>	47
Plate 4.1 (A) Mapungubwe cultural landscape and Mapungubwe Hill	67
Plate 4.1 (B) <i>Colophospermum mopane</i> Bushveld, Mapungubwe National Park.....	67
Plate 4.2 Conditions at Croc Pan during the late-winter and summer months of 2013 and 2015.....	71
Plate 4.3 Conditions at Leokwe Rock Pool during the late-winter and summer months of 2013 and 2015, respectively.	71
Plate 5.1 Extendible fiberglass ranging rod used to determine the deepest sediments for coring (A); Coring of Croc Pan using the Russian corer(B); Transferring the core sample into PVC piping in preparation for storage (C).....	74

LIST OF APPENDICES

APPENDIX A: Core sub-sampling procedure	i
APPENDIX B: Fossil pollen sample preparation.....	ii
APPENDIX C: Pollen reference slide preparation	iv
APPENDIX D: Wet sieving charcoal processing.....	vi
APPENDIX E: Interpolated calibrated ages.....	vii
APPENDIX F: Age-depth models.....	x
APPENDIX G: Raw pollen counts	xii
APPENDIX H: Raw charcoal counts	xxvii
APPENDIX I: Full species list for MNP and Limpopo Valley	xxxiii
APPENDIX J: Morphological dispersal and preservation characteristics of major Palynomorphs	l
APPENDIX K: Recent fire history of Mapungubwe National Park	lix
APPENDIX L: Pollen preservation trends at Croc Pan and Leokwe Rock Pool.....	lx

CHAPTER ONE

INTRODUCTION

1.1. Introduction

Climate change is an unavoidable and ongoing process consistently threatening global stability, prompting an applied response from environmental sciences. Furthermore, climate change poses environmental and societal risks consequently aggravating environmental conservation, economic and social challenges currently being faced globally (Adger *et al.*, 2003, Truc *et al.*, 2013). Stringer *et al.* (2009) note that the low adaptive capability of the African continent to predict future climate change makes the continent increasingly vulnerable to future climate change. Located at the interface of tropical, sub-tropical and temperate climatic systems southern Africa is particularly sensitive to climatic changes (Truc *et al.*, 2013, Stringer *et al.*, 2009). Reliable future climate projections are therefore required to minimise future risks and to maximize the regions adaptive capacity to disturbances (Truc *et al.*, 2013, Stringer *et al.*, 2009). The lack of consistent, high resolution and chronological palaeoecological records is a limiting factor for the development of climate change predictions, it therefore is important to continue climate change research (Truc *et al.*, 2013). A number of natural factors and more recently anthropogenic forcing have contributed to climatic fluctuations at a local and regional scale. This includes the exacerbation and intensification of several natural changes in climatic systems such as increased greenhouse gas emissions, increased surface temperatures beginning in the mid twentieth century, expansions and retreats of Arctic and Antarctic sea ice and increased global sea surface temperatures (Field *et al.*, 2014). According to the fifth assessment report on climate change, atmospheric and oceanic temperatures have undoubtedly increased since the 1950s (Pachauri *et al.*, 2014). These increases have been accompanied by contracting sea ice and rising sea levels having implications for both humans and the environment (Pachauri *et al.*, 2014).

In accordance with global climatic trends, recent climates show that there has been an increasingly warming trend across the African continent over the past five to ten decades with near surface temperatures increasing by about 0.5 °C (Field *et al.*, 2014). Annual mean, minimum and maximum temperatures in southern Africa increased towards the end of the 20th century (Field *et al.*, 2014). Meanwhile, increased tropical Indian Ocean sea surface temperatures (SSTs) have reduced late austral summer precipitation in some regions of southern Africa including Botswana, Zimbabwe and the western parts of South Africa (Field *et al.*, 2014).

Future climate changes are predicted from regional climatic models (Holmgren and Oberg, 2006). However, the performance of global atmosphere-ocean climate models varies at a regional scale (Overland et al., 2011). This is problematic as regional climatic simulation models are often used for the assessment and implementation of future ecological impact plans (Overland et al., 2011). Climate models and palaeoclimate proxies are two independent sources of past climatic information that are complimentary and prove to be more useful in providing climatic insights when combined (McCarroll, 2010, Phipps *et al.*, 2013). High resolution palaeoclimatic data supplements climatic model predictions by providing measurements reflecting the time and extent of past climate events (Anderson *et al.*, 2006, Holmgren and Oberg, 2006). Whilst climate models simulate climatic variables such as precipitation and temperature providing useful information regarding the drivers of climate change, the chemical and biophysical data derived from palaeoclimatic proxies are used to verify and evaluate climatic simulations (Anderson *et al.*, 2006, Phipps *et al.*, 2013). Palaeoecological data can be used to better understand past climatic changes and validate long-term climate models showing ecosystem dynamics (Anderson *et al.*, 2006). This is especially necessary with increasing climate change and ecosystem stress (Anderson *et al.*, 2006).

Fossil-based approaches to palaeoecology include pollen analysis, a tool used to interpret terrestrial and aquatic vegetation changes (Seppä and Bennett, 2003). Erdtman (2013) referred to pollen analysis as a young science, this is in agreement with pioneering researcher Van Zinderen Bakker's (1995) opinion that the science has since developed significantly since the 1940s when it was relatively new in South Africa. Another fossil based approach is charcoal analysis used to reconstruct past fire regimes in response to external and internal forces (Seppä and Bennett, 2003). Each proxy data type produces distinctive information specific to different components of the environment for example, pollen data for the analysis of vegetation, charcoal data for the analysis of peat environments, foraminifera to investigate sea level change and diatoms to assess water quality (Dincauze, 1987; Bradley, 1999). The analyses of such data can provide information that contributes to the understanding of the current environment and its prospective changes, consequently adding value to efforts towards recognizing and minimising the effects of global warming. Fossil pollen assemblages can show a snapshot of historical vegetation patterns representing a time slice (Prentice, 1985). This is a useful for understanding how modern vegetation has been formed from past vegetation shifts as a response to environmental change (Bennet and Willis, 2001). Pollen data can be used to illustrate the response of taxa to shifts in climate and the overall vulnerability of an ecosystem to past climatic disturbances can be inferred (Prentice, 1985). The study of palynological records can improve the interpretation

of vegetation dynamics due to climate change and human influences (Neumann *et al.*, 2011). According to Traverse (2007) humans have been the main contributors to environmental changes during the Holocene epoch, it is therefore important to take into consideration human and environmental factors when studying the palynomorph assemblages during this period.

Reliable and well-dated palaeoenvironmental records are scarce in southern Africa and it is often challenging to interpret many acquired proxy records as these are often incomplete, irregular and disjointed (Truc *et al.*, 2013, Quick *et al.*, 2011). The shortage of continuous and high-resolution sequences with evidence of Holocene palaeoclimates in the Southern Hemisphere as compared to the tropics and the Northern Hemisphere can be attributed to poor pollen preservation and the lack of suitable archives (Neumann *et al.*, 2008). Van Zinderen Bakker (1995) notes that the hot and dry conditions experienced in Africa limit pollen preservation ability as the pollen is oxidised and damaged under these conditions. Suitable archives include peat deposits, continuous lakes and wetlands (Neumann *et al.*, 2008). Alternative archives such as swamps, isolated pans and springs are a common resort to conduct palynological studies due to the lack of suitable sediment archives (Neumann *et al.*, 2008, Van Zinderen Bakker and Coetzee, 1988). According to Traverse (2007), archives such as lakes, bog deposits and swamps are of interest to palynologists studying the Holocene epoch as they are more reflective of local vegetation. The inability for suitable palaeoenvironmental archives to develop to such a point that they can preserve continuous and high resolution sediment sequences is partially blamed on the sensitivity of the region to climate change, and the high variability of the southern African climate (Chase *et al.*, 2012). Erratic and seasonal rainfall is a defining characteristic of the southern African climate, this is due to the regions atmospheric and hydrospheric interactions at the edge of both tropical and temperate systems and along both the cool Benguela and warm Agulhas currents (Chase *et al.*, 2012). It is therefore difficult to reliably discern the extent to which centennial and millennial timescale climatic changes have affected regional environments in southern Africa (Chase *et al.*, 2012).

Palaeoecological data provides information regarding the climatic conditions, the state of the environment and habitat structures at different temporal and spatial scales (Elton, 2008). Tools such as pollen and charcoal analysis can aid in the determination of fire regimes, vegetation dynamics and the influences of additional disturbances. Overall contributing to the understanding and facilitating the efficient conservation and management of important ecosystems.

1.2. Research aim and objectives

This research investigates the use of palaeoenvironmental techniques to study human-environment-climate relationships in the in Mapungubwe National Park, Limpopo Valley, South Africa. The aim of this research is to apply palaeoenvironmental techniques to reconstruct past environmental change in Mapungubwe National Park. The objectives of the study are as follows:

1. To use an appropriate coring procedure and sampling strategy for the extraction of minimally disturbed sediment cores.
2. To select suitable sub-samples for the determination of calibrated radiocarbon ages by accelerator mass spectrometry (AMS) to establish chronological control.
3. To reconstruct past vegetation change using fossil pollen analysis techniques and, past regional and local fire dynamics using microscopic and macroscopic charcoal as fire proxies, in order to infer late Holocene climatic and environmental conditions.
4. To compare inferred palaeoenvironmental record to land use history and previously published palaeo-records.

1.3. Thesis summary

Chapter one has contextualized the research conducted and provided a justification for the study within the field of palaeoenvironmental sciences. A framework for the research by way of defining the specific aim and objectives for the study has also been provided. Chapter Two presents a review of literature which includes a synopsis of palaeoenvironmental studies conducted in southern Africa within the late Quaternary period to provide perspective for the palaeoenvironmental trends observed in the research. The research is contextualized within the framework of the proxy analyses and, cultural and archeological contexts. Chapter Three aims to theoretically justify the field methods and the laboratory techniques applied for the analysis of each specific proxy highlighting the benefits and constraints of each technique. An overview of the study site is provided in Chapter Four contributing to an understanding of the environmental and historical aspects of the study site. Details regarding the field sampling strategy and the methods employed to accomplish the aims and objectives of the study are explained in Chapter Five. Chapter Six presents the results obtained from pollen, charcoal, radiocarbon and stratigraphic analyses. Chapter Seven synthesizes the results obtained from the study and uses information from previous and

similar palaeoenvironmental studies in southern Africa to conduct a palaeoenvironmental reconstruction of the Limpopo Valley. The overall research is synthesized and a review of the aims and objectives is provided in Chapter Eight.

1.4. Conclusion

As a UNESCO World Heritage Site (Declared in 2003), Mapungubwe National Park is one of a few unique sites in South Africa of cultural, ecological and archaeological importance. Biodiversity maintenance and wildlife management are important themes informing the park management plan. A comprehensive knowledge of the vegetation and ecology of the park is important for the understanding of the factors determining the modern day vegetation distributions. This includes a comprehension of environmental and anthropogenic influences on landscapes through time and space. The arid nature of the Limpopo-Valley has implications on the dynamics of ecologically sensitive species within the park. The interaction between fire activity and land-use changes has important implications for the vegetation dynamics of the landscape. Palaeoenvironmental data derived from techniques such as charcoal and pollen analysis in accordance with climate data can be used to investigate the responsiveness of the vegetation of the landscape to environmental pressures. Conservation and park management should be approached in a multi-disciplinary manner. Paleoecology is one of such disciplines that can contribute substantially to individual programmes aimed at optimising the overall management of the park as all activities within the park affect the ecological conditions to varying degrees. Further palaeoenvironmental research is required for a greater understanding of past environmental conditions to inform Holocene environmental changes, modern environmental trends and ultimately to inform the management semi-arid environments and savanna landscapes.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter provides an overview of the drivers of global climate change and vegetation change in savannas and how they are integrated into a southern African context. A synthesis of palaeoenvironmental case studies depicting Holocene palaeoclimates in southern African regions is provided. The reviewed sites were concentrated in South Africa with a few sites in Mozambique and Zimbabwe. Sites were chosen on the basis of ecosystem comparability where environmental conditions were similar and, studies showing Holocene conditions in the winter rainfall region of southern Africa were cited.

2.2. Drivers of climate change

Over 75% of the African continent falls within the tropics (Nash and Meadows, 2012). According to Van Zinderen Bakker (1983) southern Africa experiences a mostly arid to semi-arid climate. However, given the large spatial extent of the continent and the altitudinal differences, complex and broadly zonal climates are experienced between the low latitudes (tropical moist climate) and the northern and southwestern regions of the continent (Mediterranean-type climate) (Nash and Meadows, 2012). This section of the literature review looks at several factors driving climate change globally and in South Africa. Key factors will be explained with case studies illustrating climate change in the summer and winter rainfall regions of southern Africa.

Several studies in northern Hemisphere of Africa recognise precessional and obliquity forcing as important factors determining palaeoenvironmental changes in Africa. Glaciation in the high latitudes and elevations has been credited to Milankovitch cycles (19 000 year and 23 000 year time periods) (Partridge *et al.*, 1997, Dinauze, 2000). This implies that cyclic changes in the orbital parameters of the Earth (orbital eccentricity, axial changes and equinox precision) have influenced summer insolation levels which have affected circulation and rainfall in glacial and interglacial periods (Partridge *et al.*, 1997, Dinauze, 2000). Holmgren *et al.* (2003) and Nash and Meadows (2012) agree that palaeoenvironmental records show that the influence of precessional forcing on the climate of the interior of the southern African continent over the past 200 000 years has gradually become less apparent, other climate forcing mechanisms appear to have become more noticeable drivers of climate change.

According to Holmgren *et al.* (2003) atmospheric responses to glacial cycles in southern Africa were immediate and affected precipitation levels. Overall annual rainfall in southern Africa decreased during glacial cycles (Holmgren *et al.*, 2003). These changes in annual rainfall during glacials were a consequence of an increase in the size of the polar vortex, as a result of the expansion of Antarctic sea ice and the northward shift of the oceanic Antarctic Convergence (Holmgren *et al.* 2003). Chase and Meadows (2007) highlight the significance of polar ice expansions, stating that sea ice in the Antarctic can increase from 4 million km² to 20 million km² within just six months (March-September). In addition to the extended polar vortex, thermal gradients across Antarctica were increased and led to an intensification of atmospheric circulations (Chase and Meadows, 2007). The seasonality of rainfall was not affected by atmospheric responses to glacial cycles (Holmgren *et al.*, 2003).

The seasonal nature and distribution of southern African rainfall is attributed to the meridional displacement of the Inter Tropical Convergence Zone (ITCZ); the southwards migration of the ITCZ also has rainfall implications on the climates of regions through which it passes (Partridge *et al.*, 1997, Tyson and Preston-Whyte, 2000, Van Zinderen Bakker, 1983). Southern Africa is mainly a summer rainfall region, during this time the high-pressure belt is shifted southward and a broad continental trough deepens in lower levels (Tyson and Preston-Whyte, 2000). Tropical-cloud bands are formed at the South Indian Convergence Zone (SICZ), this is the region where the Indian Ocean High (IOH) and the Angola Low pressures cells collide due to the southwards displacement of the ITCZ (up to 20°S) relative to the equator in the austral summer (Dedekind *et al.*, 2016, Partridge *et al.*, 1997).

In the austral winter (June, July and August), the ITCZ is displaced north and rainfall is suppressed across the subcontinent because the subtropical high pressure cell is circulated over southern Africa preventing the migration and effects of cold fronts from affecting the majority of the subcontinent (Dedekind *et al.* 2016, Partridge *et al.* 1997). The southern most regions (south-western Cape and the Cape south coast) however are an exception, the prevalence of temperate frontal systems in the westerlies above these regions means that winter rainfall is more characteristic (Chase and Meadows 2007, Dedekind *et al.* 2016, Nash and Meadows, 2012). Other rainfall weather producing systems in the southern Africa include the tropical-temperate troughs (TTTs) responsible for spring and autumn rainfall and cut-off lows that receive the majority of their moisture from the tropics (Dedekind *et al.* 2016). Cut-off lows are associated with synoptic conditions such as heavy rainfall and flood activity in the interior and the south and east coast of southern Africa (Dedekind *et al.* 2016).

The warm Agulhas current and both the tropical and temperate systems act on the climate of the southern coast of southern Africa (Chase *et al.* 2013). Therefore, atmospheric and hydrosphere factors act in unison towards altering the local climate, making long-term climate change highly dynamic in the summer rainfall region (Chase *et al.* 2013). The warm Agulhas current brings about moisture and summer rainfall in the coastal regions and the north-eastern interior of southern Africa from the Indian Ocean (Van Zinderen Bakker, 1983, Van Zinderen Bakker and Coetzee, 1988). The Southern Oscillation (ENSO) system affects temperature and precipitation characteristics in the northern and southern Hemispheres (Dincauze 2000). Hulme *et al.* (2001) recognise ENSO as one of the most important factors controlling inter-annual rainfall variability for the most part of African regions. The highly variable climates of southern and tropical Africa feature frequent drought and flood activity, and are driven by regional sea surface temperatures (SSTs) and ENSO (Dedekind *et al.*, 2016). ENSO and SSTs are therefore additional factors contributing to the summer-winter rainfall dipole in southern Africa. Increased upwelling's in the south coast of southern Africa are driven by the tropical easterlies and are associated with cooler SST's and wetter conditions, whilst decreased upwelling's driven by the tropical westerlies are coupled with higher SST's and drier conditions in the south western regions of southern Africa (Chase *et al.* 2013).

Sea surface temperature (SSTs) contribute to the austral spring-summer rainfall variability of eastern, central and southern Africa (Fauchereau *et al.*, 2003, Goddard and Graham, 1999). SST forcing caused by ENSO works collectively with the wind dynamics of the region affecting moisture conditions, atmospheric circulation and rainfall seasonality and variability in the tropics and subtropics (Fauchereau *et al.*, 2003, Goddard and Graham, 1999). Dry conditions over southern Africa are often attributed to cool SSTs in the south-west Indian Ocean (Fauchereau *et al.* 2003, Goddard and Graham 1999, Hulme *et al.* 2001). This occurs because the cooler temperatures cause divergent flow and reduced convective heating, and high rainfall conditions prevail in equatorial east Africa with the occurrence of a warm ENSO event (Fauchereau *et al.* 2003, Goddard and Graham 1999, Hulme *et al.* 2001).

2.3. Drivers of vegetation change in southern African savannas

All terrestrial ecosystems in Africa are said to be affected by climate change and anthropogenic land-use change these include; savanna, grassland, desert and forest ecosystems (Field *et al.*, 2014). Details regarding the overall changes observed in terrestrial landscapes are provided in the Fifth Assessment Report on climate change; the document concludes that the following issues affect the African continent most severely: the expansion of desert area whilst overall vegetation cover and woody cover declines, reduced natural

vegetation due to increased human activity and distributional shifts of existing biomes (Field *et al.*, 2014).

This section (2.3) looks at the main factors affecting vegetation change in southern African savannas. The Kruger National Park (KNP) and Limpopo National Park (PNL) are recognized as the most comparable environments to MNP. Savanna vegetation types characterize both parks with both sites being mainly represented by *Colophospermum mopane* vegetation. There is a north-south rainfall gradient of 375-420 mm/year in the northern KNP (Pafuri region) which is comparable to 330-430 mm/year rainfall gradient in MNP. PNL differs in that annual rainfall exceeds 630 mm and therefore, local climatic conditions may differ slightly. Bottom up (water and soil nutrients) and top down (fire and herbivory activity) factors influencing savanna vegetation growth will be further elaborated in this section (2.3).

Anthropogenic actions have impacted the distribution and structure of the earth's vegetation. Humans have played a role in the modification and transformation of many ecosystems (Field *et al.*, 2014, Meadows and Linder, 1993). According to Midgley *et al.* (2002) the signs of anthropogenic climate change are now becoming more evident. This includes physiological and morphological changes of biota, changes in their productivity, range shifts and migrations causing changes in the abundance and distribution of species (Midgley *et al.*, 2002). Anthropogenic activities for economic, social and cultural purposes have been long-term occurrences in tropical Africa (Meadows and Linder, 1993).

Vitousek *et al.* (1997) identify several human-induced environmental changes acting at different spatial scales; these include: increased concentrations of carbon dioxide into the atmosphere intensifying the greenhouse effect and in turn affecting global climate change; the modification of terrestrial landscapes due to land-use changes and disturbances leading to a loss of biodiversity; the depletion of natural resources, and the introduction of alien invasive species into otherwise ecologically stable environments, having negative consequences on native species and ecosystem functioning. Such interactions date back from basic human hunter-gatherer foraging to modern day cultivation and agriculture with the extent of vegetation change being different (Ellis and Ramankutty, 2008).

There has been little focus on the effects of human populations on climate change in southern Africa (Midgley and Thuiller, 2011). Hoffmann and Jackson (2000) hypothesise that changes in albedo and surface roughness due to the reduction of woody cover in savannas has implications for precipitation, surface temperatures and to some extent circulation

patterns. Similarly, evidence from the Sahel region suggests that the feedback responses between landscape conditions and the atmosphere have had an effect on the precipitation of the region, insinuating that regional climates over Africa can also be affected by large-scale anthropogenic transformations (Nicholson, 2001). Long-term and large-scale anthropogenic forcing can therefore have cascading effects on the overall structures and distributions of biomes (Hoffmann and Jackson, 2000).

Environmental disturbances have increased in frequency and intensity due to the alteration of landscapes as a consequence of anthropogenic land-use change (Vitousek *et al.*, 1997). Ecosystem engineering by human beings using tools such as fire is credited as one of the reasons the human population has grown and the growth has been sustained for the past 500 years (Ellis and Ramankutty, 2008). Knorr *et al.* (2016) acknowledge that the majority of global biomass burning is caused by wildfires contributing largely to the abundance of atmospheric trace gases and aerosols, affecting both environmental and human health. However, it was also noted that with increasing human population size wildfires and wildfire emissions have been decreasing (Knorr *et al.*, 2016). This decline does not necessitate a reduction in fire activity but rather shows an increase in human-induced fires with respect to wildfires.

Tropical savannas have been occupied by approximately a fifth of the world population exerting much pressure on the ecosystem, the majority of which are located in protected areas (DeFries *et al.*, 2007, Hoffmann and Jackson, 2000). In comparison to primary drivers of savanna vegetation structure such as precipitation, anthropogenic land-use is considered as a secondary driver of savanna vegetation, it is therefore important to determine the extent to which humans influence the vegetation (Wessels *et al.*, 2011). The main land-uses of African savannas are subsistence farming and mixed grazing (Hoffmann and Jackson 2000). Southern African savanna landscapes are highly influenced by surrounding populations. According to Fisher *et al.* (2012) in South Africa over 9 million rural residents reside in savannas, of which about 90% primarily utilize ecosystem goods and services. Ekblom *et al.* (2011) suggest that early hunter-gatherer societies in the Limpopo Valley utilized fire for the management of the environment, and to facilitate hunting by steering their prey towards confined locations. This demonstrates that fire has been a long-standing component of this savanna ecosystem and, this is reiterated by the presence of fire-adapted taxa in the Limpopo Valley savanna landscape (Ekblom *et al.*, 2011).

Fires in savanna and grassland environments support the proliferation of invasive grasses that may have been introduced into the environment; increased fire dynamics due to human

activity in invaded areas perpetuate low habitat diversity as native species are outcompeted by invasive species (Vitousek *et al.*, 1997). Biological invasions are another form of human induced environmental change. Though it may be recognized that the spread of invasive species by humans outside of their native environments can be both deliberate and unintentional, a marked increase in these species occurs annually (Vitousek *et al.*, 1997). With the increase of invasive species, the negative ecological effects in the new environments are intensified having detrimental consequences for local biological diversity (Vitousek *et al.*, 1997).

In addition to compromising biodiversity, invaders have the ability to affect ecosystem processes such as nutrient cycling and hydrology (Vitousek *et al.*, 1997). Ekblom *et al.* (2012) deduce that it is difficult for savanna tree taxa to reach their maximum growth potential as the system is affected by many disturbances and external variables, namely rainfall, fire, herbivory changes and soil nutrient status. Bond (2008) however clarifies that the amount of nutrients present in sediments does not necessarily limit the growth of forests in savannas. It is instead the slow succession rates of trees that occurs as a consequence of low productivity due to poor soil nutrition, the recovery of forests tends to be much more delayed hence the promotion of savanna taxa in poor nutrient conditions (Bond, 2008). According to Scholes (2004) nutrient deprived savannas undergo eco-physiological adaptations. These include adaptations to water-stress demonstrated by the prevalence of flat-crowned canopies with compound leaves in arid savanna ecosystems (Scholes, 2004).

Duffin (2008) studied the influence of rainfall and fire intensity on the pollen and charcoal records at three sites in the KNP from the period of 1955 to 2005. The study sought to examine the ability of pollen and charcoal data to inform not only vegetation and fire dynamics but rainfall trends too (Duffin, 2008). Pollen percentages and charcoal concentrations were used for spatial and temporal comparative analyses with known rainfall and burning regime data, in order to examine the relationship between the two proxies and rainfall trends, and also for insight on the influence of fire intensity on the tree-grass ratio (Duffin, 2008). The results indicated a gradual increase in local fire intensity in KNP (Duffin, 2008). However, the trends for regional fire intensity could not be determined. It was then assumed that higher intensity fires burn for longer periods and consequently a range of intensities could exist within the same event. Besides the fact that this method is based on estimation, the disparity between the time lapsed and the fire intensity presents another flaw in the method (Duffin, 2008; Whitlock and Larsen, 2002). There was also an indication that increased fire intensity from controlled burning results in an influx of herbaceous cover and a decline in arboreal cover, by either destroying the tree plant or limiting their pollen production

capabilities (Duffin, 2008; Ekblom and Gillson, 2010). It is therefore important to identify the different responses of vegetation types to fire intensity (Duffin, 2008; Ekblom and Gillson, 2010).

Anthropogenic forcing has been credited for the conversion of forests and woodlands (with an ideal tree-grass ratio) to open grasslands. Although environmental factors play a large role, the expansion of grasslands has been the most common observation of the effects of human activities on tropical African vegetation (Hoffmann and Jackson, 2000, Meadows and Linder, 1993). Recent semi-deciduous forest declines in Mozambican coastal lowlands are believed to be a result of human activity (Ekblom, 2008). Agricultural and fire activity are recognised as the main drivers of contemporary Miombo woodland expansions in the Chibuenene area of coastal Mozambique (Ekblom, 2008). In the Shashe-Limpopo Valley region, it is speculated that farming activities dating back to 350-450 AD did not extensively influence the vegetation landscape (Ekblom *et al.*, 2011). Farmers preferences changed from riparian forests and woodlands to fertile and grazable grasslands, the lack of anthropogenic impacts may be attributed to low population sizes (Ekblom *et al.*, 2011). In addition to anthropogenic factors, herbivore densities in savanna regions affect tree-grass coexistence (Ekblom and Gillson, 2010). Tree recruitment is generally not affected by grasses however, large canopies have a competitive effect on smaller trees and grasses with increasing biomass and density (Scholes, 2004). In savanna environments tree-grass ratios are largely determined by disturbances that limit tree density (Scholes, 2004). Therefore, competition amongst trees is more intense than tree-grass competition (Scholes, 2004).

Ekblom and Gillson (2010) highlight the importance of paying special attention to the role of herbivory disturbances in sculpting the savanna landscape. This is an alternative stance at conservation and management focusing on the history of herbivores and, their role in altering the savanna environment (Ekblom and Gillson, 2010). This approach was used to explore the usefulness of pollen analysis methods to identify and analyse coprophilous fungi spores, so as to understand how herbivores can indicate environmental change in the KNP and PNL reserves, and the long-term effects of herbivore abundance on a landscape (Ekblom and Gillson, 2010). Spores of *Coniochaeta ligniaria* and Sordariaceae found in coprophilous fungi at KNP and PNL were good indicators of changes in herbivore densities with peaks in herbivore density seen at 1400 AD in both parks, presumably due to drought and other natural conditions. There are suggestions that peaks in coprophilous fungi spores in PNL witnessed between 800-900 AD were associated with herding and farming as they were accompanied by increases in cereal grass pollen and charcoal particles (Ekblom and

Gillson, 2010b). Thus indicating that there may have been some sort of controlled burning and agricultural management as the first millennium ended (Ekblom and Gillson, 2010b). In analysing the relationship between recent vegetation and herbivore assemblages, the results from PNL suggested that there were no correlations between current herbivore density and vegetation structures (Ekblom and Gillson, 2010b).

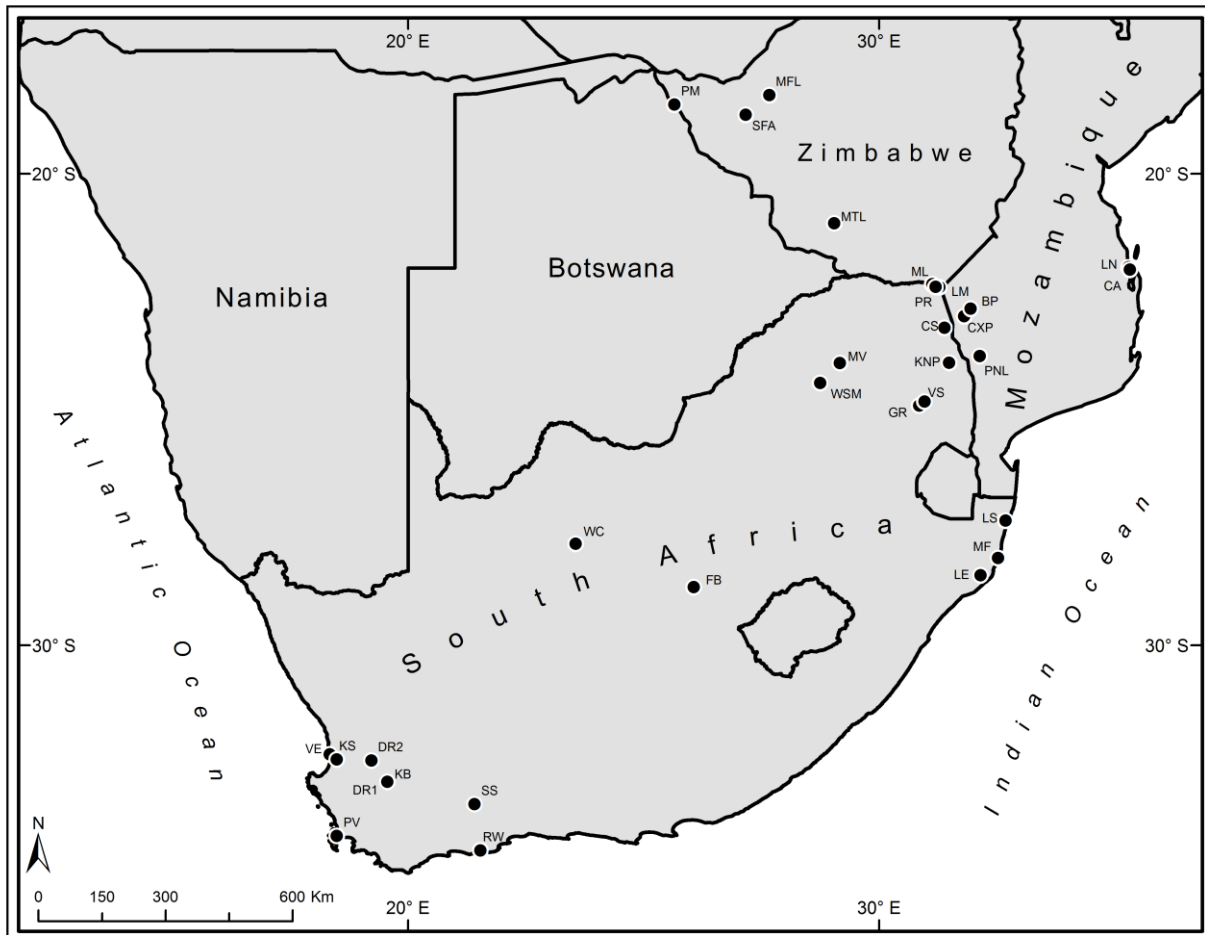


Figure 2.1 Map illustrating the study sites referenced within the text. Labeling of the map is according to study site codes recorded in the Table 2.1.

The extent to which herbivory grazing and browsing activity affect grasses and herbaceous plants varies across savanna regions and is largely dependent on herbivore densities and the structure of the system. Browsing consumption to production ratios in savannas vary according to herbivore densities (Owen-Smith and Danckwerts, 2004). Low browsing consumption to production ratios are present in savannas where low elephant population densities are maintained (Owen-Smith and Danckwerts, 2004). On the other hand, areas with large elephant populations show higher browsing consumption to production ratios (Owen-Smith and Danckwerts, 2004). *Colophospermum mopane* thicket enable Mopane

woodlands to resist elephant impacts as they are constantly in shrub phase (meaning that they do not develop into large canopies) therefore, grazing and browsing in such areas does not affect grass species richness and biomass to a large extent (Owen-Smith and Danckwerts, 2004).

2.4. Holocene palaeoenvironments of southern Africa

This section reviews case studies showing mid to late Holocene climatic changes in southern Africa. Study sites from both the summer and winter rainfall regions of southern Africa are cited, illustrating climatic variations across a range of environments with different climate forcing factors and ecosystem dynamics. Due to the scarcity of good quality, high resolution data from continuous lake sediments documenting Holocene palaeoclimates in southern Africa, a diverse range of records has been consulted in order to better understand Holocene climatic conditions in southern Africa (Scott and Lee-Thorp, 2004).

2.4.1. Mid Holocene (~7000 - 5000 cal. BP)

According to Van Zinderen Bakker (1983) the mid Holocene was characterised by initially arid conditions, there was then a transition towards more subhumid climates with short periods of aridity. The mid Holocene was also characterised by a drop in temperatures. Pollen-climate transfer functions revealed that summer temperatures at Wonderkrater spring mound on the north east of South Africa were estimated to have dropped from approximately 23.8 °C ($\pm 1.5^\circ\text{C}$) to 19.7 °C ($\pm 1.2^\circ\text{C}$), maximum temperatures for the summer rainfall zone (SRZ) site have been maintained between 21-23°C since their sharp decline after 6500 cal. BP (Truc *et al.* 2013). In the winter rainfall region of De Rif in the Cederberg Mountains, the pollen record was characterised by dry climatic conditions in the mid Holocene (*ca.* 6700-4700), this was in accordance with the Rietvlei record suggesting dry and warm conditions in the southern Cape lowlands (WRZ) during the mid Holocene (Quick *et al.* 2015).

From *ca.* 4700-4600 cal. BP, the increase in Restionaceae pollen countered by a decrease in charcoal was an indication of increased humidity at De Rif (Valsecchi *et al.* 2013). Low fire frequencies and spikes in Restionaceae are assumed to have facilitated the increase of fynbos thicket taxa (*Rhus*-type and Celastraceae) from *ca.* 4700-1900 cal. BP (Valsecchi *et al.* 2013). Comparably, due to the high abundance of Asteraceae and Chenopodiaceae in the Florisbad sequence from *ca.* 7000-6500 BP, it was suggested that there were high levels of local evaporation and relatively semi-arid conditions in the Dry Western floristic region of the central Free State during this timeframe (Scott and Nyakale, 2002). Scott and Nyakale (2002) deduced a shift to increasing moisture conditions in Florisbad at 6300 cal. BP, grass

pollen was seen to increase at this time (~ 60%) whilst Asteraceae and Chenopodiaceae/Amaranthaceae pollen counts drastically decreased.

Mid Holocene data from the Lake Eteza record showed a similar trend in the summer rainfall zone of north coastal KwaZulu-Natal for the majority of the period. Between 6800–3600 cal. BP the Lake Eteza core was dominated by forest indicators (high *Podocarpus* percentages) which corresponded with evidence derived from the Mfabeni peatlands on the Maputaland Coastal Plain (SRZ) and, included the appearance of riverine forest trees and mangrove taxa such as *Rauvolfia*, *Macaranga*, *Bruguiera* and *Anthospermum* (Baker *et al.*, 2014, Finch and Hill, 2008, Neumann *et al.*, 2010). The shift from freshwater towards more swamp-like conditions from 5000 cal. BP was supported by the abundance of *Typha*, Gentianaceae, *Persicaria* and other swamp environment indicators (Neumann *et al.*, 2010). *Melanoides tuberculata* are generally accepted as freshwater mollusc species however, these gastropods found at about 4700 cal. BP in the Lake Eteza sequence may have also been indicative of mangrove conditions (Neumann *et al.*, 2010).

A peak in Asteraceae pollen between *ca.* 5500 and *ca.* 4500 BP suggests that climate conditions at Florisbad were becoming drier and/or, there was change in moisture availability for the winter season (Scott and Nyakale 2002). For a similar period (between *ca.* 6000-3000 cal. BP) the carbon isotope values from the Makapansgat stalagmite record indicated cool but dry conditions in the Makapansgat Valley (Limpopo) SRZ, this evidence corresponded with the cool conditions also experienced at Wonderkrater Spring Mound during this time also in north eastern summer rainfall parts of South Africa (Holmgren *et al.*, 2003, Scott *et al.*, 2003).

The pollen sequence from Katbakkies Pass located in boundary of the summer and winter rainfall zone (WRZ) of the southwestern Cape illustrated rainfall variability and seasonality, in a similar way to Lake Eteza (SRZ) record mid Holocene conditions were generally perceived to be wetter (Chase *et al.*, 2015). Winter and summer rainfall conditions generally showed opposite trends throughout the Katbakkies Pass sequence, however precipitation levels for winter were higher for the most part of the sequence (Chase *et al.* 2015). Rock hyrax midden records from Katbakkies Pass showed regional climatic variability during the transition from the mid to late Holocene (6900-5600 cal. BP). From stable isotope data it was deduced that summer rainfall conditions influenced by a significant surge in easterly flow and humidity increased during the mid to late Holocene period, these conditions were indicated by Santalaceae, Celastraceae and Rubiaceae pollen types (Chase *et al.* 2015). Alternatively,

Table 2.1 The study sites referenced within the literature review text, information regarding location, age of records, type of archives and authors cited in the literature. Site codes correspond with codes cited on the referenced study sites map (Fig 2.1).

Code	Site	Country	Longitude	Latitude	Age	Type of Archive	Authors
WS	Wonderkrater Spring Mound	South Africa	28°45'E	24°26'S	20 000 ka	Thermal spring	Scott <i>et al.</i> (2003), Truc <i>et al.</i> (2013)
LM	Lake Mapimbi (KNP)	South Africa	31°16'E	22°24'S	AD 1350-present	Lake	Ekblom <i>et al.</i> (2012)
ML	Makwadzi Lake (KNP)	South Africa	31°07'E	22°20'S	AD 500-present	Lake	Ekblom <i>et al.</i> (2012)
BP	Byarinama Pan (PNL)	Mozambique	31°45'E	23°01'S	AD 500-present	Pan	Ekblom <i>et al.</i> (2012)
CS	Chinyangani Spring (PNL)	Mozambique	31°23'E	23°16'S	AD 500-present	Spring	Ekblom <i>et al.</i> (2012)
MF	Mfabeni Peatland	South Africa	32°31'E	28°09'S	0-47 000 cal. BP	Peatland	Baker <i>et al.</i> (2014)
KB	Katbakkies Pass	South Africa	19°33'E	32°53'S	700-7000 cal. BP	Rock hyrax midden	Chase <i>et al.</i> (2015)
VE	Verlorenvlei Estuary	South Africa	18°19'E	32°18'S	0-8000 cal. BP	Estuarine lake	Carr <i>et al.</i> (2015) Meadows and Baxter (2001)
KS	Klaarfontein Springs	South Africa	18°29'E	32°25'S	0-7000 cal. BP	Artesian springs	Carr <i>et al.</i> (2015)

LE	Lake Eteza	South Africa	32°08'E	28°31'S	0-10 200 cal. BP	Lake	Neumann <i>et al.</i> (2010)
DR1	De Rif (Cederberg Mountains)	South Africa	19°13'E	32°26'S	0-19 500 cal. BP	Rock hyrax midden	Quick <i>et al.</i> (2011)
DR2	De Rif (Cederberg Mountains)	South Africa	19°13'E	32°26'S	0-15 600 cal. BP	Rock hyrax midden	Valsecchi <i>et al.</i> (2013)
PV	Princess Vlei	South Africa	18°29'E	34°02'S	80-4150 cal. BP	Freshwater lake	Neumann <i>et al.</i> (2011)
LS	Lake Sibaya	South Africa	32°41'E	27°21'S	0-7100 cal. BP	Coastal lake	Neumann <i>et al.</i> (2008)
RW	Rietvlei Wetland	South Africa	21°32'E	34°21'S	0-16 000 cal. BP	Wetland	Quick <i>et al.</i> (2015)
SS	Seweweekspoort	South Africa	21°24'E	33°22'S	0-8000 cal. BP	Rock hyrax midden	Chase <i>et al.</i> (2013)
KNP	Kruger National Park	South Africa	31°29'E	24°00'S	1964-2008 cal. AD	Seasonal Pans, reservoirs, lakes	Duffin (2008)
MV	Makapansgat Valley	South Africa	29°10'E	24°01'S	0-25 000 cal. BP	Cave	Holmgren <i>et al.</i> (2003)
FB	Florisbad	South Africa	26°04'E	28°46'S	0-6500 cal. BP	Spring deposits	Scott and Nyakale (2002)
LN	Lake Nhauhache (Vilankulo region)	Mozambique	35°17'E	21°58'S	AD 200-1800	Lake	Ekblom <i>et al.</i> (2014)

CA	Chibuene Area	Mozambique	35°19'E	22°01'S	AD 1400-present	Lake Deposits	Ekblom <i>et al.</i> (2014)
PNL	Limpopo National Park	Mozambique	32°07'E	23°51'S	0-1200 cal. BP	Pans	Ekblom and Gillson (2010)
CXP	Chixuludzi Pan	South Africa	31°56'E	22°51'S	AD 800-present	Semi-permanent pan	Ekblom and Gillson (2010)
PR	Pafuri Region	South Africa	31°11'E	22°24'S	AD 980-1980	Tree rings	Woodborne <i>et al.</i> (2015)
GR	Graskop	South Africa	30°50'E	24°55'S	0-6500 cal. BP	Permanent freshwater marsh	Breman <i>et al.</i> (2012).
VS	Versailles	South Africa	30°57'E	24°49'S	0-4450 cal. BP	Small wetland	Breman <i>et al.</i> (2012).
SFA	Sikumi Forest Area (Mukwa Rainfall Record)	Zimbabwe	27°10'E	18°45'S	0-200 BP	Tree ring sample	Therrell <i>et al.</i> (2006)
MFL	Mzola Forest Land (Mukwa Rainfall Record)	Zimbabwe	27°40'E	18°20'S	0-200 BP	Tree ring sample	Therrell <i>et al.</i> (2006)
MTL	Matabeleland (Mukwa Rainfall Record)	Zimbabwe	29°20'E	21°30'S	0-200 BP	Tree ring sample	Therrell <i>et al.</i> (2006)
PM	Pandanatenga (Mukwa Rainfall Record)	Botswana	25°39'E	18°31'S	0-200 BP	Tree ring sample	Therrell <i>et al.</i> (2006)

Chase *et al.* (2015) believed that the westerly storm track shifted polewards due to a decline in Antarctic sea ice consequently decreasing winter rainfall in southern Africa.

The period from 5600-4700 cal. BP saw the expansion of the Antarctic sea ice; as a consequence the westerly storm track shifted back towards the equator from the poles, resulting in wetter conditions during the winter season at Katbakkies Pass in the southwestern Cape (Chase *et al.*, 2015). This could be related to the suggestion by Holmgren *et al.* (2003) that the low oxygen isotope values derived from the Makapansgat stalagmite record in the SRZ (Limpopo) were indicative of decreased regional temperatures due to the expansion of the circumpolar vortex in the mid Holocene. Specific pollen types such as Aizoaceae and *Felicia* indicated that summer rainfall during the same age was reduced, slightly drying the environment (Chase *et al.* 2015).

The high presence of Asteraceae, *Crassula* and Aizoaceae and the low abundance of sedge and aquatic pollen in the Princess Vlei pollen sequence indicated dry conditions in the fynbos landscape of the coastal Cape Flats for the period of 4150-3400 cal. BP in the late Holocene (Neumann *et al.* 2011). This was not the case for the Florisbad record, despite the presence of arid environment indicators such as Chenopodiaceae/Amaranthaceae, according to Scott and Nyakale (2002) the conditions at the central Free State site became relatively moist between c. 4500-c. 4000 BP as there was an increase in grass pollen. Evidence from Princess Vlei showed a shift towards more humid conditions with a prevalence of wetland indicators such as Cyperaceae, *Typha* and Restionaceae (possibly Restoid fynbos growing in waterlogged sediments) whilst Asteraceae and Poaceae percentages declined from 3400 to 2600 cal. BP in the WRZ (Neumann *et al.* 2011). This was in agreement with palynological evidence from the Klaarfontein core that suggested wetter conditions between 4000-2500 cal. BP in the WRZ of the Western Cape. Also evident in the Princess Vlei sequence were the higher fire frequencies occurring due to high levels of biomass which had built up over time (Neumann *et al.* 2011).

2.4.2. Late Holocene (~5000 cal. BP- present)

Climatic conditions during the late Holocene were dominated by abrupt shifts between high rainfall variability, several dry episodes and humid conditions at Katbakkies Pass in the summer/winter rainfall zone of the southwestern Cape (Chase *et al.* 2015). Contrasting observations were found in the Princess Vlei record in the WRZ (Neumann *et al.* 2011). Initial late Holocene conditions at Katbakkies pass were generally humid with high summer rainfall which occurred as a result of the poleward displacement of the westerlies and, increased easterly flow from the period 4700 cal. BP to 3200 cal. BP with the exception of a

drought event that occurred between 3800-3700 cal. BP (Chase *et al.* 2015). Post 3200 cal. BP until 2700 cal. BP, dry conditions and low summer rainfall persisted. Conditions at Katbakkies Pass were once again more humid from 2700 cal. BP to approximately 1600 cal. BP, and summer rainfall was increasing peaking at ~90mm between 2600-2500 cal. BP whilst winter conditions were drier towards the late Holocene until approximately 1700 cal. BP (Chase *et al.* 2015).

Evidence of a decrease in forest elements such as *Podocarpus*, *Isoglossa* and *Mimusops* at 3100 cal. BP along with an increase Poaceae and Asteraceae pollen till about 2000 cal. BP also showed a shift from wet conditions during the mid Holocene towards drier environmental conditions in the late Holocene at Lake Eteza (KZN) (Neumann *et al.* 2010). A decline in forest taxon *Podocarpus* was also witnessed at Versailles and Graskop in northeastern Mpumalanga (SRZ) after 1800 cal. BP and 1000 cal. BP at Versailles and Graskop respectively (Breman *et al.* 2012). This was due to an increase in warm, wet conditions leading to a transition from forest to open savanna and grass dominated systems at Versailles and Graskop (Breman *et al.*, 2012). Entering into the late Holocene, pollen evidence from the Florisbad record shows a shift from relatively moist conditions (high levels of Cyperaceae) to more arid environments ca. 4000 to ca. 2000 BP (Scott and Nyakale, 2002). Late Holocene conditions at Rietvlei in the Cederberg region corresponded with conditions experienced at Seweweekspoort in the southern Cape, both sites showed forest development and indications of humid conditions and low rainfall seasonality between 5000-3300 cal. BP associated with the shift of the westerlies towards the equator (Quick *et al.*, 2015).

From ca. 2600-1900 cal. BP dry conditions persisted at Princess Vlei (Neuman *et al.* 2011). Although the Haloragaceae taxon increased pollen evidence from the Princess Vlei record generally showed a decline in wetland indicators (*Typha*, *Carpacoce* and Cyperaceae), meaning that Haloragaceae may have been locally sourced and therefore overrepresented in the sequence (Neuman *et al.* 2011). The deduced conditions of decreasing moisture were validated by the simultaneous presence of *Crassula* pollen that is an indicator of succulent vegetation and Restionaceae, which generally grows on dry sites and leached dunes. This was also the case for Florisbad between ca. 2200 and ca. 1700 BP, strong evaporative conditions were inferred due to the high proportions of Poaceae and Chen/Ams pollen (Scott and Nyakale 2002). The 2500-900 cal. BP periods at Klaarfontein (Verlorenvlei record) were also perceived to be more arid, this evidence was corroborated by the presence of brackish and epiphytic diatoms in the often associated with dry conditions (Carr *et al.*, 2015). Contrastingly, (Meadows and Baxter, 2001) found that moist conditions

prevailed after 1900 BP at Klaarfontein, this was indicated by the reappearance of Chenopods and *Mesembryanthemum* signaling a rise in sea levels.

A return to moist forest conditions is evident in the Lake Eteza (KZN) record after 2000 cal. BP, this is corroborated by evidence of warm wet conditions at Makapansgat Valley (Limpopo) also in the SRZ (Neumann *et al.*, 2010, Holmgren *et al.*, 2003). Moist conditions at Lake Eteza were evident from the increase in mangrove, swamp, riverine and coastal forest elements coupled with a decrease in dry environment indicators such as Poaceae and Asteraceae (Neumann *et al.*, 2010). Although the high abundance of *Spirostachys africana* at 800 cal. BP may have been indicative of arid savanna-like conditions, the general trends for the late Holocene signify moist conditions featuring swamp and open water habitats (Neumann *et al.* 2010). There was also a suggestion of higher moisture conditions and open water habitats towards the very late Holocene at Princess Vlei in the coastal Cape Flats, arid environment pollen indicators (e.g. *Crassula* and Restionaceae) showed a decreasing trend, contrasting to damp environment indicators such as Cyperaceae, Ericaceae and *Nymphaea* (Neumann *et al.*, 2011).

Pollen evidence from lake deposits in the miombo woodlands of the Chibuene area of Mozambique show the coexistence of forest, savanna and generalist vegetation types at 1600 BP (Ekblom, 2008). At 1600 BP, Lake Nhaucati showed a good representation of savanna vegetation especially *Brachystegia* and forest or riverine forest types as indicated by pollen types such as Moraceae, *Trema* and *Celtis* which are no longer present in the Chibuene area (Ekblom, 2008). Similarly, forest, generalist and savanna taxa are well represented in pollen evidence from the Lake Xiroche sequence from 1400 BP until approximately 1450 AD (Ekblom, 2008). A decline in forest taxa in the Chibuene area is largely attributed to anthropogenic deforestation and the region has since transitioned into a savanna phase.

The beginning of the 1500 to 1000 cal. BP period at Lake Sibaya in northern KwaZulu-Natal was dominated by aquatics and swamp taxa indicating moist conditions (Neumann *et al.* 2008). Tree genus *Podocarpus* was especially abundant at this time and within close proximity to swamp vegetation till approximately 1300 cal. BP validating the moist and cool climatic conditions in the swamp forest margins (Neumann *et al.* 2008). This period was also represented by isolated incidents of high intensity fire events (Neumann *et al.* 2008). Although the site falls within the savanna and Indian Ocean Coastal Belt biomes, because the occurrence of fire events is less likely in forest environments anthropogenic activity was also considered as possible cause of the fire activity at Lake Sibaya in northern KwaZulu-

Natal (Neumann *et al.* 2008). Much like the Lake Eteza record, climatic conditions in Lake Sibaya between 850-350 cal. BP (Late Iron Age) leaned towards moister environments and had a significant number of wet habitat indicators (e.g. *Phoenix* and *Macaranga*) (Neumann *et al.* 2008).

According to the Katbakkies record, cooling caused by the expansion of Antarctic sea ice at approximately 1600 cal. BP led to the SW Cape of South Africa once again experiencing increased winter rainfall, Proteaceae, Solanaceae and *Lobostemon* pollen increased (Chase *et al.* 2015). Conversely, summer moisture availability was reduced until about 700 cal. BP (Chase *et al.*, 2015). A regional increase in rainfall in the lower Limpopo Valley was evident for the period of 800-1200 AD when palaeorecords showed a rise in water tables for KNP and PNL (Ekblom *et al.* 2012). The Lake Mapimbi diatom record from the KNP showed that rainfall continued to increase in the lower Limpopo Valley after 1300 AD with diatom data illustrating higher lake levels for this time period (Ekblom *et al.*, 2012). Contrastingly, between the period of 1000-1500 AD there was a decline in trees and shrubs in favour of grasses in the Vilankulo region of the Mozambique coastal lowlands (Ekblom *et al.*, 2014). Diatom evidence from Lake Nhauhache indicated periodic drought conditions between 1180-1700 AD (Ekblom *et al.*, 2014). This is in agreement with indications of drought from ca. 1600 AD in the Pafuri region baobab rainfall record comprised of 4 dendrochronological samples from the region. Amidst the drought conditions, there is an indication of riparian expansion after 1500 AD with an increase in trees and shrubs such as Myrtaceae and *Phyllanthus* in the Lake Nhauhache record (Ekblom *et al.*, 2014).

Pollen records from Lake Mapimbi and Makwadzi (KNP) suggested the commencement of drought conditions from 1400- 1800 AD marked by the decline in riparian taxa and, the appearance of the fungus *Glomus* in the Lake Mapimbi dataset, a fungus genus often associated with drought conditions (Ekblom *et al.* 2012). Grassland vegetation for these sites appeared to be stable regardless of the drought conditions (Ekblom *et al.* 2012). Of all the palaeorecords derived from KNP and PNL, the decline in riparian taxa at Lake Mapimbi is the only record showing vegetation response to climate change for the lower Limpopo Valley at ca. 1700 AD (Ekblom *et al.* 2012). It is speculated that the forest decline may have been associated with crop cultivation, however forest clearance is not visible in the charcoal evidence (Ekblom *et al.* 2012).

Palaeorecords suggested wetter conditions for the lower Limpopo Valley commencing at ca. 1800 AD (towards the end of the Little Ice Age (LIA)), these patterns were validated by sediment accumulation and pollen records for Chinyangani spring and Byarinama pan in the

PNL which showed high water tables and an increase in riparian taxa (Ekblom *et al.* 2012). The Mukwa rainfall record with dendrochronological data collected from 4 sites (Sikumi Forest Area, Mzola Forest Land, Matabeleland and Pandanatenga) suggests that a brief period of high rainfall episodes occurred towards the end of 1800 AD indicating wetter conditions (Therrell *et al.* 2006).

Pollen and isotope data from Chixuludzi Pan on the Limpopo River floodplains show that there has been a transition from savanna to savanna-riparian vegetation in the area from AD 1400-present (Ekblom and Gillson, 2010a). Tree recruitment is believed to be facilitated by fire and the advantage that Chixuludzi Pan is located on the floodplains of the Limpopo River (Ekblom and Gillson, 2010). The diatom assemblage from Lake Nhauhache in the miombo woodlands of the Vilankulo region suggests increased lake levels and there is an increase in aquatics and herb taxa whilst savanna taxa such as *Brachystegia* decline (Ekblom *et al.* 2014).

Diatom evidence from the Verlorenvlei records also suggested increased winter rainfall in winter rainfall regions over the past 1500 years (Carr *et al.* 2015, Quick *et al.* 2015). According to Carr *et al.* (2015) wetter conditions have prevailed in the last 700 years at Verlorenvlei, this is supported by the increase in aquatic types in the Klaarfontein pollen sequence. In addition, vegetation ecology indications for the past 170 years at Klaarfontein are believed to be influenced by humans as there is less diversity of spectra towards the very late Holocene (Meadows and Baxter, 2001). There has been an increase in disturbance indicators such as Asteraceae and succulents and a decrease in Poaceae and fynbos elements in most recent times (Meadows and Baxter, 2001). In contrast, mesic conditions have been inferred at Rietvlei in the southern Cape Lowlands for the past 1000 years, this period has been dominated by seasonal rainfall and high temperatures, coastal thicket, afro-montane forest, a marked decline in fynbos and suppressed fire regimes (Quick *et al.*, 2015).

2.5. Conclusion

This chapter provides a synthesis of the main drivers of climate and vegetation change in southern Africa citing examples of top-down and bottom-up factors affecting savannas, particularly climatic conditions and anthropogenic forcing. Palaeoenvironmental studies conducted in southern African savanna environments were reviewed with KNP and PNL recognized as the most comparable as they fall within both the savanna biome and the summer rainfall region. A comparison of conditions experienced in summer and winter rainfall regions for the mid to late Holocene was provided to gain a perception on the conditions experienced in different environments, and to have an understanding of regional

changes. During the early stages of the mid Holocene, conditions in the summer rainfall regions of South Africa were characterised by reduced temperatures and semi-aridity, followed by a shift towards drier and cooler conditions. Winter rainfall regions were initially dry and characterised by warm temperatures, transitioning to wetter more humid conditions as the mid Holocene progressed. The expansion of Antarctic sea ice towards the end of the mid Holocene resulted in reduced regional temperatures and increased humidity in summer rainfall regions and wetter winter conditions in the winter rainfall zone. The early stages of the late Holocene were characterised by humid conditions and high summer rainfall. However, the summer rainfall regions experienced more arid conditions. The main consensus is that late Holocene conditions in southern Africa have been characterised by highly variable rainfall, and in the most recent history more frequent episodes of drought. There is a lack of high resolution data detailing very late Holocene conditions in savanna environments in southern Africa. For this reason, more high resolution records need to be studied to contribute to the very late Holocene palaeoenvironmental archive in South Africa.

CHAPTER THREE

THEORETICAL METHODOLOGY

3.1. Introduction

Past environmental change is best shown by long-term sedimentary records. Short records are most useful for the illustration of past environmental change and the temporal resolution of specific events (Bronk, 2008). These precisely show the estimated timing of events and periods between the events (Bronk, 2008). Palaeoenvironmental proxy data derived from a variety of sources such as sedimentary deposits, polar ice, stable carbon isotopes and tree rings is now recognised as a useful tool for the discovery and understanding of historical climate-fire-vegetation relationships and influence of humans in sculpting the environment at different temporal and spatial scales (Conedera *et al.*, 2009). Long-term fire history can be interpreted from charred particles extracted from sediment cores and information on vegetation dynamics is conveyed by the pollen record (Pitkänen *et al.*, 2003). Pollen data illustrating the state of plant communities informs fire dynamics as fire is an evolutionary agent (Conedera *et al.*, 2009, Clark, 1988). This therefore makes pollen and charcoal analysis complementary techniques

This chapter presents a discussion of the different available methods for the quantification of pollen and charcoal. There are several factors that are taken into consideration when selecting a technique for the analysis of proxy data, amongst them are time efficiency and cost efficiency - each technique has got certain drawbacks (Weng, 2004; Whitlock and Larsen, 2002). A critical review of several available methods for sedimentary core extraction and pollen and charcoal laboratory processing is provided in this chapter. Also provided is a brief explanation of the applied proxy data dating, presentation and interpretation techniques.

3.2. Pollen analysis

Palynology is a tool that was initially developed by Lennart van Post to correlate varved lake deposits (annual layered sediment depositions) and stratified peats (Dincauze 2000). This is the study of pollen and spores, pollen is found in angiosperms and gymnosperms (seed-producing plants) and spores are found in mosses and ferns (Bennet and Willis, 2001). This is one of the popular tools used to reconstruct palaeoenvironmental landscapes, it can also be viewed as a tool used to study past environments and ecosystem dynamics over large spatial and temporal scales (Bunting *et al.*, 2004, Gaillard *et al.*, 2008). Our ability to reconstruct these past environments is informed by our ability to understand present

ecosystems and communities (Gaillard *et al.*, 2008). Fossil pollen is advantageous in this aspect as individual taxa are very similar to modern taxa in terms of environmental requirements (Gaillard *et al.*, 2008).

Fossil pollen assemblages can show a snapshot of historical vegetation patterns representing a time slice (Prentice, 1985). This is a useful tool for understanding how modern vegetation has been derived from past vegetation shifts as a response to environmental change (Bennet and Willis, 2001). Pollen data can be used to illustrate the response of taxa to shifts in climate, and the overall vulnerability of an ecosystem to past climatic disturbances can be inferred (Prentice, 1985). The ability to use pollen analysis as a tool for reconstructing long-term (decadal, centennial and millennial) vegetation dynamics and ecological processes allows for a better understanding of modern ecosystem dynamics and therefore, the better implementation of conservation and management efforts (Bunting, 2008).

It has been found that there is a direct relationship between the pollen percentage of key taxa and the proportional occurrence of these taxa in the landscape (Fletcher and Thomas, 2007, Prentice, 1985). This is in agreement with Birks and Birks (2000) who echo that the basic principle of pollen analysis is based on the notion that pollen abundance and pollen type are directly associated with the occurrence of the parent taxon in the surrounding environment. Anaerobic sites (e.g. lakes, wetlands, peat deposits) highly favour the preservation of pollen, such sites are preferred for palynological research and construction of fossil pollen assemblages (Bennett and Willis, 2002, Birks and Birks, 2000).

Pollen can also be used to inform rainfall and moisture conditions, sedge pollen such as that from the family Cyperaceae is thought to be indicative of hydrological change, specifically fluctuations in moisture conditions- a decline in Cyperaceae is believed to reflect the frequency of wetland occurrences (Duffin, 2008; Scott, 2002; Scott, 2002; DuPont *et al.*, 2008).

3.2.1. General principles of pollen analysis

The basic assumptions and limitations of pollen analysis as outlined by Birks and Birks (1980) and Dincauze (2000) are discussed below and further elaborated within the chapter:

1. Pollen grains are adapted to dispersal by anemophily and zoophily. However, humans also play a role in introducing species into environments, and pollen can undergo re-deposition from older sediments.

2. It is assumed that pollen rain is uniform across space and pollen rain composition is correlated with the abundance of parent plants.
3. Pollen production is assumed to be abundant for most plants. There is a poor discrimination between arboreal and non-arboreal plants in plant communities which can bias the pollen assemblage. This is especially the case for forest environments where tree pollen dominates non-arboreal pollen types.
4. Insect pollinated plants are not well represented in the pollen assemblage.
5. Disturbance and preservation factors influence pollen ratios.
6. Pollen grains are best preserved under anaerobic conditions and are destroyed by oxidation in aerated environments.
7. Ecological tolerances and competitive relationships of species are assumed to remain unchanged with time.
8. Fossil and modern pollen assemblages can be used to discern the associations between ancient and modern ecosystem characteristics.

3.2.2. Key concepts

A homogenous layer of pollen accumulation over a large scale for a certain period is called pollen rain, it provides a glimpse of the abundance of the historical parent vegetation during a specific era (Bennet and Willis, 2001). Pollen rain is an amalgamation of pollen taxa that have undergone different taphonomic processes (Birks and Birks, 2000, Dincauze, 2000). These taxa have been accumulated and transported in different quantities and proportions due to pollen production capabilities among different species and their adapted mode of pollen dispersal (Birks and Birks, 2000, Dincauze, 2000). Pollen dispersal mechanisms vary among different plant taxa and between species (Birks and Birks, 2000, Fletcher and Thomas, 2007). The most common modes of pollen transportation include anemophily which is wind dispersal (this is the only mode of transportation for spores), water dispersal (via the drainage system) and zoophily which is the transportation of pollen by insects and mammals (Bennett and Willis, 2002, Bunting, 2008, Hooghiemstra *et al.*, 2006).

The weightlessness and buoyancy of pollen grains allows for them to be easily dispersed by wind and descend through the atmosphere to their accumulation site (Dincauze 2000, Hooghiemstra *et al.* 2006). Pollen grains can also be incorporated in rainfall leading to an even deposition over space at a given time (Hooghiemstra *et al.*, 2006). Insect or animal pollen grains often have adhesive surfaces and small hooks promoting their attachment to furs, feathers and insects (Dincauze 2000).

Most plants are characterised by a particular mode of pollination each with certain limitations. In comparison to water and wind agents, the ability for birds and mammals to disperse pollen and seeds is reduced because they are limited to their habitat boundaries - mammals more so than birds (Chambers, 1993). Therefore, mammals and birds are unable to make a significant contribution to regional pollen accumulations (Chambers, 1993). Insect-pollinated plants also tend to produce far less pollen than wind-pollinated taxa (Traverse, 1999). For both pollen and seeds, wind dispersal tends to be more common than insect or mammal distribution. Taxa with high pollen productivity and tree pollens are often biasedly represented in the sediment pollen assemblage (Bennett and Willis, 2002, Dincauze, 2000, Gaillard *et al.*, 2008). Pollen dispersal properties are prone to change due to influences such as changes in the environmental factors (for example, wind speed), morphological variations in pollen grains (for example, pollen grain size and shape), pollen entrainment and the actual structure of the landscape (Gaillard *et al.*, 2008).

The complexity of pollen rain makes the determination of pollen source area a difficult task to accomplish because there are unique temporal and spatial differences between study sites (Birks & Birks, 2000). The pollen source area is the vegetation belt producing the accumulated pollen (Hooghiemstra *et al.*, 2006). Spatial scales of vegetation units represented by pollen data can range from a few square metres to continental magnitude (Bradshaw and Webb, 1985). According to Gaillard *et al.* (2008) vegetation from a radius of 101-102 km² can be represented in an individual pollen sequence. Therefore, pollen represents local and regional ranges (Birks, 2005). The term regional refers to a radius extending beyond several kilometres (Birks, 2005).

The spatial extent of the landscape has an effect on the source area of the pollen assemblage, however the size of the depositional basin compared to source area also has an important effect on pollen assemblages which needs to be studied more rigorously (Bunting *et al.*, 2004, Bunting *et al.*, 2005, Seppä and Bennett, 2003). The spatial distribution and areal extent of basins results in a biased representation of local diversity and associations between pollen and plants (Dincauze, 2000). According to the Prentice-Sugita

model, small lakes which have a 50m radius have a relevant source area of 300-400m while, the source area of medium sized basins with a radius of 250m is approximately 600-800m (Seppä and Bennett, 2003, Sugita, 1994). Basin sizes are usually indicative of the homogeneity or heterogeneity of the adjacent vegetation structure for example, the combination of larger basin and smaller source area usually represents a homogenous structure (Bunting *et al.*, 2005).

Small basins (1-5 hectares) source their pollen from a narrow radius, mainly from surface plants or along the margins of the basins therefore local vegetation is better represented, these are considered to be more important than large basins within the context of pollen representation (Bradshaw and Webb, 1985; Birks, 2005; Dincauze, 2000; Gaillard *et al.* 2008). In contrast, larger basins (> 1 km²) tend to have large amounts of background pollen therefore they represent a more regional range and the pollen contribution is usually wind derived or arising from influent streams (Bradshaw and Webb, 1985; Birks, 2005; Dincauze, 2000). Thus changes in basin size will affect the amount of pollen accumulated (Bradshaw and Webb, 1985).

3.2.3. Pollen preservation

Pollen grains have the shape of an ellipsoid or sphere and they can range in diameter from as little as 10µm to 100µm, with most species falling within the 20µm to 30µm bracket (Bennett and Willis, 2002, Bunting, 2008). Each pollen grain is protected by a resilient layer of cellulose and a plant polymer or exine called sporopollenin, the latter contributing to the fine preservation qualities of pollen (Bennett and Willis, 2002, Bunting, 2008, Dincauze, 2000, Traverse, 1999). Sporopollenin is best preserved in anaerobic and acidic or arid conditions (Bunting 2008, Dincauze 2000). Spores are also able to resist decay as their outer walls are protected by chitin a resistant compound (Traverse, 1999). The resistant exteriors of both pollen and spores allow for their integration in different sediment types such as clays, peat and silts however, the thickness of these exterior walls differs between pollen and spore types making some more vulnerable to decay than others (Traverse, 1999). Some archives with conducive conditions for pollen preservation include: oligotrophic lakes and ponds, peat bogs and sediments occurring below the ground water table (Bunting, 2008, Dincauze, 2000). Pollen grains from non-waterlogged conditions are more prone to displacement through bioturbation, soil mixing and damage due to anaerobic oxidation in high pH (pH > 6.0) and neutral environments, having negative implications on the dating and species representation of the pollen assemblage (Bunting, 2008, Dincauze, 2000). Amongst most chemically and physically degrading agents, this polymer is only vulnerable to damage by oxidation - polymer is essential in that it allows for pollen to be effortlessly isolated from

the sediment matrix without being compromised in the laboratory pollen extraction process (Bennet and Willis, 2001, Van Zinderen Bakker, 1995).

3.2.4. Field methods

3.2.4.1. Site selection method

Site selection should be aligned with the research objectives, this is commonly defined by the catchment size as these have implications regarding the pollen signal derived (Dincauze, 2000). In agreement, the Prentice-Sugita simulation also implies that it is important to take into consideration the size of the sampling site selected as this has got a considerable effect on the pollen representation (Seppä and Bennett, 2003, Sugita, 1994). Dincauze (2000) and Seppä and Bennett (2003) summarise that in order to obtain a regional palaeoenvironmental reconstruction, large catchment areas such as lakes should be chosen - sampling sites extending beyond a radius of 250 m are most ideal. The study of smaller basins typically narrows the investigation down to specific plant communities immediately surrounding the coring site rather than large landscapes (Dincauze, 2000, Seppä and Bennett, 2003). If the research objective is to determine the plant ecology and the influence of humans on the environment then smaller catchments such as ponds, pans and bogs should be explored (Dincauze, 2000, Seppä and Bennett, 2003).

Although wetland sediments or bog deposits are the more desirable coring locations for palaeoecologists, there are a number of site-specific biases that present challenges for the interpretation of pollen assemblages namely, confusion, dilution, filtration and succession (Bunting, 2008). Confusion relates to uncertainties regarding the origin of pollen taxa and the challenge of distinguishing between in situ and ex situ pollen derivation due to surface vegetation having such a large effect on wetland pollen sequences (Bunting, 2008). Dilution of regional pollen signals may occur due to an overrepresentation of locally sourced pollen or differential representation; ultimately compromising the stratigraphic integrity of the record (Bunting, 2008, Dincauze, 2000, Gaillard *et al.*, 2008). The filtration of pollen is essentially the removal of pollen prior to its entry into the pollen assemblage system due to changes in transportation modes and external influences such as impaction. Successional changes such as the expansion and retraction of the canopy or dry landscape also have an effect on the pollen signal derived from wetlands (Bunting, 2008). Lakes are not immune to such uncertainties regarding the pollen signal, these are often exposed to impacts such as trampling due to their prime locations for animal use (Bunting, 2008). Another major issue is the loss of the archive due to anthropogenic activities such as agriculture and forestry which are increasingly becoming a problem (Barber, 1993).

Peatlands are made up of a thick and dark organic layer, these natural ecosystems are unsurpassed when it comes to the preservation of historical biodiversity (Chambers and Charman, 2004). Peatlands are considered to be a good source for palaeoenvironmental information, their autochthonous nature allows for a greater chronological accuracy as records are preserved in stratified layers which can be coordinated with temporal scales (Chambers and Charman, 2004, Barber, 1993). Barber (1993) and De Vleeschouwer *et al.* (2010) describe two types of peatlands, ombrotrophic and minerotrophic peatlands. Ombrotrophic peatlands are solely nourished by atmospheric inputs including rainfall, snow and dust amongst others (Barber, 1993, De Vleeschouwer *et al.*, 2010). These peatlands (ombrotrophic) are typically raised above the ground water table restricting their access to groundwater or stream water supply (De Vleeschouwer *et al.*, 2010). Minerotrophic peatlands are fed by atmospheric inputs in addition to streamwater or groundwater in valleys, basins and on floodplains (De Vleeschouwer *et al.*, 2010). Ombrotrophic peatlands are the preferred type as these record past climatic and environmental changes, and human impacts over time as they capture atmospheric inputs such as pollen, volcanic ash and dust (De Vleeschouwer *et al.*, 2010). This then means that several multi-proxy analyses can be conducted using these peat sediments (De Vleeschouwer *et al.*, 2010).

Peatlands possess many advantages as proxy data sources. Some of these include their ability to preserve a continuous and undegraded record that can be dated more accurately using a number of dating tools such as radiocarbon dating and other isotope dating (Barber, 1993, Chambers and Charman, 2004). They produce high resolution records as they accumulate at an average rate of approximately 1 mm per year, and they are also cheaper and more accessible than ice sheets and oceanic sediments (Barber, 1993, Chambers and Charman, 2004). The use of sediments in pollen studies is often avoided due to issues regarding the chronological integrity of these sequences as a result of pedoturbation or pollen percolation (Dincauze, 2000). Sediments are also avoided due to problems regarding scale factors as a large range of pollen sources are incorporated in sediments (Dincauze, 2000).

Due to the scarcity of the most suitable terrestrial archives (e.g. wetlands, peatlands, lakes) in arid and semi-arid areas, multiproxy climate reconstructions are limited both spatially and temporally. Assessing the impacts of long-term ocean and atmospheric changes from palaeoenvironmental records is therefore restricted (Weldeab *et al.*, 2013). The scarcity of traditional archives has called for alternative avenues to be explored such as small basins, pans, spring deposits and hyrax middens (Chase *et al.*, 2013).

3.2.4.2. Core extraction technique

Sediments are mostly sampled by coring, however where stratigraphic layers are exposed discrete samples can be directly extracted (Dincauze, 2000). De Vleeschouwer *et al.* (2010) suggest the use of two corers for the extraction of short (up to 1 m) sediment cores in peatlands, the Wardenaar peat corer and the Malcom sampler - these work similarly as they are double-bladed corers that extract samples in the least disruptive way possible and avoid compaction.

The vibratory coring technique can be applied to a number of depositional environments (Fisher, 2004). Vibracorers can penetrate depths of 5 m at a time, however this is often limited to unconsolidated sediment material (Larson *et al.*, 1997). Compacted and non-saturated sediments are often impenetrable and the recovered sediments are limited despite developments in implemented core catchers to retain samples (Larson *et al.*, 1997). Although vibratory coring may be quick and efficient, vibracorers are often associated with heavy equipment which may be a liability regarding transportation in the field, and the stability of archives that are sensitive to weight (Larson *et al.*, 1997).

The Russian corer or the Jowsey (1966) sampler are the best tools for coring deeper sediment layers (De Vleeschouwer *et al.*, 2010). The parallel borehole technique is usually adopted for the extraction of long sediment cores, this entails the extraction of alternate overlapping cores (1 cm overlap) from two boreholes (A, B) that are less than or equal to 1 m apart (De Vleeschouwer *et al.*, 2010). The overlaps can be 10, 20 or 30 cm however this is dependent on the sampling site depth (De Vleeschouwer *et al.*, 2010). According to De Vleeschouwer *et al.* (2010) an advantage of the Russian corer is that subsequent samples are not disturbed by the extraction of the previous core. A disadvantage is that it cannot be used to neatly cut through the above ground biomass without compressing the sediments, vegetation should be removed as much as possible from the surface prior to coring (De Vleeschouwer *et al.*, 2010).

3.2.5. Laboratory methods

3.2.5.1. Troels-Smith analysis

The Troels-Smith analysis system assesses the textures, physical appearance and composition of sediments in order to categorise them into distinguished groups. This is based mainly on the account of the macroscopic fragments of the soil sample (Schnurrenberger *et al.*, 2003). This can be limiting in the sense that it is a biased representation and therefore does not accurately describe the soil (Schnurrenberger *et al.*,

2003). Conversely, Troels-Smith has an advantage in that sediments are characterized according to soil types along the entire soil profile and therefore, their diversity is not completely overlooked by means of grouping an entire sample into one (Schnurrenberger *et al.*, 2003).

3.2.5.2. Sub-sampling and laboratory process

The sediment core needs to first be cleaned and rid of any type of contamination that may have ensued after its extraction (Appendix A) (Faegri and Iversen, 1964). It is also important to determine an appropriate sampling interval by considering the length and age of the core; for a higher resolution, smaller slices should be considered. However, one should always start at wider intervals and gradually narrow these down depending on the need for more details in the sequence (Faegri and Iversen, 1964, De Vleeschouwer *et al.*, 2010). Small sampling intervals result in more precise results especially for small basins (Dincauze, 2000). Each sample should be correctly allocated for each proxy analysis for example, the various proportions of sample for pollen, charcoal and radiocarbon dating must be allocated (De Vleeschouwer *et al.*, 2010). Lastly, volumetric measurements of the sub-samples must be determined for example measuring 1 cm³ of sample for pollen analysis by displacement (De Vleeschouwer *et al.*, 2010).

The addition of an exotic marker grain aids in the calculation of absolute pollen counts and a minimum count of 250 marker grains is normally adequate (Dincauze, 2000, Moore *et al.*, 1991, Salgado-Labouriau and Rull, 1986). The difficulty of pollen extraction varies according to sediment types, pollen from sediments rich in clay and silt is easily extractable (Nakagawa *et al.*, 1998). Challenges are experienced in the extraction of pollen from sediments derived from peat deposits as the digestion and removal of extraneous material is often difficult (Nakagawa *et al.*, 1998). As an extensively used tool in the reconstruction of palaeoenvironments, there have been a number of techniques developed to isolate pollen grains from sediments (Nakagawa *et al.*, 1998). These are the removal of siliceous material using hydrofluoric acid (HF) and using acetolysis treatment to remove the extraneous material (Nakagawa *et al.*, 1998).

Deflocculation is essentially the pre-treatment of sediment samples whereby some extraneous materials are removed using hydrochloric acid (HCl) (Faegri and Iversen, 1989). The sample is then neutralized with distilled water, digested in sodium pyrophosphate (Na₄P₂O₇) and then centrifuged leaving behind pollen grains, organic remains and silt fragments (Faegri and Iversen, 1989).

Another method is the oxidation of pollen in a sodium chlorite (NaClO_3), acetic acid (CH_3COOH) and sulphuric acid (H_2SO_4) mixture to deflocculate the material, this procedure lasts for several hours (Faegri and Iversen, 1964). Thereafter, residual material is washed out and a mixture of ether and acetone is used to dry the samples. Polysaccharides are hydrolysed with 80% H_2SO_4 resulting in pollen grains being left behind. The advantage of this method is that it can be used on samples with poor pollen content as it concentrates on the pollen much better than the alkali treatment. The main limitation is that this method is more time consuming. In preparation for identification pollen grains are stained, this is done to improve the visibility of pollen grains ensuring that the various structural differences are easily distinguishable (Faegri and Iversen, 1964, Moore *et al.*, 1991). Zhang *et al.* (2004) note that staining has implications on the textural properties and appearance of pollen and spore grains and how they are perceived which may make identification a challenge.

3.2.5.3. Counting and identification

The low taxonomic resolution of pollen is one of the main limitations of pollen analysis (Dincauze, 2000, Seppä and Bennett, 2003). Pollen is commonly identified at family level and mainly representative of wind-dispersed taxa, this is a major constraint for pollen diagram interpretation and the reconstruction of palaeoenvironments (Dincauze 2000, Seppä and Bennett 2003). This is due to a mismatch existing between the number of pollen types represented in the pollen sequences and the plants within the sampling sites (Dincauze 2000, Seppä and Bennett 2003). Furthermore, uncertainties arise when a genus contains species with different requirements (Dincauze, 2000).

The outer appearance of pollen is unique for individual taxon therefore, although it may not be simple to an untrained eye, with experience one can identify the taxa (Hooghiemstra *et al.*, 2006). Due to the inability to distinguish between some species and genera, taxonomic smoothing occurs leading to difficulties concerning the interpretation of the plant species (Gaillard *et al.*, 2008). With more intricate inspection, generic level pollen identification can be achieved (Hooghiemstra *et al.*, 2006).

Although manual microscopy is the most commonly used method for pollen counting, the development of automated identification and counting technology is increasingly becoming popular due to its ability to carry out pollen counts more rapidly and more precisely, programs such as textural analysis advance pollen identification (Seppä and Bennett, 2003). Pollen grains are counted per sample and limited to a predetermined total. According to Dincauze (2000) in instances where rare pollen is not sought after, a total of 200-250 pollen grains can be counted. This is in agreement with Hill (1996) who found that Analysis of

Variance (ANOVA) statistical tests indicated that minimum counts of 250 grains per sample were sufficient for most studied plant communities in the Drakensberg. This was also the case at Lake Eteza where minimum counts rarely reached 250 grains but were still found to be statistically congruent (Neumann *et al.*, 2010). In their study of fire and grass/ tree relationships in savanna environments at KNP and PNL, Ekblom and Gillson (2010a) showed that minimum pollen counts of 350-500 grains sufficed, whilst Hill (1996) found that the Highland sourveld vegetation community of the Drakensberg required counts of at least 500 grains. Dincauze (2000) also states that in the pursuit of rare species that may be indicative of particular environmental conditions or anthropogenic effects, counts of up to 1000 grains or more should be aimed for. Hill (1996) suggests high counts (up to 1000 grains) for plant communities that are highly complex and diverse, such counts were found to be statistically significant for *Protea* savanna and *Leucosidea sericea* scrubland communities in the Drakensberg.

According to Seppä and Bennett (2003) and (Dincauze, 2000) a large array of sources can be consulted for reference material to aid pollen identification, these include pollen identification keys and guides developed from reference plant material derived from the vicinity of the sampling site and web-based pollen databases such as the African Pollen Database (APD, 2014).

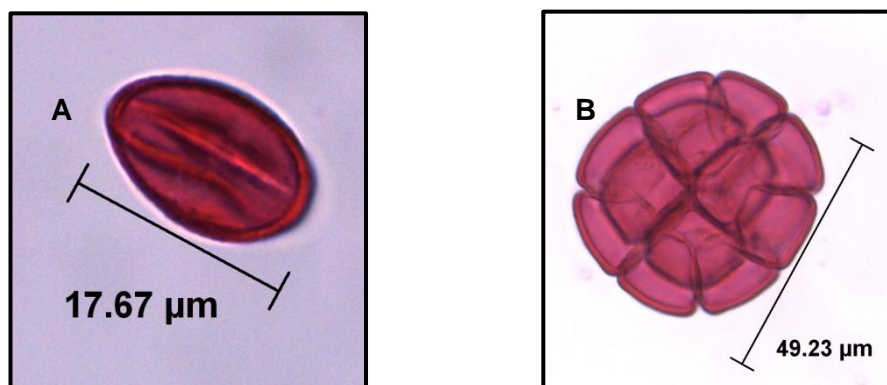


Plate 3.1 Pollen reference slides for *Capparaceae Cleome oxyphyllia* (A) and *Fabaceae Acacia nigrescens* (B).

3.3. Charcoal analysis

Fire is believed to have evolved from being a completely naturally occurring process primarily driven by climatic influences such as fuel moisture content, wind and the build-up of

biomass during the Late Devonian period, to a domesticated process progressively perpetuated by humans through anthropogenic practices between approximately 500 000 BP to 50 000 BP (Conedera *et al.*, 2009). As a result of anthropogenic forcing, fire has become an evolutionary force causing many ecosystems to become fire-adapted or fire-dependent (Conedera *et al.*, 2009). Moreover, unmanaged fire events threaten the integrity of plant communities often increasing the risk of extinction (Driscoll *et al.*, 2010). For this reason, long term human-fire-vegetation relations need to be understood so as to inform the management and preservation of contemporary ecosystems and biodiversity conservation (Conedera *et al.*, 2009). The effects of different types of burning regimes on vegetation also need to be analysed and integrated in the management plans of savanna and grassland ecosystems (Uys *et al.*, 2004).

Fire is essential for biodiversity maintenance and healthy ecosystem conditions (as it is potent). It is important that management practices are in equilibrium ensuring that fires do not fall outside of the fire requirement limits of a landscape. African savannas are both fire prone and fire dependent, fire is an integral component affecting the structure and composition of African savannas (Govender *et al.*, 2006). Planned burning practices are a typical feature in South Africa and aid in achieving a form of control over the fire dynamics of mainly grassland and savanna environments and the effective management of conservation areas (Duffin, 2008; Scott, 2002; Wooller *et al.*, 2000, van Wilgen, 2009). Fire-exclusion or treatment is described as a top-down control method meaning that it is a land-use that affects the landscape, it can be natural or human induced (Bond, 2008). Bond (2008) cites an example of the KNP which is one of the best examples of fire treatment in South Africa. He highlights that species diversity in savannas is more dependent on fire than any other resources, this is therefore a fire-driven ecosystem (Bond, 2008). The importance of herbivory activity is also highlighted with special reference to mega-herbivores such as elephants that have interfered with tree mortality and the structure of the biome - this is especially evident in KNP and MNP (Bond, 2008; O'Connor and Kiker, 2004).

Some insight into fire ecology is required to inform decision making and fire management in conservation areas, these include details regarding the fire regime viz., the frequency, intensity and seasonality of fires (Power *et al.*, 2010; Scott *et al.*, 2000; van Wilgen, 2009). Driscoll *et al.* (2010) notes that few of these fire attributes are considered in fire management because of a lack of knowledge regarding the specific response of species to fire. It is therefore important to incorporate palynological reconstructions for biodiversity conservation (Driscoll *et al.*, 2010). Conedera *et al.* (2009) describe three spheres from which fire regime data can be derived, namely, the geosphere in which geochemical data such as stable

isotopes can be derived and analysed to understand fire history, the biosphere for dendrochronological and charcoal data, and the anthroposphere for human evidence of fire activity using non-sedimentary approaches such as written records or archaeological evidence. For the purposes of this research, charcoal analysis data derived from the biosphere will be further elaborated and incorporated with non-sedimentary approaches for the most recent period of the MNP record.

Charcoal is a good indicator of fire ecology as fossil charcoal is well preserved. In some cases, plant composition can also be preserved and thus charcoal fragments can be identified and taxonomically classified (Scott, 2010). With increasing global temperatures fire activity is likely to increase in savanna environments as it did in the Holocene period (Driscoll *et al.*, 2010, Scott, 2002). Fossil charcoal and pollen can illustrate the fire history of a region and the development of the vegetation after impact. Fire therefore has an influence on the change in vegetation hence, the importance of not isolating the two proxy analyses - they complement each other in the unraveling of historical vegetation dynamics (Sugita *et al.*, 1999).

3.3.1. Key concepts

Charcoal fragments are mainly displaced by natural transportation, wind and water (Whitlock and Larsen, 2002). Primary charcoal fragments are deposited in the environment during a fire event. Secondary charcoal is often introduced into environments in times when there is no fire activity by surface run-off and other processes (Whitlock and Larsen, 2002). The final deposition and preservation of charcoal can occur over several years as secondary charcoal which is often subject to re-suspension and re-deposition (Conedera *et al.*, 2009).

Source area and dispersal of charcoal are dependent on the taphonomic effects and nature of an environment (Duffin *et al.*, 2008). According to Clark (1988) charcoal fragments of all size classes are suspended inside the turbulent flame zone, with time these fragments are slowly released from the flame zone and mixed within the atmosphere. Once mixed within the surrounding air, the particles are deposited onto nearby surfaces (Clark, 1988). This process is largely dependent on a number of factors such as the charcoal particle size, weight, fall speed, wind velocities, geomorphological features, combustion and the fire season, macroscopic fragments often descend rapidly whilst microscopic fragments remain in suspension (Clark, 1988, Conedera *et al.*, 2009).

The general consensus is that macroscopic charcoal particles represent local fires and microscopic particles represent a regional fire, because they are windborne and able to

travel further distances (Conedera *et al.*, 2009, Finsinger and Tinner, 2005, Laird and Campbell, 2000, Millsbaugh *et al.*, 2000, Peters and Higuera, 2007). The regional charcoal signal usually dominates the charcoal proportions in sediments, this is especially the case for lake sediments (Peters and Higuera, 2007). As with pollen analysis, basin size also has an effect on the reconstruction of a charcoal record, smaller basins (e.g. small lakes, peat deposits) are generally representative of local fires, whilst charcoal found in larger lakes represents more regional fires (Conedera *et al.*, 2009, Laird and Campbell, 2000, Pitkänen *et al.*, 2003).

Depending on the objectives of the study, a number of different attributes can be used to describe fire regimes including fire magnitude, frequency and intensity (Conedera *et al.*, 2009). Often details regarding both fire intensity and fire frequency are reviewed for the interpretation of fire records. Fire frequency is an estimation of the ratio of fire events against the age of the record, this is a good indicator of fire inducing climatic events and anthropogenic forcing (Conedera *et al.*, 2009). Although fire frequency can be determined by analysing charcoal records, more reliable results can be established by consulting non-sedimentary records such as remote sensing data and written records (Govender *et al.*, 2006). Fire intensity in African savannas affects tree recruitment and mortality, the informed and appropriate application of fire in these environments can encourage tree-grass coexistence and limit bush encroachment (of woody species) (Govender *et al.*, 2006).

Charcoal abundance is dependent on fire intensity, fire intensity which is determined by precipitation, humidity levels and the wind speed, is defined as the energy released per unit time (Duffin, 2008; Whitlock and Larsen, 2002). Fire intensity determines the abundance of charcoal in a fire record, the ratio of microscopic charcoal to macroscopic charcoal produced in an event and the subsequent distribution of these particles (Duffin, 2008; Whitlock and Larsen, 2002). The general assumption is that charcoal particle size is directly proportional to combustion efficiency and flame length (Clark, 1988). Low intensity fires produce many small particles because they have low combustion efficiencies and short flame lengths, therefore there is an influx in microscopic particles (Clark, 1988, Duffin *et al.*, 2008). The low lying smoke caused by the short flame lengths aids in the transportation of microscopic particles within local sites (Huttenen *et al.*, 1996). In contrast, larger macroscopic fragments are attributed to high intensity, long-flamed fires (Clark, 1988, Duffin *et al.*, 2008). Long flames have a vertical advantage and their smoke can transport macroscopic particles regionally for distances up to several kilometres at a time (Pitkänen *et al.*, 2003). An understanding of charcoal taphonomy is useful for the determination of the source area of

charcoal fragments and therefore aids in substantiating the reconstruction of past fire regimes by charcoal analysis (Duffin *et al.*, 2008).

Rainfall plays a key role in contributing to the amount of fuel biomass required to feed fires, this refers mainly to the grass cover (Duffin, 2008). It therefore indirectly influences the potential of fires viz. fire intensity and magnitude and therefore informs us why charcoal analysis can be used to inform past rainfall trends to a certain extent (Duffin, 2008). Fuel biomass can also be affected by herbivore density as grazers can significantly decrease grass biomass in savanna environments, often creating features referred to as “grazing lawns” in the landscapes - a reduction in fire frequency is thus common in such semi-arid savannas (Ekblom *et al.*, 2012).

3.3.2. Laboratory methods

Several methods are currently available for the preparation of sediments for charcoal analysis, each of which produce a different spatial and temporal resolution for charcoal. The most common methods are the pollen slide, thin sections, wet sieving and combustion-digestion methods (Finsinger and Tinner, 2005). Clark (1988) believes that sediment mixing poses a great challenge for the establishment of fire regime frequency. To minimise the unreliability of charcoal analysis, it is recommended that careful consideration is taken in the choices of sampling, analytical and interpretation techniques (Conedera *et al.*, 2009). Clark (1988) advises that continuous and high resolution samples of varved sediments be analysed in fire frequency studies. It is however noted that even the least bit of sediment mixing can distort the fire signal as strata representing high-charcoal years may be incorporated in other strata, depicting a false impression of the fire history (Clark, 1988). Clark (1988) and Conedera *et al.* (2009) agree that regional charcoal signals are not the most reliable indicators of fire characteristics (for example, fire frequency). They therefore recommend to look more into local fire reconstructions for more reliable results using the thin sections or sieving methods (Clark, 1988, Conedera *et al.*, 2009). These methods will be discussed in the context of microscopic and macroscopic charcoal size classes.

3.3.2.1. Microscopic charcoal processing

The most convenient way to analyse microscopic charcoal (<100 µm) provided it is conducted concurrently with pollen analysis is the pollen slide technique. This method is time effective because the processing of the charcoal and pollen is done together as they require the same kind of preparations (Weng, 2004; Whitlock and Larsen, 2002). The number of particles intersecting the grid line is counted and an estimate of the area of charcoal particles is made (Whitlock and Larsen, 2002). This is then shown as a percentage figure or a ratio of

the pollen that has been discovered in that sample (Whitlock and Larsen, 2002). Despite the convenience of conducting this method, much speculation arises with regard to the results that may be produced. Since the source area of microscopic charcoal is poorly defined due to its ability to travel over great distances, there can be some discrepancies regarding the spatial and temporal resolution of the fragments (Weng, 2005, Whitlock and Larsen, 2002). Pollen processing in itself is time consuming and requires each sample to be run through several processes (Appendix B) that can jeopardise the integrity of the charcoal fragments as they are exposed to fragmentation, leading to possibly erroneous estimates of the charcoal present within the sample (Clark, 1982, Weng, 2005, Whitlock and Larsen, 2002).

To calculate elemental carbon in a sample, sediments have to be run through a chemical digestion process, the Winkler (1985) chemical digestion method which is a modified version of Robinson's (1984) digestion-combustion technique is one such process in which organic carbon is extracted using nitric acid. The residual material is then ignited and combusted to determine the amount of charcoal each sample contains, this is expressed as a percentage value (Mooney and Tinner, 2011; Whitlock and Larsen, 2002). This method in comparison to the pollen slide technique can be beneficial in that it is more economical, less extensive and much less time consuming as it includes all the particle size ranges. There are however some shortcomings, although the experimental time is reduced because the samples sub-sizes are all inclusive in the process, the results tend to be biased towards indicating regional fires above local fires (Campbell and Campbell, 2000). This drawback has however been considered negligible as it is argued that the technique serves to determine the general charcoal abundance and content (Campbell and Campbell, 2000). The results produced using this method stand the risk of being unreliable in that the conditions that have led to the charcoal formation are not distinguishable, there is no discrepancy between charcoal formed by natural fires or the burning of fossil fuels and biomass (Patterson *et al.*, 1987, MacDonald *et al.*, 1991). Therefore a misrepresentation of the fire record may occur - this limitation can however be disregarded if a the burning regime of a site has been recorded and is known (Patterson *et al.*, 1987, MacDonald *et al.*, 1991).

3.3.2.2. Macroscopic charcoal processing

The petrographic thin sections technique is advantageous in that it can be used to reconstruct fire histories of any temporal scale, from annual to millennial, and any spatial context i.e. local or extra-local (Whitlock and Larsen 2002). Varved lake sediments are desiccated using acetone and then saturated in polyepoxide that hardens the sample, the sample is thereafter thin sectioned using a grid (Whitlock and Larsen, 2002). The area and number of macroscopic charcoal particles that exceed 50µm across the transverses are

determined (Whitlock and Larsen, 2002). The advantage of this method is its ability to depict the annual resolution of the record accurately, it is also a good technique for the analysis of local fire history (Conedera *et al.*, 2009, Whitlock and Larsen, 2002). The method is however more time consuming and less economically feasible than other methods (Conedera *et al.*, 2009, Whitlock and Larsen, 2002).

Image Processing is a quick method to quantify charcoal, this requires the use of specialized software, a scanner and a video camera (Mooney and Tinner, 2011, Whitlock and Larsen, 2002). The concept of optical density is used to identify the number of charcoal particles, interpretations such as the area that they cover and the size classes they fall within are made, allowing for statistical manipulations to be performed for example, calculating standard deviation (Mooney and Tinner, 2011; Whitlock and Larsen, 2002). This method is advantageous as it does not require the manual counting of each charcoal particle (Mooney and Tinner, 2011; Whitlock and Larsen, 2002). However, the image scanner cannot distinguish between charcoal and other similarly dark particles, often leading to an overrepresentation or an underrepresentation of the charcoal content and therefore rendering this method unreliable (Mooney and Tinner, 2011; Whitlock and Larsen, 2002).

The wet sieving method requires that one physically count charcoal particles falling within separate size classes. The sampling intervals can range from 1-4 cm, but these are dependent on the length and spatial resolution of the core, it would therefore have to be dated prior to commencement. The amount of sediment used as a sample can be between 1-5 cm³ (Whitlock and Larsen, 2002). The method requires each soil sample to be deflocculated - in a solution (for example sodium hexametaphosphate) - overnight and then washed through a set of sieves of mesh sizes 200 µm, 150 µm and 63 µm (Whitlock and Larsen, 2002). There are several ways to express the acquired data for example by using the number of charcoal grains per year or as charcoal concentrations (particles per cm³) (Whitlock and Larsen, 2002, Millspaugh *et al.*, 2000). Charcoal concentrations are further conveyed as charcoal accumulation whereby the charcoal concentration is divided by the determined deposition time (cm³ yr⁻¹) (Whitlock and Larsen, 2002, Millspaugh *et al.*, 2000).

Fragile particles are prone to fragmentation leading to an error in the volume of charcoal that has been represented when using this method. Furthermore, there may be difficulties in disaggregating particles of charcoal that have been combined together by superfluous material and visually appear to be a single unit - this however may be countered by using the bleaching agent hydrogen peroxide (H₂O₂) to differentiate between the two materials (Mooney and Tinner, 2011, Weng, 2005, Whitlock and Larsen, 2002). With this method,

charcoal particles are more easily and effectively identified; therefore, the results rendered can be considered more reliable in comparison to the other techniques (Rhodes, 1998, Whitlock and Larsen, 2002). It is also more cost effective and much simpler to perform (Rhodes, 1998, Whitlock and Larsen, 2002). The method does however lack standardization (Conedera *et al.*, 2009). Parameters such as minimum sieve mesh diameter are yet to be clearly defined (Conedera *et al.*, 2009).

3.3.3. Counting and identification

Charcoal particles are classified as microscopic (<100 µm) and macroscopic (>100 µm). These fragments can be recognized as black opaque objects that are angular in shape (Gil-Romera *et al.*, 2014, Mooney and Tinner, 2011, Whitlock and Larsen, 2002). They have a shine or lustre to them that differentiates them to other opaque particles in a sample, and they are easily fractured under slight pressure (Rhodes, 1998). There is no defined minimum counting sum for the pollen slide method (Finsinger and Tinner, 2005). For this reason the slide was counted until the minimum pollen count was reached or the slide was complete (Finsinger and Tinner, 2005).

3.4. Dating methods

3.4.1. Chronology

It is also imperative that sediments are meticulously dated and chronological control is established for a palaeoecological record. Spatial and temporal factors contribute to the establishment of a vegetation index (in-situ and ex-situ) (Bennett and Willis, 2002). One can compare sedimentary sequences from different locations to observe spatial variations in vegetation cover, provided their chronologies intersect at certain points (Bennet and Willis 2002). Pollen assemblages along the core profile illustrate changes in vegetation over time (Bennet and Willis 2002). The sediment samples for this study were dated by means of radiocarbon dating. Acquiring precision and accuracy in palaeoecology is desired but often compromised with the incorporation of different dating techniques (Chambers, 1993). The atomic mass spectrometry (AMS) dating method for organic materials has contributed to significant strides in improving the dating component of Quaternary science for a wide range of time-scales. Radiocarbon dating and pollen analysis allow for changes in plant communities to be tracked in time and space, one can comprehend the composition of past communities and trace their migration through different locations with time (Bradshaw and Webb III, 1985). It is also possible to track the timing of fire events (Bradshaw and Webb III, 1985).

3.4.2. Radiocarbon dating and age-depth modelling

Radiocarbon dating, first introduced by Willard Libby (1960) has been a pioneer in the development of palaeoenvironmental sciences (Ascough *et al.*, 2004, Dincauze, 2000). It is a technique focusing on the dynamics of elemental carbon in dead organisms to calculate precise and accurate ages of organic remnants (Dincauze, 2000). Three assumptions ensue: firstly; radioactive carbon ^{14}C (and stable isotopes ^{12}C and ^{13}C) is continuously produced in living organisms and is amongst the six most essential elements for life, secondly the production and distribution of ^{14}C is uniform and lastly, the intake of ^{14}C by organisms is in proportion with its occurrence in the atmosphere (Dincauze, 2000). The technique is thus based on the illustrated (Figure 3.2) principle that the decay of radioactive carbon ^{14}C with a half-life of about 5730 years is imminent with the death of an organism (Blaauw *et al.*, 2005, Dincauze, 2000). The inability for dead organisms to metabolize new carbon means that the radioactive carbon in the organism is limited and the remaining concentration of ^{14}C is therefore measurable, yielding a reliable estimate of the time span since the organism died (Dincauze, 2000).

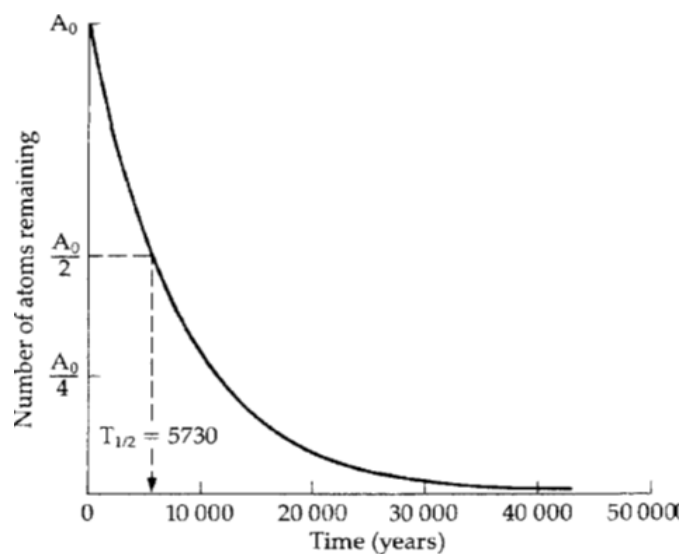


Figure 3.2. Exponential curve illustrating the radiocarbon decay of ^{14}C with time (adapted from Walker and Walker (2005)).

Beta-counting and accelerator mass spectrometry (AMS) are two methods used for the measurement of ^{14}C in organic sediments, the prior being the first method established by Libby (1960) and the latter being the more recent and preferred method in palaeosciences (Dincauze, 2000). The radiometric technique based on the counting of β particle emissions, is a conventional method limited amongst other factors by its inability to precisely date

sediments older than 30 000- 40 000 years (Dincauze, 2000). With AMS dating the radioactive atoms in a sample are isolated and counted (Dincauze, 2000). These measurements are mostly precise and accurate with the exception of inaccuracies encountered by random errors that may occur due to instabilities in the machinery (Dincauze, 2000). Accelerator Mass Spectrometry is however a more preferable method as it has an extended measurement range of approximately 70 000 BP and requires much smaller samples to yield accurate results (Dincauze, 2000, Chambers, 1993). This is of particular importance for studies where multiproxy data analyses are implemented, making it more efficient.

Dincauze (2000) points out the questionability of the assumptions in the radiocarbon dating method, noting that the radiocarbon production rate is subject to fluctuations as it is affected by geomagnetic secular variations in the Earth's magnetic field (Hughen *et al.*, 1998). This inadequacy has however been neutralized by the application of calibration curves adapted from dendrochronology (Dincauze, 2000, Yeloff *et al.*, 2006). The precision of dendrochronological measurements allows for the determination of the exact year and season representing a given time (Dincauze, 2000). This method is also considered to be more accurate than radiocarbon dating (Chambers, 1993, Dincauze, 2000). The 'reservoir effect' affecting the distribution of ^{14}C in the biosphere leads to distortions in the radiocarbon ages of marine organisms, especially in the southern hemisphere (Dincauze, 2000). This is however not of relevance to this study as plants are less affected due to their affinity towards ^{14}C (Dincauze, 2000).

Amongst other limitations with the radiocarbon dating technique requiring further study, are the uncertainties regarding the age of an event and that of the organism (Dincauze, 2000). It is argued that, if the calculated date denotes the time spanned since the organism died, this age may not necessarily translate to the date of a corresponding event. Additionally, the contamination of samples can present a source of error with the dating of organic materials giving rise to misleading ages (Dincauze, 2000, Yeloff *et al.*, 2006). This occurs when younger sediments are mixed with older sediments in the sediment profile or vice versa, owing to a number of factors including bioturbation, root intrusions and errors associated with the mishandling of the material in both the field and laboratory, this can however be minimized by adhering to standard procedures at both sites (Dincauze, 2000, Yeloff *et al.*, 2006). Lastly, due to the time factor and expense of radiocarbon dating, a few samples along the depth of the core are measured by the processes of radiocarbon dating and the ages of other samples are determined by interpolation (Bennett, 1994).

The interpolation technique was adopted for the construction of age models for the age-depth modelling of each core, a form of gradient analysis for pollen data (Birks, 2014). The purpose of age-depth models is to assign the calendar ages of sediments along the core profile, this is a commonly used approach in the palaeoecology field (Blaauw, 2010). Age-depth modeling essentially is the application of interpolation and regression techniques to assign estimated dates to undated samples along a soil profile using specialized software (Blaauw, 2010). There are a number of curve-types ranging from the simplest form which is the smooth age-depth model to the exponential, polynomial and straight forms (Blaauw, 2010). There are also softwares available for the construction of age-depth models, each varying in their capabilities. Precision and accuracy are the most important determining factors regarding software preferences.

Examples of plotting software for pollen data include Psimpoll 4.27, and CLAM 2.2 (Birks, 2014). Psimpoll 4.27 (Bennett, 2009) is graphic software using age-depth data to manipulate calibrated dates and produce a variety of age-depth curves. The main setback with Psimpoll is its incapacity to calibrate ^{14}C dates within the software, the requirement for prior calibration is the reason for the exclusion of this program for age-depth modeling process (Blaauw, 2010). Non-Bayesian classical age modelling software CLAM 2.2 which is integrated in open-source statistical software R 3.2.4 is found to be ideal for age-depth modelling as it serves several functions compared to its counterparts (Blaauw, 2010). CLAM calibrates ^{14}C dates using the standard calibration curve for SHCal13 (Southern Hemisphere) and INTCal13 (Northern Hemisphere), this variation owing to the differential atmospheric carbon in each hemisphere (Blaauw, 2010, McCormac *et al.*, 2004). The process of calibration allows for an estimate of the most probable dates representing the selected samples along the profile (Blaauw, 2010). The calibration of ^{14}C dates evades errors that could occur when analytical techniques such as interpolation are applied (Blaauw, 2010). CLAM goes further to produce text files that can aid in explaining the attributes of the created age-depth models (Blaauw, 2010), because of these advantages and because only a few dates were available (two dates per core), CLAM was used for the age-depth models for this study.

A number of numerical techniques can be applied to pollen analysis, including cross correlation analyses. Cross correlation analyses are a quantitative multi-proxy approach to integrate pollen and charcoal analysis in order to observe and interpret the long-term relationship between climate, fire, vegetation and humans (Conedera *et al.*, 2009). Cross correlation analyses were applied in this study to measure the similarity between pollen and charcoal data using IBM SPSS software (SPSS, 2011).

3.5. Data presentation

The stratigraphic layers of pollen and charcoal sequences are analysed to create diagrams illustrating the changes in the pollen and charcoal dynamics and in turn, fire regimes and vegetation and landscape changes over temporal scales ranging up to hundreds of thousands of years (Bunting 2008). Pollen grains are summed according to their identified taxon groups, this sum is then converted into a percentage of the total count for the specific sample (Dincauze, 2000). This percentage can then be further expressed as a total relative to distinguished ecological groups (Dincauze, 2000). As an alternative to the expression of pollen as percentages, absolute counts can be used by calculating the percentage of marker grains added and using this to estimate the frequency of pollen taxa in the subsample and therefore the pollen concentration (cm^3) (Dincauze, 2000). Charcoal fragments are summed according to their relevant size classes and plotted against the age-depth scale as charcoal concentrations ($\times 10 \text{ grains cm}^{-3}$) in Psimpoll 4.27 (Bennett, 2009).

The percentages of pollen taxa are also plotted against their relevant depths and radiocarbon ages in pollen diagrams created in Psimpoll 4.27 (Bennet, 2009), enabling the interpretation of the pollen and charcoal records and hence the palaeoreconstruction of the environment (Faegri and Iversen, 1964). Pollen assemblage zones where pollen composition is moderately uniform are created through the process of zonation using quantitative computer algorithms such as Constrained Incremental Sum of Squares (CONISS) (Grimm, 1987) in Psimpoll 4.27 (Bennett, 2009, Dincauze, 2000, Seppä and Bennett, 2003). Pollen zonation facilitates the comparative analysis of pollen diagrams illustrating regional and local spectra (Dincauze, 2000).

3.6. Data Interpretation

The interpretation of pollen assemblages to infer historical vegetation patterns is a challenging task (Van Zinderen Bakker, 1995). Given the challenges regarding pollen identification and representation highlighted above, several factors need to be considered to effectively interpret pollen assemblages. These include understanding the inter-species interactions and competition, and the extent of climatic control and human interference on vegetation dynamics (Dincauze, 2000). Several tools are used to interpret Quaternary pollen. The indicator species approach is applied to infer qualitative landscape characteristics and more specifically, to inform past land-uses due to the presence or absence of ecologically sensitive species (Gaillard *et al.*, 2008, Gaillard *et al.*, 1992, Dincauze, 2000). The main assumption of the indicator-species approach is that the ecological tolerances of species have not changed with time, and that competitive relationships and environments have remained constant (Dincauze, 2000, Birks and Birks,

1980, MacDonald, 1988). This involves the qualitative interpretation of pollen diagrams by specifically analysing species that are indicative particular environmental conditions (Table 3.1) for example, the identification of pollen representing of pastoral activity and cultivation (Gaillard *et al.*, 1992).

Table 3.1. List of environmental indicators according to selected pollen taxa representative of ecologically sensitive taxa of the savanna biome (adapted from Scott (1999) and (Scott and Nyakale, 2002)).

Pollen Type	Vegetation	Environment
Poaceae	Grassland/ Savanna	Often found in environments experiencing summer rainfall and regionally humid conditions.
Asteraceae	Shrubland	Found in moderately dry environments where summer rainfall is depressed and seasonal moisture distribution is experienced.
Cheno/Ams	Halophyte	Found in dry/saline conditions with strong evaporative conditions (possibly local evaporation). Also found in disturbed areas.
Combretaceae	Plain savanna	Found in areas with relatively warm temperature conditions and wide ranging moisture conditions.
Capparaceae	Kalahari thornveld savanna	Moderately dry conditions.
<i>Olea</i>	Mesic savanna	<i>Olea</i> can endure a wide variety of temperatures and sub-humid conditions.
Euphorbiaceae Fabaceae Anacardiaceae	Savanna	Generally found in areas where warm conditions where experienced and moisture conditions are moderately dry.
Cactaceae	Alien invasive	Indicates anthropogenic disturbance.

Distributions of typical savanna species such as Combretaceae, *Burkea*, Capparaceae and *Acacia* that are sensitive to changes in precipitation and temperature can be used as indicators of changes in these climatic parameters (Truc *et al.*, 2013, Scott and Nyakale, 2002). The distribution of *Aloe* and *Euclea* is dependent on precipitation but some species can be found in low temperature conditions and in dry habitats such as the Succulent Karoo and Namib Desert and, *Olea* distribution is largely controlled by precipitation, these species

do not thrive under drought stress (Truc *et al.*, 2013, Scott and Nyakale, 2002). This approach may be limiting because some pollen taxa may represent a number of different environmental conditions or land uses, and a genus can consist of species with different requirements (Gaillard *et al.*, 1992, Moore *et al.*, 1991). The indicator species approach also involves analysing the relative abundances of pollen taxa such that fluctuations in certain taxa can inform the intensity of the inferred land-use (Gaillard *et al.*, 1992).

The analog technique has been widely applied to vegetation and environmental reconstructions for pollen assemblages dating from the Last Glacial Maximum (LGM) (ca. 21 500 BP) and is a combination of the comparative and indicator-species approaches (Gaillard *et al.*, 2008, Gaillard *et al.*, 1992). This is a tool used to compare fossil pollen assemblages with modern pollen assemblages using numerical techniques such as multivariate distance metrics (Birks and Birks, 1980, Birks and Gordon, 1985, Birks *et al.*, 2010, Gaillard *et al.*, 2008, Faegri and Iversen, 1964). Analogy is based on the premise that if the fossil pollen and modern pollen assemblages share similar properties or match to a certain degree, then inferences regarding the vegetation and environment from which those assemblages were derived would also be alike (Gaillard *et al.*, 2008, Kruger, 2015). The technique is implemented by comparing the fossil pollen identified in the pollen assemblage to the composition of plant communities surrounding the coring site (for example, lake or wetland), the chosen spatial radius to which this comparison extends is a function of on the basin size and dispersal properties of the identified pollen (Gaillard *et al.*, 2008, Kruger, 2015).

Several errors can occur in the comparison of fossil and modern pollen assemblages; these include false positives whereby a particular fossil pollen assemblage is incorrectly correlated to a modern pollen assemblage, and false negatives where the inferred vegetation for a fossil pollen assemblage is in fact similar to the modern assemblage but was not recognised this way (Gaillard *et al.* 2008, Gaillard *et al.* 1992). Dincauze (2000) highlights that modern pollen assemblages complementing fossil pollen spectra are not always available, limiting analogous reasoning. Also, one cannot directly interpret pollen diagrams from vegetation or climate as uncertainties exist, however this is still regarded as a suitable approach for palaeoreconstructions and further research and amendments will allow for reliable inferences to be made (Dincauze, 2000, Gaillard *et al.*, 1992, Gaillard *et al.*, 2008). Charcoal analysis results can be compared to existing non-sedimentological data such as archaeological remnants, remote sensing data, dendrochronological data such as stable isotopes and fire scarring (Conedera *et al.*, 2009). Pollen data illustrating the state of plant communities informs fire dynamics as fire is an evolutionary agent, making pollen and charcoal analysis comparative techniques (Conedera *et al.*, 2009, Clark, 1988).

3.7. Conclusion

In this chapter, the theoretical underpinnings for each proxy technique were discussed. The different types of methods were explained and compared and the chosen method was justified. It can be seen that considerations such as time and cost efficiency need to be taken into account whilst choosing the best possible methods for analyses. A summary of radiocarbon dating and age-modeling techniques was provided and data presentation and interpretation methods were reviewed.

CHAPTER FOUR

STUDY AREA

4.1. Introduction

In this chapter a description of the study area will be provided. This includes a discussion of the geology, climate and vegetation ecology of the Mapungubwe National Park and surrounding areas, and Limpopo Valley region. Mapungubwe National Park possesses great biodiversity and cultural and archaeological significance. Although the main focus of this research is the use of pollen and charcoal proxies from two sites in Mapungubwe to determine the vegetation and fire history of the Limpopo Valley, the cultural landscape of Mapungubwe is a major component of the significance of the site. The human history of the site will be discussed in this chapter. This includes a summary of the rise and fall of the Mapungubwe society and theories regarding the factors believed to have influenced settlement patterns of different communities within the region.

4.2. Site description

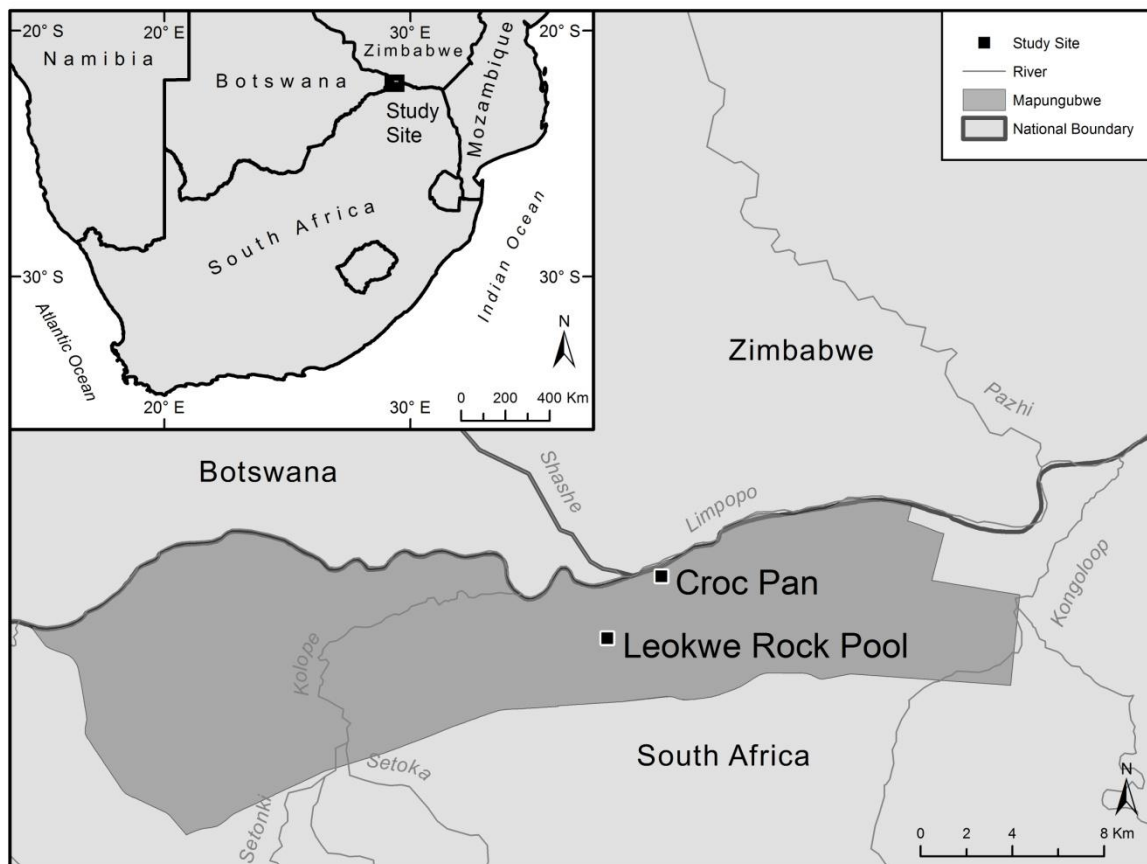


Figure 4.1 Map showing the location of Mapungubwe National Park in relation to the bordering countries of Botswana and Zimbabwe and the Shashe-Limpopo Rivers. Also indicated is the

location of specific study sites, Croc Pan and Leokwe Rock Pool within the Mapungubwe National Park, Limpopo.

The Limpopo Valley is located in the north of the Limpopo province along the Shashe and Limpopo rivers. Mapungubwe National Park (24°41'46.41"S and 27°59'29.87"E), previously known as Vhembe-Dongola National Park, is located within the lower Limpopo Valley of Limpopo Province (Figure 4.1), extending from Pontdrift (west) to Weipe (east) covering an area of 280 km² and including 22 farms. This is a cultural landscape that was declared a wildlife sanctuary in 1947 and inscribed a UNESCO World Heritage Site in 2003 (Götze *et al.*, 2008; Meyers 2000). The park is delineated by the borders of three countries within the Transfrontier region, expanding from the north of South Africa across to the international borders of the south of Zimbabwe and north eastern Botswana (Figure 4.1) (O'Connor, 2010). The site is surrounding the confluence that is the union of the Shashe and Limpopo rivers, and historic settlements are believed to have been established within this zone (Götze *et al.*, 2008, O'Connor, 2004, O'Connor, 2010).

4.2.1. Geology

The Limpopo belt that was formed by continental collisions in the Late Archaean period ("2.6- 2.7 Ga") is wedged between two provinces characterized by Archaean granite-greenstones (Kaapvaal and Zimbabwe Cratons) (Kamber *et al.*, 1995; Götze *et al.* 2003). The rock and sedimentary characteristics range from colluvium accumulations (from mass wasting) and sedimentary rocks on the plateaus of Limpopo National Park (PNL), to alluviums in the Kruger National Park (KNP) (Ekblom *et al.*, 2011, O'Connor and Kiker, 2004). Mapungubwe National Park (MNP) is geologically dominated by sandstone (80%), the other 20% is mainly comprised of shale, meta-quartzite and dolerite rocks (Ekblom *et al.*, 2011, O'Connor and Kiker, 2004).

Bangira and Manyevere (2009) describe the sediments of the Limpopo River Basin (Table 4.1) as highly variable and they state that their mineralogical properties, textures and levels of development are influenced by soil forming factors such as climate and parent material. Leached clay and sandy sediments characterise regions in the Limpopo basin receiving high levels of precipitation, and experiencing high temperature conditions, coarse sediments are generally found where the parent materials are granites, sandstones and gneisses (Bangira and Manyevere, 2009). The sediments within MNP are also variable, ranging from sandy loams (red-brown colour) to silty clays (dark brown) to sediments with high sand content, and lime rich sediments in large parts of the park (Götze *et al.*, 2003). O'Connor and Kiker (2004) estimated that MNP is comprised of about one-third of lithosolic sediments; this was

informed by the presence of calcrete and marble outcrops in the area. Another third of MNP is estimated to consist of fertile palaeofluvial and alluvial deposits found along riverine (Shashe and Limpopo rivers) and non-perennial systems on the Ia (Roman numeral) land type of MNP; these are comprised of deep (>3m) clay loam textured sediments (high clay and silt content) (Götze *et al.*, 2003, O'Connor and Kiker, 2004).

Table 4.1 The characteristics and locality of the main sediments types found in the Limpopo River Basin described according to Bangira and Manyevere (2009).

Soil type	Characteristics	Location
Luvisols	Sandy loam/fine clayey sediments	Bordering South Africa and Zimbabwe
Arenosols	Loamy sand/coarse sand (>70% sand)	NE Botswana and eastern Limpopo Basin (bordering Mozambique, South Africa and Zimbabwe)
Calcisols	Calcium carbonate accumulations	Botswana and South Africa
Vertisols	High clay content (30%), shrink/swell sediments	South Africa (15 % of Limpopo's sediments) and Zimbabwe
Fluvisols	High silt and fine sand content (prone to compaction), fertile sediments	South Africa (Along the Shashe and Limpopo river floodplains)

4.2.2. Climate

African climatic variability is determined by the influence of the Indian and Atlantic marine systems on continental systems and the Pacific El Niño Southern Oscillation (ENSO) (Jury, 2013). Drought conditions are generally associated with El Niño events. With the exception of the drought conditions experienced in the 1970s, the Pafuri rainfall record showed that an inverse correlation between El Niño and rainfall was evident for a large part of the 19th century (100 years), meaning that El Niño conditions correlated with higher rainfall (Woodborne *et al.*, 2015). Sea surface temperatures (SST) in southern Africa have been rapidly increasing by approximately 0.03°C since the 1960s compared to East Africa which has shown much more stability (Jury, 2013). Climatic controls [ENSO, zonal circulations and tropical weather systems (e.g. tropical cyclone)] therefore determine the annual climatic variability in southern Africa (Ekblom *et al.*, 2012, Malherbe *et al.*, 2012).

Warm moist air from the warm Agulhas current of the Indian Ocean is circulated by the tropical easterly winds during the summer season (Ekblom *et al.*, 2012, Jury, 2013). The cold and clear winter weather is brought about by the tropical westerlies from the cool Benguela current of South-Atlantic Ocean (Ekblom *et al.*, 2012, Jury, 2013). Easterly waves and tropical cloud bands have been deemed responsible for producing rainfall events in the summer seasons, these are often accompanied by thunderstorms (Reason *et al.*, 2005).

Rainfall variability in southern Africa is seasonal, annual and decadal (Jury, 2013; Reason *et al.*, 2005). The Limpopo Valley exhibits intra-seasonal rainfall variability (Jury 2013). The high variability is attributed to disturbances in the Inter-Tropical Convergence Zone (ITCZ) such as the variation of solar insolation and the shift of the Hadley cell (Ekblom *et al.*, 2012; Jury, 2013). The east of the Limpopo Valley receives an average of 430 mm of rainfall per year whilst the west receives approximately 329 mm per year, showing a decrease in rainfall from the east to the west of the valley (Plug, 2000). Convective summer rainfall (85% of the annual rainfall) peaks during the months of November and December afterwards, rainfall tends to be more stabilized in January and February followed by low winter rains (Ekblom *et al.*, 2012, Malherbe *et al.*, 2012, Reason and Rouault, 2005). The inconsistent nature of the rainfall in Limpopo Valley makes periodic bouts of drought a typical occurrence, for instance the Limpopo River remained stagnant between the winter seasons of 1991 to 1992 leading to considerable drought stress, and in 2000 several catchments were affected by major flood events (O'Connor and Kiker, 2004, O'Connor, 2010, Reason and Rouault, 2005).

The erratic rainfall and frequent droughts have made the Shashe-Limpopo basin no longer suitable for subsistence agriculture (Huffman, 1996). The basin situated in a rainfall trough receives 350-400 mm per year. Archaeological evidence of sorghum and millet cultivation which would be unfeasible today indicate that historical rainfall conditions fell above the threshold of 500 mm which is required for sorghum and millet cultivation (Huffman, 1996). The decreases in rainfall and the frequent occurrences of droughts are believed to have been problematic for agricultural productivity and therefore one of the possible reasons the Shashe-Limpopo basin was abandoned and the Mapugubwe society collapsed (Huffman, 1996).

Average temperatures in South Africa have been steadily increasing, temperature increments of $\sim 0.11^{\circ}\text{C}$ per decade existed from 1960 -1991 and thereafter, there have been slight increments of $\sim 0.09^{\circ}\text{C}$ for the following decade (Kruger and Shongwe, 2004, Tshiala *et al.*, 2011). The Musina region of Limpopo has shown a significant increase in temperatures in the past few decades, with the highest average increase of mean annual temperatures

across Limpopo being about 0.1°C per decade (Tshiala *et al.*, 2011). Temperature conditions in the Limpopo Valley region are typically higher even in the winter months, only reaching an average of 7.2°C (winter) to 20.3°C (summer) and 24.7°C (winter) to 32°C (spring/summer) in minimum and maximum temperatures respectively (O'Connor and Kiker, 2004, O'Connor, 2010).

4.2.3. Vegetation

The Savanna Biome covers nearly the complete Limpopo landscape, however there are some areas that are characteristic of the Grassland and Forest biomes (Figure 4.2) (Ekblom *et al.*, 2012, Götze *et al.*, 2008). About 65% of the sub-Saharan land surface is covered by the savanna vegetation type which is characterized by great structural variation, being dominated by trees and shrubs that vary in density and size, to nearly completely open grasslands with scattered trees (Hempson *et al.*, 2007).

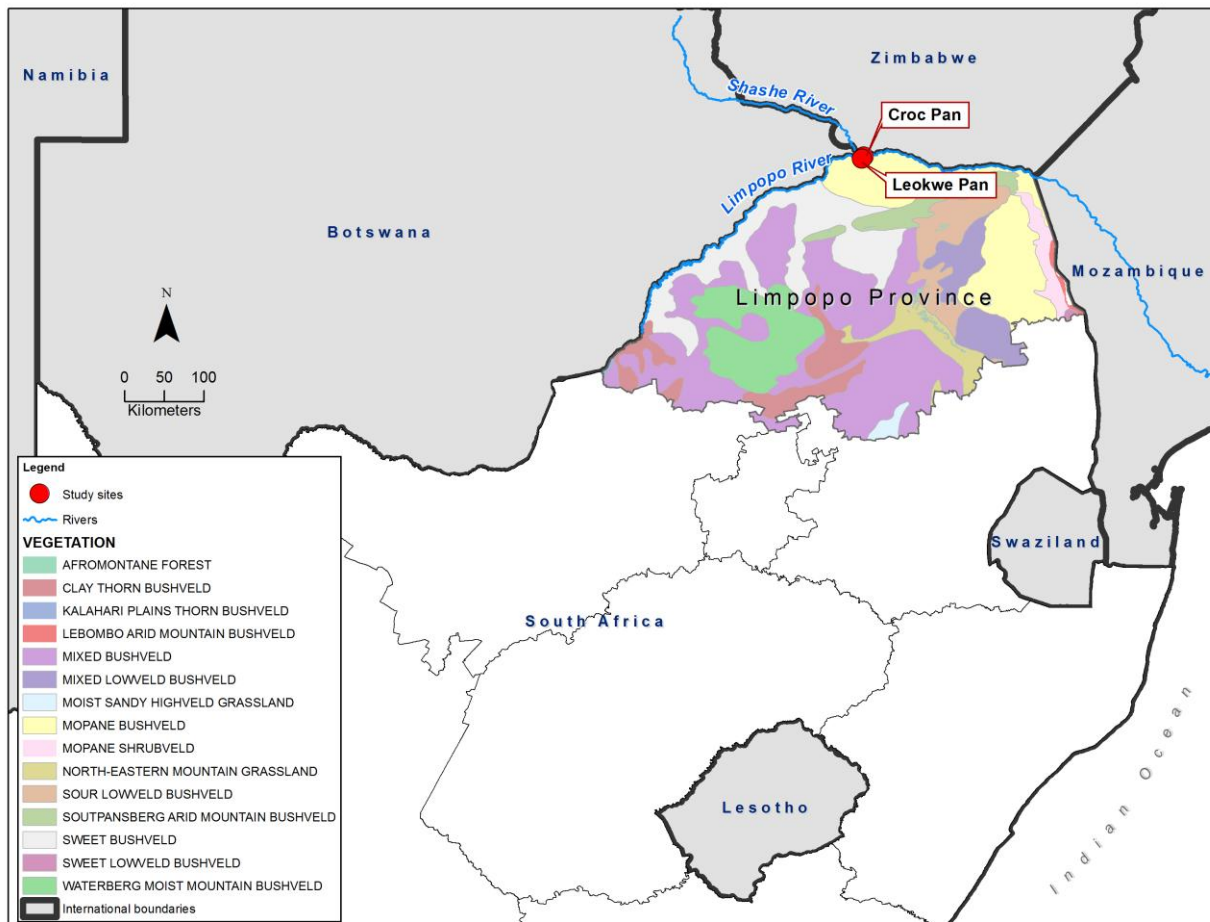


Figure 4.2 The vegetation type distribution across the Savanna Biome in the Limpopo Province, South Africa according to Acocks' (1988) classification. The study area is dominated by Mopane Bushveld and Sweet arid bushveld.

The savanna biome is a complex vegetation system therefore predicting future vegetation dynamics as a consequence of climatic change is problematic (Ekblom *et al.*, 2012). The complexity of this biome presents a dilemma within the context of ecosystem dynamics. High rainfall conditions are favourable as they facilitate a significant increase in biomass but, this increase in biomass results in a greater abundance of fire-prone grasses, potentially leading to more regular fire events and gradually limiting the maximum tree cover potential (tree cover potential is however also affected by herbivory interactions and soil nutrient status) (Ekblom *et al.*, 2012). Grass species in the Limpopo Valley have been the least affected by the shifts towards more arid climates and have shown signs of good adaptation for example, C₄ grasses which exhibit a positive response to drought stress - C₄ grasses are quick to recover from drought stress and to recolonize the affected site (Ekblom *et al.*, 2012). Gallery forests are common on strips of land along the rivers, these are slightly affected by changes in climate too (Ekblom *et al.*, 2012).

In a study of the Sandstone ridges of the National Park, Götze *et al.* (2008) identified 219 plant species, identifying this as the land type with the second highest biodiversity within the region. The vegetation types vary, ranging from bushveld, shrubveld, grassland and forest vegetation. There are three major vegetation units that are identified in the region, namely the riparian fringe occurring along the Limpopo River, the *Acacia salvadora* unit found in wetland areas and on the Limpopo River floodplains and, the mixed Mopane veld located along the edges of the river flood plains and the riparian fringe (Götze *et al.*, 2003). Mucina and Rutherford (2006) refer to this region as the Mopane bioregion as the savanna woodland is characterised mostly by Mopane Veld, dominated by *Colophospermum mopane* Bushveld (Figure 4.2, Plate 4.1) (Acocks, 1988, Makhado *et al.*, 2015). Mopane Veld which predominantly occupies hot and dry habitats, is well distributed across northern Limpopo Province into Botswana and Zimbabwe and in some parts of Namibia, Mozambique, Zimbabwe and Malawi (Makhado *et al.*, 2015).



Plate 4.1 Mapungubwe cultural landscape and Mapungubwe Hill (A) and *Colophospermum mopane* Bushveld (B), Mapungubwe National Park (Source: J. Lodder).

4.2.4. Human history

In this section, the name Mapungubwe Valley refers to both the Mapungubwe and the K2 settlements (Dongola Hill, Mapungubwe Hill (Plate 4.1) and other settlements included). Archaeological sites within the study area date back to the Early Stone Age (Götze *et al.*, 2008). Evidence of Iron Age settlements in Mapungubwe is considered to be the most significant in sub-Saharan Africa, this includes native artifacts such as gold, ivory, frankincense and rhinoceros horns (Götze *et al.*, 2008, Prinsloo *et al.*, 2005, Prinsloo *et al.*, 2011). Foreign artefacts include Chinese ceramic shards and glass beads found within the Iron Age relicts, indicating historical trade and barter as early as first century AD (Götze *et al.*, 2008, Prinsloo *et al.*, 2005, Prinsloo *et al.*, 2011). The occurrence of such remnants in different stratigraphic layers can provide significant information showing the implications of climate change on the movement of human communities at different time periods. Archaeological studies show the coexistence of livestock and wildlife in the era of human settlement in Mapungubwe could have impacted the vegetation dynamics of the site (O'Connor and Kiker, 2004).

Mapungubwe was first occupied by early Iron Age settlers who were Bantu-speaking farmers at roughly 350-450 AD, during this time the farming of sorghum and millets by Bantu farmers was popular as these flourished in the warm and wet conditions, specifically no less 15°C in night time temperatures and at least 500 mm in rainfall per year (Huffman, 2000, Huffman, 2008). This period of agricultural productivity was followed by the onset of drought conditions with decreasing rainfall and increasing temperature conditions. Evidence of 'rainmaking' pottery on 'rainmaking hills' used during periods of drought show that the region may have been occupied for some time until such a point of that the settlers abandoned the area in pursuit of better farming lands (Huffman, 2000). This led to an approximately 400 year absence of colonizers on the land (Huffman, 2000). Archaeological evidence indicates an absence of settlers between 600 and 900 AD due to the cooler, drier conditions being unfavourable for cultivation (Huffman, 2000, Huffman, 2008).

The Zhizo period began at roughly 900 AD when farming conditions became more promising and flood events of the Limpopo River were more prominent. The Zhizo communities inhabited the area, however these settlers were distributed along the peripheries of agricultural hotspots (e.g. floodplains) (Huffman, 2008). It is therefore believed that farming potential of the lands did not motivate the settlement of the Zhizo communities and, instead it

was trade opportunities that allured settlers. Archaeological evidence of ivory trade, metal artefacts and glass beads (possibly from Chinese traders) is prominent for this period, there is also evidence that some of these were redistributed, suggesting that they may have been traded with neighboring farmers for grain as farming was not common due to climatic circumstances (Huffman, 2008).

The K2 settlement south-west of Mapungubwe Hill (Plate 4.1) was occupied from 1000-1200 AD and, rainfall conditions are believed to have been improving (Huffman, 2000, Huffman, 2008). At this time, Mapungubwe Hill (Plate 4.1) was starting to become a strong economic and political contender within the Limpopo Valley (Götze *et al.*, 2008, O'Connor and Kiker, 2004). According Huffman (2000) the records of higher rainfall and warmer temperatures at this time show that the cultivation sorghum was supported as the minimum requirement of 500 mm rainfall per year was realized.

Major droughts ensued when settlers began to migrate closer to Mapungubwe Hill leading to inhabitable conditions (Huffman, 2000, 2008). Evidence suggests that Mapungubwe was then only occupied for roughly 70 years (1220 to 1300 AD) prior to its abandonment (Huffman, 2008, Götze *et al.*, 2008, O'Connor and Kiker, 2004). The main consensus is that the impact of the Little Ice Age (LIA) was the main driver of population migration from Mapungubwe as there were severe decreases in temperatures and rainfall at the time (Huffman, 2000, 2008). Changes in climate had caused hostile living and farming conditions, and populations migrated to Zimbabwe and neighbouring Venda communities. The abandonment of this region is believed to have led to the rise of the Great Zimbabwe, the nation that inherited the successes of the Mapungubwe Empire (Huffman, 2008). Icon pottery evidence shows that after the abandonment of MNP, the area was occupied by Sotho-Tswana speakers (Huffman and Woodborne, 2015). The periods of AD 1430-1450 and AD 1560-1575 were high rainfall periods, at this time Shona and Sotho-Tswana speakers interacted and eventually settled in the area and the Venda language was formed (Huffman and Woodborne, 2015).

Between the 17th and 19th centuries it is believed that there were no agricultural settlements in MNP, possibly due to the LIA bringing conditions that were unsuitable for subsistence farming (Huffman and Woodborne, 2015). By the 19th century the Limpopo Valley was occupied again by the Venda, Birwa and Sotho-Tswana people (Huffman and Woodborne, 2015). Archaeological evidence shows that hunter gatherer communities gradually adopted new behaviors as they transitioned into colonial farmer-herder societies following the Mapungubwe era (Chirikure *et al.*, 2016). Evidence from Thamaga Hill in Botswana shows

the introduction of farming tools such as potsherds and metal axes and the absence of traditional flaked stone tools suggesting the adaptation on colonialist farming techniques, further evidence of livestock bones suggested that these were farmer-herder settlers (Chirikure *et al.*, 2016). Archaeological evidence and accounts from historical documents by colonialists and missionaries suggests that the San and Tswana populations were invaded and enslaved as labourers of the colonial settlers (Chirikure *et al.*, 2016). Evidence from rock shelters on the Makgabeng Plateau near MNP and across South Africa points to similar invasions of homelands by European trekkers in the 19th century, and the marginalisation and ultimate dependency of these communities on the farmer-herder settlers with the introduction of fences (Chirikure *et al.*, 2016). It is also noted that wild-game numbers were greatly depleted during this period due to exploitation by colonialists (Chirikure *et al.*, 2016).

The most recent historical evidence shows land-use change in the region. In addition to disturbances from agricultural activities, cattle and game farming such as over-grazing and cultivation (Götze *et al.*, 2003). Recent history shows that the occupation of the area by the South African National Defence Force in the 1980s also had a large influence on the degradation of the site, this is especially evident around old camp sites. Also evident are quarries and dumpsites from mining activity in the area (Götze *et al.*, 2003). Tourism has also had significant impacts on the state of the environment due to land-use change (for e.g. building of infrastructure, increased population density and pressure on the ecosystem) (SANP 2013).

4.2.5. Croc Pan and Leokwe Rock Pool

The Croc Pan site (Figure 4.1, Plate 4.2) located at S22°11'44.7" and E29°23'10.0" is within close proximity to the Limpopo River and is a non-perennial water body estimated to measure at approximately 415 m² in area. Vegetation in the immediate vicinity of the study site included grass species *Panicum maximum*, *Pogonarthia squarossa*, *Urochloa mozambicensis* and *Cynadon dactylon*. Woody species visible at the site included *Vachellia xanthophloea*, *Vachellia tortilis*, *Combretum apiculatum*, *Salvadora australis* and *Philenoptera violacea*. There was also evidence of sedges at the site. An important observation was the absence of water during the spring season of 2015. The dryness observed during this period contradicted the conditions witnessed when the cores were extracted in the winter season of 2013 (Plate 4.3: A, B).

Cracked and compacted surfaces (Plate 4.2: A) showed signs of swelling and shrinkage with water availability, implying that the sediments comprised of a significant amount of clay. The

dry pan allowed for the bioturbation on the site to be visible, indicating possible negative implications for the chronology and preservation of the pollen and charcoal records.

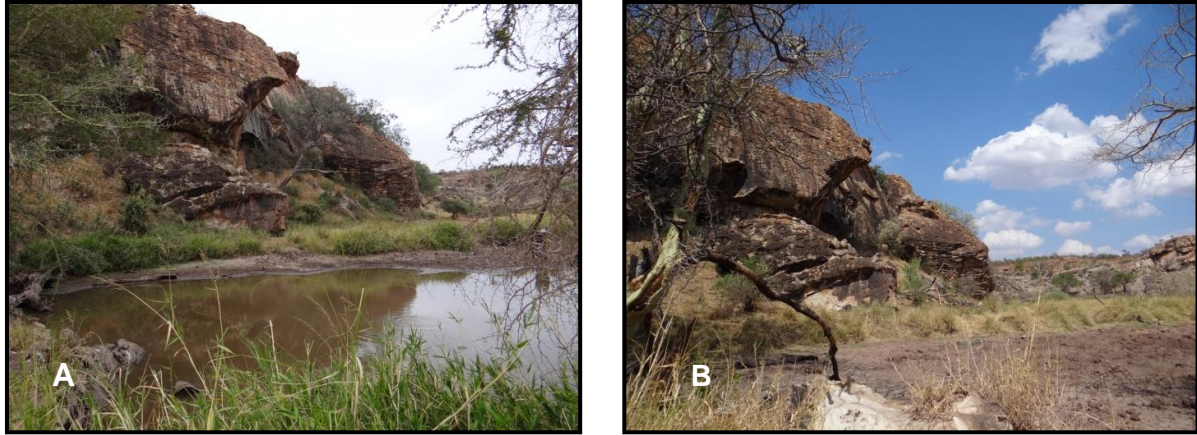


Plate 4.2 Conditions at Croc Pan during the late-winter and summer months of 2013 and 2015. The photograph on the left (A) shows CP immersed in water during the late-winter season of 2013, there is also a great abundance of green vegetation. The photograph on the right (B) hand represents the summer season of 2015 side shows CP completely dry with evidence of compaction, cracks, herbivory disturbance and dry vegetation.

Leokwe Rock Pool (Figure 4.1, Plate 4.3) located S22°13'12.0"; E29°21'53.8" believed to be spring fed, contained water during both site visits (2013, 2015) (Plate 4.4: A, B). The isolated and enclosed site is estimated to have a perimeter of approximately 54.4 m and an area of about 110 m². There were no immediate signs of bioturbation on the sandy site. The vegetation present within and surrounding the study site included grasses, sedges, ferns, *Croton megalobotrys* and *Philenoptera violacea*.

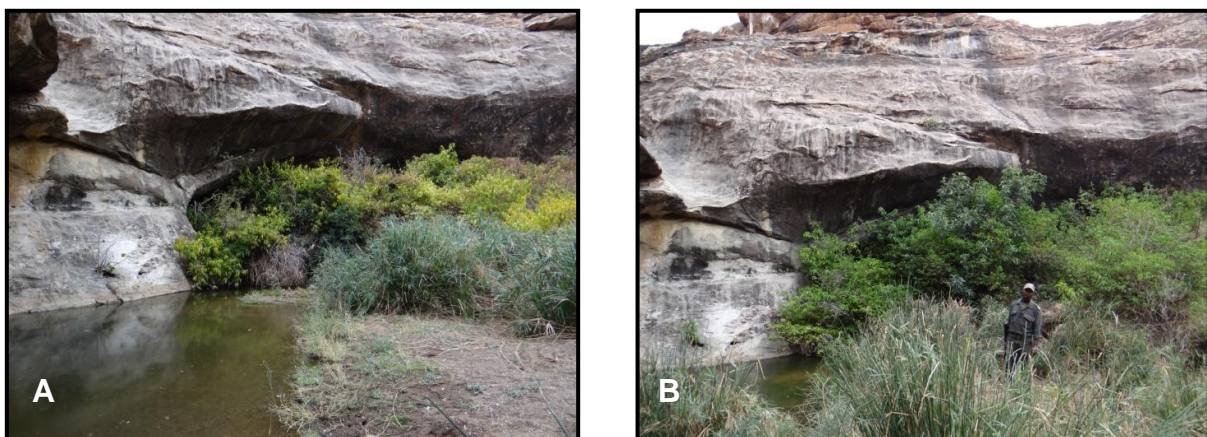


Plate 4.3 Side by side photographs illustrating the conditions at Leokwe Rock Pool during the late-winter (A) and summer months (B) in 2013 and 2015 respectively. A comparison of the site in 2013 and 2015 indicates that the pool is a perennial system, showing water during the winter and summer seasons. In 2013 we see slight evidence of compaction at the site and less vegetation than in summer 2015.

4.3. Conclusion

In this chapter an overview of the Mapungubwe cultural landscape has been provided and the climatic influences on the movement and settlement of communities have been discussed. Contemporary temperature and rainfall characteristics have been discussed for the southern Hemisphere, South Africa and the Limpopo Valley. These have shown that overall temperatures are rapidly increasing for the past few decades and that rainfall is highly variable throughout the country. A brief description of the vegetation, geological and soil characteristics has also been provided. The core extraction sites (Croc Pan and Leokwe Rock Pool) were described in terms of their conditions and surrounding vegetation, photographs were used to conduct a side by side comparison of each study site during the late-winter and summer months.

CHAPTER FIVE

METHODS

5.1. Introduction

This chapter provides an explanation of how the field and laboratory methods were executed for the research conducted. A description of the site selection and core extraction procedure will be given. A 96 cm long core (MAP-CP13-1B) and a 57 cm core (MAP-CP13-1A) were collected from Croc Pan (S22°11'44.7"; E29°23'10.0"). Trial pollen processing tests in the laboratory determined that the MAP-CP13-1A core was more suitable because it was slightly more organic.

Three cores were extracted from Leokwe Rock Pool (S22°13'12.0"; E 29°21'53.8"); MAP-LRP13-3C was not chosen on account of it being too short at 36 cm. The second core (MAP-LRP-1C) that was 83 cm long was also not chosen on account of sediment type. MAP-LRP-4A (48cm) contained more organic material and was used for analyses. Cores extracted from Mapungubwe Stream wetland were not used on account of being too short (>30 cm). Several other sites were explored and found to be unsuitable for coring.

A detailed account of how laboratory techniques were carried out is given for both charcoal and pollen analysis. This description includes details regarding the Troels-Smith analysis process, the sub-sampling and sample preparation procedures, counting and identification techniques and the use of analytical tools.

5.2. Field methodology

Extendable fiberglass rods were used to probe and identify the deepest soils at Croc Pan and Leokwe Rock Pool, the deepest points were chosen as the most suitable sites (Plate 5.1: A). A Russian peat corer was manually inserted into the sediment to recover the cores at each site (Plate 5.1: B) by a process is known as side-filling where the equipment is rotated in an anti-clockwise direction, enclosing the sediment sample within the chamber of the apparatus (Faegri and Iversen, 1964). The cores were collected in overlapping segments from parallel boreholes to achieve maximum depth/length cores and, the corer was cleaned between each extraction. Labelled PVC piping was used to carefully recover the samples from the corer, (Plate 5.1: C) and the cores were then wrapped in foil and plastic sheeting for protection, labelled again and stored in a cooler box and transported to the laboratory for refrigeration.

Flowering plants were collected as pollen reference slide material; 10 plant species were identified and these were later processed in the laboratory (Appendix C).



Plate 5.1 Extendible fiberglass ranging rod used to determine the deepest soils for coring (A); Coring of Croc Pan using the Russian corer (B); Transferring the core sample into PVC piping in preparation for storage (C) (Source: J. Finch).

5.3. Laboratory methodology

5.3.1. Troels-Smith analysis

A stratigraphic description of the cores was conducted in the laboratory using the Troels-Smith (1955) classification technique. The cores were differentiated according to zones where changes in the texture or composition of the sediments were visible. Each zone was then analysed by observation and touch to determine their physical features, texture and composition.

5.3.2. Sub-sampling

Standard sub-sampling procedures were used to extract the sub-samples from the CP and LRP cores. Using a sterilized scalpel the surfaces of the cores were carefully cleaned by

removing the top layer of the cores in a horizontal motion in order to minimise contaminated material, the scalpel was cleaned after each subsequent scraping (Faegri and Iverson 1989). Due to the short length of the cores, a narrow sampling interval of 1 cm resolution was chosen for both cores. Consequently, 56 samples and 48 samples were collected for Croc Pan (MAP-CP13-1A) and Leokwe Rock Pool (MAP-LRP-4A), respectively.

5.3.3. Chronology

The CP and LRP cores were sub-sampled for Accelerator Mass Spectrometry (AMS) radiocarbon dating. Two 2 g sub-samples were taken for each of the cores, at depths of 25 and 45 cm for CP and at 22 and 43 cm for LRP - these depths were selected on the basis of stratigraphy. Rootlets were removed and the samples were dried in an oven overnight at 80°C. The dry samples were placed in a desiccator to cool down, weighed, packaged and sent to Beta Analytic Inc. (Miami, Florida) for AMS radiocarbon dating.

Age models for the CP and LRP cores were established using Classical Age Modelling (CLAM) software integrated in the statistical environment of R open-source. The Southern Hemisphere radiocarbon calibration curve SHCal13 was used to calibrate the radiocarbon ages of the cores and age-depth models were established.

5.3.4. Pollen analysis

For the purposes of this study the “Hot, strong HF (Hydrofluoric acid) treatment” was used (Faegri and Iverson 1989):

LacCore microsphere pollen spike solution was placed on a magnetic stirrer for an hour prior to use, ensuring that microspheres were in suspension. A graduated syringe was used to add 1 ml of pollen spike to each sample for CP and LRP. Humic acids and clay minerals were removed by 15% NaOH digestion, each sample was then washed through a 180 µm sieve with distilled water. Each sample was treated with 10% HCl and subsequently digested with 40% HF in a water bath for 3 hours, ensuring the removal of clastic material. Each sample was then heated with 10% HCl and then centrifuged to remove colloidal material such as silicates. Acetolysis digestion using a 9 parts acetic anhydride ((CH₃CO)₂O) and 1 part sulphuric acid (H₂SO₄) mixture was used to remove the organic detritus. The samples were neutralized with several rinses of distilled water and tinted red with two drops of safranin stain to distinguish pollen grains from other macrofossils. Tertiary Butyl Alcohol (TBA) was added to the samples, which were then transferred into 30 ml storage vials and refrigerated.

Aquatex gel was used to mount each sample on pollen slides and coverslips were carefully lowered over the samples. It is imperative to lower the coverslip slowly as too much pressure caused by the slip can cause larger pollen grains to be misrepresented as the smaller grains are pushed towards the edges causing them to be easily overlooked (Faegri and Iversen, 1989). Pollen reference material collected from the study sites was treated similarly to fossil pollen with the exclusion of the HF treatment. To avoid repetition, the processing procedure for pollen reference material is detailed in the appendix section of the thesis (Appendix C). Pollen reference slides were created to aid in the identification of pollen grains.

Pollen counting and identification was achieved using a Leica DM750 microscope at 400X and 1000X magnification by traversing along the pollen slide in a consistent manner. To prevent overrepresentation, pollen grains clumped in groups were counted as one and pollen grains that were damaged or not completely visible were deemed unidentified and disregarded (Faegri and Iverson, 1989). A minimum count of 500 pollen grains was conducted and full slides were completed for the samples. A minimum count of 50 microspheres (pollen spike) was conducted. The total number of pollen grains per sample from the MAP-CP13-1A and MAP-LRP13-4A cores was calculated according to the following formula (Stockmarr, 1971):

$$\text{Total pollen grains in sample} = \frac{\text{pollen grains counted} \times \text{microspheres added to sample}}{\text{no. of microspheres counted}}$$

In addition to the reference slides compiled using plant specimens from the study site, other sources assisting pollen and fungal spore identification were used. Reference collections located in the African Environmental Change Lab (UKZN, Pietermaritzburg) for Cathedral Peak, Mfabeni and East Africa, and digital sources such as the African Pollen Database (APD, 2013) and European Pollen Database (EPD, 2013) were used.

Pollen grains were taxonomically classified according to the family from which they were derived and then lumped together into two sums, total pollen and main pollen. Total pollen included all pollen sums, whilst main pollen excluded aquatics and non-pollen palynomorphs. Additional subdivisions within each of these sums were conducted, based on these ecological groupings informed by Ekblom and Gillson (2010a): Savanna, Generalist, Herbs, Riparian, Aquatics and Grasses.

5.3.5. Microscopic charcoal: pollen slide technique

Microscopic charcoal, pollen counts and identifications were conducted concurrently using the pollen slide method and the same traversing technique on the Leica DM750 microscope. The fragments were identified as black, opaque and angular particles, counted until the minimum pollen count of 500 grains was reached or full slides were complete and allocated into one of three size classes: <25 µm, 25-75 µm and 75-100 µm.

5.3.6. Macroscopic charcoal: wet sieving technique

The wet sieving method was used to process macroscopic charcoal (Mooney and Tinner, 2011, Whitlock and Larsen, 2002):

The samples were deflocculated with 10 cm³ sodium hexametaphosphate (NaPO₃)₆ for a period of 24 hours. Using analytical sieve mesh sizes of 200 µm, 125 µm and 63 µm, three samples for each depth were determined. It must be noted that the 63 µm grains fell within the microscopic charcoal range. The sieved samples were then volumetrically split into eighths using a wet splitter. This process required that the wet splitter be filled with 2.5 litres of water. Each sample was then added to the water and allowed to settle. Once settled, the excess water was drained through a tube into the sink. The samples were then emptied into labelled plastic vials and all eight aliquots of sample were counted.

Macroscopic charcoal counts were conducted using a gridded petri dish and Kyowa dissecting microscope at 40x magnification. The gridded petri dish was divided into quadrants, colour-coded and numbered along the axes to ensure consistency when counting along the traverses. The charcoal fragments were identified as black, opaque and angular particles (Clark, 1988, Valsecchi *et al.*, 2013).

5.4. Data presentation and analysis

AMS radiocarbon ages were calibrated using the Southern Hemisphere calibration curve (SHCal13), and Classical Age Modeling (CLAM) software integrated in statistical software open-source R was used to create age depth models for analysis and interpretation. Raw pollen and charcoal counts were imported into Microsoft Excel 2010 (Microsoft, 2010) spreadsheets where the data was prepared for entry into the Psimpoll 4.27 software.

Psimpoll was used to create pollen (total and main) and charcoal (macroscopic and microscopic) diagrams, illustrating the relationships of proxy datasets against the AMS radiocarbon ages and along the depth of the cores for Croc Pan and Leokwe Rock Pool. Pollen zonation was conducted for the main pollen datasets of each core (CP and LRP)

using the Constrained Incremental Sum of Squares method (CONISS) (Grimm, 1987) in Psimpoll 4.27 (Bennett, 2005). This was run on regional pollen data and applied to total pollen and charcoal diagrams for interpretive purposes. The same zone files created in Psimpoll were then applied to the total pollen and charcoal datasets to facilitate the interpretation of the datasets according to common zones. Dendrograms were excluded from the total pollen and charcoal diagrams of each site. Cross correlation tests showing the strength and nature of the relationships between pollen types and charcoal were conducted in IBM SPSS software (SPSS, 2011) using the bivariate Pearson's correlation, and summary diagrams indicating pollen and charcoal trends over the periods from 1700 through 1900 to present were plotted in Grapher. Palaeoenvironmental reconstructions for the pollen data were conducted according to the indicator species approach, assessing the relationship between species climatic and environmental variables to interpret and infer trends in the fossil pollen and charcoal record.

5.5. Conclusion

This chapter has provided an explanation of the applied field and laboratory techniques, outlining the site selection and coring procedures used and the Troels-Smith and sub-sampling processes. The sample preparation procedures for both pollen (HF treatment) and macroscopic charcoal (wet sieving) were described and counting and identification techniques were discussed. A summary of the data presentation and analysis techniques, which included the creation of pollen and charcoal diagrams, age-depth models, cross correlation analyses and summary diagrams using different softwares was provided.

CHAPTER SIX

RESULTS

6.1. Introduction

Proxy data collected from the charcoal and pollen analyses is displayed and explained in this chapter. The sediment composition of each core is described according to Troels-Smith analysis for each zone of difference. This will then be followed by a description of the pollen analysis results for both the Croc Pan and Leokwe Rock Pool sites; these will be displayed for two separate datasets, main pollen and total pollen. Charcoal diagrams are used to display both the macroscopic and the microscopic charcoal counts at each site and will be briefly reviewed according to the charcoal zonation. Data from cross-correlation tests are described in this chapter.

6.2. Troels-Smith stratigraphy and chronology

The Troels-Smith (1955) stratigraphic classification scheme was used to separate the Croc Pan (CP) (Figure 6.1) and Leokwe Rock Pool (LRP) (Figure 6.2) cores into stratigraphic units. Both sediments were largely homogenous with a low organic content, making it difficult to infer past climatic changes based on the sediment characteristics. In the CP core, silt (*Argilla granosa*) was identified as a major component of the CP core occurring in the top two units of the core, there was evidence of red mottling in this unit which was present in low amounts along the length of the core (Figure 6.1). High levels of clay (*Argilla steatodes*) dominated the depths of 10-42 cm, where silt was a less significant occurrence. The base of the CP core (42-48 cm) had a high clay content mixed with sand (*Grana minor*). The texture within this unit was grittier than that of previous units. Due to the young age of the sediments, it is likely that they reflect local moisture conditions rather than past climatic conditions. They may also be a result of other soil forming factors such as parent rock and vegetation. The high levels of clay within these sediments suggests that the sediments are anaerobic and waterlogged with a low presence of oxygen – such conditions are typical for gleyed sediments; this could explain the slight mottling seen in each stratigraphic unit. This may be caused by periods when the ground water table was raised.

The Leokwe Rock Pool (LRP) core was dominated by sand particles. These were in abundance through all three identified stratigraphic units, and other sediment components included clay and silt particles (Figure 6.2). The zone from 0-28 cm was composed predominantly of sand with some clay, and some moss was noted on the surface of the LRP core. From 28-48 cm, the LRP core contained sand, silt and clay, with sand being the main

component. At the base of the core (48-57 cm), sand was dominant however silt and clay were present albeit in low amounts, plant macrofossils were also present. The high sand content may suggest that the inherent parent material is sandstone. The sediments may also be aerated meaning that there is a free movement of air within the sediments and a high infiltration rate therefore soil binding agents are more easily leached down the soil profile. It is also a possibility that the sandy sediments may also result from soil displacement and accumulation since this is a perennial water body and the area is closed off.

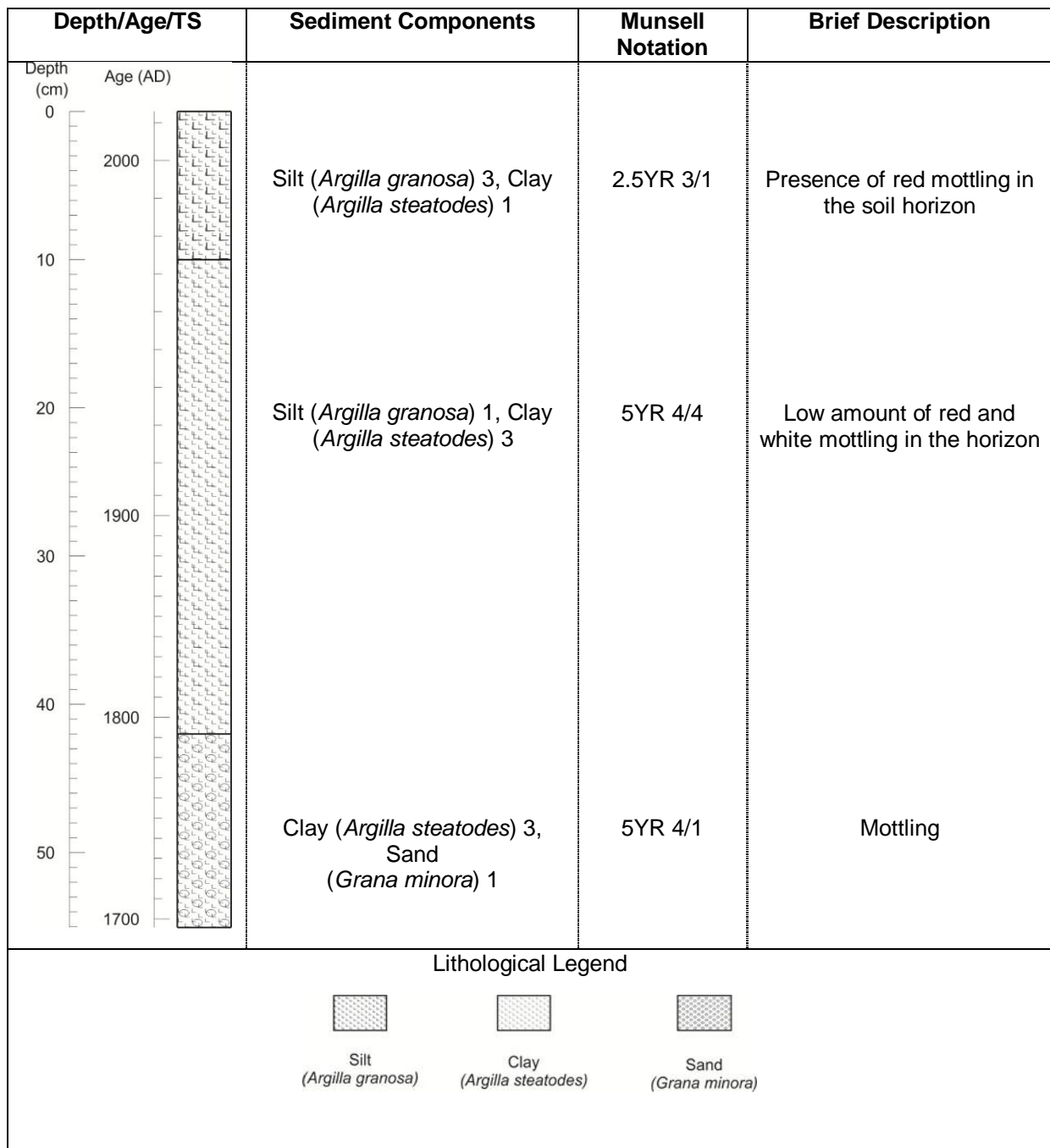


Figure 6.1. Sediment description for each distinctive stratum along the depth of Croc Pan (MAP-CP13-1A) core using Troels-Smith analysis (Kershaw, 1997).

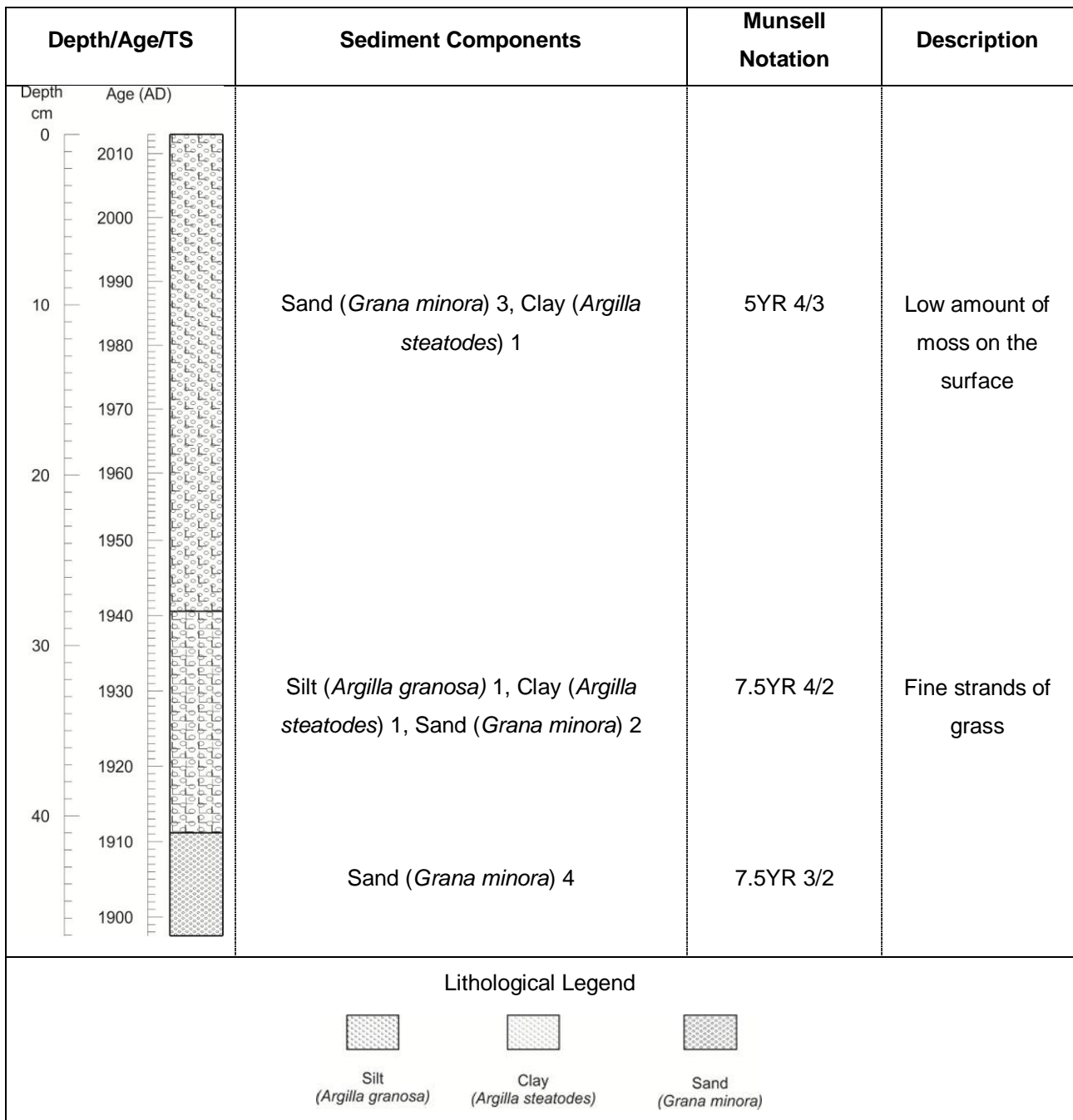


Figure 6.2. Sediment description for each distinctive stratum along the Leokwe Rock Pool (MAP-LRP13-4A) core using Troels-Smith analysis (Kershaw, 1997).

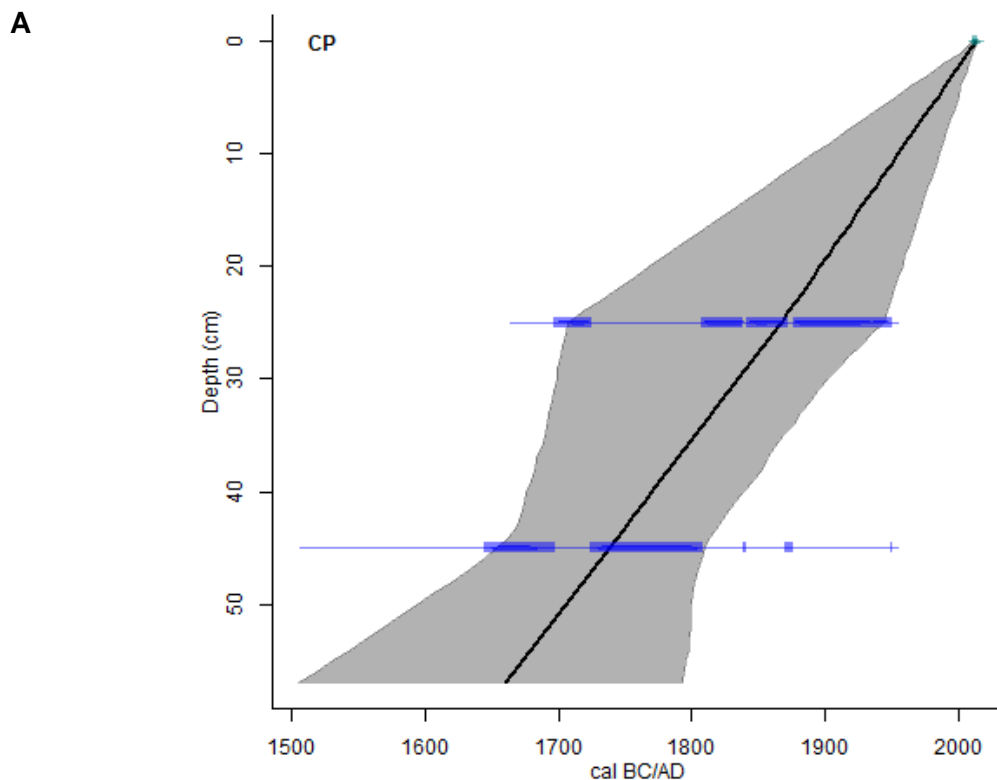
6.3. Chronology and age-depth models

Radiocarbon dates (Table 6.1) are illustrated in the form of age-depth models for the CP (Fig 6.3) and LRP (Fig 6.4) study sites. The ¹⁴C AMS dating method was used to determine the age of two samples at the depths of 25 and 45 cm for the CP core and for two samples at 22 and 43 cm for the LRP core. Basal ages were within the ranges of ca. 1724-1808 cal. AD and ca. 1877-1934 cal. AD for CP and LRP respectively. The 25 cm age for the CP core ranged from ca.1876-1950 cal. AD and, the LRP core yielded a modern result of 100±0.4

pMc at 22 cm, this sample was calibrated to 1951-1955 cal. AD. The remaining ages along the cores were determined by interpolation with the assumption that the sedimentation rate was constant (Appendix F).

Table 6.1 Uncalibrated and calibrated radiocarbon ages for Croc Pan and Leokwe Rock Pool.

Site	Lab Code	Depth (cm)	Dating Method	¹⁴ C Age	error	Calibration Data	Cal. yr. AD
Croc Pan	CP13-1A-25	25	AMS	110	30	SHCal13	1876-1950 (46.2%)
Croc Pan	CP13-1A-45	45	AMS	230	30	SHCal13	1724-1808 (66.9%)
Leokwe Rock Pool	LRP13-4A-22	22	AMS	100.6	±0.4 pMC	PostbombSH	1951-1955 (91.6%)
Leokwe Rock Pool	LRP13-4A-43	43	AMS	80	30	SHCal13	1877-1934 (47.9%)



B

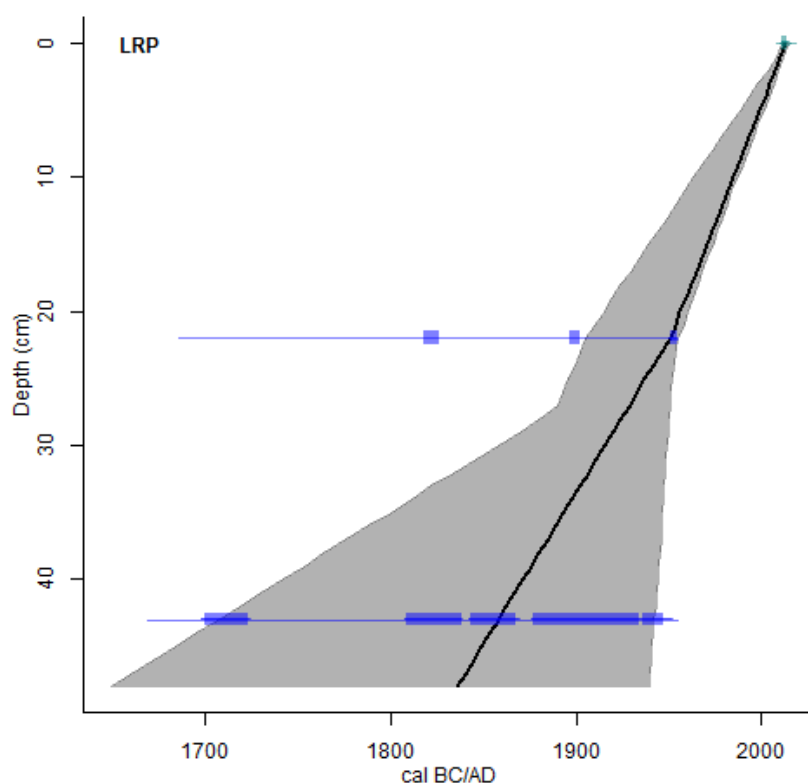


Figure 6.3. Age Depth Models for Croc Pan (A) and Leokwe Rock Pool (B) using CLAM software and integrated R. ¹⁴C dates were calibrated using the standard calibration curve SHCal13 and PostbombSH (Blaauw, 2010).

The linear interpolation curve was used to plot the age-models, this was found to be the most fitting curve to portray the data points for both the CP and LRP cores as only two dates were available per core. Supplementary age-models were created using cubic-spline and polynomial regression curve-fitting styles (Appendix H). The interpolated ages were stratigraphically consistent, showing no age reversals. According to the age-depth model, the line of 'best fit' indicates that at the depths of 25 cm and 45 cm, the samples date at approximately 1730 cal. AD and 1870 cal. AD for CP (Fig 6.3). LRP appeared to be indicating the approximate years 1865 cal. AD at 42.5cm and 1949 cal. AD at 21.5 cm (Fig 6.4).

6.4. Zonation

The Constrained Incremental Sum of Squares (CONISS) (Grimm, 1987) method was run on regional pollen data in Psimpoll 4.27 (Bennett, 2009) to complete zonation for the identification of zones of homogeneity along the depths of the CP and LRP cores and aiding in the description of pollen and charcoal data. Individual dendrograms were created for the

main pollen diagrams of CP and LRP, illustrating the hierarchical clusters characterising the relationships within each dataset (Fig 6.4). The identified zones determined from the cluster analyses were C-1 to C-4 for CP and L-1 to L-4 for LRP, C-1 and L-1 encompassing the base of the cores. Zones were applied to the local pollen and charcoal diagrams for CP and LRP.

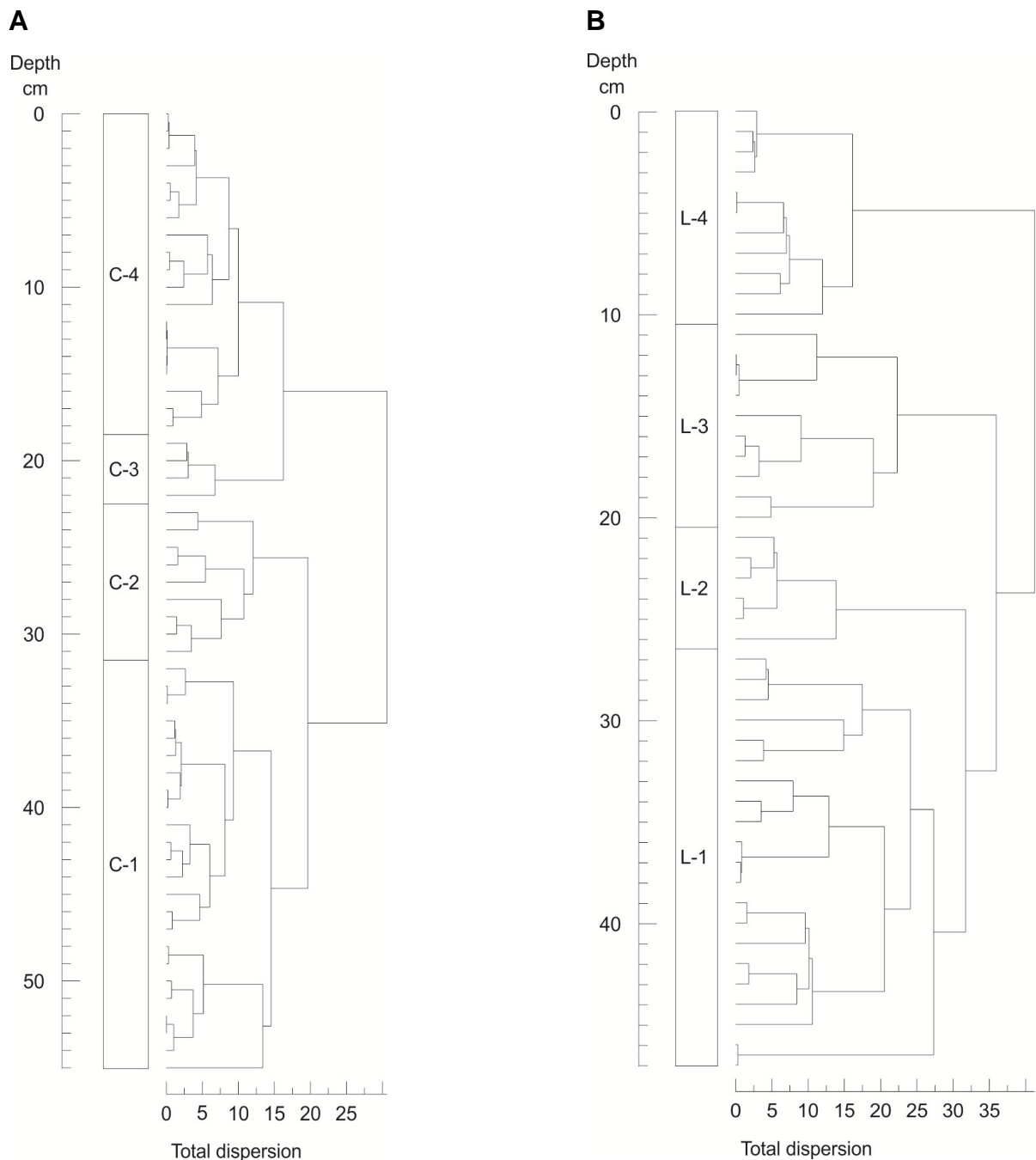


Figure 6.4. Zonation diagrams performed by stratigraphically constrained cluster analysis (CONISS) (Grimm, 1987) in Psimpoll 4.27 (Bennett, 2009) for Croc Pan (C-1:C-4) (A) and Leokwe Rock Pool (L-1:L-4) (B) according to total dispersion.

6.5. Pollen and charcoal analysis

Pollen diagrams depicting the regional and total pollen sums have been constructed. The total pollen sum diagrams (Fig 6.6, 6.8) were used to describe and make inferences on the local and aquatic taxa datasets for each study site; all other pollen was described by the main pollen sum diagrams (Fig 6.5, 6.7) for the respective sites. The pollen was divided into

Table 6.2 Classification of taxa according to ecological groupings.

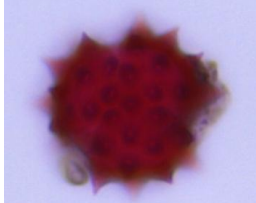
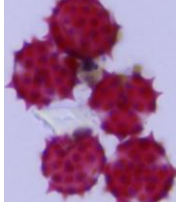
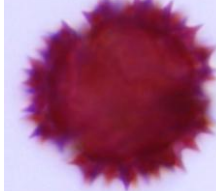
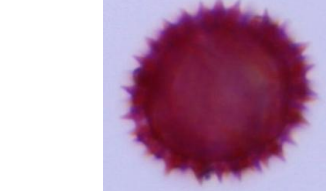
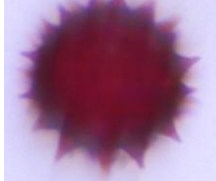


Ecological Grouping	Subgrouping	Pollen Type
Arboreal Pollen (AP)	Riparian	Boraginaceae <i>Cordia</i> Oleaceae <i>Olea</i> Moraceae undiff.
Arboreal Pollen (AP)	Savanna	Anacardiaceae undiff. Bombacaceae <i>Adansonia</i> Burseraceae undiff. Fabaceae undiff. Kirkiaceae <i>Kirkia</i> Tiliaceae <i>Grewia</i>
Arboreal Pollen (AP)	Generalist	Capparaceae undiff. Combretaceae undiff. Ebenaceae undiff. Ebenaceae <i>Euclea</i>
Ungrouped		Asphodelaceae undiff. Cactaceae undiff.
Herbs		Acanthaceae undiff. Amaranthaceae undiff. Apocynaceae undiff. Asteraceae undiff. Cucurbitaceae undiff. Convolvulaceae undiff. Euphorbiaceae undiff. Hyacinthaceae undiff. Lamiaceae undiff. Liliaceae undiff. Malvaceae undiff. Rubiaceae undiff. Solanaceae undiff. Zygophyllaceae <i>Tribulus</i>
Grasses		Poaceae undiff.
Aquatics		Cyperaceae
Spores		Pteridophyta Monoletes* Pteridophyta Triletes*

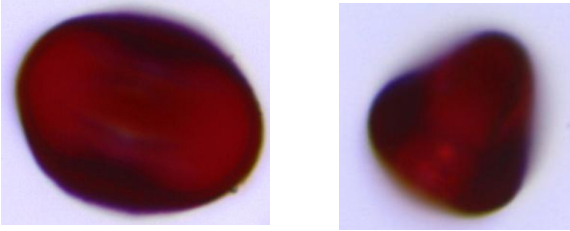
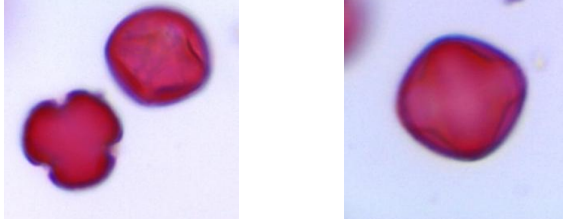
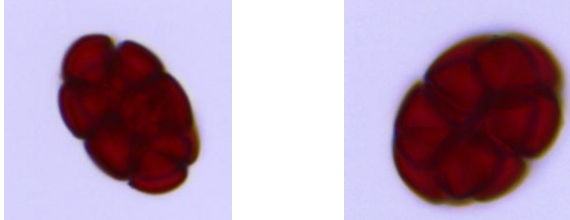
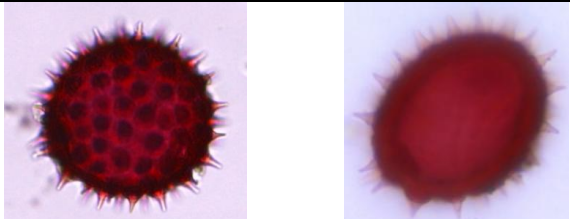
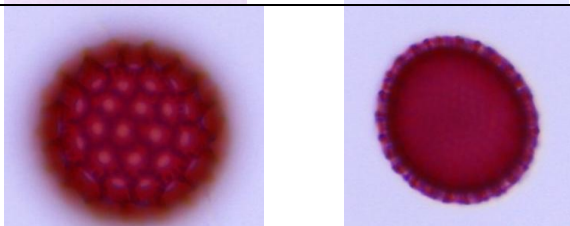
*A laesura is defined as the "The arm of a proximal fissura or scar of a spore" (Punt *et al.*, 2007, p. 38). Monolete* spores are characterised by one laesura whilst triletes* have three laesurae (Erdtman, 1986, Punt *et al.*, 2007).

ecological groups following Ekblom and Gillson's (2010) pollen groupings: arboreal pollen (AP) which was further subdivided into riparian, savanna and generalist; herbs, grasses,

aquatics, spores and ungrouped pollen species for those that did not fit into the chosen ecological groupings (Table 6.2). A total of 31 pollen taxa were identified across the two sites. Pollen preservation of major palynomorphs (for example, Fabaceae, Acanthaceae, and Combretaceae) was good throughout the two cores. The overall pollen preservation was higher for CP than LRP (Appendix L). Ten flowering plants were collected, identified and processed as pollen reference material (Table 6.3). This list is limited due to the low number of plants flowering at the time of collection and the available photographs.

Table 6.3 Species list and images of pollen reference material collected.

Asteraceae <i>Helichrysum spiralepis</i>		
Asteraceae <i>Lytogyne gariepa</i>		
Asteraceae <i>Vernonia fastigata</i>		
Asteraceae <i>Felicia mossemedenis</i>		
Acanthaceae <i>Blepharis subvolebilis</i>		

Acanthaceae <i>Justica flora</i>	
Capparaceae <i>Cleome oxyphyllia</i>	
Fabaceae <i>Acacia nigrescens</i>	
Malvaceae <i>Abutilon angulatum</i>	
Zygophyllaceae <i>Tribulus</i>	

6.5.1. Croc Pan Pollen

The pollen diagram indicates that the CP regional pollen signal is dominated by savanna and generalist arboreal taxa for the entire record (Fig 6.5.). Fabaceae undiff. is in high amounts throughout the CP core, peaking within zone C-1. The prominent herb taxa within this and all other zones of the core is Acanthaceae undiff.

6.5.1.1. Zone C-1: 55-32 cm; ca. 1696-1865 cal. AD

Fabaceae undiff. occurs at the highest frequency in zone C-1 and dominates the savanna type pollen representation within this zone peaking at approximately 30% (ca. 1830 cal. AD). Anacardiaceae undiff. is evident within the zone peaking in ca. 1785 cal. AD at ~10%. Burseraceae undiff. and *Grewia* account for between 1-2% of pollen. Capparaceae undiff.

and Combretaceae are the highest occurring generalist taxa. The Capparaceae undiff. pollen frequency peaks at ca. 1730 cal. AD (~60%) and occurs steadily through the zone ranging between ~30-40%. The most significant changes in the frequency of Combretaceae are the peak (>10%) at ca. 1760 followed by the gradual decline between ca. 1780-1820 cal. AD (<5%) and then another peak at 1835 cal. AD (ca. 7%).

There is a relatively high percentage of Acanthaceae undiff. in zone C-1 of the CP core, with the largest peak of approximately 20% occurring at ca. 1800 cal. AD. The occurrence of the herb taxon is reduced between ca. 1820-1830 cal. AD and towards the upper portion of the zone. Amaranthaceae undiff., Asteraceae undiff. and Euphorbiaceae undiff. are all mostly occurring, peaking at ~10% (ca. 1870 cal. AD), ~7% (ca. 1800 cal. AD) and ~7% (ca. 1800 cal. AD) respectively. Malvaceae undiff., Rubiaceae undiff. and Solanaceae undiff. are sparsely distributed (<5%) and the remaining taxa are almost absent. Hyacinthaceae (1-2%) is rare in this zone. The ungrouped taxa Asphodelaceae and Cactaceae undiff. are both rarely occurring within this zone. The riparian taxon Moraceae accounts for less than 2% of the pollen.

Local pollen taxa (Fig 6.6.) such as Cyperaceae and Poaceae undiff. have high frequencies, with Cyperaceae having a peak of ~42% at the base of the zone and another peak of ~40% at ca. 1800 cal. AD. Poaceae undiff. peaks at 15% (ca. 1820 cal. AD). The distribution of spores is fairly consistent through the zone with monolete spores being the most dominant (ranging from ~1-6%).

6.5.1.2. Zone C-2: 32-23 cm; ca. 1865-1923 cal. AD

The regional pollen signal of zone C-2 in CP witnesses the emergence of *Adansonia* and *Kirkia* in the sequence (Fig 6.5.). *Adansonia* emerges at ca. 1900 cal. AD, peaking at ~5% (ca. 1910 cal. AD) and, *Kirkia* is introduced into the sequence after ca. 1880 cal. AD, peaking at ~6% and thereafter rapidly declining, only to reappear at around ca. 1920 cal. AD. Anacardiaceae undiff. and Fabaceae undiff. peaking at ~10% (ca. 1900 cal. AD) and ~15% (base of zone C-2) respectively, remain the dominant savanna taxa in the sequence, however there is a general decline in the concentration of Fabaceae undiff. from the base towards the top of the zone. Combretaceae increases steadily from ~2% at the base of the zone to ~5%

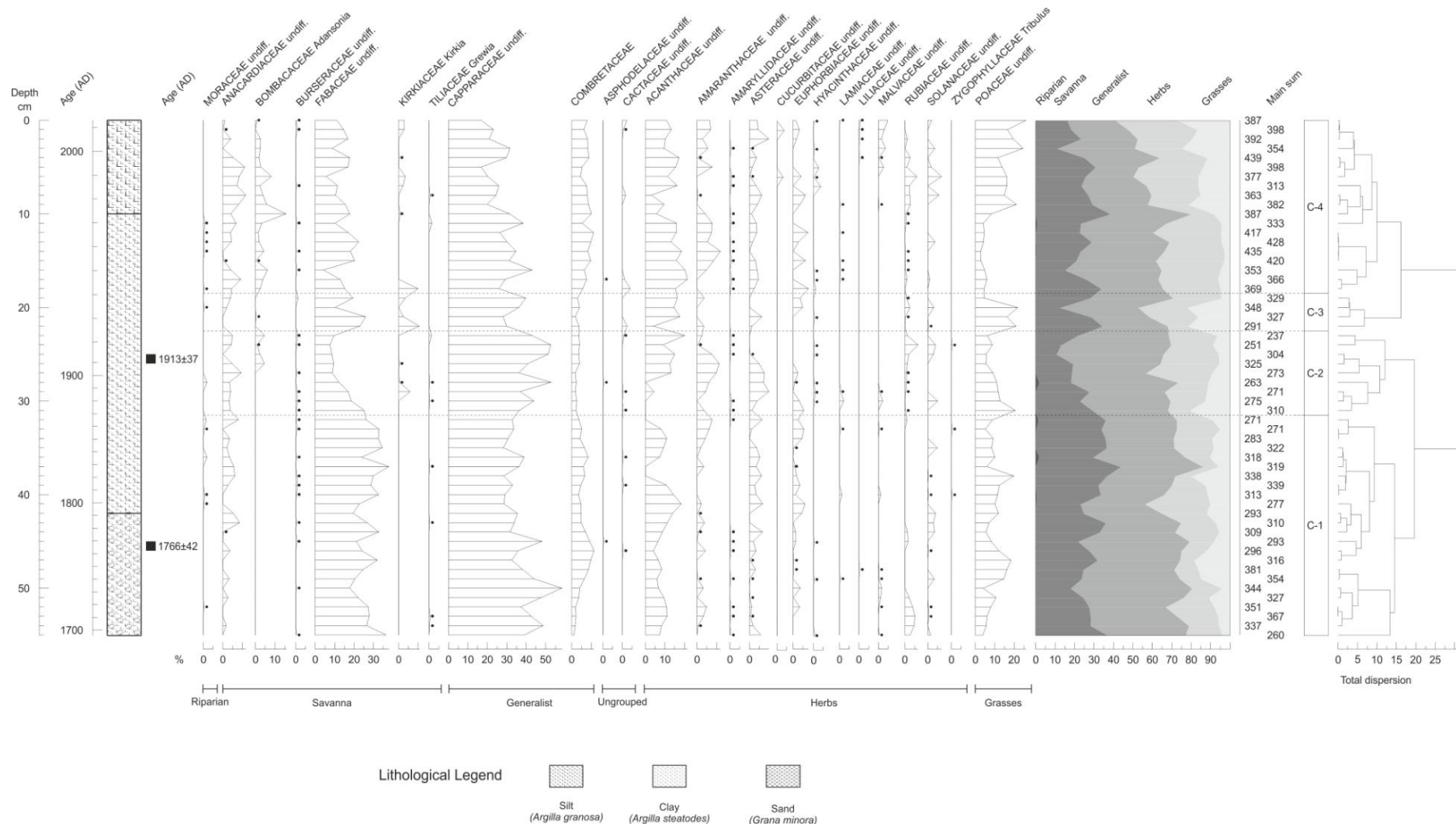


Figure 6.5. Main pollen diagram plotted against the Troels-Smith stratigraphy, age-depth scale (AD-cm) and calibrated ¹⁴C ages (AD) for Croc Pan. Included in the diagram are the sums for each depth and pollen sums for each sub-group. The CONISS (Grimm, 1987) derived dendrogram indicates the order of splits within and between the zones of the CP core.

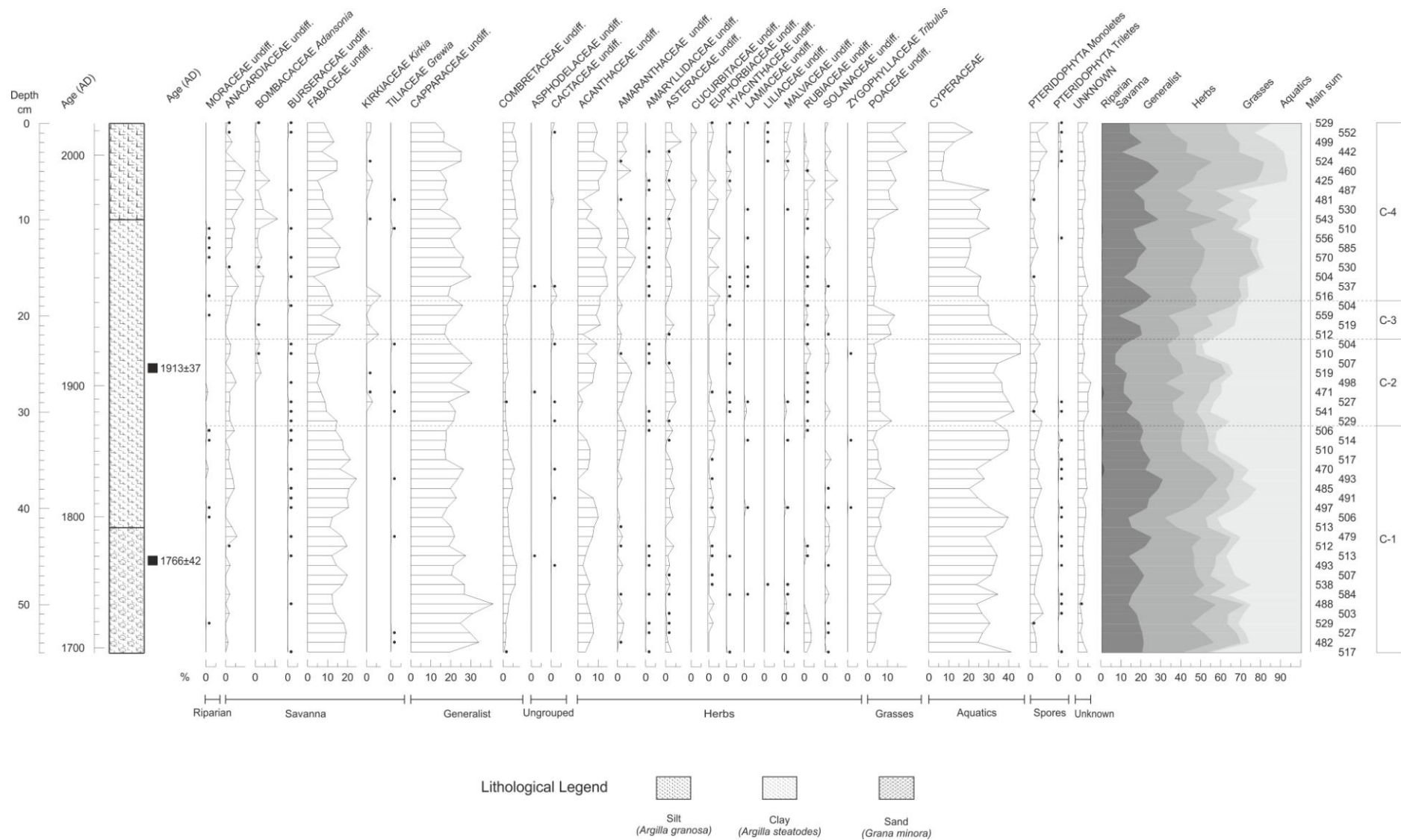


Figure 6.6. Total pollen diagram displaying for Croc Pan against the associated age-depth scale (AD-cm), ¹⁴C ages (AD), Troels-Smith stratigraphy and units determined by the zonation based on the main pollen data for CP. The sums for each sample are indicated next to the pollen sums table, including aquatics.

at the top of the zone. Capparaceae undiff. continues to occur at high frequencies, ranging from ~35-55% with a high peak occurring between ca. 1915-1920 cal. AD.

The presence of Hyacinthaceae undiff. (>2%) is more prominent within zone C-2 than in zone C-1 whilst Cucurbitaceae undiff. remains absent from the sequence. The beginning of the zone is devoid of Acanthaceae undiff., however it is introduced after ca. 1880 cal. AD (~6%) and increases to a peak of ~20% (ca. 1920 cal. AD). Amaranthaceae undiff. (~10% at ca. 1900 cal. AD) and Asteraceae undiff. (~10% at ca. 1887 cal. AD) frequencies are high however, Asteraceae undiff. tends to taper off towards the top of the zone.

Herb taxa Lamiaceae undiff. (~2-3%), Malvaceae undiff. (~2%) and Solanaceae undiff. (~5%) occur in small frequencies in Zone C-2. Rubiaceae undiff. steadily increases (~6% at ca. 1920 cal. AD) this is the highest concentration of the taxa through the sequence. Cactaceae undiff. and Asphodelaceae remain sparse through the assemblage (~1-2%). The local pollen signal remains dominated by sedge and grass pollen however, there is a general decrease in Cyperaceae and Poaceae taxa towards the top of the zone, Cyperaceae peaking at >45% between ca. 1920-1925 cal. AD (Fig 6.6.).

6.5.1.3. Zone C-3: 23-19 cm; ca. 1923-1938 cal. AD

The savanna taxon Fabaceae undiff. continues to dominate within zone C-3 of the CP core, with the highest frequency being ~30% at ca. 1940 cal. AD. Percentages of the savanna tree *Kirkia* are most elevated at the base of the zone (~10%), however this is reduced towards the top of the zone (Fig 6.5.). Generalist taxon Combretaceae undiff. remains relatively stable (~5%) whilst Capparaceae undiff. percentages are increased, the lowest frequency was found at ca. 1930 cal. AD, this was followed by a peak of ~40% at ca. 1940 cal. AD. Low pollen percentages for the herb taxon Acanthaceae undiff. are present at the beginning of the zone, followed by an increase towards a peak of ~18% at ca. 1930 cal. AD; the subsequent pollen percentages are relatively stable.

The herb taxon Asteraceae undiff. peaks between ca. 1930-1935 cal. AD (~6%). Euphorbiaceae undiff. is initially absent from the zone but appears in low amounts (~3-6%) at ca. 1930 cal. AD. The increase in Rubiaceae undiff. (5%) resonates with that of Solanaceae undiff. at 1935 cal. AD. This zone exhibits poor pollen diversity in herbaceous taxa as compared to the rest of the sequence. The pollen sum table suggests a decline in all taxa after ca. 1935 cal. AD. High Poaceae percentages are reflected in the zone, with two peaks of ~20% and ~25% at ca. 1930 and 1935 cal. AD respectively (Fig 6.7). Cyperaceae concentrations gradually decline, reaching a low of ~30% (ca. 1985 cal. AD). There is a

complete absence of trilete spores in this zone and monolete spores appear to be consistent, peaking at ~4% (ca. 1935 cal. AD).

6.5.1.4. Zone C-4: 19-0 cm; ca. 1938-2013 cal. AD

The most distinguishing feature in zone C-4 is the notable occurrence of *Adansonia* amongst the savanna taxa (Fig 6.5). The *Adansonia* pollen percentage is not particularly high however, with several peaks occur within the zone, the highest occurring at ca. 1975 cal. AD. The proportions of Anacardiaceae undiff. appear to be the highest within zone C-4 compared to previous zones; despite the lack of representation between ca. 1955-1960 cal. AD and post ca. 2009 cal. AD, pollen percentages tend to range from ~3 to >10% (ca. 1980/1995 cal. AD).

The Savanna taxon Fabaceae undiff. remains a prominent feature peaking at ~24% (ca. 1960 cal. AD) however, the pollen concentration fluctuates, reaching its lowest point in the entire sequence at approximately 1950 cal. AD (~6%). *Kirkia* is a poorly represented savanna tree, evident predominantly at the base (~9%) and the top of the zone (~4%). Generalist taxa, Capparaceae undiff. and Combretaceae undiff. are present throughout zone C-4 at consistent levels with peaks of 45% and >10%, respectively. It is noted that Capparaceae undiff. frequencies for the entire sequence are the lowest within this zone. The highest concentration of Acanthaceae undiff. (~27%) can be found at ca. 1945 cal. AD and that of Asteraceae undiff. (>10%) at ca. 2005 cal. AD both taxa occur consistently throughout the zone, however, reductions in Acanthaceae undiff. are visible at ca. 1975 and ca. 1980 cal. AD.

The pollen diversity for herb taxa is highest within zone C-4 as each type is reflected in the sequence albeit at low frequencies. Poaceae undiff. is poorly represented at the base of the zone, however there is an increase from ca. 1970-1980 and an eventual peak of >25% towards ca. 2013 cal. AD at the top of the core. The lowest concentration for sedges is ~7% (ca. 1995 cal. AD) despite the peak in Cyperaceae after ca. 1985 cal. AD (~34%), this appears to be the zone with the lowest levels of this taxon (Fig 6.6.). Monolete and trilete spores both occur at their highest levels for the sequence CP, peaking at ~7% and ~2% respectively.

6.5.2. Leokwe Rock Pool

In the LRP core, Anacardiaceae undiff. and Fabaceae undiff. co-dominate the savanna taxa in the sequence (Fig 6.7). The highest percentages for *Adansonia* are found in zone L-1. Malvaceae undiff. is abundantly occurring peaking in zone L-2. Amongst the herb taxa,

Acanthaceae undiff., Euphorbiaceae undiff. and Lamiaceae undiff. frequencies remain constant through the zones. *Cordia* is the more frequently occurring riparian taxon in the sequence.

6.5.2.1. Zone L-1: 47-26 cm; ca. 1898-1945 cal. AD

In zone L-1 of the LRP core the regional signal illustrates an increase for Fabaceae from the base towards the top of the zone, peaking at ~11% (ca. 1940 cal. AD). The presence of Anacardiaceae undiff. is constant with a peak at ~16% (ca. 1935 cal. AD). Increased *Adansonia* percentages are present in a zone L-1, reaching a peak of ~8%. The frequency of Combretaceae undiff. is increased at the base of the core (40%) between ca. 1898-1900 cal. AD, this is followed by a decline to ~17% between ca. 1900-1910 cal. AD and a subsequent increase. Tiliaceae and *Kirkia* frequencies are and discreet.

Capparaceae undiff. and Ebenaceae undiff. (~7%) dominate the pollen signal for generalist taxa in zone L-1, the presence of Capparaceae undiff. pollen increases at the base of the zone (~9%) however there is a steady decline towards ca. 1930 cal. AD (~2%), followed by a gradual incline towards the top of the zone where a peak of ~8% is reached (ca. 1945 cal. AD). *Euclea* pollen percentages are fairly stable in zone L-1, ranging from >1% to ~5%. Acanthaceae undiff. and Euphorbiaceae undiff. pollen percentages fluctuate through the zone both ranging between ~2-10% whilst Malvaceae undiff. peaks at ~20% after ca. 1904 cal. AD. Low amounts of riparian taxa *Cordia* and *Olea* are present in zone L-2 (Fig 6.8). Poaceae undiff. is abundant within the zone with a peak of ~20% at ca. 1920 cal. AD (Fig 6.8.). Cyperaceae remains consistent peaking at ~15% peak after ca. 1935 cal. AD. Trilete and Monolete spores occur at frequencies of approximately 5%.

6.5.2.2. Zone L-2: 26-21 cm; ca. 1945-1957 cal. AD

The regional pollen signal shows Anacardiaceae undiff. as a dominant savanna taxon in zone L-2 of LRP peaking at ~13% (ca. 1950 cal. AD), *Adansonia* appears and peaks at ~6% during the same period (Fig 6.7). Savanna taxa Burseraceae undiff. and Fabaceae undiff. have a simultaneous and steady decline in pollen percentages from the base to the top of zone L-2. There is a reappearance of *Kirkia*, showing a peak (~2%) at ca. 1950 cal. AD. Combretaceae undiff. frequencies occur consistently throughout the zone, reaching a maximum of ~30% at the base.

Capparaceae undiff. and Ebenaceae undiff. continue as the most prominent generalist taxa. Ebenaceae undiff. occurs at the most increased levels in zone L-2, with a peak of ~20% (ca. 1950 cal. AD), *Euclea* experiences a decline during the same time period. The herb taxa

Acanthaceae undiff. is consistently occurring through zone L-2. Euphorbiaceae undiff. parallels the patterns of Burseraceae undiff. and Fabaceae undiff. by gradually declining towards the top of the zone. Malvaceae undiff. displays the opposite trend, increasing from the base of the zone reaching an ultimate peak of ~18% at the top of the zone.

Cordia and *Olea* occur at low frequencies towards the top of zone L-2 (>2%). Poaceae levels fluctuate, the highest percentage for Poaceae undiff. (>21%) is found within this zone (Fig 6.8.). Cyperaceae percentages are consistent at ~6-9%. Trilete spores increase from the base of the zone reaching a ~6% peak after ca. 1950 cal. AD.

6.5.2.3. Zone L-3: 21-11 cm; ca. 1957-1984 cal. AD

The frequency of savanna taxon Anacardiaceae undiff. is inconsistent through zone L-3, although it occurs at high percentages between ca. 1965 and ca. 1975 cal. AD (~9%), there are several instances where Anacardiaceae is not present e.g. ca. 1960-1962 cal. AD, after ca. 1970 cal. AD and ca. 1975-1980 cal. AD (Figure 6.7.). Burseraceae undiff. gradually increases from the base of zone L-3 to ~6% at the top of the zone whilst *Adansonia* percentages are increased at the base of the zone (~7%) after ca. 1960 cal. AD, declines and then increase after ca. 1970 cal. AD (~6%). Fabaceae undiff. is prominent reaching a maximum of ~14% (after ca. 1970 cal. AD) and then gradually declining towards the top of the zone. The accumulation of pollen from the generalist taxon Combretaceae undiff. in zone L-3 is consistent (~30%). Ebenaceae undiff. and Acanthaceae undiff. are constant and *Euclea* is introduced into the zone at ~4% but declines off towards the top of the zone.

Cactaceae undiff. occur in the sequence within zone L-4, accounting for <2% of the pollen. Euphorbiaceae undiff. frequencies show an increasing trend towards the top of the zone, reaching a maximum of ~14% at ca. 1975 cal. AD. Malvaceae undiff. is consistent in the zone (~21%), the same trend applies to Poaceae undiff. and Trilete spores (Fig 6.10.). Levels of local pollen taxon Cyperaceae fluctuate through the zone, reaching a maximum after ca. 1970 cal. AD (~11%) (Fig 6.8).

6.5.2.4. Zone L-4: 11-0 cm; ca. 1984-2013 cal. AD

Anacardiaceae undiff. and Burseraceae undiff. both increase towards the top of zone L-4, peaking at ca. 15 and ~7%, respectively. Savanna taxon Fabaceae undiff. occur throughout the zone. Combretaceae undiff. continues as the highest occurring generalist taxon (~20-26%). Likewise, Capparaceae undiff. and Ebenaceae undiff. dominate the generalist taxa in zone L-4. Amongst the herb taxa, the frequencies of Acanthaceae undiff., Euphorbiaceae undiff. and Lamiaceae undiff. frequencies remain constant through the zones.

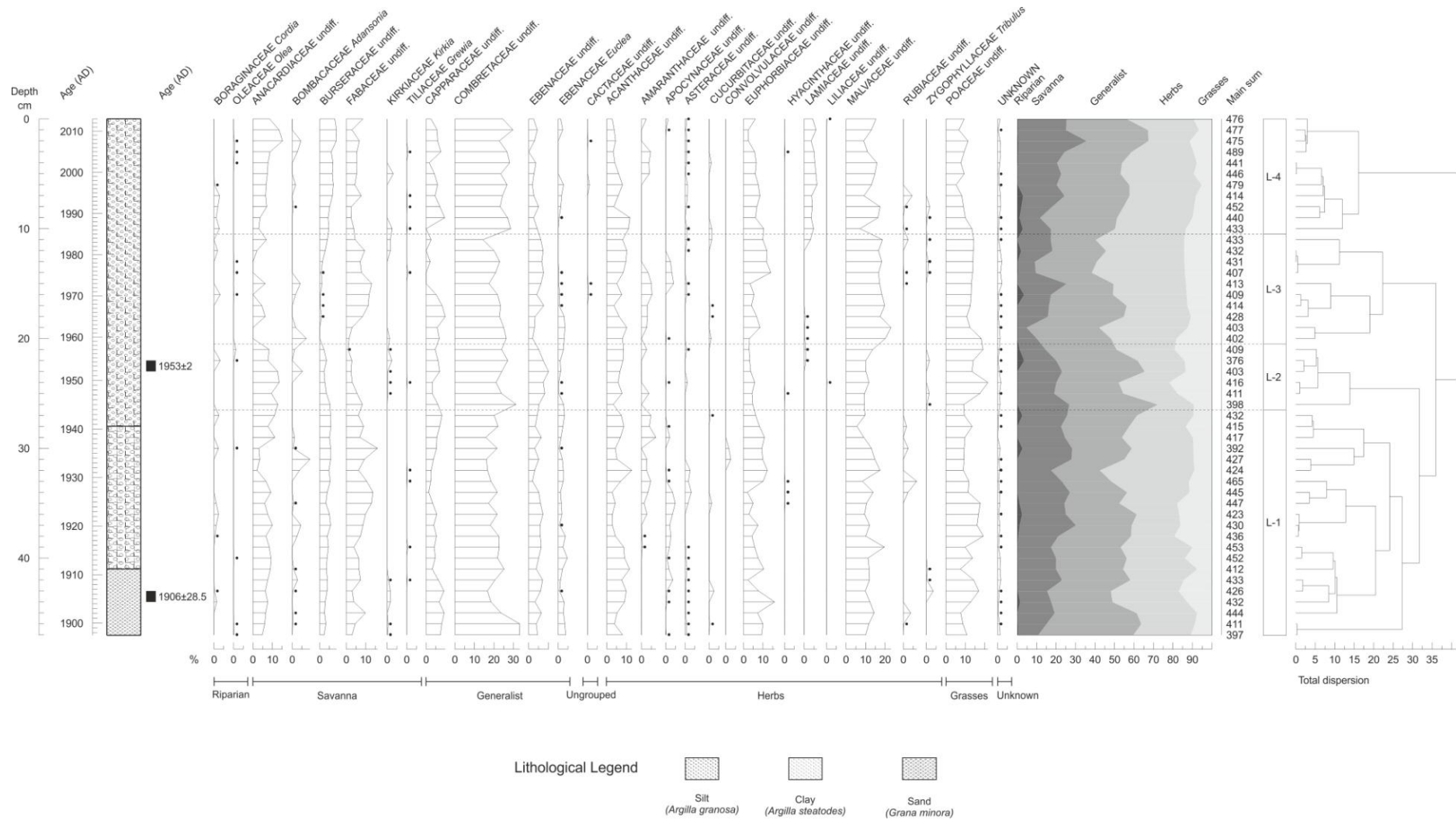


Figure 6.7. Main pollen diagram for Leokwe Rock Pool plotted against the Troels-Smith stratigraphy, age-depth scale (AD-cm) and calibrated ¹⁴C ages (AD). Also included in the diagram are the sums for each depth and pollen sums for each sub-group. A dendrogram created using CONISS (Grimm, 1987) showing the zones and order of splits for the core is also illustrated.

Zone L-4 encompasses the greatest frequencies of Lamiaceae undiff. in the sequence which ranging between ~2-6%. *Cordia* (~2-4%) is frequent at the base of the zone and then tapers off at ca. 1998 cal. AD, *Olea* is introduced into the sequence in very low amounts (~1-2%) (Fig 6.9.). Poaceae undiff. pollen percentages are generally lower in zone L-4 compared to previous zones, ranging between ~9-12% (Fig 6.7.). The levels of local aquatic pollen taxon Cyperaceae levels are highest after ca. 2000 cal. AD at ~12%, they gradually decrease towards 2013 cal. AD (~4%) (Fig 6.8).

6.5.3. *Croc Pan charcoal*

6.5.3.1. *Zone C-1: 55-32 cm; ca. 1696-1865 cal. AD*

In zone C-1 of the CP core, the distribution of 125-200 μm and >200 μm macroscopic charcoal size classes tends to be consistent within the zone, with the latter having the lowest charcoal content (Fig 6.9 (A)). A peak of ~5 x 10 grains/cm can be seen after ca. 1770 cal. AD for the 125-200 μm size class and the >200 μm size class reaches a maximum of ~13 x 10 grains/cm at the top of the zone. No charcoal fragments in the 75-100 μm size class were counted for this zone using the pollen slide technique. The predominant microscopic charcoal fragments in zone C-1 fall within the 63-125 μm size class (Fig 6.9 (A)).

The 63-125 μm size class in zone C-1 of CP increases from the base to the top of the zone, reaching a maximum concentration of ~23 x 10 grains/cm after ca. 1760 cal. AD. The 25-75 μm size class is increased at the base of the zone maximising after ca. 1700 cal. AD at ~15 x 10³ grains/cm, and again at the top of the zone with ~30 x 10³ grains/cm (after ca. 1860 cal. AD) (6.9 (B)). The <25 μm size peaks with ~45 x 10³ grains/cm charcoal at ca. 1760 cal. AD, thereafter a large drop in charcoal levels ensues between ca. 1770-1805 cal. AD followed by the second maximum of ~45 x 10³ grains/cm (after ca. 1830 cal. AD) and subsequent decreases in charcoal frequencies towards the top of the zone.

6.5.3.2. *Zone C-2: 32-23 cm; ca. 1865-1923 cal. AD*

Levels of >200 μm charcoal remain relatively stable and low (<3 x 10 grains/cm) in zone C-2 of the CP record (Fig 6.9 (A)). The charcoal content for 125-200 μm category is elevated in zone C-2 reaching a maximum of ~21 x 10 grains/cm after ca. 1915 cal. AD. Microscopic charcoal fragments >75 μm peak are increased after ca. 1700-1720 cal. AD (Fig 6.9 (B)). 63-125 μm charcoal fragments are most abundant within zone C-2; charcoal counts peak at ca. 1880 cal. AD with ~28 x 10 grains/cm. Charcoal fragments in the 25-75 μm size class

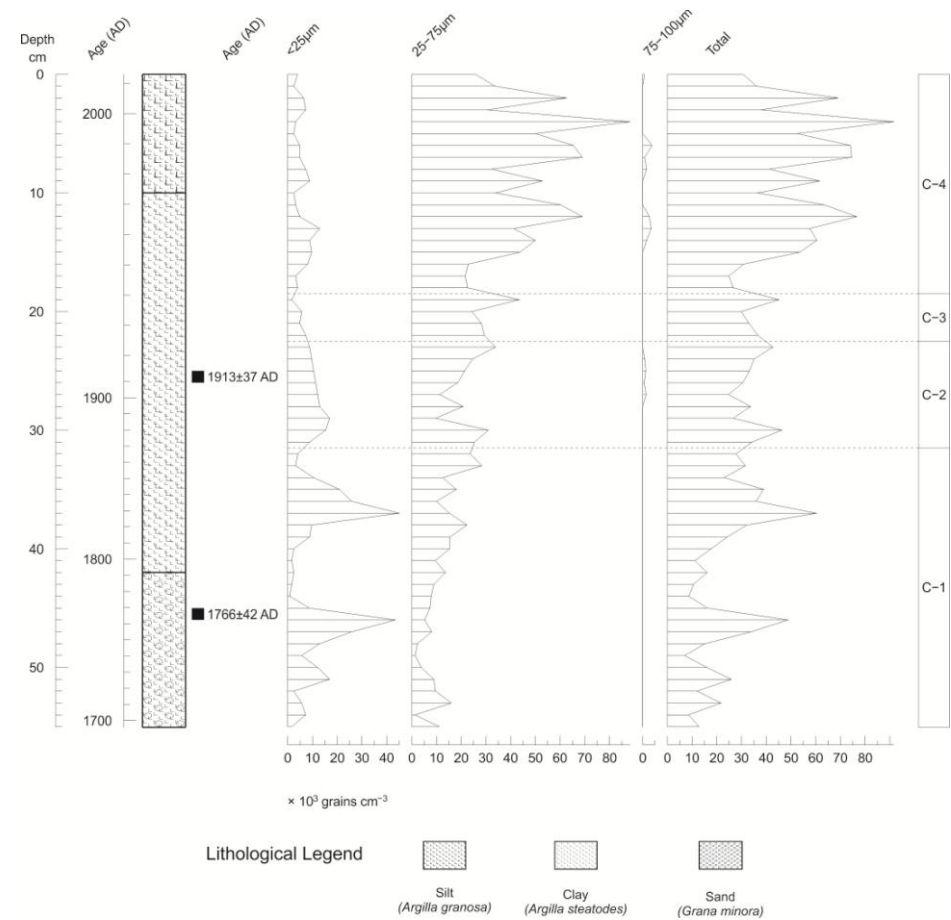
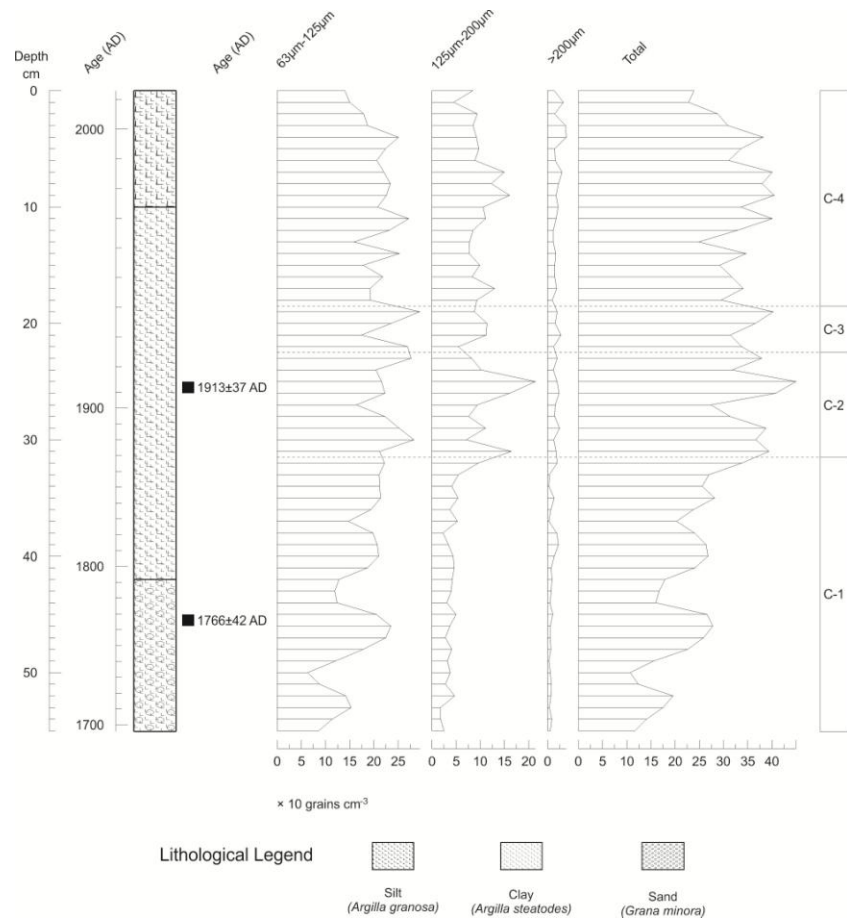
fluctuate in zone C-2, a peak of $\sim 30 \times 10^3$ grains/cm is seen after ca. 1880 cal. AD, thereafter microscopic charcoal decreases and steadily increases towards a peak of $\sim 35 \times 10^3$ grains/cm at the of the zone after ca. 1900 cal. AD. $<25 \mu\text{m}$ charcoal fragments show a decreasing trend towards the top of the zone.

6.5.3.3. Zone C-3: 23-19 cm; ca. 1923-1938 cal. AD

In zone C-3 of the CP record, $>200 \mu\text{m}$ macroscopic charcoal fragments remain stable (Fig 6.9 (A)). In the 125-200 μm size class, macroscopic charcoal fragments increase from the base to the middle of the zone, maximising at $\sim 13 \times 10$ grains/cm from ca. 1930-1935 cal. AD. The majority of microscopic charcoal content in this zone falls within the 63-125 μm size class, the charcoal content in this size class is begins at increased levels of $\sim 28 \times 10$ grains/cm at the base of the C-3 zone as it transitions from the previous zone. Subsequently, charcoal counts in the 63-125 μm size class declined after ca. 1930 cal. AD to $\sim 18 \times 10$ grains/cm, increasing again to $>28 \times 10$ grains/cm after ca. 1940 cal. AD (Fig 6.9 (A)). Charcoal of the size 25-75 μm decreased between ca. 1930 cal. AD to ca. 1935 cal. AD and then reached a maximum concentration of $\sim 45 \times 10^3$ grains/cm after ca. 1940 cal. AD (6.9 (B)). The $<25 \mu\text{m}$ charcoal concentrations decreased towards the top of the zone.

6.5.3.4. Zone C-4: 19-0 cm; ca. 1938-2013 cal. AD

$>200 \mu\text{m}$ macroscopic charcoal fragments increase towards the top of zone C-4 in the CP record, reaching a maximum after ca. 1995 cal. AD ($\sim 4 \times 10$ grains/cm) (Fig 6.9 (A)). Fragments falling within size class 125-200 μm occur consistently throughout the zone and increase to $\sim 15 \times 10$ grains/cm after ca. 1970 cal. AD. In zone C-4 there is a brief appearance of 75-100 μm size particles, with maximum charcoal content reached after ca. 1990 cal. AD ($\sim 1 \times 10^3$ grains/cm) (Fig 6.9 (B)). The 63-125 μm size class continues to contain the highest number of charcoal fragments, maximising at $\sim 27 \times 10$ grains/cm after ca. 1970 cal. AD. Minimum charcoal counts for the ~ 63 -125 μm size class can be found at the top of the zone and towards ca. 2013 cal. AD. The charcoal content in the 25-75 μm size class is increasing towards the top of the zone with several fluctuations in-between; the largest charcoal content for the 25-75 μm size class for zone C-4 occurs after ca. 1995 cal. AD. ($\sim 85 \times 10^3$ grains/cm). Fragments $<25 \mu\text{m}$ fluctuate towards throughout the zone and remain relatively low.



A

B

Figure 6.9. Charcoal Diagram displaying macroscopic wet sieving charcoal (A) and microscopic pollen slide charcoal (B) (exaggeration=10 x) plotted against an age-depth axis (AD-cm), ¹⁴C ages (AD), Troels-Smith stratigraphy and CONISS (Grimm, 1987) zonation for CP based on the main pollen data zones.

6.5.4. Leokwe Rock Pool charcoal

6.5.4.1. Zone L-1: 47-26 cm; ca. 1898-1945 cal. AD

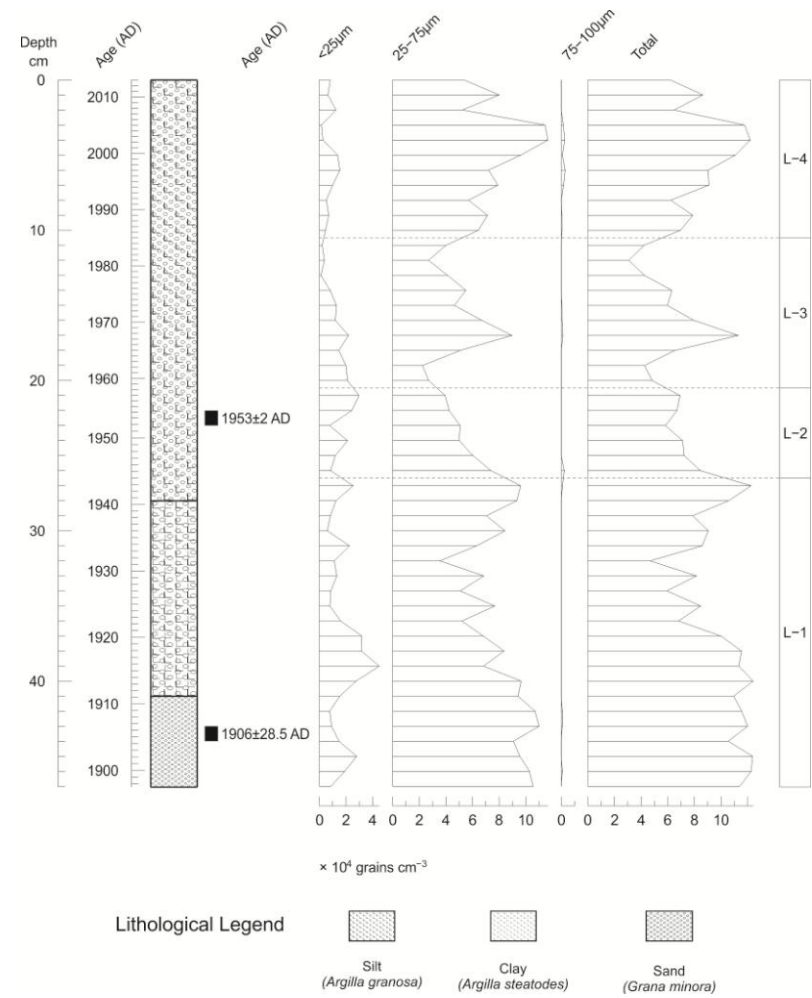
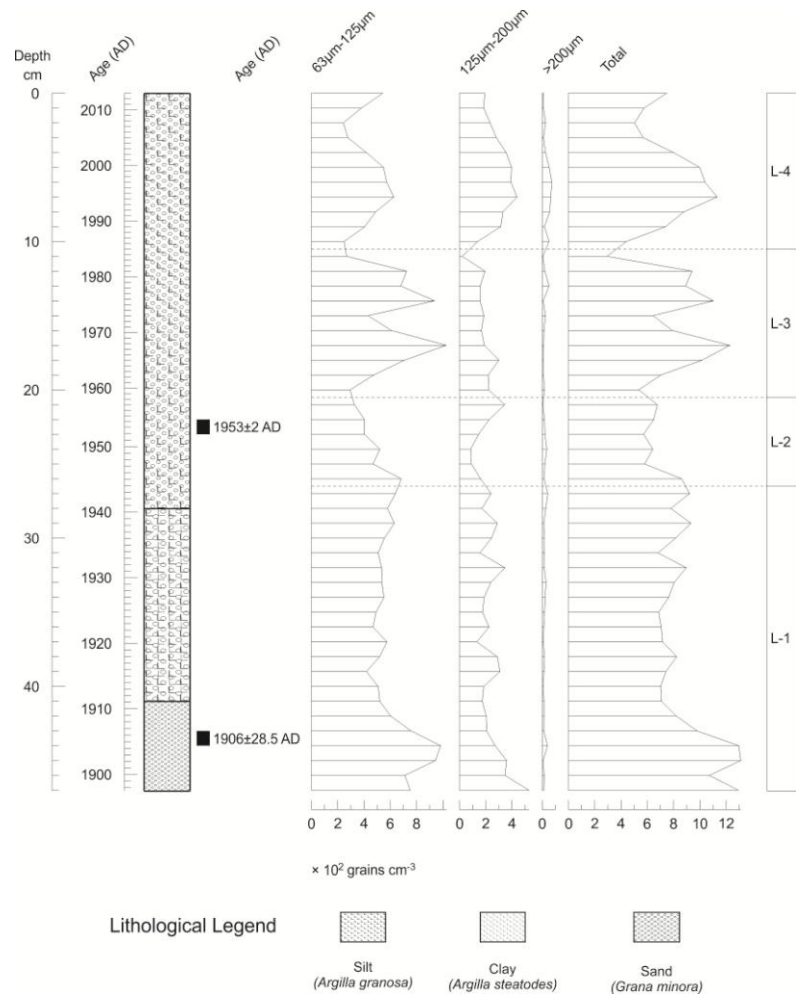
The majority of charcoal for most size classes is found at the base of zone L-1, showing an increasing trend towards the top of the zone (Fig 6.10 (A)). Macroscopic charcoal fragments in the >200 µm size class exhibit a stable trend having a maximum of $\sim 0.5 \times 10^2$ grains/cm after ca. 1910 cal. AD. The 125-200 µm size class peaks after ca. 1900 cal. AD with $\sim 5 \times 10^2$ grains/cm, this is followed by a gradual decline in charcoal frequencies. Very little charcoal content from the 75-100 µm size class is found in zone L-1. The majority of charcoal belongs to the 63-125 µm size class, the sieved sample of microscopic charcoal peaked at $\sim 9 \times 10^2$ grains/cm at ca. 1905 cal. AD (Fig 6.10 (A)). Charcoal concentrations within the 25-75 µm size class of the pollen slides were initially high at the base of zone L-1 ($\sim 10 \times 10^4$ grains/cm) decreasing trend towards ca. 1932 cal. AD, thereafter charcoal concentrations increased towards the top of the zone, reaching a peak of $\sim 10 \times 10^4$ grains/cm (Fig 6.10 (B)). A dip in charcoal concentrations in the <25 µm size class is evident between ca. 1905 cal. AD to ca. 1920 cal. AD followed by a peak of $\sim 4 \times 10^4$ grains/cm after ca. 1916 cal. AD; thereafter charcoal frequency decreases towards the top of the zone.

6.5.4.2. Zone L-2: 26-21 cm; ca. 1945-1957 cal. AD

Levels in the >200 µm macroscopic charcoal size class are low within zone L-2 in the LRP record, with the highest charcoal content found towards ca. 1950 cal. AD ($>1 \times 10^2$ grains/cm) (Fig 6.10 (A)). Charcoal fragments belonging to the 125-200 µm size class increased towards the top of the zone where a maximum of $\sim 3 \times 10^2$ grains/cm occurred following ca. 1950 cal. AD. 63-125 µm charcoal fragments display a steady decline towards the top of the zone (Fig 6.10 (A)). The highest charcoal content for Zone L-2 is found in the 25-75 µm microscopic charcoal category with $\sim 8 \times 10^4$ grains/cm found after ca. 1945 cal. AD, these levels gradually decrease towards the top of the zone (Fig 6.10 (B)). <25µm fragments are low at the base of the zone, the numbers then increase to reach a peak of $\sim 3 \times 10^4$ grains/cm between ca. 1950 cal. AD and ca. 1955 cal. AD.

6.5.4.3. Zone L-3: 21-11 cm; ca. 1957-1984 cal. AD

Charcoal frequencies in both the >200 µm and 125-200 µm size classes are fairly stable within zone L-3 of the LRP record, both declining after ca. 1985 cal. AD (Fig 6.10 (A)).



A

B

Figure 6.10. Charcoal Diagram displaying macroscopic (wet sieving) (A) and microscopic (pollen slide) (B) charcoal (exaggeration=10x) plotted against an age-depth axis (AD-cm), ^{14}C ages (AD), Troels-Smith stratigraphy and CONISS (Grimm, 1987) zonation for LRP based on the main pollen data zones.

Increased frequencies in microscopic charcoal for the 63-125 μm size class are the most prominent features of this zone, with the maximum charcoal count occurring after *ca.* 1960 cal. AD ($\sim 10 \times 10^2$ grains/cm).

Microscopic charcoal of the 25-75 μm size class is low at the base of zone L-3, increases to $\sim 9 \times 10^4$ grains/cm close to *ca.* 1970 cal. AD and gradually decreases towards the top of zone L-1 (6.10 (B)). The $<25 \mu\text{m}$ size class shows a generally decreasing trend towards the top of the zone, the maximum frequency of $<25 \mu\text{m}$ charcoal fragments occurred towards *ca.* 1970 cal. AD ($\sim 2 \times 10^4$ grains/cm), thereafter decreasing to low concentrations at the top of the zone.

6.5.4.4. Zone L-4: 11-0 cm; *ca.* 1984-2013 cal. AD

The lowest charcoal content is at the base of zone L-1 and increases steadily towards the middle of the zone for most size classes in the LRP record (Fig 6.10 (A)). Charcoal frequencies for the 125-200 μm size class increased to a peak of $\sim 4 \times 10^2$ grains/cm after *ca.* 1995 cal. AD. Microscopic charcoal fragments of the 63-125 μm size class reach maximum of $\sim 6 \times 10^2$ grains/cm towards the top of zone L-4. A more prominent appearance of 75-100 μm charcoal grains is found in this zone coinciding with charcoal peaks in the $<25 \mu\text{m}$ and 25-75 μm size classes. The microscopic charcoal abundance distribution along L-4 is noticeably jagged for the 25-75 μm sized charcoal fragments, with the highest peak occurring after *ca.* 2005 cal. AD ($\sim 15 \times 10^4$ grains/cm) (6.10 (B)). Charcoal concentrations in the $<25 \mu\text{m}$ size are lowest for the core in zone L-1, with a peak of $\sim 2 \times 10^4$ grains/cm after *ca.* 1997 cal. AD.

6.5.5. Summary of palaeoenvironmental trends and cross-correlation analyses

From *ca.* 1800 cal. AD to *ca.* 2013 cal. AD the trends between the ecological groups and charcoal in the CP record are more distinct (Fig 6.13: A), macroscopic and microscopic charcoal generally had an increasing trend with aquatics. Between *ca.* 1920 cal. AD and *ca.* 2013 cal. AD we see the opposite trend for microscopic charcoal. Microscopic charcoal continues to increase with decreasing aquatics whilst macroscopic charcoal decreases. This trend is echoed in the cross correlation analyses, negative correlations were evident for the macroscopic and microscopic charcoal versus aquatics relationships at CP neither trend was statistically significant as p-values exceeded 0.05 (Fig 6.11: E, F; Table 6.4). Cross correlation analyses show that weak positive correlations occurred for macroscopic and microscopic charcoal and aquatics at LRP (Fig 6.12: E, F), however none of the correlations

were statistically significant. Both the CP and LRP sites showed a negative correlation between aquatics and grasses (Fig 6.11, 6.12). CP showed a very strong negative correlation between grass and aquatics and, changes in one of the variables relative to the other were highly significant ($r = -0.734$, $p = 0.000$).

Table 6.4. Summary of cross-correlation trends for CP (A) and LRP (B), statistically significant relationships are shown in blue.

A) Variable	Grasses	Aquatics	Woody	Macroscopic charcoal	Microscopic charcoal
Grass			-		
Aquatics	-			-	-
Woody		-			
Macroscopic charcoal	+		-		+
Microscopic charcoal	+		+		

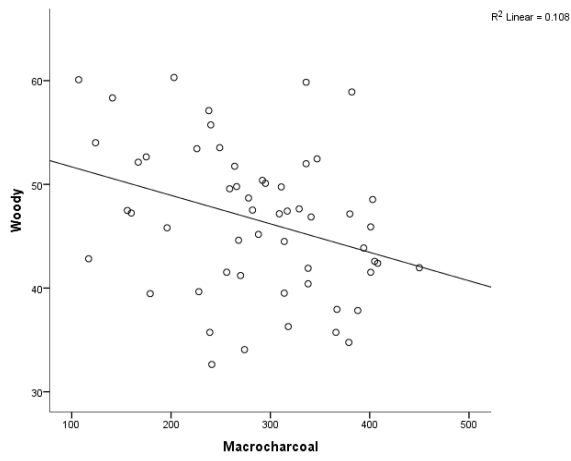
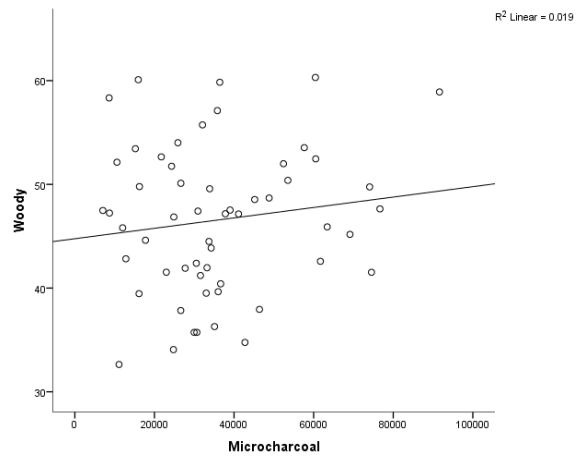
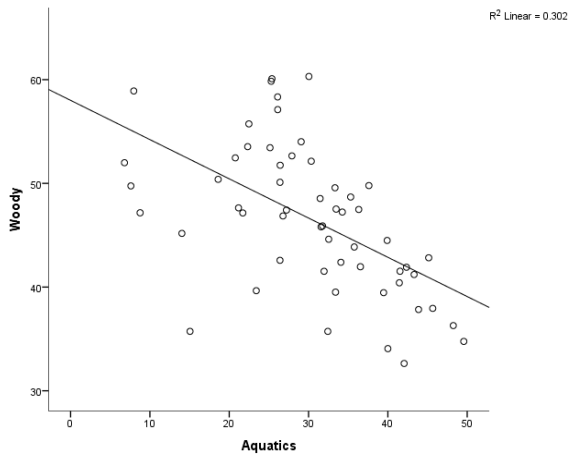
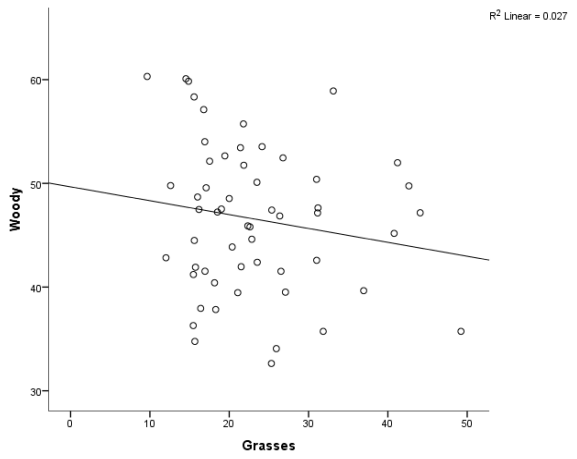
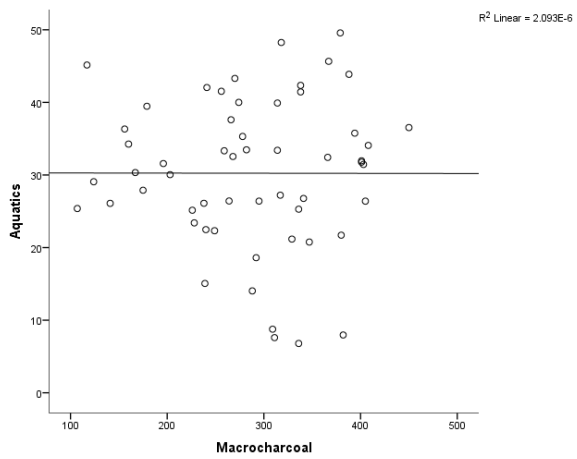
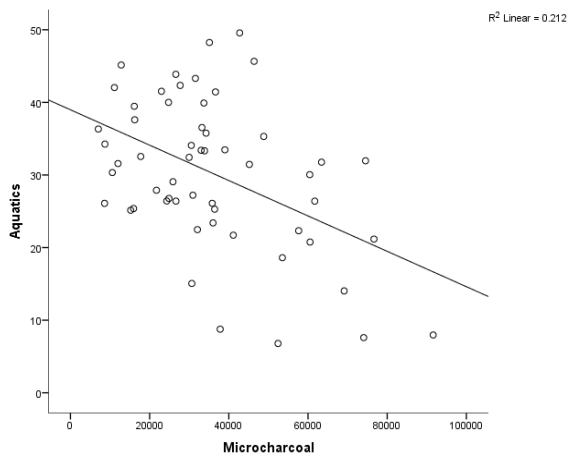
B) Variable	Grasses	Aquatics	Woody	Macroscopic charcoal	Microscopic charcoal
Grass			-		
Aquatics	-			+	+
Woody		-			
Macroscopic charcoal	-		-		+
Microscopic charcoal	-		+		

From the Pearson's correlation analyses, we can see that a weak positive relationship exists between the charcoal and grass variables at CP (Fig 6.11: H, I). The macroscopic and microscopic charcoal versus grass relationships both show positive r values that are below 1 meaning that as one of the variables increases, the other also increases. According to the sigma (2-tailed) or p -values, the observed correlation between grass and macroscopic charcoal was statistically significant as the p -values are less than 0.05 (Table 6.5). It can also be seen in the CP record that grass development generally lagged behind aquatics from *ca.* 1800 cal. AD to *ca.* 1930 cal. AD. After *ca.* 1930 cal. AD, an anti-phase relationship exists meaning that two pollen variables are showing opposing trends by progressing in different directions. An influx in grass pollen is countered by a decrease in aquatics pollen

(Fig. 6.13: A). A slightly anti-phase relationship is also evident at LRP and is more prominent after ca. 1960 cal. AD. Grass and charcoal correlations at LRP showed an inverse relationship, with microscopic charcoal displaying a strong and statistically significant relationship with grasses (Fig. 6.12: H, I).

Table 6.5. Correlations between fossil pollen ecological groups and charcoal (macroscopic and microscopic) at the Croc Pan (CP) and Leokwe Rock Pool (LRP) sites in MNP. Statistically significant values are shown in bold ($p \leq 0.05$), it is shown that there are no significant relationships common across both sites.

Variables	Statistical Value	CP (n=56)	LRP (n=48)	Graph
Aquatics/ Grasses	r	-0.734	-0.156	A
	p	0.000	0.289	
Wood(AP)/ Grasses	r	-0.165	-0.854	B
	p	0.225	0.000	
Wood(AP)/ Aquatics	r	-0.549	-0.229	C
	p	0.000	0.119	
Grasses/ Macrocharcoal	r	0.269	-0.032	D
	p	0.045	0.827	
Grasses/ Microcharcoal	r	0.432	-0.474	E
	p	0.001	0.001	
Aquatics/ Macrocharcoal	r	-0.001	0.111	F
	p	0.992	0.452	
Aquatics/ Microcharcoal	r	-0.460	0.206	G
	p	0.000	0.160	
Woody/ Macrocharcoal	r	-0.328	-0.149	H
	p	0.014	0.313	
Woody/ Microcharcoal	r	0.138	0.248	I
	p	0.312	0.089	
Microcharcoal/ Macrocharcoal	r	0.560	0.398	J
	p	0.000	0.005	

A**B****C****D****E****F**

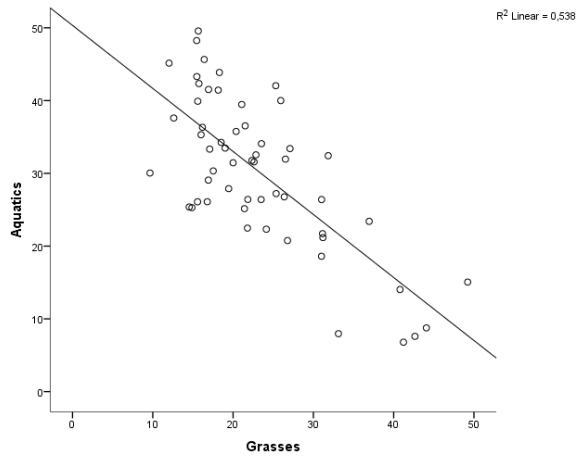
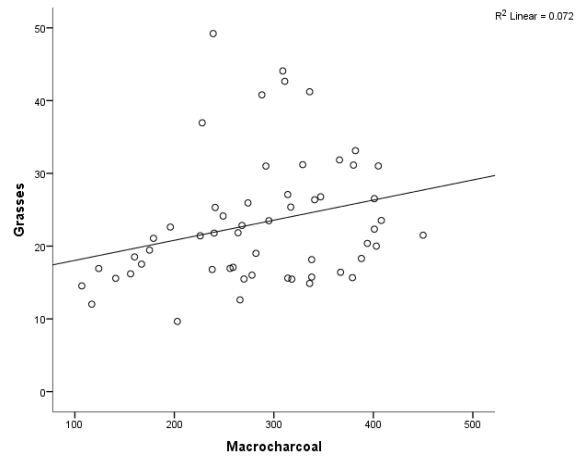
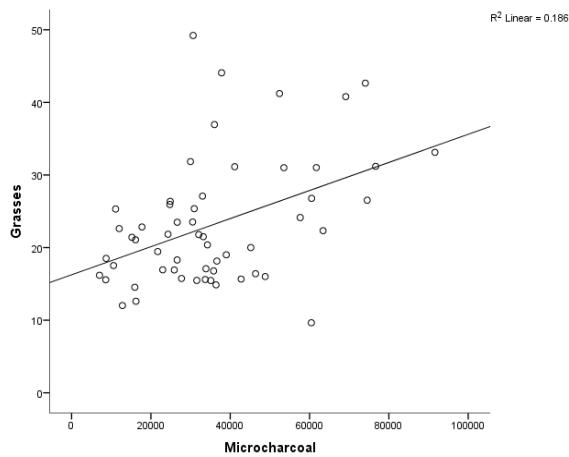
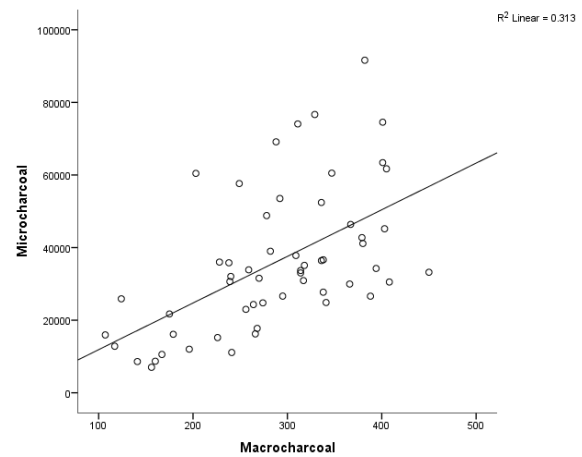
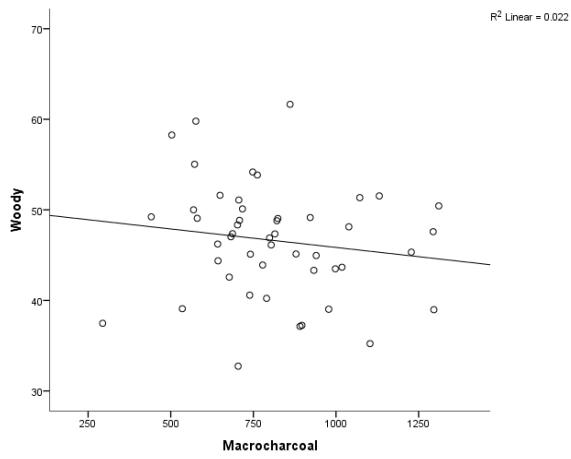
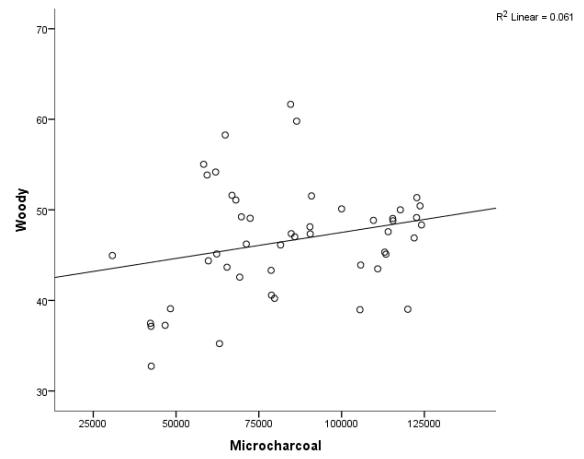
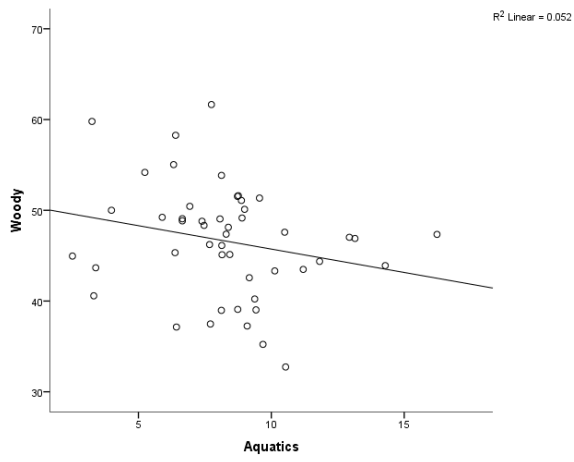
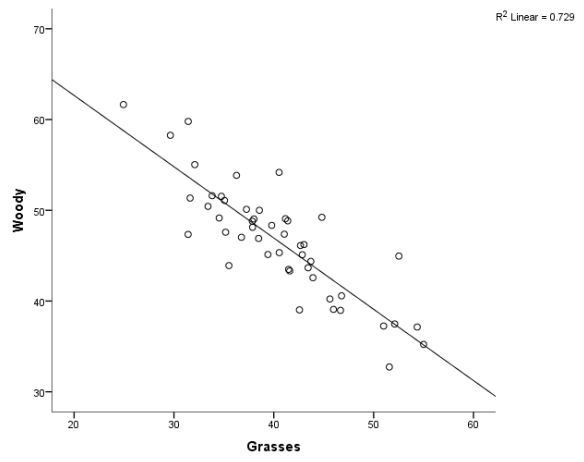
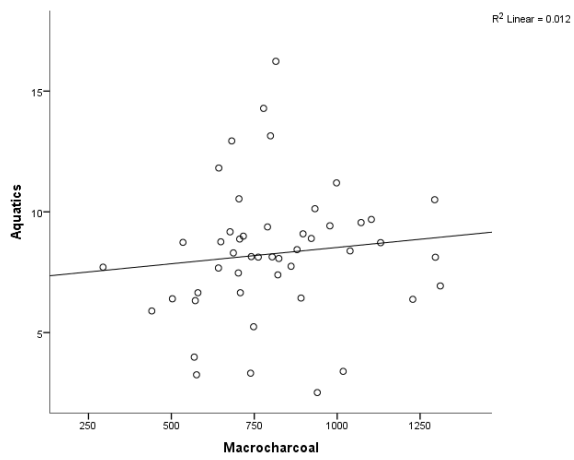
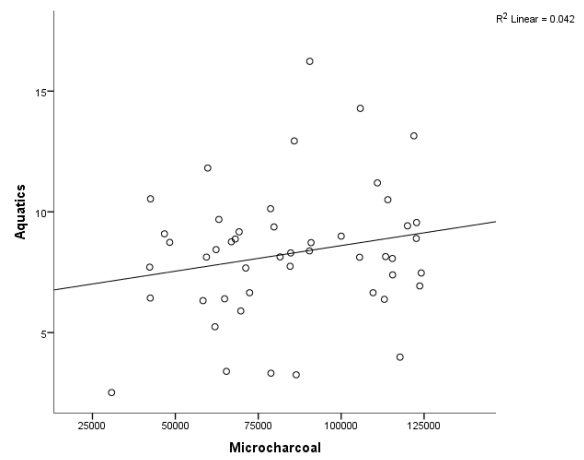
G**H****I****J**

Figure 6.11. Correlation tests for Croc Pan (A, B, C, D, E, F, G, H, I, J). These tests were run between pollen taxa groupings (woody vegetation which constitutes trees and shrubs pollen, grasses which are composed of Poaceae and herbs and, aquatics which constitutes of Cyperaceae and riparian vegetation) and macroscopic and microscopic charcoal – see table 6.4 for correlations tested.

A**B****C****D****E****F**

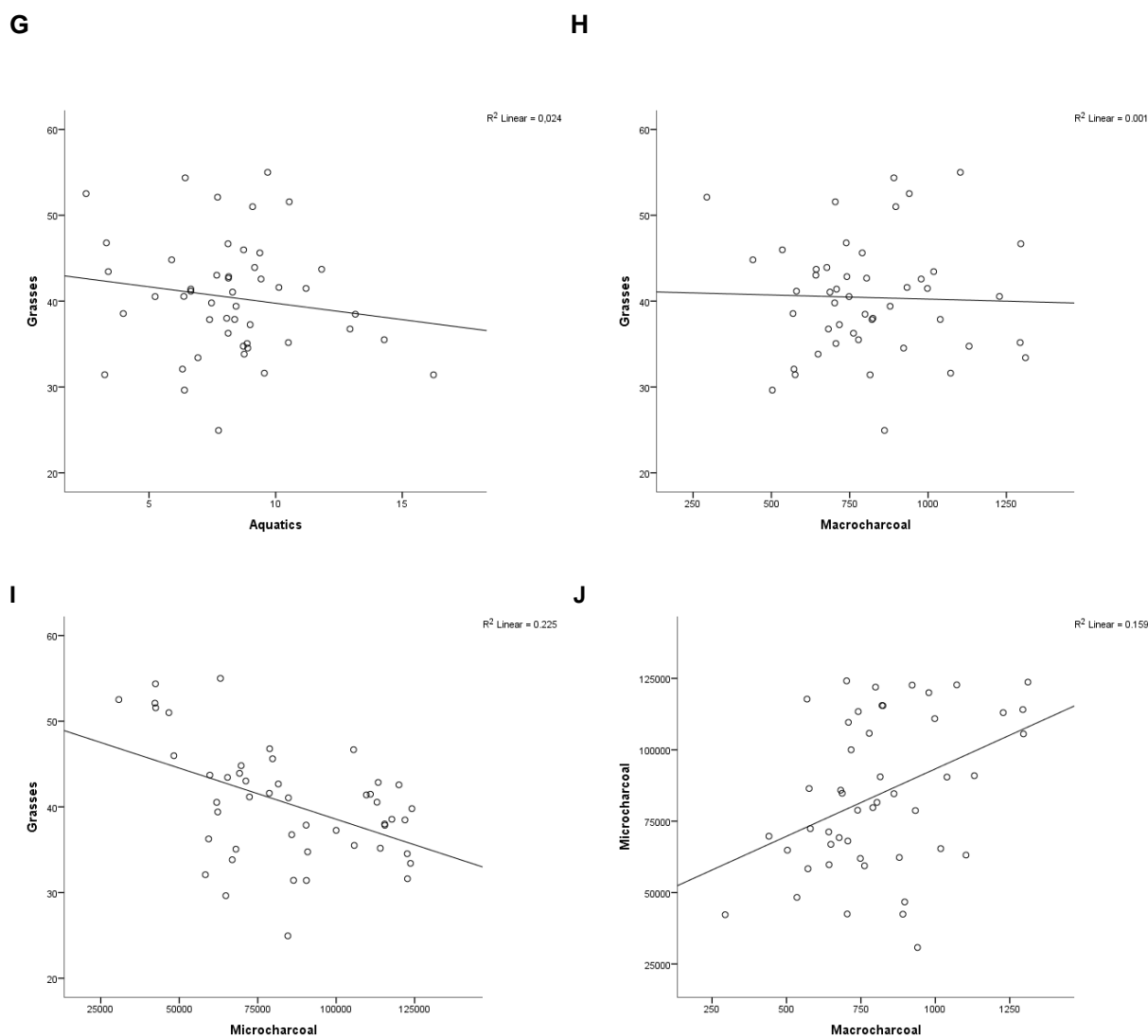


Figure 6.12. Correlation tests for Leokwe Rock Pool (A, B, C, D, E, F, G, H, I, J). These tests were run between pollen taxa groupings (wood arboreal pollen (AP) which constitutes trees and shrubs pollen, grasses which are composed of Poaceae and herbs, and aquatics which constitute of Cyperaceae and riparian vegetation) and macroscopic and microscopic charcoal – see table 6.4 for correlations tested.

Weak negative trends existed between both macroscopic charcoal and woody vegetation correlations for CP and LRP, whilst there is a weak positive relationship between microscopic charcoal and woody vegetation (Fig 6.11, 6.12: A, B). A positive relationship between macroscopic and microscopic charcoal is evident in the CP and LRP records, both of which are highly statistically significant as demonstrated by the summary diagram. General trends demonstrate that peaks in microcharcoal are broadly synchronous with those of macrocharcoal (Fig 6.11: J, 6.12: J, 6.13; Table 6.5).

Correlations between woody vegetation and grasses were negative especially at LRP where a significantly strong negative relationship was evident ($r=0.854$, $p=0.000$) (Fig 6.11: D, 6.12: D). These results are consistent with the observed trends indicated in the dataset summary diagrams, especially for LRP where the anti-phase relationship between woody vegetation and grasses is more distinct (Fig 6.13: A, B). In both pollen records (CP and LRP), woody vegetation and grasses show opposite trends. The level of correspondence between aquatics and charcoal was high at LRP where peaks in moisture indicating pollen types generally coincide with charcoal peaks. Although the patterns in grass pollen accumulation between CP and LRP were not synchronous, they remained relatively coherent between 1900-2013 cal. AD (Fig 6.13: A, B).

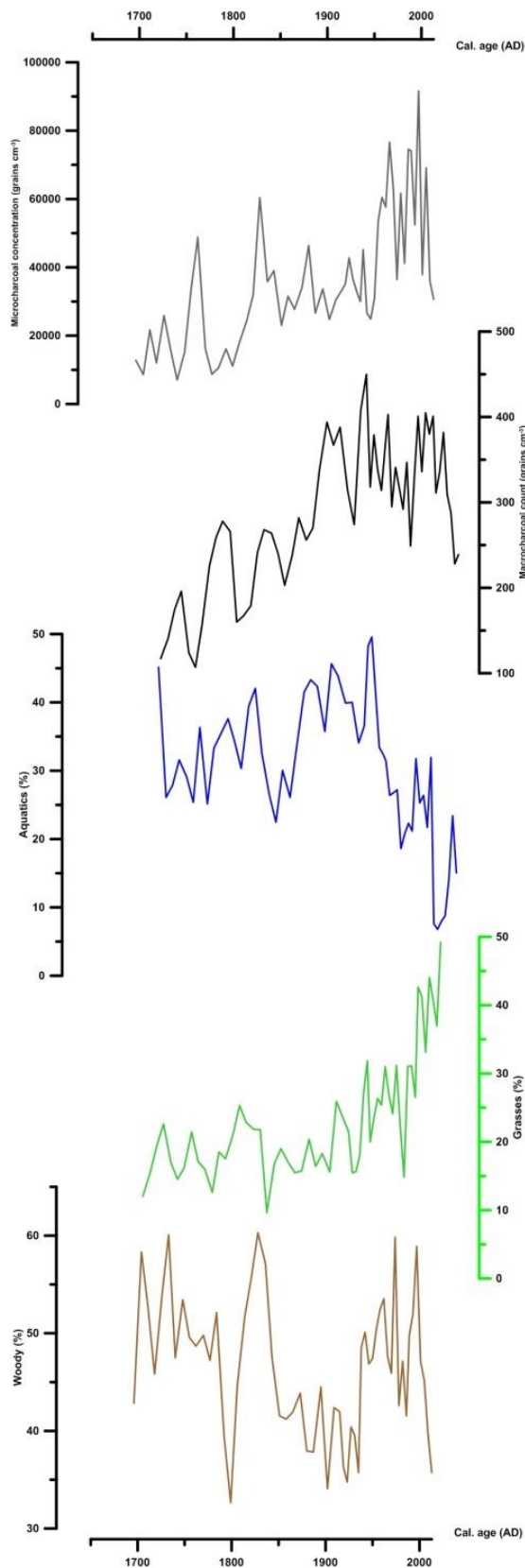
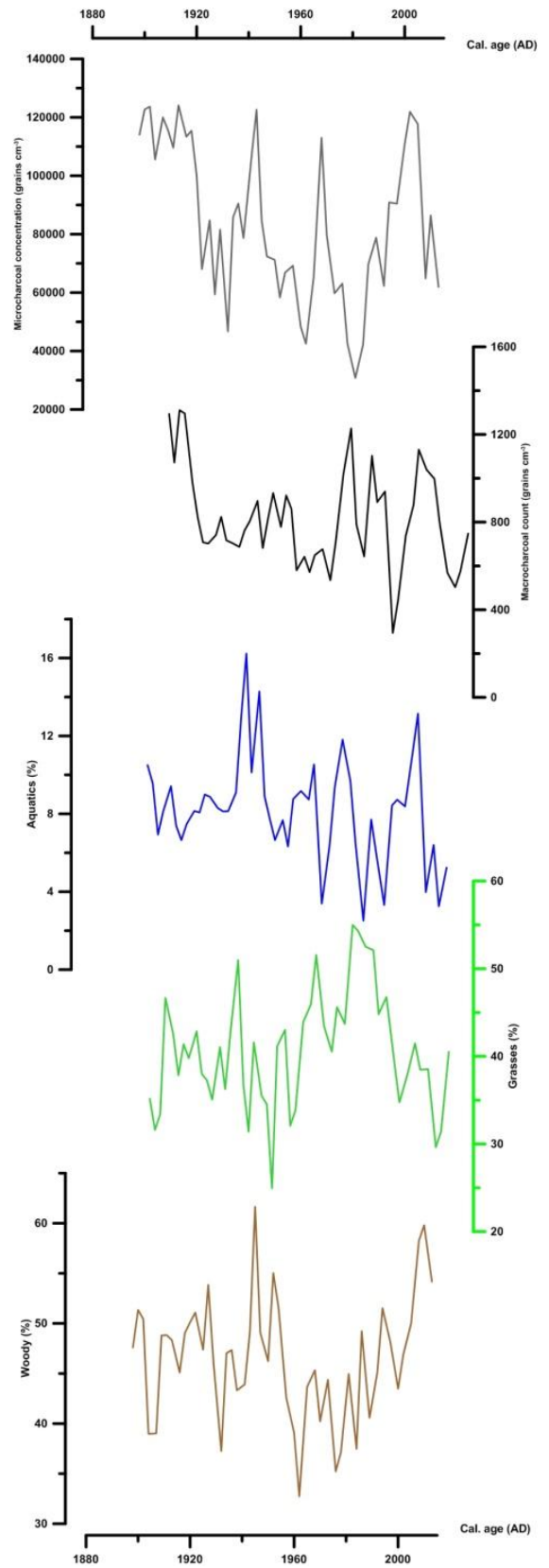
A**B**

Figure 6.13. Summary diagram showing the pollen concentration and charcoal abundance over the periods of 1700-2013 cal. AD and 1900-2013 cal. AD in Croc Pan (A) and Leokwe Rock Pool (B) respectively.

CHAPTER SEVEN

DISCUSSION

7.1. Introduction

This chapter provides a synthesis of the pollen and charcoal results obtained from Croc Pan (CP) and Leokwe Rock Pool (LRP), for the purpose of establishing a palaeoenvironmental reconstruction for Mapungubwe National Park (MNP) and the greater Limpopo Valley. A general discussion of the Croc Pan and Leokwe Rock Pool records will first be presented in the chapter, communicating the findings regarding the chronology and pollen preservation characteristics. Statistical analyses and supplementary information are used to inform palaeoreconstructions. A description of the correlation analyses will be extended to the CP and LRP records. Correlation tests were run to determine the dynamics between the ecological groups based on the data summary diagrams (Fig 6.13) and charcoal for each site. The relationships determined from the cross correlation tests were used to facilitate the understanding of the inferred vegetation and fire dynamics for MNP and the broader Limpopo Valley.

A reconstruction of the past environments will then ensue according to the recognized zones derived from CONISS (Grimm, 1987) in Psimpoll (Bennett, 2009). Although palaeoreconstructions may be limited due to the difficulty of identifying pollen taxa down to the species level, applying the indicator taxa approach can simplify this process. The ecological characteristics of indicator pollen taxa and ecological knowledge of potential parent taxa will be used to assist in the description of the observed trends (Scott, 1999, Scott and Nyakale, 2002). Previous palaeoenvironmental research for the late Holocene in the greater Limpopo area and southern Africa will be incorporated to support the interpretation of the perceived environments (Duffin *et al.*, 2008, Scott, 1999). It should be noted that overlapping timeframes exist between three zones (C-2, C-3 and C-4) of the Croc Pan record and the entire Leokwe Rock Pool sequence (ca. 1900-2013 cal. AD), for this reason these phases of the sequences will be discussed collectively.

7.2. Mapungubwe National Park Record

The CP and LRP sediment cores were determined to be young sequences representing the very late Holocene epoch, with ca. 1700 cal. AD and ca. 1900 cal. AD being the oldest interpolated dates for CP and LRP respectively, the sedimentation rate of the sediments was assumed to be constant. Pollen and charcoal trends are not likely to infer climatic and

vegetation change due to the timeframes discussed being much shorter than the lifespan of a tree. It is instead more probable that they are a reflection of the local changes and taphonomic biases in the fossil record. Despite being considerably young, the dates obtained from the MNP are comparable to those that Ekblom and Gillson (2010a) and Ekblom *et al.* (2012) derived from study sites in the Kruger National Park (KNP) and Limpopo National Park (PNL), particularly Byarinama Pan (PNL) which corresponds most closely with the dates and depths of the MNP cores.

With regards to the pollen preservation, fewer taxa were identified as compared to other sites within the Limpopo Valley (Ekblom and Gillson, 2010a, Ekblom *et al.*, 2012). The sum of woody elements was most prevalent in the pollen signals of both cores; generalist taxon Capparaceae was most common in CP, whereas Combretaceae was most abundant in LP (Fig 6.6, 6.9). With the exception of the aquatics and herbs sums, CP and LRP exhibited similar trends with regard to the fractions that each ecological group contributed to each core.

Levels of herbs generally exceeded those of grasses, and grasses surpassed riparian pollen abundances. This is in contrast to the study by Ekblom and Gillson (2010) in which grass pollen prevailed over arboreal and herb concentrations in the pollen sum for study sites at KNP and PNL. The abundance of Poaceae pollen can correspond to a host of factors such as landscape characteristics, meteorological characteristics, fire regimes and soil conditions. Some of these have been incorporated into the palaeoreconstruction of the study sites.

Aquatics accounted for a large percentage of the total pollen frequency of both sites, reflecting the moisture conditions of the local environment (Scott, 1999). According to Scott (1999), Cyperaceae does not reliably indicate regional moisture conditions but rather shows local moisture availability and fluctuations in the water table. Being a semi-arid savanna region, sedges in the CP and LRP pollen records of MNP likely reflect moisture availability in a dry environment and are therefore interpreted as local moisture availability indicators. However, it is also acknowledged that overrepresentation of Cyperaceae may not always be a true representation of moisture trends but rather an indication of the proximity of the preserved pollen grains to the parent plant (Scott, 1982).

7.3. Palaeoenvironmental synthesis for Mapungubwe National Park

7.3.2 Vegetation reconstruction of Mapungubwe National Park

7.3.2.1. Cool and dry phase, late Holocene (55-32 cm; ca. 1700-1865 cal. AD)

The presence of Anacardiaceae, Fabaceae, Capparaceae and Combretaceae undiff., all of which are semi-arid woodland-type taxa is suggestive of warm temperatures and dry local conditions (Fig 6.5). The increase in Capparaceae at ca. 1735 cal. AD can be attributed to its ability to thrive under dry conditions. A prominent decline in Cyperaceae from ca. 1705-1735 cal. AD further indicates reduced local moisture conditions. The nature of the Cyperaceae distribution during the entire period is suggestive of variable local moisture conditions.

However, increased Cyperaceae pollen levels at CP from ca. 1750-1800 AD indicated a period of wetter local conditions. After ca. 1800 cal. AD we see the highest peak in monolet spores for zone C-1, pteridophytes are plants of damp habitats and may be indicative of moist conditions at CP (Scott, 1982). The presence of warm woodland taxa, monoletes and increasing Cyperaceae during this period is an indication of a transition into warmer, wetter local conditions, this is in line with the suggestion that more rainfall and warmer conditions existed between 1750-1800 cal. AD (Ekblom and Gillson, 2010b).

After ca. 1820 cal. AD, increases in Poaceae and Asteraceae undiff. pollen indicated a change towards reduced moisture levels and increased dryness. The appearance of *Tribulus* in the same period could also be attributed to the dry conditions, this was broadly synchronous with the driest period of the Little Ice Age (LIA) (Woodborne *et al.*, 2015). This period is broadly contemporaneous with the LIA, believed to have lasted from ca. 1500-1800 AD (Holmgren *et al.*, 2003, Ekblom and Gillson, 2010a). The general trend suggested by the Pafuri baobab $\delta^{13}\text{C}$ record is that environmental conditions shifted from wetter to drier conditions after ca. 1600 AD (Woodborne *et al.*, 2015). During this time, subtropical westerlies were displaced northwards by the effect of the oceanic cooling of the warm Agulhus Current, resulting in the cool dry conditions experienced in the southern Hemisphere [temperature conditions during the LIA were approximately 1.4 °C cooler than present day] (Ekblom and Gillson, 2010b, Kruger and Shongwe, 2004, Woodborne *et al.*, 2015).

Late Holocene conditions inferred from stalagmites at Makapansgat Valley were generally warm and wet from 1200-1600 cal. BP but cool, dry conditions also persisted during the LIA period (Holmgren *et al.*, 2003). Pollen evidence from the Lake Mapimbi and Makwadzi in the lower Limpopo Valley show that drought conditions were present from 1400-1800 AD (Ekblom *et al.*, 2012). This was indicated by the presence of fungus genus *Glomus* and the low abundance of riparian taxa (Ekblom *et al.*, 2012).

Mid to late Holocene conditions in Cederberg were generally dry however, evidence from the De Rif hyrax midden record suggests that phases of wet conditions persisted during the late Holocene period broadly overlapping with the LIA (Valsecchi *et al.*, 2013). The Cederberg is situated in a different ecological and climatic environment, this evidence is reflective of trends in the winter rainfall zone (WRZ) (Valsecchi *et al.*, 2013). The presence of moisture indicators such as *Phoenix* and *Macaranga* showed that moist environments were present during the same period in the mid-late Holocene at Lake Sibaya further indicating the interchange between moist and dry phases after ca. 1700 cal. AD (Neumann *et al.*, 2008).

Pollen evidence from the coastal forest and Miombo woodlands of Vilankulo in Mozambique showed arboreal pollen increasing from AD 1700 to the end of AD 1800 when moisture levels were high as indicated by diatom evidence (Ekblom *et al.*, 2014). An incline in aquatics and herbs was also seen for the period whilst grasses had a slight decline (Ekblom *et al.*, 2014). Palaeorecords from Chinyangani spring and Byarinama pan in KNP also suggested wetter conditions for the Limpopo Valley after ca. 1800 cal. AD (Ekblom *et al.*, 2012).

7.3.2.2. Cool moist phase, late Holocene (ca. 1865-1945 cal. AD)

Increased local moisture conditions are inferred from ca. 1870 cal. AD to the early ca. 1900s cal. AD. in the CP record from the presence of the riparian taxon Moraceae and peaks in Cyperaceae (Fig 6.6). These observations correspond with rainfall indications from the Mukwa dendrochronological rainfall record. High episodes of rainfall are reflected for AD 1897-1902 in the Mukwa rainfall record, this was shown as the wettest period the record for Zimbabwe (Therrell *et al.*, 2006).

The pollen signal for the early ca. 1900 cal. AD years at LRP showed species' responses to drier conditions. Coupled with the sparse appearance of riparian taxa *Cordia* and *Olea* at LRP, an indication of low local moisture conditions is given by the Cyperaceae pollen percentages (Fig 6.8). Cyperaceae levels at LRP were generally lower than those perceived at CP and they appeared to showcase less variability in their distribution with time, this could possibly be related to site specific factors. CP is a seasonal pan whilst LRP is perennial and therefore Cyperaceae is likely to showcase less variability. In addition, elevated percentages of Cyperaceae pollen at CP could be a factor of the sites close proximity to the Limpopo River. The trends of drying local environments at LRP appeared to be in agreement with the Mukwa rainfall record and the Pafuri region baobab dendrochronological records (i.e. low but consistent moisture levels) (Therrell *et al.*, 2006, Woodborne *et al.*, 2015). The Mukwa record indicates that phases of drought also occurred from AD 1882-1896 and AD 1989-1996,

agreeing within local pollen signals at LRP indicating phases of decreased local moisture (Therrell *et al.*, 2006). The major peak in Poaceae in LRP (ca. 1919-1925 cal. AD) overlaps with that of CP, corresponding with the period of high rainfall shown by the Mukwa record (AD 1897-1902) suggesting summer rainfall (Scott and Nyakale, 2002, Therrell *et al.*, 2006).

The approach towards 1900 cal. AD was also marked by a large decline in Fabaceae and Combretaceae undiff. in CP. The taxa Anacardiaceae, *Adansonia*, Capparaceae and the herb taxon Amaranthaceae, which require warm evaporative conditions, also decreased between ca. 1920 and 1935 cal. AD (Scott, 1989). The decline in Anacardiaceae, *Adansonia* and Capparaceae was replicated at LRP for the same period confirming the decline warm woodland taxa. Whilst some of these taxa are known to occupy a large range of habitats, evidence of temperature declines in the $\delta^{13}\text{C}$ data from the Makapansgat Valley speleothem record for this period suggests they are likely reflecting the lowered temperatures (Tyson *et al.*, 2000, Holmgren *et al.*, 2003).

7.3.2.3. Dry phase, very late Holocene (ca. 1945-1960 cal. AD)

The pollen record at MNP supports drying local conditions between ca. 1944 cal. AD to ca. 1958 cal. AD. These conditions are signified by moderate to high abundances in arboreal pollen (AP) such as Capparaceae undiff. and Combretaceae undiff. both of which thrive under dry conditions (Scott, 1982). Ekblom and Gillson (2010b) emphasize the resilience of savanna elements and arboreal pollen to drought in semi-arid environments, reiterating that changes in temperatures are likely to affect evaporation rates and hence moisture conditions of local environments. The presence of *Tribulus* and the succulent Euphorbiaceae undiff. further exemplify the suggestion that drier and warmer conditions existed during this period as both are often represented in dry habitats (Scott, 1982).

Areas such as MNP experiencing rainfall below a threshold of 650 ± 134 mm generally have higher maximum tree cover than areas receiving higher rainfall (Sankaran *et al.*, 2005). Given the arid nature of MNP (and its surroundings) and the fact that the area receives only 350-400mm of inter-annual rainfall per year, it is possible that tree cover and consequently arboreal pollen may continue to increase with decreasing rainfall over time (O'Connor, 2010, O'Connor and Kiker 2004). Warm woodland taxa such as Anacardiaceae undiff., Fabaceae undiff., Capparaceae undiff. and Combretaceae undiff. were persistent throughout the CP and LRP records between ca. 1945 cal. AD and ca. 1960 cal. AD in moist and dry conditions.

Grass pollen was generally more abundant in LRP than in CP between ca. 1945 cal. AD to ca. 1960 cal. AD and higher in proportion to the sedge pollen (Fig 6.6, Fig 6.8). The peak in Poaceae is in support of warmer local conditions. Lowered water tables were implied by decreasing Cyperaceae levels in the CP and LRP suggesting local aridity. The presence of pteridophytes was low but consistent for both sites indicating low moisture availability at the time.

The anti-phase relationship (Fig 6.13) witnessed between woody vegetation and aquatics (including Cyperaceae and riparian forest elements) at CP and LRP (more prominent at CP) illustrates that woody-aquatics coexistence is largely dependent on the hydrological properties of the ecosystem (e.g. fluctuations in the water table) and the local moisture availability. This trend is consistent throughout the record. The majority of the woody vegetation at MNP is well adapted to arid conditions, therefore increased aridity results in a decline in aquatic taxa. This trend is supported by the cross correlations for both study sites (6.11, 6.12: C).

Pafuri baobab records and $\delta^{13}\text{C}$ data from the Makapansgat speleothem record during this dry phase were in support of decreasing rainfall in Limpopo Valley, and implied moderate to fairly consistent temperature conditions (Holmgren *et al.*, 2003, Tyson *et al.*, 2000, Woodborne *et al.*, 2015). According to Ekblom (2008) the Miombo woodlands of Mozambique transitioned from semi-deciduous forest with characteristic forest taxa such as *Celtis* and Moraceae to a savanna dominated landscape over the period AD of 1400-1600 when dry spells persisted. These findings show that dry conditions aid in the proliferation of savanna taxa, negatively affecting typical riparian vegetation.

7.3.2.4. Dry to moist transition phase, very late Holocene (ca. 1960-1985 cal. AD)

Moderate to high levels of Anacardiaceae undiff., Amaranthaceae undiff. and, the appearance of Capparaceae at LRP show that ca. 1957 cal. AD to ca. 1985 cal. AD was a transitioning period with variable local moisture and temperature characteristics (Fig 6.7). Increasing levels of Fabaceae undiff. pollen in CP and LRP confirm that local temperatures during this period were on a gradual incline, this could however be taphonomic bias as the sites are located within the *Colophospermum mopane* (Fabaceae) woodland. The consistently high levels of Combretaceae during this period show that the taxon is able to survive and thrive when there is a balance of warm and dry local conditions, the high levels of Euphorbiaceae undiff. further affirms this assumption of initially warm dry local conditions (Scott, 1982).

Peaks in Cyperaceae for both LRP and CP coinciding with the appearance of pteridophytes and riparian taxa *Cordia*, *Olea* and Moraceae, suggest increased local moisture availability (Fig 6.6, Fig 6.8). Abundances of grass pollen for LRP remained stable and relatively high whilst CP grass pollen began at low levels and increased with time. The increase in Poaceae in CP was accompanied by a sharp increase in Cyperaceae confirming the assumption that local moisture and humidity was increasing. These findings are in accordance with speleothem data from Makapansgat that Huffman (1996) observed, indicating that this was a period of warmer and wetter conditions in the Shashe-Limpopo Basin. The data is also in agreement with data showing increased rainfall trends from the Pafuri baobabs (Woodborne *et al.*, 2015).

7.3.2.5. Warm, variable moisture conditions phase, recent Holocene (ca. 1985-present cal. AD)

During this period there was a movement towards warmer and drier conditions as suggested by the continued presence of warm woodland taxa such as Capparaceae undiff., Combretaceae undiff. and Fabaceae undiff at MNP, and reduced rainfall trends as indicated by the Mukwa and Pafuri rainfall records (Woodborne *et al.*, 2015) (Fig 6.5, Fig 6.7). High abundances of certain plant taxa could possibly symbolise short distance transportation. In other words, if the pollen assemblage for savanna taxa was sourced locally one could expect to see any type of savanna taxa in the record for example, the Fabaceae and Capparaceae in CP and Combretaceae, Malvaceae and *Adansonia* in LRP (Breman *et al.*, 2012). Lowered Cyperaceae levels between ca. 1990 to 2000 cal. AD suggest that dry local conditions existed. This was especially evident at CP where Cyperaceae was mostly exceeded by grass pollen. Increases in Cyperaceae post ca. 2000 cal. AD at CP suggest increments in local moistures availability (Fig 6.6). During this period, woody vegetation showed an increasing trend at LRP (Fig 6.13: B) whilst grasses decreased.

Woody vegetation and grasses are in anti-phase throughout most of CP and LRP sequence, however this is especially evident at LRP in the most recent past (Fig 6.13: B). These findings are supported by strong and significant negative correlations (6.11, 6.12: D). Cross correlation tests show a positive relationship between fire (microcharcoal and macrocharcoal) and grasses at CP (6.11: H, I) whilst LRP showed the opposite trend, possibly due to site specific conditions (6.12: H, I). It can be argued that peaks in moisture availability resulted in increased biomass and therefore an increased frequency of fires, limiting the growth of woody vegetation (Ekblom *et al.*, 2011). However, although macroscopic charcoal increased during this phase, it is acknowledged that the majority of the charcoal in the CP and LRP records could represent regional fire signals (<100 µm

fragments). It is noted that aquatics and grasses are in anti-phase for both records (6.11, 6.12: G) meaning that increases in local moisture activity are contradicted by reductions in grasses. Looking at long term trends, it can be hypothesised that changes in local moisture availability were not intrinsically linked to fire activity and it can therefore be argued that tree-grass coexistence may not be determined by fire in this limited environment but rather by a combination of other factors (for example, soil nutrient status and herbivory activity).

Arboreal pollen was negatively correlated with rainfall in the KNP record over the past 50 years (Duffin, 2008). Therefore increases in arboreal pollen were indicative of dry periods (Duffin, 2008). Herbaceous plant growth in KNP for the past 50 years did not appear to be significantly affected by rainfall, this could be attributed to the many different responses of herbs in savanna environments i.e. recovery time of herbaceous plants is slow because of influences such as grazing (Duffin *et al.*, 2008). Duffin (2008) noted that the smoothing effect of bioturbation from animals in the palaeoecological record in KNP can blur the level of correspondence between pollen records and rainfall records, there was no evidence of smoothing in the MNP records and pollen records were broadly synchronous with the Mukwa and Pafuri baobab rainfall records. Chixuludzi Pan located in the *Colophospermum mopane* shrubveld at the Limpopo National Park (PNL) showed similar trends to those experienced at MNP, the abundance of grass pollen was initially very low and this was accompanied by higher levels of Cyperaceae that slightly declined towards the top of the core (ca. 2000 cal. AD) (Ekblom and Gillson, 2010b). Contrastingly, Cyperaceae pollen in Graskop and Versailles was shown to increase with time indicating wetter conditions (Breman *et al.*, 2012).

7.3.3. Fire History of Mapungubwe National Park

7.3.3.1. Cool and dry phase, late Holocene (55-32 cm; ca. 1700-1865 cal. AD)

Macroscopic charcoal was less abundant than microscopic charcoal in zone C-1, indicating that the charcoal content was possibly an indicator of regional fires rather than local fires at CP (Fig 6.9). The high abundance of microscopic charcoal may be indicative of high temperature fires as such fires commonly produce brittle charcoal particles that are prone to breakage whilst in transport (Scott, 2010).

Although some Asteraceae types e.g. *Dicoma tomentosa* and *Geigeria acaulis* are common in the Limpopo Valley and MNP, and mostly indicative of disturbed environments, the presence of these pollen grains may not directly indicate in-situ fire events but rather give a regional indication of fire disturbances in the surrounding landscapes as Asteraceae pollen have good long distance dispersal capabilities (Hamilton, 1970, Van der Walt, 2009).

Anthropogenic activity is recognised as possible cause of landscape change. The 1700 AD decline in riparian taxa at KNP and PNL has been attributed to human influences such as cultivation and forest clearance (Ekblom *et al.*, 2012).

7.3.3.2. Cool moist phase, late Holocene (ca. 1865-1945 cal. AD)

Increasing microscopic charcoal counts were found at CP from ca. 1865-1940 cal. AD suggestive of more frequent regional fire events. Cross-correlation analyses show that negative trends existed between macroscopic and microscopic charcoal and woody vegetation pairings for CP and LRP (Fig 6.9, 6.10). The higher abundance of microscopic charcoal in this zone could possibly be indicative of low intensity fires that produced a low proportion of macroscopic charcoal and may have had no effect on the tree mortality of fire resistant savanna woodland taxa in the area. According to Breman *et al.* (2012) no correlations were found between the savanna taxa and microscopic charcoal pairings at the grass dominated ecosystem of Graskop either.

7.3.3.3. Dry phase, very late Holocene (ca. 1945-1960 cal. AD)

The high variability in microscopic charcoal from ca. 1945 cal. AD to ca. 1960 cal. AD may indicate infrequent regional burning (Fig 6.9, Fig 6.10). There is also a dramatic dip in macroscopic charcoal and microscopic charcoal at CP and LRP for the most part of this phase suggesting that fire may not have been or regular occurrence. From the species composition of the MNP record we can deduce that warm woody savanna taxa were minimally affected these remained consistent and were able to withstand a variety of environmental perturbations (fire, drought, temperature and more).

7.3.3.4. Dry to moist transition phase, very late Holocene (ca. 1960-1985 cal. AD)

Charcoal particles of the size classes >200 µm and 125-200 µm were relatively consistent after ca. 1960 at CP and LRP. After ca. 1970 cal. AD there was a noticeable influx in 63-125 µm microscopic charcoal suggesting that there could have been a frequent occurrence of regional fires (Fig 6.9, Fig 6.10). In a study analysing factors that determined the establishment of woody cover in African savannas, Sankaran *et al.* (2005) found that sites with frequent fires that were on sandy sediments could sustain high levels of woody cover. It is possible that the effect of fire on woody cover at MNP was not adverse owing to the sandy nature of the sediments and the ability of some savanna woods to resist fires.

Table 7.1. Summary of palaeoenvironmental dynamics at Mapungubwe National Park.

Time period (cal. AD)	Inferred palaeoenvironmental trends	Inferred fire history
<i>Cool and dry phase</i> ca. 1700-1865	Cool dry conditions in this period were broadly contemporaneous with the LIA, there were marked by declines in arid woodland savanna taxa and Cyperaceae indicating reduced local moisture. A transition to warmer wetter conditions occurred after ca. 1800 cal. AD.	Phases marked with increases in microscopic charcoal suggesting possibly frequent, high intensity regional fire activity
<i>Cool moist phase</i> ca. 1865-1945	Generally low rainfall and temperature conditions marked by a decline in aquatics, riparian and warm savanna taxa. Incidents of increased local moisture availability were reflected by peaks in Cyperaceae.	Increase in microscopic charcoal. The charcoal record reflected that this could be a regional fire signal.
<i>Dry phase</i> ca. 945-1960	Pollen record supports drying conditions. Low rainfall and the reduced presence of Cyperaceae and pteridophytes reflect decreased water tables and dry local habitats.	A decrease in macroscopic and microscopic charcoal at CP and LRP could perhaps indicate infrequent and irregular local and regional fire activity due to low fuel biomass.
<i>Dry to moist transition phase</i> ca. 1960-1985	Transition from warm dry conditions indicated by Euphorbiaceae undiff. and Combretaceae undiff. to warm conditions and increased local moisture conditions marked by sharp peak in Cyperaceae.	A notable increase in 63-125 µm charcoal fragments suggesting increased regional fire activity or possibly charcoal particle fragmentation.
Warm, dry phase ca. 1985-present	Warm temperature and variable moisture conditions were inferred from the coincident occurrence of warm woodland vegetation with variable Cyperaceae.	Inconsistent increase in microscopic charcoal at CP suggests possible infrequent regional burning. Increase in occurrence of >200 µm and 125-200 µm macroscopic charcoal fragments could suggest local fire activity. This is coinciding with local burning record.

7.3.3.5. Warm, variable moisture conditions phase, recent Holocene (ca. 1985-present cal. AD)

Microscopic charcoal abundances for CP were high from ca. 1984 cal. AD to the present in zone C-4 portraying a probable regional fire signal. The LRP record showed an influx in both microscopic and macroscopic charcoal suggesting that both the local and regional fire signals may have been strong (Fig 6.9, Fig 6.10). The brittle nature of charcoal particles increases their vulnerability to breakage. The high representation of microscopic charcoal in this zone could therefore possibly be attributed to the susceptibility of larger fragments to breakage

(Mooney and Tinner, 2011). Alternatively, the peaks shown in this zone may be related to the distance of the charcoal deposit from the source area (Mooney and Tinner, 2011). This period (ca. 1984 cal. AD to present) coincided with the only available records for the fire history of MNP from AD 2001-2008 (see Appendix K) suggesting that charcoal may have been derived from local source areas. The high abundance and frequency of local fires observed in this zone may imply controlled burning by humans.

Peaks in charcoal also coincided with high levels of grass pollen insinuating that fuel biomass was sufficient. The high levels of accumulated grass may be attributed to the high local moisture conditions during the wetter oscillations of this period indicated by the Mukwa rainfall records (Therrell *et al.*, 2006). This is in agreement with observations by Van Wilgen *et al.* (2000) suggesting that increases in rainfall resulted in increased biomass and therefore greater fire frequencies within KNP.

7.4. Interpretation of ecologically significant observations

The Baobab *Adansonia digitata* and Cactaceae were found in both records (CP and LRP) albeit in low amounts and recognised as important ecological indicators. The appearance of *Adansonia* may be indicative of environmental conditions or alternatively the baobab dynamics. Cactaceae is assumed to have been anthropogenically introduced. This section provides a brief interpretation of both baobab and Cactaceae dynamics.

7.4.1. Baobab dynamics

Although not consistently occurring, the presence of *Adansonia* pollen in each zone of the LRP sequence is clearly visible (Fig 6.7). This corresponds with its appearance during the same timeframe in the CP sequence (ca. 1900 cal. AD-present). However, what is of interest is the absence of *Adansonia* prior to 1900 cal. AD, this could possibly be related to

taphonomic processes, climate and the characteristics of the species, these factors can play an equally important role. In an attempt to interpret the dynamics of *Adansonia* in the records, a review of the vegetation ecology is given.

The effects of climate change on baobabs includes the delayed maturation of fruit and low flowering productivity (Munyebvu, 2015). Baobab trees survive on "stem-water" reserves, hence why flowering can occur prior to the rainy season. This then means that "unfavourable" conditions that were persistent in previous seasons can affect the future flowering capacity and fruit bearing ability of baobabs due to the lack of resources (water and nutrient) reserves in the past season (Venter, 2012).

Due to the semi-arid nature of the savanna environment, in prolonged drought and low temperature episodes, the onset of the flowering process in newly established trees may vary ranging from 22 years in very moist environments to delays of up to 125-189 years (Venter, 2012). Therefore, ca. 1900 cal. AD could represent the onset of younger trees in close proximity to the sites, beginning to flower. Consistent flowering could relate to "peak flowering" months i.e. the months in which the largest number of trees are flowering at a given time - this can be variable and is highly dependent on the length of the flowering period (Venter, 2012). Given extended flowering periods, *Adansonia* pollen may become more abundant at a given time.

Adansonia digitata trees found in MNP and continental Africa are mostly bat-pollinated however, pollination by other mammals is possible provided the trees bear fruits, a final means of pollination is the detachment of flowers onto surrounding areas after the anthesis process (within 24 hours) (Baum *et al.*, 1998, Munyebvu, 2015, Venter, 2012). Animal browsing and the debarking of trees by elephants is thought to be a major cause of decline in baobab recruitment and could therefore limit observed pollen abundance (Munyebvu, 2015).

7.4.2. Cactaceae

Traces of Cactaceae undiff. found in low frequencies in the CP and LRP records after ca. 1700 cal. AD and ca. 1970 cal. AD respectively, suggest anthropogenic introduction. These plants are presumed to have been introduced into South Africa approximately 300 years ago by settlers into the semi-arid regions of South Africa by farmers to build fences separating the crops from wild animals (Ledwaba *et al.*, 2012). The most common species of Cactaceae and possible parent taxa currently of concern in MNP include *Cereus jamacaru* (Queen of the night), *Opuntia rosea* (Rosea cactus) and *Opuntia stricta* (Prickly pear) all of which are

category 1 alien invasive plants, measures to control these plants have been put in place in the MNP PMP (SANP, 2013). According to Spear *et al.* (2013), the abundance and richness of alien invasive species in National Parks is a function of the human population density in the areas surrounding the park. Therefore, there is a possibility that the dispersal and persistence of these alien invasive plants in the Limpopo Valley has been directly influenced by the surrounding populations.

7.5. Human impacts and disturbances

Pre-colonial land-use in MNP dates back to the Iron Age settlers in 350 AD (Huffman, 2000, Huffman, 2008). Subsequent settlers include the Bantu speaking farmers who farmed sorghum and millet (350-450 AD), the Zhizo farmers who were present in 900 AD until climates no longer permitted for agricultural production and lastly, the K2 settlers between 1000-1200 AD (Andrie, 2011, Huffman, 2000, Huffman, 2008). More recently land-uses have included cattle and game farming, military base camps, mining and currently, nature and heritage conservation, tourism, agriculture and mining in the surrounding private properties (SANP, 2013).

The low abundance of Poaceae pollen as compared to arboreal pollen found in both the CP and LRP pollen records is reflective of the naturally woody landscape of MNP and savanna environments. Another possible reason for positive tree recruitment in MNP is that the competition between trees and grasses is reduced in landscapes dominated by herbivores (Sankaran *et al.*, 2005, Ekblom and Gillson, 2010b). The palaeoreconstruction of MNP indicates a great abundance of microscopic charcoal. According to the park management plan for MNP, fires have been highly variable and almost absent from the system over the last 70 years (SANP 2013). With only recent fire records available (Appendix K), it is assumed that the majority of charcoal content was derived from regional sources, this is more plausible as the park is surrounded by a number of farms and is positioned at the boundary of two other countries (Botswana and Zimbabwe), information regarding fire activity at these sites is unknown. According to Duffin (2008) charcoal particles larger than 50 µm are sourced from a 4 km radius and particles less than 50 µm are sourced from a 13 km radius. Therefore, it is a possibility that charcoal fragments were sourced from fire activities at bordering privately owned properties and farms, such activities may have implications on the fire management of the park and they should therefore be integrated in the implemented park management plan (SANP, 2013).

Grass pollen throughout the MNP palaeoenvironmental record was predominantly low in comparison to comparable grassland environments and the fire events implied by charcoal

fragment size classes and abundances showed no specific trends, illustrating that chance episodes that are often incoherent and erratic may have existed. The low local fire signal has been attributed to climatic conditions becoming too poor to trigger fires within the local environment, and land-use changes. Instances of low rainfall conditions and lack of biomass to fuel fires due to overgrazing are believed to be the main reason for the reduced fire capabilities of the semi-arid savanna landscape (SANP, 2013).

The fire suppression programme which is currently being implemented by the Mapungubwe National Park Management Plan (MNP PMP) results in positive feedbacks for the establishment of tree cover (SANP, 2013). This allows for a higher growth potential for savanna trees therefore decreasing the chances of the trees succumbing to the flame zone (Khavhagali and Bond, 2008). Tree seedlings within the flame zone are prone to being destroyed by fires- consequently allowing the dominance of grasses. Evidence from Breman *et al.* (2011) illustrated this trend in the grass dominated landscapes of Graskop and Versailles in northeastern Mpumalanga, where pollen assemblages for the period of 150 cal. yr. BP showed an increase in grass pollen versus AP where fire was a contributing factor. This was especially the case for local fires (high macroscopic abundance) as these tended to be of higher intensity and consequently higher flame length, resulting in the *Podocarpus* forest disappearing in response to fire activity (Breman *et al.*, 2012).

The low abundance of macroscopic charcoal in the MNP record coupled with an increase in arboreal pollen versus grass pollen confirms that most of the warm woodland vegetation is fire resistant and has escaped the 'fire trap' in cases where fires were local. Kruger National Park has got a long history of prescribed burning and fire monitoring as a management practice, high intensity fires were established as a means of reducing and reversing the effects of bush encroachment in several zones of the sites (van Wilgen *et al.*, 2014). It was found that fire activity in areas exhibiting savanna traits in the KNP showed similar results to the deduced fire regime of MNP, that is, infrequent fire events due to the low biomass fuel as a result of grazing and high quantities of woody vegetation (van Wilgen *et al.*, 2014).

The main areas of concern regarding fire in MNP are: maintaining the integrity of the environmental and cultural landscape and sustaining the biodiversity of the ecosystem for example, the preservation of rock art as these paintings are believed to flake with fire, and conserving the already vulnerable gallery forest (SANP, 2013). Fire is not seen as a major concern in MNP due to the rarity of fire events within the reserve (SANP, 2013). The most important plan of action is therefore the monitoring of fire events in order to inform decisions regarding the protection of local biodiversity (SANP, 2013).

7.6. Limitations

This section serves to reflect on the assumptions and limitations to the study. Five limitations have been identified and will be discussed briefly:

1. Dating uncertainty: Only two radiocarbon dates were determined for each core (CP and LRP) and these reflected young sediments which can prove to be problematic. The dates showed a large error of ± 30 years, illustrating that the dates may not necessarily correspond with the deduced vegetation trends and fire history. Another limitation of young records is that trends cannot be compared to older records.
2. Effects of bioturbation: Photographic evidence from CP illustrates bioturbation by herbivores (possibly large herbivores such as elephants) (Fig 4.3). This could have had implications on the pollen and charcoal records.
3. Overrepresentation of local taxa: In both the CP and LRP records, the high presence of Cyperaceae pollen is largely reflective of a local moisture signal, affecting the ability to reconstruct regional climates for the Limpopo Valley.
4. Time lag between climate and vegetation response: The very short time frames represented by the CP and LRP records limit the extent to which vegetation response to climate change can be observed. The recorded changes are likely more reflective of changes in local ecosystem conditions as the records are too young to show major regional climate and vegetation change.
5. Flowering time lag: It is assumed that trees are flowering consistently. However, it is recognised that despite tree growth flowering may not occur for all trees each flowering season. This has an effect on the representation of certain species in the pollen assemblage at a given time.

Despite the aforementioned limitations, the study of palaeoreconstruction of CP and LRP has been useful in inferring the type of vegetation present and as result indicating possible local climatic conditions. The response of woody vegetation, grasses and aquatics in small study sites to variable local conditions and the relationship between tree-grass recruitment and fire activity in an arid savanna ecosystem is demonstrated. Duffin (2008) found that fossil pollen and charcoal records from short sedimentary records (50 years) from the KNP were useful in illustrating the role of fire in maintaining tree-grass coexistence in savanna environments. In addition, it was highlighted that Cyperaceae pollen an indicator of sedges

which are representative of moist or wetland-like conditions was useful in indicating water availability in small basins of KNP (Duffin, 2008). In agreement, Ekblom and Gillson (2010a) showed that short-term palaeorecords from KNP and PNL facilitated the understanding of the sensitivity of woody and riparian vegetation cover to different fire management policies. The CP and LRP palaeorecords provide a useful high resolution, short-term record of species present and their sensitivities to local ecosystem changes and disturbances in MNP.

7.7. Conclusion

The general trends observed in the correlation analyses (Fig 6.11, 6.12) corresponded well with evidence from the pollen (Fig 6.5, 6.6, 6.7, 6.8), charcoal (Fig 6.9, 6.10) and summary diagrams (Fig 6.13). We can conclude that the levels of correspondence between each site were variable, however there were strong consistencies observed at both sites between the charcoal versus woody vegetation, woody vegetation versus grasses and aquatics versus grasses trends. Macroscopic charcoal trends at both sites showed negative correlations with woody vegetation. The effects of ecological dynamics between 1700 cal. AD to the present day do not appear to have been significant because vegetation dynamics in MNP do not depict extreme changes at both study sites (CP and LRP). Changes that were evident occurred at a micro-scale and spanned for short periods at a time. Results derived from sites in the PNL and KNP concur with these conclusions (Ekblom and Gillson 2010). The high abundance of herbs in the study site LRP can be attributed to the high species diversity of each taxon. Fire is not identified as a direct influence on the vegetation dynamics of MNP as most of the record indicates regionally sourced charcoal particles hence, extra-local fires. Macroscopic charcoal particles in the recent fire record can be accounted for by the recorded fire history of MNP from 2000-2008 and are an indication of controlled burning (SANP 2010) (Appendix K). This however proves that fire cannot be excluded as an occurrence in the site for older dates despite the lack of records. The MNP environment has been shaped by land-use changes ranging from agriculture to mining to cattle and game farming. The appearance of Cactaceae further confirms the effects of human disturbances. The climatic trends inferred from the MNP record for the present day can be concluded as drier conditions and warmer temperatures with several phases of drought. The observed trends for the late Holocene at MNP are largely in agreement with several studies in the Limpopo Valley, with the exception of sites exhibiting grassland traits. The MNP palaeorecords have provided a high resolution short term record of local vegetation change and fire history.

CHAPTER EIGHT

CONCLUSION

8.1. Palaeoreconstruction synthesis

Environmental conditions at Mapungubwe National Park were reflective of highly variable moisture conditions experienced during the late Holocene epoch. In the middle of the LIA at ca. 1600 cal. AD initial environmental conditions at MNP were cool and dry, this was indicated by the decline in arid woodland type taxa such as Fabaceae undiff., Capparaceae undiff., Combretaceae undiff. and the low presence of riparian indicators and Cyperaceae. Evidence of cool dry conditions at MNP during the LIA was in line with evidence derived from the Pafuri baobab $\delta^{13}\text{C}$ record and the Makapansgat Valley stalagmite record (Holmgren *et al.*, 2003, Woodborne *et al.*, 2015).

The presence of monolet spores and the increase in warm woodland savanna taxa and Cyperaceae from ca. 1750 to 1800 cal. AD indicated a transition to warmer wetter conditions towards the end of the LIA. This trend was corroborated by evidence of arboreal expansion with increasing moisture conditions from the coastal forests and Miombo woodlands of Mozambique (Ekblom *et al.*, 2014). Pollen of *Adansonia* pollen appeared more frequently with the onset of wetter conditions at ca. 1900 cal. AD showing the sensitivity of the species to rainfall variation. The high abundance of microscopic charcoal fragments indicated that regional fire activity was frequent from ca. 1700 to 1865 cal. AD and that fire did not play a significant role in altering the vegetation landscape.

The Mukwa and Pafuri baobab records reflect mid-19th century decadal droughts, drought incidents and low rainfall conditions at MNP were perceived in the LRP record from ca. 1865-1945 cal. AD (Therrell *et al.*, 2006, Woodborne *et al.*, 2015). Peaks in Moraceae and Cyperaceae indicated episodes of increasing moisture at CP from ca. 1870 to early 1900 cal. AD. These high episodes of rainfall overlapped the Mukwa record for Zimbabwe from ca. 1897-1902 cal. AD (Therrell *et al.*, 2006). Fire activity from ca. 1865-1945 cal. AD reflected regional fire signals and had no effect on the tree mortality in the area. High abundances of Poaceae pollen also reflected low local fire activity.

Drying conditions evident in MNP were continued from 1945-1960 cal. AD, this is reflected in the Pafuri baobab records which show decreased rainfall conditions at this time (Woodborne *et al.*, 2015). The reduced presence of Cyperaceae and pteridophytes at MNP also indicated lowered water tables and local moisture conditions. This was supported by increases in

arboreal pollen from taxa that thrive under dry conditions such as Capparaceae undiff. and Combretaceae undiff. and, the presence of *Tribulus* and the largely succulent family Euphorbiaceae undiff. The perseverance of Poaceae in LRP can be attributed to the perennial nature of the site in wet and dry seasons (Plate 4.5). Low levels of macroscopic and microscopic charcoal indicate the high variability of regional charcoal and that fire was an infrequent and irregular occurrence, possibly due to low fuel abundances.

From ca. 1960-1985 cal. AD warm dry conditions were initially experienced in the Limpopo Valley, this was reflected by the presence of Euphorbiaceae undiff. and the consistently high occurrence of Combretaceae undiff. in the MNP sequence, both of these taxa when there is a balance of warm dry conditions. This was followed by a transition into wetter conditions reflected a sharp increase in Cyperaceae, this increase in moisture was accompanied by an increase in Poaceae, and an influx of 150µm charcoal fragments suggesting the occurrence of local fires due to increased fuel biomass. Fire activity during this period was perceived to not have had an effect on the savanna woodland taxa as these persisted through the sequence due to their fire resistance capabilities and possibly the low heat capacity of the fire. Observations of warm wet climates at MNP for ca. 1960 to 1985 cal. AD is in accordance with speleothem data from Makapansgat Valley which showed that warm and wet conditions persisted in the Limpopo Valley during this period (Huffman, 1996).

From ca. 1985 cal. AD to present declining Cyperaceae levels (this is especially evident in CP (Fig 6.7)) accompanied by increasing Poaceae levels and the presence and of warm woodland vegetation types (for example, Capparaceae undiff. And Combretaceae undiff.) were suggestive of warm temperatures and reduced moisture availability. The high proportions of macroscopic and microscopic charcoal suggested the presence of both local and regional fires. Both charcoal signals appear to peak from the early 1990s to the early 2000s and then gradually decrease to present time. However, the peaks in the macroscopic records appear to coincide with periods of known burning at MNP (Appendix K).

8.2. Review of research aim and objectives

The aim of this research was to apply palaeoenvironmental techniques to reconstruct past environmental change in Mapungubwe National Park. This was achieved through the following objectives:

1. To use an appropriate coring procedure and sampling strategy for the extraction of minimally disturbed sediment cores.

Literature pertaining to field techniques was consulted to determine the most suitable coring strategy and device to extract the sediment core. The deepest sediments within the sites were determined by inserting extendible fiberglass rods at several points. Two suitable coring sites were selected at Mapungubwe National Park and two cores (one from each site), MAP-CP13-1A (56 cm) and MAP-LRP13-4A (48 cm), were extracted using a Russian peat corer.

2. To select suitable sub-samples for the determination of calibrated radiocarbon ages by accelerator mass spectrometry (AMS) to establish chronological control.

Two suitable samples (one basal sample and one mid-depth sample) per sediment core were selected for AMS radiocarbon analysis on the basis of total core lengths and stratigraphy. The determined ages were interpolated for the remaining depths of the cores and calibrated in Classical Age Modeling (CLAM) software using the southern Hemisphere calibration curve, SHCal13 and PostbombSH. The linear interpolation curve was used to produce age-depth models, these indicated very young sediments with no age reversals (continuous/successive age estimates) for the 300 year (CP) and 100 year (LRP) records.

3. To reconstruct past vegetation change using fossil pollen analysis techniques and, past regional and local fire dynamics using microscopic and macroscopic charcoal as fire proxies, in order to infer late Holocene climatic and environmental conditions.

The CP and LRP cores were sub-sampled at a 1 cm resolution and prepared for pollen extraction using standard fossil pollen procedures adapted from reviewed literature. Using a microscope at magnifications of x400 and x1000 and, pollen reference material, a total of 56 and 48 samples were counted from CP and LRP respectively (104 samples) with a minimum of 500 absolute counts per subsample. Pollen data was differentiated according to the regional (main) and local (total: includes regional and local pollen) pollen signals. In order to facilitate interpretation, these were further separated into sub-categories according to the following identified ecological groupings: aquatics, riparian, savanna, generalist, herbs and grasses. Pollen diagrams were created for the datasets from each core and pollen zonation and dendrograms were produced using the function Constrained Incremental Sum of Squares (CONISS) (Grimm, 1987) in Psimpoll 4.27 software (Bennett, 2009).

The pollen slide technique was used to determine microscopic charcoal counts and macroscopic charcoal analysis was conducted using the macroscopic wet sieving technique (Mooney and Tinner, 2011, Whitlock and Larsen, 2002). Charcoal diagrams were created in

Psimpoll 4.27 (Bennett, 2005), showing charcoal concentrations plotted against the relevant age-depth scales and Troels-Smith stratigraphy for each sediment core, enabling the reconstruction of the past fire regime of the Limpopo Valley.

The indicator species approach was adopted for the interpretation of pollen data, this allowed for environmental indications to be determined. The derived pollen and charcoal data was used to facilitate the palaeoreconstruction of Limpopo Valley. In addition to the proxy data, a review of literature from similar savanna environments in the Limpopo Valley and surrounding areas was used to corroborate late Holocene conditions inferred from the pollen and charcoal analyses for each sediment core.

4. To compare inferred palaeoenvironmental record to land use history and previously published palaeo-records.

Literature from similar studies showing late Holocene vegetation trends and fire history in the summer and winter rainfall zones of the southern Africa was consulted for the interpretation of the results. A review of the past land-use history in MNP through the various periods of human occupation was also provided. This included the early occupation of K2 and Mapungubwe Hill, colonialist settlements in the 1900's and more recently, the use of the national park for conservation.

8.3. Conclusions

This research has provided two pollen and charcoal records from Mapungubwe National Park for the late Holocene. The ecological importance and cultural and archaeological significance of MNP and the greater Limpopo Valley warrants an understanding of the effects of environmental change and anthropogenic activity on the environment. Palaeoreconstructions of the MNP records provided insights regarding the vegetation dynamics and fire history of the Limpopo Valley region, providing an understanding of the dynamics between different vegetation types (grasses, woody and aquatics), individual taxa and fire activity. Some insight has also been provided regarding the interactions and influence of humans within the savanna ecosystem. The results rendered in this research correspond with several other studies in southern Africa. The general trend deduced was that cool dry conditions persisted from *ca.* 1700 cal. AD to *ca.* 1800 cal. AD thereafter there was a transition towards warmer wetter temperatures after 1800 cal. AD and subsequently warm dry conditions in more recent times.

Southern Africa lacks continuous high resolution palaeoenvironmental records, this is especially the case in savanna landscapes where there are shortages of suitable terrestrial archives. This study has provided a short-term record of vegetation and fire dynamics in a savanna ecosystem spanning over the past three centuries and, contributed to a body of work relating to the late Holocene palaeoenvironments in southern African savannas, improving the possibility of making reliable future climate predictions. Fire and moisture availability play a pivotal role in determining the coexistence of different vegetation types in savanna biomes, further research is required to ensure that proper management practices are employed and biodiversity is maintained.

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APPENDICES

APPENDIX A

CORE SUB-SAMPLING PROCEDURE (Faegri and Iverson, 1989):

- a. Gently remove the surface of the core with a sterilized scalpel to clean it. Do this in one direction only, parallel to the layers of the core. Wipe the scalpel with a clean cloth after every swipe.
- b. Estimate the age of the core and measure the length of the core, with these in mind select an appropriate sampling interval.
- c. Ensure that each sample is 1cm^3 when wetted by measuring 9cm^3 of distilled water in a measuring cylinder and adding sediment to the 10cm^3 mark.
- d. Transfer the sample into labeled beakers in preparation for further processing.

APPENDIX B

FOSSIL POLLEN PREPARATION PROCEDURE SAMPLES (Adapted from Faegri and Iversen (1989), Moore *et al.* (1991), Baxter (1996) and Finch (2005)):

Notes:

- Centrifuge works at a rate of 4000 rpm, unless otherwise specified.
- Use 100 ml profiled, sealable polypropylene tubes in a swing-out centrifuge.
- Water baths are done at 50-60 °C unless otherwise stated.
- All samples are label clearly.

A. Measurement of sediment

1 cm^3 wet sediment samples are used. In order to estimate this volume, 9 cm^3 of distilled water is added in a measuring cylinder. Then, sediment is added until the volume in the cylinder reaches 10 cm^3 , thus making sure that the volume is accurate.

B. Addition of pollen spike

1. The pollen spike has to be placed on a magnetic stir plate. It has to be left there for at least an hour before use.
2. Using a graduated plastic syringe add 1 ml of spike to each peat sample.

C. Removal of humic acids and clay materials (sodium hydroxide digestion)

1. Add 20 ml 15% sodium hydroxide (NaOH) to each sample and stir.
2. Place samples in a heated water bath for 10 mins and stir.
3. Use distilled water and a 180 μm sieve to wash and strain the sample.
4. Centrifuge and decant.
5. Repeat step 3 until the supernatant becomes clear.

D. Removal of clastic material (Hydrofluoric acid digestion)

1. Add 20 ml 10% Hydrochloric acid (HCl) in each sample. Stir, centrifuge and decant.
2. Add 20 ml concentrated (40%) HF in a fume cupboard. Then place the mix into polypropylene tubes in a hot water bath for 3 hours.
3. Seal the tubes, centrifuge them for 5 minutes and let them decant.
4. Add 20 ml 10% HCl. Place sample in a heated water bath for 20 mins, stirring regularly.
5. Remove from water bath, stir, centrifuge and then let it decant.

E. Acetolysis digestion of extraneous organic detritus.

1. Add 20 ml glacial acetic acid. Stir, centrifuge and decant. Make sure the supernatant is fully removed to avoid remaining acetic acid from reacting with the acetolysis mixture.
2. Add 20 ml acetolysis mixture (9 parts acetic anhydride ($[\text{CH}_3\text{CO}]_2\text{O}$) and 1 part concentrated sulphuric acid $[\text{H}_2\text{SO}_4]$). Heat it for 10-15 mins, stirring regularly.
3. Remove it from the hot water and place it in cold water to stop the reaction. Stir, centrifuge and decant again.
4. Add 20 ml glacial acetic acid. Stir, centrifuge and decant.
5. To neutralize the sample add 9 ml distilled water and 1 ml 10% NaOH.
6. Rinse 3 times with distilled water.
7. Add two drops of safranin stain to the last rinse.
8. Add 5 ml tertiary-Butanol (TBA), stir, centrifuge and decant.
9. Add 5 ml TBA, transfer the sample from the polypropylene tube into a labeled 30 ml storage vial.

F. Mounting

1. Leave the solution in a refrigerator overnight to settle it. Then, using a glass pipette, remove all the clear liquid.
2. Place a single drop of Aquatex mounting solution on a sterile glass microscope slide.
3. Take 3 drops of the pollen solution using a micropipette. Add to the Aquatex, using a toothpick to mix the pollen suspension evenly within the Aquatex.
4. Place a coverslip over the Aquatex suspension and let the mixture spread to all edges. This may be aided by applying light pressure with a dissecting needle.
5. Leave the slide still for 4 hours prior to counting, to allow the pollen to disperse evenly across the slide.

APPENDIX C

POLLEN REFERENCE SLIDE PREPARATION

Source: *adapted from Baxter (1996) and Finch (2004)*

A. Chemical preprocessing

1. Place specimen in a polypropylene tube.
2. Add 20 ml 10% NaOH to the specimen in the tube and stir it.
3. Place the tube in a heated water bath for 5 mins, stir regularly.
4. Strain and rinse through a 200 μm mesh sieve. Gently crush the material on the screen and rinse through with distilled water.
5. Centrifuge and decant.
6. Transfer the contents into a 10 ml centrifuge tube using glacial acetic acid. Stir, centrifuge and decant.
7. Add 20 ml acetolysis mixture (9 parts acetic anhydride ($[\text{CH}_3\text{CO}]_2\text{O}$) and 1 part concentrated sulphuric acid $[\text{H}_2\text{SO}_4]$) in a fume cupboard. Then place in a heated water bath for 5 minutes, stirring regularly.
8. To stop the reaction, remove from water bath and place in cold water for a few seconds.
9. Stir, centrifuge and decant.
10. Rinse the mix 3 to 5 times with distilled water.
11. Add 1-3 drops of safranin stain to the final rinse.
12. Rinse in a mild phenol solution to prevent bacteriological and fungal spoilage,.
13. Drain the tubes on to blotting paper.

B. Mounting

1. Clean and label the microscope slides. 3 replicates for each specimen should be used.
2. Cut the glycerine jelly (ideally a phenol impregnated brand) into small cubes. Then, collect pollen grains/spores from the blotting paper and wipe the glycerine jelly on the inside of the tube to pick up the pollen residue.
3. Place the glycerine jelly in the microscope slide and heat the slide over a heating plate to melt the jelly. Care must be not to allow the jelly to boil. This will cause the texture of the jelly and the structure of the pollen to be damaged.
4. Using a dissecting needle, lower a coverslip over the jelly. While the jelly is allowed to cool and set, invert the slide to allow for the grains to settle on the inside of the

coverslip, ensuring that pollen grains settle in the same focal plane.

5. After the jelly has set, scrape off the excess that may have been forced out from the coverslip.
6. Clear nail varnish should be painted around the edge of the coverslip to act as a sealant.

APPENDIX D

CHARCOAL PROCESSING

Macroscopic wet sieving procedure (Mooney and Tinner, 2011; Whitlock and Larsen, 2002).

Processing

1. Add 10cm³ of sodium hexametaphosphate solution into each 1cm³ sub-sample and stir till completely dissolved.
2. Leave the beakers covered for at least 24 hours.
3. Wash each sample through a series of 200µm, 125µm and 63µm sieves to obtain a sample for each size class.
4. Transfer each sample into labelled containers and place in the fridge for preservation.

Wet Splitting

1. Secure all the stoppers in the wet splitter and clamp the rubber tube upwards so as to avoid water spillage.
2. Fill the wet splitter to the 2.5 litre mark with distilled water.
3. Empty out each sample into the wet splitter; wait for the charcoal to settle into each segment at the base.
4. Release excess water into the sink by unclamping the rubber tube.
5. Empty out the charcoal fragments from the segments into beakers, then transfer to labeled vials. For a quarter of the sample you empty out two segments into one beaker; for an eighth of the sample you empty out one segment.

APPENDIX E

INTERPOLATED CALIBRATED AGES

Croc Pan

Depth	Cal. Min date	Cal. Max date	Best Date
0	2011	2015	2013
1	2003	2013	2009
2	1995	2013	2004
3	1985	2012	2000
4	1977	2010	1995
5	1968	2009	1990
6	1959	2007	1986
7	1951	2005	1981
8	1943	2003	1976
9	1935	2001	1971
10	1927	1998	1966
11	1919	1995	1961
12	1911	1992	1955
13	1903	1989	1950
14	1895	1985	1945
15	1887	1981	1939
16	1880	1977	1934
17	1872	1973	1928
18	1864	1969	1922
19	1857	1964	1916
20	1849	1960	1911
21	1843	1955	1905
22	1835	1950	1898
23	1828	1945	1892
24	1821	1940	1886
25	1813	1934	1880
26	1806	1929	1873
27	1798	1923	1867
28	1791	1917	1860
29	1783	1911	1854
30	1776	1905	1847
31	1769	1899	1840
32	1762	1893	1833
33	1754	1886	1826
34	1747	1878	1819
35	1740	1871	1812
36	1733	1865	1805

Depth	Cal. Min date	Cal. Max date	Best Date
37	1725	1859	1797
38	1717	1852	1790
39	1709	1844	1782
40	1701	1837	1775
41	1693	1830	1767
42	1683	1822	1760
43	1674	1815	1752
44	1663	1809	1744
45	1652	1803	1736
46	1638	1797	1728
47	1625	1794	1720
48	1610	1790	1711
49	1595	1787	1703
50	1579	1784	1695
51	1563	1781	1686
52	1546	1780	1678
53	1529	1778	1669
54	1511	1775	1660
55	1493	1774	1651

Leokwe Rock Pool

Depth	Cal. Min date	Cal. Max date	Best Date
0	2011	2015	2013
1	2008	2013	2011
2	2005	2012	2008
3	2002	2011	2006
4	1998	2010	2004
5	1995	2008	2001
6	1991	2006	1999
7	1986	2005	1996
8	1982	2002	1994
9	1977	2000	1991
10	1972	1998	1988
11	1967	1995	1985
12	1962	1992	1983
13	1958	1989	1980
14	1953	1986	1977
15	1948	1983	1974
16	1942	1979	1971
17	1936	1976	1968
18	1931	1972	1964
19	1926	1968	1961

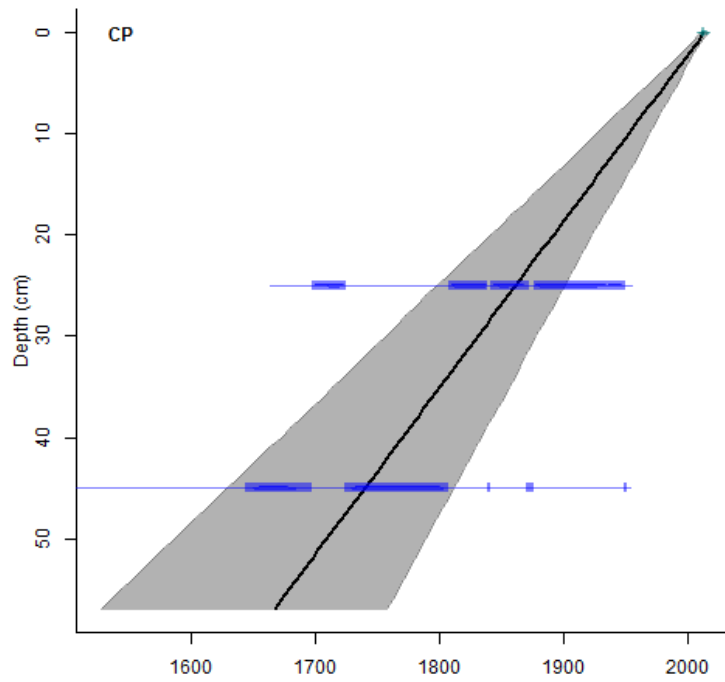
Depth	Cal. Min date	Cal. Max date	Best Date
20	1919	1964	1958
21	1913	1960	1955
22	1906	1955	1951
23	1899	1953	1948
24	1894	1951	1945
25	1890	1949	1941
26	1885	1947	1937
27	1880	1945	1934
28	1877	1943	1930
29	1873	1942	1926
30	1870	1940	1923
31	1866	1938	1919
32	1863	1937	1915
33	1860	1935	1911
34	1857	1933	1907
35	1853	1932	1903
36	1850	1931	1899
37	1847	1930	1895
38	1843	1929	1891
39	1839	1927	1886
40	1832	1926	1882
41	1825	1926	1878
42	1816	1925	1873
43	1807	1924	1869
44	1798	1923	1864
45	1789	1923	1860
46	1779	1922	1855
47	1769	1922	1850

APPENDIX F

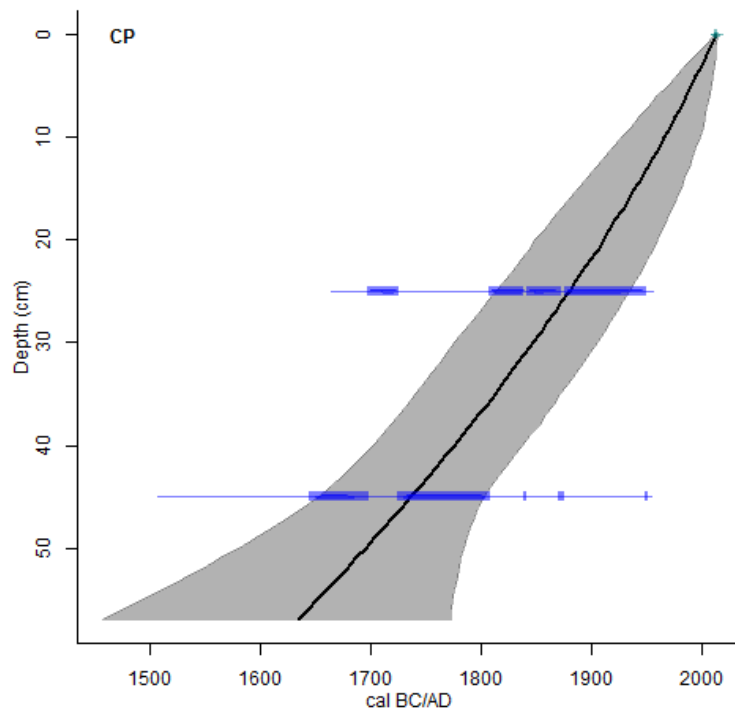
AGE-DEPTH MODELS

Croc Pan

Polynomial regression

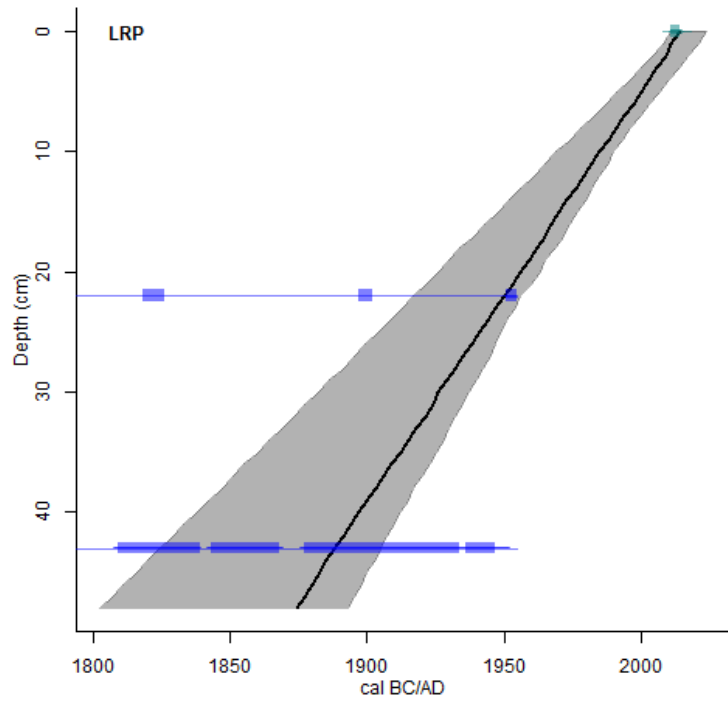


Cubic spline

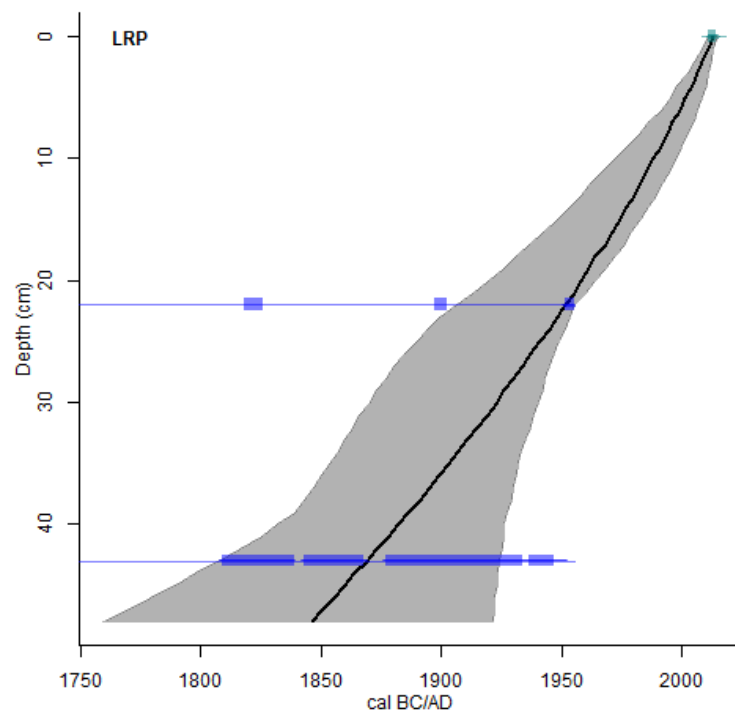


Leokwe Rock Pool

Polynomial regression



Cubic Spline



APPENDIX G

RAW POLLEN COUNTS

Leokwe Rock Pool

Depth	11	12	13	14	15	16	17	18	19	20	21
Marker count	71	78	86	80	82	79	73	65	60	59	52
BORAGINACEAE <i>Cordia</i>	0	8	0	0	0	13	0	0	0	0	0
OLEACEAE <i>Olea</i>	0	0	1	1	0	1	0	0	0	0	5
ANACARDIACEAE undiff.	30	9	0	0	26	0	19	27	0	0	34
BOMBACACEAE <i>Adansonia</i>	0	0	0	0	17	7	0	0	7	29	5
BURSERACEAE undiff.	17	12	6	3	5	1	1	4	0	0	9
FABACEAE undiff.	20	41	31	32	54	48	47	36	12	6	4
KIRKIACEAE <i>Kirkia</i>	7	7	0	0	0	0	0	0	0	5	2
TILIACEAE <i>Grewia</i>	0	0	0	2	0	0	0	0	0	0	0
CAPPARACEAE undiff.	11	0	9	0	0	21	34	42	23	27	19
CUCURBITACEAE undiff.	6	0	0	0	0	0	1	1	0	4	0
CONVOLVULACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
EBENACEAE undiff.	27	32	29	31	26	17	32	14	12	8	21
EBENACEAE <i>Euclea</i>	0	0	0	1	1	3	2	13	14	12	11
HYACINTHACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
CACTACEAE undiff.	0	0	0	0	1	2	0	0	0	0	0

ACANTHACEAE undiff.	35	44	42	34	21	31	15	27	41	32	35
AMARANTHACEAE undiff.	0	0	0	14	21	22	12	13	11	0	11
APOCYNACEAE undiff.	0	0	11	13	17	0	0	0	0	1	0
ASTERACEAE undiff.	4	1	0	0	3	3	0	0	0	0	3
EUPHORBIACEAE undiff.	43	52	51	57	14	22	17	29	34	12	12
LAMIACEAE undiff.	14	0	0	0	0	0	0	2	1	1	3
LILIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
MALVACEAE undiff.	81	72	79	68	71	75	82	75	93	81	56
RUBIACEAE undiff.	11	0	0	1	1	0	0	0	0	0	0
SOLANACEAE undiff.	62	87	99	85	72	89	97	98	101	106	98
ZYGOPHYLLACEAE <i>Tribulus</i>	1	0	4	3	0	0	0	0	0	0	0
POACEAE undiff.	62	61	60	56	54	53	52	46	50	73	78
CYPERACEAE	36	11	29	43	54	42	28	15	47	38	41
PTERIDOPHYTA Monoletes	0	0	12	0	0	0	0	0	0	0	0
PTERIDOPHYTA Triletes	10	14	17	12	9	16	20	31	21	22	21
UNDETERMINED	2	6	9	6	9	1	3	1	4	5	3
TOTAL	548	529	566	536	549	545	532	538	527	516	520

Depth	22	23	24	25	26	27	28	29	30	31	32
Marker count	74	78	73	67	65	53	52	54	58	53	76

BORAGINACEAE <i>Cordia</i>	12	0	0	0	0	11	0	0	9	0	0
OLEACEAE <i>Olea</i>	1	0	0	0	0	0	0	0	1	0	0
ANACARDIACEAE undiff.	29	51	56	39	51	48	32	47	12	15	9
BOMBACACEAE <i>Adansonia</i>	0	21	0	0	0	0	0	5	2	39	16
BURSERACEAE undiff.	13	9	11	14	21	24	24	21	22	24	20
FABACEAE undiff.	11	10	13	23	33	27	37	29	63	40	27
KIRKIACEAE <i>Kirkia</i>	9	1	1	1	0	0	0	0	0	0	0
TILIACEAE <i>Grewia</i>	0	0	1	0	0	0	0	0	0	0	1
CAPPARACEAE undiff.	23	28	13	13	24	35	29	23	21	16	11
CUCURBITACEAE undiff.	0	0	0	0	0	2	0	0	0	0	0
CONVOLVULACEAE undiff.	0	0	0	0	0	0	0	0	6	11	0
EBENACEAE undiff.	28	41	31	34	21	19	14	27	12	22	13
EBENACEAE <i>Euclea</i>	4	5	1	1	11	14	10	6	2	9	11
HYACINTHACEAE undiff.	0	0	0	1	0	0	0	0	0	0	0
CACTACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
ACANTHACEAE undiff.	31	27	24	32	13	32	36	29	17	22	54
AMARANTHACEAE undiff.	0	0	0	16	0	21	17	31	0	12	11
APOCYNACEAE undiff.	0	0	1	0	0	0	3	9	0	0	1

ASTERACEAE undiff.	0	0	5	0	0	0	0	0	0	0	11
EUPHORBIACEAE undiff.	12	15	24	18	19	27	34	45	37	42	52
LAMIACEAE undiff.	3	0	0	0	0	0	0	0	0	0	0
LILIACEAE undiff.	0	0	1	0	0	0	0	0	0	0	0
MALVACEAE undiff.	38	41	49	39	37	42	23	38	51	63	74
RUBIACEAE undiff.	0	0	0	0	0	0	7	0	10	0	0
SOLANACEAE undiff.	102	97	88	98	125	87	92	66	85	69	71
ZYGOPHYLLACEAE <i>Tribulus</i>	6	0	0	6	1	0	0	0	0	0	0
POACEAE undiff.	53	54	90	72	37	41	56	41	37	40	38
CYPERACEAE	36	27	34	29	33	42	69	47	75	63	42
PTERIDOPHYTA Monoletes	12	0	0	1	3	0	0	5	2	1	0
PTERIDOPHYTA Triletes	26	27	12	13	13	14	15	16	17	18	19
UNDETERMINED	1	3	7	4	5	2	1		5	3	4
TOTAL	523	532	528	517	507	539	550	539	539	559	557

Depth	33	34	35	36	37	38	39	40	41	42	43
Marker count	57	64	69	72	61	68	71	58	52	58	60
BORAGINACEAE <i>Cordia</i>	0	0	5	10	5	2	0	0	0	0	1
OLEACEAE <i>Olea</i>	0	0	0	0	0	0	0	1	0	0	0
ANACARDIACEAE undiff.	31	41	27	32	43	29	38	42	37	33	27

BOMBACACEAE <i>Adansonia</i>	0	0	3	0	19	11	0	0	3	12	1
BURSERACEAE undiff.	25	17	14	21	24	17	20	17	14	17	16
FABACEAE undiff.	49	61	58	42	37	32	18	29	27	32	13
KIRKIACEAE <i>Kirkia</i>	0	0	0	0	0	0	0	0	0	3	7
TILIACEAE <i>Grewia</i>	1	0	0	0	0	0	2	0	0	1	0
CAPPARACEAE undiff.	11	6	15	23	17	23	19	21	13	27	39
CUCURBITACEAE undiff.	0	0	6	0	0	0	0	0	0	0	11
CONVOLVULACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
EBENACEAE undiff.	9	23	27	31	25	26	29	23	16	31	26
EBENACEAE <i>Euclea</i>	12	5	7	8	3	16	11	21	9	5	3
HYACINTHACEAE undiff.	1	1	1	0	0	0	0	0	0	0	0
CACTACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
ACANTHACEAE undiff.	33	12	19	12	12	19	39	41	48	33	42
AMARANTHACEAE undiff.	22	15	6	12	0	1	2	0	0	0	0
APOCYNACEAE undiff.	2	16	22	15	9	12	9	3	7	16	3
ASTERACEAE undiff.	8	14	7	0	0	0	1	2	4	2	1
EUPHORBIACEAE undiff.	47	9	22	12	32	19	26	34	43	10	33
LAMIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0

LILIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
MALVACEAE undiff.	39	62	47	40	52	44	89	51	49	52	42
RUBIACEAE undiff.	32	11	0	0	0	0	0	0	0	0	0
SOLANACEAE undiff.	86	97	77	92	78	98	103	99	104	89	71
ZYGOPHYLLACEAE <i>Tribulus</i>	0	0	0	0	0	0	0	0	2	1	15
POACEAE undiff.	55	51	79	71	69	84	45	62	31	62	72
CYPERACEAE	41	39	40	41	42	38	40	36	29	34	44
PTERIDOPHYTA Monoletes	0	0	0	0	0	0	1	0	0	0	0
PTERIDOPHYTA Triletes	21	12	8	2	12	12	14	15	17	21	12
UNDETERMINED	2	4	5	2	5	3	2	6	5	7	3
TOTAL	582	556	559	536	540	551	577	555	505	539	539

Depth	44	45	46	47
Marker count	54	57	55	64
BORAGINACEAE <i>Cordia</i>	6	0	0	0
OLEACEAE <i>Olea</i>	0	0	1	1
ANACARDIACEAE undiff.	33	29	25	19
BOMBACACEAE <i>Adansonia</i>	0	1	1	0
BURSERACEAE undiff.	12	11	13	9
FABACEAE undiff.	17	44	19	12
KIRKIACEAE <i>Kirkia</i>	7	0	2	1
TILIACEAE <i>Grewia</i>	0	0	0	0

CAPPARACEAE undiff.	29	41	33	29
CUCURBITACEAE undiff.	0	0	1	0
CONVOLVULACEAE undiff.	0	0	0	0
EBENACEAE undiff.	14	29	16	18
EBENACEAE <i>Euclea</i>	13	12	14	15
HYACINTHACEAE undiff.	0	0	0	0
CACTACEAE undiff.	0	0	0	0
ACANTHACEAE undiff.	39	23	16	32
AMARANTHACEAE undiff.	0	0	0	0
APOCYNACEAE undiff.	2	0	0	1
ASTERACEAE undiff.	1	1	3	3
EUPHORBIACEAE undiff.	69	32	41	37
LAMIACEAE undiff.	0	0	0	0
LILIACEAE undiff.	0	0	0	0
MALVACEAE undiff.	53	64	48	40
RUBIACEAE undiff.	0	17	1	0
SOLANACEAE undiff.	80	105	137	132
ZYGOPHYLLACEAE <i>Tribulus</i>	0	0	0	0
POACEAE undiff.	55	34	36	43
CYPERACEAE	38	33	43	46
PTERIDOPHYTA Monoletes	0	1	0	0
PTERIDOPHYTA Triletes	21	9	11	7
UNDETERMINED	2	1	4	5
TOTAL	543	543	516	509

Croc Pan

Depth	0	1	2	3	4	5	6	7	8	9	10
Marker count	62	64	71	54	56	54	65	66	62	53	50
MORACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
ANACARDIACEAE undiff.	4	1	16	0	24	45	32	23	43	31	16
BOMBACACEAE <i>Adansonia</i>	3	0	10	9	8	11	31	7	14	22	61
BURSERACEAE undiff.	1	3	0	0	0	0	0	1	0	0	0
COMBRETACEAE	31	25	32	29	39	21	17	24	29	33	39
FABACEAE undiff.	43	58	66	31	78	67	21	36	38	59	69
<i>KIRKIACEAE Kirkia</i>	11	11	0	0	1	0	13	7	0	0	3
TILIACEAE <i>Grewia</i>	0	0	0	0	0	0	0	0	2	0	0
CAPPARACEAE undiff.	65	92	82	112	131	67	76	81	89	76	122
CUCURBITACEAE undiff.	0	15	0	0	0	0	12	0	0	0	0
HYACINTHACEAE undiff.	1	0	0	2	0	11	1	12	0	0	0
ASPHODELACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
CACTACEAE undiff.	9	2	0	0	0	0	0	0	6	0	0
ACANTHACEAE undiff.	42	53	40	34	76	62	43	51	11	37	22
AMARANTHACEAE undiff.	25	28	11	20	1	31	0	0	1	0	16
AMARYLLIDACEAE undiff.	0	0	0	2	0	0	3	2	0	0	1
ASTERACEAE undiff.	15	18	39	2	16	6	1	11	23	16	4
EUPHORBIACEAE undiff.	5	13	7	0	0	0	16	0	23	14	0
LAMIACEAE undiff.	1	0	0	0	0	0	0	0	0	1	0
LILIACEAE undiff.	3	1	1	0	1	0	0	0	0	0	0
MALVACEAE undiff.	19	12	6	13	1	11	0	0	0	1	0

RUBIACEAE undiff.	0	0	5	0	12	4	23	7	9	11	2
SOLANACEAE undiff.	8	0	0	13	0	7	27	0	21	0	0
ZYGOPHYLLACEAE <i>Tribulus</i>	0	0	0	0	0	0	0	0	0	0	0
POACEAE undiff.	101	66	77	87	51	55	61	51	54	81	32
CYPERACEAE	67	121	64	34	38	29	31	147	99	137	131
PTERIDOPHYTA Monoletes	47	18	23	37	26	19	7	10	2	0	13
PTERIDOPHYTA Triletes	3	3	7	3	2	0	0	0	0	0	0
UNDETERMINED	25	12	13	14	19	14	10	17	17	11	12
TOTAL	566	604	557	482	561	500	480	536	526	572	581

Depth	11	12	13	14	15	16	17	18	19	20	21
Marker count	54	55	57	61	65	70	67	73	70	74	71
MORACEAE undiff.	3	1	1	2	0	0	0	1	0	1	0
ANACARDIACEAE undiff.	23	17	19	0	2	15	34	17	13	7	0
BOMBACACEAE <i>Adansonia</i>	11	6	8	19	1	22	14	9	0	0	1
BURSERACEAE undiff.	2	0	0	1	0	2	0	0	4	0	0
COMBRETACEAE	18	47	42	36	41	23	28	21	10	14	6
FABACEAE undiff.	34	71	96	79	85	15	47	56	64	36	85
<i>KIRKIACEAE Kirkia</i>	0	0	0	0	0	0	0	37	11	0	8
TILIACEAE <i>Grewia</i>	5	0	0	0	0	0	0	0	0	0	0
CAPPARACEAE undiff.	128	110	129	151	131	152	107	96	131	126	92
CUCURBITACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
HYACINTHACEAE undiff.	0	0	0	0	0	1	1	4	0	0	2
ASPHODELACEAE undiff.	0	0	0	0	0	0	1	0	0	0	0
CACTACEAE undiff.	0	0	0	0	0	0	4	15	0	0	0

ACANTHACEAE undiff.	53	66	56	81	67	72	79	57	54	51	58
AMARANTHACEAE undiff.	26	31	23	52	36	17	0	0	12	0	0
AMARYLLIDACEAE undiff.	2	0	1	1	3	0	3	1	0	0	0
ASTERACEAE undiff.	12	16	7	0	13	14	17	9	0	0	21
EUPHORBIACEAE undiff.	0	32	12	0	27	0	0	29	12	17	0
LAMIACEAE undiff.	0	1	0	0	1	2	1	0	0	0	0
LILIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
MALVACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
RUBIACEAE undiff.	2	0	0	1	1	1	4	0	3	9	1
SOLANACEAE undiff.	0	0	16	0	0	0	4	0	0	11	0
ZYGOPHYLLACEAE <i>Tribulus</i>	0	0	0	0	0	0	0	0	0	0	0
POACEAE undiff.	14	19	18	12	12	17	22	17	15	76	53
CYPERACEAE	155	112	123	114	96	132	132	127	151	167	164
PTERIDOPHYTA Monoletes	7	12	22	9	0	1	12	9	13	19	13
PTERIDOPHYTA Triletes	0	1	0	0	0	0	0	0	0	0	0
UNDETERMINED	15	14	12	12	14	18	27	11	11	25	15
TOTAL	549	597	630	619	581	556	577	578	563	608	575

Depth	22	23	24	25	26	27	28	29	30	31	32
Marker count	80	62	59	77	78	71	89	62	66	65	57
MORACEAE undiff.	0	0	0	0	0	0	5	0	0	0	4
ANACARDIACEAE undiff.	0	12	11	0	16	26	9	11	9	12	22
BOMBACACEAE <i>Adansonia</i>	0	11	2	7	15	0	0	0	0	0	0
BURSERACEAE undiff.	0	2	1	0	0	1	0	2	2	1	1

COMBRETACEAE	11	9	10	11	13	5	6	5	7	7	10
FABACEAE undiff.	67	23	19	26	31	24	32	46	51	78	71
<i>KIRKIACEAE Kirkia</i>	31	0	0	0	1	0	1	16	0	0	0
TILIACEAE <i>Grewia</i>	0	3	0	0	0	0	1	0	1	0	0
CAPPARACEAE undiff.	87	102	132	156	133	99	139	100	121	113	89
CUCURBITACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
HYACINTHACEAE undiff.	0	0	1	1	0	0	1	2	1	0	0
ASPHODELACEAE undiff.	0	0	0	0	0	0	1	0	0	0	0
CACTACEAE undiff.	7	2	0	0	0	0	0	1	0	1	0
ACANTHACEAE undiff.	12	48	23	46	41	36	0	12	0	0	0
AMARANTHACEAE undiff.	10	6	1	23	37	27	16	12	0	11	21
AMARYLLIDACEAE undiff.	0	1	1	1	0	0	0	0	2	1	1
ASTERACEAE undiff.	4	0	0	1	16	21	19	27	11	4	18
EUPHORBIACEAE undiff.	0	0	0	0	0	7	2	0	9	17	7
LAMIACEAE undiff.	0	0	0	0	0	0	0	2	6	0	0
LILIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
MALVACEAE undiff.	0	0	0	0	0	0	0	2	6	0	0
RUBIACEAE undiff.	0	3	17	6	4	2	2	1	0	1	3
SOLANACEAE undiff.	1	0	10	9	0	0	0	0	14	0	0
ZYGOPHYLLACEAE <i>Tribulus</i>	0	0	1	0	0	0	0	0	0	0	0
POACEAE undiff.	61	15	22	17	18	25	29	32	35	64	24
CYPERACEAE	201	231	234	175	168	182	174	211	231	172	199
PTERIDOPHYTA Monoletes	7	25	8	16	15	11	10	19	5	31	22
PTERIDOPHYTA Triletes	0	0	0	0	0	0	0	1	2	0	0
UNDETERMINED	13	11	17	12	11	32	24	25	28	16	14

TOTAL	579	555	552	572	586	537	536	564	579	578	549
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Depth	33	34	35	36	37	38	39	40	41	42	43
Marker count	60	68	61	70	72	67	68	62	79	73	67
MORACEAE undiff.	1	0	0	6	0	0	0	2	1	0	0
ANACARDIACEAE undiff.	0	10	7	11	18	21	9	0	0	16	27
BOMBACACEAE <i>Adansonia</i>	0	0	0	0	0	0	0	0	0	0	0
BURSERACEAE undiff.	2	0	0	1	0	2	3	1	0	0	1
COMBRETACEAE	14	12	21	27	19	23	16	11	13	14	15
FABACEAE undiff.	89	92	111	76	121	101	97	102	63	57	83
KIRKIACEAE <i>Kirkia</i>	0	0	0	0	0	0	0	0	0	0	0
TILIACEAE <i>Grewia</i>	0	0	0	0	1	0	0	0	0	0	1
CAPPARACEAE undiff.	91	87	91	124	116	96	112	91	79	104	105
CUCURBITACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
HYACINTHACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
ASPHODELACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
CACTACEAE undiff.	0	0	0	1	0	0	2	0	0	0	0
ACANTHACEAE undiff.	22	31	30	23	0	0	37	45	51	41	35
AMARANTHACEAE undiff.	17	12	6	0	11	0	0	0	6	1	12
AMARYLLIDACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE undiff.	3	0	12	17	11	21	9	11	19	0	0
EUPHORBIACEAE undiff.	15	13	1	0	3	6	12	4	17	13	0
LAMIACEAE undiff.	1	0	0	0	0	0	0	4	0	0	0
LILIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0

MALVACEAE undiff.	1	0	0	0	0	0	0	4	0	0	0
RUBIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0
SOLANACEAE undiff.	0	0	16	0	0	1	0	1	0	12	9
ZYGOPHYLLACEAE <i>Tribulus</i>	1	0	0	0	0	0	0	1	0	0	0
POACEAE undiff.	14	26	27	32	19	67	42	36	28	35	22
CYPERACEAE	207	201	162	112	137	98	121	151	201	191	135
PTERIDOPHYTA Monoletes	16	9	12	21	17	27	19	11	8	13	19
PTERIDOPHYTA Triletes	5	0	4	1	1	0	0	3	1	0	1
UNDETERMINED	15	17	17	18	19	22	12	19	19	16	14
TOTAL	559	561	561	522	546	530	547	540	566	570	532

Depth	44	45	46	47	48	49	50	51	52	53	54	55
Marker count	76	68	57	62	65	72	78	67	73	84	74	58
MORACEAE undiff.	0	0	0	0	0	0	0	0	1	0	0	0
ANACARDIACEAE undiff.	1	0	11	0	0	12	0	9	0	0	6	0
BOMBACACEAE <i>Adansonia</i>	0	0	0	0	0	0	0	0	0	0	0	0
BURSERACEAE undiff.	0	2	0	0	0	0	1	0	0	0	0	1
COMBRETACEAE	22	27	34	31	33	23	14	12	7	8	6	3
FABACEAE undiff.	101	62	71	101	94	72	61	72	96	102	89	95
KIRKIACEAE <i>Kirkia</i>	0	0	0	0	0	0	0	0	0	0	0	0
TILIACEAE <i>Grewia</i>	0	0	0	0	0	0	0	0	0	2	1	0
CAPPARACEAE undiff.	98	141	106	103	145	156	201	156	131	156	164	102

CUCURBITACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0
HYACINTHACEAE undiff.	0	1	0	0	0	1	0	0	0	0	0	2
ASPHODELACEAE undiff.	0	1	0	0	0	0	0	0	0	0	0	0
CACTACEAE undiff.	0	0	1	0	0	0	0	0	0	0	0	0
ACANTHACEAE undiff.	27	19	12	21	32	21	23	31	38	41	28	19
AMARANTHACEAE undiff.	2	0	13	0	0	1	11	0	17	12	2	0
AMARYLLIDACEAE undiff.	1	1	1	0	0	1	0	0	1	1	0	1
ASTERACEAE undiff.	21	6	10	1	12	1	0	1	4	2	6	15
EUPHORBIACEAE undiff.	4	4	0	1	1	0	13	0	12	0	0	0
LAMIACEAE undiff.	0	0	0	0	0	1	0	0	0	0	0	0
LILIACEAE undiff.	0	0	0	0	1	0	0	0	0	0	0	0
MALVACEAE undiff.	0	0	0	0	1	1	6	4	1	0	0	1
RUBIACEAE undiff.	4	5	0	0	0	0	0	7	14	19	16	7
SOLANACEAE undiff.	11	0	1	0	0	12	0	0	1	2	0	4
ZYGOPHYLLACEAE <i>Tribulus</i>	0	0	0	0	0	0	0	0	0	0	0	0
POACEAE undiff.	17	24	36	58	62	52	14	35	28	22	19	10
CYPERACEAE	161	176	161	158	128	202	117	134	162	142	119	214
PTERIDOPHYTA Monoletes	29	31	21	16	12	11	21	32	4	12	14	16

PTERIDOPHYTA Triletes	1	0	1	0	0	2	2	2	0	0	0	3
UNDETERMINED	12	13	14	17	17	15	4	8	12	6	12	24
TOTAL	576	568	536	552	586	641	562	562	590	605	544	551

APPENDIX H

RAW CHARCOAL COUNTS

Leokwe Rock Pool

Pollen slide charcoal counts

Depth	0	1	2	3	4	5	6	7	8	9	10	11
<25µm	11	9	16	2	3	15	21	11	6	12	7	3
25-75µm	72	112	67	142	133	106	98	87	65	121	98	57
75-100µm	0	0	0	2	3	1	4	2	0	1	1	0
TOTAL	83	121	83	146	139	122	123	100	71	134	106	60

Depth	12	13	14	15	16	17	18	19	20	21	22
<25µm	6	2	13	21	19	32	19	24	25	31	36
25-75µm	42	71	88	76	106	131	66	27	32	41	63
75-100µm	0	0	0	1	1	2	0	0	0	0	0
TOTAL	48	73	101	98	126	165	85	51	57	72	99

Depth	23	24	25	26	27	28	29	30	31	32	33
<25µm	12	31	16	11	27	13	9	7	24	17	15
25-75µm	79	73	81	96	102	97	76	98	67	54	78
75-100µm	0	0	0	3	1	0	0	0	0	0	0
TOTAL	91	104	97	110	130	110	85	105	91	71	93

Depth	34	35	36	37	38	39	40	41	42	43	44
<25µm	11	11	23	39	43	64	32	16	9	11	16

25-75µm	65	106	75	83	114	97	112	98	124	132	98
75-100µm	0	0	0	0	0	0	0	0	1	1	0
TOTAL	76	117	98	122	157	161	144	114	134	144	114

Depth	45	46	47
<25µm	32	21	11
25-75µm	109	113	135
75-100µm	0	1	0
TOTAL	141	135	147

Wet sieving charcoal counts

Depth	0	1	2	3	4	5	6	7	8	9	10
63µm	543	381	243	277	418	548	573	627	489	407	249
125µm	194	185	233	281	355	396	392	438	332	314	139
200µm	11	10	27	11	26	54	74	66	58	18	53
TOTAL	748	576	503	569	799	998	1039	1131	879	739	441

Depth	11	12	13	14	15	16	17	18	19	20	21
63µm	268	725	679	937	431	609	1026	709	475	294	327
125µm	21	194	159	157	186	167	190	301	219	222	345
200µm	5	21	53	9	26	14	12	8	10	19	5
TOTAL	294	940	891	1103	643	790	1228	1018	704	535	677

Depth	22	23	24	25	26	27	28	29	30	31	32
63µm	404	404	521	468	684	639	579	631	555	508	534
125µm	227	146	85	91	161	240	171	289	244	156	346
200µm	18	22	36	21	16	43	28	13	16	18	17
TOTAL	649	572	642	580	861	922	778	933	815	682	897

Depth	33	34	35	36	37	38	39	40	41	42	43
63µm	536	551	492	468	575	518	419	508	520	603	758
125µm	238	188	176	225	132	289	308	185	174	204	207
200µm	30	23	19	13	10	17	14	9	14	14	13
TOTAL	804	762	687	706	717	824	741	702	708	821	978

Depth	44	45	46	47
63µm	983	944	711	752
125µm	272	359	346	529
200µm	41	8	15	13
TOTAL	1296	1311	1072	1294

Croc Pan

Pollen slide charcoal counts

Depth	0	1	2	3	4	5	6	7	8	9	10
<25µm	5	3	8	9	4	3	6	6	9	11	3
25-75µm	32	43	89	33	99	54	85	91	40	56	34

75-100µm	1	0	0	0	0	0	5	1	2	0	0
TOTAL	38	46	97	42	103	57	96	98	51	67	37

Depth	11	12	13	14	15	16	17	18	19	20	21
<25µm	4	6	16	11	12	10	4	5	2	7	6
25-75µm	65	76	47	61	57	32	29	33	61	36	40
75-100µm	0	3	4	2	0	0	0	0	0	0	0
TOTAL	69	85	67	74	69	42	33	38	63	43	46

Depth	22	23	24	25	26	27	28	29	30	31	32
<25µm	9	11	12	13	14	15	16	21	19	11	5
25-75µm	47	42	29	33	29	16	37	12	41	33	27
75-100µm	0	0	1	2	1	2	0	0	0	0	0
TOTAL	56	53	42	48	44	33	53	33	60	44	32

Depth	33	34	35	36	37	38	39	40	41	42	43
<25µm	4	13	26	32	56	12	11	3	2	3	2
25-75µm	34	17	22	14	22	30	21	19	15	20	12
75-100µm	0	0	0	0	0	0	0	0	0	0	0

TOTAL	38	30	48	46	78	42	32	22	17	23	14
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Depth	44	45	46	47	48	49	50	51	52	53	54	55
<25µm	1	11	54	32	16	7	15	21	3	7	9	2
25-75µm	12	10	6	10	3	2	6	12	14	27	2	13
75-100µm	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	13	21	60	42	19	9	21	33	17	34	11	15

Wet sieving charcoal counts

Depth	0	1	2	3	4	5	6	7	8	9	10
63µm	140	150	179	187	251	224	206	221	234	226	208
125µm	85	45	94	85	92	97	89	150	123	161	106
200µm	14	33	15	37	39	15	16	30	23	18	22
TOTAL	239	228	288	309	382	336	311	401	380	405	336

Depth	11	12	13	14	15	16	17	18	19	20	21
63µm	272	232	159	253	178	219	192	192	295	236	174
125µm	111	85	78	77	99	83	130	93	88	114	112
200µm	18	12	12	17	15	15	19	10	20	16	28
TOTAL	401	329	249	347	292	317	341	295	403	366	314

Depth	22	23	24	25	26	27	28	29	30	31	32
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63µm	270	277	204	216	223	164	223	252	283	212	222
125µm	55	82	102	214	161	94	76	111	71	164	96
200µm	13	20	12	20	24	16	15	25	13	18	20
TOTAL	338	379	318	450	408	274	314	388	367	394	338

Depth	33	34	35	36	37	38	39	40	41	42	43
63µm	211	212	214	194	147	198	207	210	187	128	119
125µm	55	41	54	37	53	23	34	44	46	42	40
200µm	4	3	14	7	3	19	23	14	8	9	8
TOTAL	270	256	282	238	203	240	264	268	241	179	167

Depth	44	45	46	47	48	49	50	51	52	53	54	55
63µm	124	205	235	225	178	121	63	88	142	153	114	86
125µm	31	50	37	28	41	32	38	28	47	18	18	25
200µm	5	11	6	6	7	3	6	8	7	4	9	6
TOTAL	160	266	278	259	226	156	107	124	196	175	141	117

APPENDIX I

FULL SPECIES LIST FOR MAPUNGUBWE AND LIMPOPO VALLEY (Adapted from SANBI Integrated Biodiversity Information System (SIBIS) and Van der Walt (2009)).

Family	Scientific Name	Source
ACANTHACEAE	<i>Anisotes rogersii</i>	Van der Walt (2009)
ACANTHACEAE	<i>Asystasia atriplicifolia</i>	Van der Walt (2009)
ACANTHACEAE	<i>Barleria affinis</i>	PRECIS
ACANTHACEAE	<i>Barleria albostellata</i>	PRECIS
ACANTHACEAE	<i>Barleria galpinii</i>	PRECIS
ACANTHACEAE	<i>Barleria lancifolia</i>	PRECIS
ACANTHACEAE	<i>Barleria lugardii</i>	PRECIS
ACANTHACEAE	<i>Barleria senensis</i>	PRECIS
ACANTHACEAE	<i>Barleria transvaalensis</i>	PRECIS
ACANTHACEAE	<i>Blepharis aspera</i>	PRECIS
ACANTHACEAE	<i>Blepharis diversispina</i>	PRECIS
ACANTHACEAE	<i>Blepharis pruinosa</i>	PRECIS
ACANTHACEAE	<i>Blepharis subvolubilis</i>	PRECIS
ACANTHACEAE	<i>Justica matammensis</i>	Van der Walt (2009)
ACANTHACEAE	<i>Justicia flava</i>	PRECIS
ACANTHACEAE	<i>Justicia odora</i>	PRECIS
ACANTHACEAE	<i>Justicia protracta</i>	PRECIS
ACANTHACEAE	<i>Lepidagathis scrabra</i>	Van der Walt (2009)
ACANTHACEAE	<i>Megalochlamys revoluta</i>	PRECIS
ACANTHACEAE	<i>Megaloclamys revoluta</i>	Van der Walt (2009)
ACANTHACEAE	<i>Monechma debile</i>	PRECIS
ACANTHACEAE	<i>Monechma divaricatum</i>	PRECIS
ACANTHACEAE	<i>Neuracanthus africanus</i>	Van der Walt (2009)
ACANTHACEAE	<i>Peristrophe cliffordii</i>	PRECIS
ACANTHACEAE	<i>Peristrophe decorticans</i>	Van der Walt (2009)
ACANTHACEAE	<i>Peristrophe paniculata</i>	Van der Walt (2009)
ACANTHACEAE	<i>Petalidium aromaticum</i>	PRECIS
ACANTHACEAE	<i>Ruellia cordata</i>	Van der Walt (2009)
ACANTHACEAE	<i>Ruellia malacophylla</i>	PRECIS
ACANTHACEAE	<i>Ruellia patula</i>	Van der Walt (2009)
ACANTHACEAE	<i>Sclerochiton ilicifolius</i>	PRECIS
AIZOACEAE	<i>Galenia pubescens</i>	PRECIS

Family	Scientific Name	Source
AIZOACEAE	<i>Trianthema salsoloides</i>	PRECIS
AIZOACEAE	<i>Trianthema triquetra</i>	PRECIS
AIZOACEAE	<i>Zaleya pentandra</i>	PRECIS
AMARANTHACEAE	<i>Achyranthes aspera</i>	PRECIS
AMARANTHACEAE	<i>Alternanthera nodiflora</i>	PRECIS
AMARANTHACEAE	<i>Amaranthus praetermissus</i>	PRECIS
AMARANTHACEAE	<i>Hermbstaedtia fleckii</i>	PRECIS
AMARANTHACEAE	<i>Hermbstaedtia odorata</i>	PRECIS
AMARANTHACEAE	<i>Kyphocarpa angustifolia</i>	PRECIS
AMARANTHACEAE	<i>Pupalia lappacea</i>	PRECIS
AMARANTHACEAE	<i>Sericorema remotiflora</i>	PRECIS
AMARANTHACEAE	<i>Sericorema sericea</i>	PRECIS
AMARYLLIDACEAE	<i>Ammocharis coranica</i>	Van der Walt (2009)
AMARYLLIDACEAE	<i>Crinum crassicaule</i>	Van der Walt (2009)
AMARYLLIDACEAE	<i>Crinum walteri</i>	Van der Walt (2009)
AMARYLLIDACEAE	<i>Nerine gaberonensis</i>	PRECIS
AMARYLLIDACEAE	<i>Pancratium tenuifolium</i>	Van der Walt (2009)
ANACARDIACEAE	<i>Ozoroa paniculosa</i>	PRECIS
ANACARDIACEAE	<i>Searsia pyroides</i>	PRECIS
ANNONACEAE	<i>Artabotrys brachypetalus</i>	PRECIS
ANNONACEAE	<i>Hexalobus monopetalus</i>	PRECIS
ANTHERICACEAE	<i>Chlorophytum galpinii</i>	PRECIS
APIACEAE	<i>Alepidea peduncularis</i>	PRECIS
APIACEAE	<i>Steganotaenia araliacea</i>	PRECIS
APOCYNACEAE	<i>Adenium oleifolium</i>	Van der Walt (2009)
APOCYNACEAE	<i>Calotropis procera</i>	Van der Walt (2009)
APOCYNACEAE	<i>Gomphocarpus fruticosus</i>	Van der Walt (2009)
APOCYNACEAE	<i>Hoodia currorii</i>	Van der Walt (2009)
APOCYNACEAE	<i>Huernia zebrina</i>	PRECIS
APOCYNACEAE	<i>Marsdenia sylvestris</i>	PRECIS
APOCYNACEAE	<i>Orbea carnosa</i>	PRECIS
APOCYNACEAE	<i>Orbea maculata</i>	PRECIS
APOCYNACEAE	<i>Orbea rogersii</i>	Van der Walt (2009)
APOCYNACEAE	<i>Pergularia daemia</i>	PRECIS
APOCYNACEAE	<i>Secamone filiformis</i>	PRECIS
APOCYNACEAE	<i>Secamone parvifolia</i>	PRECIS
APOCYNACEAE	<i>Stapelia gigantea</i>	Van der Walt

Family	Scientific Name	Source
		(2009)
APOCYNACEAE	<i>Stomatostemma monteiroae</i>	PRECIS
APONOGETONACEAE	<i>Aponogeton stuhlmannii</i>	PRECIS
ASPARAGACEAE	<i>Asparagus nelsii</i>	PRECIS
ASPARAGACEAE	<i>Asparagus nodulosus</i>	PRECIS
ASPARAGACEAE	<i>Asparagus suaveolens</i>	PRECIS
ASTERACEAE	<i>Adenostemma caffrum</i>	PRECIS
ASTERACEAE	<i>Berkheya zeyheri</i>	PRECIS
ASTERACEAE	<i>Brachylaena huillensis</i>	PRECIS
ASTERACEAE	<i>Calostephane divaricata</i>	PRECIS
ASTERACEAE	<i>Conyza scabrida</i>	PRECIS
ASTERACEAE	<i>Dicoma arenaria</i>	Van der Walt (2009)
ASTERACEAE	<i>Dicoma tomentosa</i>	PRECIS
ASTERACEAE	<i>Doellia cafra</i>	Van der Walt (2009)
ASTERACEAE	<i>Felicia clavipilosa</i>	Van der Walt (2009)
ASTERACEAE	<i>Felicia mossamedensis</i>	PRECIS
ASTERACEAE	<i>Flaveria bidentis</i>	Van der Walt (2009)
ASTERACEAE	<i>Geigeria acaulis</i>	Van der Walt (2009)
ASTERACEAE	<i>Geigeria burkei</i>	PRECIS
ASTERACEAE	<i>Helichrysum argyrsphaerum</i>	Van der Walt (2009)
ASTERACEAE	<i>Helichrysum callicomum</i>	PRECIS
ASTERACEAE	<i>Helichrysum epapposum</i>	PRECIS
ASTERACEAE	<i>Helichrysum kraussii</i>	PRECIS
ASTERACEAE	<i>Helichrysum mixtum</i>	PRECIS
ASTERACEAE	<i>Helichrysum uninervium</i>	PRECIS
ASTERACEAE	<i>Laggera decurrens</i>	PRECIS
ASTERACEAE	<i>Litogyne gariepina</i>	PRECIS
ASTERACEAE	<i>Nidorella resedifolia</i>	PRECIS
ASTERACEAE	<i>Pechuel-Loeschea leubnitziae</i>	Van der Walt (2009)
ASTERACEAE	<i>Pegolettia retrofracta</i>	PRECIS
ASTERACEAE	<i>Pegolettia senegalensis</i>	Van der Walt (2009)
ASTERACEAE	<i>Psiadia punctulata</i>	PRECIS
ASTERACEAE	<i>Schistostephium crataegifolium</i>	PRECIS
ASTERACEAE	<i>Senecio viminalis</i>	PRECIS
ASTERACEAE	<i>Verbesina encelioides</i>	PRECIS
ASTERACEAE	<i>Vernonia cinerascens</i>	Van der Walt (2009)
ASTERACEAE	<i>Vernonia fastigiata</i>	PRECIS

Family	Scientific Name	Source
ASTERACEAE	<i>Versonia fastigata</i>	Van der Walt (2009)
AYTONIACEAE	<i>Asterella bachmannii</i>	PRECIS
AYTONIACEAE	<i>Asterella muscicola</i>	PRECIS
AYTONIACEAE	<i>Asterella wilmsii</i>	PRECIS
AYTONIACEAE	<i>Mannia capensis</i>	PRECIS
AYTONIACEAE	<i>Plagiochasma rupestre</i>	PRECIS
BALANITACEAE	<i>Balanites pedicellaris</i>	PRECIS
BARTRAMIACEAE	<i>Philonotis africana</i>	PRECIS
BIGNONIACEAE	<i>Catophractes alexandri</i>	PRECIS
BIGNONIACEAE	<i>Markhamia zanzibarica</i>	PRECIS
BIGNONIACEAE	<i>Rhigozum zambesiicum</i>	PRECIS
BORAGINACEAE	<i>Cordia sinensis</i>	PRECIS
BORAGINACEAE	<i>Heliotropium ciliatum</i>	PRECIS
BORAGINACEAE	<i>Heliotropium giessi</i>	Van der Walt (2009)
BORAGINACEAE	<i>Heliotropium nelsonii</i>	PRECIS
BORAGINACEAE	<i>Heliotropium ovalifolium</i>	PRECIS
BORAGINACEAE	<i>Heliotropium stringosum</i>	Van der Walt (2009)
BORAGINACEAE	<i>Heliotropium zeylanicum</i>	Van der Walt (2009)
BRYACEAE	<i>Brachymerium acuminatum</i>	PRECIS
BRYACEAE	<i>Bryum alpinum</i>	PRECIS
BRYACEAE	<i>Bryum argenteum</i>	PRECIS
BRYACEAE	<i>Bryum capillare</i>	PRECIS
BRYACEAE	<i>Bryum pycnophyllum</i>	PRECIS
BUDDLEJACEAE	<i>Nuxia congesta</i>	PRECIS
BURSERACEAE	<i>Commiphora africana</i>	PRECIS
BURSERACEAE	<i>Commiphora edulis</i>	PRECIS
BURSERACEAE	<i>Commiphora glandulosa</i>	PRECIS
BURSERACEAE	<i>Commiphora tenuipetiolata</i>	PRECIS
BURSERACEAE	<i>Commiphora viminea</i>	PRECIS
CAPPARACEAE	<i>Boscia foetida</i>	PRECIS
CAPPARACEAE	<i>Cadaba aphylla</i>	Van der Walt (2009)
CAPPARACEAE	<i>Cadaba termitaria</i>	PRECIS
CAPPARACEAE	<i>Cleome angustifolia</i>	PRECIS
CAPPARACEAE	<i>Cleome gynandra</i>	Van der Walt (2009)
CAPPARACEAE	<i>Cleome hirta</i>	PRECIS
CAPPARACEAE	<i>Cleome kalachariensis</i>	PRECIS
CAPPARACEAE	<i>Cleome monophylla</i>	Van der Walt (2009)
CAPPARACEAE	<i>Cleome oxyphylla</i>	PRECIS
CAPPARACEAE	<i>Maerua angolensis</i>	PRECIS

Family	Scientific Name	Source
CAPPARACEAE	<i>Maerua edulis</i>	PRECIS
CAPPARACEAE	<i>Maerua juncea</i>	Van der Walt (2009)
CAPPARACEAE	<i>Maerua parvifolia</i>	Van der Walt (2009)
CARYOPHYLLACEAE	<i>Polycarpaea corymbosa</i>	PRECIS
CELASTRACEAE	<i>Gymnosporia buxifolia</i>	PRECIS
CELASTRACEAE	<i>Gymnosporia senegalensis</i>	PRECIS
CELASTRACEAE	<i>Maytenus undata</i>	PRECIS
CELASTRACEAE	<i>Pterocelastrus echinatus</i>	PRECIS
CHENOPODIACEAE	<i>Chenopodium carinatum</i>	PRECIS
CHENOPODIACEAE	<i>Chenopodium cristatum</i>	PRECIS
COLCHICACEAE	<i>Gloriosa superba</i>	PRECIS
COMBRETACEAE	<i>Combretum apiculatum</i>	PRECIS
COMBRETACEAE	<i>Combretum imberbe</i>	PRECIS
COMBRETACEAE	<i>Combretum mossambicense</i>	PRECIS
COMBRETACEAE	<i>Terminalia brachystemma</i>	PRECIS
COMBRETACEAE	<i>Terminalia prunioides</i>	PRECIS
COMMELINACEAE	<i>Commelina benghalensis</i>	PRECIS
COMMELINACEAE	<i>Floscopa glomerata</i>	PRECIS
CONVOLVULACEAE	<i>Cuscuta campestris</i>	PRECIS
CONVOLVULACEAE	<i>Evolvulus alsinoides</i>	PRECIS
CONVOLVULACEAE	<i>Ipomoea magnusiana</i>	Van der Walt (2009)
CONVOLVULACEAE	<i>Ipomoea adenioides</i>	PRECIS
CONVOLVULACEAE	<i>Ipomoea coptica</i>	PRECIS
CONVOLVULACEAE	<i>Ipomoea crassipes</i>	Van der Walt (2009)
CONVOLVULACEAE	<i>Ipomoea dichroa</i>	Van der Walt (2009)
CONVOLVULACEAE	<i>Ipomoea magnusiana</i>	PRECIS
CONVOLVULACEAE	<i>Ipomoea sinensis</i>	Van der Walt (2009)
CONVOLVULACEAE	<i>Merremia kentrocaulos</i>	PRECIS
CONVOLVULACEAE	<i>Merremia palmata</i>	PRECIS
CONVOLVULACEAE	<i>Merremia pinnata</i>	PRECIS
CONVOLVULACEAE	<i>Seddera suffruticosa</i>	PRECIS

Family	Scientific Name	Source
CRASSULACEAE	<i>Kalanchoe rotundifolia</i>	PRECIS
CUCURBITACEAE	<i>Corallocarpus bainesii</i> (MNP creeper)	Van der Walt (2009)
CUCURBITACEAE	<i>Cucumis anguria</i>	PRECIS
CUCURBITACEAE	<i>Cucumis metuliferus</i>	PRECIS
CUCURBITACEAE	<i>Cucumis zeyheri</i>	Van der Walt (2009)
CUCURBITACEAE	<i>Kedrostis limpopoensis</i>	PRECIS
CUCURBITACEAE	<i>Momordica balsamina</i>	PRECIS
CYPERACEAE	<i>Bolboschoenus glaucus</i>	PRECIS
CYPERACEAE	<i>Bulbostylis hispidula</i>	PRECIS
CYPERACEAE	<i>Coleochloa pallidior</i>	PRECIS
CYPERACEAE	<i>Cyperus compressus</i>	PRECIS
CYPERACEAE	<i>Cyperus decurvatus</i>	PRECIS
CYPERACEAE	<i>Cyperus distans</i>	PRECIS
CYPERACEAE	<i>Cyperus dubius</i>	PRECIS
CYPERACEAE	<i>Cyperus fastigiatus</i>	PRECIS
CYPERACEAE	<i>Cyperus indecorus</i>	PRECIS
CYPERACEAE	<i>Cyperus iria</i>	PRECIS
CYPERACEAE	<i>Cyperus laevigatus</i>	Van der Walt (2009)
CYPERACEAE	<i>Cyperus longus</i>	PRECIS
CYPERACEAE	<i>Cyperus obtusiflorus</i>	PRECIS
CYPERACEAE	<i>Cyperus pseudokyllingioides</i>	PRECIS
CYPERACEAE	<i>Cyperus rotundus</i>	PRECIS
CYPERACEAE	<i>Cyperus rupestris</i>	PRECIS
CYPERACEAE	<i>Cyperus sexangularis</i>	PRECIS
CYPERACEAE	<i>Cyperus squarrosus</i>	PRECIS
CYPERACEAE	<i>Fimbristylis ferruginea</i>	PRECIS
CYPERACEAE	<i>Fuirena pubescens</i>	PRECIS
CYPERACEAE	<i>Kyllinga alba</i>	PRECIS
CYPERACEAE	<i>Lipocarpa chinensis</i>	PRECIS
CYPERACEAE	<i>Pycnus pelophilus</i>	Van der Walt (2009)
CYPERACEAE	<i>Pycnus unioloides</i>	PRECIS
CYPERACEAE	<i>Schoenoplectus muricinux</i>	PRECIS
CYPERACEAE	<i>Schoenoplectus senegalensis</i>	PRECIS
DICRANACEAE	<i>Campylopus catarractilis</i>	PRECIS
DICRANACEAE	<i>Campylopus robillardei</i>	PRECIS
DICRANACEAE	<i>Campylopus savannarum</i>	PRECIS
DRACAENACEAE	<i>Sansevieria aethiopica</i>	PRECIS
DRACAENACEAE	<i>Sansevieria pearsonii</i>	PRECIS
EBENACEAE	<i>Diospyros lycioides</i>	PRECIS
EBENACEAE	<i>Euclea crispa</i>	PRECIS
EBENACEAE	<i>Euclea natalensis</i>	PRECIS

Family	Scientific Name	Source
ELATINACEAE	<i>Bergia capensis</i>	PRECIS
EUPHORBIACEAE	<i>Acalypha indica</i>	PRECIS
EUPHORBIACEAE	<i>Acalypha pubiflora</i>	PRECIS
EUPHORBIACEAE	<i>Acalypha indica</i>	Van der Walt (2009)
EUPHORBIACEAE	<i>Caperonia stuhlmannii</i>	PRECIS
EUPHORBIACEAE	<i>Clutia pulchella</i>	PRECIS
EUPHORBIACEAE	<i>Croton gratissimus</i>	PRECIS
EUPHORBIACEAE	<i>Croton megalobotrys</i>	PRECIS
EUPHORBIACEAE	<i>Croton menyharthii</i>	PRECIS
EUPHORBIACEAE	<i>Croton pseudopulchellus</i>	PRECIS
EUPHORBIACEAE	<i>Dalechampia capensis</i>	PRECIS
EUPHORBIACEAE	<i>Euphorbia griseola</i>	Van der Walt (2009)
EUPHORBIACEAE	<i>Euphorbia guerichiana</i>	PRECIS
EUPHORBIACEAE	<i>Euphorbia limpopoana</i>	Van der Walt (2009)
EUPHORBIACEAE	<i>Euphorbia monteiroi</i>	PRECIS
EUPHORBIACEAE	<i>Euphorbia neopolycnemoides</i>	PRECIS
EUPHORBIACEAE	<i>Euphorbia serpens</i>	PRECIS
EUPHORBIACEAE	<i>Euphorbia tirucalli</i>	PRECIS
EUPHORBIACEAE	<i>Jatropha spicata</i>	PRECIS
EUPHORBIACEAE	<i>Tragia dioica</i>	Van der Walt (2009)
EXORMOTHECACEAE	<i>Exormotheca pustulosa</i>	PRECIS
FABACEAE	<i>Acacia burkei</i>	PRECIS
FABACEAE	<i>Acacia nigrescens</i>	PRECIS
FABACEAE	<i>Acacia nilotica</i>	PRECIS
FABACEAE	<i>Acacia robusta</i>	PRECIS
FABACEAE	<i>Acacia schweinfurthii</i>	PRECIS
FABACEAE	<i>Acacia stuhlmannii</i>	PRECIS
FABACEAE	<i>Acacia tortilis</i>	PRECIS
FABACEAE	<i>Aeschynomene indica</i>	PRECIS
FABACEAE	<i>Albizia brevifolia</i>	PRECIS
FABACEAE	<i>Chamaecrisa absus</i>	Van der Walt (2009)
FABACEAE	<i>Chamaecrista absus</i>	PRECIS
FABACEAE	<i>Chamaecrista mimosoides</i>	Van der Walt (2009)
FABACEAE	<i>Colophospermum mopane</i>	PRECIS
FABACEAE	<i>Crotalaria damarensis</i>	Van der Walt (2009)
FABACEAE	<i>Crotalaria distans</i>	Van der Walt (2009)
FABACEAE	<i>Crotalaria laburnifolia</i>	Van der Walt (2009)
FABACEAE	<i>Crotalaria schinzii</i>	PRECIS

Family	Scientific Name	Source
FABACEAE	<i>Crotalaria sphaerocarpa</i>	PRECIS
FABACEAE	<i>Crotalaria steudneri</i>	Van der Walt (2009)
FABACEAE	<i>Crotalaria heidmannii</i>	Van der Walt (2009)
FABACEAE	<i>Decorsea schlechteri</i>	Van der Walt (2009)
FABACEAE	<i>Elephantorrhiza obliqua</i>	Van der Walt (2009)
FABACEAE	<i>Eriosema psoraleoides</i>	PRECIS
FABACEAE	<i>Indigastrum costatum</i>	PRECIS
FABACEAE	<i>Indigastrum parviflorum</i>	PRECIS
FABACEAE	<i>Indigofera astragalina</i>	Van der Walt (2009)
FABACEAE	<i>Indigofera bainessi</i>	Van der Walt (2009)
FABACEAE	<i>Indigofera charlieriana</i>	PRECIS
FABACEAE	<i>Indigofera circinnata</i>	PRECIS
FABACEAE	<i>Indigofera daleoides</i>	PRECIS
FABACEAE	<i>Indigofera dolichothyrsa</i>	PRECIS
FABACEAE	<i>Indigofera enormis</i>	PRECIS
FABACEAE	<i>Indigofera flavicans</i>	PRECIS
FABACEAE	<i>Indigofera heterotricha</i>	PRECIS
FABACEAE	<i>Indigofera hochstetteri</i>	PRECIS
FABACEAE	<i>Indigofera holubii</i>	PRECIS
FABACEAE	<i>Indigofera ingrata</i>	Van der Walt (2009)
FABACEAE	<i>Indigofera melanadenia</i>	PRECIS
FABACEAE	<i>Indigofera schimperi</i>	PRECIS
FABACEAE	<i>Indigofera trita</i>	PRECIS
FABACEAE	<i>Indigofera vicioides</i>	PRECIS
FABACEAE	<i>Lotononis brachyantha</i>	PRECIS
FABACEAE	<i>Mundulea sericea</i>	PRECIS
FABACEAE	<i>Neorautanenia amboensis</i>	Van der Walt (2009)
FABACEAE	<i>Ooptera burchellii</i>	PRECIS
FABACEAE	<i>Philenoptera violacea</i>	PRECIS
FABACEAE	<i>Pterocarpus rotundifolius</i>	PRECIS
FABACEAE	<i>Ptychlobium contortum</i>	PRECIS
FABACEAE	<i>Rhyanchosia totta</i>	Van der Walt (2009)
FABACEAE	<i>Rhynchosia minima</i>	PRECIS
FABACEAE	<i>Schotia brachypetala</i>	PRECIS
FABACEAE	<i>Schotia capitata</i>	PRECIS
FABACEAE	<i>Senna italica</i>	Van der Walt (2009)
FABACEAE	<i>Sesbania bispinosa</i>	Van der Walt (2009)

Family	Scientific Name	Source
FABACEAE	<i>Sesbania sesban</i>	PRECIS
FABACEAE	<i>Stylosanthes fruticosa</i>	Van der Walt (2009)
FABACEAE	<i>Stylosanthes fruticosa</i>	PRECIS
FABACEAE	<i>Tephrosia kraussiana</i>	Van der Walt (2009)
FABACEAE	<i>Tephrosia longipes</i>	Van der Walt (2009)
FABACEAE	<i>Tephrosia polystachya</i>	PRECIS
FABACEAE	<i>Tephrosia purpurea</i>	PRECIS
FABACEAE	<i>Tephrosia retusa</i>	Van der Walt (2009)
FABACEAE	<i>Tephrosia rhodesia</i>	Van der Walt (2009)
FABACEAE	<i>Tephrosia rhodesica</i>	PRECIS
FABACEAE	<i>Tephrosia semiglabra</i>	Van der Walt (2009)
FABACEAE	<i>Tephrosia uniflora</i>	PRECIS
FABACEAE	<i>Tephrosia villosa</i>	PRECIS
FABACEAE	<i>Tephrosia villosa</i>	Van der Walt (2009)
FABACEAE	<i>Tephrosia virgata</i>	PRECIS
FABACEAE	<i>Vigna unguiculata</i>	PRECIS
FABACEAE	<i>Zornia glochidiata</i>	PRECIS
FISSIDENTACEAE	<i>Fissidens ovatus</i>	PRECIS
FISSIDENTACEAE	<i>Fissidens submarginatus</i>	PRECIS
FOSSOMBRONIACEAE	<i>Fossombronina crispera</i>	PRECIS
FOSSOMBRONIACEAE	<i>Fossombronina gemmifera</i>	PRECIS
GENTIANACEAE	<i>Swertia welwitschii</i>	PRECIS
GERANIACEAE	<i>Monsonia glauca</i>	PRECIS
GERANIACEAE	<i>Monsonia senegalensis</i>	PRECIS
GERANIACEAE	<i>Pelargonium luridum</i>	PRECIS
GISEKIACEAE	<i>Gisekia africana</i>	PRECIS
HETEROPYXIDACEAE	<i>Heteropyxis natalensis</i>	PRECIS
HYACINTHACEAE	<i>Drimia intricata</i>	PRECIS
HYCACINTHACEAE	<i>Albuca glauca</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Drima sanguinea</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Drimia altissima</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Drimia indica</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Ledebouria cooperi</i>	Van der Walt (2009)

Family	Scientific Name	Source
HYCACINTHACEAE	<i>Ledebouria luteola</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Ledebouria macowanii</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Ledebouria marginata</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Ledebouria sandersonii</i>	Van der Walt (2009)
HYCACINTHACEAE	<i>Ornithogalum seineri</i>	Van der Walt (2009)
HYDROCHARITACEAE	<i>Lagarosiphon muscoides</i>	PRECIS
KIRKIAEAE	<i>Kirkia acuminata</i>	PRECIS
LAMIACEAE	<i>Acrotome inflata</i>	PRECIS
LAMIACEAE	<i>Clerodendrum ternatum</i>	Van der Walt (2009)
LAMIACEAE	<i>Endostemon tenuiflorus</i>	PRECIS
LAMIACEAE	<i>Endostemon tereticaulis</i>	PRECIS
LAMIACEAE	<i>Leucas glabrata</i>	Van der Walt (2009)
LAMIACEAE	<i>Leonotis nepetifolia</i>	Van der Walt (2009)
LAMIACEAE	<i>Leonotis ocymifolia</i>	PRECIS
LAMIACEAE	<i>Leucas glabrata</i>	PRECIS
LAMIACEAE	<i>Leucas sexdentata</i>	Van der Walt (2009)
LAMIACEAE	<i>Ocimum americanum</i>	PRECIS
LAMIACEAE	<i>Rotheca myricoides</i>	PRECIS
LAMIACEAE	<i>Syncolostemon canescens</i>	PRECIS
LAMIACEAE	<i>Tinnea rhodesiana</i>	PRECIS
LAMIACEAE	<i>Vitex rehmannii</i>	PRECIS
LENTIBULARIACEAE	<i>Utricularia prehensilis</i>	PRECIS
LOPHIOCARPACEAE	<i>Corbichonia decumbens</i>	PRECIS
LOPHIOCARPACEAE	<i>Corbichonia rubriviolacea</i>	PRECIS
LORANTHACEAE	<i>Agelanthus natalitius</i>	PRECIS
LORANTHACEAE	<i>Agelanthus sambesiacus</i>	PRECIS
LORANTHACEAE	<i>Plicosepalus kalachariensis</i>	PRECIS
LORANTHACEAE	<i>Tapinanthus oleifolius</i>	PRECIS
LYTHRACEAE	<i>Nesaea schinzii</i>	PRECIS
MALVACEAE	<i>Abutilon angulatum</i>	PRECIS
MALVACEAE	<i>Abutilon fruitcosum</i>	Van der Walt (2009)
MALVACEAE	<i>Abutilon fruticosum</i>	PRECIS
MALVACEAE	<i>Abutilon grandiflorum</i>	PRECIS
MALVACEAE	<i>Abutilon hirtum</i>	PRECIS

Family	Scientific Name	Source
MALVACEAE	<i>Abutilon pycnodon</i>	PRECIS
MALVACEAE	<i>Abutilon ramosum</i>	PRECIS
MALVACEAE	<i>Abutilon rehmannii</i>	Van der Walt (2009)
MALVACEAE	<i>Azanza garckeana</i>	PRECIS
MALVACEAE	<i>Cienfuegosia digitata</i>	PRECIS
MALVACEAE	<i>Corchorus olitorius</i>	PRECIS
MALVACEAE	<i>Corchorus trilocularis</i>	PRECIS
MALVACEAE	<i>Gossypium herbaceum</i>	Van der Walt (2009)
MALVACEAE	<i>Grewia bicolor</i>	PRECIS
MALVACEAE	<i>Grewia flava</i>	PRECIS
MALVACEAE	<i>Grewia flavescens</i>	PRECIS
MALVACEAE	<i>Grewia villosa</i>	PRECIS
MALVACEAE	<i>Hermannia boraginiflora</i>	PRECIS
MALVACEAE	<i>Hermannia glanduligera</i>	PRECIS
MALVACEAE	<i>Hermannia modesta</i>	PRECIS
MALVACEAE	<i>Hermannia stellulata</i>	PRECIS
MALVACEAE	<i>Hibiscus caesius</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus coddii</i>	PRECIS
MALVACEAE	<i>Hibiscus dongolensis</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus engleri</i>	PRECIS
MALVACEAE	<i>Hibiscus micranthus</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus mutatus</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus palmatus</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus physaloides</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus platycaylx</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus sidiformis</i>	PRECIS
MALVACEAE	<i>Hibiscus subreniformis</i>	PRECIS
MALVACEAE	<i>Hibiscus trionum</i>	Van der Walt (2009)
MALVACEAE	<i>Hibiscus waterbergensis</i>	PRECIS
MALVACEAE	<i>Melhanian acuminata</i>	PRECIS
MALVACEAE	<i>Melhanian burchellii</i>	PRECIS
MALVACEAE	<i>Melhanian rehmannii</i>	Van der Walt (2009)
MALVACEAE	<i>Pavonia burchellii</i>	PRECIS
MALVACEAE	<i>Pavonia dentata</i>	PRECIS
MALVACEAE	<i>Pavonia dentate</i>	Van der Walt (2009)
MALVACEAE	<i>Sida cordifolia</i>	Van der Walt (2009)

Family	Scientific Name	Source
MALVACEAE	<i>Sida dregei</i>	PRECIS
MALVACEAE	<i>Sida ovata</i>	PRECIS
MALVACEAE	<i>Sida ovate</i>	Van der Walt (2009)
MALVACEAE	<i>Sida rhombifolia</i>	PRECIS
MALVACEAE	<i>Sterculia rogersii</i>	PRECIS
MALVACEAE	<i>Triumfetta rhomboidea</i>	PRECIS
MALVACEAE	<i>Waltheria indica</i>	PRECIS
MARCHANTIACEAE	<i>Marchantia debilis</i>	PRECIS
MENISPERMACEAE	<i>Cocculus hirsutus</i>	PRECIS
MENISPERMACEAE	<i>Tinospora fragosa</i>	PRECIS
MOLLUGINACEAE	<i>Glinus lotoides</i>	PRECIS
MOLLUGINACEAE	<i>Hypertelis salsoloides</i>	PRECIS
MOLLUGINACEAE	<i>Limeum fenestratum</i>	PRECIS
MOLLUGINACEAE	<i>Limeum sulcatum</i>	PRECIS
MOLLUGINACEAE	<i>Limeum viscosum</i>	PRECIS
MOLLUGINACEAE	<i>Mollugo cerviana</i>	PRECIS
MOLLUGINACEAE	<i>Mollugo nudicaulis</i>	PRECIS
MORACEAE	<i>Ficus abutilifolia</i>	PRECIS
MORACEAE	<i>Ficus salicifolia</i>	PRECIS
MORACEAE	<i>Ficus tettensis</i>	PRECIS
MYRTACEAE	<i>Syzygium guineense</i>	PRECIS
NYCTAGINACEAE	<i>Boerhavia coccinea</i>	PRECIS
NYCTAGINACEAE	<i>Boerhavia diffusa</i>	PRECIS
NYCTAGINACEAE	<i>Boerhavia erecta</i>	PRECIS
NYCTAGINACEAE	<i>Boerhavia repens</i>	PRECIS
NYCTAGINACEAE	<i>Commicarpus fallacissimus</i>	PRECIS
NYCTAGINACEAE	<i>Commicarpus pilosus</i>	PRECIS
NYCTAGINACEAE	<i>Commicarpus plumbagineus</i>	PRECIS
OCHNACEAE	<i>Ochna inermis</i>	PRECIS
OCHNACEAE	<i>Ochna pulchra</i>	PRECIS
OLACACEAE	<i>Ximenia americana</i>	PRECIS
OLEACEAE	<i>Jasminum fluminense</i>	Van der Walt (2009)
OPHIOGLOSSACEAE	<i>Ophioglossum polyphyllum</i>	PRECIS
ORCHIDACEAE	<i>Brachycorythis pubescens</i>	PRECIS
ORCHIDACEAE	<i>Brachycorythis tenuior</i>	PRECIS
OROBANCHACEAE	<i>Alectra pumila</i>	PRECIS
OROBANCHACEAE	<i>Sopubia cana</i>	PRECIS
OROBANCHACEAE	<i>Striga gesnerioides</i>	PRECIS

Family	Scientific Name	Source
PALLAVICINIACEAE	<i>Symphyogyna brasiliensis</i>	PRECIS
PAPAVERACEAE	<i>Argemone ochroleuca</i>	PRECIS
PEDALIACEAE	<i>Ceratotheca triloba</i>	PRECIS
PEDALIACEAE	<i>Dicerocaryum senecioides</i>	PRECIS
PEDALIACEAE	<i>Holubia saccata</i>	PRECIS
PEDALIACEAE	<i>Sesamothamnus lugardii</i>	PRECIS
PEDALIACEAE	<i>Sesamum triphyllum</i>	PRECIS
PHYLLANTHACEAE	<i>Antidesma venosum</i>	PRECIS
PHYLLANTHACEAE	<i>Bridelia mollis</i>	PRECIS
PHYLLANTHACEAE	<i>Flueggea virosa</i>	PRECIS
PHYLLANTHACEAE	<i>Phyllanthus parvulus</i>	PRECIS
PHYLLANTHACEAE	<i>Phyllanthus reticulatus</i>	PRECIS
PHYLLANTHACEAE	<i>Pseudolachnostylis maprouneifolia</i>	PRECIS
PLUMBAGINACEAE	<i>Plumbago zeylanica</i>	PRECIS
POACEAE	<i>Acrachne racemosa</i>	PRECIS
POACEAE	<i>Aristida adscensionis</i>	PRECIS
POACEAE	<i>Aristida canescens</i>	PRECIS
POACEAE	<i>Aristida congesta</i>	PRECIS
POACEAE	<i>Aristida meridionalis</i>	PRECIS
POACEAE	<i>Aristida rhiniochloa</i>	PRECIS
POACEAE	<i>Aristida spectabilis</i>	PRECIS
POACEAE	<i>Aristida stipitata</i>	PRECIS
POACEAE	<i>Bothriochloa insculpta</i>	PRECIS
POACEAE	<i>Bothriochloa radicans</i>	PRECIS
POACEAE	<i>Brachiaria advena</i>	PRECIS
POACEAE	<i>Brachiaria deflexa</i>	PRECIS
POACEAE	<i>Brachiaria nigropedata</i>	PRECIS
POACEAE	<i>Cenchrus ciliaris</i>	PRECIS
POACEAE	<i>Chloris roxburghiana</i>	PRECIS
POACEAE	<i>Chloris virgata</i>	PRECIS
POACEAE	<i>Cynodon dactylon</i>	PRECIS
POACEAE	<i>Dactyloctenium aegyptium</i>	PRECIS
POACEAE	<i>Dactyloctenium giganteum</i>	PRECIS
POACEAE	<i>Danthoniopsis dinteri</i>	PRECIS
POACEAE	<i>Dichanthium annulatum</i>	PRECIS
POACEAE	<i>Digitaria eriantha</i>	PRECIS
POACEAE	<i>Digitaria perrottetii</i>	PRECIS

Family	Scientific Name	Source
POACEAE	<i>Digitaria ternata</i>	PRECIS
POACEAE	<i>Dinebra retroflexa</i>	PRECIS
POACEAE	<i>Echinochloa colona</i>	PRECIS
POACEAE	<i>Elionurus muticus</i>	PRECIS
POACEAE	<i>Enneapogon cenchroides</i>	PRECIS
POACEAE	<i>Enneapogon desvauxii</i>	PRECIS
POACEAE	<i>Enneapogon scoparius</i>	PRECIS
POACEAE	<i>Enteropogon macrostachyus</i>	PRECIS
POACEAE	<i>Eragrostis aethiopica</i>	PRECIS
POACEAE	<i>Eragrostis chloromelas</i>	PRECIS
POACEAE	<i>Eragrostis cilianensis</i>	PRECIS
POACEAE	<i>Eragrostis cylindriflora</i>	PRECIS
POACEAE	<i>Eragrostis lehmanniana</i>	PRECIS
POACEAE	<i>Eragrostis nindensis</i>	PRECIS
POACEAE	<i>Eragrostis pallens</i>	PRECIS
POACEAE	<i>Eragrostis porosa</i>	PRECIS
POACEAE	<i>Eragrostis rigidior</i>	PRECIS
POACEAE	<i>Eragrostis rotifer</i>	PRECIS
POACEAE	<i>Eragrostis stapfii</i>	PRECIS
POACEAE	<i>Eragrostis superba</i>	PRECIS
POACEAE	<i>Eragrostis trichophora</i>	PRECIS
POACEAE	<i>Eriochloa meyeriana</i>	PRECIS
POACEAE	<i>Fingerhuthia africana</i>	PRECIS
POACEAE	<i>Heteropogon contortus</i>	PRECIS
POACEAE	<i>Heteropogon melanocarpus</i>	PRECIS
POACEAE	<i>Hyparrhenia hirta</i>	PRECIS
POACEAE	<i>Melinis repens</i>	PRECIS
POACEAE	<i>Microchloa caffra</i>	PRECIS
POACEAE	<i>Odyssea paucinervis</i>	PRECIS
POACEAE	<i>Oropetium capense</i>	PRECIS
POACEAE	<i>Panicum coloratum</i>	PRECIS
POACEAE	<i>Panicum deustum</i>	PRECIS
POACEAE	<i>Panicum maximum</i>	PRECIS
POACEAE	<i>Pennisetum glaucocladum</i>	PRECIS
POACEAE	<i>Phragmites mauritanus</i>	PRECIS
POACEAE	<i>Pogonarthria squarrosa</i>	PRECIS
POACEAE	<i>Sacciolepis typhura</i>	PRECIS
POACEAE	<i>Schmidtia pappophoroides</i>	PRECIS
POACEAE	<i>Setaria incrassata</i>	PRECIS
POACEAE	<i>Setaria lindenbergiana</i>	PRECIS
POACEAE	<i>Setaria sagittifolia</i>	PRECIS
POACEAE	<i>Setaria sphacelata</i>	PRECIS

Family	Scientific Name	Source
POACEAE	<i>Setaria verticillata</i>	PRECIS
POACEAE	<i>Sorghum bicolor</i>	PRECIS
POACEAE	<i>Sporobolus acinifolius</i>	PRECIS
POACEAE	<i>Sporobolus consimilis</i>	PRECIS
POACEAE	<i>Sporobolus ioclados</i>	PRECIS
POACEAE	<i>Sporobolus spicatus</i>	PRECIS
POACEAE	<i>Sporobolus welwitschii</i>	PRECIS
POACEAE	<i>Stipagrostis uniplumis</i>	PRECIS
POACEAE	<i>Tetrapogon tenellus</i>	PRECIS
POACEAE	<i>Tragus berteronianus</i>	PRECIS
POACEAE	<i>Tricholaena monachne</i>	PRECIS
POACEAE	<i>Trichoneura eleusinoides</i>	PRECIS
POACEAE	<i>Triraphis schinzii</i>	PRECIS
POACEAE	<i>Urochloa mosambicensis</i>	PRECIS
POACEAE	<i>Urochloa stolonifera</i>	PRECIS
POACEAE	<i>Urochloa trichopus</i>	PRECIS
POLYGALACEAE	<i>Polygala africana</i>	PRECIS
POLYGALACEAE	<i>Polygala leptophylla</i>	PRECIS
POLYGALACEAE	<i>Polygala virgata</i>	PRECIS
POLYGALACEAE	<i>Securidaca longepedunculata</i>	PRECIS
POLYGONACEAE	<i>Oxygonum delagoense</i>	PRECIS
POLYGONACEAE	<i>Polygonum plebeium</i>	PRECIS
PONTEDERIACEAE	<i>Heteranthera callifolia</i>	PRECIS
PORTULACACEAE	<i>Portulaca hereroensis</i>	PRECIS
PORTULACACEAE	<i>Portulaca quadrifida</i>	PRECIS
PORTULACACEAE	<i>Talinum tenuissimum</i>	PRECIS
POTAMOGETONACEAE	<i>Potamogeton octandrus</i>	PRECIS
POTTIACEAE	<i>Trichostomum brachydontium</i>	PRECIS
PROTEACEAE	<i>Protea welwitschii</i>	PRECIS
PTERIDACEAE	<i>Actiniopteris dimorpha</i>	PRECIS
PTERIDACEAE	<i>Actiniopteris radiata</i>	PRECIS
RHAMNACEAE	<i>Berchemia discolor</i>	PRECIS
RHAMNACEAE	<i>Berchemia zeyheri</i>	PRECIS
RICCIACEAE	<i>Riccia atropurpurea</i>	PRECIS
RICCIACEAE	<i>Riccia congoana</i>	PRECIS
RICCIACEAE	<i>Riccia moenkemeyeri</i>	PRECIS
RUBIACEAE	<i>Anthospermum welwitschii</i>	PRECIS
RUBIACEAE	<i>Coddia rudis</i>	PRECIS
RUBIACEAE	<i>Coptosperma supra-axillare</i>	PRECIS
RUBIACEAE	<i>Kohautia caespitosa</i>	PRECIS

Family	Scientific Name	Source
RUBIACEAE	<i>Kohautia caespitose</i>	Van der Walt (2009)
RUBIACEAE	<i>Kohautia cynanchica</i>	PRECIS
RUBIACEAE	<i>Pachystigma triflorum</i>	PRECIS
RUBIACEAE	<i>Psydrax livida</i>	PRECIS
RUBIACEAE	<i>Spermacoce senensis</i>	PRECIS
RUBIACEAE	<i>Tricalysia junodii</i>	PRECIS
RUBIACEAE	<i>Tricalysia lanceolata</i>	PRECIS
RUTACEAE	<i>Toddalopsis bremekampii</i>	PRECIS
SAPINDACEAE	<i>Cardiospermum corindum</i>	PRECIS
SAPINDACEAE	<i>Pappea capensis</i>	PRECIS
SAPOTACEAE	<i>Mimusops zeyheri</i>	PRECIS
SCROPHULARIACEAE	<i>Aptosimum lineare</i>	PRECIS
SCROPHULARIACEAE	<i>Craterostigma plantagineum</i>	PRECIS
SCROPHULARIACEAE	<i>Dopatrium junceum</i>	PRECIS
SCROPHULARIACEAE	<i>Freylinia tropica</i>	PRECIS
SCROPHULARIACEAE	<i>Limosella maior</i>	PRECIS
SCROPHULARIACEAE	<i>Peliostomum leucorrhizum</i>	PRECIS
SCROPHULARIACEAE	<i>Peliostomum virgatum</i>	PRECIS
SCROPHULARIACEAE	<i>Stemodiopsis rivae</i>	PRECIS
SELAGINELLACEAE	<i>Selaginella dregei</i>	PRECIS
SINOPTERIDACEAE	<i>Cheilanthes parviloba</i>	PRECIS
SINOPTERIDACEAE	<i>Pellaea calomelanos</i>	PRECIS
SOLANACEAE	<i>Datura ferox</i>	Van der Walt (2009)
SOLANACEAE	<i>Datura inoxia</i>	Van der Walt (2009)
SOLANACEAE	<i>Datura stramonium</i>	PRECIS
SOLANACEAE	<i>Lycium horridum</i>	PRECIS
SOLANACEAE	<i>Lycium schizocalyx</i>	Van der Walt (2009)
SOLANACEAE	<i>Nicotiana glauca</i>	PRECIS
SOLANACEAE	<i>Nicotiana glauca</i>	Van der Walt (2009)
SOLANACEAE	<i>Solanum catombelense</i>	Van der Walt (2009)
SOLANACEAE	<i>Solanum nigrum</i>	Van der Walt (2009)

Family	Scientific Name	Source
SOLANACEAE	<i>Solanum tettense</i>	PRECIS
SOLANACEAE	<i>Withania somnifera</i>	PRECIS
TARGIONIACEAE	<i>Targionia hypophylla</i>	PRECIS
VAHLIACEAE	<i>Vahlia capensis</i>	PRECIS
VELLOZIACEAE	<i>Xerophyta humilis</i>	PRECIS
VELLOZIACEAE	<i>Xerophyta schlechteri</i>	PRECIS
VELLOZIACEAE	<i>Xerophyta viscosa</i>	PRECIS
VERBENACEAE	<i>Chascanum incisum</i>	PRECIS
VERBENACEAE	<i>Lantana rugosa</i>	PRECIS
VERBENACEAE	<i>Priva meyeri</i>	PRECIS
VIOLACEAE	<i>Hybanthus capensis</i>	PRECIS
VIOLACEAE	<i>Hybanthus enneaspermus</i>	PRECIS
VISCACEAE	<i>Viscum rotundifolium</i>	PRECIS
VISCACEAE	<i>Viscum verrucosum</i>	PRECIS
VITACEAE	<i>Cyphostemma segmentatum</i>	PRECIS
VITACEAE	<i>Cyphostemma spinosopilosum</i>	PRECIS
VITACEAE	<i>Rhoicissus digitata</i>	PRECIS
VITACEAE	<i>Rhoicissus revouillii</i>	PRECIS
VITACEAE	<i>Rhoicissus tomentosa</i>	PRECIS
ZYGOPHYLLACEAE	<i>Tribulus terrestris</i>	PRECIS
ZYGOPHYLLACEAE	<i>Tribulus zeyheri</i>	PRECIS

APPENDIX J

Morphological dispersal and preservation characteristics of major Palynomorphs (after Lodder, 2011, Geer, 2013 and Deeva Lata Baboolal, 2013):

ACANTHACEAE

Identified as: Undifferentiated

Genus found at Mapungubwe National Park: Several Acanthaceae species (Appendix I)

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): Acanthaceae pollen can be separated into six morphological types; i) *Blepharis*, ii) *Justicia*-type, iii) *Monechmatype*, iv) *Macrorungia*-type, v) *Dicliptera*-type, vi) Acanthaceae no 462, vii) Acanthaceae no 452. Types vi and vii are rare and recorded only in the Rietvlei deposits, and no herbarium reference material of such grains is available; they are tentatively identified as Acanthaceae (Scott, 1982a).

Ecology: Acanthaceae is a large family of herbs with 43 genera found in South Africa (Pooley, 2005) usually indicative of open veld environments rather than swamp environments (Scott, 1982a).

Dispersal and preservation characteristics: Acanthaceae is considered to be widely distributed (Scott, 1982a) but poorly dispersed (Hamilton, 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

ANACARDIACEAE

Identified as: Undifferentiated

Genera found at Mapungubwe National Park: *Ozoroa paniculosa*, *Searsia pyroides*

Likely parent taxa: *Unknown*

Pollen morphological characteristics: No morphological features are available for this research.

Ecology: Montane and subalpine grasslands (Killick, 1963), also occurs in savannas (Scott, 1989).

Dispersal and preservation characteristics: There are over 20 species of trees and shrubs belonging to the genera *Rhus* occupying a wide range of habitats in the bushveld and Highveld areas. While the genus is insect pollinated, it does produce pollen in large numbers. It is considered to be moderately to well dispersed over long distances, often found in pollen samples although not in high numbers (Scott, 1982a; Hamilton, 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

ASTERACEAE

Identified as: *Vernonia*-type

Genera found at Mapungubwe National Park: *Vernonia amygdalina*, *V. myriantha*, *V. Fastigiata* *V. triflora*, *V. steetziana*

Likely parent taxa: *Vernonia* species

Pollen morphological characteristics (on Genus level): highly distinctive palynomorph. Trizonocolporate, echinate, fenestrate. 25-48 µm (Finch *et al.*, 2009).

Ecology: A well represented genus of herbs, shrubs and small trees commonly occurring within secondary or disturbed forest types between 2000 and 3200 m. Ecology is variable due to a large number of potential parent taxa; nevertheless, *Vernonia* pollen has been viewed as indicative of agriculturally-related disturbance (Finch *et al.* 2009).

Dispersal and preservation characteristics: This pollen type is dispersed over long distances but is considered poorly dispersed (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-arboreal

AMARANTHACEAE

Identified as: Undifferentiated

Genera found at Mapungubwe National Park: *Achyranthes aspera*, *Alternanthera nodiflora*, *Amaranthus praetermissus*, *Hermbstaedia fleckii*, *Hermbstaedia odorata*, *Kyphocarpa angustifolia*, *Pupalia lappacea*, *Sericorema remotiflora*, *Sericorema sericea*

Likely parent taxa: Amaranthaceae

Pollen morphological characteristics (on Family level): cribellate; spherical; ellipsoidal or polyhedral with rounded edges; 12-35 µm diameter. Foramina: 12-60 µm; circular, sometimes wavy margins; 2.5-8.6 µm diameter, sometimes situated in deep, straight or funnel shaped depressions; membrane has the same sculpturing as rest of exine or is flecked with granules which tend to aggregate towards centre and fuse; or with operculum; Exine: 1- 5.7 µm; thick; granulate; sexine baculate; sometimes tegillate; nexine only 0.5-1.5 µm thick (Van Zinderen Bakker, 1953).

Ecology: Amaranthaceae are halophytes favouring dry, saline conditions with summer rainfall and warmer evaporative conditions (Scott *et al.*, 2005; Scott, 1993; Scott, 1982a).

Dispersal and preservation characteristics: Amaranthaceae are wind-pollinated (van Zinderen Bakker, 1953), dispersed over long distances (Hamilton, 1972) and occur in most parts of the country in a wide-range of habitats (Scott, 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

BORAGINACEAE

Identified as: *Cordia*

Genera found at Mapungubwe National Park: *Cynoglossum*, *Echium*, *Ehretia*, *Lithospermum*, *Myosotis*, *Tysonia*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Cordia* is found typically in lowland forest (Finch *et al.* 2009) and as forest patches in edaphic grasslands (Mumbi *et al.* 2008)

Dispersal and preservation characteristics: *Cordia* is typically insect pollinated and thus produce pollen in relatively low concentrations, as a result it is generally under-represented in pollen record (Connor *et al.* 2004).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

Identified as: *Heliotropium*

Genera found in Cathedral Peak: *Heliotropium ciliatum*, *Heliotropium giessi*, *Heliotropium nelsonii*, *Heliotropium ovalifolium*, *Heliotropium stringosum*, *Heliotropium zeylanicum*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Heliotropium* occurs in Lowland forest (Finch *et al.* 2009)

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

CAPPARACEAE

Identified as: Undifferentiated

Genera found at Mapungubwe National Park: *Boscia foetida*, *Cadaba aphylla*, *Cadaba termitaria*, *Cleome angustifolia*, *Cleome gynandra*, *Cleome hirta*, *Cleome kalachariensis*, *Cleome monophylla*, *Cleome oxyphylla*, *Maerua angolensis*, *Maerua edulis*, *Maerua juncea*, *Maerua parvifolia*

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): 3-colporate, prolate to subprolate, ambit foss aperturate; polar axis 14-42 um; long colpi; exine tegillate, sometimes c. punctitegillate, or with LO- to OL-pattern, faintly granulate, or with minute spinules.

Ecology: Capparaceae are generally well adapted to arid conditions (Gil-Romera *et al.* 2007) often being found in warm, low-land savanna, occurs within the Kalahari Thornveld vegetation and in steppe, semi-desert to desert conditions. As such, Capparaceae is indicative of drier conditions with less rainfall (Scott 1999; Gil-Romera *et al.*, 2006; Dupont *et al.*, 2008).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

COMBRETACEAE

Identified as: *Combretum*

Genera found at Mapungubwe National Park : *Combretum apiculatum*, *Combretum imberbe*, *Combretum mossambicense*

Likely parent taxa: *Combretum* species

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: Found in woodland areas and bushveld savanna with sandy soils (Scott, 1982).

Dispersal and preservation characteristics: Moderately to well dispersed.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

Identified as: Undifferentiated

Genera found at Mapungubwe National Park: *Terminalia brachystemma*, *Terminalia prunioides*

Likely parent taxa: *Combretum* species

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: Found in woodland areas and bushveld savanna with sandy soils (Scott, 1982).

Dispersal and preservation characteristics: Moderately to well dispersed.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

CYPERACEAE

Identified as: Cyperaceae undifferentiated

Genera found at Mapungubwe National Park: A great number of Cyperaceae occur in MNP (refer to Appendix I)

Likely parent taxa: members of the Cyperaceae family

Ecology: Typically found in wetlands in aquatic (Scott, 1982a), semi aquatic and swamp like environments (Scott 1999) with shallow water or damp soil (Scott and Nyakale, 2002).

Dispersal and preservation characteristics: This pollen is considered to be moderately well dispersed (Hamilton, 1972)

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

EBENACEAE

Identified as: Euclea

Genera found at Mapungubwe National Park: *Diospyros lycioides*, *Euclea crispa*, *Euclea natalensis*

Likely parent taxa: *Euclea* species

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Euclea* are found in a wide range of habitats in the bushveld as well as the Highveld (Scott, 1982a).

Dispersal and preservation characteristics: *Euclea* are regarded as rare to common in fossil and surface samples often occurring in dry bushveld where grass pollen production is apparently low (Scott, 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

EUPHORBIACEAE

Identified as: *Acalypha*

Genera found at Mapungubwe National Park: *Acalypha indica*, *Acalypha pubiflora*, *Acalypha indica*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: *Acalypha* species are herbaceous found in the sub-alpine grasslands (Killick, 1963; Scott, 1982a) and montane forests (Hamilton, 1972).

Dispersal and preservation characteristics: *Acalypha* are herbaceous, have very well, long distance dispersal pollen (Hamilton 1972) which occur as montane forests in East Africa.

They can have unrealistic over-representation and should be considered excluded from pollen sum (Scott 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: Euphorbia

Genera found at Mapungubwe National Park: *Euphorbia griseola*, *Euphorbia guerichiana*, *Euphorbia limpopoana*, *Euphorbia monteiroi*, *Euphorbia neopolycnemoides*, *Euphorbia serpens*, *Euphorbia tirucalli*

Likely parent taxa: Unknown

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: Herbaceous, have very well, long distance dispersal pollen (Hamilton 1972) which occur as montane forests in East Africa. They can have unrealistic over-representation and should be considered excluded from pollen sum (Scott 1982a).

Dispersal and preservation characteristics: Well dispersed pollen over long distances (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

Identified as: Undifferentiated

Genera found at Mapungubwe National Park: *Caperonia stuhlmannii*, *Clutia pulchella*, *Croton gratissimus*, *Croton megalobotrys*, *Croton menyharthii*, *Croton pseudopulchellus*, *Dalechampia capensis*, *Jatropha spicata*, *Tragia dioica*

Likely parent taxa: Unknown

Pollen morphological characteristics (on Genus level): No morphological description available for this research.

Ecology: Herbaceous, have very well, long distance dispersal pollen (Hamilton 1972) which occur as montane forests in East Africa. They can have unrealistic over-representation and should be considered excluded from pollen sum (Scott 1982a).

Dispersal and preservation characteristics: Well dispersed pollen over long distances (Hamilton 1972).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

FABACEAE

Identified as: Undifferentiated

Genus found at Mapungubwe National Park: Various Fabaceae genera found at MNP (Appendix I)

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): No morphological characteristics available for this research.

Ecology: Second largest plant family. Found in grasslands, varying from damp to rocky (Pooley, 2005)

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local/ Regional: Regional

Arboreal/Non-arboreal: Non-arboreal

HYACINTHACEAE

Identified as: Undifferentiated

Genera found in Cathedral Peak: *Albuca glauca*, *Drima sanguine*, *Drimia altissima*, *Drimia indica*, *Ledebouria cooperi*, *Ledebouria luteola*, *Ledebouria macowanii*, *Ledebouria marginata*, *Ledebouria sandersonii*, *Ornithogalum seineri*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: There is no available information on the ecology of this taxon.

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

LILIACEAE

Identified as: Undifferentiated

Genera found at Mapungubwe National Park: Unknown

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): mostly monosulcate, sometimes anaperturate or trichotomosulcate; exine psilate, pitted, granulate or reticulate, subchinate or echinate (van Zinderen Bakker 1953).

Ecology: Liliaceae are insect pollinated with low concentrations of pollen being produced; therefore the pollen may be under-represented in pollen rain and sediment records (van Zinderen Bakker 1953).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local/Regional: Local

Arboreal/Non-arboreal: Non-arboreal

LAMIACEAE

Identified as: *Undifferentiated*

Genera found at Mapungubwe National Park: *Acrotome inflata*, *Clerodendrum ternatum*, *Endostemon tenuiflorus*, *Endostemon tereticaulis*, *Leucas glabrata*, *Leucas sexdentata*, *Ocimum americanum*, *Rothea myricoides*, *Syncolostemon canescens*, *Tinnea rhodesiana*, *Vitex rehmannii*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for this research.

Ecology: No ecological data is available for this research.

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Leonotis*

Genera found at Mapungubwe National Park: *Leonotis nepetifolia*, *Leonotis ocymifolia*

Likely parent taxa: *Leonotis*

Pollen morphological characteristics: No morphological description available for this research.

Ecology: No ecological data is available for this research.

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal

MORACEAE

Identified as: *Undifferentiated*

Genera found in Cathedral Peak: *Ficus abutilifolia*, *Ficus salicifolia*, *Ficus tettensis*

Likely parent taxa: *Ficus*

Pollen morphological characteristics (on Family level): 2-4 proate; spherical; mostly aspidate; sometimes very small size; very little ornamentation or granulate surface (van Zinderen Bakker 1953).

Ecology: *Ficus* is found in the montane grasslands of Cathedral Peak (Killick 1963).

Dispersal and preservation characteristics: No dispersal or preservation characteristics available for this research.

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

OLEACEAE

Identified as: Undifferentiated

Genus found at Mapungubwe National Park: *Jasminum fluminense*

Likely parent taxa: *Olea*

Pollen morphological characteristics (on Family level): May be difficult to distinguish from Celastraceae pollen (Scott, 1982a)

Ecology: Most likely pollen grains of *Olea africana*, associated with rocky slopes

Dispersal and preservation characteristics: Considered to be well dispersed in East Africa (Scott, 1982a)

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

POACEAE

Identified as: Undifferentiated

Genera found at Mapungubwe National Park: Large number of genera and species (Appendix I)

Likely parent taxa: Members of the Poaceae family

Pollen morphological characteristics (on Family level): spheroidal or more or less ovoidal; 22-little +100 µm; single germ spore surrounded by thickened rim; psilate; wild grass usually 20-25µm; spherical / ellipsoidal; less 1µm exine; impossible to ID different grasses species based on size (van Zinderen, Bakker 1953).

Ecology: Poaceae are found in regional humid conditions with summer rainfall (Scott and Nyakale 2002) under strong evaporative conditions (Scott *et al.*, 2005).

Dispersal and preservation characteristic: Poaceae are well dispersed (Hamilton, 1972).

Local / Regional: Local

Arboreal / Non-Arboreal: Non-Arboreal

APPENDIX K

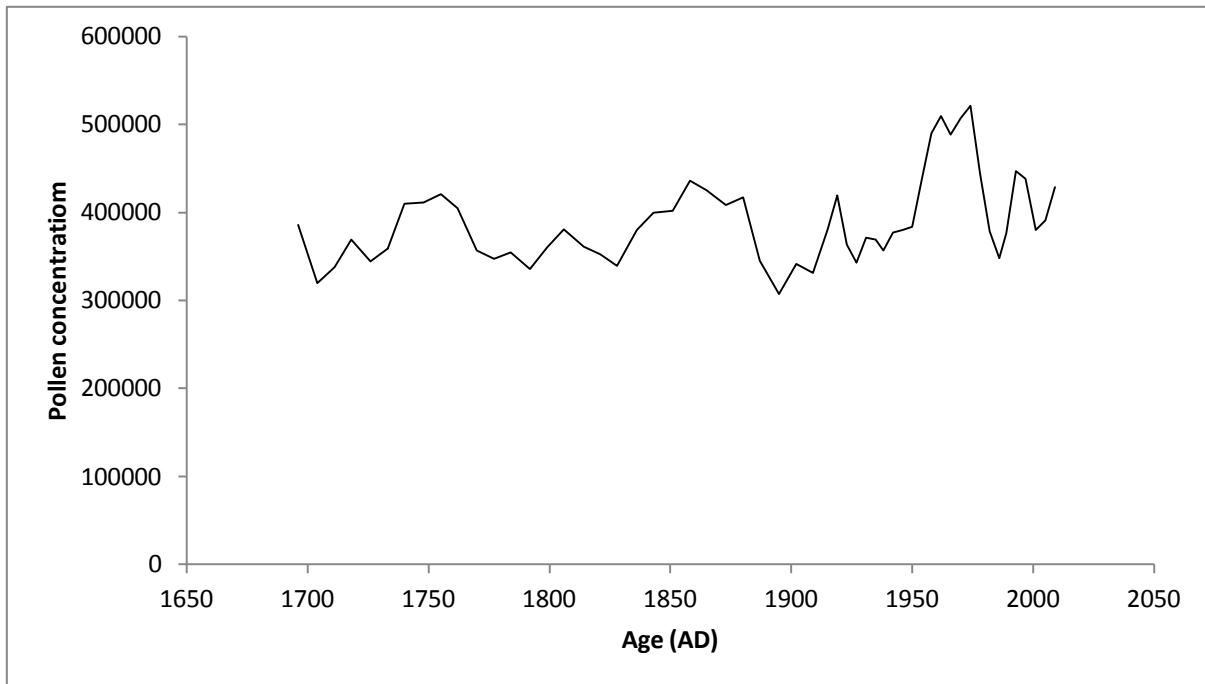
Recent fire history of Mapungubwe National Park (adapted from MNP park management plan draft update 4 March 2010 (Page 55) (SAN Parks, 2010)):

Year of fire event	Date
2001	5-Sep
2001	15-Nov
2002	4-Nov
2003	20-Jul
2003	5-Jul
2003	20-Sep
2005	11-Oct
2005	30-May
2007	12-Jul
2008	5-Feb
2008	3-Mar

APPENDIX L

Pollen preservation trends at Croc Pan and Leokwe Rock Pool calculated according to Stockmarr (1971):

Croc Pan



Leokwe Rock Pool

