A 40,000-YEAR RECORD OF VEGETATION AND FIRE HISTORY FROM THE TATE VONDO REGION, NORTHEASTERN SOUTPANSBERG, SOUTH AFRICA

BY

DEEVA LATA BABOOLAL

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School of Agricultural, Earth and Environmental Sciences
University of KwaZulu-Natal
Westville

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ABSTRACT

Records from the Quaternary period are used to confirm possible inferred climatic changes, reveal the responses of species to these changes, and serve as an archive against which modern environmental dynamics can be assessed. Fueled by a need to understand current climatic changes, the call for palaeoclimatic research in the southern African subregion has become more compelling. In southern Africa, such research has been largely restricted to springs and swamps as the subregion lacks natural lakes, with some exception of a few coastal lakes such as Lake Sibaya and Lake Eteza. Due to the arid and semi-arid landscapes which prevail in southern Africa, there is a paucity of suitable sedimentary deposits in the region. The highly organic peat deposit of Mutale Wetland, situated in the Tate Vondo region of the northeastern Soutpansberg presents an ideal opportunity for conducting palaeoenvironmental research. The Mutale Wetland contains relatively old sediments dating back to >30,000 cal years BP, placing this record within the late Quaternary period. Palaeoenvironmental techniques including radiocarbon, pollen and charcoal analyses were applied to produce a palaeoenvironmental reconstruction for Tate Vondo. A 302 cm sedimentary core was extracted from the Mutale Wetland. Detailed analyses show that prior to *ca.* 34,000 cal yr BP, conditions were fairly warm and dry. This is inferred from a dominance of open grassland vegetation. An expansion of *Podocarpus* forests together with an increase in fynbos elements suggest a shift to cool, subhumid conditions during the LGM. Cooler conditions persisted until *ca.* 12,000 cal yr BP. Thereafter, a climatic amelioration was experienced. The appearance of low charcoal concentrations throughout the late Pleistocene suggests that fire was infrequent. Between *ca.* 4000 – 1500 cal yr BP, conditions became warmer and drier, inferred from the development of arid savanna vegetation. The sharp increase in charcoal after *ca.* 4000 cal yr BP, broadly coinciding with the arrival of the first agriculturalists in the area, has implications for the history of human occupation in the Soutpansberg rather than shifts in climate. The succession from savanna to fynbos vegetation together with expanded forests implies a return to cool and moist conditions from *ca.* 1500 – 400 cal yr BP. Arid savanna persists from *ca.* 400 to the present, implying warmer and drier conditions towards the present day. Furthermore, from *ca.* 400 cal yr BP, the pollen and charcoal record indicate that the majority of recent changes in vegetation have been driven by anthropogenic activity. This record has contributed to an improved understanding of late

Quaternary changes in climate, vegetation history and human impact in the northeastern Soutpansberg.

PREFACE

This research was conducted through the School of Agricultural, Earth and Environmental Sciences at the University of KwaZulu-Natal, Westville, from January 2012 to February 2014, under the supervision of Dr J.M. Finch.

This research 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 by the work of others, it is duly acknowledged in the text.

…………………….

Deeva Lata Baboolal

(candidate)

…………………….

Dr J.M. Finch

(supervisor)

DECLARATION ONE - PLAGIARISM

I, ……………………………**DEEVA LATA BABOOLAL**……..……………… declare that

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CHAPTER ONE: INTRODUCTION

Climate change is a natural process that has been occurring over millions of years. The global climate has been fluctuating between glacial and interglacial conditions ever since the Precambrian era (Deacon and Lancaster, 1988; Cowling *et al.*, 1999; Fox and Rowntree, 2000; Ridley, 2004; Berger and Yin, 2011). The number of fluctuations recorded during the Quaternary period, in particular the last two million years, has exceeded those recorded during any other period (McCarroll, 2010), however this may be because climate fluctuations during the Quaternary are better documented than other periods. The periodic growth and retreat of high latitude ice sheets, as well as Milankovitch cycles have been the primary driving forces behind changing global Quaternary climates). Glacial periods are characterized by cool and dry conditions whilst interglacials are periods of higher temperatures which last thousands of years and separate glacial periods (Berger and Yin, 2011). More recently, there has been a significant increase in evidence in support of anthropogenically driven climate change. According to the latest report published by the Intergovernmental Panel on Climate Change (IPCC, 2013), recent climate change has been unequivocally exacerbated by human impact. Thus, there has been a rising interest in understanding long term perspectives on natural and anthropogenic climate change, the drivers of climate change, as well as the impacts thereof.

During the last one million years, glacial climate extremes have increased significantly across the African continent, and climatic cycles became longer, lasting approximately 100,000 years (deMenocal, 1995; Berger and Yin, 2011). Recent climatic fluctuations have had considerable effects on the geographical distributions of species (Midgley *et al.*, 2002; Ridley, 2004; Hannah *et al.*, 2007; Huntley *et al.*, 2010). As climate changes, species gradually adapt to new environmental conditions by adapting their physiological structures, productivities or growth rates (Midgley *et al.*, 2002). The ability of a species to effectively adapt to new surroundings is dependent on the rate at which climate is altered. If climate changes occur too rapidly, some species may not be able to adapt fast enough and will face extinction (Midgley *et al*., 2002). In addition to adapting to new climates, many species are able to migrate to preferred habitats of environmental suitability during adverse conditions (Huntley *et al*., 2010). Such areas are known as refugia (Bennett and Provan, 2008; Birks and Willis, 2008; Rull, 2009). Compared to faunal species, floral species are faced with a greater number of challenges associated with migration. According to Willis *et al.* (2013), analysing the palaeo-record is one way of evaluating the effects of future climate change on African bitota. Although prediction models using modern datasets provide useful insight, palaeo data are able to provide crucial additional information that would not normally be established solely through modelling approaches (Willis *et al*., 2013). Thus, our ability to understand current vegetation distributions as well as predict future distributions rests in our understanding of past climatic changes (Zubakov and Bozenkova, 1990; Anderson *et al.,* 2006; Wanner *et al*., 2008).

Significant advances have been made toward greater understanding of Quaternary climate changes and variability through the simultaneous use of global climate models and various proxy data (Wanner *et al*., 2008; Knutti, 2011). The only way to test the validity of these models is through comparisons of produced simulations of climate change with present and palaeoclimatic data (COHMAP, 1988; Wright *et al*., 1993; Knutti, 2011). A number of projects have been initiated in an attempt to gather global palaeo data. The Palaeovegetation Mapping Project (BIOME 6000) of the International Geosphere-Biosphere Programme (IGBP) is one such project (Prentice and Webb, 1998; Prentice *et al*., 2000). This project, updated on a continual basis, was proposed as a means of creating a global dataset of palaeovegetation from pollen and plant macrofossils (Wanner *et al*., 2008) with the intention of using the dataset as a benchmark to validate palaeoclimatic and vegetation models (Prentice *et al*., 2000; Wanner *et al*., 2008). More recently, The Palaeoclimate Modelling Intercomparison Project (PMIP) has been initiated to understand past warm climates in an effort to potentially better predict future changes (Haywood *et al*., 2009; Haywood *et al*., 2011). The Global Pollen Database, a freely available archive, is another successful initiative to collate palaeo data (Gajewski, 2008).

It is clear that palaeoenvironmental data is key to understanding the drivers and effects of global climate change; however, there is still a lack of high resolution palaeoenvironmental data for the southern African region (Meadows, 2001; Salzmann and Hoelzmann, 2005) which has consequently restricted the validation of regional climate models (Valsecchi *et al*., 2013).

Palynology, or pollen analysis, defined as 'a technique for reconstructing former vegetation by means of the pollen grains it produced' (Faegri and Iverson, 1989, p. 1), remains the most widely used palaeoenvironmental technique used in Quaternary studies (Gaillard *et al*., 2008; Smith, 2011). Pollen analysis is regarded as a remote sensing tool (Prentice, 1988), allowing for the detection of past vegetation changes at a range of spatial and temporal resolutions, to make inferences regarding palaeo climates and palaeoenvironments (Birks and Birks, 2000; Willis *et al.,* 2007). Pollen grains are abundant within the fossil record, are widely and evenly dispersed, and have robust, decay-resistant exines, making them well suited to detailed analysis (Bunting, 2008). When waterlogged, aerobic decay of fossil pollen is virtually absent, thus allowing for preservation within sediments for thousands (Bunting, 2008), or even millions of years. More importantly, stratigraphic archives such as wetland and limnological deposits that often contain continuous polliniferous and organic material (Anderson *et al*., 2007; Bunting, 2008), including other microfossils such as phytoliths, diatoms, isotopes and macrobotanical remains including geochemical signatures e.g. isotopes. These stratigraphic archives allow for sediments to be dated, thus providing chronological context to palynological data (Blaauw and Christen, 2005).

Pollen analysis, is based on the assumption that the number of pollen grains deposited per unit time in a given area is directly representative of the regional vegetation present (Birks and Birks, 2000; Fletcher and Thomas, 2007). However differences in pollen rain across species, taphonomical problems, difficulty in defining the pollen source area, low taxonomic resolution and overrepresentation of local taxa within the pollen record hamper the interpretation of pollen data (Birks and Birks, 2000). Thus, pollen analysis requires careful ecological consideration during interpretation of data.

1.1 The role of human impacts in shaping vegetation distributions

Aside from understanding the effects and responses of ecosystems to global environmental change, the role of anthropogenic activities as a determinant for modern vegetation distributions has become increasingly evident (Goudie, 1990; Chapman and White, 1970; Meadows and Linder, 1993) especially in the African context. Humans are able to alter vegetation distributions directly, through introduction of exotic species, vegetation clearance, grazing of livestock and burning (Huffman, 1996; 2008; Mitchell, 2002) as well as indirectly, through utilization of natural resources. According to Meadows and Linder (1993), the number of pristine habitats in existence on the African continent today is minimal and almost every vegetation pattern has been altered in some way by human activity. As global populations continue to rise, increasing strain is placed on existing natural resources causing widespread ecosystem transformation.

The effects of human activities on vegetation patterns are well documented for the tropical African region (e.g. East Africa). Anthropogenic activity in the form of burning and clearing of forests has long been a part of the history of this region (Hamilton *et al*., 1986; Rodgers, 1993; Marchant *et al*., 1997; Rucina *et al*., 2009; Ekblom *et al*., 2011). Dependence on natural resources for cultural and economic livelihoods has resulted in wide scale deforestation in the Afromontane region. As a result, grasslands were previously thought to have become more widespread, replacing forests and woodlands in this region (Chapman and White, 1970; Acocks, 1953).

Bredenkamp *et al*. (2002), have however stated that high altitude grasslands are more likely a product of southern Africa's altitudinal cooling during the Oligocene, and suggest that the modern distribution of grasslands does not differ much in comparison with the Holocene. According to Bredenkamp *et al*. (2002), the historical distributions of modern grasslands have only recently been altered by human activities such as agriculture and burning during the late Holocene. In the Soutpansberg, Hahn (2007) has noted a replacement of natural grasslands by monocultures and secondary bush encroachment over the past 150 years. Moreover, the destruction of grasslands in the

Soutpansberg has been directly related to the aridification of aquifers during the recent past (Hahn, 2007).

There is a need to determine the relative importance of climate and anthropogenic activities, such as deforestation and burning, as controls on vegetation distribution. Through the analysis of palaeoclimatic data (charcoal and pollen data) it is possible to establish the extent to which each factor contributes to past as well as present climates. Palaeoenvironmental research is undoubtedly crucial to advancing our knowledge of past and present climatic shifts and ecological systems (Bradley, 2000; Willis and Birks, 2006; Willis *et al*., 2010); despite this, there seems to be a general lack of high resolution palaeoclimatic data, with the exception of the Tswaing Crater and Wonderkrater records (Scott, 1999), particularly in southern Africa.

1.2 The Soutpansberg

The Soutpansberg, a mountainous region in South Africa's Limpopo Province, is a region of incredibly high floristic and biological diversity (Foord *et al*., 2002). According to Hahn (2007), an estimated 2500 – 3000 vascular plant taxa, consisting of 1066 genera and 240 families occur in the Soutpansberg. The region comprises of diverse habitats and a number of different biomes (Hahn, 2007), including forest, grassland, savannah, arid savannah and moist savannah. According to Hahn (2007) and Van Wyk and Smith (2001), the region is currently regarded as a centre of floristic endemism and is unique in comparison to other centres of endemism as it is exceptionally diverse and species rich despite its size. Moreover, the Soutpansberg is also home to a unique relic population of *Brachystegia* woodland, known as Gundani. Like most other natural environments, the Soutpansberg's natural vegetation is widely transformed due to increased human pressure.

Aside from its rich botanical diversity, the Soutpansberg is also rich in cultural and archaeological value, including rock art. According to Foord *et al.* (2002), the western Soutpansberg contains the highest concentration of Natural Heritage Sites in South Africa and efforts are being made to recognize the Soutpansberg as a World Heritage Site

(Hahn, 2007). Mapungubwe, the site of the earliest class-based southern African Iron Age kingdom (Loubser, 1989; Schoeman, 2011; Schoeman and Pikirayi, 2011) is also located in the Soutpansberg region and has been listed as a UNESCO World Heritage Site, due to its implications for the interchange of human values, which ultimately led to changes in trade and social structures in southern Africa between the ninth to the fourteenth centuries AD (Carruthers, 2006; Schoeman, 2011).

1.3 Motivation for study

In the Soutpansberg region, an area of exceptional botanical and cultural diversity, a thorough understanding of the environmental and anthropogenic effects on present day vegetation distributions is crucial to the effective management of these environments (Hahn, 2007). Moreover, such understanding is needed to effectively manage sensitive ecological populations such as the Gundani *Brachystegia spiciformis* woodland patch, located in the northeastern Soutpansberg.

The Mutale Wetland, a highly organic peat wetland, situated near Tate Vondo, Venda, in the eastern Soutpansberg region of the Limpopo Province, contains relatively old sediments dating back to >30,000 cal yr BP. Scott (1987a) conducted a palynological study for this particular deposit, covering only the last 12,000 years. Radiocarbon data in this study showed anomalous dates, which has hampered interpretation. Thus, the Mutale Wetland site demonstrates great potential for reanalysis.

As with any other arid area of the world, Quaternary deposits suitable for pollen analysis are rare in southern Africa (Scott and Lee-Thorp, 2004; Salzmann and Hoelzmann, 2005; Norström *et al.*, 2009; Chase *et al.*, 2011; Chase *et al.*, 2012), thus, the Mutale peat deposit, in particular the new MUT-12-01 sediment core, presents a valuable opportunity for palaeoenvironmental research. Furthermore, long-term records covering the last glacial maximum (LGM) are quite rare for southern Africa, consequently, reanalysis of sediments from the Mutale Wetland are expected to contribute significantly towards our understanding of environmental change in the southern African region. Being situated in broadly the same region as the Gundani *Brachystegia spiciformis* woodland patch, this deposit may potentially allow for the reconstruction of miombo woodland in the northeastern Soutpansberg region during the late Quaternary. According to Hahn (2007), limited research has been undertaken on past climate conditions within the Limpopo Province, further highlighting the need to undertake palaeoenvironmental research in the region.

According to Scott (1993), additional research needs to be conducted in order to broaden our understanding of past environmental conditions. With the likelihood of severe environmental and climatic shifts predicted for the future, it is crucial to obtain a thorough understanding of past environmental conditions, such that effective long-term mitigation measures can be formulated (Anderson *et al*., 2006; Bunting 2008). This research aims to provide an understanding of the late Quaternary environmental conditions of the Limpopo Province's eastern Soutpansberg region of Tate Vondo, using a sediment core extracted from the Mutale Wetland.

1.4 Aim and objectives

This research is aimed at investigating late Quaternary palaeoenvironmental change in the northeastern Soutpansberg region of Limpopo Province by applying palaeoenvironmental techniques (pollen and charcoal analyses) to a sedimentary record from Mutale Wetland, Tate Vondo. Specific objectives are as follows:

(i) To use a suitable coring methodology and sampling strategy to extract a minimally disturbed continuous sediment core from the Mutale Wetland;

(ii) To determine accelerator mass spectrometry (AMS) radiocarbon ages for selected subsamples, appropriately calibrated, and supported by pollen time-stratigraphic markers to establish independent chronological control;

(iii) To conduct relative and absolute fossil pollen counts along the length of the core with the aim of reconstructing late Quaternary vegetation history for the area, and to increase the resolution of the previous palynological study of Mutale Wetland done by Scott (1987a);

(iv) To conduct microscopic charcoal analysis along the length of the core, such that a fire history may be reconstructed for the area;

(v) To infer climatic and environmental conditions during the LGM, last glacial-interglacial transition (LGIT) and the Holocene in the Tate Vondo region; and

(vi) To contribute to existing palaeoenvironmental studies that have been conducted in the region as well as to assess the extent to which these data concur.

1.5 Thesis outline

The purpose of this chapter has been to provide a rationale for this research and introduce this study in terms of its palaeoenvironmental significance. Furthermore, this chapter has outlined the aim and objectives of this study, thereby presenting a framework of the methods adopted in this research. A literature review, presented in Chapter Two, provides a synthesis of late Quaternary palaeoecological studies conducted in southern Africa, providing a context within which to interpret results from this study. Chapter Three provides a theoretical background for the methods applied in this study, *viz*. pollen, charcoal and radiocarbon analyses. Here, each method is discussed in terms of its advantages and limitations. To provide a background into the study site and the surroundings of Mutale Wetland, an overview of the Soutpansberg is provided in Chapter Four. Specific methodologies used in this research are described in Chapter Five. The results from radiocarbon, pollen and charcoal are presented and described in Chapter Six. A palaeoenvironmental reconstruction for the Tate Vondo region is presented in Chapter Seven. This reconstruction is discussed in terms of results obtained from other studies, thus placing it within the context of previous palaeoenvironmental studies in southern Africa. Chapter Eight provides a synthesis of the palaeoenvironmental changes at Tate Vondo, and also assesses the extent to which the aim and objectives outlined initially have been met.

CHAPTER TWO: LITERATURE REVIEW

This review is divided into two sections. The first section provides a broad overview of the drivers of climate change across the African continent. The focus of the second section is to review existing palaeoenvironmental research that has been conducted specifically in southern Africa[1] in order to gain an understanding of past environmental change in the region. This review will be structured according to the major periods of the late Quaternary that are relevant to this work and will cover research that has been conducted using a range of proxies. Owing to the primary focus of this research, more emphasis will be placed on palynological studies. Where possible, records displaying strong chronologies have been selected for this review, however, due to the limited number of studies for southern Africa, this was not always possible. For the purpose of standardization, all dates have been converted to calibrated years before present (cal yr BP) using SHCal04 (McCormac *et al.*, 2004).

2.1 Drivers of climate change

Over three quarters of the African continent is located within the tropics, making Africa the most tropical of all continents (Goudie, 1996). Due to the vast distance across which Africa spans, the continent is host to an array of complex environments. Aside from the Atlas Ranges, East African highlands and the Drakensberg escarpment, there are few major mountain ranges, resulting in broadly zonal climatic patterns on either side of the equator (Summerfield, 1996). These climates range from moist tropical low altitude regions to Mediterranean type climates in the northern and southwestern regions (Griffiths, 1972).

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[1] Here, the southern African subregion is defined as South Africa, Lesotho, Swaziland, Mozambique, Namibia, Angola, Zambia, Malawi, Zimbabwe and Botswana (Chase and Meadows, 2007).

At present, dry climates and strongly seasonal precipitation regimes prevail over much of the southern African subcontinent (Deacon and Lancaster, 1988). The latitudinal positioning of southern Africa largely influences these climates (Deacon and Lancaster, 1988). On the west coast, the cold Benguela current influences climates, whilst the warm Agulhas and Mozambique currents influence climates on the east coast. Altitudes vary over the subcontinent, with many areas exceeding elevations of 1000 m (Deacon and Lancaster, 1988; Stankiewicz and de Wit, 2005), which influences climate patterns to a certain degree.

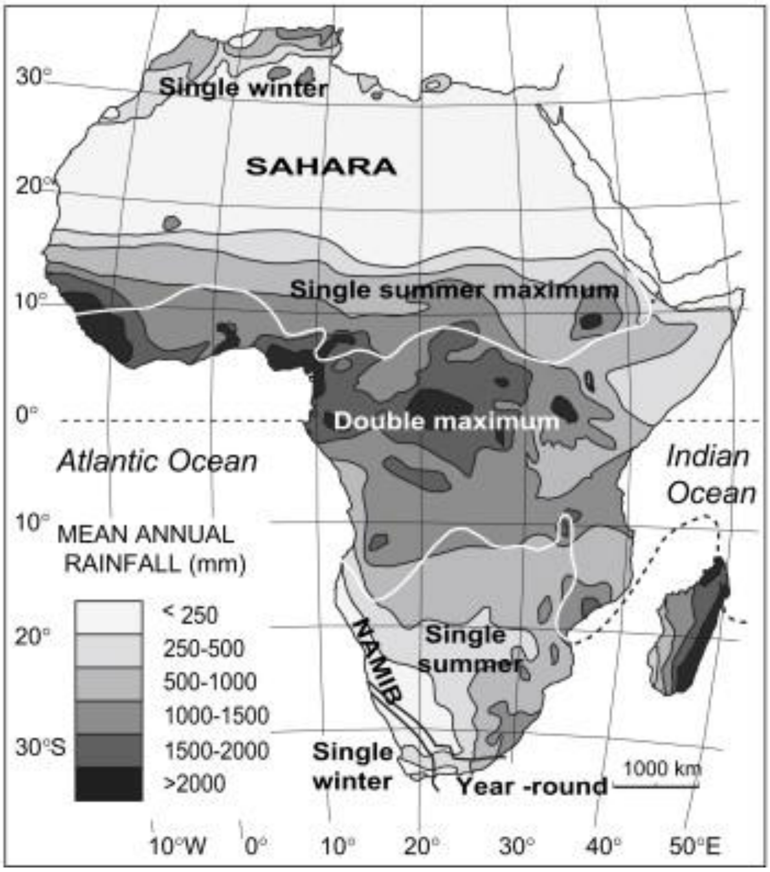

Figure 2.1 Precipitation regimes across the African continent (after Nash and Meadows, 2012)

Aside from the complex contemporary climate dynamics, Africa has experienced numerous climatic upheavals during the Quaternary. These past climatic shifts have shaped modern African environments, and it is thus worth investigating them and the potential driving forces of these changes (Nash and Meadows, 2012).

According to Nash and Meadows (2012), climatic drivers responsible for the variations observed in African climates during the Quaternary operated over different timescales. The most noteworthy climatic drivers include orbital variations, the volume of northern hemisphere ice sheets, variations in atmospheric transparency, shifts in atmospheric CO_2 and CH_4 and changes in surface boundary conditions (Nash and Meadows, 2012).

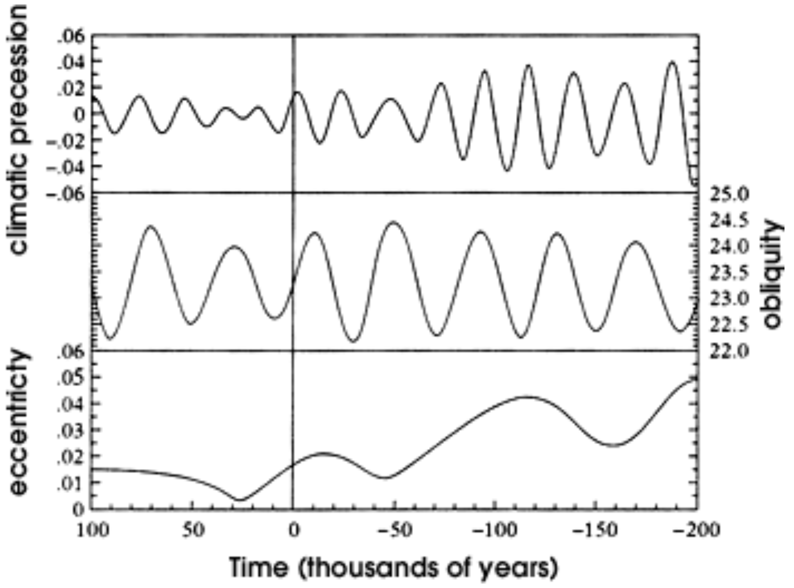

Figure 2.2 Timescale of orbital parameters (after Berger and Loutre, 1991)

Since the mid 1980’s, it was understood that the 19,000 – 23,000 year orbital precessional cycle (Milankovitch cycle) was largely responsible for Quaternary hydrological variability (Kutzbach and Guetter, 1986). This is the result of variations in insolation patterns, which influence the strength of tropical monsoons (Kutzbach, 1981). The geometry of orbital precession results in differences in solar insolation patterns (Gasse, 2000). The amount of solar insolation is thought to be antiphase between hemispheres (Berger, 1978). According to Kutzbach *et al.* (1993), an increase in summer insolation causes enhanced monsoon circulation by increasing the contrast between ocean and land pressure, which attracts monsoonal winds inland. According to the theory of orbital forcing, the northern tropics would have experienced dry conditions during the last glacial maximum (LGM), whilst the southern tropics are predicted to have experienced increased monsoon rainfall (Gasse, 2000). At the Pretoria Salt Pan, for example, numerous studies have linked the rainfall maxima to peaks in summer insolation (Thomas and Shaw, 2002). It is suggested that a 15% increase in solar radiation is associated with a 68% increase in precipitation (Thomas and Shaw, 2002). In the Zambezi catchment, variations in rainfall and discharge have been attributed to changes in local insolation coupled with latitudinal ITCZ shifts (Schefuß *et al.*, 2011).

Numerous studies conducted in northern hemisphere Africa, demonstrated the importance of the orbital precessional cycle in determining palaeoenvironmental conditions on the African continent (Nash and Meadows, 2012). However, in the southern hemisphere, and more specifically, southern Africa, palaeoenvironmental data for the LGM are often in discord with orbital forcing predictions. Aside from the winter rainfall region in South Africa, most sites within the sub-continent attest to a drier LGM, and thus cannot be explained by the Milankovitch theory of changes in the Earth's orbital parameters (Gasse, 2000). Examples of such sites include Mfabeni (Finch and Hill, 2008), Makapansgat (Holmgren *et al.*, 2003) and Wonderkrater (Scott, 1982a; Truc *et al.*, 2013). Moreover, numerous African records suggest that high frequency climate variations, that have occurred at both millennial and sub-millenial timescales, cannot be accounted for by insolation changes and orbital precession (Nash and Meadows, 2012). For example, Schefuß *et al.* (2005), have suggested that precipitation across central Africa was largely governed by differing sea surface temperatures (SST) between the tropics and subtropics of the South Atlantic Ocean.

LGM conditions in the southern tropics can be better accounted for by examining changes in sea surface temperatures and ocean-atmosphere interaction (Gasse, 2000). According to Guilderson *et al.* (1994); Beck *et al.* (1997) and Bard *et al.* (1997), tropical sea surface temperature (SST) decreased during the LGM, largely due to changes in the El Niño Southern Oscillation (ENSO). Reduced lower SSTs would have resulted in lowered evaporation rates at lower altitudes, ultimately causing a loss of water vapour (Gasse, 2000). This loss of atmospheric water vapour, would have led to a decrease in total greenhouse gas in the atmosphere, and thus enhanced cooling during the time of the LGM (Gasse, 2000). This has been clearly demonstrated in marine records obtained off the coast of Angola, where low SSTs have been documented together with cool and dry conditions during the LGM (Dupont *et al.*, 2008). In southern Africa, dune building in the Northern Kalahari has been linked to lowering of southeast Atlantic SSTs that have forced aridity in the region (Stokes *et al.*, 1998). Following this, SSTs rose in accordance with postglacial warming (Dupont *et al.*, 2008).

Recent climatic simulation models have predicted cool and dry conditions for most of the tropics during the LGM, however, increased precipitation was predicted for the winter rainfall region of southern Africa (Ganopolski *et al.*, 1998). Similarly, an LGM simulation done by Bush and Philander (1998) predicted a weakened global hydrological cycle, with a decline in evaporation and precipitation by approximately 10%. For southern Africa, these predictions made by simulation models concur with LGM conditions obtained from palaeoenvironmental records. Likewise, the biomization method has predicted shifts in biome distributions over the past 6000 years for Africa and the Arabian Peninsula (Jolly *et al.*, 1998). According to Jolly *et al.* (1998), this is reflective of climatic changes, in particular precipitation, which implies changes in monsoon extent.

The Holocene climatic patterns experienced over tropical Africa are characterized by extreme variations in precipitation patterns (Mulitza and Rühleman, 2000; Burrough and Thomas, 2013). Most southern African sites tend to suggest a wetter Holocene (Burrough and Thomas, 2013), however, certain geoproxy records from the Kalahari are seemingly conflicting (Thomas and Burrough, 2012; Scott *et al.*, 2012). According to Stree and Grove (1979), high lake levels across Africa between 12,000 and 5000 cal yr BP were a result of enhanced monsoon precipitation. Similarly, at the Makgadikgadi Basin in central southern Africa, geoproxy evidence implies that lake levels were high in the early Holocene (Burrough and Thomas, 2013) despite a drier surrounding environment. Burrough and Thomas (2013) however suggest that a wetter early Holocene was not a spatially uniform characteristic of the early Holocene in central southern Africa. This was followed by a period of aridity during the mid-late Holocene. In Namibia however, Chase *et al.* (2010) has proposed an overall Holocene aridification trend. For the most part, humid conditions during the early Holocene are attributed to high summer insolation in the northern hemisphere (Kutzbach and Liu, 1997). According to Mulitza and Rühleman (2000) however, there have been a few documented rapid declines in lake levels following the LGM.

Street-Perrott and Perrott (1990) suggest that this was due to a reduction of meltwater, and hence a slight lowering of temperatures. This is in accord with evidence obtained from climatological maps, which suggest that arid conditions occur during periods when north Atlantic SSTs are fairly cool and south Atlantic SSTs are warm (Lamb, 1978; Folland *et al.*, 1986). The drier conditions are associated with a weakened land-sea pressure gradient over the eastern south Atlantic and increased strength of the North Atlantic high-pressure cell. According to DeMenocal and Rind (1993), this causes a decline in incoming moist air from the equatorial Atlantic. Thomas and Burrough (2012), have suggested that conflicting evidence for Holocene conditions in the Kalahari may be due to poor resolution and low precision chronologies, or, this may be the result of their climatic insensitivity. Alternativey, Thomas and Burrough (2012) have recommended that the environmental contexts of such sites needs to be considered with more sensitivity.

Extreme solar heating around the equator results in increased SSTs, causing a rise in the air above, thus leaving an area of low pressure behind (Conway, 2009). This area is known as the Intertropical Convergence Zone (ITCZ). This zone is characterized by heavy rainfall, which is the result of increased rising of warm, moist air. The seasonal shifts of the ITCZ have been related to past climatic changes (Marchant and Hooghiemstra, 2004; Vincens *et al.*, 2007). Investigating the migration of the ITCZ has been key in determining Holocene moisture variations (Martin *et al.*, 1997). For example, in southern Africa, it is thought that drought conditions have been induced due to the ITCZ not migrating further south as usual. At Lake Masoko in Tanzania, shifts in the mean position of the ITCZ over the last 45,000 cal yr BP have been linked to variations in the length and severity of arid seasons (Vincens *et al.*, 2007). However, the migration of the ITCZ further north has been associated with heavy rainfall and flooding in north Africa (Conway, 2009). The positioning of the ITCZ is influenced by the tilt of the Earth’s axis, and is thus linked to orbital forcing mechanisms. Furthermore, seasonal shifts in the positioning of the ITCZ have also been linked to the ENSO.

The concentrations of greenhouse gases, CO_2 and CH_4 play a significant role in climate change, especially when gas concentrations enhance the effects of variations in solar insolation (Cerling, 1991; Ruddiman and Raymo, 2003). The link between greenhouse gases and glacial-interglacial climatic shifts was initially uncovered through the analysis of trapped air in ice cores from Greenland and the Antarctic (Lorius *et al.*, 1990) (Fig. 2.2). These studies revealed that atmospheric CO_2 content within the cores was much lower during the LGM, as compared to the Holocene. Data from the Vostok ice core verified the strong association between ρCO_2 and climate change (Raynaud *et al.*, 1998). In tropical regions of Africa for example, enhanced atmospheric CO_2, coupled with changes in temperature and moisture are likely to have resulted in changes in vegetation (Bennett and Willis, 2000). For example, in a study by Jolly and Haxeltine (1997) which investigated the effect of low atmospheric glacial CO_2 on tropical African montane vegetation, it was determined that low ρCO_2 levels coupled with low CO_2/O_2 ratios and reduced moisture availability during the LGM affected the competitive balance between C_3 and C_4 plants, enabling C_4 plant taxa such as some grasses and succulents to have a selective advantage (Jolly and Haxeltine, 1997).

A similar relationship between CH_4 and climate change was also revealed. According to Lorius *et al.* (1990), increased CH_4 concentrations were documented between the LGM and the Holocene. Evidence from the Vostok record linked CH_4 to temperature conditions, showing that Antarctic cooling was related to notable decreases in CH_4 concentration (Lorius *et al.*, 1990). Minimum Holocene CH_4 levels have been detected during the mid-Holocene. This is in keeping with documented mid-Holocene arid conditions (Marchant and Hooghiemstra, 2004). Seltzer *et al.* (2002) state that a change in hydrological patterns in the tropics may have contributed to a loss of atmospheric CH_4 at the time. According to Marchant and Hooghiemstra (2004), lake desiccation, resulting in a loss of wetlands would have caused a decline in CH_4 levels.

Although the mechanisms of climate change, for the most part, have been discussed separately, it is clearly unlikely that a single forcing mechanism has been responsible for driving important climatic events during the late Quaternary. Rather, a combination of forcing mechanisms is required to explain the variations in palaeoclimates (Marchant and Hooghiesmstra, 2004; Berger and Yin, 2011). Moreover, the drivers of climate change are seemingly interrelated (Marchant and Hooghiesmstra, 2004). A change in one factor often leads to variations in another, as discussed with CO_2, which amplifies the effects of solar insolation. Variations in SST, resulting from changes in the ENSO, seem to be the major forcing mechanism acting over southern Africa, however, many more studies need to be undertaken to fully understand the drivers of climatic shifts over the African continent (Marchant and Hooghiesmstra, 2004). According to Berger and Yin (2011), astronomical induced insolation is at the centre of most climatic changes observed during the Quaternary, however, much more research needs to be undertaken to understand changes over the last three million years.

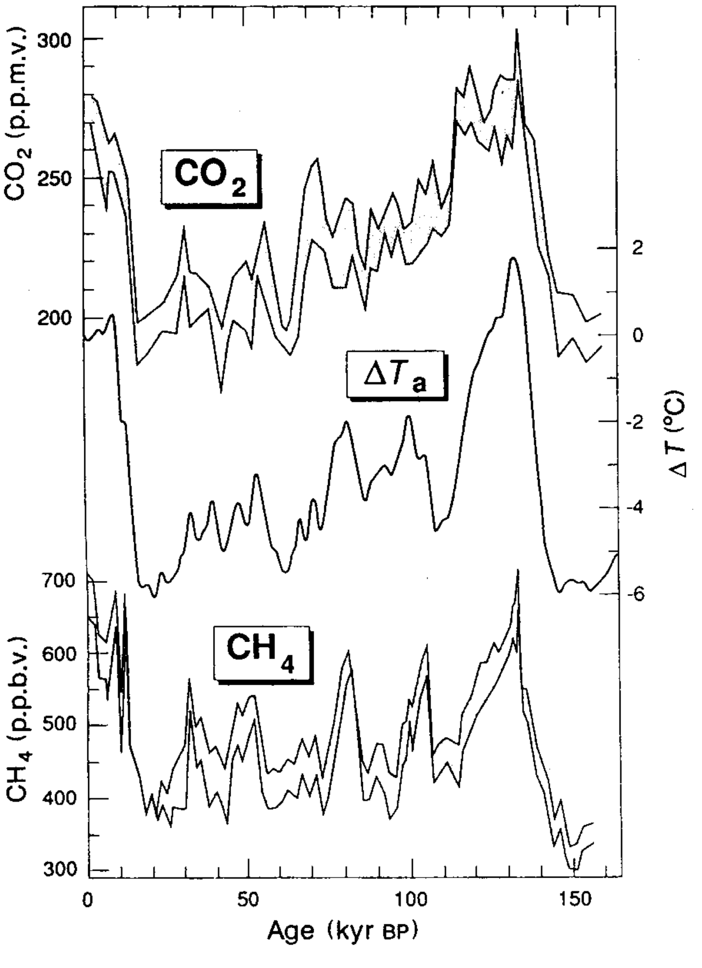

Figure 2.3 Variations in atmospheric concentrations of CO_2, CH_4 and atmospheric temperature over the last climate cycle, as derived from data from the Vostok ice core (after Lorius *et al.*, 1990).

2.2 Current understanding of past environmental change in southern Africa

For the African continent, and more specifically the southern African region, relatively few studies have been conducted, resulting in a limited number of available pollen records for the region. Palaeoenvironmental records for southern Africa have been described as ‘frustratingly incomplete’ (Quick *et al*., 2011, p. 1). In southern Africa, palaeoenvironmental studies have been largely restricted to springs and swamps and a limited number of lake systems (Neumann *et al*., 2008). The arid and semi-arid conditions that prevail are not conducive to pollen preservation, resulting in a paucity of suitable sites (Norström *et al*., 2009; Chase *et al*., 2011; Chase *et al*., 2012). In comparison with temperate Europe and North America, the temporal and spatial resolution of available palaeoenvironmental records remains poor (Nash and Meadows, 2012; Salzmann and Hoelzmann, 2005). Currently, the European Pollen Data Base has over 1000 late Quaternary records, whilst the African Pollen Database records less than 270.

In southern Africa, palaeoenvironmental data are slowly being compiled mainly through the use of pollen, charcoal, isotopes, geochemical data, speleothem analysis and more recently through the analysis of hyrax middens (Chase *et al*., 2012). Furthermore, quantitative palaeo reconstructions are starting to be developed for southern Africa, which will facilitate more robust comparisons between palaeoenvironmental proxy data and general circulation models (Truc *et al*., 2013). There are many reasons why it is crucial to develop a thorough understanding of Quaternary environmental changes in this region, however, the most beckoning reason for undertaking Quaternary studies in southern Africa is that ‘so little is known about it’ (Meadows, 2001, p. 40). There is a rising consensus that a thorough understanding of evidence from the most recent geological past is key to understanding changes in the human relationship with the biophysical environment (Meadows, 2012).

2.2.1 Early last glacial (> ca. 60,000)

Although the pollen sequence from the Pretoria Saltpan (Tswaing Crater) is not continuous and has an uncertain chronology, it is the longest late Quaternary record that exists from South Africa (Partridge *et al*., 1993; Scott, 1999), covering a total period of approximately 190,000 years. The Pretoria Saltpan pollen record constitutes an important sequence for the southern African region.

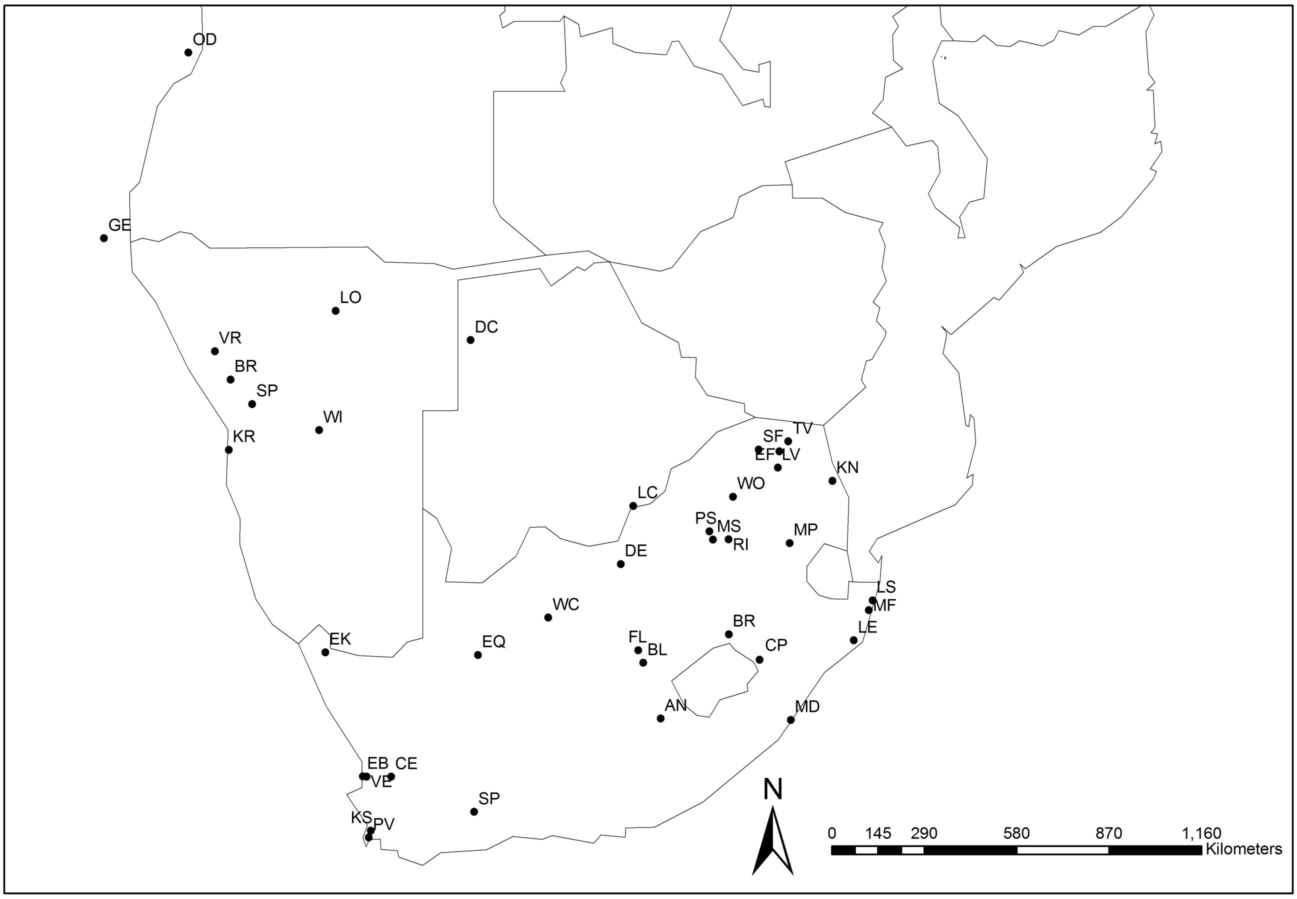

Figure 2.4 Map of sites mentioned in text. Codes correspond with sites presented in table 2.1

During the last 190,000 years, it is evident that rainfall has largely fluctuated in response to changes in summer insolation (Nash and Meadows, 2012). Although poor pollen preservation has hampered interpretation for parts of the core, pollen analysis has suggested generally cooler conditions between *ca.* 80,000 yr BP (extrapolated age)– 37,555 cal yr BP (33,000 yr BP) however, this was interspersed with at least three short periods of warmer conditions (Scott, 1999).

The Crevice Cave speleothem record from Pinnacle Point, an all year rainfall site near Mossel Bay on the south coast of South Africa is the first long, well dated late Quaternary record for the south coast of South Africa (Bar-Matthews *et al.*, 2010). This sequence provides isotopic evidence for changes in prominence of winter and summer rainfall, and also records the effects of these shifts on changes in the composition of C_3 and C_4 grasses in the area. From 90,000 to 53,000 cal yr BP, Bar-Matthews *et al.* (2010) suggests that a shift to C_3 dominated grasses has corresponded with increased warm conditions and associated increases in winter rainfall. Although C_4 grasses may indicate warmer tropical conditions, Bar-Matthews *et al.* (2010) have suggested an increase in summer rainfall brought on by cooler conditions has resulted in an increase in C_4 grasses in the area. This evidence implies that winter rainfall along the south coast was not enhanced by cooler glacial conditions despite predictions by certain climate models, but rather, evidence from this record are in accord with older predictions (Bar-Mathews *et al.*, 2010). Shifts in the record are generally in concert with changes in sea surface temperatures and southern hemisphere temperatures, inferred from ice core data, implying that climatic and environmental changes correspond well with recorded global climate change between 90,000 – 53,000 cal yr BP (Bar-Mathews *et al.*, 2010). Despite this, these results must treated with caution due to the problematic chronology of Bar-Mathews *et al.* (2010)

2.2.2 Pre-last glacial maximum (ca. 60,000 – 25,000 cal yr BP)

Longer records, preceding the LGM are very rare in southern Africa and are not distributed evenly across the subcontinents, although, there are a few records from which a regional synthesis is starting to be compiled (Nash and Meadows, 2012).

Table 2.1 List of sites mentioned in text

Code	Site	Country	Latitude	Longitude	Altitude (above sea level)	Age (cal yr BP)	Type	Authors
OD	(Ocean Drilling Program Site 1078)	Angola-Namibia highlands	11°55'S	13°24'E	426 below sea level	0 – *ca.*30,000	marine	(Dupont *et al.*, 2008)
GE	GeoB1023-5	Angola-Namibia highlands	17°09'S	11°01'E	1978	0 – *ca.*21,000	marine	(Shi *et al.*, 2000; Shi *et al.*, 1998)
DC	Drotsky's Cave	Botswana	19°57'S	21°13'E	1100	0 – *ca.*1200	cave	(Thomas and Shaw, 2002)
LC	Lobatse Cave	Botswana	25°12'S	25°39'E	1113	0 – *ca.* 50,000	cave speleothem	(Holmgren *et al.*, 1995)
BR	Brandberg	Namibia	21°08'S	14°35'E	2000	0 – *ca.*30,000	hyrax middens	(Scott *et al.*, 2004)
SP	Spitzkoppe	Namibia	21° 49'S	15° 11'E	1784	0 – *ca.*11,700	rock hyrax	(Chase *et al.*, 2009; Beaumont *et al.*, 1984)
VR	Vrede	Namibia	20°19' S	14°10'E	540	0 – *ca.*6000	hyrax middens	(Gil-Romera *et al.*, 2006)
LO	Lake Otjikato	Namibia	19°11'S	17°32'E	1212	0 – *ca.*3170	lake	(Scott *et al.*, 1991)
KR	Kuseib River	Namibia	23°40'S	15°01'E	400	0 – *ca.* 2000	hyrax middens	(Scott, 1996)
WI	Windhoek	Namibia	22°44'S	13°03'E	1650	0 – *ca.* 7000	spring deposits	(Scott *et al.*, 1991)
PS	Pretoria Saltpan	South Africa	25°34'S	28°04'E	1100	0 – *ca.* 190,000	salt pan	(Partridge *et al.*, 1993; Scott, 1999; Kristin *et al.*, 2007; Scott, 1993; Scott, 2002)

Code	**Site**	**Country**	**Latitude**	**Longitude**	**Altitude (above sea level)**	**Age (cal yr BP)**	**Type**	**Authors**
EF	Elim Farm	South Africa	28°48'S	28°41'E	1890	0 – *ca*.4000	organic silt	(Scott, 1989)
WO	Wonderkrater	South Africa	24°26'S	28°45'E	110	0 – *ca*.34,500	spring peat site	(Scott, 1982a; Scott and Vogel,1983; Scott, 1993; 1999; Tyson *et al*., 2000; Scott, 2002; Truc *et al*., 2013)
MF	Mfabeni	South Africa	28°9'S	32°31'E	11	0 – *ca*.44,000	peatland	(Finch and Hill, 2008)
MD	Mdlanzi Swamp	South Africa	27°36'S	32° 28'E	40	0 –*ca*. 1500	swamp	(Turner and Plater, 2004)
VE	Verlorenvlei	South Africa	32°19'S	18°24'E	12	0 – *ca*.5000	estuarine lake	(Baxter, 1996; Meadows, 2001; Chase and Meadows, 2007; Stager *et al*., 2012)
CE	Cederberg	South Africa	32°12'S	18°56'E	2026	0 – *ca*.19,500	vlei/hyrax middens	(Meadows and Sugden. 1990; Meadows and Baxter, 1999; Quick *et al*., 2011; Valsecchi *et al*., 2012)
SP	Seweweekspoort	South Africa	32°22'S	21°24'E	1100	0- *ca*. 8000	middens	(Chase *et al*., 2013)
EB	Elands Bay Cave	South Africa	32°14'S	18°21'E	37	0 – 20,500	cave	(Scott, 1994; Parkington *et al*., 2000)
EQ	Equus Cave	South Africa	27°27'S	24°46'E	1250	undated	hyaena corprolites	(Scott *et al*., 2012; Beaumont *et al*., 1984; Johnston *et al*., 1997;Scott 1987b)
WC	Wonderwerk Cave	South Africa	27°59'S	23°24'E	1480	0 – *ca.* 10,000	vlei	(Scott *et al*., 2012; Tusenius, 1989)
EK	Eksteenfontein	South Africa	28°49'S	17°14'E	1040	0 – *ca*. 11890	spring	(Scott *et al*., 2012)
AN	Aliwal North	South Africa	30°39'S	26°42'E	1370	undated	thermal spring	(Coetzee, 1967)
RI	Rietvlei	South Africa	25°50'S	28°20'E	1480	0 – *ca*. 10,500	peat deposit	(Tusenius, 1989; Scott, 1993; 1999; Scott and Vogel, 1983)
CP	Cathedral Peak	South Africa	28°59'S	29°15'E	1899	0 – *ca*.15,500	peat deposit	(Lodder, 2010)

Code	Site	Country	Latitude	Longitude	Altitude (above sea level)	Age (cal yr BP)	Type	Authors
MS	Moreletta stream	South Africa	25°44'S	28°18'E	1310	0 – *ca*. 5500	drainage line	(Tusenius, 1989)
BH	Braamhoek	South Africa	28°14'S	29°35'E	1700	0 – 16,000	wetland	(Scott *et al*., 2012; Norström *et al*., 2009)
LE	Lake Eteza	South Africa	28° 31'S	32° 8'E	14	0 – *ca*.10,200	lake	(Scott *et al*., 2012; Neumann et al., 2010)
TV	Tate Vondo	South Africa	22°53'S	30°19'E	1100	0 – *ca*.12,000	swamp	(Scott, 1993; 1999;1987a)
FL	Florisbad	South Africa	28°46'S	26°04'E	1270	0 – *ca*.8200	spring deposits	Scott and Nyakale, 2002)
DE	Deelpan	South Africa	29°15'S	25°40'E	1321	0 – *ca*.4000	pan	(Scott, 1988; Scott and Brink, 1992)
BL	Blydefontein	South Africa	31°09'S	25°05'E	1700	0 – *ca*.11,850	hyrax middens	(Scott *et al*., 2005)
KS	Klaarfontein Springs	South Africa	32°25'S	18°29'E	14	0 – *ca*.7000	artesian springs	(Meadows and Baxter, 2001)
MA	Maputaland	South Africa	27°06'S	32°49'E	15	0 – *ca*. 6080	peat deposit	(Mazus, 2000)
LV	Limpopo valley	South Africa	23°16' S	31°23'E	312	0 – *ca*. 1500	lake, spring and pan	(Ekblom *et al*., 2013
PV	Princess Vlei	South Africa	34°02'S	18°29'E	2.4	0 – *ca*. 4150	vlei	(Neumann *et al*., 2011)
LS	Lake Sibaya	South Africa	27°21'S	32°37'E	14.5	0 – *ca*.7700	lake	(Neumann *et al*., 2008; Stager *et al*., 2013)
KN	Kruger National Park	South Africa	23°59'S	31°33'E	305	0 – *ca*.50	pan deposits	Duffin (2008)
SF	Scot’s Farm	South Africa	22°57'S	29°24'E	823	0 – *ca*.5000	spring deposit	(Scott, 1982b)
MP	Mpumalanga	South Africa	24°55'S	30°50'E	1447	0 – *ca*.6500	wetland	(Breman *et al*., 2011)

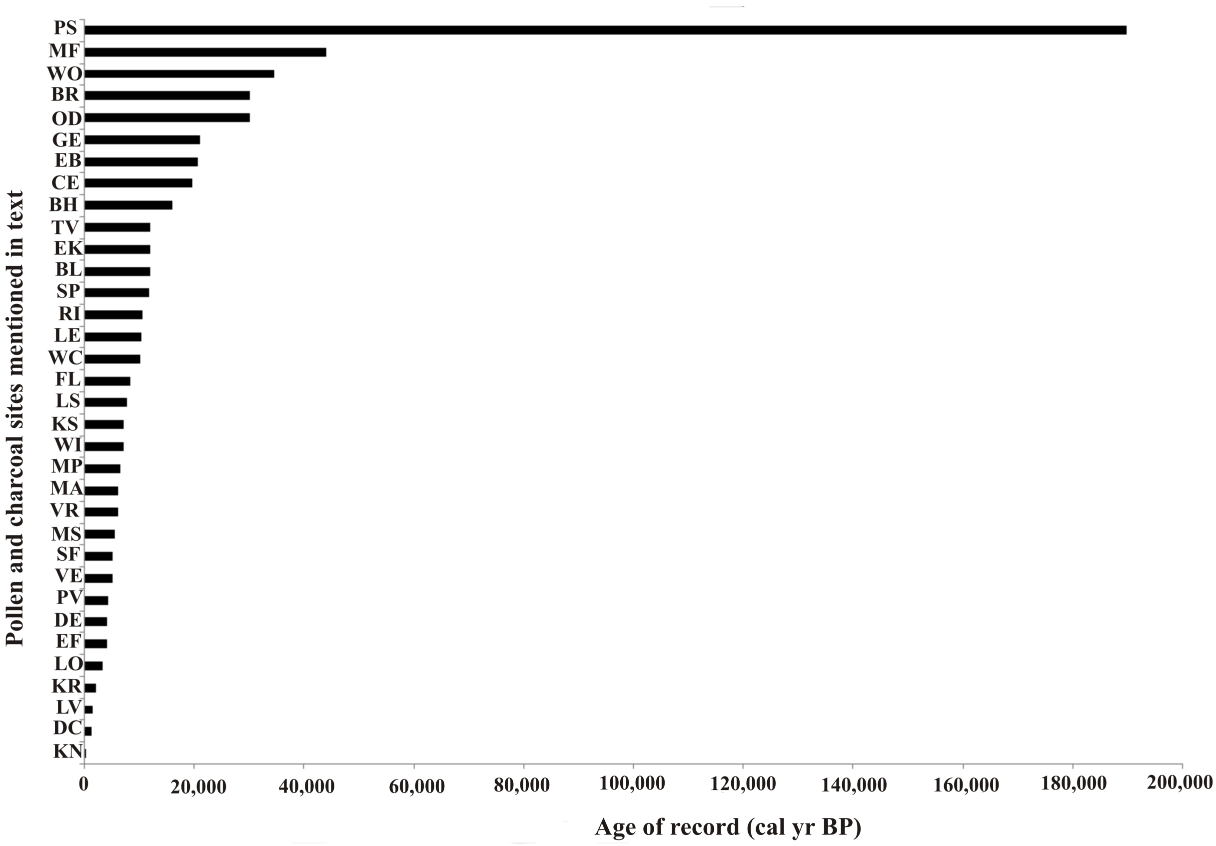

Figure 2.5 Length of palaeoenvironmental records mentioned in text (Source: D.L. Baboolal)

From approximately 36,914 – 38197 cal yr BP (33,000 yr BP), conditions remained cooler up until 11,000 years BP at the Pretoria Saltpan (Partridge *et al.*, 1993; Scott, 1999). High percentages of Cyperaceae were recorded at Elim Farm, in the Free State, up until *ca.* 34,507 – 34,835 cal yr BP (*ca.* 30,000 yr BP), suggesting locally moist conditions (Scott, 1989). Following this, an increase in fynbos elements imply a shift to cooler conditions leading up to the LGM. At Wonderkrater, in Limpopo, pollen data suggests a relatively dry savanna, interspersed with mesic savanna elements such as Capparaceae and Combretaceae between *ca.* 38,824 – 28,170 cal yr BP (*ca.* 34,000 – 23,370 years BP) (Scott, 1999). During this time, montane forests coexisted. Furthermore, the presence of *Typha* indicates open water. High percentages of Cyperaceae pollen also support moist conditions (Scott, 1982a). The pollen data for Wonderkrater suggest a cool temperate, moist subhumid climate for the pre-LGM (Scott, 1982a).

Prior to the LGM, relatively cool and wet conditions have been inferred from the pollen record at Mfabeni, along the north coast of KwaZulu-Natal (Finch and Hill, 2008), although inferences from this site must be carefully considered due to the problematic chronology. This is in keeping with palynological evidence obtained at the Pretoria Salt Pan, which documents wet and cool conditions approximately 43,000 years ago (Partridge *et al.*, 1993; Scott, 1999). From approximately 33,000 cal yr BP, a decline of *Podocarpus* is recorded at Mfabeni, implying forest retreat (Finch and Hill, 2008). Following this, the dominance of Poaceae coupled with a constant decline of Cyperaceae at 24,000 cal yr BP suggest local drying occurred (Finch and Hill, 2008). A shift to drier conditions at this time is further supported by increased frequencies of herbaceous taxa such as Asteraceae (Finch and Hill, 2008). According to Finch and Hill (2008), this shift to arid conditions is most likely representative of an early onset of the LGM.

Carbon and oxygen isotope analyses of a speleothem record from Lobatse II Cave in Botswana reveal warm, humid conditions between *ca.* 51,000 – 46,000 (51,000 - 43,000 years BP) and *ca.* 31,268 – 24,906 cal yr BP (27,000 – 21,000 years BP) (Holmgren *et al.*, 1995), however, a 2°C drop in temperature was likely to have occurred between the two periods.

From these records, it is evident that conditions were moist, becoming drier and cooler toward the onset of the LGM.

2.2.3 Last glacial maximum (LGM) (ca. 25,000 – 18,000 cal yr BP)

The LGM is well documented at Wonderkrater in northeastern South Africa. A decrease in arboreal pollen is recorded during this time. According to Scott (1982a), the composition of arboreal pollen within the pollen record is indicative of bushveld vegetation. Low percentages of *Podocarpus* suggest that Afromontane forest existed in restricted patches during the LGM at Wonderkrater (Scott, 1982a). The presence of Tarchonantheae, Capparaceae, Oleaceae and Proteaceae, among others, implies drier conditions. Together with the occurrence of fynbos elements, the reconstructed vegetation patterns at Wonderkrater suggest cool and dry conditions prevailed during the LGM (Scott, 1982a; Truc *et al.*, 2013). Truc *et al.* (2013) have estimated that temperatures during the LGM at Wonderkrater were 6 ± 2° C cooler than the mid-Holocene, and approximately 4 ± 2° C cooler than present. This is in agreement with predicted variations in rainfall in southern Africa in response to orbital forcing mechanisms and northern hemisphere cooling (Truc *et al.*, 2013).

Pollen data obtained from sites such as Wonderwerk Cave and Wonderkrater in South Africa indicate a slight warming episode between 20,000 and 19,000 cal yr BP (Scott *et al.*, 2012). The stalagmite record from Makapansgat in northern South Africa is indicative of dry, cool conditions with a decline in grass cover between 23,000 – 21,000 and 19,500 – 17,500 cal yr BP (Holmgren *et al.*, 2003). According to analysis of organic/inorganic matter and the geochemistry of sediments obtained from the Pretoria Saltpan, cool and arid conditions prevailed during the LGM (Kristen *et al.*, 2007). Pollen data from Elim in the Free State, indicate that maximum LGM cooling occurred at approximately 22,277 – 22,697 cal yr BP (19,000 yr BP) (Scott, 1989).

Analysis of sediments obtained from Verlorenvlei, located in the southwestern Cape's winter rainfall zone, suggests that widespread scrub forests dominated the LGM, suggesting cooler and wetter conditions at the time (Baxter, 1996; Meadows, 2001). At Cederberg, also situated in the winter rainfall zone, reconstructions are suggestive of cooler and moister conditions during the LGM (Meadows and Sugden. 1990; Meadows and Baxter, 1999). Prior to 23,468 – 24,122 cal yr BP (20,000 yr BP), Afromontane rainforest and riverine woodland taxa were prevalent at Elands Bay Cave (Cowling *et al.*, 1999). Xeric communities similar to contemporary communities seen presently then replaced this. Changes in the structuring of vegetation communities at Cederberg imply an overall decrease in rainfall since 20,000 cal yr BP (Quick *et al.*, 2011).

More open vegetation and an increase in desert and semi desert elements in Angola, inferred from a marine pollen record (Ocean Drilling Program Site 1078), indicate drier and cooler conditions during the last glacial (Dupont *et al.*, 2008). A marine pollen record (GeoB1023-5) extracted off the southwestern coast of Africa are indicative of arid conditions in the region between 21,000 and 17,500 cal yr BP (Shi *et al.*, 2000).

Speleothem growth is recorded at Drotsky's Cave in Botswana between 30,471 – 30991 cal yr BP (26,000 years BP) and 24,618 – 25,205 (21,000 years BP) (Brook *et al.*, 1998) suggesting an increase in moisture. Analysis of pollen in hyrax middens obtained from Brandberg in Namibia indicate cool and moist conditions between 24,618 – 25,205 cal yr BP (21,000 yr BP) (Scott *et al.*, 2004). Moreover, a seasonal lake was present near Tsodilo Hills in Botswana between 27,000 – 22,000 cal yr BP and 19,000 – 12,000 cal yr BP (Thomas *et al.*, 2003) also indicating increased moisture.

Although many sites indicate that dry and cool conditions prevailed over southern Africa during the LGM, contrasting results, suggesting that conditions during the LGM were cool and moist, have been found at other sites. According to Meadows and Baxter (1999), this is to be expected as there are marked regional differences between rainfall seasonality and amount between the winter and summer rainfall regions.

2.2.4 The last glacial-interglacial transition (ca. 18,000 – 11,700 cal yr BP)

The period between 18,800 and 15,000 cal yr BP in Angola was associated with increased moisture conditions, inferred from high levels of *Podocarpus* recorded within a marine pollen record (Dupont *et al.*, 2008). The existence of a lake near Tsodilo Hills, Botswana, in the northwestern Kalahari, up until 12,000 cal yr BP suggests increased precipitation following the LGM (Thomas *et al.*, 2003). According to Thomas and Shaw (2002), wet periods are recorded at Drotsky's Cave in Botswana between 19,000 – 14,000 and 12,500 – 11,000 cal yr BP (Thomas and Shaw, 2002). In contrast, the use of diatom and geochemistry analyses to reconstruct palaeolake levels at Lake Ngami in northwest Botswana revealed shallower lake levels after the LGM, which suggests a reduced inflow (Huntsman-Mapila *et al.*, 2006). The analysis of rock hyrax middens at the De Rif site in the Cederberg Mountains, revealed increased moisture availability between 19,000 and 17,000 cal yr BP coupled with exceptionally high peaks in charcoal (Scott and Woodborne, 2007) in South Africa's winter rainfall zone. This is in accord with other results obtained at De Rif, which suggests that the last glacial interglacial transition (LGIT) was slightly wetter than the LGM (Chase *et al.*, 2011). Although we suspect that Ericaceae fynbos may indicate wetter conditions than Restionaceae fynbos, Valsecchi *et al.* (2013) have inferred a shift from drier conditions to wetter conditions through an observed change from Ericaceae type fynbos to Restionaceae type fynbos between *ca.* 15,500 – 13,300 cal yr BP in the Cederberg area. Within this period of increased humidity however, a phase of lower moisture availability was recorded between *ca.* 15,400 – 14,500 cal yr BP. Contemporaneously, microscopic charcoal reached a maximum (Valsecchi *et al.*, 2013). This implies that increased fire frequencies and intensities in Cederberg are most likely the product of prolonged, intense dry seasons (Valsecchi *et al.*, 2013).

Pollen records from Equus Cave and Wonderwerk Cave in the Northern Cape, South Africa, reveal cooler conditions prior to 17,000 cal yr BP (Scott *et al.*, 2012). A peak in moisture is recorded at 17,146 cal yr BP. Following 17,000 cal yr BP, gradual warming occurs. This is in accord with stable isotope evidence obtained from the Makapansgat speleothem record (Holmgren *et al.*, 2003) and the Stampriet (Stute and Talma, 1997) and Uitenhage aquifers (Heaton *et al.*, 1986) which indicate that the onset of post-glacial warming occurred at 17,000 cal yr BP. The Makapansgat stalagmite record, documents a cool period between 15,000 and 13,500 cal yr BP (Holmgren *et al.*, 2003). Increased warming is recorded at Makapansgat after 13,000 cal yr BP. According to the Wonderkrater pollen sequence, maximum cooling was experienced at approximately 20,431 – 21,184 cal yr BP (17,500 years BP) (Scott, 1982a) inferred from pollen data. These conditions coincide with those obtained by Thomas *et al.* (2000) and Partridge *et al.* (1997), who also document dry and cool conditions in the region. The pollen record at Wonderkrater coincides with the Makapansgat δ^{18}O record (Figure 2.5), which indicates rapid warming, accompanied by increased wet conditions after 17,500 cal yr BP (Holmgren *et al.*, 2003). Cooler conditions return at approximately 15,000 cal yr BP, followed by warmer conditions after 13,000 cal yr BP. Conversely, Scott *et al.* (2012) records an increase in temperatures together with variable dry and moist conditions at around 15,000 years BP. The pollen record from Wonderkrater (Scott 1999) indicates slight warming between 17,974 – 18,519 cal yr BP (15,000 yr BP), followed by cooling at 16,807 – 17,188 (14,000 years BP). Cool temperatures occurred at Eksteenfontein from 15,200 to 13,600 cal yr BP, with warm conditions occurring after 12,500 cal yr BP (Scott *et al.*, 2012). Moist conditions are recorded between 19,650 – 19903 cal yr BP (16,600 years BP) and 13,213 – 13,410 (11,500 yr BP) at Aliwal North (Coetzee, 1967). A rise in temperature of about 4 °C relative to the LGM is recorded at Wonderkrater from 13,600 – 12,500 cal yr BP (Truc *et al*., 2013). This is reflected in the pollen record by an increase in savanna elements such as Combretaceae, *Tarconanthus* and Capparaceae, together with a decrease in fynbos taxa and Chenopodiaceae (Truc *et al.*, 2013).

At Braamhoek Wetland (Norström *et al*., 2009), cool and dry conditions, inferred from high percentages of Poaceae, Asteraceae and Chenopodiaceae pollen, have been recorded from 15,000 to 14,300 cal yr BP. This is accompanied by high charcoal concentrations, suggesting that fires occurred frequently during dry conditions (Norström *et al*., 2009). This is in contrast to suggestions made by Daniau *et al.* (2013) who propose that fires in South African grasslands are linked to humid conditions.

Forest pollen remains low during this time period. Intense fires tends to restrict the growth of forests (Noström *et al*., 2009). Following this, a return to moister conditions resulted in a decline in charcoal concentration.

On the banks of the southern Phuthiatsana River in Lesotho, Roberts *et al.* (2013) detected an overall shift in vegetation from purely C_3 vegetation during the LGM, towards an increased proportion of C_4 vegetation during the Holocene, thus denoting a change to warmer conditions. Between 11,200 and 9500 cal yr BP, stable carbon isotope evidence suggests that a rapid fluctuations in temperature of up to 4 °C occurred in the area.

Moist conditions at Aliwal North were interrupted by slight dry conditions between 16,768 – 17,094 cal yr BP (13,900 years BP) and 12,664 – 12,929 cal yr BP (11,000 yr BP) which may correspond with the northern hemisphere Younger Dryas (Coetzee, 1967). Enriched stable carbon and nitrogen isotope values at De Rif Cederberg, from approximately 13,000 – 11,500 cal yr BP concur with both the Heinrich Event 1 and the Younger Dryas (Quick *et al*., 2011).

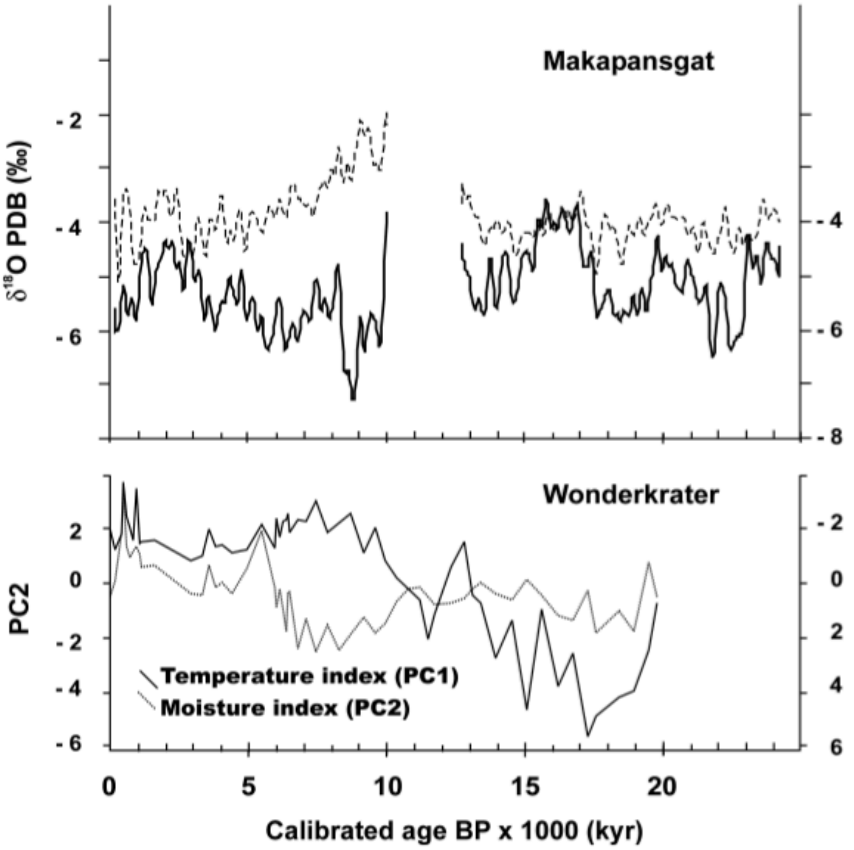

Figure 2.6 Comparison of Wonderkrater temperature and moisture indices with $\delta^{18}O$ and $\delta^{13}C$ record from the Makapansgat speleothems (after Scott *et al.*, 2003).

Records from Wonderkrater and Eksteenfontein reveal a dry episode between approximately 13,000 and 11,500 cal yr BP that coincides with the Younger Dryas (Scott *et al.*, 2012). Truc *et al.* (2013) documented cooling between 12,300 – 10,500 cal yr BP. During this period, the pollen record showed a marked increase in the abundance of fynbos taxa, and it is estimated that temperatures within this period were similar to those recorded during the LGM (Truc *et al.*, 2013). However, the accuracy of the Wonderkrater chronology (Scott *et al.*, 2003) has hampered the degree to which this cool period can be accurately linked to the Younger Dryas (Truc *et al.*, 2013). Similarly, drier conditions at Equus Cave and Wonderwerk after 12,600 cal yr BP also correspond with the Younger Dryas (Scott *et al.*, 2012). Cool and dry conditions are recorded at Lake Malawi between 12,000 and 10,300 cal yr BP, inferred from a decline in the mass accumulation rate of biogenic silica (Johnson *et al.*, 2002). Records of the Younger Dryas in southern Africa remain scattered and unclearly represented owing to a lack of resolution. Chase and Meadows (2007) state that the impact of the Younger Dryas in southern Africa is not yet fully understood.

2.2.5 Early Holocene (ca. 11,700 – 6000 cal yr BP)

At Cederberg, Valsecchi *et al*. (2013) documented a shift to a proteoid dominated fynbos until *ca.* 11,200. This was followed by an increase in fynbos thicket taxa such as *Dodonaea* after *ca.* 10,400, suggesting an increase in moisture and temperature. This is supported by evidence obtained by Chase *et al*. (2011) and Scott and Woodborne (2007), which point to a more humid early Holocene at De Rif in Cederberg. Scott and Woodborne (2007) detected peaks in *Olea* and Cyperaceae after 9000 cal yr BP, suggesting that moist conditions persisted. The Seweweekspoort middens record, from the southern Cape, that documents increased humidity between 7300 – 6600 cal yr BP, 6200 – 5700 cal yr BP and 5200 – 4500 cal yr BP (Chase *et al*., 2013). However, this was interspersed with a number of arid periods. Chase *et al*. (2013) have observed a pattern of increased aridity during warmer periods. This is most likely the result of shifts in the southern westerly storm track possibly due to variations in the extent of Antarctic sea ice (Chase *et al*., 2013). In the study by Scott and Woodborne (2007), an Asteraceae shrubland was recorded to have developed by 8000 cal yr BP. Together with the absence of Ericacea and *Passerina*, this implies the existence of Karroid conditions in the Cederberg region.

A return to warmer conditions, inferred from the Cango Caves δ^{18}O stalagmite record (Talma and Vogel, 1992) and the Wonderkrater temperature index (Holmgren *et al*., 2003), was recorded for the start of the early Holocene. According to Partridge *et al*. (1999), maximum Holocene temperatures, described as the Holocene Altithermal, occurred between 8000 and 6000 cal yr BP. Nash and Meadows (2012) state that there is variability among the timing of maximum Holocene temperatures at different sites in southern Africa. For instance, analysis of speleothem isotopes at Uitenhage (Heaton *et al*., 1983; Nash and Meadows, 2012) indicate that the warm phase occurred between 8000 to 4500 cal yr BP, however, based on records obtained from Stampriet aquifer (Stute and Talma, 1998; Nash and Meadows, 2012), maximum warming occurred at approximately 9000 to 6000 cal yr BP. Generally, records from the early Holocene suggest fairly dry conditions for the southern African subcontinent (Scott and Lee-Thorp, 2004), with the exception of the southwestern winter rainfall region and Namibia (Gil-Romera, 2006), which was relatively mesic (Scott and Lee-

Thorp, 2004).

Evidence from charcoal studies conducted at Wonderkrater, Rietvlei and Moreletta stream suggest cool and dry conditions between 11,951 – 12,093 cal yr BP (10,300 – 8500 years BP), followed by dry conditions and a rise in temperature up until 8195 – 8337 cal yr BP (7500 years BP) (Tusenius, 1989). Scott (1982a) recorded increasing temperatures at Wonderkrater between 10,120 – 10,198 cal yr BP (9000 years BP) and 6715 – 6801 cal yr BP (6000 years BP). This is accompanied by a rise in moisture levels at 6500 cal yr BP. According to Truc *et al.* (2013), maximum warming at Wonderkrater occurred between 8300 – 6500 cal yr BP. During this time, the pollen record documents marked vegetation changes. The pollen sequence is characterised by an increase in savannah elements, particularly *Tarconanthus* and Capparaceae, coupled with a corresponding decline in cool fynbos taxa (Truc *et al.*, 2013). An increase in C_3 vegetation in the South African highland suggests cooler conditions at 10,000, 9500 and 8000 cal yr BP (Scott and Lee-Thorp, 2004). This was intercepted by warmer conditions inferred from an increase in C_4 grasses at 9900, 9000 and after 7600 cal yr BP (Scott and Lee-Thorp, 2004).

A significant depletion in $\delta^{13}C$ values at Makapansgat between 10,200 to 8400 cal yr BP indicates increased C_3 woody vegetation, together with a decline in C_3 grass cover (Holmgren *et al.*, 2003). This, coupled with low organic content found within the core during this time, suggests a sparsely vegetated, dry environment (Holmgren *et al.*, 2003). Dry conditions are recorded at 10,500 cal yr BP at Wonderkrater and Equus Cave, however, records from Braamhoek wetland (Norström *et al.*, 2009) in the eastern Free State and Lake Eteza (Neumann *et al.*, 2010) on the north coast of KwaZulu-Natal show a wet phase at 10,000 cal yr BP (Scott *et al.*, 2012). Following this, an increase in grassy environments after 8500 cal yr BP indicates a shift to wetter conditions with a combination of grassy and woody environments (Holmgren *et al.*, 2003).

According to Shi *et al.* (1998), analysis of a marine pollen sequence, obtained off the west coast of Angola, revealed that dry conditions prevailed near the border of Namibia and Angola prior to 7500 cal yr BP. Conditions in northwestern Namibia, inferred from fluvial deposits, indicate arid conditions between 12,000 cal yr BP until the mid-Holocene, however, conditions were not as dry as the terminal Pleistocene (Eitel *et al*., 2006). Warm, moist conditions, with grass and woodland dominated environments are inferred in Windhoek, Namibia, between 8576 – 8651 cal yr BP and 7243 – 7323 cal yr BP (7900 – 6400 years BP) (Scott *et al*., 1991). Similarly, isotope data from the Spitzkoppe midden record in central Namibia indicate a wetter early Holocene (Chase *et al*., 2009). Periods of increased moisture have been documented at Spitzkoppe between 8700 – 7500 and 6900 – 6700 cal yr BP. However, contradictory results are produced from speleothem records in northern Namibia, which suggest low water tables during the same time (Thomas *et al*., 2002). Records from Angola, which show an increase in dry forest and a retreat in rain forest elements between 10,000 and 7800 cal yr BP are in accordance with climatic conditions found at other sites within the Namibia-Angola region (Dupont *et al*., 2008). Between 5600 – 4900 and 4200 – 3500 cal yr BP, increases in humidity have been recorded at Spitzkoppe (Chase *et al*., 2009). This is corroborated by the fossil hyrax middens records near Vrede in western-central Namibia where high moisture levels were inferred between 6000 and 1000 cal yr BP by increases in the abundance of Poaceae, Cyperaceae and Chenopodiaceae pollen (Gil-Romera *et al*., 2006). However, other areas such as northern Namibia, Angola and southern Zimbabwe show increased aridity during the mid-Holocene (Nash and Meadows, 2012).

Pollen studies at Drotsky's Cave and speleothem records from the middle Kalahari also indicate arid conditions (Brook *et al*., 1997; 1998). Dune activity is recorded until about 8000 cal yr BP in Zimbabwe (Stokes *et al*., 1998; Nash and Meadows, 2012) and Zambia (O'Connor and Thomas, 1999). This concurs with evidence from Equus Cave (Beaumont *et al*., 1984; Johnston *et al*., 1997; Scott, 1987b) and pollen and macrofauna data from Wonderwerk Cave (Van Zinderen Bakker, 1982; Tusenius, 1989), which are also in support of dry early Holocene conditions, followed by moister and warmer conditions after 7000 cal yr BP. Moreover, pollen records suggest a short wet period in the area between 3000 and 1000 cal yr BP. Drier conditions were recorded for the last 5000 years. These records are in keeping with those obtained from charcoal records from Siphiso Rock Shelter in Swaziland (Prior and Price Williams, 1985) which suggest wetter conditions between approximately 8647 – 8810 cal yr BP and 7697 – 7834 cal yr BP (8000 – 7000 years BP), followed by a drier period, with a return to moister conditions at approximately 4345 – 4442 cal yr BP to 3057 – 3167 cal yr BP (4000 – 3000 years BP).

Although regional variations occur, the warmest Holocene period, represented by the Holocene Altithermal, occurred between *ca.* 8000 – 4000 cal yr BP (Chase and Meadows, 2007). Evidence from eastern South Africa suggests that maximum warming, coinciding with the Holocene Altithermal, occurred between *ca.* 8800 and 5700 cal yr BP (8000 – 5000 years BP) (Partridge *et al.*, 1990). In northeast Mpumalanga, forest, which were most abundant at *ca.* 6500 cal yr BP, retreated after the warm, dry mid-Holocene Altithermal (Breman *et al.*, 2011).

The expansion of semi-arid Kalahari Thornveld vegetation at Wonderkrater, Rietvlei, Tate Vondo and Pretoria Saltpan during this time is indicative of arid conditions and an increase in temperature (Scott, 1993; 1999). According to Scott and Vogel (1983), the highest temperatures recorded at Wonderkrater were between *ca.* 8728 – 5663 cal yr BP to 5607 – 5720 (8000 to 5000 years BP).

Evidence obtained from Elands Bay Cave charcoal record, shows a decline of mesic thicket vegetation from 11,300 to 4700 cal yr BP (Parkington *et al.*, 2000). Between 6300 and 4800 cal yr BP, dry forests replaced Afromontane elements in the Angola-Namibia border (Shi *et al.*, 2000), as inferred from a marine pollen record. This points to drier conditions during the mid-Holocene. Gradual mid-Holocene cooling from 6000 to 3000 cal yr BP is inferred from both the Makapansgat stalagmite record and the Wonderkrater temperature record (Holmgren *et al.*, 2003). Scott *et al.* (2012) also documented a shift from warm conditions in the mid-Holocene to cooler conditions during the late Holocene between 6000 to 1500 cal yr BP. An increase in xeric elements at Verlorenvlei after 7156 – 7254 cal yr BP (6300 years BP) also suggests a shift to drier conditions during the mid-Holocene (Meadows *et al.*, 1996). Lee-Thorp *et al.* (2001) infer warmer and wetter conditions together with increased representation of C_3 vegetation at Makapansgat between 6400 to 5100 cal yr BP. Similar results were obtained by Holmgren *et al.* (2003). In the Highveld, abundant C_4 vegetation present at 7600 cal yr BP suggests warm conditions (Smith *et al.*, 2002).

2.2.6 Late Holocene (ca. 6000 cal yr BP- present)

Pollen, charcoal and geochemical isotope data support increased aridification in southern Africa after 5000 cal yr BP (Scott and Lee-Thorp, 2004). Contrary to this, speleothem records from the Cango Caves and Makapansgat show increased C_4 vegetation after 4000 cal yr BP, suggesting an increase in moisture conditions (Scott and Lee-Thorp, 2004). Following the Younger Dryas, enriched isotope values detected within the Makapansgat speleothem suggests a return to warmer, moister conditions during the late Holocene (Repinski *et al*., 1999). Furthermore, oxygen isotopes from the Makapansgat stalagmite record also indicate a moist and warm period from 4300 to 3200 cal yr BP (Lee-Thorp *et al*., 2001).

Dry conditions after *ca.* 7000 cal yr BP are recorded at Florisbad in the Free State (Scott and Nyakale, 2002), however, periods of increased moisture are documented at 6895 – 7326 cal yr BP (6290 years BP) and later at 4419 – 4962 cal yr BP (4220 years BP). This is intercepted by an arid period between 5500 and 4500 cal yr BP. Increased moisture levels are recorded at 3637 – 3729 cal yr BP (3500 years BP) at Florisbad (Scott and Nyakale, 2002) and at Deelpan in the Free State (Scott, 1988). Analysis of stable carbon and nitrogen isotope data from rock hyrax middens, obtained from the Klein Spitzkoppe, in western-central Namibia, suggests a wet phase from 4200 to 3500 cal yr BP (Chase *et al*., 2009). This is supported by fossil pollen evidence from Lake Otjikato in Namibia (Scott *et al*., 1991) and Wonderwerk Cave (Beaumont *et al*., 1984). Following 3500 cal yr BP at Spitzkoppe, an increase in aridity occurred until *ca* 300 cal yr BP (Chase *et al*., 2009). Increased dune activity in Zambia between 6000 to 2000 cal yr BP supports these findings (O' Connor and Thomas, 1999; Nash and Meadows, 2012). Stalagmite isotopes from Cango Caves provide evidence for cooling at around 3000 cal yr BP (Scott and Lee-Thorp, 2004). These conditions are in accord with those found at Blydefontein (Scott *et al*., 2005). According to Scott (1988), conditions between *ca.* 4393 – 838 cal yr BP (4000 – 1000 years BP) remained constant at Deelpan, however, a shift to dry conditions is recorded toward the end of this period. Results obtained from Makapansgat stalagmite record for the past 3000 years coincide with those obtained at Wonderkrater (Tyson *et al*., 2000). The abundance of grass and Asteraceae pollen at Wonderkrater accords with the isotope record, which indicates a cool, grassy environment between 3000 and 2000 cal yr BP (Tyson *et al*., 2000; Holmgren *et al*., 2003).

At Lake Eteza in KwaZulu-Natal (Neumann *et al*., 2010), humid conditions have been recorded between *ca.* 6800 – 3600 cal yr BP. During this time, several peaks in charcoal have been recorded, the highest peak occurring at *ca.* 6000 cal yr BP. Neumann et al. (2010) suggest that these peaks most likely represent the occurrence of regional fires.

A decline in oxygen isotope values in the Makapansgat stalagmite record represents a shift to moister conditions from 2900 to 2100 cal yr BP. This accords with peaks in forest elements at Scot's Farm in the Soutpansberg at the same intervals (Scott, 1982b). Conditions at Florisbad at 1946 – 2061 cal yr BP (2100 years BP) were warm and dry to subhumid (Scott, 1998). This is supported by increased C_4 vegetation at the Cango Caves and Makapansgat (Holmgren *et al*., 1999). Analysis of hyrax dung from the Kuiseb River bed in the Namib Desert suggests variable moist conditions from *ca.* 2000 cal yr BP (Scott, 1996). This corroborates with pollen records from northern Namibia (Scott *et al*., 1991) and diatom records from Lake Sibaya (Stager *et al*., 2013) and Princess Vlei (Neumann *et al*., 2011).

Quick *et al*. (2011) established that warmer, arid vegetation types became prevalent from approximately 2000 cal yr BP at the De Rif site in the Cederberg Mountains of the south Western Cape. This is corroborated by results obtained by Chase *et al.* (2011). Stable carbon and nitrogen isotopes values become enriched toward the top of the sequence, signifying a slight decrease in moisture availability, particularly from approximately 2500 to 950 cal yr BP (Quick *et al*., 2011). This in in keeping with charcoal evidence recorded at De Rif (Chase *et al*., 2011) which shows an increase in charcoal in response to drier conditions. However, it must be noted that only small-scale variations were observed, thus suggesting relatively stable environmental conditions in Cederberg during the late Holocene. Fossil pollen, analysed within a sediment core from Klaarfontein Springs in the Western Cape, revealed moist conditions up until 1900 cal yr BP (Meadows and Baxter, 2001). In Maputaland, a retreat in *Podocarpus* further north suggests increased dryness at 1300 cal yr BP (Mazus, 2000).

Following these dry conditions, warm and wet conditions are recorded at Makapansgat (Holmgren *et al*., 2003) between 1200 and 600 cal yr BP. The pollen sequence at Deelpan sheds light on conditions during the past 1700 years (Scott, 1998; Scott and Brink, 1992). Dry and warm conditions are recorded during this time (Scott, 1998; Scott and Brink, 1992).

In the Pretoria Saltpan (Tswaing Crater) sequence, charcoal concentrations frequently peaked during the warm Holocene (Scott, 2002). Conversely, in the Wonderkrater sequence, charcoal concentrations were comparatively low during this period. Results obtained from these sequences show no correlation between temperature and strong variations in charcoal concentrations (Scott, 2002). Thus, Scott (2002) has proposed that climate may not have been a key factor in establishing charcoal peaks over extended periods in South Africa (Scott, 2002). In the Wonderkrater sequence, the highest charcoal peaks occurred after *ca.* 1000 cal yr BP. This corresponds to periods during which Middle and Later Stone Age cultures prevailed in the region (Scott, 2002). Coinciding with this is an increase in Chenopodiacae pollen from approximately 1000 cal yr BP which may signify an increase in disturbance (Scott, 2002).

Prominent warm events occurring during the late Holocene have been documented in records globally (Nash and Meadows, 2012). These events, known as the Medieval Warm Period have been poorly represented in most southern African records most likely due to poor resolution of existing records. According to Tyson *et al.* (2000), medieval warming reached its maximum at approximately 567 – 596 cal yr BP (AD 1250), where temperatures were up to 3 – 4°C higher than present day conditions. At Spitzkoppe, the Medieval Warm Period was documented from *ca.* 750 – 1150 cal yr BP and 350 – 550 cal yr BP respectively (Chase *et al.*, 2009). Evidence for the Medieval warming was also found in the Cold Air Cave stalagmite record from *ca.* 2900 – 2100 cal yr BP (*ca.* 900 – 100 BC) (Holmgren *et al.*, 2001). The vegetation at two sites, Versailles and Graskop, in Mpumalanga showed different responses to Medieval warming (Breman *et al.*, 2011). At Versailles, a documented decline in *Podocarpus* was seen following *ca.* 1800 cal yr BP, whilst *Podocarpus* existed until the end of the Medieval Warm Period (*ca.* 600 cal yr BP) at Graskop (Breman *et al.*, 2011). Breman *et al.* (2011) argue that the higher altitude site, Graskop, which experiences cooler temperatures than Versailles, most likely remained cool and moist enough to allow for the presence of *Podocarpus* through the Medieval Warm Period (Breman *et al*., 2011).

The most significant climatic event during the past 2000 years is the Little Ice Age (LIA), occurring from around 615 – 150 cal yr BP (AD 1300 – 1800) (Tyson *et al*., 2000). According to Marker (1997), a decline in sea level around the southern coast between 492 and 442 cal yr BP may have been representative of widespread sea level change during this period. The Little Ice Age is well represented in the Makapansgat stalagmite record (Holmgren *et al*., 1999). According to Holmgren *et al.* (1999; 2003), the most recent cool, arid period was between 486 – 502 (1500 AD) and *ca.* 150 (1800 AD), corresponding with the northern hemisphere Little Ice Age. The lowest average temperature recorded within the Makapansgat stalagmite sequence occurred at around 250 cal yr BP (1700 AD) (Holmgren *et al*., 1999; Holmgren *et al*., 2003; Sundqvist *et al*., 2013), and is estimated to be approximately 1.4°C cooler than today (Sundqvist *et al*., 2013). Tyson and Lindesay (1992) identify a prominent cool period in southern Africa coinciding with the Little Ice Age, between 712 and 162 cal yr BP. This was interrupted by a warm phase between 512 to 337 cal yr BP. The Little Ice Age is clearly represented within the Makapansgat record, with the lowest temperature recorded at 312 cal yr BP (Holmgren *et al*., 1999). According to Repinski *et al*. (1999), depleted carbon and oxygen isotope values within the Makapansgat speleothems after 600 cal yr BP is suggestive of drier, cooler conditions which corresponds to the Little Ice Age. This evidence is supported by nitrogen isotope data from rock hyrax middens collected from Spitzkoppe in Namibia (Chase *et al*., 2009), which indicates a dry period between 562 and 362 cal yr BP. In the lower Limpopo valley, the onset of the Little Ice Age was characterised by an increase in grasses, savanna elements and generalist taxa with a corresponding decline in riparian and forest taxa, suggesting decreased moisture conditions (Ekblom *et al*., 2011; 2012). Similarly, Gillson and Ekblom (2009a) recorded a cool and dry phase between *ca.* 550 – 150 cal yr BP at the Kruger National Park, corresponding with the LIA. Following this, conditions became warmer and wetter towards the present (Gillson and Ekblom, 2009a). Despite a return of cool and dry conditions during the LIA, *Podocarpus* forests in northeast Mpumalanga did not return, implying that the prevention of forest recovery is due to factors other than climate (Breman *et al*., 2011). The most likely scenario seems that a grass dominated system, with enough biomass to support fire, returned during forest retreat. Resulting from this, a positive feedback mechanism between vegetation and fire would have prevented reestablishment of forests by suppressing recruitment of saplings despite favourable climatic conditions (Breman *et al.*, 2011). At Lake Eteza, the onset of the LIA was possibly the cause of decreased charcoal values through a reduction in moisture and consequently a reduced fuel load (Neumann *et al.*, 2010).

Opposing evidence is found in the winter rainfall region, which shows marked increases in precipitation during this time (Meadows *et al.*, 1996; Meadows and Baxter, 2001; Baxter and Meadows, 1999; Stager *et al.*, 2012). According to Stager *et al.* (2012), increased precipitation during the LIA, in the South African winter rainfall zone, corresponding with variations in chemistry within Antarctic ice cores, suggests that varying precipitation during the LIA was possibly due to shifts in westerlies. From approximately 300 cal yr BP, the majority of environmental changes at Verlorenvlei have been driven by human activities (Baxter and Meadows, 1999; Meadows, 2001; Meadows and Baxter, 2001). Similarly, palaeoenvironmental analyses for Princess Vlei, in KwaZulu-Natal, also suggest an increase in human activity from 300 cal yr BP (Neumann *et al.*, 2011). Palaeoenvironmental records document an overall decline in vegetation at Verlorenvlei, which can be linked to anthropogenic related activities such as over-grazing and clearing of vegetation for agriculture. Moreover, these activities have been responsible for increased sedimentation rates that have been observed within the palaeoenvironmental record (Meadows, 2001). Neumann *et al.* (2011) has documented multiple fluctuations in the natural fynbos vegetation at Princess Vlei, which have been associated with climate change and the relative water-table changes. Anthropogenic disturbance has been detected in this record from approximately 300 cal yr BP onwards by the introduction of *Pinus* and *Zea mays* at the time. High charcoal peaks are present throughout the late Holocene, corresponding to an increase in available fuel load (Neumann *et al.*, 2011). However, charcoal analyses reveal more intense fires following the arrival of European settlers, suggesting a possible anthropogenic source of fire during this time. The results obtained by Neumann *et al.* (2011) concur with those obtained by Meadows (2001), suggesting that prior to 300 cal yr BP, vegetation changes were mainly driven by climate change. At Klaarfontein, human impact has been a significant factor in shaping vegetation over the past 170 years (Meadows and Baxter, 2001). This has been inferred from a rapid increase in asteraceous taxa, which is most likely disturbance related, coupled with a noticeable decline in Poaceae.

Likewise, evidence from Lake Sibaya in northern KwaZulu-Natal show an increase in cereal and *Pinus* pollen as well as algae from approximately 300 cal yr BP, together with a decrease in *Podocarpus*, *Isoglossa* and *Celtis*, suggesting an increase in human disturbance at the time (Neumann *et al*., 2008). Peaks in charcoal following the onset of the Iron Age suggests increased human induced fire activity (Neumann *et al*., 2008), Neumann *et al*. (2008) state that moist climatic conditions prevalent during the Iron Age were not conducive to the spread of natural fires, and thus anthropogenic activities have enhanced the intensity and frequency of fires over the past 2000 years in KwaZulu-Natal. Although, it is still difficult to determine with certainty, whether this increase in fires were natural or human induced as high Poaceae pollen was recorded contemporaneously (Neumann *et al*., 2008). Between *ca.* 1200 – 400 cal yr BP, a drastic decline in charcoal concentration was recorded. Neumann *et al*. (2008) attribute this to a decline in available fuel load due to overgrazing and high erosion rates brought on by anthropogenic activity. Most recently, lowered fire frequencies and a consequent drop in charcoal concentration are the result of better management of the Lake Sibaya by the Greater St. Lucia Wetland Park (Neumann *et al*., 2008). At Lake Eteza, the presence of *Zea mays*, *Pinus* and *Casuarina* pollen in younger sediments indicate increased human activity during the most recent past (Neumann *et al*., 2010). This is in keeping with results from Mdlanzi Swamp, also situated on the north coast of KwaZulu-Natal (Turner and Plater, 2004), where the greatest concentration of introduced tree pollen from *Pinus*, *Casuarina* and *Eucalyptus* were found in the most recent sediments. The presence of these pollen types, together with a decline in forest pollen indicates that exotic tree plantations replaced local dune forest after *ca.* 350 cal yr BP (AD 1600).

Similarly, Ekblom and Gillson (2010b) noted an increase in domestic livestock, suggested by abundant coprophilous fungal spores together with charcoal in the Limpopo floodplain. Maize cultivation in the Limpopo Valley began after 450 cal yr BP (Ekblom *et al*., 2011). In the Kruger National Park, high charcoal frequencies coupled with an increase in cereal pollen suggests an increase in agricultural activity after *ca.* 350 cal yr BP (Ekblom and Gillson, 2010a). Over the last 50 years in the

Kruger National Park in Limpopo, Duffin (2008) recorded increased herbaceous cover together with decreased woody cover during periods of high fire intensity. According to Duffin (2008), increases in charcoal abundance together with high percentages of Cyperaceae pollen are in agreement with periods of high rainfall. Since fire plays an important role in the functioning of savanna and grassland biomes (Duffin, 2008; Duffin *et al.*, 2008), fossil pollen and charcoal records from these biomes are useful in reconstructing palaeo fire intensities, and ultimately variations in rainfall patterns. With regard to the Kruger National Park, results obtained by Ekblom and Gillson (2010) indicate that fire frequencies during the twentieth century are higher than that of any other period. These results are consistent with those obtained by Duffin (2008).

2.2.7 Conclusion

The LGM (21,000 – 18,000 cal yr BP) and the Holocene Altithermal (8000 – 6000 cal yr BP) (Partridge *et al.*, 1999) were the most important climatic events recorded during the late Quaternary in southern Africa. There has also been a recent recognition of other short-lived events such as the Younger Dryas, Medieval Warm Period and The Little Ice Age. There is a general consensus that conditions during the LGM were cool and dry across the sub-region, however, evidence from sites in the winter rainfall region suggest cool and wet conditions during the LGM. Following maximum LGM cooling, which occurred approximately between 18,000 and 17,000 cal yr BP, postglacial warming occurred over most of southern Africa (Scott *et al.*, 2012). A few records document a return to cool and arid conditions, which coincides with the Younger Dryas, however, this event is absent from the majority of southern African palaeoenvironmental records. The early Holocene was characterized by fairly dry and warm conditions on the African subcontinent (Scott and Lee-Thorp, 2004), with the exception of the southwestern winter rainfall region, which was relatively mesic (Scott and Lee-Thorp, 2004). Lake Eteza and Braamhoek wetland, both in the summer rainfall region, were also wetter during the early Holocene (Scott *et al.,* 2012). The late Holocene is characterized by increasing human impacts on vegetation throughout southern Africa (Nash and Meadows, 2012). The Medieval Warm Period, a prominent warm phase documented in global records has been documented in the

Spitzkoppe middens record (Chase *et al*., 2009) and the Cold Air Cave stalagmite sequence (Holmgren *et al*., 2001), however owing to a lack of resolution, this period is very poorly represented in other existing Holocene records. There was an overall increase in moisture conditions from the mid Holocene to the late Holocene during this time (Scott *et al*., 2012), however this was interspersed with periods of cool and dry conditions, the most significant of which being the Little Ice age which occurred between *ca.* 615 – 150 cal yr BP (Tyson *et al*., 2000). Human influence has been inferred from decreases in natural vegetation together with the introduction of *Pinus*, *Zea mays* and cereals. In addition to this, coprophilous dung fungal spores may be used to indicate the presence of livestock and thus the presence of human activity (Ekblom and Gillson, 2010b) during the last hundred years. The timing of climatic events varies across the southern African sub-region, however, records from most sites fit general climatic trends.

This section has provided a synthesis of environmental changes which have occurred at numerous sites across the southern African subcontinent during the late Quaternary. Whilst longer records are generally lacking for the subcontinent, many reliable, high resolution records are available for the Holocene. It is crucial that palaeoenvironmental data be compared between sites, such that an improved regional understanding of environmental change may be developed. Whilst this synthesis does not claim to be comprehensive, it does provide some insight into regional changes that have occurred across southern Africa through comparisons between different sites. This review of past climatic change in southern Africa has provided a palaeoenvironmental background for this research. This will allow for the comparison of results obtained with known climatic shifts.

CHAPTER THREE:

THEORETICAL METHODOLOGY

Climate and environmental change can be assessed using a number of different techniques. Palaeoclimatic information can be extracted through the study of tree rings, stable carbon isotope ratios within trees or polar ice, and sedimentary deposits from lakes and wetlands (McCarroll, 2010). The study of fossil pollen preserved in organic wetland sediments has provided much insight into past vegetation dynamics, climate change and the role of anthropogenic impacts in shaping vegetation patterns. In northern hemisphere Quaternary studies, independent chronological control can be supplied by counts of varved, annually laminated sediments, palaeomagnetism and short-lived isotopes. However, in most palaeoecological studies, radiocarbon dating is the most commonly used method of achieving independent chronological control (Blaauw and Christen, 2011). In most studies, correlations between climate, vegetation and anthropogenic activities can be drawn by examining pollen data in conjunction with charcoal, isotope and other proxy data from the same sedimentary core (Whitlock and Larsen, 2001).

In this chapter, the theoretical background of each of the palaeoenvironmental techniques applied in this research will be discussed. These include fossil and modern pollen, charcoal and radiocarbon analyses. Owing to the primary focus of this research, pollen analysis will be discussed in the greatest detail.

3.1 Pollen analysis

3.1.1 Background

Palynology, or pollen analysis, defined as ‘a technique for reconstructing former vegetation by means of the pollen grains it produced’ (Faegri and Iverson, 1989, p. 1), is one of the most widely used techniques in Quaternary studies (Davis, 1963; Lowe and Walker, 1997; Fletcher and Thomas, 2007; Gaillard *et al.*, 2008; Smith, 2011).

The ability to offer direct insight into past vegetation dynamics makes palynology ideal to studying vegetation and climatic history. The technique was pioneered by Lennart von Post in 1916, who used it to investigate Quaternary vegetation history, although the application of palynology is not restricted to the Quaternary (Birks and Birks, 1980). Von Post's technique involved plotting pollen percentages against corresponding stratigraphic points within the sediment (Birks and Birks, 1980). In this study, the term 'pollen' or 'palynomorphs' will be used to refer to both pollen and spores.

The basic assumption of palynology is that the number of pollen grains deposited per unit time in a given area is directly correlated to the abundance of the corresponding parent taxa in the surrounding environment (Birks and Birks, 2000; Davis, 1963; Fletcher and Thomas, 2007), although it must be noted that vegetation-pollen relationships are very complex and a direct correlation is not always possible. However, pollen diagrams depict only proportions of the total pollen sum, rather than the exact numbers of each pollen type (Davis, 1963). Due to the numerous syndromes by which plants disperse pollen, production and dispersal varies between and within species, hence the need for taphonomic studies (Fletcher and Thomas, 2007). Coupled with problems associated with preservation, interpretation of fossil pollen spectra is sometimes difficult. Pollen grains are produced in large quantities, are widely and evenly dispersed and have robust, decay resistant walls, thus making them well suited to pollen analysis (Bunting, 2008). Palynological studies have thus focused largely on waterlogged sediments, hence it is possible to infer past abundances of species from the amount of pollen that has been preserved in sediments.

Pollen analysis has been used to investigate vegetation changes over many different spatial scales, with the largest being at the biome scale (Seppä and Bennett, 2003). Palynology has a wide range of applications, including taxonomy, chronological correlation, reconstructing vegetation histories, the study of human impacts on vegetation and climate change (Moore *et al*., 1991). Palynological datasets are often used as a benchmark against which predictions generated by global climate change models are tested (Wanner *et al*., 2008). Hence, one of the most important applications of palynological data is to validate such predictions. In doing so, predictions regarding vegetation responses to future climate change may be strengthened (Wanner *et al*., 2008).

Palaeoecological data, extracted from pollen records, sheds light on palaeoclimatic change and palaeovegetational change (Gosling *et al*., 2003; Willis *et al*., 2010). However, to accurately interpret fossil pollen records, greater insight into the relationship between fossil pollen taxa and the characteristics and environmental requirements of their modern pollen spectra is required (Gosling *et al*., 2003). Thus, understanding the modern pollen rain is essential for interpreting late Quaternary fossil pollen data (Gaillard *et al*., 1992). Furthermore, modern pollen studies are used to study pollen productivity of species or plant communities, which is a critical aid to fossil pollen interpretation. The relationship of the fossil pollen type with key climatic variables may be assessed by looking at the presence of pollen in the modern spectra with observed (modern) climatic conditions (Seppä and Bennett, 2003). Terrestrial modern pollen samples are generally obtained from pollen traps and soil surface samples (e.g. Hill, 1996). In arid regions, such as the southern African region, where moss polsters are generally lacking, pollen is usually obtained from pollen traps and surface soil samples (Moore *et al*., 1991).

3.1.2 Basic principles and assumptions

The basic principles of pollen analysis have been outlined by Birks and Birks (1980) as follows:

(i) Pollen grains and spores are produced abundantly by most plants;
(ii) Most pollen grains are unable to facilitate reproduction, rather they fall to the ground and are dispersed within sediments;
(iii) Unless pollen grains are deposited in anaerobic environments, pollen will rapidly decompose;
(iv) The pollen rain over an area is uniform;
(v) The number of parent plants influences the representation of each pollen type within the pollen rain;
(vi) Pollen may be identified down to various taxonomic levels (usually down to family although certain exceptions occur where pollen may be identified down to a genus or species level); and

(vii) If pollen is examined from sediments of a known age, they may be chronologically correlated as well as compared with pollen spectra from different areas to assess differences in vegetation changes through time, although this is not always the case, and modern analogues may occur.

3.1.3 Advantages

Pollen analysis has proved to be advantageous to studies relating to the Quaternary. Its exceptional value in reconstructing floristic and vegetational history has been widely recognized (Birks and Birks, 2000). Palynological data provides evidence for changes in vegetation, and thus allows inferences to be made regarding palaeoclimates and palaeoenvironments. Pollen is produced abundantly by plants; consequently, the fossil pollen record is the most abundant palaeoecological record available (Odgaard, 1999). Moreover, pollen is dispersed among a number of different environments, allowing pollen analysis to be conducted on a wide variety of deposits (Moore *et al.*, 1991). Pollen grains have tough exines, which are decay resistant, as a result, pollen grains may be preserved within deposits for millions of years (Bunting, 2008). Most importantly, as sedimentary layers develop in lakes and wetlands, pollen is trapped within a stratigraphic archive (Bunting, 2008). This allows for sediments to be dated, thus providing a chronological context to palynological data (Blaauw and Christen, 2005).

3.1.4 Limitations

The main limitations associated with pollen analysis, outlined by Birks and Birks (2000), are as follows:

(i) Limited taxonomic resolution associated with pollen identification;
(ii) Pollen grains of different taxa are sometimes indistinguishable;
(iii) Pollen rain is not uniform across species; and
(iv) The source area of pollen is difficult to determine

Low taxonomic resolution, compounded by overrepresentation of local taxa, is a major shortcoming of pollen analysis. There are a number of common palynomorphs that can only be identified down to family level, such as Poaceae and Cyperaceae (Odgaard, 1999; Kershaw and Bulman, 1996), as a result, the number of pollen types represented in pollen diagrams does not correspond with the numbers of plants in and around the sampling site (Kershaw and Bulman, 1996; Seppä and Bennett, 2003). This can result in an oversimplification of the pollen sequence and subsequent analysis (Ortu *et al.*, 2006). Identification of common taxa such as Poaceae and Cyperaceae has not been improved, and according to Seppä and Bennett (2003), improvement in identification of such taxa is unlikely to be accomplished with current microscopy techniques but rather requires the use of complementary proxies, such as phytoliths and grass cuticles, to overcome this problem. The compilation of high quality pollen databases and pollen identification keys has improved pollen-analytical precision (Seppä and Bennett, 2003). Digital photography, together with the Internet have allowed for the rapid transportation of pollen images around the world (Seppä and Bennett, 2003). Scanning electron microscopy (SEM) has allowed improved clarity of fine detail, thus making pollen images easier to interpret and permitting more pollen grains to be identified (Pilcher, 1968). However, SEM can be costly and laborious, and is thus unfeasible in pollen analysis, which requires analysis of thousands of pollen grains. Moreover, there are also numerous taphonomical problems, such as differential preservation of pollen grains which affect identifications as well as interpretations.

A suitable pollen sum needs to be chosen in order to achieve an accurate representation of fossil plant taxa (Janssen, 1970). According to Janssen (1970), the following need to be considered when selecting a pollen sum:

(i) A pollen sum adopts an ecological identity and is thus reflective of a vegetation type;
(ii) When selecting a pollen sum, one needs to establish which vegetation produced which pollen type; and
(iii) The pollen sum may be adjusted according to taxa of interest.

A pollen sum may be regional or local. A local pollen sum includes all local taxa within the pollen assemblage, whilst a regional pollen sum excludes local and aquatic taxa. Some local taxa may have very high pollen inputs, resulting in inaccurate fluctuations of other taxa on pollen diagrams; as a result, local taxa are excluded from the regional pollen sum (Moore *et al.*, 1991). This requires that local taxa be differentiated from regional taxa (Rybnickova and Rybnicek, 1971), which may pose additional problems. Similarly, aquatic plant taxa, which are also likely to be overrepresented within the pollen record, are also omitted from the regional pollen sum (Moore *et al*., 1991).

Furthermore, differential pollen transport and production also limits pollen analysis. Zoophilous (animal pollinated) taxa tend to produce limited amounts of pollen, which are locally dispersed, whilst pollen from anemophilous (wind pollinated) taxa is produced more abundantly and dispersed more evenly though the environment (Faegri and Iverson, 1964; Birks and Birks 1980; Birks and Birks, 2000). As a result, anemophilous taxa are inclined to be overrepresented within the pollen record whilst zoophilous taxa are poorly represented (MacDonald, 1993). Furthermore, pollen originating from zoophilous taxa is usually sticky and tends to clump together (Faegri and Iverson, 1964), further complicating the interpretation of zoophilous taxa within the pollen record, although this problem is usually resolved during chemical pre-processing which dissolves most clumps.

Determining the pollen source area is another problematic aspect of pollen analysis (Sugita, 1994; Seppä and Bennett, 2003). Jacobson and Bradshaw (1981) define the pollen source area as ‘the area from which a fixed percentage (e.g. 70%) of the pollen sampled at a site is derived’ (Jacobson and Bradshaw, 1981, p. 80) Palaeoecologists often have difficulty in determining whether pollen has been locally or regionally derived. Pollen may be distributed through various processes such as rain-wash, stream flow, wind dispersal, and animal dispersal (Jacobson and Bradshaw, 1981). Following this, pollen grains may be redistributed depending on basin characteristics (Jacobson and Bradshaw, 1981; Bradshaw and Webb, 1985), thus further confounding the process of defining the pollen source area. Various simulation models such as the Prentice-Sugita model (Sugita, 1994; Bunting *et al*., 2004) and HUMPOL (Bunting and Middleton, 2005) have been introduced as quantitative approaches to estimating the relevant source area of pollen (RSAP).

Modern pollen analysis is valuable for quantitative reconstructions of past vegetation; however the use of surface soil samples may be limited by (i) the inclusion of older pollen by sediment mixing, (ii) selective pollen decay and (iii) long-term accumulation of pollen within the soil, although this can be easily avoided by only sampling topsoil (Moore *et al*., 1991). However, key limitations lie in the statistical and numerical methods with which pollen spectra are compared. Although multivariate correlation analysis is useful for visual comparison, it is however subjective, particularly when the fossil pollen spectrum falls between two or more modern pollen spectra (Liu and Lam, 1985). Moreover, pollen taxa are merely grouped together with taxa which portray similar behavioural characteristics (Faegri and Iverson, 1989). However, the reasons why these taxa are grouped together cannot be determined by mathematical methods. Thus, ecological knowledge is required for interpreting results from multivariate correlation analyses (Faegri and Iverson, 1989).

3.1.5 Field techniques

3.1.5.1 Site selection

Quaternary palynomorphs may be preserved in a range of natural archives, including terrestrial and marine sediments, ice caps, which is a rather unusual pollen archive, faecal material and cave deposits (MacDonald, 1988; Moore *et al.*, 1991; Chase and Meadows, 2007), however, stratigraphic peat and lacustrine deposits, containing the best pollen sequences for palaeoclimatic and palaeovegetational reconstruction, remain at the forefront of palaeoenvironmental studies (MacDonald, 1988; Anderson *et al.*, 2007).

Peatlands are natural accumulations of organic material (Chambers and Charman, 2004) that develop in stratified sequences (Moore *et al.*, 1991). According to Chambers and Charman (2004), peatlands are advantageous for palaeoenvironmental research as they are usually more accessible than ice caps and oceanic sediments and are relatively inexpensive to core compared with ice sheets, oceanic and lacusrtrine sediments. In addition, peatlands contain large amounts of soil carbon (Inbushi *et al.*, 2003), allowing sediments to be dated through radiocarbon dating techniques, which is crucial to palaeoenvironmental reconstructions.

When selecting sites for pollen analysis, the size, elevation and hydrological conditions (inflow and outlet of the basin) should be taken into account (Jacobson and Bradshaw, 1981). Furthermore, in a study by Bradshaw and Webb (1985), it was concluded that smaller basins have smaller source areas than larger basins. Thus, the type of site selected should also depend on the type of pollen signal (local or regional) targeted by the study.

3.1.5.2 Core extraction

Sediment cores may be extracted from peat wetlands using a Hiller sampler, Russian corer or a vibratory corer. The Hiller sampler is composed of a rotating chamber together with an auger head (Moore and Webb, 1978). The auger head allows the Hiller sampler to be rotated as it is pushed into the sediment. This is advantageous as it allows for penetration of harder or more fibrous sediment (Moore *et al*., 1991). Sediment samples are collected by rotating the auger head in the opposite direction, which allows the chamber to be opened and for sediment to be pushed into the chamber (Moore *et al*., 1991). There are a number of disadvantages associated with this type of corer. Firstly, during descent into the sediment, the Hiller sampler is likely to trap roots as well as other plant material, hence resulting in contamination of samples (Moore and Webb, 1978; Moore *et al*., 1991). In general however, this problem cannot be avoided. Furthermore, twisting of the auger head during penetration disturbs material. However, the most significant downfall of the Hiller sampler is the inability to remove intact sediment cores from the chamber (Moore and Webb, 1978; Moore *et al*., 1991). Rather, samples from each depth need to be removed separately in the field before another core can be extracted. Consequently, this hinders a detailed reconstruction of sediment stratigraphy, which is key to understanding and interpreting pollen diagrams (Moore *et al*., 1991). For this reason, the Hiller sampler is generally avoided, except in instances where sediment is too stiff to use alternative coring methods.

The Russian sampler, designed by Jowsey (1966), is one of the most widely used instruments for sampling peat and conducting stratigraphic work due to its efficiency and clean action (Moore *et al*., 1991). Unlike the Hiller sampler, the Russian sampler lacks an auger head, and thus cannot be rotated during its descent. Instead, it is pushed vertically into the sediments (Moore and Webb, 1978; Moore *et al*., 1991). There are two approaches that may be used to obtain a sediment core using a Russian sampler, either by using single or paired boreholes (DeVleeschouwer *et al*., 2010). Using a single borehole is not advised as the nose of the corer will disturb the upper peat layer of the next sample which should be taken from directly beneath the first sample (De Vleeschouwer *et al*., 2010). Using two boreholes eliminates disturbance of samples. This technique involves retrieving alternate, overlapping samples from two parallel boreholes (De Vleeschouwer *et al*., 2010). Boreholes should be no more than 1 m apart. The target depth for each sample must be carefully calculated (De Vleeschouwer *et al*., 2010). Generally, overlaps of 10, 20 or 30 cm are used depending on the depth of the wetland (De Vleeschouwer *et al*., 2010). Compared with the Hiller sampler, the Russian sampler is advantageous, as sediment samples are not disturbed by the rotating action of the auger head and compaction is minimal. Furthermore, an intact sediment core can be removed from the chamber (Moore and Webb, 1978; Moore *et al*., 1991). This is ideal for conducting stratigraphic work in soft sediments.

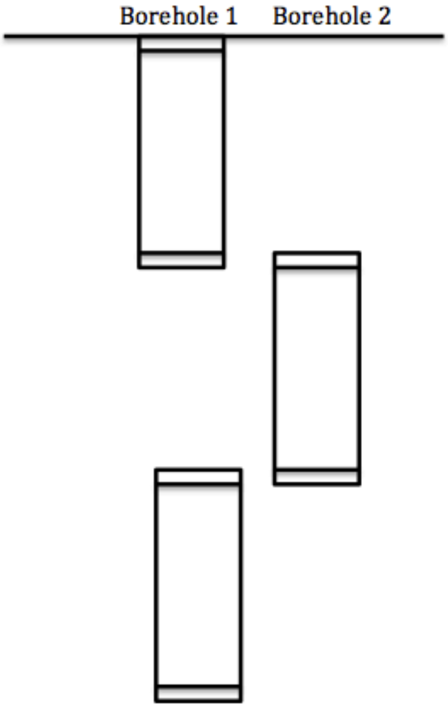

Figure 3.1 Parallel boreholes and overlapping sampling strategy (Source: D.L Baboolal)

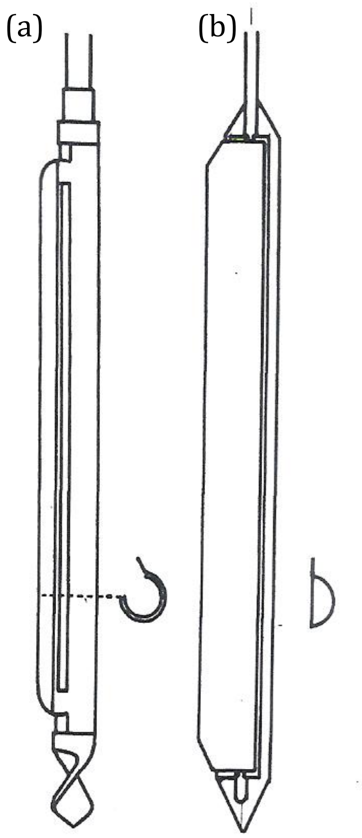

Figure 3.2 (a) Hiller corer (b) Russian corer (Source: Faegri and Iverson, 1989)

Vibratory corers, also referred to as 'vibracorers', are used to collect sediment samples from lacustrine, offshore marine and coastal environments (Larson *et al.*, 1997). A vibracorer is composed of a frame, coring tube/barrel, as well as a vibrator that is attached to a drive head. Unlike the previous two corers, the vibracorer is able to penetrate up to 5 m or more of unconsolidated sediment, and is able to obtain a single, continuous core (Larson *et al.*, 1997). However, this is dependent on the nature of the sediment. According to Larson *et al.* (1997), even if good penetration has been achieved, the amount of sediment recovered may be very little due to compaction of sediment or loss of sediment during recovery. Compared with the previous coring techniques, operation of the vibracorer is easy, and cores can be removed within minutes. A disadvantage of the vibracorer is that it is unable to core non-saturated environments (Fisher, 2004), it cannot be carried to remote or inaccessible locations, and moreover, the use of a vibracorer in core extraction often leads to sediment compaction (Fisher, 2004).

3.1.5.3 Soil surface samples

For soil surface sampling, the number of soil samples must be chosen such that a suitable representative sample is obtained (Hill, 1996). For each site, soil samples are collected from concentric circles, within a specified radius, around the sampling point (Mack and Bryant, 1974). Soil samples must be obtained at a specified depth (usually as close to the surface as possible). Furthermore, the surface area of each sample must remain constant (Hill, 1996). Samples are placed in plastic bags and transported back to the laboratory. The soil samples are mixed thoroughly and subsampled before undergoing standard laboratory preprocessing which has been outlined previously (Mack and Bryant, 1974). Thereafter, samples are stained and mounted before being counted and identified.

3.1.6 Laboratory techniques

3.1.6.1 Subsampling and standard laboratory process

Faegri and Iverson (1964, pp. 66) state that the purpose of processing sediment samples is to ‘concentrate any spores or pollen grains present and render them as visible as possible.’ MacDonald (1988) has outlined a standard laboratory processing sequence as follows:

(i) Sub-sampling at specified intervals;
(ii) Addition of exotic palynomorphs or markers;
(iii) Removal of carbonates, humic acids, pyrite, silica and cellulose using various chemical and physical laboratory techniques;
(iv) Dehydration of samples; and
(v) Staining and preparation of pollen slides.

The sediment core is subsampled at regular intervals along the entire length of the core. At each interval, a standard volume of sediment is subsampled (MacDonald, 1988). The subsampling interval is dependent on the characteristics of the deposit as well as the degree of precision needed to detect changes over time (Moore *et al.*, 1991). The general technique of determining a suitable sampling interval is to begin with wide intervals, often between 10 or 20 cm, and then filling in the gaps should more detail be required (Moore *et al.*, 1991). If little or no change is observed in pollen assemblages between wide intervals, it is assumed that subsampling at a smaller interval is unnecessary. However, one should always aim to subsample in as high a resolution as possible such that short-term fluctuations are not overlooked.

Some studies require that the absolute density of pollen grains be known; hence absolute extraction techniques need to be employed. One such method is the exotic marker grain method, whereby a known number of exotic palynomorphs or artificial markers are added to a known volume of sample prior to processing (Salgado-Labouriau and Rull, 1986). In doing so, the abundance of each taxon of interest may be determined in relation to the number of exotic marker grains rather than in relation to other taxa that are present (Stockmarr, 1971; Salgado-Labouriau and Rull, 1986; Moore *et al.*, 1991). *Lycopodium* spore tablets, containing equal numbers of spores per tablet are commonly used (Salgado-Labouriau and Rull, 1986). This eliminates the process of making an exotic suspension. *Lycopodium* spore tablets cannot be used in many areas where indigenous *Lycopodium* species are present (Salgado-Labouriau and Rull, 1986; Moore *et al.*, 1991), in which case, glass, plastic or polystyrene microspheres (e.g. LacCore polystyrene microspheres) may be used instead (Salgado-Labouriau and Rull, 1986). Generally, a minimum *Lycopodium* spore count of 250 is sufficient. Volumetric methods may also be used to determine absolute pollen densities. This requires that the sample volume be determined prior to extraction of pollen grains from sediment (Moore *et al.*, 1991). Once extraction is complete, the pellet is suspended in mounting fluid of a known volume such that subsamples can be obtained and the total number of pollen grains belonging to each taxon can be acquired (Moore *et al.*, 1991). This is most easily achieved through displacement of the sample in water (Bonny, 1972). If absolute techniques are not used, the pollen grains are expressed as a percentage of the total sum, in which case Moore *et al.* (1991) advise that all pollen grains on a slide be counted. In comparison with absolute pollen frequencies, interpretation of relative frequencies such as the total pollen count, total arboreal pollen and so on may be problematic as the abundance of each pollen type is dependent on variations in other taxa (Moore *et al.*, 1991).

Carbonates, humic acids, pyrite, silica and cellulose are removed through chemical and physical processes to ensure that pollen grains are countable. The aim is to produce pollen rich samples. Depending on the composition of the sample, different chemical processes may be chosen (Faegri and Iverson, 1964; Moore *et al.*, 1991). These include NaOH, HCl and HF digestion. Sodium Hydroxide is used to remove humic acids, HCl removes carbonates and HF treatment siliceous matter (Faegri and Iverson, 1989). Heavy density separation may also be used to concentrate pollen (Faegri and Iverson, 1989; Robertsson, 1989; Moore *et al.*, 1991). Bromoform, zinc bromide or zinc chloride, each with a density of between 2.0 – 2.3, may be used as a heavy liquid (Robertsson, 1989). Sodium polytungstate is also often used (Robertsson, 1989). When sediment is placed in heavy liquid, mineral grains, with a density of over 2.6, sink to the bottom, whilst pollen grains with a density of between 1.3 and 1.7, float to the surface (Robertsson, 1989). This method results in clean, highly concentrated samples, and no HF treatment is required (Robertsson, 1989). Furthermore, siliceous microfossils are not always dissolved during this process, and may be identified on slides in conjunction with pollen and spores (Robertsson, 1989). In some cases, acetolysis is also required.

Once samples are processed, they may or may not be stained before being mounted and counted. According to Faegri and Iverson (1989), staining of samples is a matter of personal choice. Staining is used to highlight as much structural detail as possible, thus improving observation and identification of pollen and spores (Faegri and Iverson, 1989; Moore *et al.*, 1991). Zhang *et al.* (2004) however, state that staining alters the textural appearance of pollen grains and spores under the microscope and structural detail may be brought out through the use of phase contrast (Faegri and Iverson, 1989). Aside from bringing out structural detail, it is argued that staining reduces the chance of badly crumpled and fragmented grains to be overlooked. Furthermore, staining may allow for pollen and microfossils of similar structure but different chemical composition to be differentiated (Faegri and Iverson, 1989).

3.1.6.2 Pollen counts and identification

Pollen counts and identification should be conducted under a microscope along regular traverses across slides, preferably at a magnification of x400 with the availability of an x1000 oil immersion magnification objective for smaller grains (Birks and Birks, 1980). When a mounted sample is covered, smaller grains tend to disperse towards the edges of a slide (Faegri and Iverson, 1989), thus it is recommended that full slides be counted in order to account for non-random positioning of certain sized pollen grains on the slide and to ensure better identification (Faegri and Iverson, 1989).

The number of pollen grains counted depends largely on the problem at hand. A count of 300 pollen grains is generally sufficient (Weng *et al*., 2006), however some analysts prefer to test the statistical significance of different counts before deciding on the number of pollen grains to count. Moore *et al*. (1991) suggest that 500 regional/terrestrial pollen grains be counted.

In studies conducted in Verlorenvlei, Western Cape (Meadows *et al*., 1996), Tsoaing River, Lesotho (Grab *et al*., 2005) and Lake Eteza, KwaZulu-Natal (Neumann *et al*., 2010), a minimum pollen count of 250 regional pollen grains was found to be statistically significant. Although, in the case of Lake Eteza, authors tried their best to reach a pollen sum of 500, but often the pollen count was too low. Similarly, for the Drakensberg region, Hill (1996) found that there was no significant difference between counts of 250, 500 and 1000 pollen grains. Scott and Nyakale (2002) found that a pollen count of greater than 250 was required for sediments from Florisbad in the Free State. Scott (1982a), Scott (1982b), Scott and Vogel (1983) conducted two counts of 200 pollen grains per sample from various sites in the Transvaal and Limpopo Province. The first count included all taxa, whilst the second count excluded well-represented, possibly local taxa. In studies conducted in the Kruger National Park however, Duffin (2008) counted a total of 400 pollen grains, whilst Gillson and Ekblom (2009) counted between 400-500 pollen grains. In many South African studies, 250 pollen grains per sample is have been counted.

Pollen grains are usually identified with the aid of pollen reference collections that are compiled from fresh samples from site (Moore *et al*., 1991). Databases such as the European Pollen Database (EPD, 2013) and the African Pollen Database (APD, 2013) and pollen atlases are often used to aid identification. The UKZN and the East African pollen reference collections, both located at UKZN, were also used.

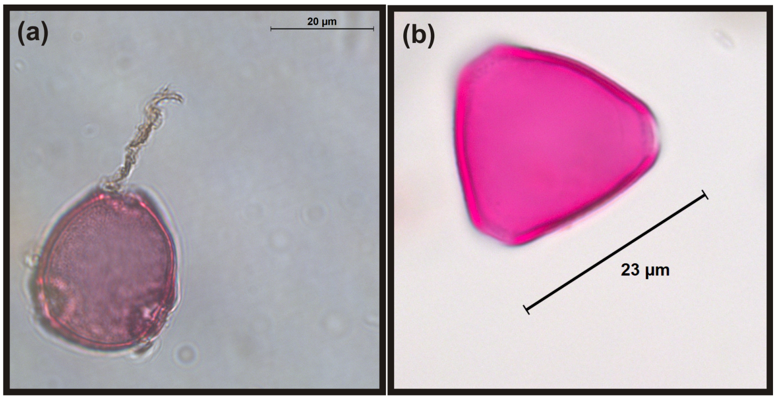

Plate 3.1 Examples of digital reference slides (a) *Celtis africana*; (b) *Protea simplex* (Source: D.L Baboolal)

Pollen can be separated into two categories. These are determinable and indeterminable pollen (Birks and Birks, 1980). Essentially, indeterminable pollen grains are those that cannot be identified due to some obscurity (Birks and Birks, 1980). This may be due to deterioration of the exine, unsuitable positioning of the pollen grains on the slide, the pollen grain or part of the pollen grain may either be broken or hidden by debris or other material on the slide, or the analyst may not be able to identify the pollen grain simply because it is unknown or not present in the reference collection (Birks and Birks, 1980). In pollen analysis, indeterminable pollen is a measure of accuracy. The higher the number of indeterminable pollen, the lower the accuracy of the total pollen count (Birks and Birks, 1980). The accuracy and precision of palynological data has been vastly improved through automated pollen counts and identification (Seppä and Bennett, 2003), however there are still many improvements to be made before analysts can rely solely on automation.

Pollen from certain taxa, such as entomophulous taxa, tends to stick together, forming clumps (Faegri and Iverson, 1989). Faegri and Iverson (1989) suggest that clusters of the same pollen grains should be counted as a single unit to avoid overrepresentation.

3.1.7 Data presentation

To facilitate interpretation of pollen data, data are presented as pollen diagrams, which plot changes in pollen counts or percentages against their corresponding depths and radiocarbon ages (Faegri and Iverson; 1964; Moore *et al.*, 1991). Pollen diagrams demonstrate the change in abundance of taxa in relation to other taxa in the pollen record (Moore *et al.*, 1991). If absolute techniques were employed during laboratory processing, it is possible to examine changes in abundance of taxa through time, independently of other taxa (Moore *et al.*, 1991. Two software programs, amongst others, namely Tilia (Grimm, 1992) and Psimpoll (Bennett, 2005) have been developed to create pollen diagrams and facilitate statistical analysis.

3.1.7.1 Pollen zonation

The number of stratigraphic levels and the numbers of fossil pollen taxa counted and represented in pollen data are generally so intricate as to require further subdivision into fewer sequences or units (Gordon and Birks, 1972). The most commonly used subdivision is the pollen zone. Birks (1972) defines a pollen zone as a body of sediment containing homogenous pollen content, and can be differentiated from adjacent sediment bodies by variations in the type and frequencies of pollen grains it contains. Cushing (1964), who first put forward the idea of a pollen zone, states that a pollen zone is a biostratigraphical unit. In other words, it is a unit that is defined solely by its pollen count (Moore *et al.*, 1991).

Pollen zones may be demarcated either by visual inspection, numerical methods or a combination thereof. As numerical methods provide consistent criteria for demarcating zones, these methods are generally preferred (Birks and Gordon, 1985; Grimm, 1988). The majority of numerical methods involve constrained cluster analyses. The Constrained Incremental Sum of Squares (CONISS) (Grimm, 1987) method is popularly used for pollen zonation.

CONISS is fundamentally based on cluster analysis (Bennett, 1996) with the condition that clusters or zones are derived on the basis of hierarchical agglomeration. The basic premise is that samples that are stratigraphically adjacent are more related and hence will be clustered together (Bennett, 1996 and Grimm, 1987). Clusters are represented by dendrograms which are plotted next to charcoal and pollen diagrams. Dendrograms depict the hierarchical relationships between clusters (Grimm, 1987) and are used to demarcate suitable zones.

3.1.8 Interpretation

Pollen stratigraphy documents past vegetation shifts, which allows for inferences to be made regarding past climates as well as land use history (Moore *et al*., 1991). According to Moore and Webb (1978), there are two steps involved in interpretation of pollen diagrams. These are, interpretation from fossil pollen data to vegetation, and from vegetation to palaeoenvironments (Moore and Webb, 1978). These reconstructions benefit from drawing on all available proxy evidence reflecting past conditions (Battarbee, 1986). There are three main approaches to quantitative reconstructions of past environments with the use of palynological data. These are:

(i) The indicator species approach;
(ii) Modern analogue technique; and
(iii) The assemblage approach (numerical transfer function approach).

3.1.8.1 Indicator species approach

Certain taxa are able to provide insight into past climatic conditions due to their precise environmental requirements (Moore *et al*., 1991; Birks *et al*., 2010). Such taxa are referred to as indicator species, whose presence or absence warrants conclusive statements regarding past environmental conditions. This approach to reconstruction is based on the assumption that the physiological requirements of the taxon have remained constant through time (Birks and Birks, 1980; MacDonald, 1988). Consequently, this approach is best suited to stable species with very few ecotypes (Moore *et al*., 1991).

Indicator species may also be used to detect an anthropogenic signal within the pollen record, although this has shown to be very difficult (Moore *et al*., 1991). Generally, analysts rely on species whose ecology can be related to the effects of anthropogenic activities on the environment such as fire, soil disturbance, nitrogen flushing and open canopies (Moore *et al*., 1991). In addition, pollen from exotic and agricultural plants such as maize (Gillson and Ekblom, 2009), cereal (Neumann *et al.,* 2008) and *Cannabis sativa* (Rucina *et al*., 2010) are also indicative of human activities.

The indicator species approach is ideal for reconstructing late Holocene environments as the majority of recent communities originated from species that were present during the late Holocene (Janssen, 1970). According to Janssen (1970), the indicator species approach works well for the late Holocene, however, the application of this approach to earlier periods may result in doubtful reconstructions. Another limitation of this approach is that it assumes a simplistic relationship between climate and the abundance of a species. Birks (1981) has emphasized that only one or two climatic variables are used to account for changes in species' distributions and abundance. Moreover, variables such as invasion rates, competition, herbivory, plant pathogens and anthropogenic activities, among others, should also be considered. Additionally, indicator species may be ambiguous, meaning that the presence of certain indicator species may imply differing or opposing climatic conditions depending on its geographical location (Noss, 1990).

3.1.8.2 Modern analogue technique

The modern analogue technique involves the comparison of fossil pollen assemblages with modern pollen assemblages, which have been obtained from modern surface samples (Jackson and Williams, 2004). This involves the use of statistical and numerical tools which assign quantitative estimates of the similarity and dissimilarity between modern and fossil pollen assemblages (Birks and Birks, 1980; Birks and Gordon, 1985; Minckley *et al.*, 2008; Birks *et al.*, 2010), which allows known environmental elements to be allocated to fossil pollen spectra, thus enabling past conditions to be inferred.

There are a number of methods used to compare modern and fossil pollen spectra.

In studies focused on a limited number of pollen types, data, presented as tabulated percentages or as pollen diagrams, may be visually compared (Davis, 1969).

With larger, complex multivariate datasets, it is necessary to employ numerical and statistical methods in order to make comparisons between modern and fossil pollen spectra (Faegri and Iverson, 1989).

Table 3.1 Generalised environmental indicators of selected pollen taxa from the savanna biome (adapted from Scott, 1999)

Pollen type	**Vegetation**	**Inferred environmental conditions**
Podocarpaceae (*Podocarpus*)	Forest	Relatively moist conditions
Myricaceae (*Myrica*)		Sub-humid conditions
Pteridophyta	Forest edge	
Flacourtiaceae (*Kiggelaria*)	Woodland	
Proteaceae (*Protea*) Oleaceae (*Olea*) Mimosoideae (*Burkea*)	Upland or mesic savanna	Wide range of temperatures, subhumid conditions
Fabaceae (*Acacia, Dichrostachys*) Anacardiaceae (*Sclerocarya*) Euphorbiaceae (*Spirostachys*)	Savanna	Fairly warm conditions, wide ranging moisture conditions, *Acacia* related to deep local soils
Ericaceae Thymeleaceae (*Passerina*) Rosaceae (*Cliffortia*) Asteraceae (*Stoebe* type)	Fynbos	Relatively even seasonal moisture distribution, cool sub-humid conditions
Chenopodiaceae/Amaranthaceae	Halophytes	Local evaporation/ dry conditions, disturbance.
Cyperaceae	Semi-aquatics	Local swamp, shallow water or damp soil
Poaceae	Grassland or savanna	Usually indicates summer rainfall
Cannabaceae (*Cannabis sativa*) Pinaceae (*Pinus*) *Zea mays*		Indicative of human disturbance

Multivariate correlation analysis is commonly used to make comparisons between the modern and fossil spectra (Faegri and Iverson, 1989). Here, the spectra are assigned their own space within a multidimensional space. The aim here is to reduce the multidimensional space of the original data to allow data to be more easily interpreted (Faegri and Iverson, 1989). The most commonly used method is the principal component analysis (PCA), although correspondence analysis (CA) and canonical variates analysis (CANOCO) are also used. The scores of pollen spectra are plotted along two dimensions, usually in the form of a scatter plot (Liu and Lam, 1985). The relatedness between the two pollen spectra can be measured by the distance between the two pints on the axes (Liu and Lam, 1985).

This technique is useful for late Holocene assemblages, however, older fossil assemblages may lack modern pollen analogues (Jackson and Williams, 2004). Thus, the modern analogue technique is limited by no-analogue situations, which are frequently encountered for the late glacial period as well as older periods (Jackson and Williams, 2004). Furthermore, this technique requires large, high quality modern datasets. This technique has been used for South African sites and results have been presented in Scott *et al*. (2012).

3.1.8.3 Assemblage approach

With the assemblage approach, the entire pollen assemblage is used to infer past environmental conditions. By using the entire assemblage, it is assumed that a more accurate reflection of environmental conditions can be reconstructed (Moore *et al*., 1991). The relationship between the assemblage and the environment can be converted to a numerical function (Howe and Webb, 1983) by means of multiple linear analyses (Birks and Gordon, 1985). This is known as a transfer function. Transfer functions are valuable in detailed climate reconstructions; however, like the modern analogue technique, they require large, high quality datasets (Moore *et al*., 1991).

Driven by the need to better understand past vegetation changes and evaluate climate models, quantitative methods of paleoreconstructions have been gaining impetus (Ni *et al*., 2010). Biomization (Prentice and Webb, 1998) is one such method that utilizes quantitative pollen assemblages (Ni *et al*., 2010). Here, each pollen taxon in the assemblage is assigned to a plant functional type (PFT). A PFT is defined on the basis of a species' biological and biogeographical characteristics (Ni *et al*., 2010). Using matrices, each assemblage is assigned to the biome most likely to have produced the pollen assemblage (Ni *et al*., 2010).

In southern Africa, where there are very few high quality palaeoenvironmental records (e.g. Truc *et al*., 2013) and large modern pollen datasets (Salzmann and Hoelzmann, 2005), such approaches to environmental reconstructions are hampered.

3.2 Charcoal analysis

3.2.1 Charred particle analysis in palaeoecology

The presence of high levels of charred particles in certain ecosystems has been observed by scientists from as early as the nineteenth century (Carcaillet, 2007). Iverson (1941) was the first to recognize charred particles as a palaeoenvironmental proxy. Charcoal remained a poorly understood proxy until the 1970s. However, prior to the mid 1990's, the use of charred particles in environmental reconstruction has gained much popularity among the Quaternary scientific community (Carcaillet, 2007).

Two research fields emerged in order to undertake charcoal studies. Archeological research, using material from archeological sites containing high abundances of charred particles, was developed for the reconstruction of woody environments (Carcaillet, 2007). Research conducted through soil profile analysis allowed for similar reconstructions to be made.

During the 1970's, studies involving the quantification of charcoal in Quaternary sediments began to surface. These studies were fueled by the emergence of palaeofires as a key ecological factor of ecosystem changes (Carcaillet, 2007). Such studies were fully developed by Clark during the 1990s who proposed various methods and concepts for fire history reconstruction using charred particles (Carcaillet, 2007).

Charred particles are distributed and deposited into the surrounding environment during and after a fire event. Fire is influenced by rainfall, herbivory, hydrology and topography of the landscape, all of which vary at seasonal-geological timescales (Ekblom and Gillson, 2010a; Daniau *et al*., 2013). Charcoal records extracted from sedimentary cores are commonly used as a proxy for past fire events over long geological timescales (Duffin, 2008). In conjunction with data records of known fire events, charcoal records analysed from sedimentary cores aid in the understanding of charcoal taphonomy (production, transport and deposition) (Duffin, 2008).

Charcoal, an inorganic carbon compound, is the result of incomplete combustion of organic material at temperatures ranging between 280 to 500°C (Braadbart and Poole, 2008) and therefore serves as a direct indication of burning (Conedera *et al*., 2009). The abundance and availability of atmospheric oxygen influences the ability of the combustion process to proceed (Mooney and Tinner, 2011). When oxygen is readily available, combustion proceeds uninterrupted, resulting in the production of ash (Mooney and Tinner, 2011). However, low concentrations of oxygen disrupt the process, resulting in the formation of charred particles (Mooney and Tinner, 2011). The rate of accumulation of charcoal is dependent upon the characteristics of the fire as well as the processes transporting and delivering charcoal to the site (Whitlock and Larsen, 2001). Resistance to oxidation and microbial activity allow charcoal fragments to be maintained on a geological timescale (Mooney and Tinner, 2011). Charcoal is said to have an age-depth relationship within the core. It is presumed that fragments found closer to the surface are younger than fragments which occur lower down within the core.

Charcoal may be primary or secondary. Primary charcoal refers to charred particles which accumulate during or soon after a fire event (Whitlock and Larsen, 2001), whereas secondary charcoal accumulates during non-fire periods through surface run-off, wind transportation, sediment mixing and various other processes (Whitlock and Larsen, 2001).

Charcoal fragments can be transported over large distances, hence, the source of charcoal can be broadly classified into two categories. The origin of charcoal can either be classified as local or regional (Conedera *et al*., 2009). Based on the premise that smaller particles can be transported over larger distances, microscopic is assumed to be the product of regional fires, whilst local fires are indicated by macroscopic charcoal fragments (Peters and Higuera, 2007). Microscopic charcoal can be defined as those fragments which fall into the <100 µm size class, whilst macroscopic charcoal refers to any fragments which are larger than <100 µm (Mooney and Tinner, 2011).

3.3.4 Methods used in the quantification of charcoal

The quantification of charcoal from each source (regional or local) warrants different techniques. Microscopic particles, indicative of regional fires, are usually counted in conjunction with palynological indicators (Whitlock and Larsen, 2001; Mooney and Tinner, 2011) whilst macroscopic charcoal fragments, which are related to local fires, tend to be quantified in isolation (Mooney and Tinner, 2011). This study will focus on microscopic charcoal, hence microscopic charcoal techniques will be discussed.

3.3.5 Microscopic methods

Studies of microscopic charcoal (< 100 µm) are based on charcoal particles analysed from pollen slides, hence this type of charcoal is also referred to as pollen-slide charcoal (Mooney and Tinner, 2011). There are two widely used techniques for analyzing microscopic charcoal content. The first one is the point count technique (Clark, 1982). Here, the microscope slides are divided into transects and the abundance of the charcoal is determined by measuring the percentage of points along each transect which overlie charcoal (Clark, 1982; Whitlock and Larsen, 2001). The area of the charcoal is also determined by using a grid of squares of known area in a microscopic eyepiece (Clark, 1982). Using the estimated charcoal area on a slide, it is possible to estimate the area of charcoal present in a unit of volume of sediment or the annual influx rate per unit area. However, this is dependent on a known volume of subsample on the slide. Should the volume of the subsample be unknown, it is possible to use exotic pollen markers to calculate the ratio of the area charcoal to the area of pollen on each slide (Clark, 1982). This technique of integrating pollen counts with charcoal counts was first introduced to gain better insight into identifying fire events. This was based on the premise that an increase in charcoal should correlate with a decrease in pollen owing to burned vegetation (Whitlock and Larsen, 2001).

The second technique is the size class technique. This technique assesses the charcoal content by differentiating each particle into a particular size class. First, the area of each particle is estimated using a gridded eyepiece placed in the microscope. Based on the estimated area or size, each particle is assigned to a size class. The sum of charcoal in each size class can then be obtained.

One of the main limitations of the point count technique is that it tends to generate values of zero (Clark, 1982). Moreover, it appears that the method of generating ratios between charcoal and pollen is inclined to widen and reduce charcoal peaks based on accumulation rates (Whitlock and Larsen, 2001). In addition to this, this method is unable to identify all fire events (Whitlock and Larsen, 2001). Compared with the point count technique, the size class method is an easier and faster option. In general, the pollen slide method is advantageous as it allows for microscopic charcoal to be tallied from pollen slides thus requiring no further preparation (Clark, 1982). Microscopic charcoal is used to determine the importance of fire on a centennial to millennial time scale and hence, fire events or regimes are often reconstructed with poor spatial and temporal resolution.

There are a number of chemical digestion methods available for quantifying charcoal in peat and other sediments. The Winkler (1985) method is most extensively used in palaeoenvironmental studies (Mooney and Tinner, 2011). Sediments are treated with concentrated nitric acid (HNO_3) to extract organic carbon, leaving behind charcoal. The sample is then weighed before being ignited at 500°C and then weighed once more. The elemental carbon within the sample is then calculated by expressing the difference in mass before and after ignition as a percentage (Mooney and Tinner, 2011).

The advantage of this method is that it allows for analysis of all particle size ranges simultaneously. However, it appears that this advantage is far outweighed by the numerous weaknesses of this method. In some studies, it is clear that chemical digestion is unable to successfully digest fibrous peats (Rhodes, 1998), is prone to experimental error when samples contain low elemental carbon content (Mooney and Tinner, 2011), and the technique is unable to differentiate between charred products resulting from biomass burning and fossil fuel combustion (Patterson *et al.*, 1987). This is problematic when analyzing recent sediments. Chemical digestion methods are deemed unreliable and thus are not favoured in quantifying charcoal in sediments.

3.4. Dating techniques

The need for establishing independent chronological control for pollen stratigraphic data is essential to documenting changes in vegetation through time. There are several dating methods available, the most popular being radiocarbon dating. Radiocarbon dating will be used for this study; hence this method will be discussed.

3.4.1 Radiocarbon dating

Radiocarbon ^{14}C dating is a technique used for dating organic remains. It is based on the premise that an overall equilibrium of radiocarbon is present within all living organisms. According to Ascough *et al.* (2004), the primary assumption of the theory of radiocarbon dating is that the activity of radiocarbon is uniform across all living organisms. The amount of radiocarbon decays at a rate which is equal to the rate of uptake by the organism (Brady and Holum, 1993). Once an organism dies, the amount of radiocarbon within it decays with a half-life of approximately 5720 years. A radiocarbon age can be determined by measuring the amount of radiocarbon remaining in an organism (Blaauw and Christen, 2005). The radiometric technique of dating organic remains was first introduced by Libby in 1960; however, newer methods such as the accelerator mass spectrometer (AMS) radiocarbon dating technique have subsequently been developed (Brady and Holum, 1993). Unlike the conventional radiometric method, AMS is able to separate radiocarbon atoms from other carbon isotopes and allows all atoms to be quantified as opposed to only those which decay (Brady and Holum, 1993). Hence, results can be obtained from much smaller samples, more efficiently and precisely.

In studies of the Quaternary, radiocarbon dating techniques are popularly used as a means of establishing independent chronological control for palaeoecological data (Blaauw and Christen, 2005). This allows for the establishment of a relationship between the depth of sediments and their corresponding ages (Boreux *et al.*, 1997). According to Levin *et al.* (1980), the residence time of radiocarbon, which is defined as the average duration for which a carbon atom remains within an organism before it is exchanged into the atmosphere, is approximately one or two decades. Thus, radiocarbon dating has been largely limited to studies of the late Quaternary. Radiocarbon ages cannot be established at every point within the core as there is often a limited amount of suitable material for dating (Blaauw and Christen, 2005).

Moreover, radiocarbon dating can be both expensive and time consuming, and it is often not feasible to establish a radiocarbon date for every level of the core. As a result, interpolation between dated levels is required (Bennett, 1994), and this can lead to inaccuracies. Additionally, radiocarbon dating methods may also be hampered by contamination of sediments (Yeloff *et al*., 2006). This may be caused by younger plant roots, mixing of sediment due to surface runoff or by poor sampling methods, in which case careful sampling and laboratory procedures may lower the risk of contamination (Yeloff *et al*., 2006).

The amount of atmospheric carbon has fluctuated through time, consequently it is important to calibrate ages to calendar years to compensate for these fluctuations (Stuiver *et al*., 1998). Radiocarbon dates are calibrated by means of calibration curves such as the international calibration model (INTCal09) (Reimer *et al*., 2009), which is the recommended calibration curve (Yeloff *et al*., 2006). Due to variations in atmospheric carbon between the two hemispheres, the southern hemisphere calibration model (SHCal04) has been developed (McCormac *et al*., 2004). However, SHCal04 has a limited timescale and should only be used up to 11,000 cal yr BP (McCormac *et al*., 2004).

Using calibrated dates as well as the accumulation rates of sediment between these dates, it is possible to estimate the calendar ages of non-dated depth levels within a sequence using age-depth models (Blaauw, 2010). There are two types of age models, Bayesian (Blaauw and Christen, 2005) and 'classical' age depth models (Blaauw, 2010). Bayesian methods produce high resolution, reliable age-depth modeling (Blaauw, 2010), however, since these methods are complex, most studies apply 'classical' or basic age depth models which are simpler and work well for sites with limited large determinations.

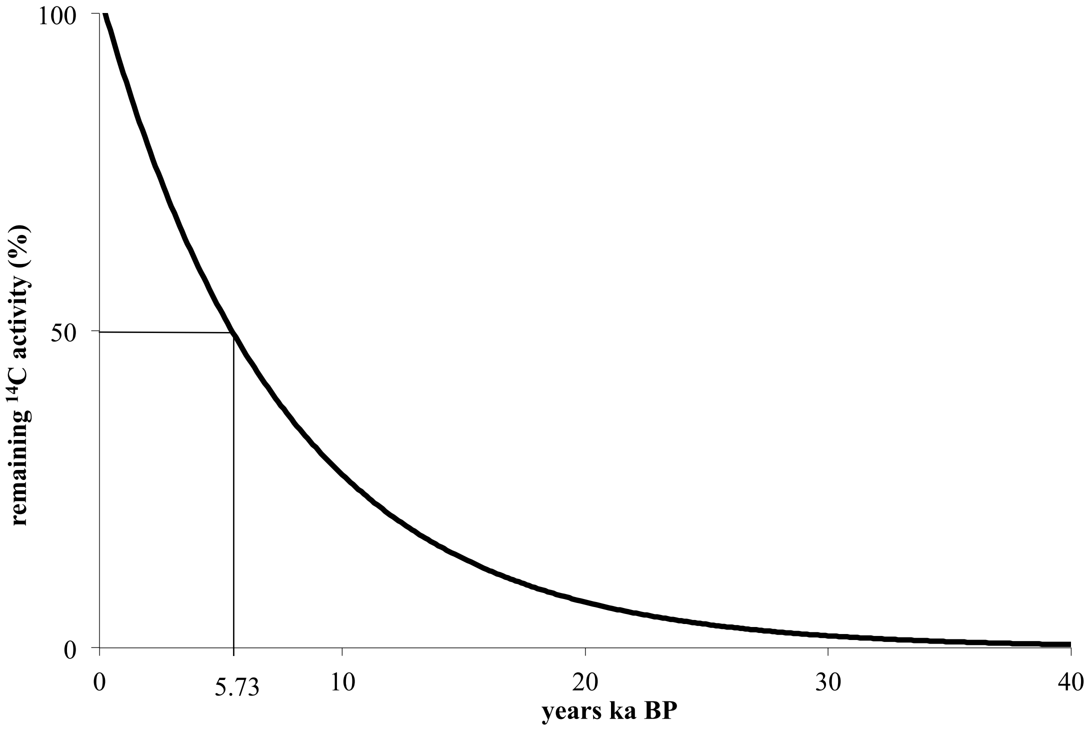

Figure 3.3: Radiocarbon decay curve (after Walker, 2005)

An age depth model for a sequence is established by first estimating age distributions of individual dated depths, and then determining ages for the remaining depths, which is done by modeling the rate of sediment accumulation through time (Blaauw, 2010). Commonly used basic age depth models include linear interpolation, spline interpolation and polynomial line fitting/regression (Bennett, 2004; Blaauw, 2010). The most likely or most parsimonious age model must be chosen. For example, deposits from stable environments are likely to have developed with fewer hiatus events or changes in the sedimentation rate in comparison to more fluctuating environments, and thus should be modeled using a smooth age-depth model such as a spline (Blaauw, 2010). Sequences which are likely to have undergone abrupt changes in sedimentation rates should be modeled using the linear interpolation age-depth model, which is the most commonly used model. Some sequences, which contain numerous hiatus events, require more complex age-depth model techniques to be used, in which case, polynomial regression is used to estimate dates for undated depths (Blaauw, 2010).

3.4.2 Limitations

One of the most important limitations to radiocarbon dating is that it lacks precision. Uncertainties in radiocarbon dating may occur at all stages, including sampling, laboratory processing, calibration, as well as during age modeling. Sources of error arise from atmospheric radiocarbon fluctuations, isotopic fractionation and contamination (Walker, 2005; Anderson *et al.*, 2007).

The amount of atmospheric radiocarbon has fluctuated over time, thus radiocarbon dates cannot be directly compared to calendar years (Saarnisto, 1988). As a result, errors in calibration may occur. However, in some cases, this may be corrected for if the nature of the variation is known (Terasmae, 1984) although it is still important to note that calendar years are ultimately based on the best estimate of radiocarbon content (Terasmae, 1984) and are thus not completely reliable even after corrections. Furthermore, the error associated with radiocarbon dates increases with older ages, and radiocarbon dating is limited to samples that are less than 50,000 years old (Guilderson *et al.*, 2005).

Studies have shown that isotopic fractionation of carbon isotopes occur during the growth of all organic materials (Anderson *et al.*, 2007). Thus isotope ratios can differ between species, as well as between different locations within the same organism (Terasmae, 1984).

Contamination may either arise from incorrect laboratory processing, whereby subsampling is not performed carefully; or from external sources (Saarnisto, 1988; Blockley *et al.*, 2007). In the case of external contamination, contamination may arise from mixing of old and young carbon due to root penetration, humic acid percolation and carbonate contamination due to mixing with groundwater (Blockley *et al.*, 2007). Other potential problems include reservoir effects and the old wood effect (Yeloff *et al.*, 2006).

Aside from this, radiocarbon dating is also limited by sample size (Anderson *et al.*, 2007). According to Terasmae (1984), approximately 5 to 10 grams of carbon are required for bulk radiocarbon dating. This can be problematic for samples that are poor in organic matter content. However, this problem has been largely overcome by the development of the AMS dating technique (Brady and Holum, 1993). Moreover, the radiocarbon dating technique is very expensive and may be problematic for projects with limited funds (Terasmae, 1984).

Despite these limitations, radiocarbon dating remains one of the most popular dating methods. Due to the advantages of AMS radiocarbon dating, this method has been employed in this research to provide stratigraphic descriptions of sediment samples.

3.5 Conclusion

This chapter serves as a theoretical background to the palaeoenvironmental techniques used in this research. Pollen analysis has been discussed in terms of its basic principles, advantages, limitations, methodology (both fieldwork and laboratory methods), presentation and interpretation. Additionally, the theoretical backgrounds to charcoal analysis and radiocarbon dating have also been discussed.

CHAPTER FOUR: STUDY AREA

4.1 Site description

The Soutpansberg Mountains, located in Limpopo Province, constitute South Africa's northernmost mountain range. Due to its unique geological history and geographical location, the Soutpansberg has an exceptionally high biological diversity (Foord *et al*., 2002). Here we describe geology, climate, contemporary vegetation and human history.

4.1.1 Geology

According to Barton (1979), the Soutpansberg represents an important group of Proterozoic rocks, suggesting that the development of the Soutpansberg range occurred sometime during the Precambrian era as the Proterozoic falls under this era. The Soutpansberg mountain range has an east-west orientation (Bristow, 1986; Mostert *et al*., 2008), forming a continuous south-facing escarpment between Kruger National Park and Vivo (Bumby, 2000). The range expands roughly 210 km long, and is approximately 60 km wide at its widest point (Hahn, 2007). The altitude ranges from 200 m a.s.l, to 1748 m a.s.l at Lajuma (Hahn, 2007).

The geology of the Soutpansberg consists predominantly of pink erosion resistant quartzite and sandstone, which is a result of the upwelling of basaltic lavas, accompanied by the deposition of alluvial sediments which eventually solidified, forming sedimentary rocks (Bristow, 1986; Bumby, 2000; Brandl, 2003). Rocks such as shale, conglomerate, basalt and diabase intrusions are also present, but less frequently than quartzite and sandstone (Bristow, 1986; Mostert *et al*., 2008). Soils in the region originate from quartzite and sandstone and are thus relatively shallow, acidic, gravelly, well drained and are fairly nutrient deficient (Mostert *et al*., 2008). Fine textured, clayey, deep, well-weathered soils originate from basalt and diabase intrusions (Mostert *et al*., 2008).

Certain areas along the northern Soutpansberg comprise only of exposed underlying materials, whilst along the cool, high lying areas, peat soils occur within wetlands (Mostert *et al.*, 2008). Upon observation of the landscape, it was found that the north eastern Soutpansberg displayed four landscape zones, ranging from the gently sloping terrace at the foot of the plateau, moderately sloping ridge tops, moderately steep rocky surfaces and steep ridge sides (Saidi and Tshipala-Ramatshimbila, 2006).

4.1.2 Climate

The Soutpansberg, which experiences a subtropical climate (Geldenhuys and Murray, 1993), falls within South Africa's summer rainfall region and thus experiences most of its rainfall during the summer months (November to March). Due to the east-west orientation of the mountain range, the region experiences orographic rainfall (Geldenhuys and Murray, 1993; Mostert *et al.*, 2008). Local annual rainfall in the eastern Soutpansberg is generally high, exceeding 1000 mm (Jackson, 1961). At Entabeni, located in the eastern Soutpansberg, the average annual rainfall recorded is 1874 mm, the highest average annual rainfall in the Soutpansberg (Hahn, 2007). The lowest average annual rainfall is recorded at Punda Maria, located in the western Soutpansberg (Hahn, 2007). Due to rain shadows, Waterpoort has the lowest annual rainfall of 367 mm (Hahn, 2007). Generally, the Soutpansberg range is relatively dry and undergoes periodic droughts caused by the El Niño effect (Hahn, 2007). Mean temperatures during summer reach beyond 25 °C, whilst the area experiences moderate, frost-free winters (Jackson, 1961).

4.1.3 Contemporary vegetation

Floristically, the Soutpansberg is very diverse, comprising a range of different vegetation environments, which include savannah bushveld, forests, sensitive wetlands and fynbos (Foord *et al.*, 2002). Moreover, the Soutpansberg is regarded as a centre of floristic endemism (van Wyk and Smith, 2001; Mucina and Rutherford, 2006; Hahn, 2007). Afromontane forests dominate the south, whilst the north consists of a more savanna bushveld type vegetation. Hahn (1997) estimated that the Soutpansberg contains a total of between 2500—3000 vascular plant taxa, encompassing 1066 genera and 240 families, covering an area of 6800 km^2, thus containing the largest diversity per surface area in southern Africa. According to van Wyk and Simth (2001), approximately 41% of the total southern African genera and 68% southern African families are represented within the Soutpansberg Centre of Endemism. A total of 594 tree taxa currently occur in the Soutpansberg, constituting approximately one third of known tree taxa present in southern Africa (Hahn, 2007). The Soutpansberg is thus regarded as unique in comparison with other South African centres of endemism (Hahn 1997). Similarly, van Wyk and Smith (2001) deemed the Soutpansberg a 'floristic hotspot'.

Plate 4.1 Western Soutpansberg mountain range (Source: D.L. Baboolal)

Table 4.1 Biomes present in the Soutpansberg (adapted from Hahn, 2007)

Biome	**Author**
Forest	(Rutherford and Westfall, 1987; Low and Rebelo, 1996; Siegfried, 1991; Mucina and Rutherford, 2006)
Grassland	(Siegfried, 1991; Mucina and Rutherford, 2006)
Savanna	(Rutherford and Westfall, 1987; Low and Rebelo, 1996; Mucina and Rutherford, 2006)
Arid savanna	(Siegfried, 1991)
Moist savanna	(Siegfried, 1991)

According to Hahn (2007), the Soutpansberg is best represented by the biome classification compiled by Siegfried (1991), most likely due to the differentiation between arid and moist savanna (Table 4.1). Mucina and Rutherford (2006) have also placed the Soutpansberg region into the Savanna biome. In addition to this, they have further identified 6 bioregions within this biome. Of these six bioregions, four are present in Limpopo Province. These are, the Central Bushveld, Mopane, Mesic Highveld Grassland and Lowveld bioregions. Fynbos type vegetation patches also occur in the Soutpansberg on steep slopes or at higher altitudes (Mucina and Rutherford, 2006). These bioregions are further split into vegetation units which can be viewed in Mucina and Rutherford (2006). Presently, the grassland biome has been almost eradicated, in particular, the eastern high rainfall grasslands which have been converted into exotic *Pinus* and *Eucalyptus* plantations (Hahn, 2007).

The presence of an isolated *Brachystegia spiciformis* woodland patch located in the northeastern Soutpansberg adds to the intrigue surrounding the Soutpansberg. *Brachystegia spiciformis* is a key element of miombo woodland, the most extensive woodland type on the African continent, spanning a total area of approximately 2.7 million km^2 (Campbell, 1996). It is the dominant woodland type in Angola, Democratic Republic of Congo, Malawi, Tanzania, Zambia and Zimbabwe, previously thought to reach its southern most recognized distribution in Mozambique (Campbell, 1996).

Aside from being the dominant woodland type on the African continent, miombo woodlands are also the key element of the Zambezian Region, a phytogeographical unit covering a total extent of roughly 3.8 million km^2 (Hurter and Van Wyk, 2001). Despite this region extending southward to encompass most of South Africa's Limpopo Province, miombo woodlands have been noticeably absent from South Africa (Hurter and Van Wyk, 2001). According to Rutherford *et al*. (1999), *Brachystegia spiciformis*, the defining constituent of dry miombo, could successfully establish in northeast South Africa, under predicted global climate shifts. However, given that dispersal amongst most dominant miombo species, including *Brachystegia,* is low (Campbell, 1996), coupled with the knowledge that the nearest population occurred outside South Africa in the neighboring countries of Mozambique and Zimbabwe, natural dispersal southward into South Africa across the Limpopo valley seemed improbable. The absence of *Brachystegia spiciformis* from South Africa has raised much interest within the botanical community (Frost, 1996), leading to various proposed explanations. Wild (1968) suggested that the genetic instability of the genus *Brachystegia*, inferred from recurrent hybridizing between species, could possibly indicate an ability to rapidly adapt to new environments and expand their range. Thus, 'the southern limit (the Limpopo Valley) to the distribution of *Brachystegia spiciformis* may therefore be due to a real impediment or barrier or may be a transitional limit reached in time and so be merely imaginary' (Wild, 1968, p. 212).

In 2000, Erich van Wyk and Johan Hurter discovered a patch of miombo like woodland in Venda, in the northeastearn Soutpansberg region of the Limpopo Province (Burrows *et al*., 2003). This patch, referred to as the Gundani *Brachystegia spiciformis* (miombo) woodland, contains approximately 2000 *Brachystegia spiciformis* trees (Burrows *et al*., 2003). Furthermore, upon visiting the Gundani miombo woodland in 2002, the Mpumalanga Plant Specialist Group discovered a single specimen of *Brachystegia utilis* (Burrows *et al*., 2003). Other associated miombo taxa were also encountered within the Gundani miombo woodland patch. The presence of another species of *Brachystegia* aside from *Brachystegia spiciformis*, together with other miombo species suggests that this patch is a relict of a vegetation type rather than a relict of a single species (Burrows *et al*., 2003).

Plate 4.2 Gundani *Brachystegia spiciformis* woodland (Source: D.L. Baboolal)

The presence of *Brachystegia* pollen within pollen records from Wonderkrater (Scott, 1982a) and Tate Vondo (Scott, 1987a) in Limpopo province for the past 20,000 years up until 1000 cal yr BP has suggested that it is possible that *Brachystegia* has been present in South Africa for at least 20,000 years. The implications of these findings suggest that conditions in South Africa during this time favoured the establishment of *Brachystegia*. Since *Brachystegia* is no longer found anywhere south of the Soutpansberg, the presence of *Brachystegia* pollen so recently within the pollen record suggests that the species declined rapidly. There is a lack of evidence to support a sudden climatic shift during this period (Campbell, 1996), thus, suggesting that fine scale climatic shifts within the greater Limpopo area may have been the cause of the possible decline in *Brachystegia* woodland.

4.1.4 History of human occupation and impacts in the Soutpansberg

The Soutpansberg and its surroundings have a unique history of human occupation. Although most southern African archaeological sites have produced limited graves, a relatively high number of skeletal remains have been discovered within the Soutpansberg and Limpopo Valley (Steyn and Nienaber, 2000). According to Klapwijk (2001), fossils and archaeological evidence from Makapansgat support proto-human and human occupation, as well as resource exploitation dating back from 3.32 million years ago through to the present.

The discovery of numerous artefacts within the region suggests that early man inhabited the Soutpansberg from since the Early Stone Age (Steyn and Nienaber, 2000). Moreover, the variety of Middle to Late Stone Age tools reflects changing occupations by different cultures (Hahn, 2007). Interestingly, Coles and Higgs (1975) have suggested that certain types of tools may indicate differing climates. For example, the discovery of Sangoan-type wood shavers dating back to 40,000 years ago indicates that a cooler and moister climate prevailed during this time.

An archaeological deposit containing Smithfield stone tools indicates that the Smithfield stone-age culture occurred within the Soutpansberg at the end of the last glacial period, approximately 12,000 – 10,000 years ago (Hahn, 1992). According to Hahn (2007), the site must have undergone aridification toward the end of the last glacial, as the area is currently too wet to encourage human occupation.

Following this, the Khoisan and the earliest metalworking people occupied the Soutpansberg mountain range (Hahn, 1992). From approximately 3000 cal yr BP, evidence suggests that the first agriculturalists began utilizing the soils of the Soutpansberg foothills to implement agricultural techniques, as well as to practice livestock farming (Voigt and Plug, 1984). Eventually, these early cultures resulted in the formation of Mapungubwe, one of the most important Iron Age cultures in southern Africa. Mapungubwe, which occurred between *ca*. 793-723 cal yr BP (Schoeman and Pikirayi, 2011), was important in establishing trade between the southern African interior and the ports of Beira and Sofala. Archaeological evidence suggests that Mapungubwe was a class-based culture, where elite hill-top settlements were reserved only for royalty (Loubser, 1989). Evidence suggests that such settlements only occurred to the north of the Soutpansberg, the largest being Mapungubwe Hill, where the production and export of gold and ivory was strictly controlled by royalty (Fouche, 1933; Loubser, 1989).

The Venda tribe, who still occupy the area today, arrived in the area between 363 – 263 cal yr BP (Geldenhuys and Murray, 1993). They practiced iron-ore smelting and agriculture. According to Geldenhuys and Murray (1993), the Venda people frequently cleared away large tracts of forests to make way for grazing and agriculture.

According to Tempelhoff (1999), the last phase of the transition in occupation of the Soutpansberg began in the 1820s when Dutch settlers, Coenraad de Buys and Louis Trichardt, who arrived later in 1836, settled in the Soutpansberg. Along with these settlers, a European lifestyle was introduced to the region (Hahn, 2007). This had serious ramifications for the natural environment as natural resources began to be exploited for financial advance (DasNeves, 1987; Geldenhuys and Murray, 1993). Indigenous forests were exploited for timber, and game was hunted on a large scale (DasNeves, 1987; Geldenhuys and Murray, 1993). More recently, natural bushveld was replaced by exotic *Eucalyptus* and *Pinus* plantations, and avocados, Macadamias, mangoes, coffee and bananas were planted as cash crops (Hahn, 2007). Moreover, agricultural crops such as maize were also planted to boost agricultural productivity in the region. Currently, the

Soutpansberg's bushveld unit, part of the savanna biome, is regarded as 'vulnerable' due to pressure from exotic plantations (Mucina and Rutherford, 2006).

4.1.5 Mutale Wetland

The Mutale Wetland site (22° 53' 47.0394" S; 30° 19' 36.0834" E; 1193 m a.s.l) is located in a mountainous area near Tate Vondo, Venda, in the eastern Soutpansberg region. The area falls within the Northeastern Mountain Sourveld (Acocks, 1953), of the Afromontane Region. However, with the exception of small indigenous forest patches present within the vicinity, exotic *Pinus* plantations have largely replaced indigenous vegetation.

The Mutale Wetland is a highly organic peat wetland located within a valley. The wetland is spring fed, and a small stream drains towards the Mutale River. There is a standing pool of water on the northern side, however the wetland was much drier than when previously visited (van der Waal personal communication, 2012) and cattle presence was detected on site. The vegetation within the wetland includes *Sphagnum* moss, grasses, drossera (sundews), tree ferns, and *Passerina* and *Hypericum revolutum* along the edges. No sedges were located within this wetland. Apart from *Pinus, Pteridium aquilinum* (bracken fern) and *Hypericum* bushes are also invading the wetland. According to Scott (1987), the peat covers an approximate area of 30,000 m^2, however, due to the spread of *Pinus* plantations, parts of the peat deposit have been destroyed or disturbed. According to Hahn (2007), *Pinus* plantations in Tate Vondo were established in approximately 1939, and other parts of the Soutpansberg were under *Pinus* cultivation in the early 1900s.

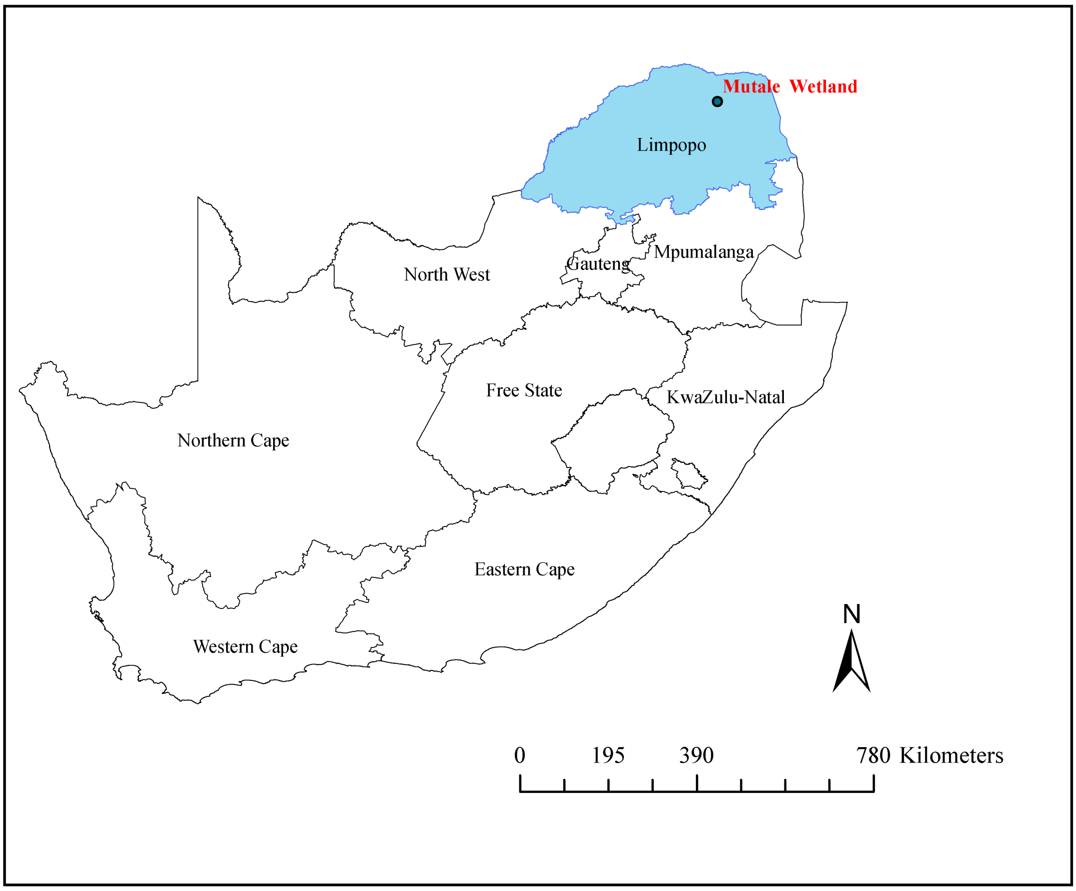

Figure 4.1 Location of Mutale Wetland in Limpopo Province, South Africa

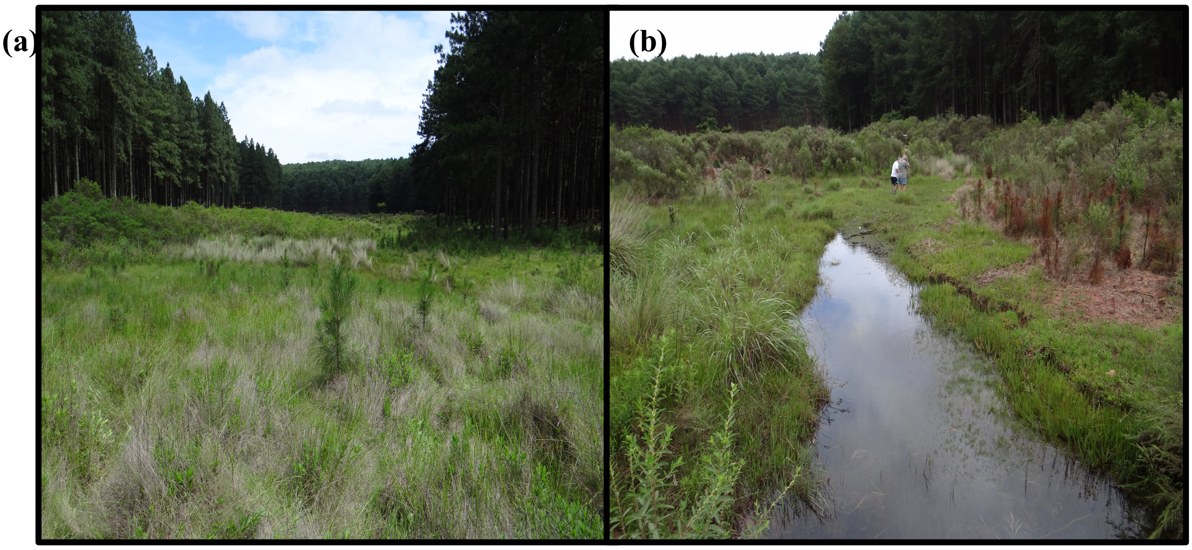

Plate 4.3 (a) Mutale Wetland site surrounded by exotic pine plantations (b) standing pool of water on the northern boundary of the site (Source: D.L. Baboolal)

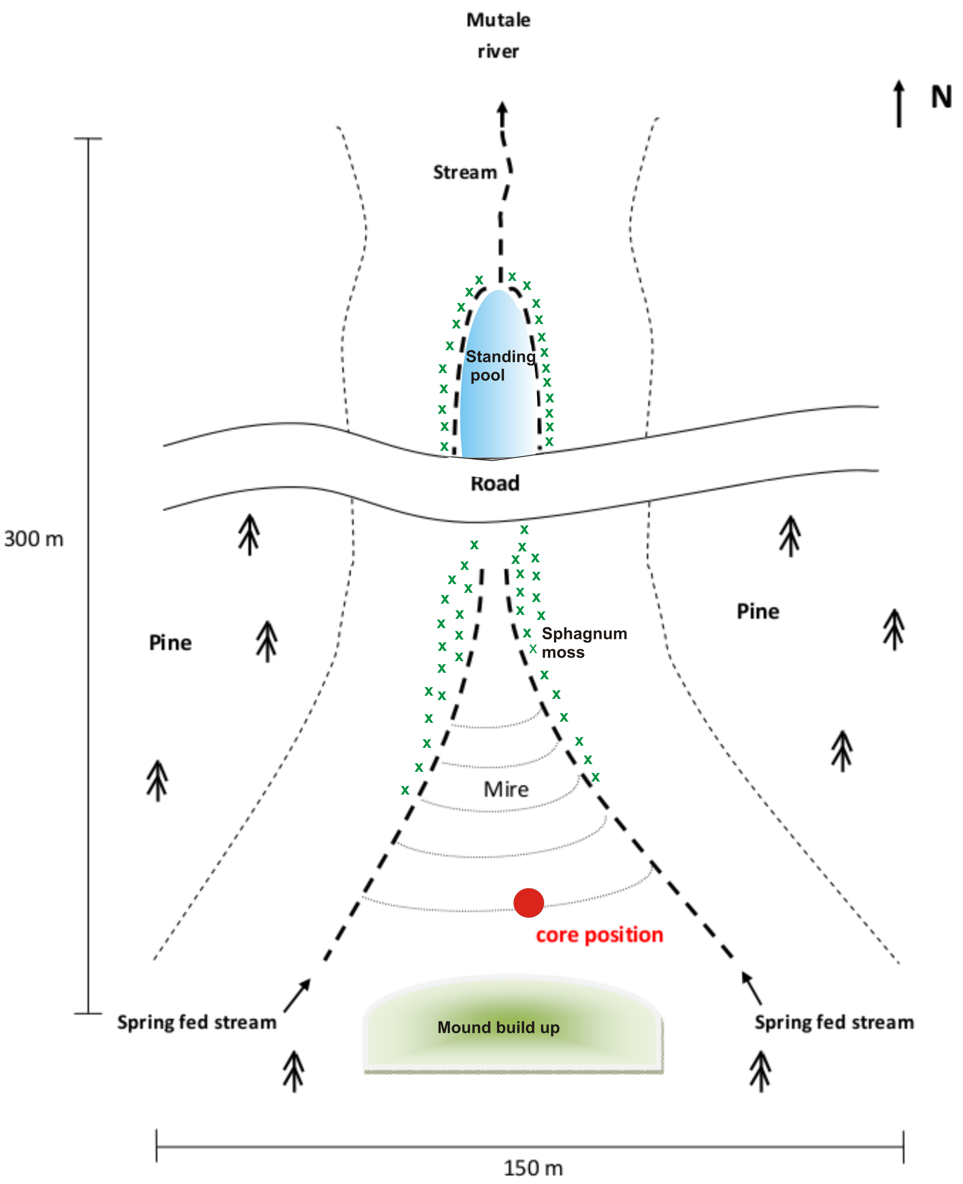

Figure 4.2 Schematic diagram of site according to approximate scale

CHAPTER FIVE: METHODOLOGY

5.2 Field techniques

5.2.1 Core extraction

Extendible one-meter fiberglass rods were inserted as depth probes at various points within each wetland to determine the deepest sections for coring. At each site, a Russian peat corer was used to extract minimally disturbed, semi-continuous sediment cores from parallel boreholes with overlapping segments. Each segment had an overlap of 1 cm on either side. These overlaps were carefully removed after each segment was placed into labeled, 48 cm PVC piping. Each core was stratigraphically described using the Troels-Smith sediment classification scheme (Troels-Smith, 1955; Kershaw, 1997). This was done in the field as the colour of sediments may fade and stratigraphic boundaries may not be clearly visible. Segments were then packaged in heavy-duty aluminium foil and then wrapped in plastic sheeting before being transported to the laboratory where they were stored in a refrigerator.

A 302 cm highly organic sediment core (MUT-12-01) was extracted from Mutale Wetland. A 221 cm sediment core (LAJ-12-01) was extracted from Lajuma Wetland in the western Soutpansberg area. A 219 cm highly fibrous sediment core (FUN-12-01) was recovered from Fundudzi Swamp, part of the Lake Fundudzi inlet stream. This research focused on the Mutale Wetland core, which was the longest and most organic core and is located within reasonable proximity to the Gundani *Brachystegia* Woodland. Due to time constraints only a single site was analysed.

A reference collection was created to aid in identification of fossil pollen grains. This involved the collection and identification of 18 flowering specimens at the Mutale Wetland site.

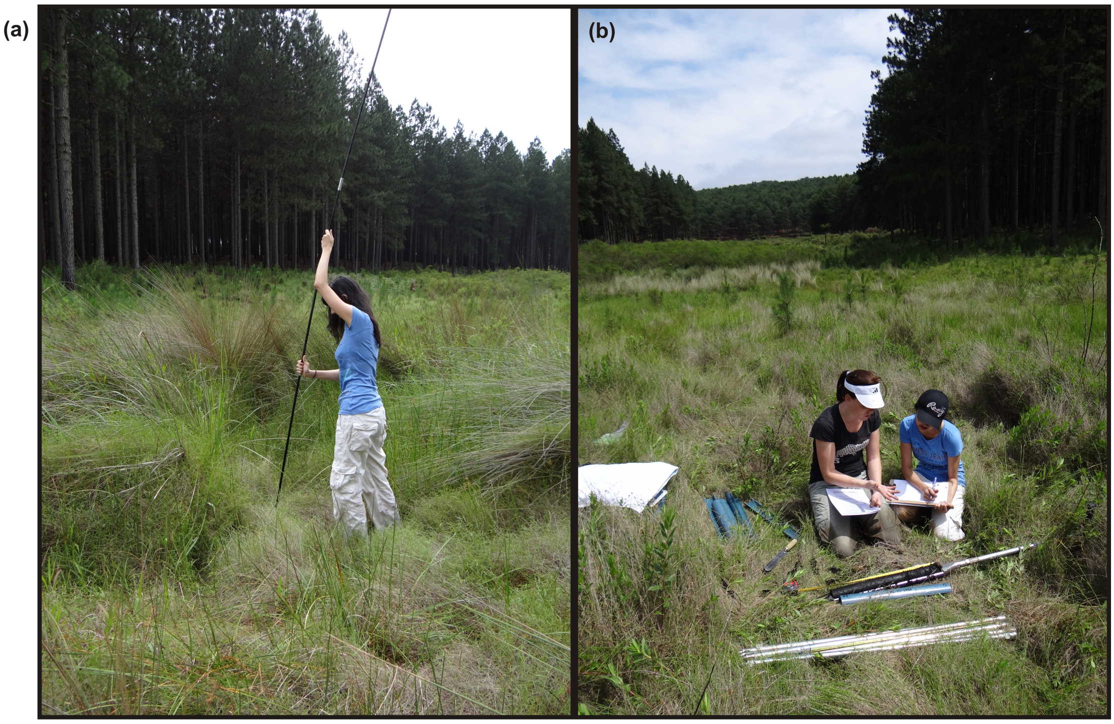

Plate 5.1 (a) Using fiberglass rods to determine the best coring location; (b) Conducting Troels-Smith sediment classification in the field (Source: D.L. Baboolal)

5.3 Laboratory techniques

5.3.1 Subsampling

The core was subsampled at fixed intervals of 4 cm along the length of the core for both pollen and charcoal analysis. Where further detail in proxy data was required, the subsampling interval was increased to 2 cm. Where minimal change was detected between wider intervals of 4 cm, it was determined that further subsampling was not required (Appendix A). A total of 85 subsamples were extracted. Subsamples were sealed in labeled polypropylene bags and refrigerated.

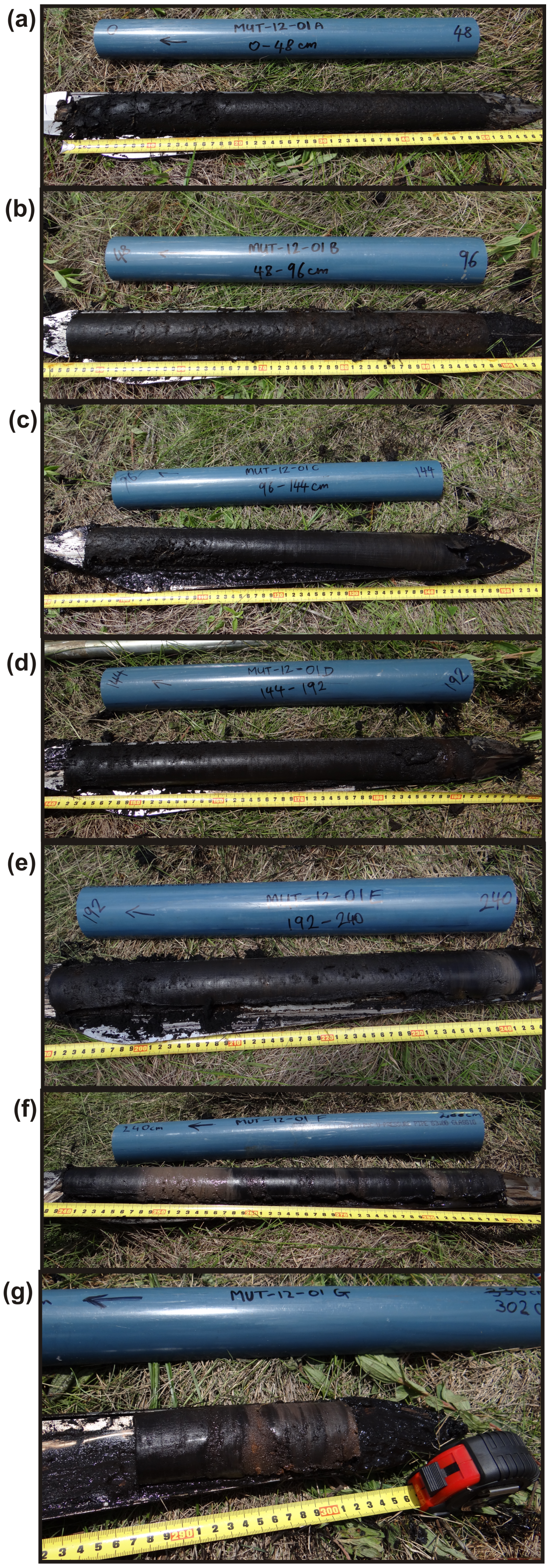

Plate 5.2 Segments of the MUT-12-01 core (a) 0 - 48 cm; (b) 48 – 96 cm; (c) 96 – 144 cm; (d) 144 – 192 cm; (e) 192 – 240 cm; (f) 240 – 88 cm; (g) 288 – 302 cm (Source: D.L. Baboolal)

5.3.2 Chronology

5.3.2.1 Radiocarbon dating

Subsamples were obtained from suitable basal and intermediate layers, based on stratigraphy, for radiocarbon dating. Approximately 2 g of carbon was subsamples for AMS radiocarbon dating. Subsamples were dried overnight in an oven at 100 °C. Once the subsamples were dry, they were weighed before being packaged in propylene bags. The samples were sent to Lund University Radiocarbon Dating Laboratory in Sweden and Beta Analytic Inc. in Miami, Florida. The Classical Age Modelling (CLAM) technique (Blaauw, 2010) was used to establish an age model for the sedimentary core. The radiocarbon ages were calibrated using the southern hemisphere calibration model (SHCal04) dataset (McCormac *et al.,* 2004) dataset, in conjunction with the glued curves function which extends this curve to 50,000 years using the northern hemisphere curve and applying an offset (Blaauw, 2010), to establish an age-depth model for the MUT-12-01 sediment core.

5.3.2.2 Time- stratigraphic marker horizons

Humans have played a major role in altering natural vegetation; thus it is not only imperative that such impacts be considered when interpreting pollen diagrams (Faegri and Iverson, 1989), but also to use historical records of human presence and the occurrence of exotic or introduced pollen taxa as stratigraphic markers. This method has been used in a study by Stager *et al.* (2013). *Pinus* is one such taxa which can be used as a stratigraphic marker in the Tate Vondo region. *Pinus* was first introduced into the Soutpansberg in the early 1900's (Hahn, 2007). The Klein Australia plantation was established in 1914, Old Entabeni in 1918, Hanglip in 1920 and the Tate Vondo plantation was established in 1939 (Hahn, 2007). *Pinus* trees produce cones after approximately 5 years (Richardson, 2000), hence it is possible to calculate the earliest possible expected date that *Pinus* should appear in the pollen record if the historical date of introduction is known. Based on historical documentation of pine plantations in the Soutpansberg, *Pinus* was plotted as a time stratigraphic marker on the age model (Fig. 5.2) *Pinus* was expected to be recorded within the pollen record from *ca.* 94 cal yr BP. This age constraint is plotted against the age model for visual comparison, however, this does not contribute to the age model.

5.3.3 Chemical processing

All samples required absolute pollen counts, therefore a known number of pollen microspheres (LacCore-Appendix D) were added as markers, such that the abundance of each taxon could be determined in relation to marker grains rather than in relation to other taxa present (Salgado-Labouriau and Rull, 1996; Moore *et al*., 1991). The microsphere solution was placed on a magnetic stirrer for at least one hour before use. This was done to ensure even suspension of microspheres within the solution. Exactly 0,5 ml of pollen spike was added to each subsample prior to chemical processing. Subsamples were chemically treated using standard palynological digestion methods (Faegri and Iverson, 1989). Each sample was treated with 15% NaOH, washed and sieved through a 180 µm sieve to ensure removal of humic acids and clay materials. Samples were then treated with 10% HCl before being subjected to a hot HF treatment using concentrated (40%) HF. These processes ensured the removal of all extraneous material such as humic acids, clay and clastic materials (Appendix B) such that pollen and charcoal rich samples were produced. The samples were then acetolysised to remove extraneous organic detritus (Appendix B) using an acetolysis mixture comprising 9 parts acetic anhydride ($[CH_3CO]_2O$) : 1 part concentrated sulphuric acid [H_2SO_4]. The samples were mounted onto semi-permanent microscope slides using an Aquatex, an aquamount solution. Slides were refrigerated for at least 24 hours prior to analysis. This allowed the solution to set, and prevented movement of pollen grains and charcoal during analysis.

Pollen reference material was chemically treated using standard HCL and NaOH digestion (Appendix C). Pollen reference slides were made and digitally photographed.

5.3.4 Microscopy

At each level, both absolute and relative pollen counts were calculated. Pollen counts and identification were conducted under a microscope along regular traverses along the slide, by means of an adjustable stage. Pollen counts excluded indeterminable pollen grains that were corroded, folded or damaged (Faegri and Iverson, 1989). Clusters of the same pollen grain type were grouped together and counted as a single unit, as recommended by Faegri and Iverson (1989), to avoid overrepresentation.

Pollen identification was carried out with the aid of a number of reference material data sets including reference slides made from samples collected at Mutale Wetland, UKZN reference collection and the African Pollen Database and Scott's (1982c) compilation of Transvaal pollen types.

The sample size and minimum pollen sum were determined in order to maintain maximum resolution and accurate pollen assemblage representivity for all samples. To begin with, pollen counts were conducted at 4 cm resolution along the length of the core. Where further detail was required, gaps were filled in at 2 cm resolution. In order for a representative sample of the parent vegetation to be obtained, a minimum of 500 pollen grains were counted for each sample (Neumann *et al.*, 2008; 2011). Variations in the number of transects required to be counted were due to differences in pollen preservation and concentration of the samples. For each sample, complete slides were analysed even once the minimum of 500 pollen grains were achieved. A minimum of 50 marker grains were counted. Statistics for the marker grains have been attached in Appendix D.

The number of pollen grains in a sample from the MUT012-01 core is calculated as follows (Stockmarr, 1971):

$$\text{Total pollen grains in sample} = \frac{\text{pollen grains counted x microspheres added to sample}}{\text{microspheres counted}}$$

Fungal spores and additional unidentified non-pollen palynomorphs were also counted along with pollen grains. This was done until a minimum of 500 pollen grains were tallied (Ekblom and Gillson, 2010b). Fungal spores were identified using various keys (e.g. Ellis and Ellis, 1997; 1998; Ekblom and Gillson, 2010b; van Geel *et al.*, 2003; 2011). Efforts were made to differentiate coprophilous fungal spores from other spores.

The pollen was split into regional, local, aquatic, arboreal, non-arboreal, neophyte and non-palynomorph sums. The regional pollen excluded local, aquatic and non pollen palynomorph sums.

The regional pollen was further subdivided according to the following ecological groupings:

(i.) Forest
(ii.) Generalist bushveld
(iii.) Dry bushveld savanna
(iv.) Moist bushveld savanna
(v.) Grassland
(vi.) Fynbos

These groupings were based on those defined by Scott (1982a) and (1982c) for sites located in Limpopo Province, similar to this study site. It must be stressed that these groupings are tentative, and we are by no means claiming that the taxon identified in this study are restricted to or exclusive to a particular ecological grouping.

5.3.5 Microscopic charcoal counts

Microscopic charcoal counts were conducted together with pollen counts and identification. To maintain the pollen to charcoal ratio, and to avoid overrepresentation of charcoal at depths where pollen abundances were low, charcoal fragments were counted along the same number of traverses as pollen. Only fragments that were black, completely opaque and angular were counted. The size class technique (Whitlock and Larsen, 2001) was used to analyze microscopic charcoal content in this study. For each sample, individual charcoal fragment size was measured with the aid of an eyepiece graticule in the microscope. Charcoal fragments were classified according to size into the following classes: <25 µm; 25—75 µm and 75—100 µm. The sum of charcoal in each size class, at each depth, was then calculated. Charcoal data was then expressed as charcoal concentrations using marker grains, and expressed as number of particles per volume of sample (Stockmarr, 1971).

5.3.6 Data analysis and interpretation

Final pollen and charcoal tallies for each sample were then entered into Microsoft Excel 2010 software (Microsoft, 2010) before being imported into Psimpoll 4.25

(Bennett, 2005). To facilitate interpretation of pollen data, changes in pollen counts or percentages were plotted against their corresponding depths and radiocarbon ages, and presented as pollen diagrams. Separate pollen diagrams were produced for absolute and relative pollen counts. Similarly, absolute charcoal concentrations were plotted against a depth scale and their associated radiocarbon ages.

Pollen data was divided into zones using the Constrained Incremental Sum of Squares (CONISS) method available in Psimpoll 4.25 (Bennett, 2005). The purpose of zonation is primarily for descriptive purposes, as well as to identify zones of homogenous pollen and charcoal content (Grimm, 1987).

The CONISS algorithm was applied to regional pollen and charcoal data to produce a dendrogram. The algorithm divided the pollen and charcoal diagram into four zones based on the hierarchical arrangement of clusters within the dendrogram such that third order splits were given precedence over fourth order splits and so on. Various criteria can be used to identify appropriate clusters. Here, total dispersion at each stage was used.

The indicator species approach was used to facilitate a palaeoenvironmental reconstruction using the pollen data. This approach utilizes comparisons between modern taxa and contemporary climatic conditions, thus making inferences regarding the precise environmental requirements of these taxa. However, due to its limitations, this approach has been merely used to guide interpretation.

CHAPTER SIX: RESULTS

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6.1 Troels-Smith stratigraphic description

The sediment core was divided into stratigraphic units according to the Troels-Smith (1955) stratigraphic classification scheme which has been described from the base towards the top of the core. Stratigraphic boundaries were identified at the following depths: 31, 96, 111, 248, 257 and 296 cm (Fig 6.1). Basal sediments (302-296 cm) comprise clay (*Argilla steatodes*) and sand (*Grana minora*). An iron oxide band is present within this layer and sediment is very coarse and gritty (Appendix E). Humus (*Substantia humosa*) appears from 296 cm upwards. Light grey to dark grey banding is present between 279-288 cm. From 248-111 cm, sediments become very smooth, consisting of humus (*Substantia humosa*), clay (*Argilla steatodes*) and a smaller sand (*Grana minora*) fraction compared with basal sediments. Between 111-96 cm, sediments become more fibrous. Herb detritus (*Detritus herbosa*), humus (*Substantia humosa*) and clay (*Argilla steatodes*) is present in this layer. The upper portion of the core, between 96-31 cm consists of very dark brown fibrous layer containing fine detritus (*Detritus granosa*), humus (*Substantia humosa*) and clay (*Argilla steatodes*). A fibrous vegetation network, comprising moss and grass is present at the very top of the core (Appendix E).

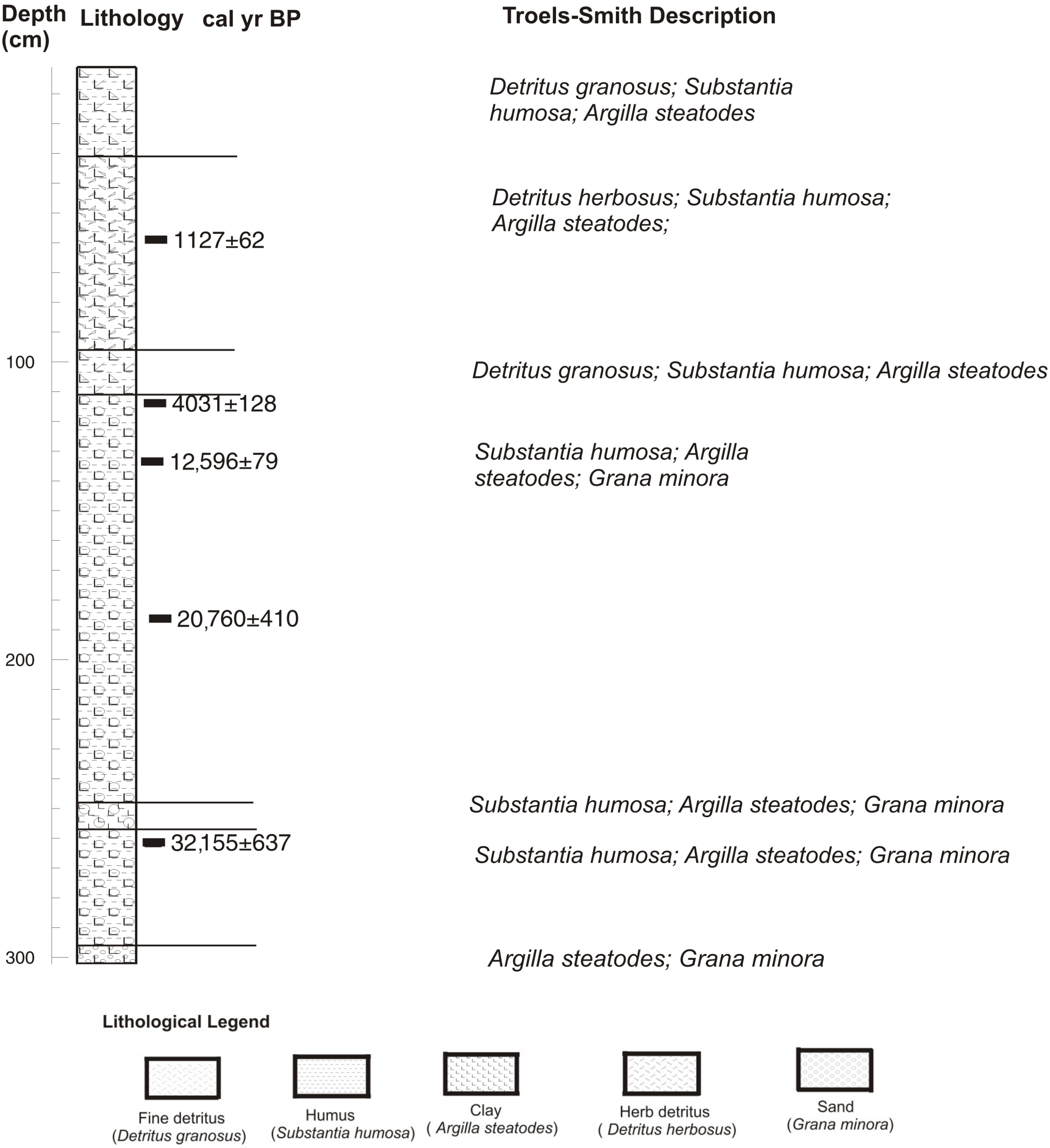

Figure 6.1 Troels-Smith stratigraphic description of core MUT-12-01, indicating radiocarbon ages

6.2 Radiocarbon results

The basal sample, taken between 261-263 cm indicates an age of 32,155 ± 637 cal yr BP (Table 6.1), placing this record within the late Pleistocene. No age reversals are evident in the age model (Fig. 6.2). There is a possible hiatus between depths 136 and 111 cm as evidenced by the change in sedimentation rate. Furthermore, there appears to be quite a large difference in age, but only a narrow depth.

Table 6.1 Radiocarbon results for the Mutale Wetland core (MUT-12-01) indicating calibrated and uncalibrated ages

Sample ID	Lab code	Depth (cm)	^{14}C yr BP	Cal BP range (2 SD)
MUT59	Beta - 363191	59-61	1280 ± 30	1065 - 1188
MUT111	LuS 10522	111-113	3765 ± 45	3903 - 4158
MUT134	Beta - 363192	134-136	10,680 ± 50	12,517 - 12675
MUT186	Beta - 363193	186-188	17,450 ± 70	20,350 - 21,169
MUT261	LuS 10523	261-263	27,990 ± 200	31,518 - 32,792

6.2.1 Age model

The first appearance of *Pinus* occurs at an age of *ca.* 272 cal yr BP and a depth of 16 cm. A summary of all calibrated ages was created (Appendix G). On the basis of parsimony, the linear interpolated calibration curve was chosen to portray the age-depth model for Mutale Wetland; however, additional age-models were established using other interpolation styles (Appendix H).

6.2.2 Sedimentation rates

Between 32,155 - 12,596 cal yr BP, a sedimentation rate of 0,0065 cm/yr is recorded. This depth range includes an extrapolation of sediment rates as the calculated rates between 263 – 188 cm and 188- 136 cm are approximately the same. Thereafter, the average sedimentation rates increase to 0,003 cm/yr and 0,018 cm/yr between the ranges 12,596 – 4030 cal yr BP and 4030 – 1126 cal yr BP respectively (Table 6.2) Between the present and 1126 cal yr BP, the sedimentation rate at Mutale Wetland are the highest, reaching a rate of 0,054 cm/yr (Table 6.2). Sedimentation rates for the previous Mutale core have been calculated and presented in Table 6.3. Between 9634 – 8737 cal yr BP, a sedimentation rate of 0,056 cm/yr is recorded. This is followed by an increase to 0,071 cm/yr between 9634 – 8652 cal yr BP. Thereafter sedimentation rates decline towards the top of the core.

Table 6.2 Average sediment accumulation rates for Mutale Wetland

Depth range (thickness) (cm)	Age range (cal yr BP)	Average accumulation rate (cm/yr)
0 - 61	Present - 1126	0,054
61 - 113	1126 - 4030	0,018
113 - 136	4030 – 12,596	0,003
136 - 263	12,596 – 32,155	0,0065

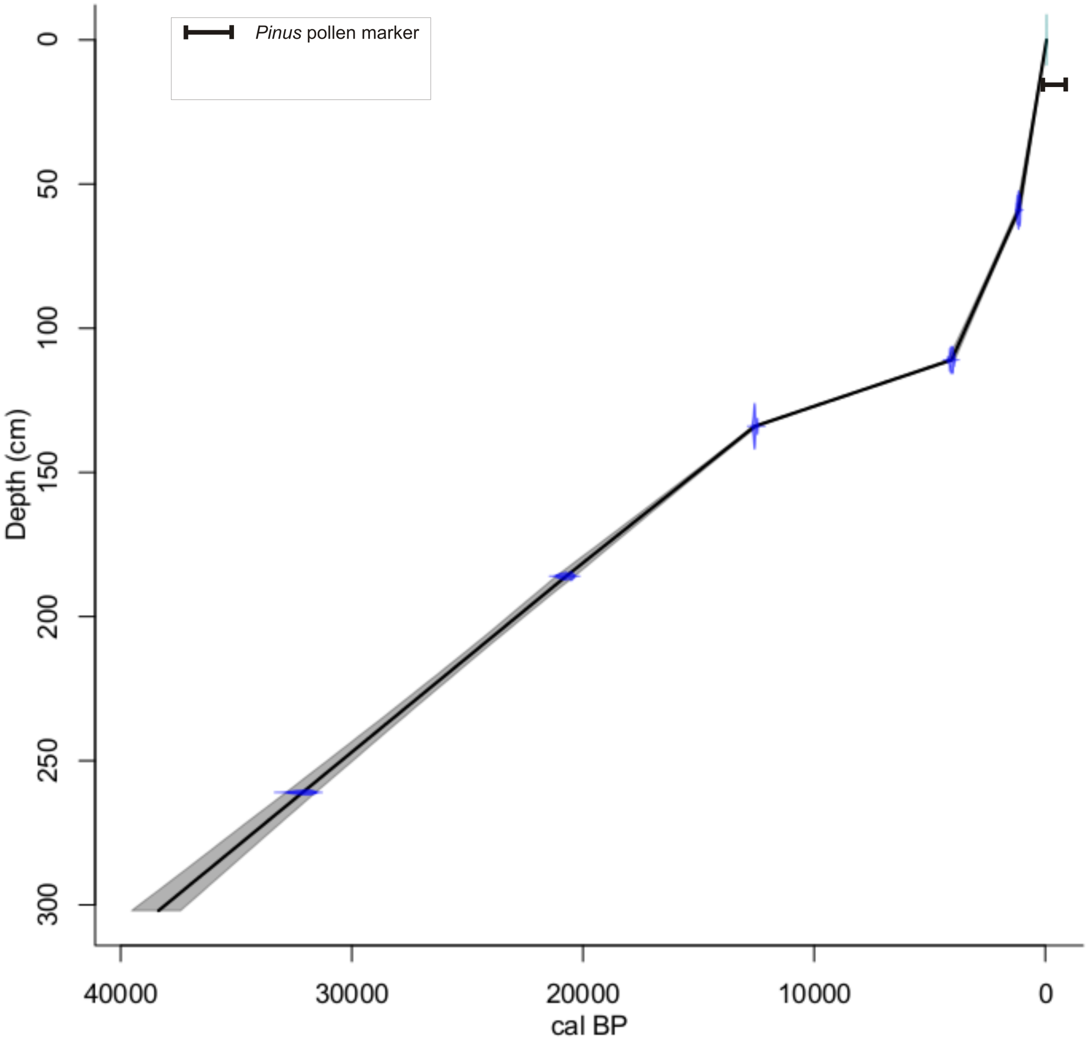

Figure 6.2 Calibrated linear age-depth model for Mutale Wetland with plotted *Pinus* pollen marker

6.3 Zonation

Pollen and charcoal data was divided into zones using the Constrained Incremental Sum of Squares (CONISS) method available in Psimpoll. The purpose of zonation is primarily for descriptive purposes as well as to identify zones of homogenous charcoal and pollen content (Grimm, 1987).

The CONISS algorithm was applied to regional pollen data (Fig 6.11) to produce a dendrogram. The algorithm divided the pollen diagram into four zones based on the hierarchical arrangement of clusters within the dendrogram such that third order splits were given precedence over fourth order splits and so on. Various criteria can be used to identify appropriate clusters.

Four zones were identified (Fig. 6.11), however, the zonation process has its limitations, and often, not all sections of the profile are divided uniformly, thus, zones were further subdivided manually. For the Mutale core, the zone M-2 identified by CONISS was too narrow (Fig. 6.11), whilst zone M-1 was too wide to facilitate description of proxy data (Fig. 6.11), thus zone M-2 was deleted, and zone M-1 was split into two zones. Thus, zonations for the profile were based on a combination of CONISS and visual interpretation. The regional pollen zonation was applied to all diagrams.

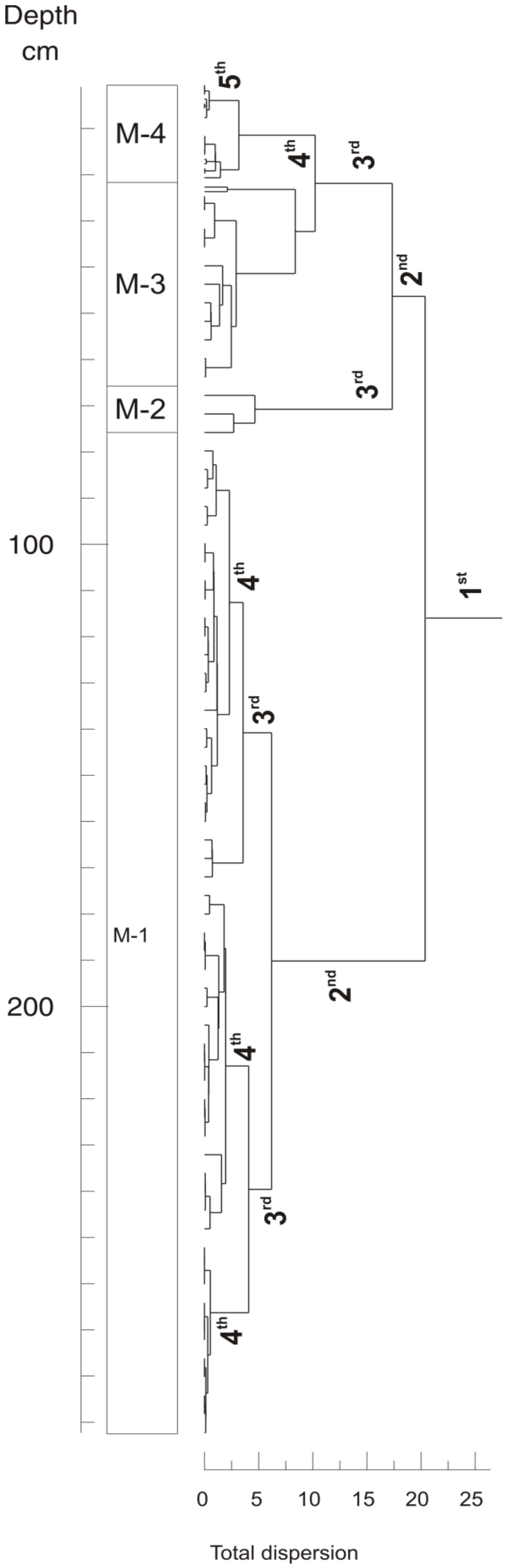

Figure 6.3 CONISS zonation showing order of splits based on total dispersion

6.4 Pollen analysis

Pollen diagrams have been constructed using relative pollen data. Additional diagrams have been constructed for regional and local taxa using absolute count data. Inferences will be made from the relative data, whilst absolute data will be used to verify trends present in the relative data so as to confirm that these trends are real, or determine whether they are the result of fluctuations in other taxa.

Pollen taxa have been divided into four primary groupings: local, regional, arboreal (AP) and non-arboreal pollen taxa (NAP). Neophytes, aquatic taxa, herb taxa, and undetermined taxa were distinguished between, and regional data were separated into forest, savanna bushveld, grassland and fynbos taxa.

Diversity was high and a total of 62 pollen taxa were identified and plotted according to different groupings. Preservation was good for the majority of the core, however, beyond 292 cm, sediments demonstrated low levels of pollen preservation. It must be noted that certain samples contained very low regional pollen counts, thus these samples may be unreliable.

The following pollen diagrams were plotted against the lithology and age-depth profile of the core:

(i) Regional (forest, savanna bushveld, grassland, fynbos) – Figure 6.4
(ii) Regional (focused diagram for the last *ca.* 2000 years) – Figure 6.5
(iii) Local – Figure 6.6
(iv) Disturbance indicators – Figure 6.7
(v) Regional (arboreal vs. non-arboreal) – Figure 6.8
(vi) Regional (absolute) – Figure 6.9
(vii) Local (absolute) – Figure 6.10
(viii) Regional (arboreal vs. non-arboreal) showing CONISS splits – Figure 6.11
(vii) Local (aquatic vs. ubiquitous taxa) – Appendix K
(viii) Summary (dominant regional vs. local taxa) – Appendix K

Table 6.3 Classification of taxa according to regional, local, neophyte, arboreal and non-arboreal groupings (indicates rare taxa with total counts of <1%)**

Regional pollen taxa according to main ecological groupings

Ecological grouping	Taxa
Forest	AQUIFOLIACEAE *Ilex mitis* (AP)
Forest	ASTERACEAE *Vernonia* (NAP)
Forest	CELTIDACEAE *Celtis* (AP)
Forest	CORNACEAE *Cornus* (AP)
Forest	EUPHORBIACEAE *Clutia* (AP)
Forest	FABACEAE *Psoralea* type (AP)
Forest	FLACOURTIACEAE *Kiggelaria africana* (AP)
Forest	MYRICACEAE *Myrica* (AP)
Forest	**MYRSINACEAE *Myrsine* (AP)
Forest	MYRTACEAE undiff. (AP)
Forest	PODOCARPACEAE *Podocarpus* (AP)
Generalist bushveld savanna	ANACARDIACEAE *Rhus* (AP)
Generalist bushveld savanna	ANACARDIACEAE undiff. (AP)
Generalist bushveld savanna	CELASTRACEAE undiff. (AP)
Generalist bushveld savanna	COMBRETACEAE *Combretum* (AP)
Generalist bushveld savanna	EBENACEAE *Euclea* (AP)
Generalist bushveld savanna	STERCULIACEAE *Dombeya* (AP)
Generalist bushveld savanna	TILIACEAE *Grewia* (AP)
Dry bushveld savanna	CAPPARACEAE undiff.(AP)
Dry bushveld savanna	EUPHORBIACEAE *Spirostachys africana* (AP)
Dry bushveld savanna	EUPHORBIACEAE undiff. (AP)
Dry bushveld savanna	ASTERACEAE *Tarconanthus* (AP)
Moist bushveld savanna	FABACEAE *Burkea africana* (AP)
Moist bushveld savanna	FABACEAE undiff. (AP)
Moist bushveld savanna	OLEACEAE undiff. (AP)
Moist bushveld savanna	PROTEACEAE *undiff.* (AP)
Moist bushveld savanna	RUBIACEAE *Canthium* (AP)
Moist bushveld savanna	SAPOTACEAE *Englerophytum* (AP)
Grassland	ACANTHACEAE undiff. (NAP)
Grassland	AIZOACEAE undiff.(NAP)
Grassland	ASPARAGACEAE *Asparagus* (NAP)
Grassland	ASTERACEAE *Gerbera* (NAP)
Grassland	ASTERACEAE *Artemisia* (NAP)
Grassland	ASTERACEAE *Stoebe* (NAP)
Grassland	ASTERACEAE undiff. (NAP)
Grassland	CHENOPODIACEAE undiff. (NAP)
Grassland	COMMELINACEAE undiff. (NAP)
Grassland	EUPHORBIACEAE *Acalypha* (NAP)
Grassland	ZYGOPHYLLACEAE *Tribulus* (NAP)
Fynbos	ERICACEAE undiff. (NAP)
Fynbos	RESTIONACEAE undiff. (NAP)
Fynbos	ROSACEAE *Cliffortia* (NAP)
Fynbos	THYMELEACEAE *Passerina* (NAP)

Local pollen taxa

POACEAE <40 µm
CAMPANULACEAE *Wahlenbergia* (NAP)
CARYOPHYLLACEAE undiff. (NAP)
CRASSULACEAE *Crassula* (NAP)
CYPERACEAE *Ascolepis* (NAP)
CYPERACEAE undiff. (NAP)
TYPHACEAE *Typha* (NAP)
GENTIANACEAE undiff. (NAP)
HALOROGACEAE *Gunnera* (NAP)
HALOROGACEAE undiff. (NAP)
LAMIACEAE undiff. (NAP)
LILIACEAE *Aloe* type (NAP)
LILIACEAE *Tulbhagia* (NAP)
ANTHOCEROTACEAE *Anthoceros* (NAP)
POLYPODIACEAE undiff. (NAP)
MONOLETES undiff. (NAP)
OPHIOGLOSSACEAE undiff. (NAP)
TRILETES undiff. (NAP)

Neophyte

PINACEAE *Pinus*

Non-pollen palynomorphs

Undetermined
SORDARIACEAE *Gelasinospora*
SORDARIACEAE undiff.
CHAETOMIACEAE *Chaetomium*
FUNGAL SPORES other

Table 6.4 Depth boundaries of pollen zones

Pollen zone	Depth (cm)
Zone M-1	292 – 170
Zone M-2	170 – 66
Zone M-3	66 - 22
Zone M-4	22 - 0

6.4.1 Zone M-1 (292 - 170 cm; ca. 36,000 – 18,000 cal yr BP)

The pollen record commences with a dominance of Poaceae (95%) (Fig. 6.6) as well as Asteraceae (60%) (Fig. 6.4). The absolute regional diagram (Fig. 6.9) displays a similar trend. Arboreal pollen percentages are very low (15%) (Fig. 6.8) during the early part of this zone, thereafter decreasing further to 5% at *ca.* 35,000 cal yr BP. Arboreal percentages continue to fluctuate during this zone, culminating in a clear decline towards the end of zone M-1. This trend is confirmed in the absolute regional diagram (Fig. 6.9). *Podocarpus* percentages start off low (10 %) (Fig. 6.4), thereafter increasing to 20%, and fluctuating slightly towards the end of the zone. *Ilex mitis, Vernonia, Cornus*, and *Kiggelaria africana* are also recorded within this zone, albeit in low percentages (Fig. 6.4). Savanna bushveld elements such as *Rhus,* Celastraceae*, Combretum,* Capparaceae, *Tarconanthus* and Oleaceae occur frequently throughout this zone, however, percentages remain low (Fig. 6.4). *Stoebe* occurs in the highest percentages (20%) at the earliest part of this zone, this corresponds closely with the presence other fynbos elements including Ericaceae*, Cliffortia*, and *Passerina.* Asteraceae remains the dominant grassland taxon present within this zone, however, the occurrence of other grassland herb taxa, including Acanthaceae and Chenopodiaceae are also noted (Fig. 6.4). The local pollen signal does not record any systematic changes in Cyperaceae, with Cyperaceae percentages fluctuating slightly around 10% (Fig. 6.6). Aside from a sharp peak (25%) in trilete spores, Pteridophyte percentages remain relatively low for this zone (Fig 6.6). Compared with the rest of the sequence, fynbos pollen sum is recorded in the highest proportion in zone M-1

(Fig. 6.4), whilst the grassland, bushveld savannah and forest pollen sums remain relatively stable overall.

6.4.2 Zone M-2 (170 - 66 cm; ca. 18,000 – 1500 cal yr BP)

Arboreal percentages record an overall increase from 20% to 40% within this zone (Fig. 6.8). The absolute regional diagram confirms this (Fig. 6.9). This is mainly attributed to an increase in savanna bushveld taxa which increase to approximately 40% toward the end of this zone (Fig. 6.4). Prominent savanna bushveld taxa include *Combretum*, which records an increase to 10% at the end of the zone, as well as Anacardiaceae, Capparaceae and *Burkea africana*. *Tarconanthus* is present in low amounts during the early phase of this zone. Furthermore, Proteaaceae is recorded for the record at *ca.* 9000 cal yr BP (Fig. 6.4). *Podocarpus* percentages start off at 20% at the beginning of the zone M-1, thereafter decreasing towards the middle of this zone, reaching <5% at approximately 4000 cal yr BP (Fig. 6.4). Correspondingly, *Kiggelaria africana* becomes somewhat scarcer, before disappearing from the pollen records after *ca.* 3000 cal yr BP. *Ilex mitis* is recorded at *ca.* 18,000, 14,000 and later at 3000 cal yr BP. *Myrica* occurs in low amounts between *ca.* 17,000 and 15,000 cal yr BP and again after 3000 cal yr BP. Asteraceae percentages fluctuate, whilst remaining relatively high for the most part of this zone, before decreasing sharply to 30% towards the end of the zone (Fig. 6.4). Other grassland herb taxa present include Chenopodiaceae, *Acalypha* and Acanthaceae; however, Acanthaceae shows a clear decline between the previous zone and zone M-2. Ericaceae persists until *ca.* 12,000 cal yr BP, thereafter becoming scarcer within this zone. Similarly, *Cliffortia* and Ericaceae pollen becomes more sparsely recorded during this zone, whilst other fynbos taxa, *Stoebe* and *Passerina* are absent within this zone. Overall, the lowest proportion of fynbos pollen in the record is found in this zone (Fig. 6.4). The forest pollen sum remains relatively stable in zone M-2, declining slightly towards the top, whilst the bushveld pollen sum displays a marked increase. The grassland pollen sum remains relatively stable.

In the local record, Poaceae declines slightly between *ca.* 14,000 – 3000 cal yr BP (Fig 6.6). Cyperaceae percentages do not reflect any major changes; however, a slight decrease is recorded after *ca.* 3000 cal yr BP. This decrease is also reflected in percentages of *Ascolepis*. Monolete and trilete spores remain low within this zone, both decreasing to approximately 5% toward the end of this zone (Fig. 6.6). Coprophilous fungal spores, *Gelasinospora* and Sordariaceae are present after 9000 cal yr BP (Fig. 6.6). The presence of both *Gelasinospora* and Sordariaceae at *ca.* 3000 cal yr BP is also noted (Fig 6.6).

6.4.3 Zone M-3 (66 - 22 cm; ca. 1500 – 400 cal yr BP)

Arboreal pollen percentages show an increase between *ca.* 1500 – 700 cal yr BP (Fig. 6.8), thereafter decreasing slightly and then increasing sharply at approximately 450 cal yr BP. These fluctuations are also reflected in the absolute regional diagram (Fig. 6.9). This is largely due to the increase in *Podocarpus* observed within this zone. *Podocarpus* increases to 40% until *ca.* 960 cal yr BP, thereafter declining sharply to 10% at *ca.* 560 cal yr BP, before increasing again to 40% at *ca.* 400 cal yr BP (Fig. 6.4). *Rhus*, Anacardiaceae undiff., *Combretum* and *Dombeya* remain frequent, but low throughout this zone, *Tarconanthus* reappears within the record toward the end of this zone at *ca.* 760 cal yr BP, as does Capparaceae (Fig. 6.4). *Myrica* reaches its highest peak (10%) toward the end of this zone. *Gerbera* becomes prominent for the first time during this zone. However, a clear decline in other Asteraceous taxa to <10% is documented until *ca.* 760 cal yr BP. Thereafter, Asteraceae increases (50%) towards the end of zone M-2. (Fig. 6.4). Other grassland taxa recorded within this zone include Chenopodiaceae, recorded up to percentages of 10%, as well as *Acalypha* and Commelinaceae, both of which are recorded at lower percentages. The return of *Passerina* at *ca.* 1200 cal yr BP, together with Ericaceae and *Cliffortia* after 760 cal yr BP is documented within this zone (Fig. 6.4). Both forest and bushveld pollen sums increase markedly in zone M-3 (Fig. 6.4), whilst the fynbos pollen sum remains relatively stable throughout this zone.

In terms of the local pollen record, a documented decrease (50%) in Poaceae is observed until *ca.* 530 cal yr BP (Fig. 6.6). Thereafter, Poaceae increases slightly to 65% at 500 cal yr BP, before beginning to decline towards the end of this zone (Fig 6.6). Aquatic taxa such as Cyperaceae and *Typha* show a marked increase from the early part of this zone until *ca.* 800 cal yr BP, before declining towards the end of this zone (Fig 6.6). Both monoletes and trilete spores show an overall increase within this zone. Coprophilous fungal spores, *Gelasinospora, Chaetomium* and Sordariaceae undiff. are present within this zone, however, at very low percentages (Fig. 6.6).

6.4.4 Zone M-4 (22 - 0 cm; ca. 400 cal yr BP – present)

This zone represents the most recent section of the MUT-12-01 core. Overall, arboreal pollen percentages, with the exception of *Pinus*, decline between the zone M-3 and M-4 boundary (Fig. 6.8). This trend is confirmed in the absolute regional pollen diagram (Fig. 6.9). A clear decrease in *Podocarpus* is recorded for this zone (Fig. 6.4), whilst *Pinus* is present for this first time within the record at 231 cal yr BP, increasing significantly after 109 cal yr BP. *Cornus* is recorded in low amounts during this zone. This is supported by the presence of moist *Psoralea* and Oleaceae (Fig. 6.4 – 6.5). According to studies conducted by (Scott,1982a;1987a), these three taxa have been associated with moist conditions. Myrtaceae is recorded regularly within this zone, as is *Myrica. Rhus, Combretum*, Capparaceae and *Tarconathus*, although at low percentages (Fig. 6.4 – 6.5).

Asteraceous taxa occur frequently in zone M-4 at high percentages (approximately 50%) (Fig. 6.4; 6.5; 6.7) together with regular appearances of other disturbance indicators, such as coprophilous fungal spores (Fig. 6.6; 6.7). This is followed by an overall decrease to 40% during the most recent past (Fig. 6.4; 6.5; 6.7). Other grassland taxa recorded within this zone include Acanthaceae, *Asparagus*, and Commelinaceae, all of which occur in very low percentages. Chenopodiaceae is recorded at its highest percentage (18%) during the earliest phase of this zone, thereafter declining but remaining frequent within the zone. Overall, the regional pollen record documents a decline in forest, savanna bushveld and grassland taxa, whilst a corresponding increase in exotic *Pinus* is recorded (Fig. 6.4 – 6.5). Overall, forest and natural bushveld pollen decline in zone M-4, most likely being replaced by exotic *Pinus* (Fig. 6.4).

The local record documents a clear decline in Poaceae (40%) until the present. This is confirmed in the absolute local pollen diagram (Fig. 6.10). Furthermore, an increase in Cyperaceae (20%), coupled with an increase in *Typha* is also recorded (Fig. 6.6). Monolete spores show a slight decrease towards the present, whilst trilete spores record a marked increase to 20% towards the present.

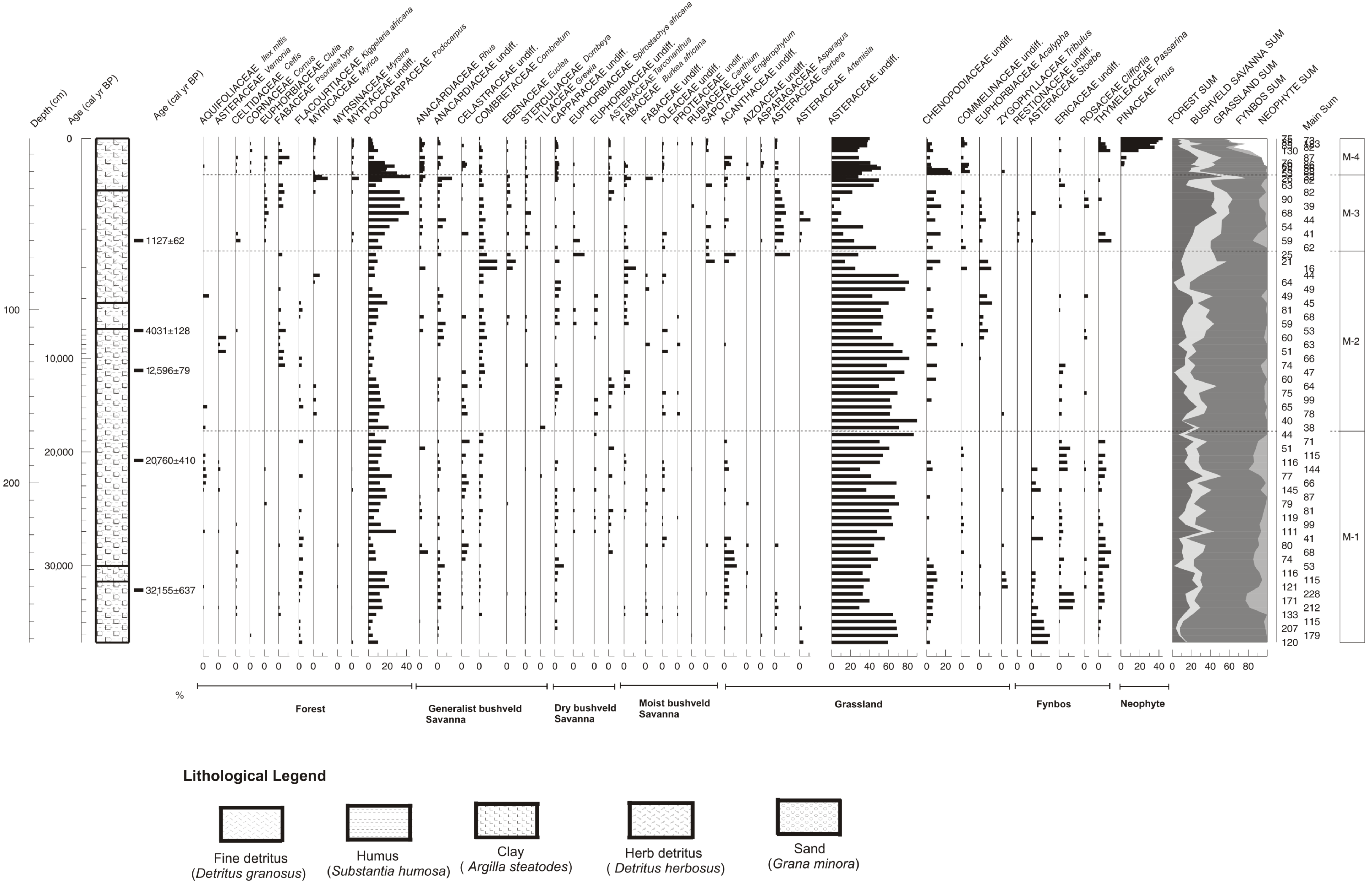

Figure 6.4 Primary regional pollen diagram showing forest, bushveld savanna, grassland and fynbos taxa, plotted against a dual age-depth axis with associated Troels-Smith stratigraphy

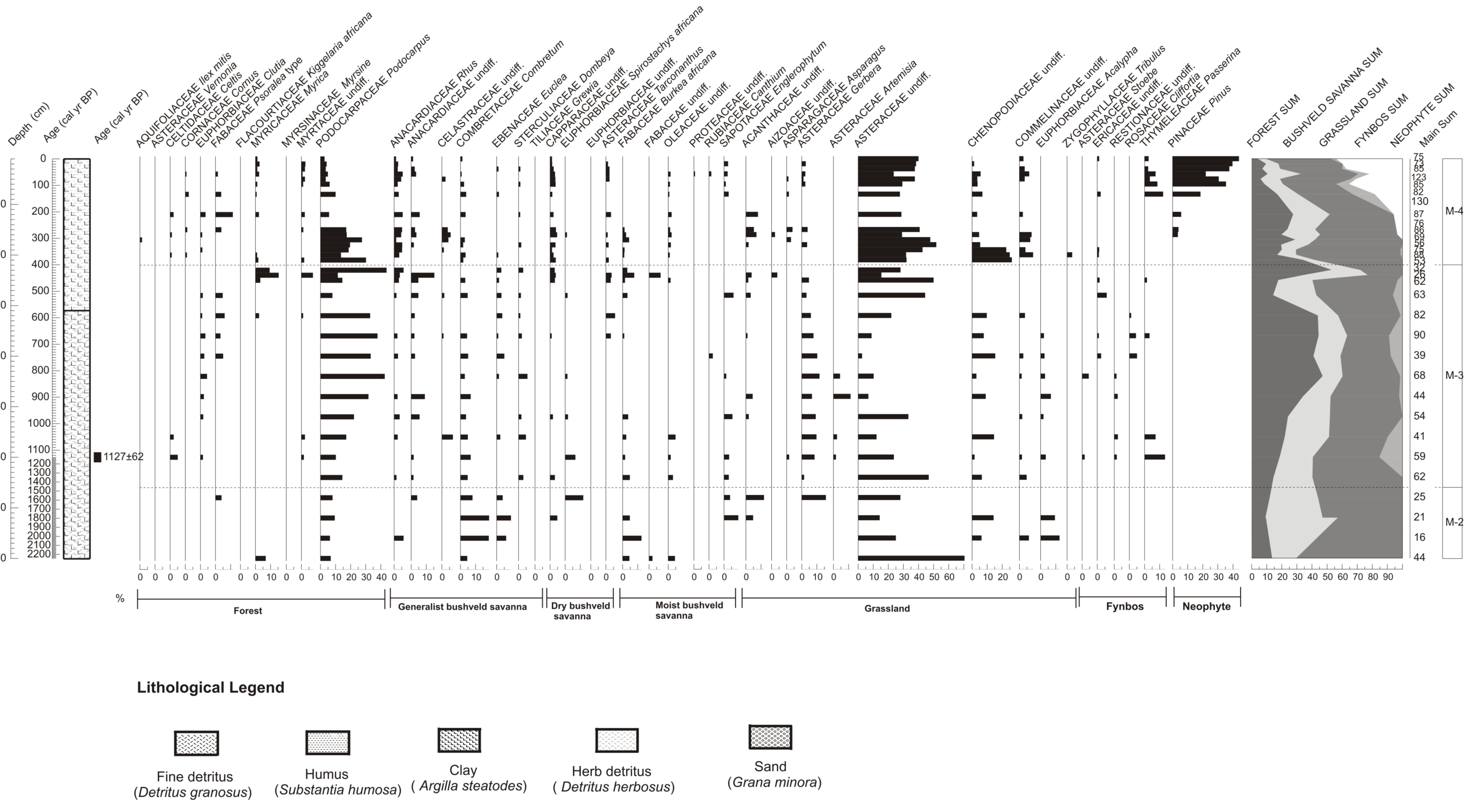

Figure 6.5 Focussed regional diagram for the last *ca.* 2000 years plotted against a dual age-depth axis with associated Troels-Smith stratigraphy

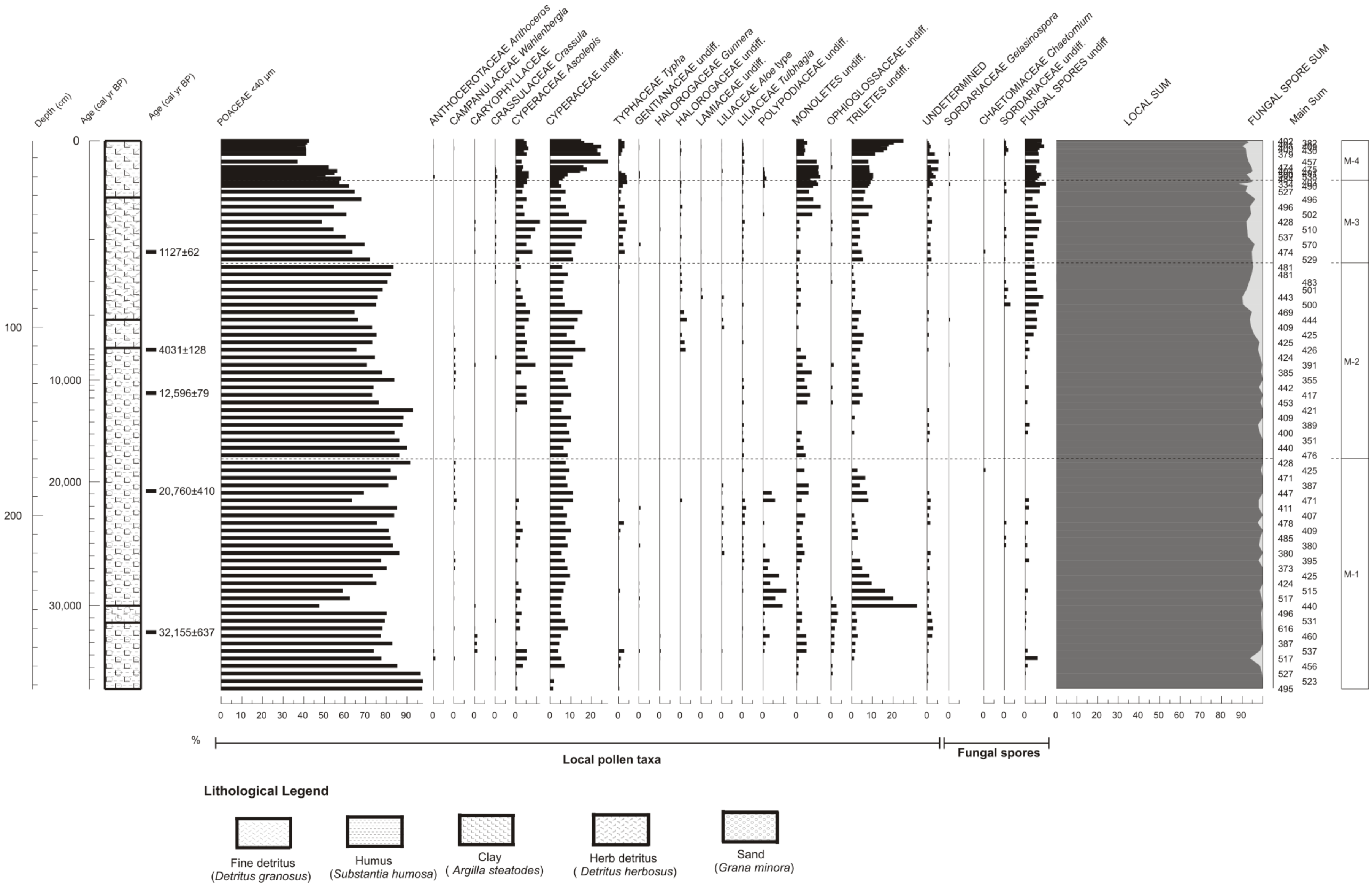

Figure 6.6 Local pollen diagram plotted against a dual age-depth axis with associated Troels-Smith stratigraphy

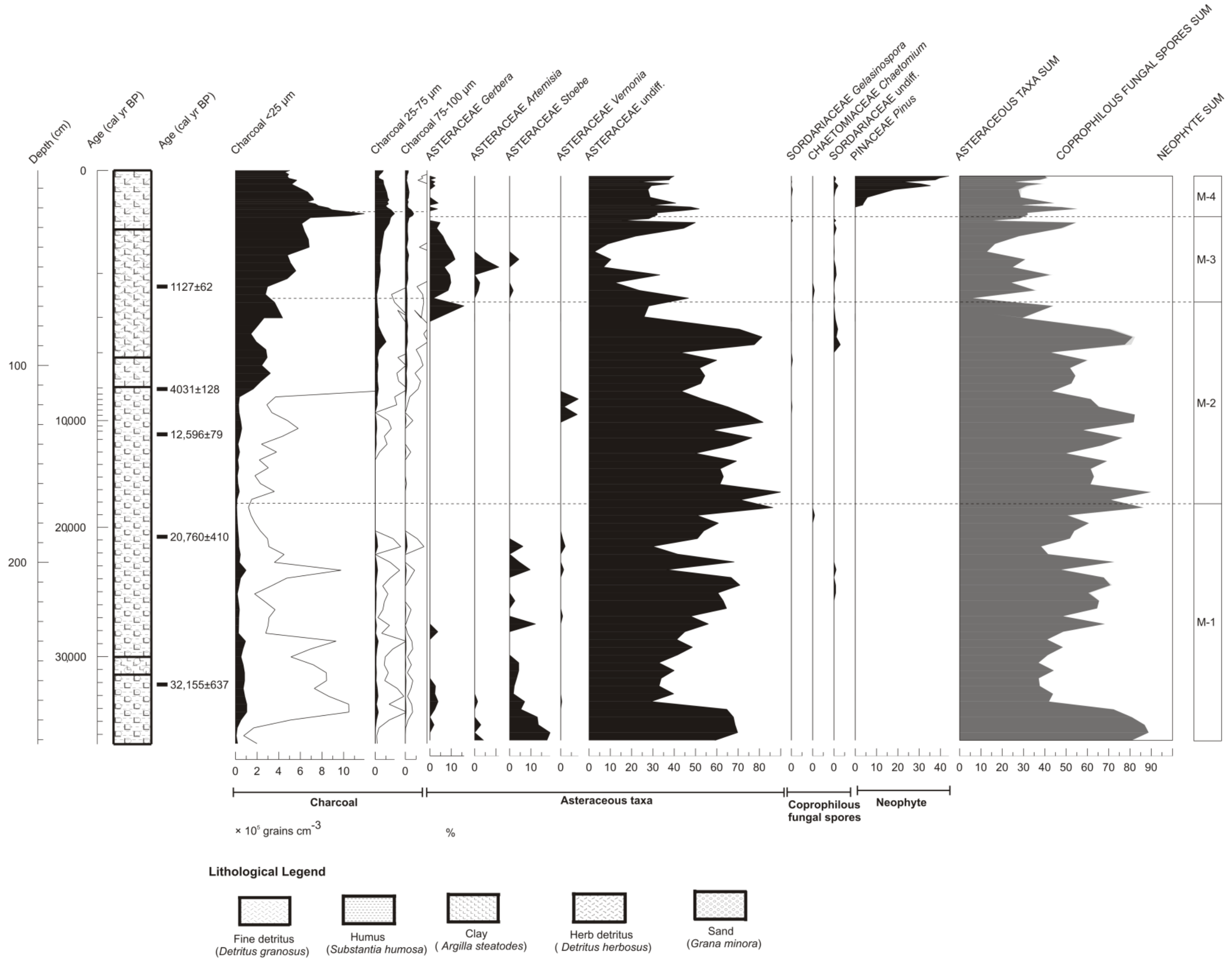

Figure 6.7 Diagram showing charcoal and selected disturbance indicators, plotted against a dual age-depth axis with associated Troels-Smith stratigraphy

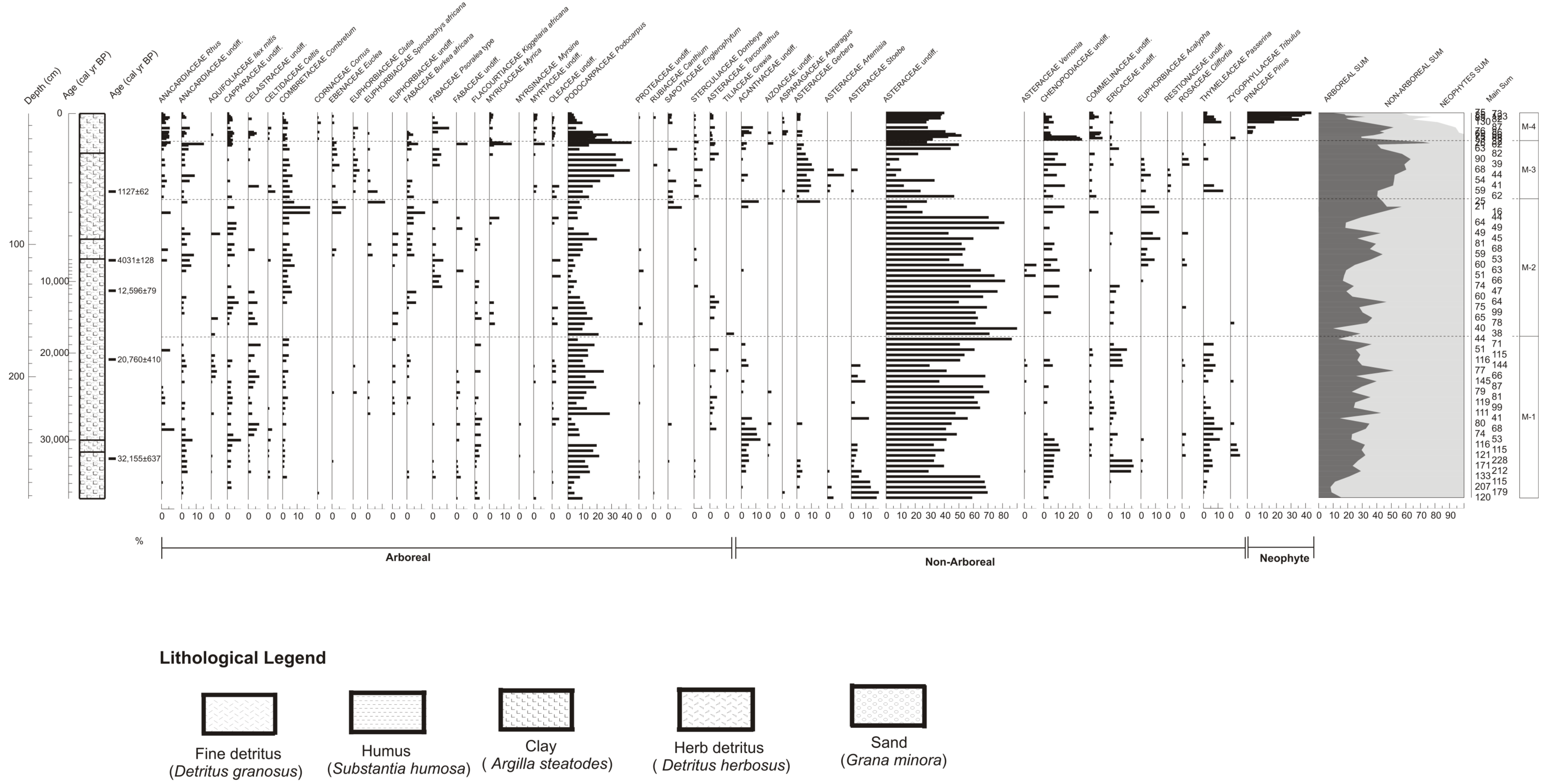

Figure 6.8 Regional (arboreal vs. non-arboreal) pollen diagram plotted against a dual age-depth axis with associated Troels-Smith stratigraphy

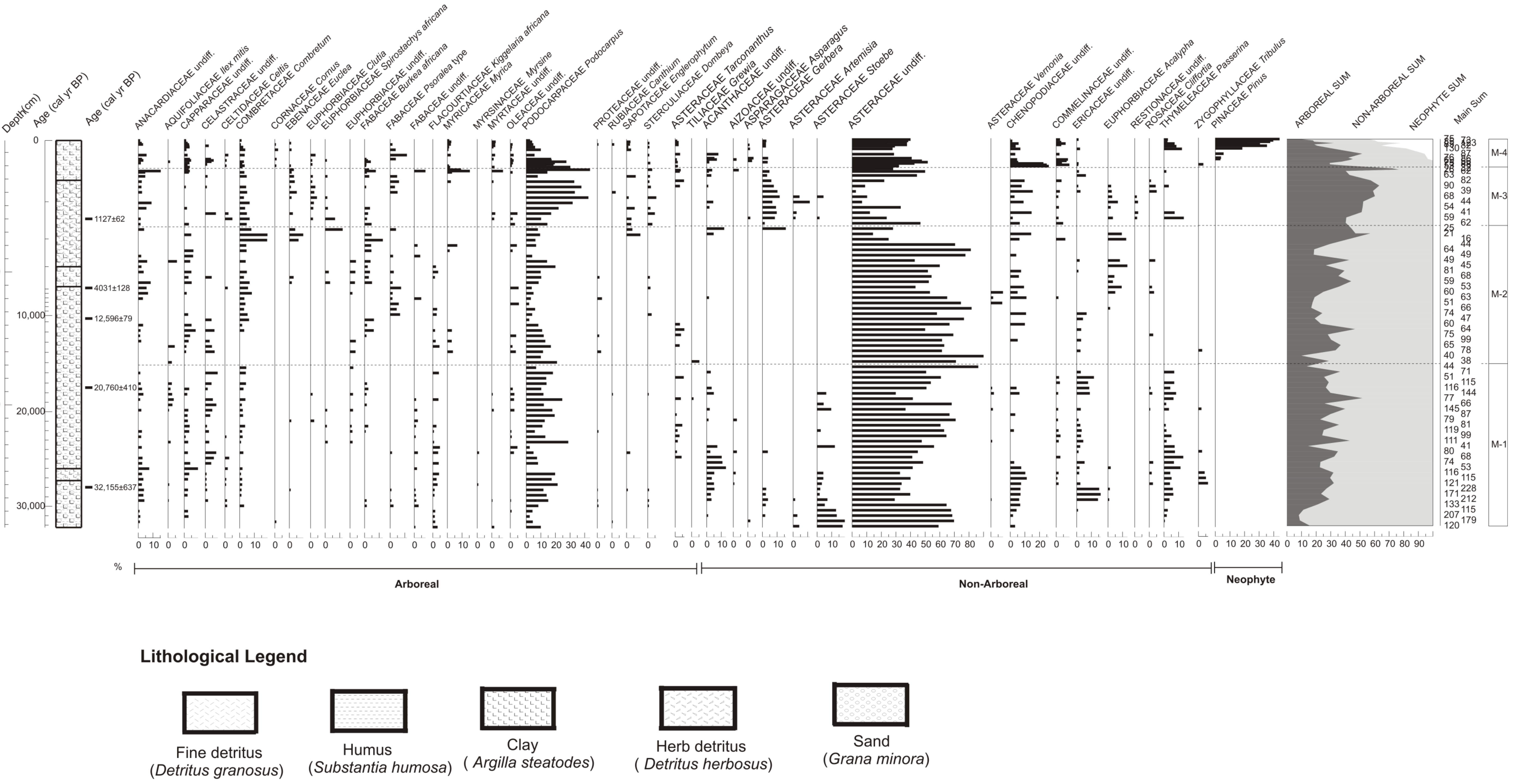

Figure 6.9 Regional (absolute) pollen diagram, showing arboreal vs. non-arboreal taxa, plotted against a dual age-depth axis with associated Troels-Smith stratigraphy

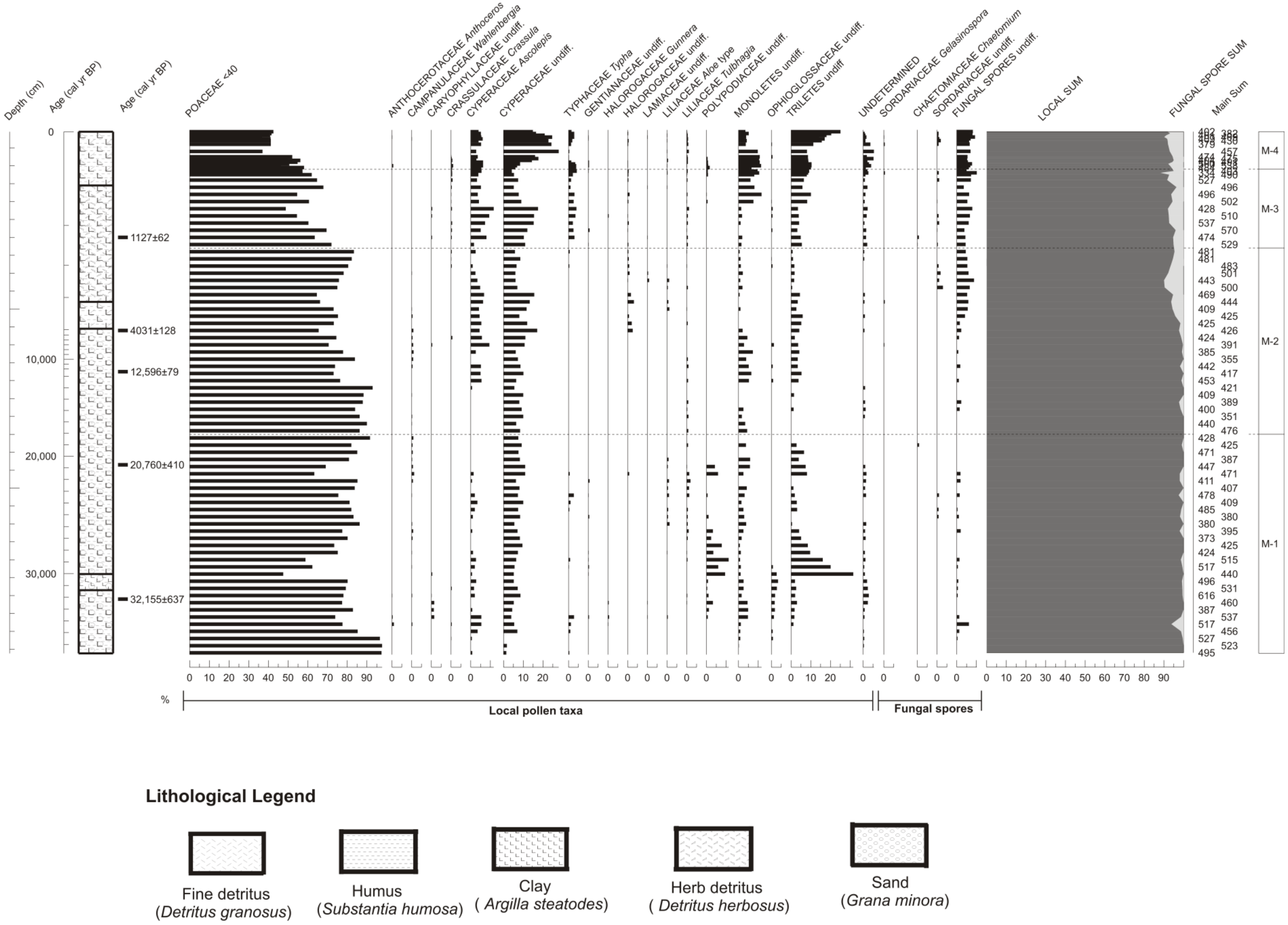

Figure 6.10 Local (absolute) pollen diagram plotted against a dual age-depth axis with associated Troels-Smith stratigraphy

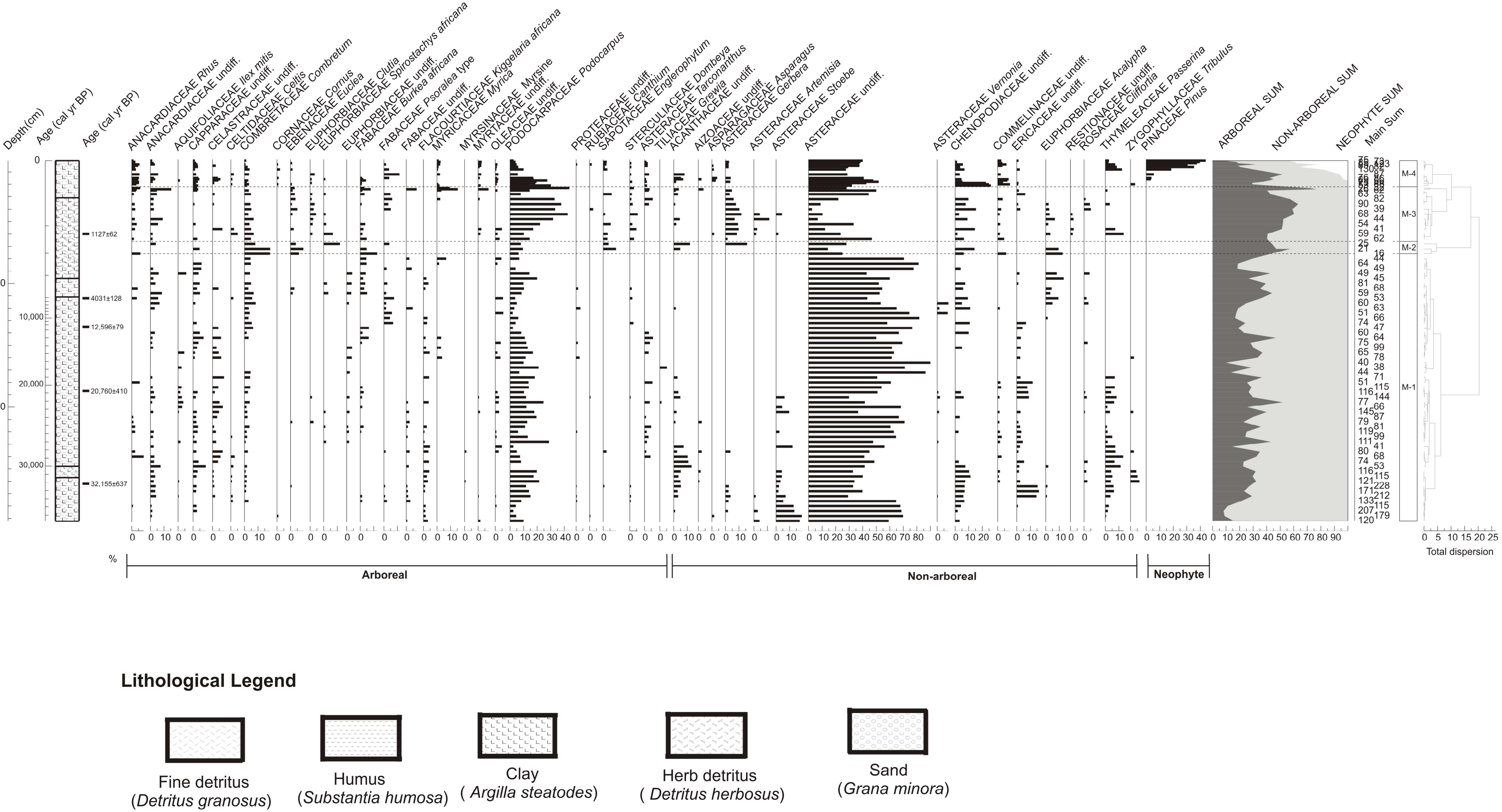

Figure 6.11 Regional pollen diagram (arboreal vs. non-arboreal) plotted against a dual age-depth axis with associated Troels-Smith stratigraphy, showing the order of splits and zones derived through CONISS

6.5 Charcoal analysis

The data show a general decreasing trend in charcoal concentrations as depth increases (Fig. 6.12). All size classes show similar increases and decreases down the core, and charcoal peaks in the <25 µm size class are closely matched by those within the 25 – 75 µm and 75 – 100 µm size classes.

6.5.1 Zone M-1 (292 - 170 cm; ca. 36,000 – 18,000 cal yr BP)

Charcoal fragments in zone M-1 occur predominantly in the <25 µm size class. In this zone total charcoal concentrations appear to be very low across all size classes, particularly in the 75 – 100 µm size class (Fig. 6.12). The highest charcoal concentration (1 x 10^5 grains/cm) in this zone occur between *ca.* 35, 000 – 29,000 cal yr BP and later at *ca.* 23,000 cal yr BP in the <25 µm size class. The exaggerated values show corresponding peaks in the both the 25 - 75 µm and 75 - 100 µm size classes.

6.5.2 Zone M-2 (170 - 66 cm; ca. 18,000 – 1500 cal yr BP)

In comparison with the previous zone, charcoal concentration is much higher in the <25 µm size class, whilst overall charcoal concentrations in the 25 – 75 µm and 75 – 100 µm size classes remain fairly low. There is a distinct increase in concentration to 3 x 10^5 grains/cm in charcoal in the <25 µm size class after 4000 cal yr BP (Fig. 6.12). This is followed by a decrease in charcoal concentration after 3000 cal yr BP, followed by an increase to 4 x 10^5 grains/cm at *ca.* 2000 cal yr BP. A single peak in charcoal concentration in the 25 – 75 µm is observed at *ca.* 2600 cal yr BP (Fig. 6.12).

6.5.3 Zone M-3 (66 - 22 cm; ca. 1500 – 400 cal yr BP)

Concentrations remain consistently high for the <25 µm size class, however, there is a marked increase in charcoal concentrations for all size classes at the boundary of zones M-3 and M-4. For the <25 µm size class, this zone begins with a minimum of 3 x 10^5 grains/cm, increasing with minor fluctuations, and then culminating in the highest peak within the record, where the charcoal concentration reaches a maximum of >10 x 10^5 grains/cm at *ca.* 400 cal yr BP (Fig 6.12).

6.5.4 Zone M-4 (22 - 0 cm; ca. 400 cal yr BP – present)

Overall, charcoal concentrations remain relatively high for all size classes; however, a steady decrease in concentration is recorded for the 25 µm size class after *ca.* 400 cal yr BP until the present. Similarly, a slight decrease in concentration is recorded in the 25 – 75 µm size class, however, this is followed by a slight increases from 150 cal yr BP onwards. In the 75 – 100 µm size class, the earliest part of the zone documents a sharp decrease in the concentration of charcoal toward present (Fig 6.12).

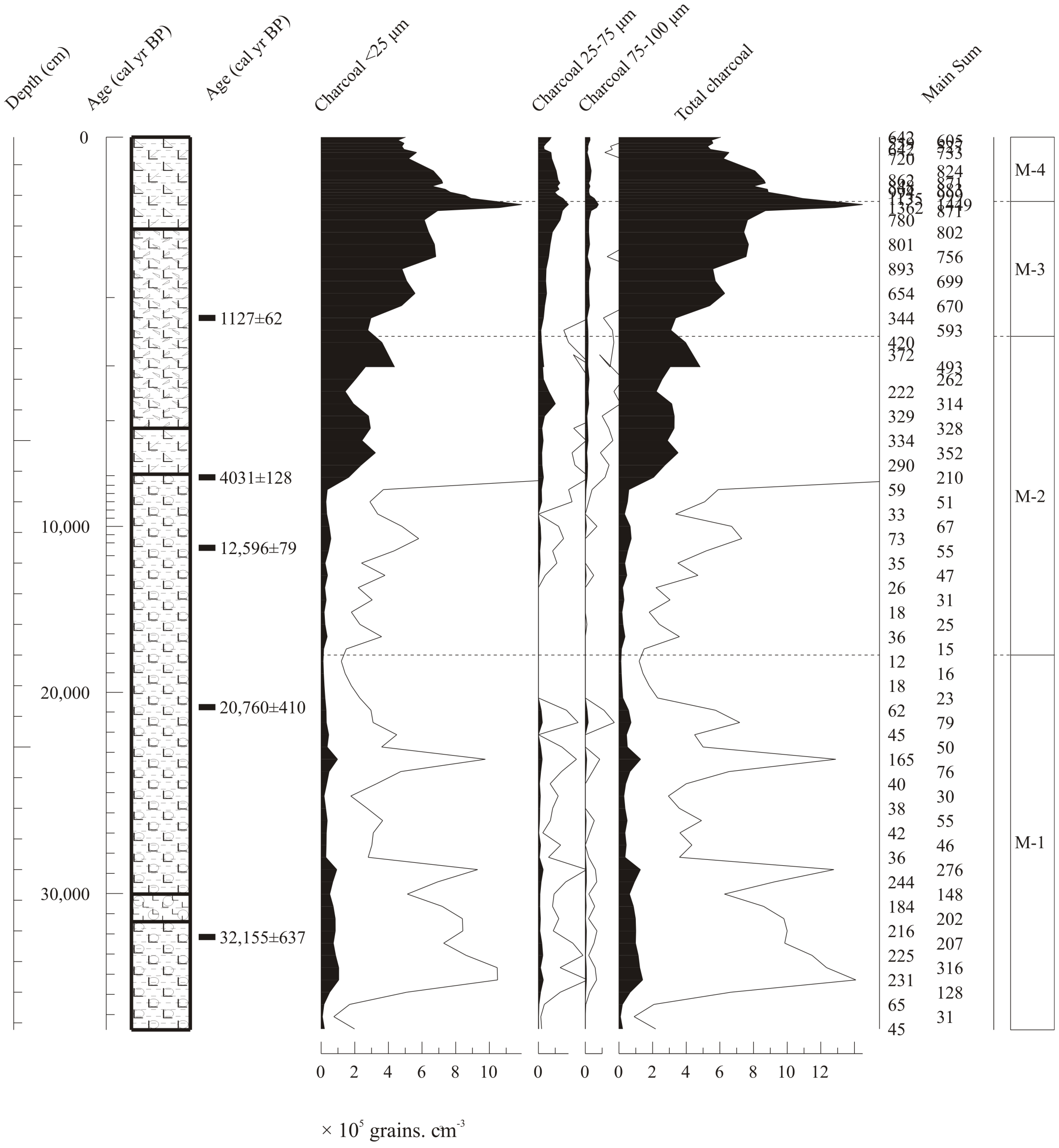

Figure 6.12 Charcoal diagram for Mutale Wetland plotted on a dual age-depth axis with associated Troels-Smith stratigraphy, showing a 10x exaggeration

CHAPTER 7: DISCUSSION

In the first section of this chapter, specific results relating to pollen preservation and chronology for the Mutale record will be discussed. This will be compared with previous results obtained by Scott (1987a). A palaeoenvironmental reconstruction for the Mutale record will be presented in the second section of this chapter. Results from both pollen and charcoal analyses will be drawn upon to facilitate this reconstruction. Data will be discussed according to important time periods relevant to this record and will be discussed and described with the aid of a list of morphological, ecological and distributional information of major pollen taxa (Appendix M). Palaeoclimatic inferences will be made using generalised indicator taxa (Scott, 1999). The palaeoreconstruction will be compared with previous results from Mutale Wetland (Scott, 1987a), and will also be discussed in light of previous palaeoenvironmental work conducted in southern Africa. However, it must be stressed that the ability to make comparisons with other records is limited by data availability in terms of long-term records.

7.1 Mutale record

7.1.1 Pollen preservation

For the majority of the Mutale record, pollen preservation is good, however, the earliest part of the record (302 – 296 cm) is characterised by coarse, sandy sediment and extremely poor pollen preservation. For this reason, pollen data was only obtained up to 292 cm. Poor pollen preservation could possibly be the result of a lowered wetland water table, causing exposure of sediment to air and thus facilitating oxidation. Alternatively, poor pollen preservation may be due to weathering, increased run-off or a disturbance event, causing sediment to mix and resulting in the removal of polleniferous material. Although it is difficult to determine the exact cause of low pollen preservation, it seems likely that this may be the result of a combination of factors. The very low Cyperaceae percentages towards the bottom of the core suggest that the local swamp vegetation was not well developed, thus the wetland was probably more exposed. Furthermore, the lack of swamp vegetation most likely resulted in increased run-off, possibly causing mixing of sediment. Similarly, in a previous palynological study of the Mutale Wetland, Scott (1987a) suggests that the change from very sandy sediment in the lower 60 cm of the core, to a virtually sand free upper 150 cm, indicates that run-off was stabilized as the swamp deposit developed and obstructed drainage.

7.1.2 Chronology

The chronology of the MUT-12-01 core is based on five calibrated accelerator mass spectrometry (AMS) radiocarbon dates. Based on the age model, it is evident that no age reversals have occurred. Scott (1987a) recorded an age reversal toward the lower portion of the previous sequence, possibly due to contamination. Compared with dates obtained by Scott (1987a), the new age model for the Mutale Wetland indicates that sediments are much older. It is likely that the new core has penetrated a deeper section than that of the Scott (1987a) core, causing a discrepancy between the chronologies. This is supported by the observation that the upper levels of both cores correspond well aside from the apparent younger contamination at some levels in the older core. This discrepancy may be due to different dating methods used in each study (AMS vs. conventional radiometric dating).

At the Mutale Wetland, the sedimentation rate increases towards the top of the core, however, in comparison with other summer rainfall records (e.g. Neumann *et al.*, 2006; 2008), the sedimentation rates recorded at Mutale Wetland are relatively (Table 7.1). In comparison with the study conducted by Scott (1987a) overall sedimentation rates were lower than in this study, although an overall trend of increased sedimentation rates towards the top of the core was evidenced in both studies. A possible break in sedimentation was recorded near the top of the previous core between ca. 6000 – 1500 cal yr BP (Scott, 1987a). In this study, a possible hiatus was detected between *ca.* 13,000 – 4000 cal yr BP. This is evidenced by the low sedimentation rates during this period. Alternatively, results may indicate that low sedimentation rates during this period may have been due to environmental conditions. Comparing the sedimentation rates from both studies, it seems that the Early Holocene is better resolved for Scott (1987a) study than it is for this study.

Table 7.1 Average sediment accumulation rates for previous Mutale Wetland core (Scott, 1987a).

Depth range (thickness) (cm)	Age range (cal yr BP)	Average accumulation rate (cm/yr)
0 - 22	Present - 1343	0,0164
22 - 50	1343 - 7326	0,0047
50 - 80	7326 - 8652	0,023
80 – 150	8652 - 9634	0,071
150 - 200	9634 - 8737	0,056

The lack of any *Pinus* pollen in the uppermost sample directly beneath the surface, suggests that the most recent period, following the introduction of *Pinus* plantations in the area, is absent from the previous Mutale record (Scott, 1987a). This is in contrast to the new MUT-12-01 record which documents the presence of *Pinus* pollen in the most recent portion of the record. Although there is a discrepancy between the historical date of *Pinus* introduction and the date at which *Pinus* first appears in the pollen record, this is most likely attributed to the error margin of the radiocarbon dating of the record. Moreover, a 178-year offset within a long timescale of roughly 40,000 years is very close indeed, hence, *Pinus* may be used successfully as a time-stratigraphic marker for the Mutale record. Although careful consideration was taken to correctly distinguish between *Podocarpus* and *Pinus* pollen, it is possible that pollen grains may have been incorrectly identified due to similarities in morphology. However, it seems more plausible that this discrepancy is the result of the error margin in radiocarbon dating, particularly at the top of the core where sedimentation rates reach their highest.

7.2 Palaeoenvironmental reconstruction for Mutale Wetland

7.2.1. Open, dry grassland pre-LGM phase (292 – 274cm; ca. 38,000 - 34,000 cal yr BP)

Prior to *ca.* 34,000 cal yr BP, high relative frequencies of Poaceae and Asteraceae, coupled with low Cyperaceae and arboreal pollen percentages, suggest the presence of open, dry grassland surrounding the Mutale Wetland. The composition of vegetation is indicative of fairly warm and dry conditions. Microscopic charcoal (<25 μm), although recorded at low concentrations for the early part of the sequence, records peaks between *ca.* 35,000 – 29,000 cal yr BP, indicating that fires were a regular phenomenon within the regional landscape (Whitlock and Larsen, 2001; Duffin *et al*., 2008), most likely due to an abundance of fuel loads. The presence of drier vegetation during this period may be associated with increased charcoal concentrations. The prominence of Stoebe pollen during this time supports inferred drier vegetation (Scott, 1999). Fuel loads comprising lower moisture are more prone to combustion than those with a higher moisture content (Adie *et al.*, 2011). This explanation is supported by a decrease in charcoal, coupled with an increase in moister vegetation types, for example fynbos (Scott 1987b; 1999) until *ca* 18,000 cal yr BP. Alternatively, the low charcoal concentrations may be explained by the increased aridity. According to Daniau *et al.* (2013), high charcoal values are indicative of rather wet conditions in southern African grasslands possibly due to a decline in biomass. The presence of very low charcoal values together with inferred aridity supports inferences made by Daniau *et al.* (2013). Despite this, Scott (2002) has suggested that evidence of long-term fluctuations in microscopic charcoal during the Middle and Upper Pleistocene in South Africa are seemingly independent of past climates and moisture conditions.

According to Coetzee (1967), the appearance of *Podocarpus* pollen >20% in pollen diagrams suggests a close proximity of this taxon to the site. Applying this finding to the appearance of low *Podocarpus* pollen prior to *ca.* 34,000 cal yr BP, it is likely that *Podocarpus* forests occurred in distant or restricted patches in the region during this time. Low percentages of *Kiggelaria africana*, a forest taxon, support this inference. The presence of distant forest patches was also documented at Wonderkrater (Scott, 1982a). Scott (1982a) inferred that montane forest patches coexisted with dry bushveld between *ca.* 38,824 – 28,170 cal yr BP. This is in keeping with results obtained by Finch and Hill (2008), who document restricted forest patches at Mfabeni after *ca.* 44,000 cal yr BP together with a dominance of Poaceae and Asteraceae, suggesting the presence of open vegetation.

7.2.2 Cool subhumid pre-LGM phase (274 – 201 cm; ca. 34,000 – 30,000 cal yr BP)

Following *ca* 34,000 cal yr BP, *Podocarpus* increases until *ca.* 30,000 cal yr BP, together with a minor increase in *Kiggelaria africana* and *Celtis*, suggesting a slight forest expansion (Scott, 1999), which implies a shift to moister conditions. This increase in forests is supported by a slight increase in Pteridophytes, which are often characteristic of forest margins (Scott, 1999). *Ilex mitis*, which occupies moist habitats (Orwa *et al.*, 2009; Pooley, 2005; Appendix M), appears for the first time in the record between *ca.* 34,000 – 30,000 cal yr BP, supporting a shift to moist conditions. These results are in contrast to the Mfabeni pollen record which shows a decline in *Podocarpus* after *ca.* 33,000 cal yr BP together with an increase in herbaceous taxa such as Asteraceae, implying a shift to drier conditions (Finch and Hill, 2008). This shift to cooler and subhumid conditions is supported by an increase in fynbos elements including *Stoebe*, Ericaceae, Restionaceae, *Cliffortia* and *Passerina* (Scott, 1987b; 1999; Appendix M). A weak chronology in both records for this time period makes it difficult for a direct comparison to be made. According to Cowling *et al.* (1997), fynbos type vegetation occurring in the interior of southern Africa suggests cool and moist conditions, and is typically found at high altitudes. This is supported by Scott (1987b) who states that *Stoebe* and *Passerina* occur in subhumid southern and eastern parts of South Africa and is typical of both higher latitudes and altitudes. Furthermore, Ericaceae vegetation is restricted by aridity and is not present in relatively dry areas (Scott, 1987b). Quick *et al.* (2011) have suggested that fynbos taxa are associated with winter rainfall, winter humidity and winter evaporation. Mutale Wetland is found at an altitude of 1193 m a.s.l, whilst Lajuma, the highest peak in the Soutpansberg mountain range, occurs at an altitude of 1748 m a.s.l. The consistent appearance of fynbos elements until *ca.* 18,000 cal yr BP, suggests that high altitudinal vegetation belts may have extended to lower altitudes during the late glacial period, implying much colder climatic conditions. Moreover, the fynbos pollen is present in the highest amounts between *ca.* 37,000 – 18,000 cal yr BP, supporting the inference that this may have been the coldest period within the Mutale sequence.

A slight decrease in Poaceae between *ca.* 36,000 – 30,000 cal yr BP indicates that local conditions also became slightly cooler, although overall Poaceae percentages remain high. Cooler conditions are supported by high fynbos percentages found at the same time. A more regular appearance of Cyperaceae after *ca*. 35,000 cal yr BP suggests an increase in local moisture.

The occurrence of Chenopodiaceae, an indicator of increased temperatures and dryness (Scott, 1999), between *ca.* 34,000 – 30,000 cal yr BP does not support the inference of moister and cooler conditions. However, according to Scott (1982a), an increase in Chenopodiaceae may be favoured by an increase in disturbance. Since this was a period of change in climatic conditions, it is possible that the increase in Chenopodiaceae during this time may be attributed to disturbance, although the possibility of increased aridification cannot be ruled out. The increase in Chenopodiaceae coincides with peaks in charcoal concentration and Asteraceae, supporting inferred disturbance.

7.2.3 Warmer pre-LGM phase (253 – 201 cm; ca. 30,000 – 23,000 cal yr BP)

From *ca.* 30,000 – 23,000 cal yr BP, low percentages (<20%) of *Podocarpus*, together with low amounts of other forest taxa including *Kiggelaria africana* and *Celtis,* suggest the existence of restricted forest patches in the region. The regular occurrence of savanna bushveld trees such as *Rhus*, Anacardiaceae, Celastraceae and Combretaceae, as well as a slight increase in Poaceae during this period indicates a more open, savanna type environment with relatively warmer conditions. This coincides with a slight peak in charcoal concentrations across all size classes, which implies that fires increased both regionally and locally in response to increased fuel loads (Bond and Keeley, 2005; Duffin, 2008). Larger fragments tend to indicate local fire events whilst smaller fragments suggest regional fires (Whitlock and Larson, 2001). Increased fires may be linked to the growth of a grassy understory in areas that were once forested, thus producing enough fuel load to support fire (Breman *et al.*, 2011). Breman *et al.* (2011) suggest that positive feedback mechanisms between open vegetation and fire would most likely prevent reestablishment of forests by suppressing recruitment of tree seedlings. Aside from the inferred warmer climate, this may have aided the decline of climatically stressed forests during this time. The presence of *Tarconanthus* and Capparaceae implies that conditions became drier (Scott, 1999). The appearance of Aizoaceae, representative of succulents (Scott, 1999), is in support of warm and dry conditions (Scott, 1999). Moreover, these conditions are corroborated by a decline in fynbos elements between *ca.* 30,000 – 23,000 cal yr BP. Likewise, warmer temperatures have been recorded at Lobatse II Cave in Botswana between *ca.* 31,268 – 24,906 cal yr BP (Holmgren *et al.*, 1995), although evidence suggests that the climate was warm and humid as opposed to the warm and dry signal detected at Mutale Wetland.

Overall, the reconstructed vegetation suggests that the broader pre-last glacial maximum (LGM) period was cooler and wetter, with a brief period of climatic amelioration between *ca.* 30,000 – 23,000 cal yr BP. This concurs with evidence from Wonderkrater (Scott, 1982a) which suggests a cool temperate, moist subhumid climate for the pre-LGM, becoming drier toward the LGM. Similar pre-LGM conditions have been documented for Mfabeni (Finch and Hill, 2008) and the Pretoria Saltpan (Partridge *et al.*, 1999).

7.2.4 Cool, moist LGM phase (201 – 169 cm; ca. 23,000 – 18,000 cal yr BP)

From *ca.* 23,000 – 18,000 cal yr BP, the decrease in dry savanna bushveld taxa, *Tarconanthus* and Capparaceae, suggest a possible increase in moisture. The occurrence of moist bushveld taxa, Oleaceae and *Burkea africana* supports this. The presence of *Ilex mitis* during the LGM signifies wetter conditions. An expansion of fynbos elements, particularly Ericaceae, during the LGM also suggests moister conditions as well as a shift to cooler temperatures (Scott, 1987b; 1999; Appendix M). Despite the assertion by Duffin (2008) that increased precipitation in African savannas leads to a rise in fires through an increased fuel load, charcoal concentrations remain low for the duration of the LGM. The increased moisture possibly led to an abundance of a more mesic grass and herbaceous layer, hampering combustion (Adie *et al.*, 2011). This inference is supported by Jolly and Haxeltine (1997) who concluded that low atmospheric CO_2 coupled with low CO_2/O_2 ratios and reduced moisture availability during the LGM affected the competitive balance between C_3 and C_4 plants, enabling C_4 plant taxa such as grasses and succulents to have a selective advantage. Wetter LGM conditions at Mutale are in accordance with the theory of orbital forcing, which predicts dry LGM conditions for the northern tropics, whilst the southern tropics are predicted to have experienced increased monsoonal rainfall (Gasse, 2000). Interestingly, these results do not correspond with LGM conditions inferred from other long Quaternary records from Limpopo and southern Africa, and aside from the winter rainfall region in South Africa, most sites within the subcontinent attest to a drier LGM, and thus cannot be explained by the Milankovitch theory of changes in the Earth's orbital parameters (Gasse, 2000). At Wonderkrater (Scott, 1982a; Truc *et al.*, 2013) and Makapansgat (Holmgren *et al.*, 2003), cool and dry overall conditions have been inferred for the LGM. Although cool and dry conditions were recorded overall, Holmgren *et al.* (2003) documented numerous fluctuations during the LGM. Similar results have been documented for the Pretoria Saltpan (Kristen *et al.*, 2007), Elim in the Free State (Scott, 1989) and Mfabeni (Finch and Hill, 2008). The only evidence supporting a cool and wet LGM in southern Africa comes from the far afield Brandberg site in Namibia (Scott *et al.*, 2004). However, it is appreciated that this site falls under a very different rainfall and climate regime and the similar LGM conditions may be due to very different factors. Moreover, inferred LGM conditions coincide well with those obtained at Verlorenvlei, (Baxter, 1996; Meadows, 2001), Cederberg (Meadows and Sugden, 1990; Meadows and Baxter, 1999) and Elands Bay Cave (Scott, 1994), suggesting that LGM conditions for Mutale Wetland share support from winter rainfall sites in southern Africa. However, certain summer rainfall sites located in the Kalahari and along the southern African east coast document increased moisture during the LGM. On the east coast of southern Africa, a marine record implies increased precipitation around *ca.* 17,000 cal yr BP (Schefuß *et al.*, 2011), supporting LGM conditions experienced at Mutale. Thus, results from Mutale Wetland echo the caution of Nash and Meadows (2012) and Scott *et al.* (2012) who have advised that it is no longer appropriate to apply a standard model of colder and drier conditions to southern Africa's summer rainfall region as a whole.

7.2.5 Last glacial-interglacial transition (169 – 130 cm; ca. 18,000 – 10,000 cal yr BP)

The persistent occurrence of Ericaceae, together with the sporadic appearance of *Cliffortia* until at least *ca.* 12,000 cal yr BP suggest that cool subhumid conditions

(Scott, 1999) characterised the last glacial interglacial transition (LGIT) at Mutale. This is supported by the regular appearance of *Podocarpus* between *ca*. 18,000 – 12,000 cal yr BP, as well as the presence of *Ilex mitis* during this time. At Equus Cave and Wonderwerk Cave, a peak in moisture recorded at *ca.* 17,000 cal yr BP (Scott *et al*., 2012) corresponds with inferred subhumid conditions at Mutale. These conditions are substantiated by those obtained at the Pretoria Saltpan (Partridge *et al*., 1993; Scott, 1999) where evidence implies that conditions remained cooler up until *ca.* 11,000 cal yr BP. This is corroborated by the Wonderkrater pollen record and the Makapansgat δ^{18}O record, which both indicate that increased wet conditions occurred after 17,500 cal yr BP (Holmgren *et al*., 2003). A cool and moist LGIT is documented for Angola, where Dupont *et al*. (2008) inferred increased wetness and a cooler climate from high levels of *Podocarpus* pollen recorded between *ca.* 18,000 and 15,000 cal yr BP. Elsewhere in southern Africa, in particular Tsodilo Hills (Thomas *et al*., 2003) and Drotsky's Cave (Thomas and Shaw, 2002) in Botswana, conditions during this time were also cooler and moister. Sites in the winter rainfall zones also depict a moist LGIT (Quick *et al*., 2011; Chase *et al*., 2011; Valsecchi *et al*., 2013), however, it is noted that this region is subjected to unique climatic conditions which differ vastly from the rest of southern Africa, and thus the cause of such conditions are not trivially equated. Conversely, in the Cathedral Peak region of the Drakensberg, Lodder (2011) inferred cool and dry conditions between 15,500 – 14,000 cal yr BP. This may however represent an early onset of a shift to drier conditions toward the end of the LGIT. Charcoal concentrations continue to remain low during the LGIT despite very high Poaceae percentages. Again, this may suggest that the fuel composition during this time consisted of moister vegetation types (Adie *et al.,* 2011). Moreover, the presence of *Podocarpus* pollen suggests that forest patches, with a poor understory, may have acted as a barrier that prohibited fires from spreading to grassland patches (Breman *et al*., 2011). The slight increase in Capparaceae and *Tarconanthus* suggests conditions started becoming drier and warmer. This is supported by an increase in Chenopodiaceae towards 12,000 cal yr BP. This coincides with records from Wonderkrater and Eksteenfontein that reveal a dry episode between *ca.* 13,000 and 11,500 cal yr BP (Scott *et al*., 2012). A rise in savanna taxa is documented at Wonderkrater between ca. 13,600 – 12,500 (Truc *et al*., 2013). According to Truc *et al*. (2013), temperatures during the LGIT rose 4 °C relative to the LGM.

Following *ca.* 12,000 cal yr BP, an overall decrease in *Podocarpus*, together with a clear decline in fynbos elements marks a shift to warmer and drier conditions (Scott, 1999). A return to warmer conditions is substantiated by evidence from Makapansgat (Holmgren *et al.*, 2003) and Eksteenfontein (Scott *et al.*, 2012). The regular appearance of *Combretum*, Anacardiaceae, Capparaceae and *Tarconanthus* indicates a warm, arid savanna dominated environment (Scott, 1999). The increase in Chenopodiaceae concurs with this. A marked increase in fynbos elements recorded at Wonderkrater (Truc *et al.*, 2013) between 12,300 – 10,500 cal yr BP indicates a possible discrepancy in temperature between the Wonderkrater and Mutale pollen records, although this cannot be stated with a high degree of certainty as there is a possible hiatus in the Mutale record during this time. Truc *et al.* (2013) estimates that temperatures within this period were similar to those recorded during the LGM. At Wonderkrater, Eksteenfontein and Equus Cave, Scott *et al.* (2012) have associated dry conditions between *ca.* 13,000 – 11,000 cal yr BP with the Younger Dryas. However, Truc *et al.* (2013) have warned that the degree to which this cool and dry period may be reliably associated with the Younger Dryas is restricted by the accuracy of the Wonderkrater chronology (Scott, 1982a). For the Mutale record, it is interesting to note that the increase in Capparaceae, *Tarconanthus* and Chenopodiaceae corresponds well with the Wonderkrater record (Scott, 1982a) after *ca.* 13,000 cal yr BP, however like the Wonderkrater chronology, the Mutale dating resolution is far too low in this section of the core to allow for speculation about the Younger Dryas.

7.2.6 Holocene (130 – 111 cm; ca. 11,000 – 4000 cal yr BP)

The increasing frequencies of *Combretum* and Capparaceae, coupled with low *Podocarpus* percentages between *ca.* 11,000 – 4000 cal yr BP indicate that relatively warm and dry conditions may have occurred between the early Holocene until the middle of the late Holocene. The low fynbos percentages, together with the presence of Chenopodiaceae and the high percentages of Poaceae and Asteraceae, show possible support for increased aridity and temperature. Evidence from charcoal studies carried out at Wonderkrater, Rietvlei and Moreletta stream accords with results found at Mutale (Tusenius, 1989), however, this is not certain as this there is a possibility of a hiatus during this period in the core. At these sites, warm and dry conditions were documented from *ca.* 12,000 – 8000 cal yr BP (Tusenius, 1989). Possible evidence for a warm and dry early Holocene documented at Mutale are further corroborated by the Wonderkrater pollen record (Scott, 1982) where overall warming was documented between *ca.* 10,000 – 6700 cal yr BP. Maximum warming at Wonderkrater occurred between *ca.* 8300 – 6500 cal yr BP (Truc *et al*., 2013). During this time, the pollen record displayed similar trends to the Mutale record, where an increase in savanna elements such as Capparaceae, together with a decline in fynbos taxa was recorded (Truc *et al*., 2013). At Makapansgat, a significant depletion in $\delta^{13}C$ values, a decline in C_3 grass cover and low organic content found between *ca.* 10,200 – 8400 suggests a sparsely vegetated, dry environment (Holmgren *et al*., 2003). An arid early Holocene is also supported by evidence from Equus Cave (Beaumont *et al*., 1984; Johnston *et al*., 1997; Scott, 1987b) as well as pollen and macrofauna data from Wonderwerk Cave (Van Zinderen Bakker, 1982; Tusenius, 1989). Generally, records from the early Holocene between *ca.* 11,000 – 7000 cal yr BP suggest fairly dry conditions for the southern African subcontinent (Scott and Lee-Thorp, 2004). Results obtained for the Mutale record generally concur with this, although these inferences must be treated with caution due to the possible break in sedimentation during this period. The inferred increases in temperature and aridity may be associated with the Holocene Altithermal, which occurred between *ca.* 8000 – 4000 cal yr BP (Chase and Meadows, 2007), although the reliability of this is questionable. This is in keeping with records from Deelpan (Scott, 1988), which suggest a shift to dry and warm conditions approaching the late Holocene.

Certain records however, such as the Spitzkoppe (Chase *et al*., 2009) and the Seweweekspoort (Chase *et al*., 2013) middens records from central Namibia, indicate a wetter early Holocene. The observed increase in *Psoralea* documented in the Mutale pollen record, possibly representative of the moist fountain bush (Scott, 1987a) between *ca.* 10,000 – 4000 cal yr BP reflects an increase in moisture towards the late Holocene. This is in keeping with the Makapansgat record that documents a shift to wetter regional conditions after *ca.* 8500 cal yr BP inferred from an increase in grassy environments (Holmgren *et al*., 2003). Records from Braamhoek wetland (Norström *et al*., 2009) in the eastern Free State and Lake Eteza (Neumann *et al*., 2010) on the north coast of KwaZulu-Natal show a wet phase at *ca.*10, 000 cal yr BP (Scott *et al*., 2012). Thereafter, conditions between *ca.* 6000 – 4000 cal yr BP are rather dry at Braamhoek and Rietvlei (Norström *et al.* 2008) whilst evidence from Lake Eteza points to humid conditions (Neumann *et al.*, 2010). At Cederberg, Valsecchi *et al.* (2013) have documented a shift to warm and humid conditions at the onset of the early Holocene, as opposed to the warm and dry conditions recorded at Mutale. However, Scott (1987a), who recorded increased *Psoralea* percentages between *ca.* 9000 – 6500 cal yr BP at Mutale Wetland, suggests that the prominence of *Psoralea* is more likely of local significance. In the local pollen record, this is supported by a slight increase in Cyperaceae, reflecting an increase in local wetness toward the late Holocene.

7.2.7 Early human disturbance phase (111 – 66 cm; ca. 4000 – 1500 cal yr BP)

The decline of *Podocarpus* forests between *ca.* 3000 – 1400 cal yr BP may be due to climatic stress brought on by warmer and drier conditions. Warm and dry conditions during this time are supported in evidence from Florisbad (Scott and Nyakale, 2002), Makapansgat and Cango Caves (Holmgren *et al.*, 1999). However, evidence from Tswaing Crater and Wonderkrater, located much closer to Mutale, show rather subhumid conditions (Scott *et al.*, 2012). This forest retreat at Mutale Wetland coincides with a retreat in *Podocarpus* further north in Maputaland after 1300 cal yr BP (Mazus, 2000), supporting inferred dryness. At lake Eteza, a retreat in *Podocarpus* together with an increase in Poaceae is also noted by Neumann *et al.* (2010) and has been attributed to increased aridity. In the previous Mutale study (Scott, 1987a), a decline in of arboreal pollen was observed between ca. 4000 – 1500, although this is not detailed enough to confirm with much certainty as a hiatus is present during this period. The high percentages of Poaceae and Asteraceae signify a shift to more open, dry vegetation in response to forest retreat. This in turn may have resulted in the occurrence of a positive feedback mechanism with fire, resulting in increased charcoal concentrations, denoting an increase in fire frequency and intensity during this time (Breman *et al.*, 2011). At Cederberg, Quick *et al.* (2011) recorded a similar increase in charcoal in response to increased aridity after *ca.* 2000 cal yr BP. Alternatively, the decrease in *Podocarpus* may be attributed to the appearance of the first agriculturalists who exploited the Soutpansberg foothills for agriculture and livestock farming from *ca.* 3000 (Voigt and Plug, 1984). The sharp increase in charcoal towards *ca.* 1500 cal yr BP supports this. This is in keeping with evidence of the first Iron Age settlements which date back to 1550 cal yr BP south of the Limpopo River, and several hundred years earlier in northern Limpopo (Carrión *et al*., 2000). The rates of settlements seem to be determined by fluctuations in climate. In the study by Carrión *et al*. (2000), iron age settlements increased during warmer and moister periods, whilst decreasing during colder and drier periods. Moreover, the appearance of Sordariaceae and *Gelasinospora*, coprophilous fungal spores (van Geel *et al*., 2003), supports the presence of livestock and human settlements close by. This is supported by peaks in coprophilous fungal spores in the Limpopo valley between *ca.* 1150 – 1050 cal yr BP (Ekblom and Gillson, 2010b). According to Huffman (2000), cattle herding in the Limpopo valley region become significant toward the end of the first millennium, thus the early peaks in coprophilous fungal spores may be linked to livestock farming and herding. Ekblom and Gillson (2010b) have cautioned that this inference may only be tentatively accepted until archaeological surveys, providing direct evidence in support of this, are conducted. It is difficult to determine whether the decline of *Podocarpus* forests are due solely to climatic or anthropogenic activity, although, a plausible scenario may be that anthropogenic pressure may have placed additional strain on climatically stressed forests. Also, the effects of increased fire on vegetation, brought on by an increase in biomass, were possibly exacerbated by human induced fire at this time. According to Duffin (2008), there is a negative correlation between fire intensity and arboreal cover. Thus, the rise in intensities and frequencies of fires may have also contributed to a decline in forest cover (Duffin, 2008).

7.2.8 Recent disturbance phase (66 – 0 cm; ca. 1500 cal yr BP – present)

Between *ca.* 1500 – 350 cal yr BP, there is a distinct overall increase in *Podocarpus*, indicating a return to cooler and moister conditions. This is supported by a decline in Asteraceae until *ca*. 760 cal yr BP, together with a slight decrease in Poaceae and relatively high levels of arboreal pollen. Furthermore, it is possible that the increase in *Podocarpus* forests may be due to a positive feedback mechanism brought on by a decline in grassy cover due to competition of resources such as sunlight, promoting the growth of tree saplings (Breman *et al*., 2011). It is also possible that despite continued human disturbance, as evidenced by the frequent presence of coprophilous fungal spores and high charcoal concentrations during this time, the return of more favourable climatic conditions allowed *Podocarpus* forests to recover. The return of fynbos elements, Restionaceae, *Stoebe*, Ericaceae, *Cliffortia* and *Passerina* at *ca*. 760 cal yr BP supports this return to cooler and subhumid conditions (Scott 1999; Appendix M). This is further corroborated by the decrease in Capparaceae and *Tarconanthus* after *ca.* 1500 cal yr BP. This is validated by evidence from Makapansgat (Holmgren *et al*., 2003), that records warm and wet conditions from *ca.* 1200 and 600 cal yr BP.

Myrica becomes prominent in the record towards *ca.* 400 cal yr BP. This corresponds well with a contemporaneous peak in charcoal concentrations across all size classes, suggesting that fires increased both locally and regionally. According to Hemp (2006), *Myrica* is fire adaptive and is also quick to invade disturbed areas. Since fire is a form of disturbance, the peak in charcoal corresponding with the peak in *Myrica* concurs with this explanation. Currently, the only Myricaceae parent taxon recorded at Mutale Wetland is *Myrica pilulifera* (Appendix L). This taxon generally occurs in mountainous areas with high rainfall or alongside streams (Pooley, 1997). This is in keeping with the environment surrounding Mutale Wetland. *Myrica* is fire resistant (Pooley, 1997). The presence of *Myrica* at Mutale wetland during the last *ca.* 1500 cal yr BP is supported by the previous palynological study of Mutale Wetland (Scott, 1987a).

Certain weedy Asteraceae taxa, such as vernonia and stoebe are indicators of disturbance in some parts of South Africa (Neumann *et al*., 2010). According to Baxter and Davies (1994), some Asteraceous taxa increase following agricultural clearing and anthropogenic disturbances. The increase in Asteraceae *Gerbera* between *ca.* 1500 – 400 cal yr BP, coupled with high levels of charcoal may be representative of a rise in anthropogenic disturbance. The increased presence of Sordariaceae, a coprophilous fungal spore often associated with domestic cattle (Ekblom and Gillson, 2010b), supports this. Similarly, at Wonderkrater, the highest charcoal peaks occurred after *ca.* 1000 cal yr BP. This corresponds to periods during which Middle and Later Stone Age civilizations prevailed in the region (Scott, 2002).

Cyperaceae increases until *ca.* 760 cal yr BP, implying a shift to wetter conditions locally. The regular presence of *Typha* after *ca.* 1500 cal yr BP supports this. This is followed by a slight decrease in moisture towards *ca.* 350 cal yr BP, evidenced by a decline in Cyperaceae. An increase in local moisture is corroborated by an increase in Pteridophytes.

The period following *ca.* 400 cal yr BP represents major changes in vegetation. An overall decline in arboreal pollen is recorded, which is most likely a consequence of the recent vegetation history of the region and probably linked to the arrival of European settlers (Hahn, 2007). Like previous results obtained by Scott (1987a), this reduction primarily involves the decrease of *Podocarpus*. *Podocarpus* records an abrupt decline from *ca.* 400 cal yr BP to the present, providing a possible indication of deforestation. This coincides with the arrival of the Venda Tribe, who appeared in the Soutpansberg between 363 – 263 cal yr BP (Geldenhuys and Murray, 1993), and have been responsible for clearing large tracts of forests to make way for agriculture and grazing (Geldenhuys and Murray, 1993). According to Loubser (1989), the venda tribe developed in the mid-sixteenth century, however their ancestors arrived centuries earlier. This is supported by Huffman (2007) and Carión *et al.* (2000). Results are also in keeping with Ekblom *et al.* (2011), who have documented the onset of maize cultivation in the Limpopo Valley after *ca.* 450 cal yr BP, together with an increase in domestic livestock inferred from a rise in coprophilous fungal spores. This differs from results obtained at Lake Sibaya which documents the onset of maize cultivation earlier, between 650 – 500 cal yr BP. In the Kruger National Park, high charcoal frequencies coupled with an increase in cereal pollen suggest an intensification of agricultural activity. This is in accord with results obtained by Scott (1987a), who recorded a decline in arboreal pollen, in particular *Podocarpus* pollen, after *ca.* 1500 cal yr BP in Tate Vondo. According to Scott (1987a), this reduction in arboreal pollen is most likely not due to a shift in climate, but rather due to possible burning and forest clearing by Iron Age people. This inference is supported by evidence in the charcoal record, which depicts high levels of charcoal across all size classes, and indicates a rise in the frequency and intensity of both local and regional fires. Charcoal data obtained for the Kruger National Park (Ekblom and Gillson, 2010), indicate that fire frequencies during the twentieth century are higher than that of any other period. These results are consistent with those obtained by Duffin (2008).

Moreover, exotic *Pinus* has been documented to decrease water yield in surrounding areas, possibly causing a decline in *Podocarpus* (Bosch, 1979; Lesch and Scott, 1997). *Pinus* appears in the record for the first time at *ca.* 272 cal yr BP, increasing systematically from *ca.* 109 cal yr BP toward the present. There is a discrepancy between the historical date of introduction of *Pinus* to the area and the recorded date of appearance in the pollen record, however, given the error margin in radiocarbon dating and the long timescale, first appearance of *Pinus* within the record is in broad agreement with historical records that document the introduction of *Pinus* to the region at *ca.* 94 cal yr BP (Hahn, 2007).

The presence of *Cornus*, recorded in low amounts after *ca.* 400 cal yr BP indicates that moist taxa may be restricted to favourable niches within the region. This is supported by the presence of Oleaceae and *Psoralea*. The presence of *Combretum*, Capparaceae and *Tarconanthus* suggests the presence of arid, savanna type vegetation, implying warmer and drier conditions (Scott, 1999). With the exception of *Passerina,* the overall decline in fynbos is in keeping with inferred drier conditions and warmer conditions. Moreover, the almost absence of fynbos during the last 400 years implies a shift of the altitudinal vegetation belt in the area higher up, corroborating inferences of a warmer climate. Warm and dry conditions are supported by numerous proxy analyses that support increased aridification during the late Holocene in southern Africa (Scott and Lee-Thorp, 2004). However, certain sites in the Karoo, Fynbos and coastal areas show a shift to moisture conditions toward the late Holocene (Scott *et al.*, 2012). Furthermore, moisture fluctuations corresponding with variations in temperature have been recorded at Wonderkrater during the late Holocene (Scott *et al.*, 2003). It is however apparent that moisture declines sharply after *ca.* 1000 cal yr BP at Wonderkrater. This is in keeping with results obtained at Mutale. The presence of Myrtaceae regularly within the most recent past may represent the increase in exotic *Eucalyptus* plantations within the region; however, it is also likely to represent *Syzygium* which was seen growing in the region (personal observation).

The decline in Poaceae from *ca.* 400 cal yr BP toward the present, together with low percentages of grassland taxa recorded for until present suggests a decline in natural grasslands within the region. An increase in Chenopodiaceae, favoured by human disturbances in natural grasslands, indicates a possible anthropogenic cause for the documented decline in grasslands in the pollen record. The frequent presence of *Myrica* during the past 400 years, most likely related to an increase in disturbance brought on by anthropogenic burning, supports this. The high frequencies of Asteraceae recorded during this time correspond with peaks in charcoal, implying a possible proliferation of weedy Asteraceae due to human disturbances. Moreover, human disturbance may result in an increase in woody encroachment by shrubby *Rhus* species (Neumann *et al.*, 2008). The frequent occurrence of *Rhus* recorded within this between *ca.* 400 and the present could possibly be due anthropogenic disturbance. This supports the observation that natural grasslands in the Soutpansberg have declined due to increased human activity (Hahn, 2007), however this may also be due to a statistical effect given that *Pinus*, generally overrepresented in pollen diagrams, increases sharply.

Local swamp conditions became wetter as evidenced by an increase in Cyperaceae and *Typha* from *ca.* 1000 cal yr BP towards present. A vast increase in trilete fern spores is observed after *ca.* 400 cal yr BP until present. This may be representative of *Pteridium aquilinum* or brackenfern as it is more commonly known which was observed to have been invading the site. *Pteridium aquilinum* is known to rapidly invade disturbed areas (Killick, 1963). The increase in trilete fern spores corresponds with high charcoal concentrations recorded during the recent part of the record. This could be explained by the strong ability of the rhizomes to withstand grass fires (Killick 1963). According to Gliessman (1978), optimum conditions for the establishment of bracken are comparable to those experienced subsequent to a fire event. The high charcoal content recorded after *ca.* 400 cal yr BP implies frequent burning, which makes the region susceptible to invasion by *Pteridium aquilinum.* Moreover, bracken contains lower fuel moisture than grasses and indigenous vegetation, thus promoting combustion and causing more intense fires (Adie *et al.*, 2011). Aside from fire, higher rainfall and increased moisture conditions have been documented to positively influence the growth rate of *Pteridium aquilinum* (Portela *et al.*, 2009); hence, the higher occurrence of trilete fern spores is supported by increased *Typha* and Cyperaceae which indicate relatively wet local conditions. However, it can not be ruled out that the spores may belong to Riccia, Pteris or other cryptograms. The decline in charcoal concentrations across all size classes in the most recent past could signify improved management of the Tate Vondo region. A similar inference was made by Neumann *et al.* (2008), who interpreted the recent decline in fire frequencies and a consequent drop in charcoal concentration as the result of better management of the Lake Sibaya by the iSiMangalisoWetland Park.

Table 7.2 Summary of vegetation history and inferred palaeoenvironmental changes at Mutale Wetland.

Time period (cal years BP)	Vegetation history	Inferred environmental conditions
ca. 400 – Present	Arid savanna, deforestation, exotic plantations	Warm and dry
ca. 1500 – 400	Expanded forests and fynbos	Cool and moist
ca. 4000 -1500	Arid savanna, increased fire coinciding with the appearance of the first agriculturalists	Warm and dry
ca. 10,000 – 4000	Local expansion of *Cyperaceae* and *Psoralea*	Locally wetter
ca. 12,000 – 10,000	Expansion of arid savanna, reduced forests	Warm and dry
ca. 18,000 – 12,000	Persistent fynbos and regular appearance of *Podocarpus*	Cool and subhumid
ca. 23,000 – 18,000	Expansion of fynbos, mesic savanna and forests	Cool and wet
ca. 30,000 – 23,000	Arid savanna with restricted forests	Slightly warm semiarid
ca. 34,000 – 30,000	Open grassland with fynbos elements, expanded forests	Cool subhumid
>34,000	Grassland/savanna dominated	Slightly warm and dry

7.3 Human impacts

The last *ca.* 2000 years, in particular since the arrival of European settlers, has recorded substantial increases in impacts on natural environments across southern Africa (Deacon and Lancaster, 1988). In the Soutpansberg, early agriculturalists began exploiting the fertile soils of the Soutpansberg foothills from as early as *ca.* 3000 cal yr BP (Voigt and Plug, 1984). In the charcoal record, a sharp increase in charcoal after *ca.* 4000 cal yr BP indicates an increase in the frequency and intensity of fire regimes in the area that broadly coincides with the appearance of the first agriculturalists (Voigt and Plug, 1984). Corresponding with this, high peaks in Asteraceae, a disturbance indicator, have also been recorded after *ca.* 4000 cal yr BP. The appearance of coprophilous fungal spores supports the presence of livestock and proximal human settlements. No other direct anthropogenic indicators e.g. *Zea mays* have been documented at Mutale during this time despite historical records of agricultural activity. Following this, it is believed that Iron Age people occupied the northeastern Soutpansberg from as early as *ca.* 1700 cal yr BP (Scott, 1987). Relatively high peaks in charcoal during the late Holocene suggest that fire was frequently used by the Iron Age people in the area. The sharp decline in arboreal pollen after *ca.* 252 cal yr BP, together with a decline in *Podocarpus* coincides with the presence of the Venda tribe who practiced agriculture and livestock farming in the Soutpansberg (Geldenhuys and Murray, 1993). Subsequently, *Podocarpus* continues to decline together with an increase in exotic *Pinus*, coinciding with the arrival of European settlers in the Soutpansberg during the 1800's (Tempelhoff, 1999). Charcoal concentrations reach a maximum during the most recent past, implying that unlike Iron Age settlers, modern farmers caused an intensification of fire regimes and wide scale damage to the natural vegetation. Moreover, a decline in grassland taxa documented within the record supports the observation made by Hahn (2007) who suggested that natural grasslands have been destroyed due to anthropogenic activities.

7.4 Past range shifts of *Brachystegia* woodland in the northeastern Soutpansberg

In a previous study of the sediments from Mutale Wetland (Scott, 1987a), trace amounts of *Brachystegia* pollen were detected in sediments between *ca.* 7000 to 1000 cal yr BP. The presence of this pollen type is most likely representative of the Gundani *Brachystegia* woodland patch located in the northeastern Soutpansberg. In this study however, no *Brachystegia* pollen was present in the pollen sequence and thus past range shifts of *Brachystegia* could not be detected. This may have been due to the resolution being too low. According to Campbell (1996), dispersability amongst most dominant miombo genera, including *Brachystegia,* is low as they are mostly insect pollinated. This could possibly account for the lack of *Brachystegia* pollen within the Mutale record. Moreover, upon visiting the Gundani *Brachystegia* population in March 2002, Burrows *et al*. (2004) did not observe any evidence of pods or flowers. Similarly, no evidence of flowering was recorded upon visiting the site in December 2012 (personal observation). According to Sutherland (2000), it is not uncommon for small, isolated populations to experience a reduction in reproductive ability mainly due to loss of genetic variation due to increased homozygosity. However, some of the younger trees show intermediate leaf characters between *Brachystegia spiciformis* and *Brachystegia utilis*, implying that some reproduction is taking place. However, poor dispersability is preventing *Brachystegia* pollen grains from being deposited in sediments.

7.5 Conclusion

The late Quaternary at Mutale was characterised by successional changes from grassland to savanna to *Podocarpus* forests, mainly due to changes in moisture availability. Prior to the LGM, conditions at Mutale fluctuated between warm and semiarid to cool and subhumid. Charcoal concentrations during this time remained very low and showed minor fluctuations, suggesting that fire was not a regular phenomenon during this time. Whilst the indication of a cool and wet LGM, evidenced by an expansion of fynbos, mesic savanna and forests between *ca.* 23,000 and 18,000 cal yr BP, is not supported by other palynological sites within Limpopo Province, these conditions share support in a few other summer rainfall sites as well as the majority of winter rainfall sites in southern Africa. However, it is acknowledged that these sites are subjected to very different climate systems and are geographically far apart. Following the LGM, the persistence of fynbos and the regular appearance of *Podocarpus* suggests cool and subhumid conditions occurred up until 12,000 cal yr BP. Between 12,000 to 10,000 cal yr BP, the expansion of arid savanna and the apparent reduction in forests, indicate that conditions were warm and dry. However, this cannot be accepted with a high degree of certainty as a possible hiatus was present during this time. Warm and dry conditions persisted until 1500 cal yr BP. Thereafter, an expansion of forests and fynbos between 1500 – 400 cal yr BP suggest cool and moist conditions. Following this, warm and dry conditions persist until the present. Whereas a similar sequence of Holocene vegetational changes have been recorded from a previous Mutale record (Scott, 1987a), inconsistencies in the timing of these changes are most likely a result of chronological discrepancies. Trends established within the Mutale Wetland charcoal record indicate an intensification of fire in the recent past, which coincides with anthropogenic activity. The constantly low charcoal concentrations prior to *ca.* 4000 cal yr BP suggest that fires occurred occasionally in the region since the late Pleistocene, albeit at lower intensities than the late Holocene.

Results found in this study differ slightly other sites in southern Africa. Scott *et al.* (2012) states that most regions, with the exception of east-coast woodlands show that overall moisture levels appear to have increased during the last 2000 years. This is in contrasts to results obtained at Mutale which support a gradual warming and shift to drier conditions during the late Holocene.

The Mutale Wetland record is one of the few South African records transcending the LGM. Overall, this study has contributed significantly to existing bodies of information regarding palaeoenvironmental conditions in Tate Vondo during the late Quaternary. However, like other regions within southern Africa, palaeoenvironmental reconstructions for the Soutpansberg region remain rare.

CHAPTER 8: SYNTHESIS AND CONCLUSION

The purpose of this chapter is to provide a brief synthesis of palaeoenvironmental changes in Tate Vondo, emphasizing the most important findings of this study. The aim and objectives are reviewed and finally, further research considerations are suggested.

8.1 Synthesis of palaeoenvironmental changes

Prior to *ca.* 34,000 cal yr BP, warm, fairly dry conditions are inferred from a dominance of open grassland vegetation. An expansion of forests together with an increase in fynbos elements suggests a shift to cool subhumid conditions between *ca.* 34,000 – 30,000 cal yr BP. The appearance of low charcoal concentrations throughout the late Pleistocene suggests that fire was infrequent. From *ca.* 30,000 – 23,000 cal yr BP, arid savanna replaced open fynbos grasslands and forests, indicating a warm semiarid environment. The expansion fynbos, mesic savanna elements and forests between *ca.* 23,000 – 18,000 cal yr BP, implies a cool and wet last glacial maximum (LGM). Although this does not concur with the majority of LGM conditions inferred for South Africa's summer rainfall sites, LGM conditions inferred for Mutale Wetland and the surrounding area accords with predictions by the Milankovitch theory of orbital changes, which predicts increased monsoonal rainfall in the southern tropics during the LGM (Gasse *et al.*, 2000). Cooler conditions persisted until *ca.* 12,000 cal yr BP, before a climatic amelioration was experienced. A local expansion of Cyperaceae as well as *Psoralea* between *ca.* 10,000 – 4000 cal yr BP suggests wetter conditions locally. Between *ca.* 4000 – 1500 cal yr BP, conditions became warmer and drier, inferred from the development of arid savanna vegetation. The sharp increase in charcoal after *ca.* 4000 cal yr BP may have implications for the history of human occupation in the Soutpansberg rather than shifts in climate. The rise in charcoal coincides with the recorded appearance of the first agriculturalists after *ca.* 3000 cal yr BP in the Soutpansberg region (Voigt and Plug, 1984). Unfortunately, the lack of robust human indicators (e.g. cereals) in the pollen record does not allow for this inference to be made with great certainty, however, archaeological evidence seems to support this. As Scott (2002) has stated, climate may not have been a major determinant of charcoal peaks in South Africa. This provides a possible explanation for the relatively low charcoal concentrations at Mutale during the late Pleistocene despite numerous shifts in climate and vegetation. The succession from savanna to fynbos vegetation together with expanded forests implies a return to cool and moist conditions from *ca.* 1500 – 400 cal yr BP. Arid savanna persists from *ca.* 400 to the present, implying warmer and drier conditions towards the present. Furthermore, from *ca.* 400 cal yr BP, the pollen and charcoal record indicate that the majority of changes in vegetation have been driven by anthropogenic activity.

8.2 Review of aim and objectives

This research is aimed at investigating late Quaternary palaeoenvironmental change in the northeastern Soutpansberg region of Limpopo Province by applying palaeoenvironmental techniques (pollen and charcoal analyses) to a sedimentary record from Mutale Wetland, Tate Vondo. Specific objectives are as follows:

(i) To use a suitable coring methodology and sampling strategy to extract a minimally disturbed continuous sediment core from the Mutale Wetland.

Appropriate literature was reviewed such that a suitable coring device could be chosen. Based on the literature, a Russian peat corer was chosen for the purpose of core extraction from the Mutale Wetland. Extendible fiberglass rods were inserted at various points within the wetland, such that the deepest point in the wetland could be located. Based on these findings, a suitable coring site was determined and a minimally disturbed, continuous 302 cm sediment core was extracted from the wetland for further analysis.

(ii) To determine accelerator mass spectrometry (AMS) radiocarbon ages for selected subsamples, appropriately calibrated, and supported by pollen

time-stratigraphic markers to establish independent chronological control.

Subsamples were extracted from suitable basal and intermediate layers based on the stratigraphy of the core. A total of five subsamples were chosen for AMS radiocarbon analysis such that independent chronological could be achieved for the sediment core. Radiocarbon ages were calibrated in CLAM (Classical Age Modelling) software (Blaauw, 2010) in conjunction with the SHCal04 dataset (McCormac *et al.*, 2004), which together with the glued.curves function, extends this curve to 50,000 years using the northern hemisphere curve and applying an offset (Blaauw, 2010). A linear age-depth model was created for the 36,000-year-old record, and no age reversals were observed.

In the Mutale record, *Pinus* was used as a time-stratigraphic marker. On the basis of historical documentation, *Pinus* plantations were established in the Soutpansberg approximately 100 years ago. *Pinus* pollen appears in the pollen record from *ca.* 272 cal yr BP, however, given the wide error margin on the calibrated radiocarbon date near the top of the core, the appearance of *Pinus* at *ca.* 272 cal yr BP fits quite closely with the age model and can thus be used to further constrain the minimum age of the more recent section of the sequence. The success of the use of Pinus as a time-stratigraphic marker in this study can be better assessed through an additional radiocarbon date at this depth. Given financial constraints, this is not currently possible.

(iii) To conduct relative and absolute fossil pollen counts along the length of the core with the aim of reconstructing late Quaternary vegetation history for the area, and to increase the resolution of the previous palynological study of Mutale Wetland done by Scott (1987a).

Both relative and absolute pollen counts were conducted at 4 cm resolution along the Mutale profile. Where further detail was required, the sampling resolution was increased at 2 cm intervals. This was a significant improvement on the previous study, where pollen analysis was conducted at 10 cm intervals

(Scott, 1987a). Absolute counts were determined using polystyrene markers (LacCore). Analysis was carried out up to 292 cm, as the remaining samples lacked fossil pollen. A minimum of 500 pollen grains were counted for each subsample, with 85 subsamples being counted in total. Pollen diagrams were constructed for relative count data, and the Constrained Incremental Sum Of Squares (CONISS) was used in the zonation of relative pollen data. Where zones demarcated by CONISS were too narrow, these were adjusted based on visual inspection of the data, whilst taking into consideration splits made by CONISS. Local and regional taxa were differentiated between, and regional taxa were further grouped into forest, bushveld, grassland and fynbos taxa to aid interpretation of data. Separate pollen diagrams were constructed for absolute pollen diagrams for local and regional data. Absolute diagrams were used as a means of verifying trends in the relative pollen diagrams.

(iv) To conduct microscopic charcoal analysis along the length of the core, such that a fire history may be reconstructed for the area.

Microscopic charcoal was analysed using the size-class technique to determine charcoal counts. Microscopic charcoal was analysed up to 292 cm, as the remaining samples beyond this point were not suitable for microscopic charcoal analysis. Charcoal counts were then expressed as charcoal concentrations using marker grains, and expressed as number of particles per volume of sample (Stockmarr, 1971). Using Psimpoll 4.25 (Bennett, 2005) charcoal concentrations were plotted against a depth scale and their associated radiocarbon ages to produce charcoal diagrams and hence reconstruct a fire history for the Tate Vondo area.

(v) To infer climatic and environmental conditions during the LGM, last glacial-interglacial transition (LGIT) and the Holocene in the Tate Vondo region.

An understanding of late Quaternary conditions in Tate Vondo was derived through the analysis of pollen data in conjunction with charcoal data obtained from Mutale Wetland. Pollen data were interpreted using the indicator species approach, which uses certain indicator taxa whose presence or absence warrants conclusive statements regarding past environmental conditions (Moore *et al.*, 1991). Environmental indications derived from the pollen record were integrated with those from the charcoal record such that the palaeoreconstruction could be better understood. Using this approach, a detailed palaeoreconstruction covering the LGM, LGIT and the Holocene has been provided.

(vi) To contribute to existing palaeoenvironmental studies that have been conducted in the region as well as to assess the extent to which these data concur.

This research has contributed to the existing body of palaeoenvironmental information gathered for the southern African summer rainfall region. The Mutale palaeoreconstruction was compared with previous studies from the Limpopo region as well as with other southern African studies in order to assess the degree to which this record concurs with other records. This record is one of the few southern African palaeoenvironmental records that extend beyond the LGM. In a region where longer Quaternary records are lacking, results from this study have provided valuable insight into late Quaternary conditions.

8.3 Conclusion

The results of this study are generally in accordance with palaeoenvironmental indications obtained from other studies in southern Africa with the exception of LGM conditions. They support gradual warming and a shift to drier conditions towards the late Holocene.

In a region such as the Soutpansberg, an area of exceptional botanical and cultural diversity, the need for understanding environmental change is therefore justified and warranted. According to Hahn (2007), a comprehensive understanding of environmental change and the effects of anthropogenic activity of past vegetation distributions is crucial to the effective management of present day vegetation distributions. It is recommended that further high-resolution palaeoenvironmental research be conducted across the Soutpansberg such that a more precise understanding of past environmental change may be developed.

According to Scott (2000, p. 349), successful modeling of environmental change in southern Africa warrants an increase in pollen analytical studies across a ‘much closer grid of sites’. This research has provided a continuous palaeoenvironmental record for the past ca. 36,000 years at the Mutale Wetland, thus contributing to palaeoenvironmental research in Tate Vondo, and Limpopo Province as a whole. Through providing a record extending beyond the LGM, this research has made a significant contribution to our understanding of the late Quaternary in the southern African summer rainfall region where such long-term records are lacking.

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APPENDIX A

PROCEDURE FOR SUBSAMPLING

Source: adapted from Faegri and Iverson (1989) and Finch (2005)

1. Using a clean scalpel or razor blade, clean the surface of the core. This can be done by gently scraping material off the surface, ensuring that this is performed parallel to the strata in order to avoid contamination.

2. Determine a suitable sampling interval by taking into account the estimated age of basal sediments, the total length of the core and the stratigraphy such that samples are taken on either side of distinct chronological or stratigraphic boundaries. Initially, a wide sampling interval of 8 cm was chosen for pollen and microscopic charcoal analysis of the MUT-12-01 core. Where further detail was required, in-between samples were taken at 4 cm intervals.

3. Each sample should contain approximately 1- 2 cm^3 of sediment. Where the exact volume of sediment is not needed, samples may be cut out using a scalpel or spatula.

4. Transfer each sample into an airtight plastic storage vial.

5. For C^{14} dating, samples it is necessary for samples to represent the shortest possible period, and should thus consist of thin slices across the whole core. Peat samples of approximately 50g should be stored within polythene bags and refrigerated.

APPENDIX B

PROCEDURE FOR PREPARING FOSSIL POLLEN SAMPLES

Source: adapted from Faegri and Iverson (1989), Moore *et al*. (1991), Baxter (1996) and Finch (2005)

Note:

- Centrifuge at 4000 rpm for 3 mins, unless otherwise specified.
- Use 100 ml profiled, sealable polypropylene tubes in a swing-out centrifuge.
- The temperature of the water bath should maintained between 50-60°C unless otherwise stated.
- Label all samples clearly.

A. Measurement of sediment

Each sample should contain 1 cm^3 of wet sediment. In this study, accurate sample volumes were obtained by measuring out 9 cm^3 of distilled water into a measuring cylinder and adding sediment until the total volume in the measuring cylinder reached 10 cm^3 .

B. Addition of pollen spike

1. Place pollen spike solution on a magnetic stir plate for at least 1hour prior to use.
2. Add 1 ml of spike to each peat sample using a graduated plastic syringe.

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

1. To each sample, add 20 ml 15% sodium hydroxide (NaOH) and stir.
2. Place samples in a heated water bath for 10 mins and stir.
3. Wash and strain through a 180 μm sieve using distilled water.
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. In a fume cupboard, add 20 ml concentrated (40%) HF, place in polypropylene tubes in a heated water bath for 3 hours, stirring regularly.
3. Seal centrifuge tubes, centrifuge for 5 mins and decant.
4. Add 20 ml 10% HCl. Place sample in a heated water bath for 20 mins, stirring regularly.
5. Remove from water bath.
6. Stir, centrifuge and decant.

E. Acetolysis digestion of extraneous organic detritus.

1. Add 20 ml glacial acetic acid. Stir, centrifuge and decant, making sure to discard as much as the supernatant as possible to avoid remaining acetic acid from reacting with the acetolysis mixture.
2. Add 20 ml acetolysis mixture (Containing 9 parts acetic anhydride ($[CH_3CO]_2O$) : 1 part concentrated sulphuric acid [H_2SO_4]). Place in a heated water bath for 10-15 mins, stirring regularly.
3. To stop the reaction, remove from water bath and place in cold water for a few seconds. Stir, centrifuge and decant.
4. Add 20 ml glacial acetic acid. Stir, centrifuge and decant.
5. Add 9 ml distilled water and 1 ml 10% NaOH to neutralize sample.
6. Rinse 3 times with distilled water, add two drops of safranine stain to the last rinse.
7. Add 5 ml tertiary butyl (TBA), stir, centrifuge and decant.
8. Add 5 ml TBA, transfer the sample from the polypropylene tube into a labeled 30 ml storage vial.

F. Mounting

1. Allow the processed solution to settle overnight in a refrigerator. Using a glass pipette, remove the clear liquid so as to concentrate the pollen and

charcoal.

2. Place a single drop of Aquatex mounting solution on a sterile glass microscope slide.
3. Use a micropipette or a blunt toothpick to extract approximately 3 drops of the pollen solution. 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. The slide should be allowed to stand for at least 4 hours prior to counting, to allow the pollen to disperse evenly across the slide.

APPENDIX C

PREPARATION PROCEDURE FOR REFERENCE COLLECTION POLLEN

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

Note:

- Centrifuge at 4000 rpm for 3 mins, unless otherwise specified.
- Use 100 ml profiled, sealable polypropylene tubes in a swing-out centrifuge.
- The temperature of the water bath should maintained between 50-60°C unless otherwise stated.
- Label all samples clearly.

A. Chemical preprocessing

1. Place specimen in a polypropylene tube.
2. Add 20 ml 10% NaOH to the specimen and stir.
3. Place 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. Using glacial acetic acid, transfer the contents into a 10 ml centrifuge tube. Stir, centrifuge and decant.
7. In a fume cupboard, add 20 ml acetolysis mixture (Containing 9 parts acetic anhydride ($[CH_3CO]_2O$) : 1 part concentrated sulphuric acid $[H_2SO_4]$) and place in a heated water bath for 5 mins, 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 3-5 times with distilled water, and add 1-3 drops of safranine stain to the final rinse.
11. To prevent bacteriological and fungal spoilage, rinse in a mild phenol

solution.

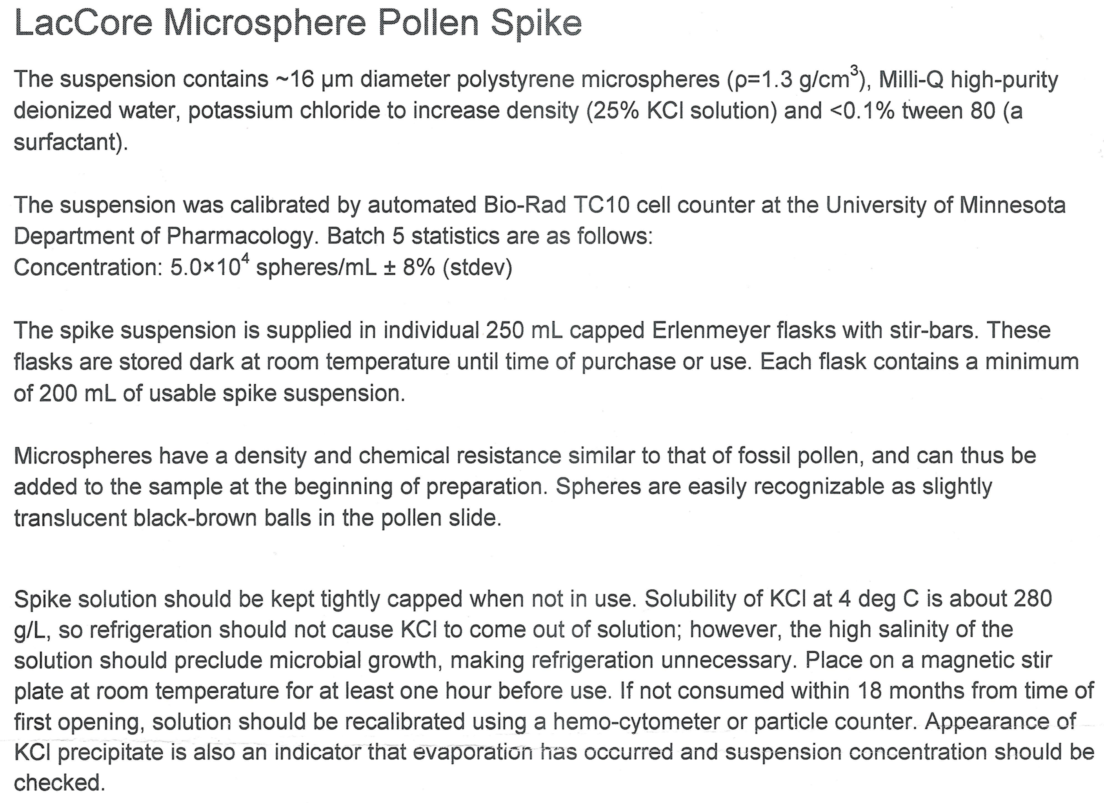
12. Invert the tubes onto blotting paper and allow to drain.

B. Mounting

1. Clean and label the microscope slides, preferably 3 replicates for each specimen.
2. Cut small cubes of gylcerine jelly (ideally a phenol impregnated brand), and with the use of a dissecting needle, collect pollen grains/spores from the blotting paper. Wipe the glycerine jelly around the inside of the tube to pick up the pollen residue.
3. Place the glycerine jelly in the middle of the microscope slide and heat the slide over a heating plate to melt the jelly, being careful not to allow the jelly to boil as 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

INFORMATION FOR POLLEN SPIKE (LacCore)



LacCore Microsphere Pollen Spike

The suspension contains ~16 µm diameter polystyrene microspheres (ρ=1.3 g/cm^3), Milli-Q high-purity deionized water, potassium chloride to increase density (25% KCl solution) and <0.1% tween 80 (a surfactant).

The suspension was calibrated by automated Bio-Rad TC10 cell counter at the University of Minnesota Department of Pharmacology. Batch 5 statistics are as follows:
Concentration: 5.0×10^4 spheres/mL ± 8% (stdev)

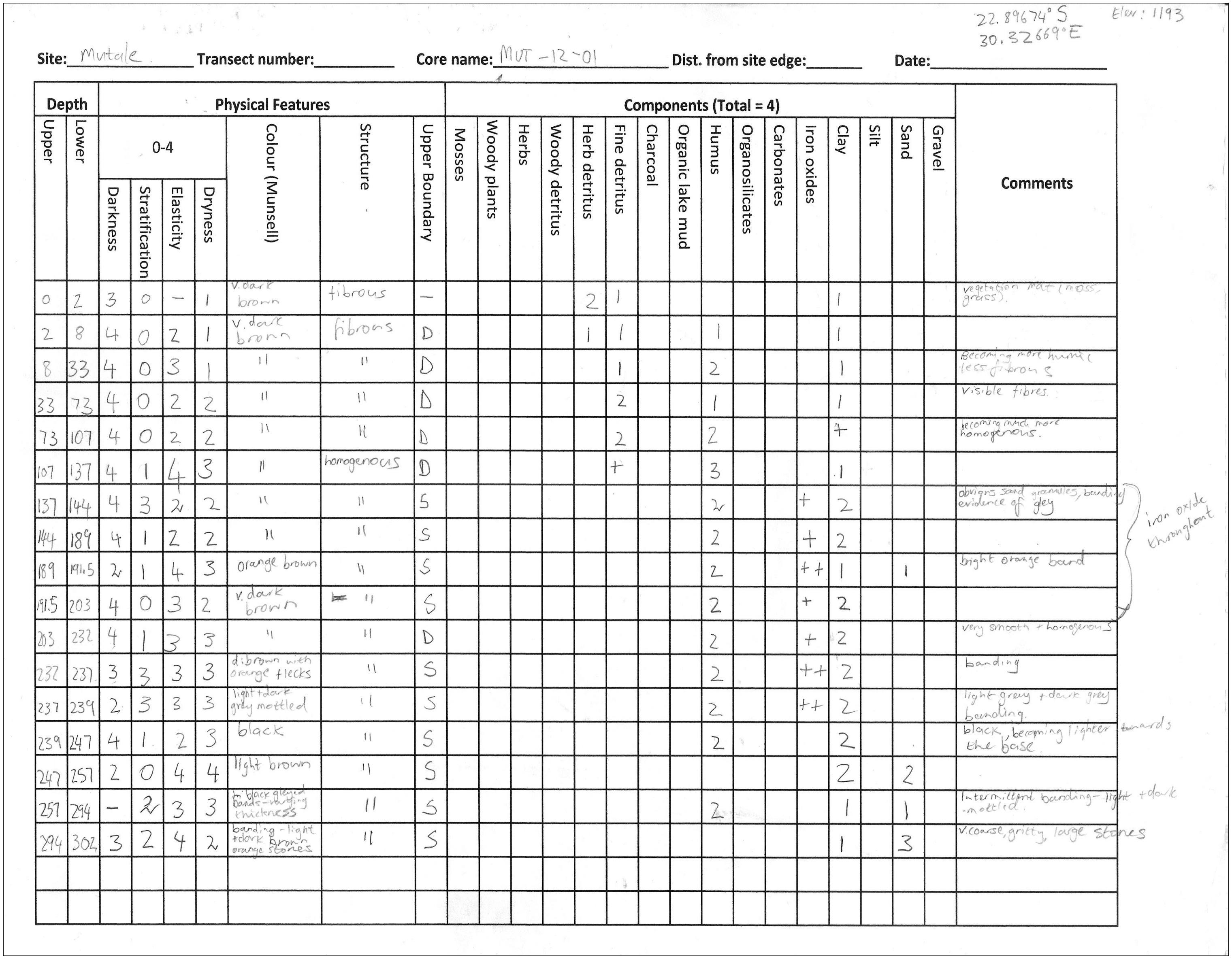
The spike suspension is supplied in individual 250 mL capped Erlenmeyer flasks with stir-bars. These flasks are stored dark at room temperature until time of purchase or use. Each flask contains a minimum of 200 mL of usable spike suspension.

Microspheres have a density and chemical resistance similar to that of fossil pollen, and can thus be added to the sample at the beginning of preparation. Spheres are easily recognizable as slightly translucent black-brown balls in the pollen slide.

Spike solution should be kept tightly capped when not in use. Solubility of KCl at 4 deg C is about 280 g/L, so refrigeration should not cause KCl to come out of solution; however, the high salinity of the solution should preclude microbial growth, making refrigeration unnecessary. Place on a magnetic stir plate at room temperature for at least one hour before use. If not consumed within 18 months from time of first opening, solution should be recalibrated using a hemo-cytometer or particle counter. Appearance of KCl precipitate is also an indicator that evaporation has occurred and suspension concentration should be checked.

APPENDIX E

TROELS-SMITH DATA SHEETS FOR SEDIMENT CORE MUT-12-01 (Field stratigraphy).



22.89674°S
30.32669°E
Elev: 1193

Site: Mutale Transcript number: ______ Core name: MUT-12-01 ______ Dist. from site edge: ______ Date: ______

Depth: Upper	Depth: Lower	0-4: Darkness	0-4: Stratification	0-4: Elasticity	0-4: Dryness	Colour (Munsell)	Structure	Upper Boundary	Mosses	Woody plants	Herbs	Woody detritus	Herb detritus	Fine detritus	Charcoal	Organic lake mud	Humus	Organosilicates	Carbonates	Iron oxides	Clay	Silt	Sand	Gravel	Comments
0	2	3	0	—	1	v. dark brown	fibrous	—					2	1							1				vegetation mat (moss, grass).
2	8	4	0	2	1	v. dark brown	fibrous	D					1	1			1				1				
8	33	4	0	3	1	"	"	D						1			2				1				Becoming more humic less fibrous
33	73	4	0	2	2	"	"	D						2			1				1				visible fibres.
73	107	4	0	2	2	"	"	D						2			2				+				becoming much more homogenous.
107	137	4	1	4	3	"	homogenous	D						+			3				1				
137	144	4	3	2	2	"	"	S									2			+	2				obvious sand granules, banding evidence of gley
144	189	4	1	2	2	"	"	S									2			+	2				
189	191.5	2	1	4	3	orange brown	"	S									2			++	1		1		bright orange band
191.5	203	4	0	3	2	v. dark brown	~~=~~ "	S									2			+	2				
203	232	4	1	3	3	"	"	D									2			+	2				very smooth + homogenous
232	237	3	3	3	3	d. brown with orange flecks	"	S									2			++	2				banding
237	239	2	3	3	3	light + dark grey mottled	"	S									2			++	2				light grey + dark grey banding.
239	247	4	1	2	3	black	"	S									2				2				black, becoming lighter towards the base.
247	257	2	0	4	4	light brown	"	S													2		2		
257	294	—	2	3	3	~~li~~ black gleyed bands – varying thickness	"	S									2				1		1		Intermittent banding – light + dark -mottled.
294	302	3	2	4	2	banding – light + dark brown orange stones	"	S													1		3		V. coarse, gritty, large stones

Components (Total = 4)

iron oxide throughout

(Lab stratigraphy)

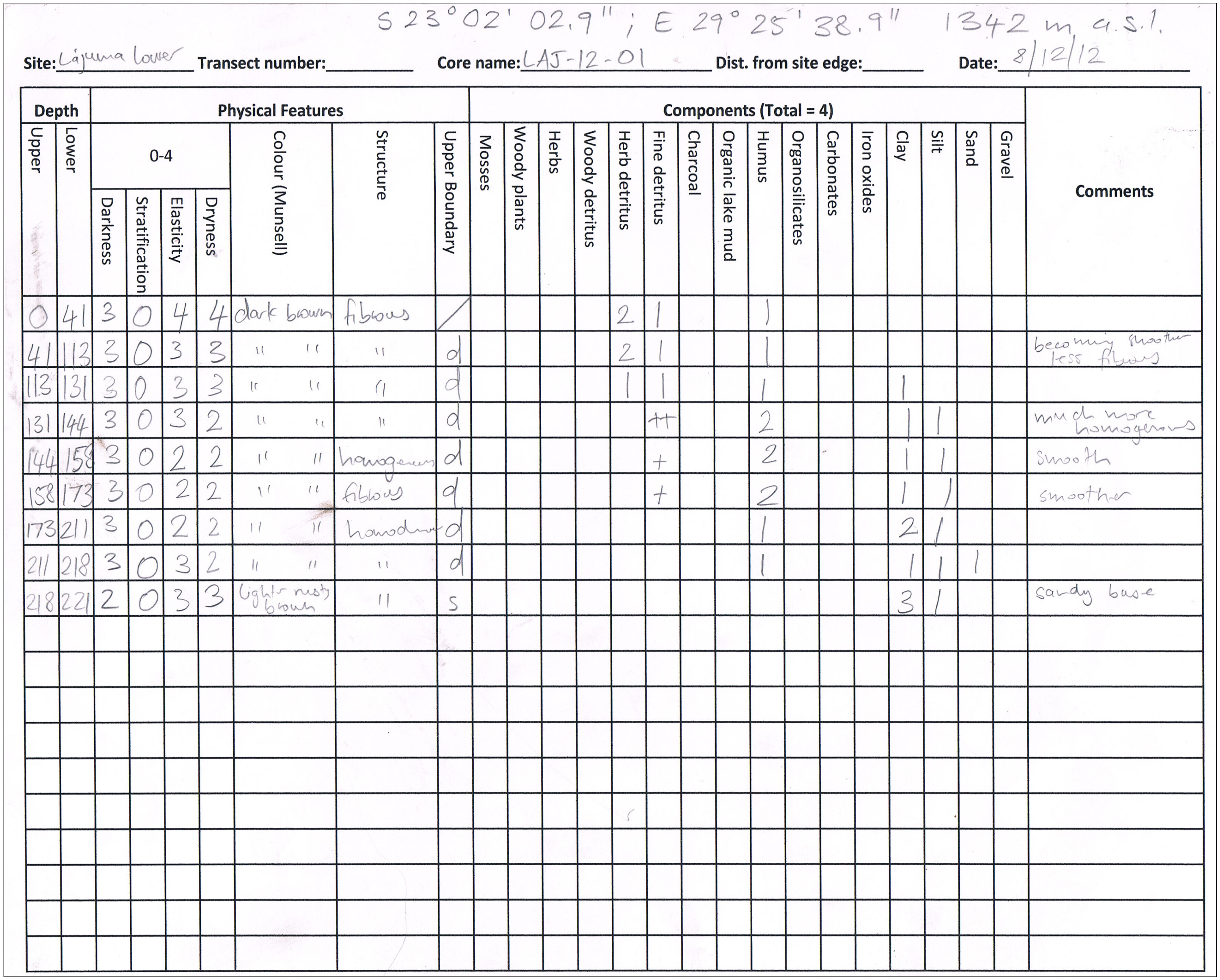
22.89674°S Elev: 1193
30.32669°E

Done in LAB

Site: Mutale Transect number:________ Core name: MUT-12-01 Dist. from site edge:______ Date:__________

Depth		Physical Features							Components (Total = 4)																Comments
Upper	Lower	0-4				Colour (Munsell)	Structure	Upper Boundary	Mosses	Woody plants	Herbs	Woody detritus	Herb detritus	Fine detritus	Charcoal	Organic lake mud	Humus	Organosilicates	Carbonates	Iron oxides	Clay	Silt	Sand	Gravel	
		Darkness	Stratification	Elasticity	Dryness																				
0	31	4	0	3	1	V.dark brown	fibrous	–						1			2				1				Vegetation mat at very top (moss, grass).
31	96	4	0	3	2	V.dark brown	fibrous	D					2	+			1				1				V.fibrous
96	111	4	0	3	3	v.dark brown	fibrous	D						1			2				1				becoming more humic, less fibrous
111	248	4	0	2	3	v.dark brown	homogenous	D									2				1		1		v.smooth, homogenous,
248	257	–	2	1	3	light brown–black/grey banding	homogenous	S									1				2		1		
257	279	4	0	3	3	v.dark brown	homogenous	S									1				2		1		
279	288	3	2	3	3	V.dark brown–banding–light brown	homogenous	S									1				2		1		light grey, dark grey banding.
288	296	4	0	4	2	V.dark brown	homogenous	D									2				1		1		
296	302	3	1	1	2	dark brown	homogenous	S													1		3		Iron oxide band, v. coarse gritty

TROELS-SMITH DATA SHEETS FOR SEDIMENT CORE LAJ-12-01 (Field stratigraphy).



S 23° 02' 02.9" ; E 29° 25' 38.9" 1342 m a.s.l.

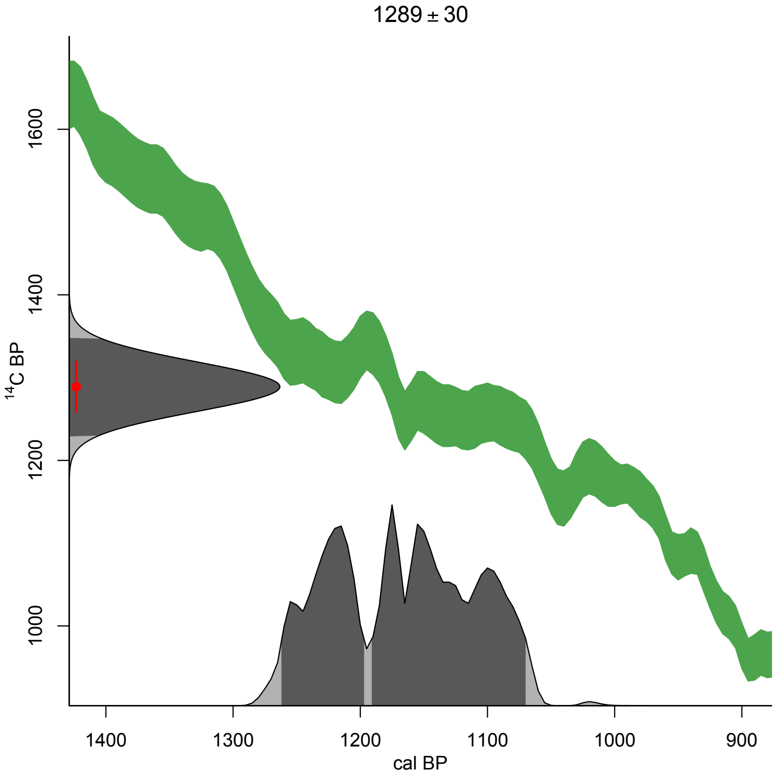
Site: Lajuma Lower Transect number:______ Core name: LAJ-12-01 Dist. from site edge:______ Date: 8/12/12

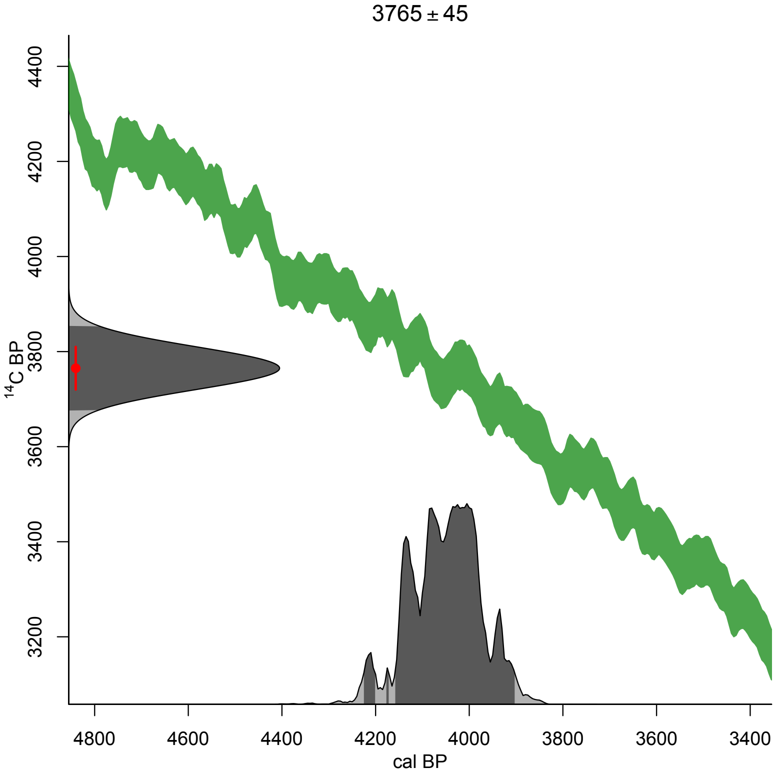
Depth		Physical Features							Components (Total = 4)																Comments
Upper	Lower	0-4				Colour (Munsell)	Structure	Upper Boundary	Mosses	Woody plants	Herbs	Woody detritus	Herb detritus	Fine detritus	Charcoal	Organic lake mud	Humus	Organosilicates	Carbonates	Iron oxides	Clay	Silt	Sand	Gravel	
		Darkness	Stratification	Elasticity	Dryness																				
0	41	3	0	4	4	dark brown	fibrous	/					2	1			1								
41	113	3	0	3	3	" "	"	d					2	1			1								becoming smoother less fibrous
113	131	3	0	3	3	" "	"	d					1	1			1				1				
131	144	3	0	3	2	" "	"	d						++			2				1	1			much more homogenous
144	158	3	0	2	2	" "	homogenous	d						+			2				1	1			smooth
158	173	3	0	2	2	" "	fibrous	d						+			2				1	1			smoother
173	211	3	0	2	2	" "	homogenous	d									1				2	1			
211	218	3	0	3	2	" "	"	d									1				1	1	1		
218	221	2	0	3	3	lighter rusty brown	"	s													3	1			sandy base

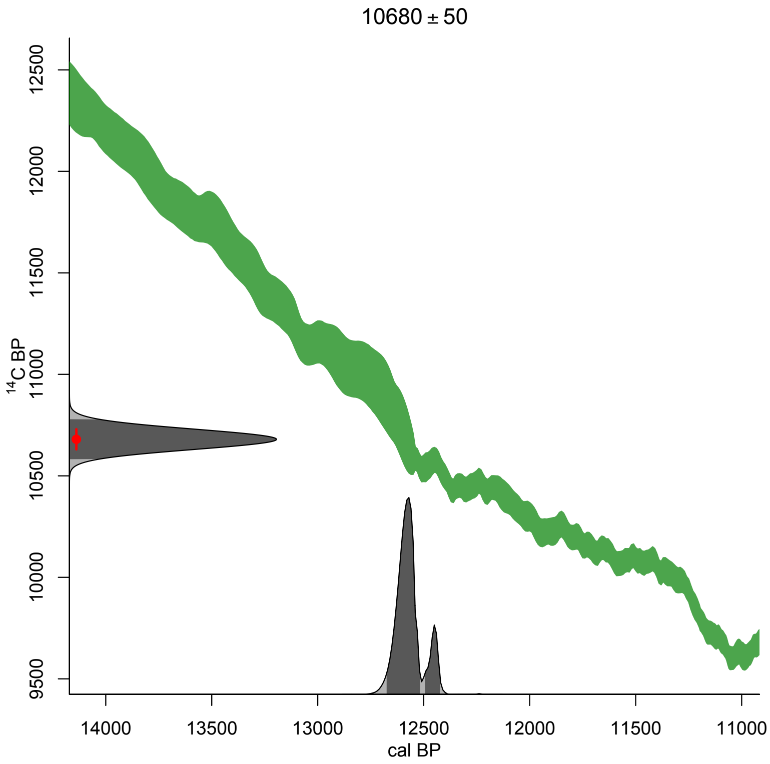
- A Troels-Smith stratigraphy for the Fundudzi sequence (FUN-12-01) was not conducted due to time constraints in the field

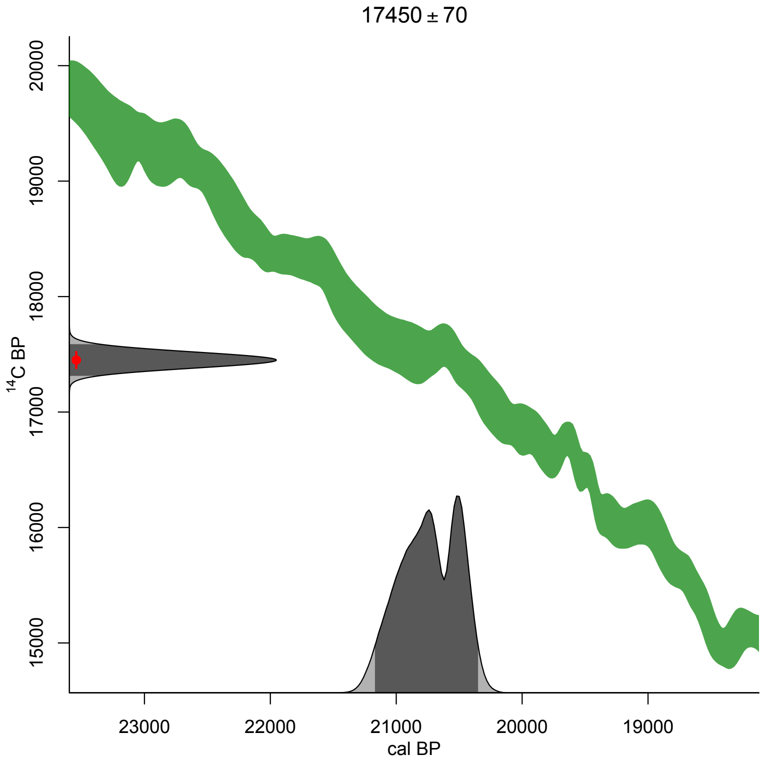
APPENDIX F

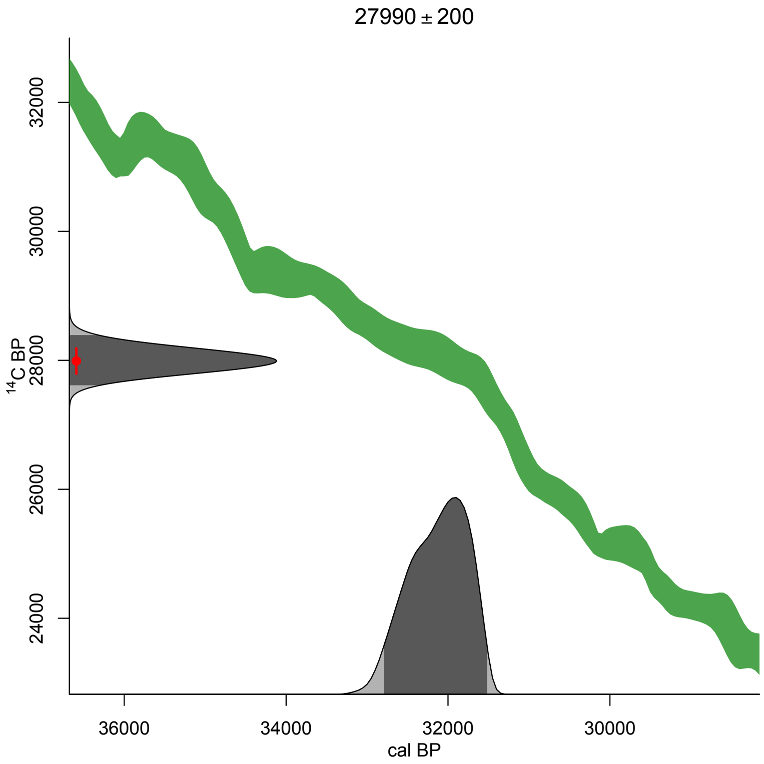
CALIBRATED AGES OF INDIVIDUAL SAMPLES






10680 ± 50
12500
12000
11500
11000
10500
10000
9500
^{14}C BP
14000
13500
13000
12500
12000
11500
11000
cal BP


17450 ± 70
20000
19000
18000
17000
16000
15000
^{14}C BP
23000
22000
21000
20000
19000
cal BP


27990 ± 200
32000
30000
28000
26000
24000
^{14}C BP
36000
34000
32000
30000
cal BP

APPENDIX G

INTERPOLATED CALIBRATED AGES

Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
0	-57	-53	-55
1	-37	-32	-35
2	-18	-10	-14
3	1	12	6
4	20	34	27
5	40	56	47
6	59	78	68
7	78	100	88
8	97	123	109
9	116	145	129
10	135	167	150
11	154	189	170
12	173	211	190
13	192	234	211
14	211	256	231
15	230	278	252
16	249	300	272
17	268	322	293
18	287	345	313
19	306	367	334
20	325	389	354
21	344	411	374
22	363	433	395
23	382	456	415
24	401	478	436
25	420	500	456
26	439	522	477
27	458	545	497
28	477	567	518
29	495	589	538
30	514	611	559
31	533	633	579
32	552	656	599
33	571	678	620
34	590	700	640

Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
35	609	722	661
36	628	744	681
37	647	767	702
38	666	789	722
39	685	811	743
40	704	833	763
41	723	855	784
42	742	878	804
43	761	900	824
44	780	922	845
45	799	944	865
46	818	966	886
47	837	989	906
48	856	1011	927
49	875	1033	947
50	894	1055	968
51	913	1077	988
52	932	1100	1009
53	951	1122	1029
54	970	1144	1049
55	989	1166	1070
56	1008	1188	1090
57	1027	1211	1111
58	1046	1233	1131
59	1065	1255	1152
60	1123	1309	1208
61	1179	1364	1263
62	1236	1418	1319
63	1294	1472	1375
64	1351	1527	1431
65	1407	1580	1487
66	1464	1633	1542
67	1520	1689	1598
68	1577	1745	1654
69	1633	1800	1710
70	1689	1855	1766
71	1745	1912	1821
72	1800	1968	1877
73	1856	2023	1933
74	1912	2079	1989

Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
75	1967	2134	2045
76	2022	2190	2100
77	2077	2247	2156
78	2132	2303	2212
79	2187	2359	2268
80	2242	2415	2324
81	2297	2470	2379
82	2353	2526	2435
83	2407	2583	2491
84	2462	2641	2547
85	2517	2698	2603
86	2572	2756	2658
87	2627	2814	2714
88	2681	2872	2770
89	2735	2930	2826
90	2788	2986	2882
91	2843	3044	2938
92	2896	3102	2993
93	2950	3160	3049
94	3004	3218	3105
95	3058	3276	3161
96	3111	3334	3217
97	3164	3391	3272
98	3217	3450	3328
99	3272	3509	3384
100	3326	3568	3440
101	3379	3627	3496
102	3432	3686	3551
103	3485	3746	3607
104	3539	3805	3663
105	3591	3863	3719
106	3645	3922	3775
107	3699	3982	3830
108	3753	4041	3886
109	3806	4099	3942
110	3860	4158	3998
111	3914	4217	4054
112	4289	4580	4424
113	4665	4944	4794
114	5041	5309	5164

Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
115	5417	5671	5534
116	5792	6035	5905
117	6167	6398	6275
118	6544	6762	6645
119	6918	7128	7015
120	7289	7491	7385
121	7661	7858	7756
122	8032	8225	8126
123	8401	8592	8496
124	8769	8961	8866
125	9136	9330	9236
126	9504	9698	9607
127	9870	10065	9977
128	10238	10434	10347
129	10605	10804	10717
130	10972	11177	11087
131	11338	11548	11458
132	11704	11921	11828
133	12069	12295	12198
134	12433	12668	12568
135	12592	12824	12725
136	12752	12980	12882
137	12909	13138	13039
138	13066	13298	13196
139	13223	13452	13352
140	13378	13612	13509
141	13534	13774	13666
142	13689	13937	13823
143	13846	14098	13980
144	14002	14260	14137
145	14158	14421	14294
146	14313	14583	14451
147	14465	14746	14608
148	14618	14910	14764
149	14774	15074	14921
150	14927	15237	15078
151	15082	15401	15235
152	15236	15562	15392
153	15391	15726	15549
154	15545	15890	15706

Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
155	15698	16055	15863
156	15850	16219	16019
157	15999	16381	16176
158	16152	16545	16333
159	16305	16711	16490
160	16454	16875	16647
161	16604	17037	16804
162	16756	17202	16961
163	16909	17363	17118
164	17061	17528	17275
165	17211	17693	17431
166	17360	17858	17588
167	17509	18024	17745
168	17661	18189	17902
169	17811	18353	18059
170	17961	18514	18216
171	18112	18681	18373
172	18261	18847	18530
173	18414	19011	18686
174	18567	19175	18843
175	18716	19340	19000
176	18867	19504	19157
177	19016	19671	19314
178	19166	19839	19471
179	19315	20006	19628
180	19465	20172	19785
181	19615	20337	19942
182	19764	20501	20098
183	19914	20667	20255
184	20064	20833	20412
185	20214	20999	20569
186	20364	21164	20726
187	20521	21307	20878
188	20678	21457	21030
189	20841	21601	21182
190	21002	21751	21334
191	21157	21899	21486
192	21312	22045	21638
193	21466	22197	21790
194	21619	22347	21942

Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
195	21769	22497	22094
196	21924	22644	22246
197	22079	22797	22398
198	22235	22945	22550
199	22385	23091	22702
200	22538	23238	22854
201	22688	23382	23006
202	22840	23534	23158
203	22992	23686	23311
204	23141	23832	23463
205	23291	23983	23615
206	23444	24133	23767
207	23595	24282	23919
208	23751	24437	24071
209	23902	24594	24223
210	24053	24747	24375
211	24204	24901	24527
212	24352	25054	24679
213	24502	25209	24831
214	24652	25362	24983
215	24802	25517	25135
216	24950	25674	25287
217	25100	25831	25439
218	25253	25987	25591
219	25396	26141	25743
220	25545	26292	25895
221	25691	26450	26047
222	25838	26613	26199
223	25989	26771	26351
224	26140	26928	26503
225	26290	27085	26655
226	26438	27242	26807
227	26587	27394	26959
228	26736	27555	27111
229	26884	27714	27263
230	27032	27870	27415
231	27184	28027	27567
232	27330	28185	27720
233	27474	28343	27872
234	27619	28498	28024

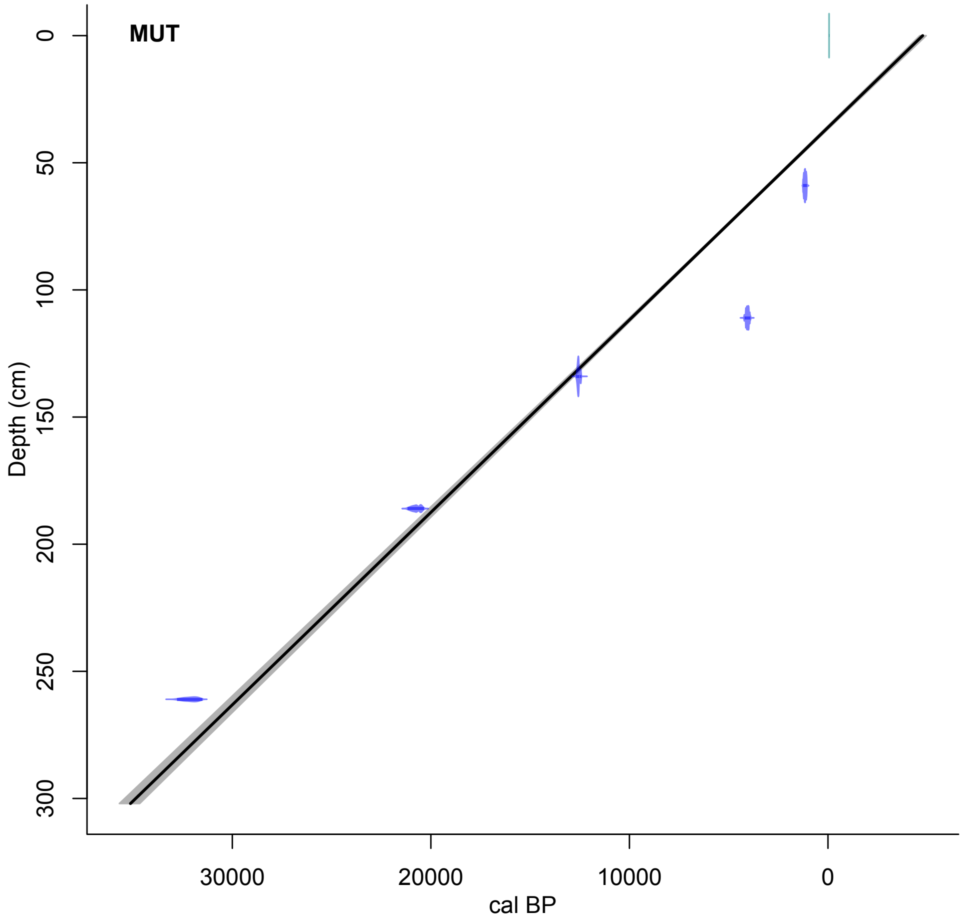
Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
235	27767	28658	28176
236	27917	28816	28328
237	28064	28978	28480
238	28210	29140	28632
239	28358	29302	28784
240	28504	29464	28936
241	28652	29627	29088
242	28796	29787	29240
243	28941	29944	29392
244	29089	30102	29544
245	29234	30263	29696
246	29376	30428	29848
247	29520	30585	30000
248	29665	30744	30152
249	29810	30906	30304
250	29957	31067	30456
251	30102	31230	30608
252	30249	31392	30760
253	30396	31554	30912
254	30541	31716	31064
255	30688	31879	31216
256	30834	32042	31368
257	30982	32204	31520
258	31126	32361	31672
259	31272	32520	31824
260	31419	32681	31977
261	31563	32843	32129
262	31707	33007	32281
263	31851	33172	32433
264	31994	33337	32585
265	32139	33501	32737
266	32280	33664	32889
267	32422	33829	33041
268	32568	33994	33193
269	32714	34156	33345
270	32858	34320	33497
271	33000	34484	33649
272	33144	34647	33801
273	33288	34809	33953
274	33430	34971	34105

Depth (cm)	Cal. Min. date	Cal. Max. date	Best Date
275	33573	35131	34257
276	33715	35291	34409
277	33857	35455	34561
278	33999	35618	34713
279	34141	35779	34865
280	34284	35940	35017
281	34427	36097	35169
282	34570	36259	35321
283	34711	36422	35473
284	34853	36584	35625
285	34994	36746	35777
286	35138	36909	35929
287	35280	37071	36081
288	35422	37233	36233
289	35563	37397	36386
290	35705	37560	36538
291	35846	37724	36690
292	35988	37886	36842
293	36132	38048	36994
294	36272	38211	37146
295	36413	38376	37298
296	36554	38541	37450
297	36696	38707	37602
298	36838	38872	37754
299	36982	39037	37906
300	37125	39199	38058
301	37268	39361	38210
302	37410	39523	38362

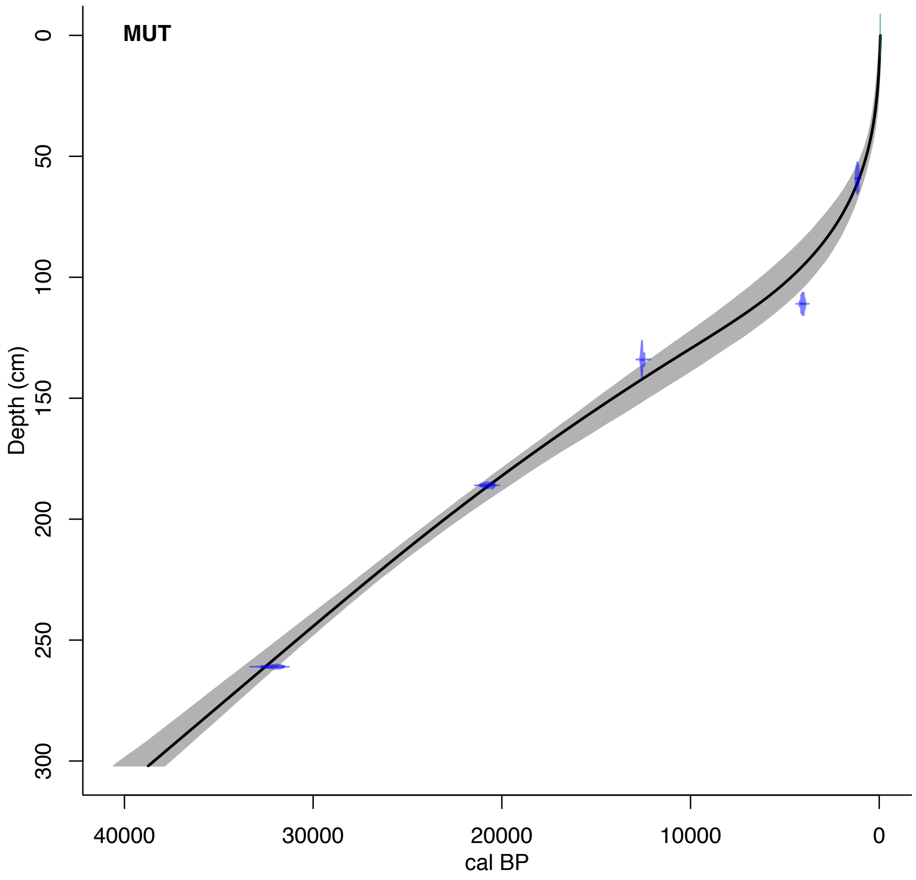
APPENDIX H

AGE-DEPTH MODELS

Polynomial regression



Smooth spline



APPENDIX I

RAW POLLEN COUNTS

Depth	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**12**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Marker count	53	55	50	50	59	56	58	51	50	50	53	50	56	50	52
ACANTHACEAE undiff.	0	0	0	0	0	0	0	7	4	6	0	1	0	0	0
AIZOACEAE undiff.	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
ANACARDIACEAE *Rhus*	1	2	2	7	4	2	4	5	4	4	1	3	4	3	0
ANACARDIACEAE undiff.	1	0	2	4	0	0	0	5	2	3	0	1	0	0	0
ANTHOCEROTACEAE *Anthoceros*	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0
AQUAFOLIACEAE *Ilex mitis*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
ASPARAGACEAE *Asparagus*	0	0	0	0	1	0	2	0	3	0	2	0	0	0	0
ASTERACEAE *Artemisia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Gerbera*	0	2	0	3	1	2	0	0	3	0	0	2	0	0	0
ASTERACEAE *Stoebe*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Tarconanthus*	0	1	2	3	2	0	0	3	0	1	0	1	0	0	1
ASTERACEAEundiff.	30	28	32	29	32	24	36	25	31	25	33	29	32	28	17
ASTERACEAE *Vernonia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CAMPANULACEAE *Wahlenbergia*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
CAPPARACEAE undiff.	1	1	2	4	3	3	2	2	3	4	0	2	1	2	2
CARYOPHYLLACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CELASTRACEAE undiff.	0	0	0	0	2	0	0	0	3	5	3	0	1	0	0
CELTIDACEAE *Celtis*	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0
CHENOPODIACEAE undiff.	0	1	0	7	3	3	9	3	0	4	0	3	17	22	14
COMBRETACEAE *Combretum*	1	0	0	1	0	2	5	3	0	0	2	1	0	3	1
COMMELINACEAE undiff.	2	0	3	8	3	0	0	2	0	7	5	0	3	8	0
CORNACEAE C*ornus*	0	0	0	1	0	0	3	0	1	0	0	0	0	1	0
CRASSULACEAE *Crassula*	0	0	0	0	0	0	0	0	1	2	3	0	2	6	3

Depth	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**12**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
CYPERACEAE A*scolepis*	16	20	18	22	25	17	20	13	17	14	11	31	28	34	26
CYPERACEAE undiff.	60	63	84	101	89	98	92	128	76	84	58	39	42	37	29
EBENACEAE *Euclea*	0	0	1	0	0	0	2	0	0	0	0	0	0	1	0
ERICACEAE undiff.	1	0	0	0	0	0	3	0	0	0	0	0	1	1	0
EUPHORBIACEAE *Acalypha*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE *Clutia*	0	0	0	0	0	0	0	3	0	1	0	0	1	0	0
EUPHORBIACEAE *Spirostachys africana*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
EUPHORBIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FABACEAE *Burkea africana*	0	0	0	0	0	0	0	0	1	2	3	0	1	1	0
FABACEAE *Psoralea* type	0	0	0	2	0	0	5	10	3	0	0	0	0	0	0
FABACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FLACOURTIACEAE *Kiggelaria africana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GENTIANACEAE undiff.	0	0	0	1	1	0	0	0	0	0	0	2	0	2	0
HALOROGACEAE *Gunnera*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HALOROGACEAE undiff.	0	1	0	0	0	2	1	0	0	0	0	1	0	1	0
LAMIACEAE undiff.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
LILIACEAE *Aloe* type	0	0	1	0	0	1	0	1	0	0	2	0	0	1	0
LILIACEAE *Tulbhagia*	1	1	2	0	3	2	3	5	2	3	0	3	0	1	0
MONOLETES undiff.	14	20	12	16	12	18	14	45	51	50	40	53	52	62	32
MYRICACEAE *Myrica*	1	2	1	3	0	1	1	2	0	0	0	0	0	1	1
MYRSINACEAE *Myrsine*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYRTACEAE undiff.	0	2	2	1	2	1	0	2	1	0	0	0	0	0	1
OLEACEAE undiff.	0	0	0	2	0	1	1	2	1	2	0	1	0	1	0
OPHIOGLOSSACEAE undiff.	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0

Depth	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**12**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
PINACEAE *Pinus*	33	29	32	27	26	29	24	5	3	3	0	0	0	0	0
POACEAE <40 µm	171	159	164	150	168	177	156	169	247	236	227	269	253	249	281
PODOCARPACEAE *Podocarpus*	2	3	3	6	3	5	13	5	13	15	19	11	14	12	16
POLYPODIACEAE undiff.	0	0	0	0	0	0	0	0	0	3	0	4	0	5	8
PROTEACEAE undiff.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
RESTIONACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ROSACEAE *Cliffortia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUBIACEAE *Canthium*	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
SAPOTACEAE *Englerophytum*	0	2	0	3	0	1	4	0	0	0	0	0	0	0	0
STERCULIACEAE *Dombeya*	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0
THYMELEACEAE *Passerina*	2	0	2	9	3	7	16	0	0	0	0	0	0	0	0
TILIACEAE *Grewia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRILETES undiff.	101	78	72	58	70	67	43	37	41	32	35	43	52	56	49
TYPHACEAE *Typha*	6	11	8	12	6	8	5	2	1	1	1	7	17	21	19
ZYGOPHYLLACEAE *Tribulus*	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
UNDETERMINED	0	3	5	7	0	5	14	25	9	25	7	11	15	22	7
Sordariaceae *Gelasinospora*	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0
Chaetomiaceae *Chaetomium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sordariaceae undiff.	0	3	3	1	5	8	3	0	0	0	0	0	0	0	0
FUNGAL SPORES other	33	23	32	38	29	27	25	32	26	25	20	28	39	37	30
Pseudoschizea	10	8	5	7	6	8	11	9	11	14	3	8	3	6	9
TOTAL	**477**	**455**	**486**	**532**	**494**	**512**	**509**	**544**	**550**	**561**	**473**	**547**	**575**	**626**	**537**

Depth	**23**	**24**	**25**	**28**	**32**	**36**	**40**	**44**	**48**	**52**	**56**	**60**	**64**	**68**	**72**
Marker count	50	53	50	51	54	52	50	80	61	52	62	51	96	53	51
ACANTHACEAE undiff.	0	1	1	2	0	1	0	0	2	1	0	0	0	3	0
AIZOACEAE undiff.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
ANACARDIACEAE *Rhus*	2	1	2	1	0	2	1	0	1	2	1	0	1	0	1
ANACARDIACEAE undiff.	0	4	3	3	2	2	1	0	4	3	0	1	1	1	0
ANTHOCEROTACEAE *Anthoceros*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AQUAFOLIACEAE *Ilex mitis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASPARAGACEAE *Asparagus*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
ASTERACEAE *Artemisia*	0	0	0	0	0	0	0	3	5	0	1	1	0	0	0
ASTERACEAE *Gerbera*	0	0	3	2	5	7	4	8	3	5	4	5	1	4	0
ASTERACEAE *Stoebe*	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0
ASTERACEAE *Tarconanthus*	0	1	2	0	5	3	0	0	0	0	0	0	0	0	0
ASTERACEAEundiff.	9	4	31	28	18	8	1	7	3	18	5	14	29	7	4
ASTERACEAE *Vernonia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CAMPANULACEAE *Wahlenbergia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CAPPARACEAE undiff.	1	1	2	0	0	1	0	0	0	1	0	0	2	0	0
CARYOPHYLLACEAE undiff.	0	0	0	0	0	0	0	2	2	0	0	2	0	0	0
CELASTRACEAE undiff.	0	0	0	1	0	1	0	0	0	0	3	0	0	0	0
CELTIDACEAE *Celtis*	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0
CHENOPODIACEAE undiff.	0	0	0	0	8	7	6	2	4	0	6	1	4	0	1
COMBRETACEAE *Combretum*	0	0	2	3	0	4	2	2	3	2	2	4	3	2	3
COMMELINACEAE undiff.	0	0	0	0	3	0	1	1	0	1	0	1	3	0	1
CORNACEAE C*ornus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRASSULACEAE *Crassula*	2	2	3	4	2	1	1	2	0	3	3	2	0	2	2
CYPERACEAE A*scolepis*	22	12	19	17	26	18	21	50	48	39	29	38	9	12	5
CYPERACEAE undiff.	17	14	26	39	26	38	45	75	79	82	69	49	58	28	32
EBENACEAE *Euclea*	1	0	1	2	3	1	2	1	0	0	1	0	0	1	1
ERICACEAE undiff.	0	0	1	4	0	1	1	0	0	0	0	0	0	0	0
EUPHORBIACEAE *Acalypha*	0	0	0	0	0	2	1	2	3	1	0	2	0	0	2

Depth	**23**	**24**	**25**	**28**	**32**	**36**	**40**	**44**	**48**	**52**	**56**	**60**	**64**	**68**	**72**
EUPHORBIACEAE *Clutia*	0	0	0	1	1	3	1	3	1	1	0	1	0	0	0
EUPHORBIACEAE *Spirostachys africana*	0	0	0	1	0	0	0	1	0	1	0	4	0	3	0
EUPHORBIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FABACEAE *Burkea africana*	1	2	1	2	0	1	0	0	0	2	1	1	3	0	2
FABACEAE *Psoralea* type	0	0	0	3	5	3	2	0	0	0	0	0	0	1	0
FABACEAE undiff.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
FLACOURTIACEAE *Kiggelaria africana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GENTIANACEAE undiff.	1	0	0	0	0	0	0	0	0	0	4	0	1	0	0
HALOROGACEAE *Gunnera*	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
HALOROGACEAE undiff.	2	0	2	2	0	5	2	0	1	3	1	0	2	2	4
LAMIACEAE undiff.	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
LILIACEAE *Aloe* type	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1
LILIACEAE *Tulbhagia*	2	1	1	2	0	2	1	5	3	3	1	3	3	1	1
MONOLETES undiff.	39	35	39	32	40	58	38	6	9	6	0	9	8	3	6
MYRICACEAE *Myrica*	3	4	2	0	2	0	0	0	0	0	0	0	0	0	0
MYRSINACEAE *Myrsine*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYRTACEAE undiff.	0	2	0	0	1	0	0	0	0	0	1	1	0	0	0
OLEACEAE undiff.	0	0	1	0	0	0	0	0	0	0	2	1	2	0	0
OPHIOGLOSSACEAE undiff.	0	0	0	0	0	0	1	3	3	0	3	0	0	0	3
PINACEAE *Pinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POACEAE <40 µm	231	191	304	341	337	271	304	209	278	324	396	301	381	401	389
PODOCARPACEAE *Podocarpus*	14	3	9	5	27	34	13	29	14	12	7	6	9	2	1
POLYPODIACEAE undiff.	3	0	4	0	0	1	3	0	0	0	0	0	0	0	0
PROTEACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RESTIONACEAE undiff.	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0
ROSACEAE *Cliffortia*	0	0	0	0	1	4	2	0	0	0	0	0	0	0	0
RUBIACEAE *Canthium*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Depth	**23**	**24**	**25**	**28**	**32**	**36**	**40**	**44**	**48**	**52**	**56**	**60**	**64**	**68**	**72**
SAPOTACEAE *Englerophytum*	0	0	0	4	0	0	0	1	0	3	0	2	2	1	0
STERCULIACEAE *Dombeya*	1	0	0	1	1	2	0	4	0	1	2	0	2	0	0
THYMELEACEAE *Passerina*	0	0	1	0	0	3	0	0	0	0	3	8	0	0	0
TILIACEAE *Grewia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRILETES undiff.	37	29	39	34	29	50	41	15	20	22	18	23	29	4	8
TYPHACEAE *Typha*	17	1	11	7	5	15	13	17	18	12	14	14	0	3	2
ZYGOPHYLLACEAE *Tribulus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UNDETERMINED	9	9	6	5	11	6	4	10	9	4	9	7	11	3	0
Sordariaceae *Gelasinospora*	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetomiaceae *Chaetomium*	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0
Sordariaceae undiff.	0	3	0	6	0	0	1	0	4	6	1	0	2	0	4
FUNGAL SPORES other	20	34	36	38	18	31	27	34	34	33	22	21	24	22	26
Pseudoschizea	7	5	3	11	7	5	12	15	3	9	7	7	5	3	8
TOTAL	**435**	**360**	**552**	**590**	**578**	**586**	**541**	**496**	**554**	**591**	**611**	**533**	**591**	**506**	**499**

Depth	**76**	**80**	**84**	**88**	**92**	**96**	**100**	**104**	**108**	**112**	**116**	**120**	**124**	**128**	**132**
Marker count	53	51	50	50	50	50	58	50	53	51	50	50	49	50	50
ACANTHACEAE undiff.	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
AIZOACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANACARDIACEAE *Rhus*	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0
ANACARDIACEAE undiff.	0	0	0	1	3	1	3	0	5	3	4	2	0	0	0
ANTHOCEROTACEAE *Anthoceros*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AQUAFOLIACEAE *Ilex mitis*	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
ASPARAGACEAE *Asparagus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Artemisia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Gerbera*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Stoebe*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Tarconanthus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAEundiff.	3	31	52	38	21	27	42	37	31	23	32	41	38	54	43
ASTERACEAE *Vernonia*	0	0	0	0	0	0	0	0	0	0	5	1	4	0	0
CAMPANULACEAE *Wahlenbergia*	0	1	0	0	0	0	1	2	0	4	2	3	4	3	2
CAPPARACEAE undiff.	1	0	4	3	2	0	4	2	3	0	1	0	0	0	2
CARYOPHYLLACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
CELASTRACEAE undiff.	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
CELTIDACEAE *Celtis*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
CHENOPODIACEAE undiff.	3	0	0	2	0	0	6	4	0	5	3	7	0	0	8
COMBRETACEAE *Combretum*	4	2	3	0	2	0	4	2	4	3	5	2	2	2	4
COMMELINACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
CORNACEAE C*ornus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRASSULACEAE *Crassula*	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0

Depth	**76**	**80**	**84**	**88**	**92**	**96**	**100**	**104**	**108**	**112**	**116**	**120**	**124**	**128**	**132**
CYPERACEAE A*scolepis*	0	12	15	24	32	28	17	19	23	19	24	37	10	0	23
CYPERACEAE undiff.	41	30	27	35	73	59	48	34	51	73	47	42	24	26	38
EBENACEAE *Euclea*	2	0	0	0	0	0	0	2	1	0	0	0	0	0	0
ERICACEAE undiff.	0	0	0	0	1	0	1	0	0	0	0	0	0	0	5
EUPHORBIACEAE *Acalypha*	2	0	0	0	4	6	0	3	2	5	3	0	0	1	0
EUPHORBIACEAE *Clutia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE *Spirostachys africana*	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0
EUPHORBIACEAE undiff.	0	0	0	0	2	0	3	0	2	0	1	0	0	0	0
FABACEAE *Burkea africana*	1	2	3	0	2	1	3	2	3	0	0	0	0	0	0
FABACEAE *Psoralea* type	0	0	0	1	0	0	2	0	1	4	1	1	3	3	5
FABACEAE undiff.	0	1	0	2	0	0	0	0	0	0	0	3	0	0	0
FLACOURTIACEAE *Kiggelaria africana*	0	0	0	0	0	1	3	1	0	0	0	0	0	2	2
GENTIANACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HALOROGACEAE *Gunnera*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HALOROGACEAE undiff.	3	5	1	0	8	14	0	3	9	11	0	0	0	0	0
LAMIACEAE undiff.	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0
LILIACEAE *Aloe* type	0	0	5	2	0	3	5	0	0	0	0	0	0	0	0
LILIACEAE *Tulbhagia*	0	0	0	3	0	0	1	0	2	0	0	0	0	2	4
MONOLETES undiff.	5	11	4	10	3	0	4	0	0	9	19	11	28	14	23
MYRICACEAE *Myrica*	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
MYRSINACEAE *Myrsine*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYRTACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OLEACEAE undiff.	0	2	1	0	0	0	0	0	0	3	0	0	3	0	0
OPHIOGLOSSACEAE undiff.	1	0	0	0	0	0	0	0	0	0	0	5	0	0	3
PINACEAE *Pinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POACEAE <40 µm	396	392	336	375	303	294	299	320	311	279	316	276	300	298	326
PODOCARPACEAE *Podocarpus*	2	3	0	2	7	9	8	7	5	2	3	2	1	4	3

Depth	**76**	**80**	**84**	**88**	**92**	**96**	**100**	**104**	**108**	**112**	**116**	**120**	**124**	**128**	**132**
POLYPODIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PROTEACEAE undiff.	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0
RESTIONACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ROSACEAE *Cliffortia*	0	0	0	0	2	0	0	0	0	1	2	0	0	0	0
RUBIACEAE *Canthium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAPOTACEAE *Englerophytum*	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STERCULIACEAE *Dombeya*	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2
THYMELEACEAE *Passerina*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TILLIACEAE *Grewia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRILETES undiff.	5	9	7	3	21	15	11	25	22	18	8	14	16	12	15
TYPHACEAE *Typha*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZYGOPHYLLACEAE *Tribulus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UNDETERMINED	3	0	0	0	4	3	0	4	0	3	0	0	0	0	0
Sordariaceae *Gelasinospora*	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0
Chaetomiaceae *Chaetomium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sordariaceae undiff.	0	9	5	15	0	0	0	0	0	0	0	0	0	0	0
FUNGAL SPORES other	26	30	39	33	25	26	23	18	7	10	5	0	3	0	8
Pseudoschizea	2	7	0	5	6	13	4	9	6	4	7	5	0	0	0
TOTAL	**502**	**545**	**507**	**549**	**518**	**489**	**490**	**493**	**484**	**479**	**484**	**454**	**436**	**421**	**516**

Depth	**136**	**140**	**144**	**148**	**152**	**156**	**160**	**164**	**168**	**172**	**176**	**180**	**184**	**188**	**192**
Marker count	53	50	50	59	51	50	52	50	50	50	56	50	50	54	55
ACANTHACEAE undiff.	0	0	0	0	0	0	0	0	0	0	2	0	0	4	7
AIZOACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANACARDIACEAE *Rhus*	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
ANACARDIACEAE undiff.	0	2	1	1	2	0	0	0	0	0	1	0	2	3	5
ANTHOCEROTACEAE *Anthoceros*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AQUAFOLIACEAE *Ilex mitis*	0	0	0	0	0	3	0	0	1	0	0	0	3	2	4
ASPARAGACEAE *Asparagus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Artemisia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Gerbera*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Stoebe*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
ASTERACEAE *Tarconanthus*	0	2	4	3	0	2	0	0	0	0	0	3	0	0	0
ASTERACEAEundiff.	36	40	32	52	61	41	48	36	27	38	36	31	62	59	43
ASTERACEAE *Vernonia*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
CAMPANULACEAE *Wahlenbergia*	0	0	0	1	0	0	1	1	0	4	2	3	1	3	6
CAPPARACEAE undiff.	0	3	5	3	3	1	1	0	0	0	0	0	0	4	3
CARYOPHYLLACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CELASTRACEAE undiff.	2	0	4	0	3	3	5	0	0	0	6	0	5	2	0
CELTIDACEAE *Celtis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHENOPODIACEAE undiff.	0	6	0	0	5	0	0	0	0	0	0	0	0	5	9
COMBRETACEAE *Combretum*	3	1	2	0	0	0	0	0	0	2	3	0	5	3	0
COMMELINACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	1	3	0	2
CORNACEAE C*ornus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRASSULACEAE *Crassula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPERACEAE A*scolepis*	21	25	3	0	0	0	0	0	0	0	0	0	0	0	7
CYPERACEAE undiff.	42	29	23	41	31	37	35	28	40	32	39	36	32	49	52
EBENACEAE *Euclea*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Depth	**136**	**140**	**144**	**148**	**152**	**156**	**160**	**164**	**168**	**172**	**176**	**180**	**184**	**188**	**192**
ERICACEAE undiff.	2	0	2	0	3	0	2	0	0	0	2	6	9	10	13
EUPHORBIACEAE *Acalypha*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE *Clutia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
EUPHORBIACEAE *Spirostachys africana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE undiff.	0	0	0	0	4	0	3	0	0	1	0	0	0	0	3
FABACEAE *Burkea africana*	3	1	4	1	0	0	0	0	0	0	0	0	2	3	2
FABACEAE *Psoralea* type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FABACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FLACOURTIACEAE *Kiggelaria africana*	0	0	1	0	2	3	0	0	0	0	3	0	0	0	0
GENTIANACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HALOROGACEAE *Gunnera*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HALOROGACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
LAMIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LILIACEAE *Aloe* type	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0
LILLIACEAE *Tulbhagia*	0	3	0	0	3	1	3	0	4	0	3	0	0	1	6
MONOLETES undiff.	27	24	0	0	0	10	6	15	21	0	16	0	23	26	12
MYRICACEAE *Myrica*	0	0	2	0	3	0	3	0	0	0	0	0	0	0	0
MYRSINACEAE *Myrsine*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYRTACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
OLEACEAE undiff.	0	0	0	3	0	1	3	0	0	0	0	0	0	2	4
OPHIOGLOSSACEAE undiff.	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
PINACEAE *Pinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POACEAE <40 µm	305	346	391	361	342	336	303	396	411	392	349	401	313	309	298
PODOCARPACEAE *Podocarpus*	1	5	7	9	13	11	9	4	8	3	13	7	16	12	17
POLYPODIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	19	28
PROTEACEAE undiff.	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0
RESTIONACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Depth	**136**	**140**	**144**	**148**	**152**	**156**	**160**	**164**	**168**	**172**	**176**	**180**	**184**	**188**	**192**
ROSACEAE *Cliffortia*	0	0	0	2	0	0	0	0	0	0	0	0	0	1	3
RUBIACEAE *Canthium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SAPOTACEAE *Englerophytum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STERCULIACEAE *Dombeya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
THYMELEACEAE *Passerina*	0	0	0	0	0	0	0	0	0	0	5	0	8	5	12
TILLIACEAE *Grewia*	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
TRILETES undiff.	22	17	0	6	0	5	0	0	0	0	12	31	15	33	38
TYPHACEAE *Typha*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
ZYGOPHYLLACEAE *Tribulus*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
UNDETERMINED	0	0	4	0	4	5	3	0	0	0	0	0	0	5	8
Sordariaceae *Gelasinospora*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetomiaceae *Chaetomium*	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
Sordariaceae undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FUNGAL SPORES other	0	5	0	0	9	6	0	0	0	0	0	0	0	0	9
Pseudoschizea	3	0	8	6	0	0	2	4	4	5	4	11	3	8	16
TOTAL	**464**	**513**	**485**	**484**	**488**	**465**	**429**	**480**	**514**	**472**	**496**	**522**	**502**	**563**	**615**

Depth	**196**	**200**	**204**	**208**	**212**	**216**	**220**	**224**	**228**	**232**	**236**	**240**	**244**	**248**	**252**
Marker count	50	50	64	58	50	51	53	56	58	53	50	108	132	118	107
ACANTHACEAE undiff.	0	0	3	0	1	0	0	0	0	3	2	7	8	7	6
AIZOACEAE undiff.	0	0	0	0	2	0	0	0	0	0	2	0	0	0	2
ANACARDIACEAE *Rhus*	0	0	0	1	1	2	3	0	0	0	2	6	0	0	0
ANACARDIACEAE undiff.	1	0	3	0	0	0	3	2	0	1	0	2	2	4	3
ANTHOCEROTACEAE *Anthoceros*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AQUAFOLIACEAE *Ilex mitis*	3	2	1	0	0	0	0	0	2	0	0	0	0	0	0
ASPARAGACEAE *Asparagus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Artemisia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTERACEAE *Gerbera*	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
ASTERACEAE *Stoebe*	0	3	14	0	0	0	3	0	0	5	0	0	0	0	5
ASTERACEAE *Tarconanthus*	3	0	0	1	0	4	2	3	2	0	1	3	0	0	0
ASTERACEAEundiff.	32	45	53	58	56	49	75	64	53	23	36	28	36	22	38
ASTERACEAE *Vernonia*	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0
CAMPANULACEAE *Wahlenbergia*	3	0	1	0	0	0	1	3	2	0	1	0	1	0	0
CAPPARACEAE undiff.	0	0	4	2	2	3	4	1	3	0	2	0	3	5	4
CARYOPHYLLACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
CELASTRACEAE undiff.	4	5	7	3	0	1	3	0	3	0	6	4	3	0	1
CELTIDACEAE *Celtis*	0	0	0	0	0	0	0	1	0	0	0	2	0	1	0
CHENOPODIACEAE undiff.	0	0	0	3	0	0	3	0	0	0	0	0	2	4	12
COMBRETACEAE *Combretum*	3	1	3	2	0	3	2	2	1	0	2	0	0	1	1
COMMELINACEAE undiff.	0	0	2	0	1	0	2	3	2	0	0	2	0	0	2
CORNACEAE C*ornus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRASSULACEAE *Crassula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPERACEAE A*scolepis*	3	0	10	14	10	4	0	3	0	0	5	14	11	3	14
CYPERACEAE undiff.	26	33	35	41	36	32	21	28	31	41	31	33	29	23	26
EBENACEAE *Euclea*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ERICACEAE undiff.	0	0	4	0	1	2	4	3	5	1	1	0	4	1	2
EUPHORBIACEAE *Acalypha*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Depth	**196**	**200**	**204**	**208**	**212**	**216**	**220**	**224**	**228**	**232**	**236**	**240**	**244**	**248**	**252**
EUPHORBIACEAE *Clutia*	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE *Spirostachys africana*	0	0	2	0	0	1	0	0	2	0	0	0	0	0	0
EUPHORBIACEAE undiff.	0	0	3	0	0	1	2	0	2	0	0	0	0	0	0
FABACEAE *Burkea africana*	0	1	0	0	0	2	1	0	0	0	0	0	0	0	0
FABACEAE *Psoralea* type	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
FABACEAE undiff.	1	0	3	0	2	1	0	1	0	0	2	0	0	1	0
FLACOURTIACEAE *Kiggelaria africana*	3	0	0	0	0	2	1	0	1	2	3	0	3	0	5
GENTIANACEAE undiff.	3	0	1	0	0	2	0	0	0	0	1	1	2	1	0
HALOROGACEAE *Gunnera*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HALOROGACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAMIACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LILIACEAE *Aloe* type	4	2	5	0	3	2	5	0	0	0	1	0	0	0	0
LILIACEAE *Tulbhagia*	8	5	6	0	3	2	2	4	2	0	1	2	0	0	0
MONOLETES undiff.	0	17	15	6	12	11	15	10	6	3	5	4	6	5	13
MYRICACEAE *Myrica*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYRSINACEAE *Myrsine*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
MYRTACEAE undiff.	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
OLEACEAE undiff.	2	0	4	0	0	0	1	1	0	2	2	0	0	0	0
OPHIOGLOSSACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	4	12	17
PINACEAE *Pinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POACEAE <40 µm	350	341	361	332	398	316	328	306	299	312	319	303	322	209	398
PODOCARPACEAE *Podocarpus*	19	8	26	17	10	9	7	13	32	1	4	5	6	0	23
POLYPODIACEAE undiff.	0	0	3	0	0	4	0	13	9	33	15	58	31	42	4
PROTEACEAE undiff.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
RESTIONACEAE undiff.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ROSACEAE *Cliffortia*	0	0	1	0	0	0	0	0	0	0	0	0	2	0	2
RUBIACEAE *Canthium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Depth	**196**	**200**	**204**	**208**	**212**	**216**	**220**	**224**	**228**	**232**	**236**	**240**	**244**	**248**	**252**
SAPOTACEAE *Englerophytum*	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
STERCULIACEAE *Dombeya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
THYMELEACEAE *Passerina*	5	1	5	0	0	1	2	5	2	3	6	9	5	6	5
TILIACEAE *Grewia*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRILETES undiff.	0	5	9	12	15	0	2	16	19	36	41	83	104	139	10
TYPHACEAE *Typha*	0	0	13	4	2	0	0	0	0	0	0	4	1	0	0
ZYGOPHYLLACEAE *Tribulus*	0	0	3	0	0	0	0	0	0	0	2	0	0	0	5
UNDETERMINED	6	4	7	0	0	0	6	4	5	0	4	6	3	4	10
Sordariaceae *Gelasinospora*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetomiaceae *Chaetomium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sordariaceae undiff.	0	0	5	0	4	3	0	0	0	0	0	0	0	0	0
FUNGAL SPORES other	8	0	7	0	2	4	0	8	0	0	0	7	3	0	4
Pseudoschizea	12	8	5	8	14	10	12	8	13	4	6	9	12	9	8
TOTAL	**488**	**473**	**623**	**496**	**564**	**461**	**499**	**494**	**484**	**466**	**504**	**583**	**591**	**493**	**612**

Depth	**256**	**260**	**264**	**268**	**272**	**276**	**280**	**284**	**288**	**292**
Marker count	103	108	105	98	128	82	96	156	172	103
ACANTHACEAE undiff.	4	6	12	5	7	0	0	2	0	0
AIZOACEAE undiff.	0	1	0	0	0	0	0	0	0	0
ANACARDIACEAE *Rhus*	0	0	0	0	0	0	1	0	0	0
ANACARDIACEAE undiff.	4	3	9	6	9	0	1	3	2	0
ANTHOCEROTACEAE *Anthoceros*	0	1	0	0	2	5	0	0	0	0
AQUAFOLIACEAE *Ilex mitis*	0	1	0	0	1	0	0	0	0	0
ASPARAGACEAE *Asparagus*	0	0	0	0	0	0	0	0	3	0
ASTERACEAE *Artemisia*	0	0	0	0	3	0	0	6	0	5
ASTERACEAE *Gerbera*	0	0	6	4	8	3	0	4	0	0
ASTERACEAE *Stoebe*	5	4	5	3	15	7	15	28	34	21
ASTERACEAE *Tarconanthus*	0	0	0	0	0	0	0	0	0	0
ASTERACEAEundiff.	46	41	75	68	62	86	78	142	125	71
ASTERACEAE *Vernonia*	0	0	0	0	1	0	0	0	0	0
CAMPANULACEAE *Wahlenbergia*	0	2	0	0	0	2	0	0	0	0
CAPPARACEAE undiff.	3	0	6	4	0	0	3	6	0	0
CARYOPHYLLACEAE undiff.	0	1	7	5	8	0	0	0	0	0
CELASTRACEAE undiff.	1	1	3	0	4	0	0	0	0	0
CELTIDACEAE *Celtis*	1	1	0	0	3	2	0	0	0	0
CHENOPODIACEAE undiff.	13	9	16	12	13	9	5	4	0	4
COMBRETACEAE *Combretum*	2	2	3	2	0	4	0	0	0	0
COMMELINACEAE undiff.	1	2	0	0	0	0	0	0	0	0
CORNACEAE C*ornus*	0	0	0	0	0	0	0	0	2	0
CRASSULACEAE *Crassula*	2	0	0	0	0	2	0	1	0	0
CYPERACEAE A*scolepis*	9	13	0	3	29	28	16	3	0	4
CYPERACEAE undiff.	38	53	24	17	21	28	32	0	9	7
EBENACEAE *Euclea*	0	0	2	0	0	0	0	0	0	0
ERICACEAE undiff.	0	3	35	28	31	0	1	0	0	0
EUPHORBIACEAE *Acalypha*	0	0	3	0	2	0	0	0	0	0
EUPHORBIACEAE *Clutia*	0	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE *Spirostachys africana*	0	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE undiff.	0	0	0	0	0	0	0	0	0	0
FABACEAE *Burkea africana*	0	0	0	0	3	2	0	0	0	0

Depth	**256**	**260**	**264**	**268**	**272**	**276**	**280**	**284**	**288**	**292**
FABACEAE *Psoralea* type	0	0	2	0	2	3	0	0	0	0
FABACEAE undiff.	0	0	2	2	3	4	0	0	0	1
FLACOURTIACEAE *Kiggelaria africana*	3	4	3	2	0	0	2	3	3	4
GENTIANACEAE undiff.	0	0	0	0	2	0	0	0	0	0
HALOROGACEAE *Gunnera*	0	0	2	0	3	1	0	0	0	0
HALOROGACEAE undiff.	0	0	0	0	0	0	0	0	0	0
LAMIACEAE undiff.	0	0	1	0	1	0	0	0	0	0
LILIACEAE *Aloe* type	0	0	0	0	2	0	0	0	0	0
LILLIACEAE *Tulbhagia*	0	2	1	0	0	0	0	0	0	0
MONOLETES undiff.	14	10	21	19	26	6	4	5	1	0
MYRICACEAE *Myrica*	0	0	0	0	0	0	0	0	0	0
MYRSINACEAE *Myrsine*	0	1	0	0	0	0	0	0	0	0
MYRTACEAE undiff.	0	0	0	0	1	0	0	0	0	2
OLEACEAE undiff.	0	0	0	0	1	0	1	0	0	0
OPHIOGLOSSACEAE undiff.	15	12	8	7	7	0	3	4	0	0
PINACEAE *Pinus*	0	0	0	0	0	0	0	0	0	0
POACEAE <40 µm	421	481	356	321	397	401	389	509	511	482
PODOCARPACEAE *Podocarpus*	20	26	27	24	32	11	5	5	8	12
POLYPODIACEAE undiff.	2	7	15	5	4	0	0	0	0	0
PROTEACEAE undiff.	0	0	1	0	1	1	0	0	0	0
RESTIONACEAE undiff.	0	0	0	0	0	0	0	0	0	0
ROSACEAE *Cliffortia*	0	3	0	0	0	0	0	0	0	0
RUBIACEAE *Canthium*	0	0	0	0	0	0	0	0	1	0
SAPOTACEAE *Englerophytum*	0	0	2	0	0	0	0	0	0	0
STERCULIACEAE *Dombeya*	0	0	2	0	2	1	0	0	0	0
THYMELEACEAE *Passerina*	6	5	14	11	8	0	3	4	1	0
TILIACEAE *Grewia*	0	0	0	0	0	0	0	0	0	0
TRILETES undiff.	14	13	14	7	9	6	0	0	0	0
TYPHACEAE *Typha*	0	0	0	0	15	6	4	0	0	2
ZYGOPHYLLACEAE *Tribulus*	6	8	0	0	0	0	0	0	0	0
UNDETERMINED	13	18	11	3	4	0	2	3	2	0
Sordariaceae *Gelasinospora*	0	0	0	0	0	0	0	0	0	0

Depth	**256**	**260**	**264**	**268**	**272**	**276**	**280**	**284**	**288**	**292**
Chaetomiaceae *Chaetomium*	0	0	0	0	0	0	0	0	0	0
Sordariaceae undiff.	0	0	0	0	0	0	0	0	0	0
FUNGAL SPORES other	3	3	0	0	7	32	6	2	0	0
Pseudoschizea	10	12	13	11	16	19	3	2	0	3
TOTAL	**646**	**737**	**688**	**558**	**749**	**650**	**571**	**734**	**702**	**615**

APPENDIX J

RAW CHARCOAL COUNTS

Depth	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**12**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**23**	**24**
Marker count	53	55	50	50	59	56	58	51	50	50	53	50	56	50	52	50	53
Charcoal <25 µm	532	502	493	480	582	636	603	680	716	723	699	738	861	857	927	1192	1123
Charcoal 25—75 µm	81	72	46	32	41	84	92	108	117	128	119	123	109	115	152	179	168
Charcoal 75—100 µm	29	31	20	15	19	13	25	36	29	20	30	22	24	27	56	78	71
TOTAL	**642**	**605**	**559**	**527**	**642**	**733**	**720**	**824**	**862**	**871**	**848**	**883**	**994**	**999**	**1135**	**1449**	**1362**

Depth	**25**	**28**	**32**	**36**	**40**	**44**	**48**	**52**	**56**	**60**	**64**	**68**	**76**	**72**	**80**	**84**	**88**
Marker count	50	51	54	52	50	80	61	52	62	51	96	53	51	53	51	50	50
Charcoal <25 µm	693	626	690	701	682	769	621	581	593	302	533	383	445	341	208	143	192
Charcoal 25—75 µm	143	132	90	73	61	74	53	51	46	31	29	19	33	22	31	62	101
Charcoal 75—100 µm	35	22	22	27	13	50	25	22	31	11	31	18	15	9	23	17	21
TOTAL	**871**	**780**	**802**	**801**	**756**	**893**	**699**	**654**	**670**	**344**	**593**	**420**	**493**	**372**	**262**	**222**	**314**

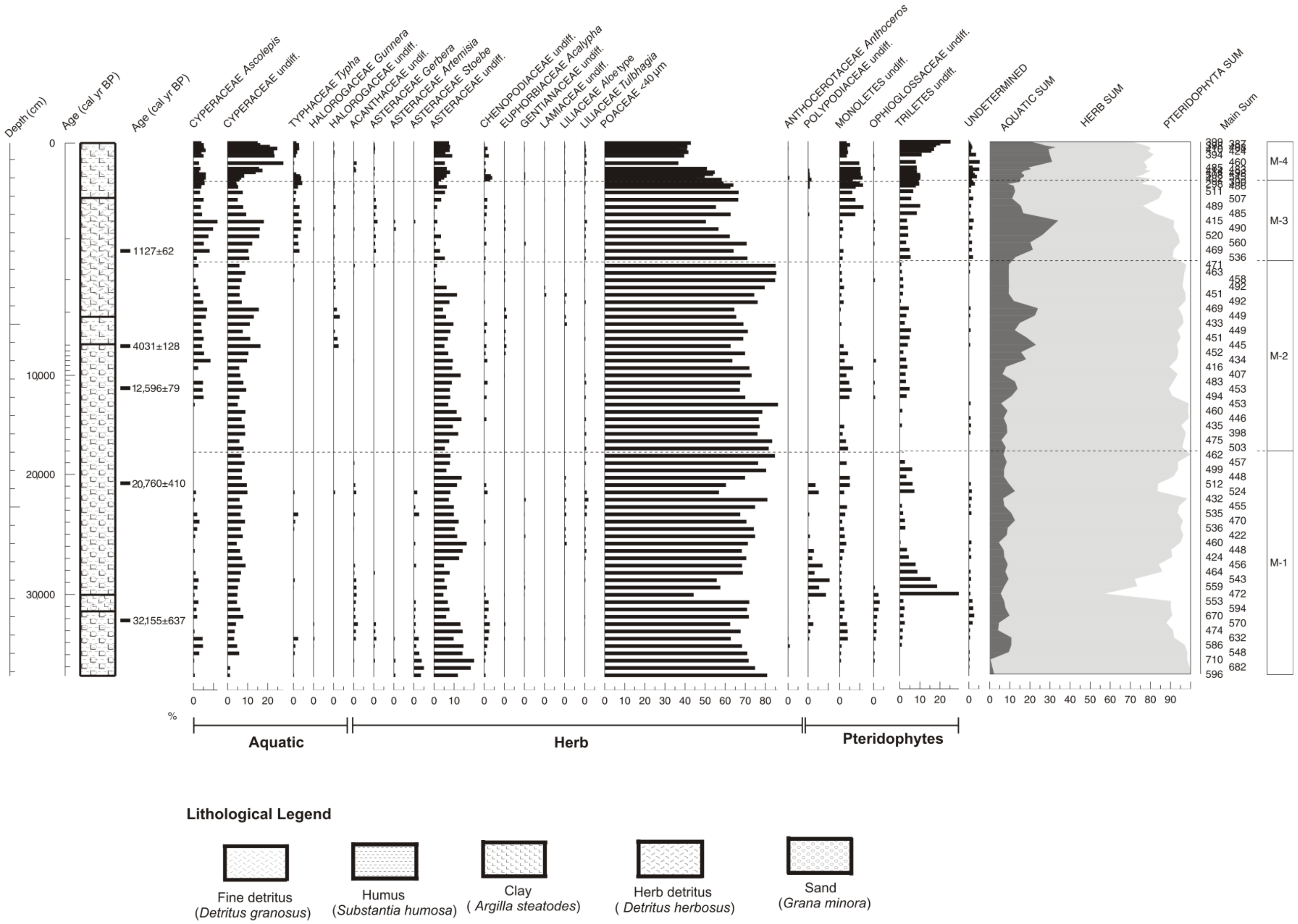
Depth	**92**	**96**	**100**	**104**	**108**	**112**	**116**	**120**	**124**	**128**	**132**	**136**	**140**	**144**	**148**	**152**	**156**
Marker count	50	50	58	50	53	51	50	50	49	50	50	53	50	50	59	51	50
Charcoal <25 µm	282	293	282	323	252	167	37	29	33	48	58	46	24	38	26	31	18
Charcoal 25—75 µm	37	21	33	20	23	31	18	20	0	12	15	9	11	4	0	0	0
Charcoal 75—100 µm	10	14	19	9	15	12	4	2	0	7	0	0	0	5	0	0	0
TOTAL	**329**	**328**	**334**	**352**	**290**	**210**	**59**	**51**	**33**	**67**	**73**	**55**	**35**	**47**	**26**	**31**	**18**

Depth	**160**	**164**	**168**	**172**	**176**	**180**	**184**	**188**	**192**	**196**	**200**	**204**	**208**	**212**	**216**	**220**	**224**
Marker count	52	50	50	50	56	50	50	54	55	50	50	64	58	50	51	53	56
Charcoal <25 µm	24	36	15	12	16	18	23	32	34	45	36	125	55	33	18	29	41
Charcoal 25—75 µm	0	0	0	0	0	0	0	18	26	0	14	29	16	7	12	9	8
Charcoal 75—100 µm	1	0	0	0	0	0	0	12	19	0	0	11	5	0	0	0	6
TOTAL	**25**	**36**	**15**	**12**	**16**	**18**	**23**	**62**	**79**	**45**	**50**	**165**	**76**	**40**	**30**	**38**	**55**

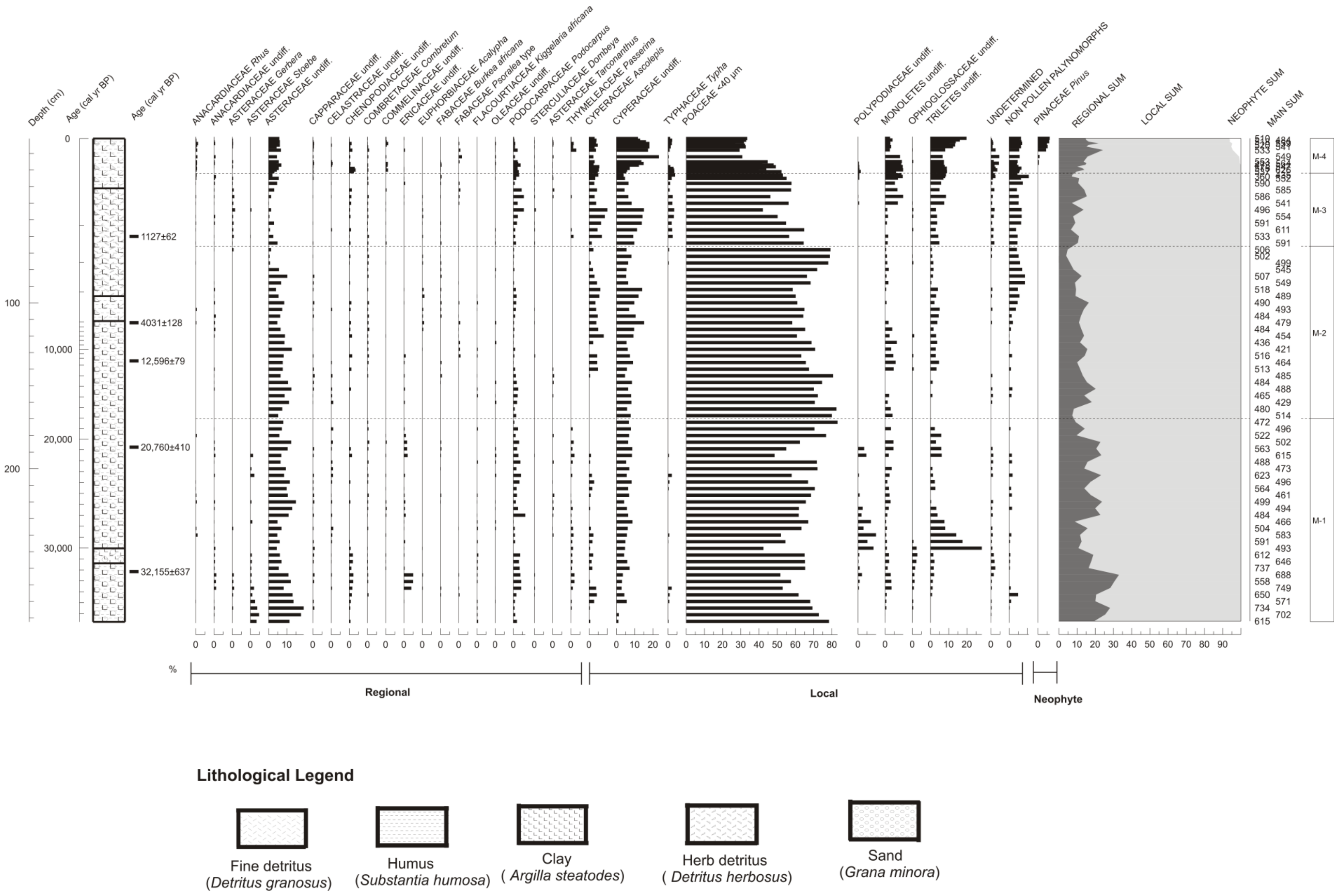
Depth	**228**	**232**	**236**	**240**	**244**	**248**	**252**	**256**	**260**	**264**	**268**	**272**	**276**	**280**	**284**	**288**	**292**
Marker count	58	53	50	108	132	118	107	103	108	105	98	128	82	96	156	172	103
Charcoal <25 µm	36	32	28	201	183	121	154	173	182	153	169	268	172	98	53	26	41
Charcoal 25—75 µm	3	14	6	62	43	22	18	25	19	43	52	33	48	25	11	5	4
Charcoal 75—100 µm	3	0	2	13	18	5	12	4	15	11	4	15	11	5	1	0	0
TOTAL	**42**	**46**	**36**	**276**	**244**	**148**	**184**	**202**	**216**	**207**	**225**	**316**	**231**	**128**	**65**	**31**	**45**

APPENDIX K

ADDITIONAL POLLEN DIAGRAMS



Appendix K: Local pollen diagram showing aquatic vs. ubiquitous pollen taxa, plotted against a dual age-depth axis with associated Troels-Smith stratigraphy



Appendix K: Summary pollen diagram showing dominant regional and local taxa, plotted against a dual age-depth axis, showing Troels-Smith stratigraphy

APPENDIX L

SPECIES LIST OF MUTALE WETLAND (adapted from SANBI Integrated Biodiversity Information System).

Family	Scientific name	Collection code
ACANTHACEAE	*Barleria transvaalensis*	Gardens (KBG)
ACANTHACEAE	*Isoglossa sp.*	Gardens (KBG)
ACANTHACEAE	*Thunbergia atriplicifolia*	PRECIS
ACANTHACEAE	*Dyschoriste depressa*	PRECIS
ACANTHACEAE	*Chaetacanthus burchellii*	PRECIS
ACANTHACEAE	*Ruellia cordata*	PRECIS
ACANTHACEAE	*Crossandra greenstockii*	PRECIS
ACANTHACEAE	*Dicliptera minor subsp. pratis-manna*	PRECIS
ACANTHACEAE	*Thunbergia neglecta*	PRECIS
ACANTHACEAE	*Justicia campylostemon*	PRECIS
ACANTHACEAE	*Justicia protracta subsp. protracta*	PRECIS
ACANTHACEAE	*Thunbergia amoena*	PRECIS
ACANTHACEAE	*Phaulopsis imbricata subsp. imbricata*	PRECIS
ACANTHACEAE	*Crabbea hirsuta*	PRECIS
ACANTHACEAE	*Asystasia schimperi*	PRECIS
ACANTHACEAE	*Hypoestes triflora*	PRECIS
ACANTHACEAE	*Justicia betonica*	PRECIS
ACANTHACEAE	*Barleria elegans*	PRECIS
ACANTHACEAE	*Monechma divaricatum*	PRECIS
ACANTHACEAE	*Dyschoriste rogersii*	PRECIS
ACANTHACEAE	*Barleria saxatilis*	PRECIS
ACHARIACEAE	*Rawsonia lucida*	PRECIS
ACHARIACEAE	*Kiggelaria africana*	PRECIS
AGAPANTHACEAE	*Agapanthus inapertus subsp. inapertus*	PRECIS
AIZOACEAE	*Zaleya pentandra*	PRECIS
AMARANTHACEAE	*Amaranthus thunbergii*	PRECIS
AMARANTHACEAE	*Alternanthera sessilis*	PRECIS
AMARANTHACEAE	*Alternanthera pungens*	PRECIS
AMARANTHACEAE	*Kyphocarpa angustifolia*	PRECIS
AMARANTHACEAE	*Gomphrena celosioides*	PRECIS
AMARANTHACEAE	*Achyropsis avicularis*	PRECIS
AMARANTHACEAE	*Aerva leucura*	PRECIS
AMARANTHACEAE	*Pupalia lappacea var. lappacea*	PRECIS
AMARANTHACEAE	*Achyranthes aspera var. pubescens*	PRECIS
AMARANTHACEAE	*Amaranthus hybridus subsp. cruentus*	PRECIS
AMARANTHACEAE	*Hermbstaedtia odorata var. odorata*	PRECIS

Family	Scientific name	Collection code
AMARANTHACEAE	*Amaranthus praetermissus*	PRECIS
AMARANTHACEAE	*Hermbstaedtia fleckii*	PRECIS
AMARYLLIDACEAE	*Clivia caulescens*	Gardens (KBG)
AMARYLLIDACEAE	*Scadoxus puniceus*	PRECIS
AMARYLLIDACEAE	*Crinum macowanii*	PRECIS
ANACARDIACEAE	*Ozoroa paniculosa var. paniculosa*	MSB
ANACARDIACEAE	*Mangifera indica*	PRECIS
ANACARDIACEAE	*Lannea discolor*	PRECIS
ANACARDIACEAE	*Lannea edulis var. edulis*	PRECIS
ANACARDIACEAE	*Searsia rehmanniana var. rehmanniana*	PRECIS
ANACARDIACEAE	*Searsia pentheri*	PRECIS
ANACARDIACEAE	*Searsia transvaalensis*	PRECIS
ANACARDIACEAE	*Ozoroa albicans*	PRECIS
ANACARDIACEAE	*Searsia pyroides var. pyroides*	PRECIS
ANACARDIACEAE	*Searsia chirindensis*	PRECIS
ANACARDIACEAE	*Ozoroa insignis subsp. reticulata*	PRECIS
ANACARDIACEAE	*Searsia leptodictya forma leptodictya*	PRECIS
ANACARDIACEAE	*Sclerocarya birrea subsp. caffra*	PRECIS
ANNONACEAE	*Annona senegalensis subsp. senegalensis*	PRECIS
ANNONACEAE	*Xylopia parviflora*	PRECIS
ANTHERICACEAE	*Chlorophytum bowkeri*	PRECIS
ANTHERICACEAE	*Chlorophytum recurvifolium*	PRECIS
ANTHERICACEAE	*Chlorophytum galpinii var. galpinii*	PRECIS
APIACEAE	*Centella asiatica*	PRECIS
APIACEAE	*Alepidea peduncularis*	PRECIS
APIACEAE	*Heteromorpha arborescens var. abyssinica*	PRECIS
APIACEAE	*Apium graveolens*	PRECIS
APOCYNACEAE	*Carissa edulis*	PRECIS
APOCYNACEAE	*Carissa bispinosa*	PRECIS
APOCYNACEAE	*Secamone filiformis*	PRECIS
APOCYNACEAE	*Orbea melanantha*	PRECIS
APOCYNACEAE	*Rauvolfia caffra*	PRECIS
APOCYNACEAE	*Raphionacme procumbens*	PRECIS
APOCYNACEAE	*Pachycarpus asperifolius*	PRECIS
APOCYNACEAE	*Landolphia kirkii*	PRECIS
APOCYNACEAE	*Riocreuxia torulosa var. torulosa*	PRECIS
APOCYNACEAE	*Tabernaemontana elegans*	PRECIS
APOCYNACEAE	*Schizoglossum cordifolium*	PRECIS
APOCYNACEAE	*Pergularia daemia subsp. daemia*	PRECIS
APOCYNACEAE	*Pergularia daemia var. daemia*	PRECIS
APOCYNACEAE	*Acokanthera oppositifolia*	PRECIS
APOCYNACEAE	*Pachycarpus sp.*	PRECIS
APOCYNACEAE	*Marsdenia sylvestris*	PRECIS
APOCYNACEAE	*Adenium multiflorum*	PRECIS

Family	**Scientific name**	**Collection code**
APOCYNACEAE	*Schizoglossum garcianum*	PRECIS
APOCYNACEAE	*Asclepias multicaulis*	PRECIS
ARACEAE	*Zantedeschia albomaculata subsp. albomaculata*	PRECIS
ARACEAE	*Stylochaeton natalensis*	PRECIS
ARALIACEAE	*Schefflera umbellifera*	PRECIS
ARALIACEAE	*Cussonia spicata*	PRECIS
ASPARAGACEAE	*Asparagus asparagoides*	PRECIS
ASPARAGACEAE	*Asparagus racemosus*	PRECIS
ASPARAGACEAE	*Asparagus virgatus*	PRECIS
ASPARAGACEAE	*Asparagus buchananii*	PRECIS
ASPARAGACEAE	*Asparagus angusticladus*	PRECIS
ASPARAGACEAE	*Asparagus cooperi*	PRECIS
ASPARAGACEAE	*Asparagus setaceus*	PRECIS
ASPHODELACEAE	*Aloe greatheadii var. davyana*	MSB
ASPHODELACEAE	*Aloe verecunda*	PRECIS
ASPHODELACEAE	*Aloe vogtsii*	PRECIS
ASPHODELACEAE	*Trachyandra saltii var. saltii*	PRECIS
ASPHODELACEAE	*Aloe petrophila*	PRECIS
ASPHODELACEAE	*Aloe lutescens*	PRECIS
ASPHODELACEAE	*Aloe chabaudii var. chabaudii*	PRECIS
ASPLENIACEAE	*Asplenium phillipsianum*	PRECIS
ASTERACEAE	*Vernonia amygdalina*	MSB
ASTERACEAE	*Vernonia myriantha*	MSB
ASTERACEAE	*Helichrysum kraussii*	PRECIS
ASTERACEAE	*Helichrysum nudifolium var. nudifolium*	PRECIS
ASTERACEAE	*Phymaspermum bolusii*	PRECIS
ASTERACEAE	*Helichrysum setosum*	PRECIS
ASTERACEAE	*Tripteris auriculata*	PRECIS
ASTERACEAE	*Gymnanthemum crataegifolium*	PRECIS
ASTERACEAE	*Ageratum conyzoides*	PRECIS
ASTERACEAE	*Laggera crispata*	PRECIS
ASTERACEAE	*Spilanthes mauritiana*	PRECIS
ASTERACEAE	*Helichrysum adenocarpum subsp. adenocarpum*	PRECIS
ASTERACEAE	*Inula glomerata*	PRECIS
ASTERACEAE	*Sigesbeckia orientalis*	PRECIS
ASTERACEAE	*Coreopsis sp.*	PRECIS
ASTERACEAE	*Cineraria sp.*	PRECIS
ASTERACEAE	*Gymnanthemum coloratum*	PRECIS
ASTERACEAE	*Senecio pleistocephalus*	PRECIS
ASTERACEAE	*Gazania krebsiana subsp. serrulata*	PRECIS
ASTERACEAE	*Senecio pterophorus*	PRECIS
ASTERACEAE	*Senecio inaequidens*	PRECIS
ASTERACEAE	*Senecio latifolius*	PRECIS
ASTERACEAE	*Berkheya zeyheri subsp. rehmannii var. rehmannii*	PRECIS
ASTERACEAE	*Berkheya sp.*	PRECIS

Family	**Scientific name**	**Collection code**
ASTERACEAE	*Senecio sp.*	PRECIS
ASTERACEAE	*Sonchus oleraceus*	PRECIS
ASTERACEAE	*Launaea nana*	PRECIS
ASTERACEAE	*Gerbera ambigua*	PRECIS
ASTERACEAE	*Gerbera jamesonii*	PRECIS
ASTERACEAE	*Brachylaena discolor subsp. transvaalensis*	PRECIS
ASTERACEAE	*Nidorella resedifolia subsp. resedifolia*	PRECIS
ASTERACEAE	*Pseudognaphalium oligandrum*	PRECIS
ASTERACEAE	*Helichrysum harveyanum*	PRECIS
ASTERACEAE	*Hilliardiella oligocephala*	PRECIS
ASTERACEAE	*Vernonia fastigiata*	PRECIS
ASTERACEAE	*Macledium zeyheri subsp. zeyheri*	PRECIS
ASTERACEAE	*Vernonia triflora*	PRECIS
ASTERACEAE	*Cotula anthemoides*	PRECIS
ASTERACEAE	*Senecio madagascariensis*	PRECIS
ASTERACEAE	*Felicia mossamedensis*	PRECIS
ASTERACEAE	*Senecio gerrardii*	PRECIS
ASTERACEAE	*Tithonia diversifolia*	PRECIS
ASTERACEAE	*Helichrysum odoratissimum var. odoratissimum*	PRECIS
ASTERACEAE	*Schistostephium heptalobum*	PRECIS
ASTERACEAE	*Berkheya bipinnatifida subsp. echinopsoides*	PRECIS
ASTERACEAE	*Hilliardiella aristata*	PRECIS
ASTERACEAE	*Gamochaeta coarctata*	PRECIS
ASTERACEAE	*Senecio polyanthemoides*	PRECIS
ASTERACEAE	*Senecio deltoideus*	PRECIS
ASTERACEAE	*Helichrysum panduratum var. transvaalense*	PRECIS
ASTERACEAE	*Gymnanthemum amygdalinum*	PRECIS
ASTERACEAE	*Pulicaria scabra*	PRECIS
ASTERACEAE	*Hilliardiella hirsuta*	PRECIS
ASTERACEAE	*Felicia muricata subsp. muricata*	PRECIS
ASTERACEAE	*Pseudognaphalium luteo-album*	PRECIS
ASTERACEAE	*Artemisia afra var. afra*	PRECIS
ASTERACEAE	*Conyza sumatrensis var. sumatrensis*	PRECIS
ASTERACEAE	*Conyza attenuata*	PRECIS
ASTERACEAE	*Brachylaena sp.*	PRECIS
ASTERACEAE	*Brachylaena transvaalensis*	PRECIS
ASTERACEAE	*Acanthospermum hispidum*	PRECIS
ASTERACEAE	*Crassocephalum x picridifolium*	PRECIS
ASTERACEAE	*Senecio erubescens var. erubescens*	PRECIS
ASTERACEAE	*Bothriocline laxa*	PRECIS
ASTERACEAE	*Dimorphotheca caulescens*	PRECIS
ASTERACEAE	*Senecio albanensis var. doroniciflorus*	PRECIS
ASTERACEAE	*Berkheya latifolia*	PRECIS
ASTERACEAE	*Sphaeranthus peduncularis subsp. peduncularis*	PRECIS
ASTERACEAE	*Helichrysum lineare*	PRECIS

Family	**Scientific name**	**Collection code**
ASTERACEAE	*Linzia glabra*	PRECIS
ASTERACEAE	*Helichrysum truncatum*	PRECIS
ASTERACEAE	*Helichrysum lepidissimum*	PRECIS
ASTERACEAE	*Helichrysum cephaloideum*	PRECIS
ASTERACEAE	*Athrixia phylicoides*	PRECIS
ASTERACEAE	*Blumea dregeanoides*	PRECIS
ASTERACEAE	*Denekia capensis*	PRECIS
ASTERACEAE	*Litogyne gariepina*	PRECIS
ASTERACEAE	*Aspilia mossambicensis*	PRECIS
ASTERACEAE	*Pechuel-Loeschea leubnitziae*	PRECIS
ASTERACEAE	*Pluchea bojeri*	PRECIS
ASTERACEAE	*Helichrysum umbraculigerum*	PRECIS
ASTERACEAE	*Vernonia steetziana*	*PRECIS*
ASTERACEAE	*Dicoma tomentosa*	*PRECIS*
ASTERACEAE	*Eclipta prostrata*	*PRECIS*
AYTONIACEAE	*Asterella wilmsii*	*PRECIS*
BARTRAMIACEAE	*Philonotis dregeana*	*PRECIS*
BIGNONIACEAE	*Tecoma capensis*	*PRECIS*
BORAGINACEAE	*Cordia caffra*	*PRECIS*
BORAGINACEAE	*Ehretia rigida subsp. nervifolia*	*PRECIS*
BORAGINACEAE	*Ehretia amoena*	*PRECIS*
BORAGINACEAE	*Trichodesma zeylanicum*	*PRECIS*
BORAGINACEAE	*Cynoglossum lanceolatum*	*PRECIS*
BORAGINACEAE	*Cordia africana*	*PRECIS*
BORAGINACEAE	*Heliotropium zeylanicum*	*PRECIS*
BORAGINACEAE	*Trichodesma physaloides*	*PRECIS*
BORAGINACEAE	*Heliotropium ovalifolium*	*PRECIS*
BRASSICACEAE	*Lepidium schinzii*	*PRECIS*
BRASSICACEAE	*Lepidium africanum subsp. africanum*	*PRECIS*
BRASSICACEAE	*Rorippa nudiuscula*	*PRECIS*
BRYACEAE	*Brachymenium pulchrum*	*PRECIS*
BRYACEAE	*Bryum pycnophyllum*	*PRECIS*
BRYACEAE	*Bryum argenteum*	*PRECIS*
BRYACEAE	*Rhodobryum roseum*	*PRECIS*
BUDDLEJACEAE	*Nuxia floribunda*	*PRECIS*
BURSERACEAE	*Commiphora africana var. africana*	*PRECIS*
BURSERACEAE	*Commiphora mollis*	*PRECIS*
CAMPANULACEAE	*Wahlenbergia virgata*	*PRECIS*
CAPPARACEAE	*Cleome monophylla*	*MSB*
CAPPARACEAE	*Capparis fascicularis var. fascicularis*	*PRECIS*
CAPPARACEAE	*Cadaba termitaria*	*PRECIS*
CAPPARACEAE	*Capparis tomentosa*	*PRECIS*
CAPPARACEAE	*Cleome gynandra*	*PRECIS*
CAPPARACEAE	*Maerua juncea subsp. crustata*	*PRECIS*
CAPPARACEAE	*Maerua parvifolia*	*PRECIS*

Family	**Scientific name**	**Collection code**
CARYOPHYLLACEAE	*Pollichia campestris*	*PRECIS*
CELASTRACEAE	*Catha edulis*	*PRECIS*
CELASTRACEAE	*Maytenus undata*	*PRECIS*
CELASTRACEAE	*Gymnosporia senegalensis*	*PRECIS*
CELASTRACEAE	*Gymnosporia harveyana subsp. harveyana*	*PRECIS*
CELASTRACEAE	*Gymnosporia buxifolia*	*PRECIS*
CELASTRACEAE	*Pterocelastrus echinatus*	*PRECIS*
CELASTRACEAE	*Elaeodendron transvaalense*	*PRECIS*
CELTIDACEAE	*Trema orientalis*	*PRECIS*
CELTIDACEAE	*Celtis africana*	*PRECIS*
CELTIDACEAE	*Chaetacme aristata*	*PRECIS*
CHENOPODIACEAE	*Chenopodium cristatum*	*MSB*
CHENOPODIACEAE	*Chenopodium carinatum*	*PRECIS*
CHENOPODIACEAE	*Chenopodium album*	*PRECIS*
CHRYSOBALANACEAE	*Parinari curatellifolia*	*PRECIS*
CLADONIACEAE	*Cladonia sp.*	*PRECIS*
COLCHICACEAE	*Gloriosa superba*	*PRECIS*
COMBRETACEAE	*Combretum erythrophyllum*	*PRECIS*
COMBRETACEAE	*Combretum hereroense*	*PRECIS*
COMBRETACEAE	*Combretum collinum subsp. suluense*	*PRECIS*
COMBRETACEAE	*Combretum molle*	*PRECIS*
COMBRETACEAE	*Combretum imberbe*	*PRECIS*
COMBRETACEAE	*Terminalia sericea*	*PRECIS*
COMBRETACEAE	*Combretum collinum subsp. gazense*	*PRECIS*
COMBRETACEAE	*Combretum zeyheri*	*PRECIS*
COMBRETACEAE	*Combretum paniculatum*	*PRECIS*
COMBRETACEAE	*Combretum kraussii*	*PRECIS*
COMBRETACEAE	*Combretum microphyllum*	*PRECIS*
COMBRETACEAE	*Combretum sp.*	*PRECIS*
COMMELINACEAE	*Commelina erecta*	*PRECIS*
COMMELINACEAE	*Cyanotis speciosa*	*PRECIS*
COMMELINACEAE	*Commelina benghalensis*	*PRECIS*
COMMELINACEAE	*Commelina africana var. africana*	*PRECIS*
COMMELINACEAE	*Aneilema aequinoctiale*	*PRECIS*
CONNARACEAE	*Cnestis polyphylla*	*PRECIS*
CONVOLVULACEAE	*Xenostegia tridentata subsp. angustifolia*	*MSB*
CONVOLVULACEAE	*Convolvulus farinosus*	*PRECIS*
CONVOLVULACEAE	*Ipomoea papilio*	*PRECIS*
CONVOLVULACEAE	*Ipomoea albivenia*	*PRECIS*
CONVOLVULACEAE	*Ipomoea crassipes var. crassipes*	*PRECIS*
CONVOLVULACEAE	*Evolvulus alsinoides*	*PRECIS*
CONVOLVULACEAE	*Convolvulus sagittatus*	*PRECIS*
CONVOLVULACEAE	*Ipomoea involucrata var. involucrata*	*PRECIS*
CONVOLVULACEAE	*Ipomoea cairica var. cairica*	*PRECIS*
CONVOLVULACEAE	*Ipomoea wightii var. wightii*	*PRECIS*

Family	**Scientific name**	**Collection code**
CONVOLVULACEAE	*Ipomoea magnusiana*	*PRECIS*
CONVOLVULACEAE	*Seddera suffruticosa*	*PRECIS*
CONVOLVULACEAE	*Ipomoea shirambensis*	*PRECIS*
CONVOLVULACEAE	*Ipomoea robertsiana*	*PRECIS*
CONVOLVULACEAE	*Ipomoea simplex*	*PRECIS*
CONVOLVULACEAE	*Dichondra repens*	*PRECIS*
CORNACEAE	*Curtisia dentata*	*PRECIS*
CRASSULACEAE	*Crassula lanceolata subsp. transvaalensis*	*PRECIS*
CRASSULACEAE	*Kalanchoe rotundifolia*	*PRECIS*
CRASSULACEAE	*Crassula vaginata subsp. vaginata*	*PRECIS*
CUCURBITACEAE	*Cucurbita sp.*	*Gardens (KBG)*
CUCURBITACEAE	*Momordica cardiospermoides*	*PRECIS*
CUCURBITACEAE	*Cucumis zeyheri*	*PRECIS*
CUCURBITACEAE	*Coccinia adoensis*	*PRECIS*
CUCURBITACEAE	*Momordica foetida*	*PRECIS*
CUCURBITACEAE	*Cucumis africanus*	*PRECIS*
CUCURBITACEAE	*Lagenaria sphaerica*	*PRECIS*
CUPRESSACEAE	*Widdringtonia nodiflora*	*PRECIS*
CYPERACEAE	*Pycreus pelophilus*	*PRECIS*
CYPERACEAE	*Cyperus sexangularis*	*PRECIS*
CYPERACEAE	*Isolepis sepulcralis*	*PRECIS*
CYPERACEAE	*Cyperus keniensis*	*PRECIS*
CYPERACEAE	*Cyperus latifolius*	*PRECIS*
CYPERACEAE	*Isolepis costata*	*PRECIS*
CYPERACEAE	*Cyperus dives*	*PRECIS*
CYPERACEAE	*Cyperus dichroostachyus*	*PRECIS*
CYPERACEAE	*Cyperus fastigiatus*	*PRECIS*
CYPERACEAE	*Pycreus mundii*	*PRECIS*
CYPERACEAE	*Pycreus nitidus*	*PRECIS*
CYPERACEAE	*Pycreus polystachyos var. polystachyos*	*PRECIS*
CYPERACEAE	*Fimbristylis dichotoma subsp. dichotoma*	*PRECIS*
CYPERACEAE	*Cyperus sphaerospermus*	*PRECIS*
CYPERACEAE	*Lipocarpha chinensis*	*PRECIS*
CYPERACEAE	*Bulbostylis contexta*	*PRECIS*
CYPERACEAE	*Schoenoplectus brachyceras*	*PRECIS*
CYPERACEAE	*Cyperus distans*	*PRECIS*
CYPERACEAE	*Kyllinga melanosperma*	*PRECIS*
CYPERACEAE	*Pycreus muricatus*	*PRECIS*
CYPERACEAE	*Cyperus cyperoides subsp. cyperoides*	*PRECIS*
CYPERACEAE	*Carex rhodesiaca*	*PRECIS*
CYPERACEAE	*Cyperus esculentus var. esculentus*	*PRECIS*
CYPERACEAE	*Fuirena stricta var. stricta*	*PRECIS*
CYPERACEAE	*Cyperus austro-africanus*	*PRECIS*

Family	**Scientific name**	**Collection code**
CYPERACEAE	*Kyllinga alba*	*PRECIS*
CYPERACEAE	*Cyperus rupestris var. rupestris*	*PRECIS*
CYPERACEAE	*Schoenoplectus muricinux*	*PRECIS (KZN)*
DENNSTAEDTIACEAE	*Pteridium aquilinum subsp. aquilinum*	*PRECIS*
DICRANACEAE	*Campylopus robillardei*	*PRECIS*
DIOSCOREACEAE	*Dioscorea cotinifolia*	*PRECIS*
DIOSCOREACEAE	*Dioscorea sylvatica var. sylvatica*	*PRECIS*
DIOSCOREACEAE	*Dioscorea quartiniana*	*PRECIS*
EBENACEAE	*Diospyros lycioides subsp. sericea*	*PRECIS*
EBENACEAE	*Euclea crispa subsp. crispa*	*PRECIS*
EBENACEAE	*Diospyros villosa var. parvifolia*	*PRECIS*
EBENACEAE	*Diospyros mespiliformis*	*PRECIS*
EBENACEAE	*Euclea sp.*	*PRECIS*
EBENACEAE	*Euclea divinorum*	*PRECIS*
EBENACEAE	*Diospyros lycioides subsp. guerkei*	*PRECIS*
ENTODONTACEAE	*Entodon macropodus*	*PRECIS*
EQUISETACEAE	*Equisetum ramosissimum subsp. ramosissimum*	*PRECIS*
ERICACEAE	*Erica simii*	*PRECIS*
ERPODIACEAE	*Aulacopilum trichophyllum*	*PRECIS*
ESCALLONIACEAE	*Choristylis rhamnoides*	*PRECIS*
EUPHORBIACEAE	*Synadenium cupulare*	*PRECIS*
EUPHORBIACEAE	*Jatropha zeyheri*	*PRECIS*
EUPHORBIACEAE	*Euphorbia natalensis*	*PRECIS*
EUPHORBIACEAE	*Acalypha glabrata var. glabrata*	*PRECIS*
EUPHORBIACEAE	*Acalypha villicaulis*	*PRECIS*
EUPHORBIACEAE	*Ricinus communis var. communis*	*PRECIS*
EUPHORBIACEAE	*Croton sylvaticus*	*PRECIS*
EUPHORBIACEAE	*Euphorbia indica*	*PRECIS*
EUPHORBIACEAE	*Clutia affinis*	*PRECIS*
EUPHORBIACEAE	*Acalypha peduncularis*	*PRECIS*
EUPHORBIACEAE	*Ctenomeria capensis*	*PRECIS*
EUPHORBIACEAE	*Manihot esculenta*	*PRECIS*
EUPHORBIACEAE	*Euphorbia transvaalensis*	*PRECIS*
EUPHORBIACEAE	*Euphorbia tirucalli*	*PRECIS*
FABACEAE	*Acacia polyacantha subsp. campylacantha*	*MSB*
FABACEAE	*Acacia rehmanniana*	*MSB*
FABACEAE	*Chamaecrista plumosa var. erecta*	*MSB*
FABACEAE	*Tylosema fassoglense*	*PRECIS*
FABACEAE	*Piliostigma thonningii*	*PRECIS*
FABACEAE	*Senna petersiana*	*PRECIS*
FABACEAE	*Acacia sp.*	*PRECIS*
FABACEAE	*Acacia karroo*	*PRECIS*
FABACEAE	*Senna septemtrionalis*	*PRECIS*
FABACEAE	*Chamaecrista absus*	*PRECIS*
FABACEAE	*Acacia permixta*	*PRECIS*

Family	**Scientific name**	**Collection code**
FABACEAE	*Pterolobium stellatum*	*PRECIS*
FABACEAE	*Peltophorum africanum*	*PRECIS*
FABACEAE	*Bauhinia galpinii*	*PRECIS*
FABACEAE	*Acacia davyi*	*PRECIS*
FABACEAE	*Acacia tortilis subsp. heteracantha*	*PRECIS*
FABACEAE	*Mucuna coriacea subsp. irritans*	*PRECIS*
FABACEAE	*Crotalaria natalitia var. natalitia*	*PRECIS*
FABACEAE	*Crotalaria laburnifolia subsp. australis*	*PRECIS*
FABACEAE	*Crotalaria lanceolata subsp. lanceolata*	*PRECIS*
FABACEAE	*Crotalaria distans subsp. mediocris*	*PRECIS*
FABACEAE	*Listia bainesii*	*PRECIS*
FABACEAE	*Acacia sieberiana var. woodii*	*PRECIS*
FABACEAE	*Dichrostachys cinerea subsp. nyassana*	*PRECIS*
FABACEAE	*Dichrostachys cinerea subsp. africana var. africana*	*PRECIS*
FABACEAE	*Pterocarpus rotundifolius subsp. rotundifolius*	*PRECIS*
FABACEAE	*Rhynchosia minima var. prostrata*	*PRECIS*
FABACEAE	*Indigofera heterotricha*	*PRECIS*
FABACEAE	*Albizia harveyi*	*PRECIS*
FABACEAE	*Philenoptera violacea*	*PRECIS*
FABACEAE	*Erythrina humeana*	*PRECIS*
FABACEAE	*Acacia ataxacantha*	*PRECIS*
FABACEAE	*Senna occidentalis*	*PRECIS*
FABACEAE	*Rhynchosia hirta*	*PRECIS*
FABACEAE	*Cajanus cajan*	*PRECIS*
FABACEAE	*Acacia gerrardii subsp. gerrardii var. gerrardii*	*PRECIS*
FABACEAE	*Acacia caffra*	*PRECIS*
FABACEAE	*Vigna sp.*	*PRECIS*
FABACEAE	*Albizia adianthifolia var. adianthifolia*	*PRECIS*
FABACEAE	*Rhynchosia caribaea*	*PRECIS*
FABACEAE	*Sesbania bispinosa var. bispinosa*	*PRECIS*
FABACEAE	*Teramnus labialis subsp. labialis*	*PRECIS*
FABACEAE	*Stylosanthes fruticosa*	*PRECIS*
FABACEAE	*Alysicarpus zeyheri*	*PRECIS*
FABACEAE	*Neonotonia wightii*	*PRECIS*
FABACEAE	*Argyrolobium transvaalense*	*PRECIS*
FABACEAE	*Albizia versicolor*	*PRECIS*
FABACEAE	*Otholobium polyphyllum*	*PRECIS*
FABACEAE	*Lessertia prostata*	*PRECIS*
FABACEAE	*Ormocarpum trichocarpum*	*PRECIS*
FABACEAE	*Indigofera arrecta*	*PRECIS*
FABACEAE	*Tephrosia rhodesica var. rhodesica*	*PRECIS*
FABACEAE	*Tephrosia purpurea subsp. leptostachya var. leptostachya*	*PRECIS*
FABACEAE	*Pseudarthria hookeri var. hookeri*	*PRECIS*
FABACEAE	*Alysicarpus rugosus subsp. perennirufus*	*PRECIS*
FABACEAE	*Pterocarpus angolensis*	*PRECIS*

Family	**Scientific name**	**Collection code**
FABACEAE	*Indigofera sanguinea*	*PRECIS*
FABACEAE	*Tephrosia burchellii*	*PRECIS*
FABACEAE	*Abrus laevigatus*	*PRECIS*
FABACEAE	*Sesbania sesban subsp. sesban var. nubica*	*PRECIS*
FABACEAE	*Eriosema psoraleoides*	*PRECIS*
FABACEAE	*Eriosema nutans*	*PRECIS*
FABACEAE	*Vigna vexillata var. vexillata*	*PRECIS*
FABACEAE	*Sphenostylis angustifolia*	*PRECIS*
FABACEAE	*Lablab purpureus subsp. uncinatus*	*PRECIS*
FABACEAE	*Zornia capensis subsp. capensis*	*PRECIS*
FABACEAE	*Mundulea sericea subsp. sericea*	*PRECIS*
FABACEAE	*Sesbania macrantha var. levis*	*PRECIS*
FABACEAE	*Psoralea latifolia*	*PRECIS*
FABACEAE	*Psoralea arborea*	*PRECIS*
FABACEAE	*Senna italica subsp. arachoides*	*PRECIS*
FABACEAE	*Argyrolobium tomentosum*	*PRECIS*
FABACEAE	*Desmodium repandum*	*PRECIS*
FABACEAE	*Caesalpinia decapetala*	*PRECIS*
FABACEAE	*Crotalaria vasculosa*	*PRECIS*
FABACEAE	*Abrus precatorius subsp. africanus*	*PRECIS*
FABACEAE	*Ormocarpum sp.*	*PRECIS*
FABACEAE	*Dalbergia melanoxylon*	*PRECIS*
FABACEAE	*Erythrina latissima*	*PRECIS*
FABACEAE	*Desmodium gangeticum*	*PRECIS*
FABACEAE	*Crotalaria pallida var. pallida*	*PRECIS*
FABACEAE	*Senna didymobotrya*	*PRECIS*
FABACEAE	*Tephrosia polystachya var. polystachya*	*PRECIS*
FABACEAE	*Rhynchosia monophylla*	*PRECIS*
FABACEAE	*Calpurnia aurea subsp. aurea*	*PRECIS*
FABACEAE	*Cassia abbreviata subsp. beareana*	*PRECIS*
FABACEAE	*Xanthocercis zambesiaca*	*PRECIS*
FABACEAE	*Bolusanthus speciosus*	*PRECIS*
FABACEAE	*Indigofera trita subsp. subulata*	*PRECIS*
FABACEAE	*Eriosema angustifolium*	*PRECIS*
FABACEAE	*Schotia brachypetala*	*PRECIS*
FABACEAE	*Acacia nigrescens*	*PRECIS*
FABACEAE	*Tephrosia longipes subsp. longipes var. longipes*	*PRECIS*
FABACEAE	*Desmodium setigerum*	*PRECIS*
FABACEAE	*Indigofera trita subsp. scabra*	*PRECIS*
FABACEAE	*Rhynchosia totta var. totta*	*PRECIS*
FABACEAE	*Indigofera vicioides var. rogersii*	*PRECIS*
FABACEAE	*Ptycholobium contortum*	*PRECIS*
FABACEAE	*Tephrosia villosa subsp. ehrenbergiana var. daviesii*	*PRECIS*
FABACEAE	*Acacia senegal var. rostrata*	*PRECIS*
FABACEAE	*Erythrina lysistemon*	*PRECIS*

Family	**Scientific name**	**Collection code**
FABACEAE	*Indigofera lupatana*	*PRECIS*
FABACEAE	*Neorautanenia mitis*	*PRECIS*
FABACEAE	*Indigastrum costatum subsp. macrum*	*PRECIS*
FABACEAE	*Tephrosia villosa subsp. ehrenbergiana var. ehrenbergiana*	*PRECIS*
FABRONIACEAE	*Fabronia rehmannii*	*PRECIS*
FABRONIACEAE	*Fabronia pilifera*	*PRECIS*
FISSIDENTACEAE	*Fissidens sp.*	*PRECIS*
FISSIDENTACEAE	*Fissidens rufescens*	*PRECIS*
FLACOURTIACEAE	*Kigelia africana*	*PRECIS*
FLACOURTIACEAE	*Aphloia theiformis*	*PRECIS*
FUNARIACEAE	*Funaria hygrometrica*	*PRECIS*
GENTIANACEAE	*Sebaea leiostyla*	*PRECIS*
GENTIANACEAE	*Anthocleista grandiflora*	*PRECIS*
GESNERIACEAE	*Streptocarpus cyaneus subsp. nigridens*	*Gardens (KBG)*
GUNNERACEAE	*Gunnera perpensa*	*PRECIS*
HALORAGACEAE	*Laurembergia repens subsp. brachypoda*	*PRECIS*
HEDWIGIACEAE	*Hedwigidium integrifolium*	*PRECIS*
HETEROPYXIDACEAE	*Heteropyxis natalensis*	*PRECIS*
HYACINTHACEAE	*Eucomis autumnalis subsp. clavata*	*PRECIS*
HYACINTHACEAE	*Drimiopsis burkei subsp. burkei*	*PRECIS*
HYACINTHACEAE	*Albuca sp.*	*PRECIS*
HYPNACEAE	*Hypnum cupressiforme var. cupressiforme*	*PRECIS*
HYPOXIDACEAE	*Rhodohypoxis baurii var. confecta*	*PRECIS*
HYPOXIDACEAE	*Hypoxis rigidula var. rigidula*	*PRECIS*
ICACINACEAE	*Pyrenacantha grandiflora*	*PRECIS*
IRIDACEAE	*Dietes iridioides*	*PRECIS*
IRIDACEAE	*Freesia grandiflora*	*PRECIS*
IRIDACEAE	*Crocosmia aurea subsp. aurea*	*PRECIS*
JUBULACEAE	*Frullania ericoides*	*PRECIS*
LAMIACEAE	*Ocimum sp.*	*Gardens (KBG)*
LAMIACEAE	*Syncolostemon transvaalensis*	*Gardens (KBG)*
LAMIACEAE	*Pycnostachys urticifolia*	*Gardens (KBG)*
LAMIACEAE	*Hyptis pectinata*	*PRECIS*
LAMIACEAE	*Clerodendrum glabrum*	*PRECIS*
LAMIACEAE	*Endostemon obtusifolius*	*PRECIS*
LAMIACEAE	*Satureja biflora*	*PRECIS*
LAMIACEAE	*Tinnea rhodesiana*	*PRECIS*
LAMIACEAE	*Plectranthus verticillatus*	*PRECIS*
LAMIACEAE	*Leucas martinicensis*	*PRECIS*
LAMIACEAE	*Hoslundia opposita*	*PRECIS*
LAMIACEAE	*Ocimum labiatum*	*PRECIS*
LAMIACEAE	*Orthosiphon rubicundus*	*PRECIS*
LAMIACEAE	*Ocimum gratissimum subsp. gratissimum var. gratissimum*	*PRECIS*
LAMIACEAE	*Leucas glabrata var. glabrata*	*PRECIS*
LAMIACEAE	*Ocimum obovatum subsp. obovatum var. galpinii*	*PRECIS*

Family	**Scientific name**	**Collection code**
LAMIACEAE	*Syncolostemon obermeyerae*	*PRECIS*
LAMIACEAE	*Plectranthus hereroensis*	*PRECIS*
LAMIACEAE	*Plectranthus esculentus*	*PRECIS*
LAMIACEAE	*Leonotis ocymifolia*	*PRECIS*
LAMIACEAE	*Plectranthus laxiflorus*	*PRECIS*
LAMIACEAE	*Syncolostemon petiolatus*	*PRECIS*
LAMIACEAE	*Stachys natalensis var. natalensis*	*PRECIS*
LAMIACEAE	*Leonotis ocymifolia var. raineriana*	*PRECIS*
LAMIACEAE	*Stachys grandifolia*	*PRECIS*
LAMIACEAE	*Endostemon tereticaulis*	*PRECIS*
LAURACEAE	*Cassytha filiformis*	*PRECIS*
LAURACEAE	*Cryptocarya transvaalensis*	*PRECIS*
LEJEUNEACEAE	*Dicranolejeunea phyllorhiza*	*PRECIS*
LEJEUNEACEAE	*Frullanoides tristis*	*PRECIS*
LEJEUNEACEAE	*Dicranolejeunea sp.*	*PRECIS*
LEJEUNEACEAE	*Lejeunea eckloniana*	*PRECIS*
LENTIBULARIACEAE	*Utricularia stellaris*	*PRECIS*
LESKEACEAE	*Pseudoleskeopsis claviramea*	*PRECIS*
LESKEACEAE	*Pseudoleskea leskeoides*	*PRECIS*
LOBARIACEAE	*Lobaria retigera*	*PRECIS*
LOBARIACEAE	*Pseudocyphellaria aurata*	*PRECIS*
LOBELIACEAE	*Lobelia flaccida subsp. mossiana*	*PRECIS*
LOBELIACEAE	*Monopsis stellarioides subsp. stellarioides*	*PRECIS*
LOBELIACEAE	*Lobelia erinus*	*PRECIS*
LOBELIACEAE	*Lobelia pinifolia*	*PRECIS*
LOPHIOCARPACEAE	*Corbichonia decumbens*	*PRECIS*
LORANTHACEAE	*Tapinanthus quequensis*	*PRECIS*
LYCOPODIACEAE	*Lycopodiella cernua*	*PRECIS*
MAESACEAE	*Maesa lanceolata*	*PRECIS*
MALPIGHIACEAE	*Sphedamnocarpus pruriens subsp. pruriens*	*PRECIS*
MALPIGHIACEAE	*Sphedamnocarpus pruriens subsp. galphimiifolius*	*PRECIS*
MALVACEAE	*Dombeya rotundifolia var. rotundifolia*	*PRECIS*
MALVACEAE	*Hermannia grandifolia*	*PRECIS*
MALVACEAE	*Grewia flavescens*	*PRECIS*
MALVACEAE	*Triumfetta welwitschii var. welwitschii*	*PRECIS*
MALVACEAE	*Sida dregei*	*PRECIS*
MALVACEAE	*Hibiscus calyphyllus*	*PRECIS*
MALVACEAE	*Sida pseudocordifolia*	*PRECIS*
MALVACEAE	*Pavonia columella*	*PRECIS*
MALVACEAE	*Dombeya burgessiae*	*PRECIS*
MALVACEAE	*Hermannia glanduligera*	*PRECIS*
MALVACEAE	*Grewia monticola*	*PRECIS*
MALVACEAE	*Grewia occidentalis var. occidentalis*	*PRECIS*
MALVACEAE	*Grewia subspathulata*	*PRECIS*
MALVACEAE	*Melhania prostrata*	*PRECIS*

Family	**Scientific name**	**Collection code**
MALVACEAE	*Hibiscus praeteritus*	*PRECIS*
MALVACEAE	*Pavonia burchellii*	*PRECIS*
MALVACEAE	*Grewia caffra*	*PRECIS*
MALVACEAE	*Triumfetta pilosa var. tomentosa*	*PRECIS*
MALVACEAE	*Hibiscus altissimus*	*PRECIS*
MALVACEAE	*Abutilon austro-africanum*	*PRECIS*
MALVACEAE	*Ceiba pentandra*	*PRECIS*
MALVACEAE	*Hermannia sp.*	*PRECIS*
MALVACEAE	*Triumfetta angolensis*	*PRECIS*
MALVACEAE	*Corchorus olitorius var. olitorius*	*PRECIS*
MALVACEAE	*Corchorus trilocularis*	*PRECIS*
MALVACEAE	*Triumfetta rhomboidea var. rhomboidea*	*PRECIS*
MALVACEAE	*Abutilon mauritianum*	*PRECIS*
MALVACEAE	*Sida alba*	*PRECIS*
MALVACEAE	*Sida acuta subsp. acuta*	*PRECIS*
MALVACEAE	*Abutilon sonneratianum*	*PRECIS*
MALVACEAE	*Azanza garckeana*	*PRECIS*
MALVACEAE	*Hibiscus surattensis*	*PRECIS*
MALVACEAE	*Hermannia floribunda*	*PRECIS*
MALVACEAE	*Grewia sulcata var. sulcata*	*PRECIS*
MALVACEAE	*Hibiscus pusillus*	*PRECIS*
MALVACEAE	*Hibiscus schinzii*	*PRECIS*
MALVACEAE	*Waltheria indica*	*PRECIS*
MALVACEAE	*Melhania forbesii*	*PRECIS*
MALVACEAE	*Hibiscus coddii subsp. barnardii*	*PRECIS*
MALVACEAE	*Hermannia modesta*	*PRECIS*
MALVACEAE	*Sida rhombifolia subsp. rhombifolia*	*PRECIS*
MARSILEACEAE	*Marsilea ephippiocarpa*	*PRECIS*
MELASTOMATACEAE	*Dissotis canescens*	*PRECIS*
MELIACEAE	*Ekebergia capensis*	*PRECIS*
MELIACEAE	*Turraea nilotica*	*PRECIS*
MELIACEAE	*Turraea sp.*	*PRECIS*
MELIACEAE	*Trichilia dregeana*	*PRECIS*
MELIACEAE	*Entandrophragma caudatum*	*PRECIS*
MELIACEAE	*Melia azedarach*	*PRECIS*
MELIANTHACEAE	*Bersama tysoniana*	*PRECIS*
MENISPERMACEAE	*Cissampelos torulosa*	*PRECIS*
MENISPERMACEAE	*Cocculus hirsutus*	*PRECIS*
MESEMBRYANTHEMACEAE	*Delosperma sp.*	*PRECIS*
METEORIACEAE	*Papillaria africana*	*PRECIS*
MOLLUGINACEAE	*Glinus lotoides var. virens*	*PRECIS*
MOLLUGINACEAE	*Hypertelis bowkeriana*	*PRECIS*
MONIMIACEAE	*Xymalos monospora*	*PRECIS*
MORACEAE	*Ficus sycomorus subsp. sycomorus*	*PRECIS*
MORACEAE	*Ficus ingens*	*PRECIS*

Family	**Scientific name**	**Collection code**
MORACEAE	*Ficus sur*	*PRECIS*
MORACEAE	*Ficus thonningii*	*PRECIS*
MORACEAE	*Ficus sansibarica subsp. sansibarica*	*PRECIS*
MORACEAE	*Trilepisium madagascariense*	*PRECIS*
MORACEAE	*Ficus stuhlmannii*	*PRECIS*
MORACEAE	*Ficus glumosa*	*PRECIS*
MORACEAE	*Ficus capreifolia*	*PRECIS*
MORACEAE	*Ficus abutilifolia*	*PRECIS*
MUSACEAE	*Ensete ventricosum*	*PRECIS*
MYRICACEAE	*Morella pilulifera*	*PRECIS*
MYRSINACEAE	*Myrsine africana*	*PRECIS*
MYRTACEAE	*Syzygium cordatum subsp. cordatum*	*PRECIS*
MYRTACEAE	*Syzygium legatii*	*PRECIS*
MYRTACEAE	*Syzygium gerrardii*	*PRECIS*
MYRTACEAE	*Eugenia woodii*	*PRECIS*
MYRTACEAE	*Eugenia sp.*	*PRECIS*
NYCTAGINACEAE	*Boerhavia diffusa var. diffusa*	*PRECIS*
NYMPHAEACEAE	*Nymphaea nouchali var. caerulea*	*PRECIS*
NYMPHAEACEAE	*Nymphaea lotus*	*PRECIS*
OCHNACEAE	*Ochna natalitia*	*PRECIS*
OCHNACEAE	*Ochna inermis*	*PRECIS*
OLACACEAE	*Ximenia caffra var. caffra*	*PRECIS*
OLEACEAE	*Jasminum abyssinicum*	*Gardens (KBG)*
OLEACEAE	*Jasminum fluminense subsp. fluminense*	*PRECIS*
OLEACEAE	*Olea europaea subsp. africana*	*PRECIS*
OLEACEAE	*Jasminum streptopus var. transvaalensis*	*PRECIS*
OLEACEAE	*Schrebera alata*	*PRECIS*
OLEACEAE	*Chionanthus battiscombei*	*PRECIS*
ORCHIDACEAE	*Bonatea porrecta*	*PRECIS*
ORCHIDACEAE	*Calanthe sylvatica*	*PRECIS*
ORCHIDACEAE	*Eulophia streptopetala*	*PRECIS*
ORCHIDACEAE	*Polystachya ottoniana*	*PRECIS*
ORCHIDACEAE	*Eulophia angolensis*	*PRECIS*
ORCHIDACEAE	*Satyrium hallackii subsp. ocellatum*	*PRECIS*
ORCHIDACEAE	*Aerangis verdickii var. verdickii*	*PRECIS*
ORCHIDACEAE	*Eulophia hereroensis*	*PRECIS*
OROBANCHACEAE	*Striga asiatica*	*PRECIS*
OROBANCHACEAE	*Striga forbesii*	*PRECIS*
OROBANCHACEAE	*Cycnium tubulosum subsp. tubulosum*	*PRECIS*
OROBANCHACEAE	*Harveya huttonii*	*PRECIS*
OROBANCHACEAE	*Alectra orobanchoides*	*PRECIS*
ORTHOTRICHACEAE	*Schlotheimia ferruginea*	*PRECIS*
ORTHOTRICHACEAE	*Macrocoma tenuis subsp. tenuis*	*PRECIS*
ORTHOTRICHACEAE	*Macrocoma lycopodioides*	*PRECIS*
PARMELIACEAE	*Parmotrema reticulatum*	*PRECIS*

Family	Scientific name	Collection code
PARMELIACEAE	*Xanthoparmelia subconspersa*	*PRECIS*
PARMELIACEAE	*Usnea undulata*	*PRECIS*
PARMELIACEAE	*Usnea nodulosa*	*PRECIS*
PARMELIACEAE	*Xanthoparmelia subramigera*	*PRECIS*
PASSIFLORACEAE	*Adenia digitata*	*PRECIS*
PASSIFLORACEAE	*Adenia gummifera var. gummifera*	*PRECIS*
PEDALIACEAE	*Dicerocaryum senecioides*	*PRECIS*
PEDALIACEAE	*Sesamum orientale*	*PRECIS*
PEDALIACEAE	*Sesamum alatum*	*PRECIS*
PHYLLANTHACEAE	*Antidesma venosum*	*PRECIS*
PHYLLANTHACEAE	*Flueggea virosa subsp. virosa*	*PRECIS*
PHYLLANTHACEAE	*Bridelia micrantha*	*PRECIS*
PHYLLANTHACEAE	*Phyllanthus incurvus*	*PRECIS*
PHYLLANTHACEAE	*Bridelia mollis*	*PRECIS*
PHYLLANTHACEAE	*Phyllanthus reticulatus var. reticulatus*	*PRECIS*
PHYLLANTHACEAE	*Phyllanthus nummulariifolius var. nummulariifolius*	*PRECIS*
PHYLLANTHACEAE	*Pseudolachnostylis maprouneifolia var. maprouneifolia*	*PRECIS*
PHYLLANTHACEAE	*Phyllanthus maderaspatensis*	*PRECIS*
PHYSCIACEAE	*Heterodermia lutescens*	*PRECIS*
PHYTOLACCACEAE	*Phytolacca dioica*	*PRECIS*
PITTOSPORACEAE	*Pittosporum viridiflorum*	*PRECIS*
PLANTAGINACEAE	*Plantago major*	*PRECIS*
PLUMBAGINACEAE	*Plumbago zeylanica*	*PRECIS*
POACEAE	*Eragrostis lappula*	*PRECIS*
POACEAE	*Setaria incrassata*	*PRECIS*
POACEAE	*Trachypogon spicatus*	*PRECIS*
POACEAE	*Heteropogon contortus*	*PRECIS*
POACEAE	*Setaria sphacelata var. sphacelata*	*PRECIS*
POACEAE	*Themeda triandra*	*PRECIS*
POACEAE	*Melinis repens subsp. repens*	*PRECIS*
POACEAE	*Melinis nerviglumis*	*PRECIS*
POACEAE	*Hemarthria altissima*	*PRECIS*
POACEAE	*Digitaria milanjiana*	*PRECIS*
POACEAE	*Sorghum sp.*	*PRECIS*
POACEAE	*Leersia hexandra*	*PRECIS*
POACEAE	*Digitaria sp.*	*PRECIS*
POACEAE	*Tragus berteronianus*	*PRECIS*
POACEAE	*Bothriochloa insculpta*	*PRECIS*
POACEAE	*Bothriochloa bladhii*	*PRECIS*
POACEAE	*Stereochlaena cameronii*	*PRECIS*
POACEAE	*Sporobolus festivus*	*PRECIS*
POACEAE	*Brachiaria brizantha*	*PRECIS*
POACEAE	*Tristachya leucothrix*	*PRECIS*
POACEAE	*Cymbopogon nardus*	*PRECIS*
POACEAE	*Sporobolus pyramidalis*	*PRECIS*

Family	**Scientific name**	**Collection code**
POACEAE	*Paspalum distichum*	*PRECIS*
POACEAE	*Urochloa sp.*	*PRECIS*
POACEAE	*Echinochloa sp.*	*PRECIS*
POACEAE	*Hyparrhenia cymbaria*	*PRECIS*
POACEAE	*Hyperthelia dissoluta*	*PRECIS*
POACEAE	*Eragrostis viscosa*	*PRECIS*
POACEAE	*Perotis sp.*	*PRECIS*
POACEAE	*Hyparrhenia dichroa*	*PRECIS*
POACEAE	*Hyparrhenia variabilis*	*PRECIS*
POACEAE	*Hyparrhenia dregeana*	*PRECIS*
POACEAE	*Hyparrhenia hirta*	*PRECIS*
POACEAE	*Hyparrhenia rudis*	*PRECIS*
POACEAE	*Phragmites mauritianus*	*PRECIS*
POACEAE	*Sporobolus natalensis*	*PRECIS*
POACEAE	*Sporobolus sp.*	*PRECIS*
POACEAE	*Sporobolus nitens*	*PRECIS*
POACEAE	*Sporobolus ioclados*	*PRECIS*
POACEAE	*Hyparrhenia filipendula var. pilosa*	*PRECIS*
POACEAE	*Trichoneura grandiglumis*	*PRECIS*
POACEAE	*Setaria sphacelata var. torta*	*PRECIS*
POACEAE	*Echinochloa colona*	*PRECIS*
POACEAE	*Eragrostis gummiflua*	*PRECIS*
POACEAE	*Panicum deustum*	*PRECIS*
POACEAE	*Aristida congesta subsp. barbicollis*	*PRECIS*
POACEAE	*Eragrostis superba*	*PRECIS*
POACEAE	*Panicum maximum*	*PRECIS*
POACEAE	*Hyparrhenia gazensis*	*PRECIS*
POACEAE	*Eragrostis curvula*	*PRECIS*
POACEAE	*Pennisetum purpureum*	*PRECIS*
POACEAE	*Eleusine coracana subsp. africana*	*PRECIS*
POACEAE	*Imperata cylindrica*	*PRECIS*
POACEAE	*Rottboellia cochinchinensis*	*PRECIS*
POACEAE	*Pennisetum macrourum*	*PRECIS*
POACEAE	*Perotis patens*	*PRECIS*
POACEAE	*Loudetia simplex*	*PRECIS*
POACEAE	*Diandrochloa namaquensis*	*PRECIS*
POACEAE	*Hyparrhenia rufa var. rufa*	*PRECIS*
POACEAE	*Paspalum scrobiculatum*	*PRECIS*
POACEAE	*Hyparrhenia filipendula var. filipendula*	*PRECIS*
POACEAE	*Hyparrhenia anamesa*	*PRECIS*
POACEAE	*Cynodon dactylon*	*PRECIS*
POACEAE	*Setaria sp.*	*PRECIS*
POACEAE	*Cynodon aethiopicus*	*PRECIS*
POACEAE	*Panicum infestum*	*PRECIS*
POACEAE	*Eragrostis sp.*	*PRECIS*

Family	**Scientific name**	**Collection code**
POACEAE	*Sporobolus acinifolius*	*PRECIS*
POACEAE	*Urochloa stolonifera*	*PRECIS*
POACEAE	*Pogonarthria squarrosa*	*PRECIS*
POACEAE	*Fingerhuthia africana*	*PRECIS*
POACEAE	*Ischaemum afrum*	*PRECIS*
POACEAE	*Leptochloa eleusine*	*PRECIS*
POACEAE	*Aristida bipartita*	*PRECIS*
POACEAE	*Digitaria eriantha*	*PRECIS*
POACEAE	*Aristida adscensionis*	*PRECIS*
POACEAE	*Urochloa mosambicensis*	*PRECIS*
POACEAE	*Eragrostis trichophora*	*PRECIS*
POACEAE	*Aristida congesta subsp. congesta*	*PRECIS*
POLYGALACEAE	*Polygala virgata var. decora*	*PRECIS*
POLYGALACEAE	*Polygala sphenoptera var. sphenoptera*	*PRECIS*
POLYGONACEAE	*Persicaria attenuata subsp. africana*	*PRECIS*
POLYGONACEAE	*Persicaria decipiens*	*PRECIS*
POLYGONACEAE	*Rumex sagittatus*	*PRECIS*
POLYGONACEAE	*Rumex rhodesius*	*PRECIS*
POLYGONACEAE	*Oxygonum sinuatum*	*PRECIS*
POLYGONACEAE	*Persicaria lapathifolia*	*PRECIS*
POLYGONACEAE	*Polygonum aviculare*	*PRECIS*
POLYTRICHACEAE	*Polytrichum commune*	*PRECIS*
PORTULACACEAE	*Portulaca oleracea*	*PRECIS*
POTAMOGETONACEAE	*Potamogeton octandrus*	*PRECIS*
POTAMOGETONACEAE	*Potamogeton schweinfurthii*	*PRECIS*
POTAMOGETONACEAE	*Potamogeton crispus*	*PRECIS*
POTTIACEAE	*Trichostomum brachydontium*	*PRECIS*
PROTEACEAE	*Faurea rochetiana*	*PRECIS*
PROTEACEAE	*Faurea saligna*	*PRECIS (KZN)*
PROTEACEAE	*Grevillea robusta*	*Protea Atlas*
PROTEACEAE	*Protea caffra subsp. caffra*	*Protea Atlas*
PTERIDACEAE	*Adiantum capillus-veneris*	*PRECIS*
PTERIDACEAE	*Pteris cretica*	*PRECIS*
PTERIDACEAE	*Pteris catoptera var. catoptera*	*PRECIS*
PTERIDACEAE	*Adiantum poiretii*	*PRECIS*
PTERIDACEAE	*Actiniopteris radiata*	*PRECIS*
PTYCHOMITRIACEAE	*Ptychomitrium microblastum*	*PRECIS*
PUTRANJIVACEAE	*Drypetes gerrardii var. gerrardii*	*PRECIS*
RACOPILACEAE	*Racopilum capense*	*PRECIS*
RANUNCULACEAE	*Clematis brachiata*	*PRECIS*
RANUNCULACEAE	*Ranunculus multifidus*	*PRECIS*
RANUNCULACEAE	*Knowltonia transvaalensis var. transvaalensis*	*PRECIS*
RHAMNACEAE	*Helinus integrifolius*	*PRECIS*
RHAMNACEAE	*Ziziphus mucronata subsp. mucronata*	*PRECIS*
RHAMNACEAE	*Ziziphus rivularis*	*PRECIS*

Family	**Scientific name**	**Collection code**
RHAMNACEAE	*Berchemia discolor*	*PRECIS*
RHAMNACEAE	*Berchemia zeyheri*	*PRECIS*
RHAMNACEAE	*Scutia myrtina*	*PRECIS*
RHIZOCARPACEAE	*Hypotrachyna dactylifera*	*PRECIS*
RICCIACEAE	*Riccia stricta*	*PRECIS*
RICCIACEAE	*Riccia congoana*	*PRECIS*
RICCIACEAE	*Riccia atropurpurea*	*PRECIS*
RICCIACEAE	*Riccia albolimbata*	*PRECIS*
RICCIACEAE	*Riccia runssorensis*	*PRECIS*
ROSACEAE	*Rubus cuneifolius*	*PRECIS*
ROSACEAE	*Rubus pinnatus*	*PRECIS*
ROSACEAE	*Alchemilla cryptantha*	*PRECIS*
RUBIACEAE	*Sericanthe andongensis subsp. andongensis var. andongensis*	*PRECIS*
RUBIACEAE	*Canthium armatum*	*PRECIS*
RUBIACEAE	*Pavetta trichardtensis*	*PRECIS*
RUBIACEAE	*Pavetta schumanniana*	*PRECIS*
RUBIACEAE	*Pentodon pentandrus var. minor*	*PRECIS*
RUBIACEAE	*Pavetta gardeniifolia var. gardeniifolia*	*PRECIS*
RUBIACEAE	*Cephalanthus natalensis*	*PRECIS*
RUBIACEAE	*Coddia rudis*	*PRECIS*
RUBIACEAE	*Gardenia ternifolia subsp. jovis-tonantis var. goetzei*	*PRECIS*
RUBIACEAE	*Anthospermum herbaceum*	*PRECIS*
RUBIACEAE	*Spermacoce natalensis*	*PRECIS*
RUBIACEAE	*Richardia scabra*	*PRECIS*
RUBIACEAE	*Vangueria cyanescens*	*PRECIS*
RUBIACEAE	*Canthium ciliatum*	*PRECIS*
RUBIACEAE	*Rubia cordifolia subsp. conotricha*	*PRECIS*
RUBIACEAE	*Kohautia virgata*	*PRECIS*
RUBIACEAE	*Agathisanthemum bojeri subsp. bojeri*	*PRECIS*
RUBIACEAE	*Anthospermum welwitschii*	*PRECIS*
RUBIACEAE	*Vangueria infausta subsp. infausta*	*PRECIS*
RUBIACEAE	*Psychotria capensis subsp. capensis var. capensis*	*PRECIS*
RUBIACEAE	*Psychotria zombamontana*	*PRECIS*
RUBIACEAE	*Pavetta lanceolata*	*PRECIS*
RUBIACEAE	*Fadogia tetraquetra*	*PRECIS*
RUBIACEAE	*Oldenlandia cephalotes*	*PRECIS*
RUBIACEAE	*Otiophora calycophylla subsp. verdcourtii*	*PRECIS*
RUBIACEAE	*Psydrax livida*	*PRECIS*
RUBIACEAE	*Rothmannia globosa*	*PRECIS*
RUBIACEAE	*Breonadia salicina*	*PRECIS*
RUBIACEAE	*Tricalysia junodii var. kirkii*	*PRECIS*
RUTACEAE	*Calodendrum capense*	*PRECIS*
RUTACEAE	*Zanthoxylum capense*	*PRECIS*
RUTACEAE	*Toddalia asiatica*	*PRECIS*
RUTACEAE	*Clausena anisata var. anisata*	*PRECIS*

Family	**Scientific name**	**Collection code**
SALICACEAE	*Oncoba spinosa subsp. spinosa*	*PRECIS*
SALICACEAE	*Dovyalis zeyheri*	*PRECIS*
SALICACEAE	*Dovyalis caffra*	*PRECIS*
SALICACEAE	*Scolopia zeyheri*	*PRECIS*
SALICACEAE	*Salix mucronata subsp. woodii*	*PRECIS*
SALICACEAE	*Homalium dentatum*	*PRECIS*
SALICACEAE	*Trimeria grandifolia subsp. grandifolia*	*PRECIS*
SALICACEAE	*Salix sp.*	*PRECIS*
SANTALACEAE	*Osyridicarpos schimperianus*	*PRECIS*
SAPINDACEAE	*Cardiospermum halicacabum var. microcarpum*	*PRECIS*
SAPINDACEAE	*Dodonaea angustifolia*	*PRECIS*
SAPINDACEAE	*Allophylus transvaalensis*	*PRECIS*
SAPINDACEAE	*Allophylus decipiens*	*PRECIS*
SAPINDACEAE	*Allophylus melanocarpus*	*PRECIS*
SAPOTACEAE	*Mimusops zeyheri*	*PRECIS*
SAPOTACEAE	*Englerophytum magalismontanum*	*PRECIS*
SCROPHULARIACEAE	*Jamesbrittenia micrantha*	*PRECIS*
SCROPHULARIACEAE	*Limosella maior*	*PRECIS*
SCROPHULARIACEAE	*Aptosimum lineare var. lineare*	*PRECIS*
SCROPHULARIACEAE	*Melanospermum sp.*	*PRECIS*
SCROPHULARIACEAE	*Diclis reptans*	*PRECIS*
SCROPHULARIACEAE	*Veronica anagallis-aquatica*	*PRECIS*
SEMATOPHYLLACEAE	*Sematophyllum sphaeropyxis*	*PRECIS*
SINOPTERIDACEAE	*Cheilanthes viridis var. glauca*	*PRECIS*
SINOPTERIDACEAE	*Cheilanthes viridis var. viridis*	*PRECIS*
SINOPTERIDACEAE	*Cheilanthes inaequalis var. inaequalis*	*PRECIS*
SINOPTERIDACEAE	*Cheilanthes concolor*	*PRECIS*
SINOPTERIDACEAE	*Cheilanthes hirta var. hirta*	*PRECIS*
SINOPTERIDACEAE	*Cheilanthes involuta var. obscura*	*PRECIS*
SMILACACEAE	*Smilax anceps*	*PRECIS*
SOLANACEAE	*Withania somnifera*	*PRECIS*
SOLANACEAE	*Solanum panduriforme*	*PRECIS*
SOLANACEAE	*Solanum aculeatissimum*	*PRECIS*
SOLANACEAE	*Physalis peruviana*	*PRECIS*
SOLANACEAE	*Datura ferox*	*PRECIS*
SOLANACEAE	*Lycium shawii*	*PRECIS*
SOLANACEAE	*Solanum coccineum*	*PRECIS*
SOLANACEAE	*Solanum aculeastrum subsp. aculeastrum*	*PRECIS*
SOLANACEAE	*Solanum seaforthianum var. disjunctum*	*PRECIS*
SOLANACEAE	*Solanum retroflexum*	*PRECIS*
SOLANACEAE	*Solanum nodiflorum*	*PRECIS*
SOLANACEAE	*Solanum giganteum*	*PRECIS*
STEREOPHYLLACEAE	*Stereophyllum natalense*	*PRECIS*
STRELITZIACEAE	*Strelitzia caudata*	*PRECIS*
STRYCHNACEAE	*Strychnos spinosa subsp. spinosa*	*PRECIS*

Family	**Scientific name**	**Collection code**
STRYCHNACEAE	*Strychnos usambarensis*	*PRECIS*
TECTARIACEAE	*Tectaria gemmifera*	*PRECIS*
TELOSCHISTACEAE	*Teloschistes flavicans var. flavicans*	*PRECIS*
THELOTREMATACEAE	*Diploschistes sp.*	*PRECIS*
THELYPTERIDACEAE	*Christella dentata*	*PRECIS*
THELYPTERIDACEAE	*Pneumatopteris unita*	*PRECIS*
THELYPTERIDACEAE	*Cyclosorus interruptus*	*PRECIS*
THELYPTERIDACEAE	*Christella gueinziana*	*PRECIS*
THELYPTERIDACEAE	*Thelypteris confluens*	*PRECIS*
THEOPHRASTACEAE	*Samolus valerandi*	*PRECIS*
THYMELAEACEAE	*Gnidia sp.*	*PRECIS*
THYMELAEACEAE	*Gnidia kraussiana var. kraussiana*	*PRECIS*
THYMELAEACEAE	*Passerina montana*	*PRECIS*
THYMELAEACEAE	*Gnidia capitata*	*PRECIS*
TILIACEAE	*Sparrmannia ricinocarpa var. ricinocarpa*	*Gardens (KBG)*
TURNERACEAE	*Tricliceras longepedunculatum var. longepedunculatum*	*PRECIS*
TURNERACEAE	*Piriqueta capensis*	*PRECIS*
TURNERACEAE	*Tricliceras sp.*	*PRECIS*
UNKNOWN	*Unknown sp.*	*PRECIS*
URTICACEAE	*Pouzolzia mixta var. mixta*	*PRECIS*
URTICACEAE	*Laportea peduncularis subsp. peduncularis*	*PRECIS*
URTICACEAE	*Pouzolzia parasitica*	*PRECIS*
VELLOZIACEAE	*Xerophyta retinervis*	*PRECIS*
VERBENACEAE	*Verbena officinalis*	*PRECIS*
VERBENACEAE	*Priva meyeri var. meyeri*	*PRECIS*
VERBENACEAE	*Lantana rugosa*	*PRECIS*
VERBENACEAE	*Lantana camara*	*PRECIS*
VERBENACEAE	*Lippia javanica*	*PRECIS*
VERBENACEAE	*Duranta erecta*	*PRECIS*
VERBENACEAE	*Priva cordifolia var. abyssinica*	*PRECIS*
VERBENACEAE	*Priva flabelliformis*	*PRECIS*
VERBENACEAE	*Lantana mearnsii var. latibracteolata*	*PRECIS*
VERBENACEAE	*Verbena aristigera*	*PRECIS*
VISCACEAE	*Viscum oreophilum*	*PRECIS*
VITACEAE	*Rhoicissus tomentosa*	*Gardens (KBG)*
VITACEAE	*Rhoicissus tridentata subsp. tridentata*	*PRECIS*
VITACEAE	*Cissus cornifolia*	*PRECIS*
VITACEAE	*Cyphostemma oleraceum*	*PRECIS*
VITACEAE	*Cyphostemma sp.*	*PRECIS*
VITACEAE	*Cyphostemma woodii*	*PRECIS*
VITACEAE	*Rhoicissus rhomboidea*	*PRECIS*
VITACEAE	*Cyphostemma spinosopilosum*	*PRECIS*
VITACEAE	*Rhoicissus revoilii*	*PRECIS*
XYRIDACEAE	*Xyris capensis*	*PRECIS*
ZINGIBERACEAE	*Siphonochilus aethiopicus*	*PRECIS*

Collection Code	**Collection Information**
Gardens (KGB)	Kirstenbosch Botanical Gardens (Cape Town)
MSB	Millenium Seedbank (Royal Botanic Gardens and SANBI)
PRECIS	National Herbarium Pretoria Computerised Information System
PRECIS (KZN)	National Herbarium Pretoria Computerised Information System (KZN)
Protea Atlas	Protea Atlas (SANBI)

APPENDIX M

MORPHOLOGICAL, PRESERVATION AND DISPERSAL CHARACTERISTICS OF MAJOR PALYNOMORPHS (after Lodder, 2011 and Geer, 2013)

ACANTHACEAE

Identified as: undifferentiated

Genus found at Mutale Wetland: Various Acanthaceae species (Appendix L)

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) *Monechma*-type, 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: *Rhus*

Genera found at Mutale Wetland: Unknown

Likely parent taxa: *Rhus*

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

AQUIFOLIACEAE
Identified as: *Ilex mitis*

Genus found at Mutale Wetland: Unknown

Likely parent taxa: *Ilex mitis*

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

Ecology: Most frequently on river banks, and in moist evergreen forests (Palgrave, 2002; Orwa *et al*., 2009). High counts of *Ilex mitis* pollen are considered an indicator of wet conditions (van Zinderren Bakker and Coetzee, 1988).

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

Local / Regional: Regional
Arboreal / Non-Arboreal: Arboreal

ASTERACEAE
Identified as: *Artemisia*

Genera found at Mutale Wetland: *Artemisia afra*

Likely parent taxa: *Artemisia afra*

Pollen morphological characteristics (on Genus level): Low spined (Scott *et al.,* 2006).

Ecology: *Artemisia* is found in grasslands (Scott, 1982a), sandy areas under local sub-humid conditions (Scott and Nyakale, 2002) with relatively even seasonal moisture distribution (Scott, 1999). It is an indication of somewhat drier conditions (Scott, 1982a).

Dispersal and preservation characteristics: *Artemisia* occurs in a wide range of habitats in eastern South Africa. It is often rare in pollen samples although it is considered moderately dispersed. However, according to Hamilton (1972), this pollen type is dispersed over long distances but is considered poorly dispersed.

Local / Regional: Regional
Arboreal / Non-Arboreal: Non-arboreal

Identified as: *Stoebe*

Genera found at Mutale Wetland: Unknown

Likely parent taxa: *Stoebe* species

Pollen morphological characteristics (on Genus level): Low spined (Scott *et al.,* 2006).

Ecology: *Stoebe* occurs in grasslands (Scott, 1982a), fynbos (Scott, 1991) shrubland, and dry karroid veld under conditions of less summer rain (Scott and Nyakale, 2002) but with a relatively even seasonal moisture distribution (Scott, 1999). It is indicative of different seasonal climatic distributions with weaker summer rainfall. It is not usually dominant in summer rain regions (Scott *et al.,* 2005).

Dispersal and preservation characteristics: *Stoebe* is common in disturbed habitats and suggest cooler, drier conditions. It is considered a moderately well dispersed pollen (Scott, 1982a; Hamilton 1972) being dispersed over long distances (Hamilton 1972).

Local / Regional: Regional
Arboreal / Non-Arboreal: Non-Arboreal

Identified as: *Vernonia*-type

Genera found at Mutale Wetland: *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

Identified as: *Tarconanthus*

Genera found at Mutale Wetland: Unknown

Likely parent taxa: *Tarconanthus*

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

Ecology: Occurs within a wide range of habitats and are also important components of the Kalahari Thornveld (Scott, 1991). The occurrence of this pollen type within sediments is indicative of warm and dry conditions (Scott, 1982a).

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

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

CAPPARACEAE

Identified as: Capparaceae undifferentiated

Genera found at Mutale Wetland: *Cleome monophylla; Capparis fascicularis; Cadaba termitaria; Cappari stormentosa; Cleome gynandra; Maeruajuncea; Maeruaparvifolia*

Likely parent taxa: Unknown

Pollen morphological characteristics (on Family level): 3-colporate, prolate to subprolate, ambit foss apertuarate; 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 Thornveldvegetation 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

CELASTRACEAE

Identified as: Celastraceae undifferentiated

Genera found at Mutale Wetland: *Catha edulis; Maytenus undata; Gymnosporia senegalensis; Gymnosporia harveyana subsp; Gymnosporia buxifolia; Pterocelastrus echinatus; Elaeodendron transvaalense.*

Likely parent taxa: Unknown

Pollen morphological characteristics: No morphological description available for thisresearch.

Ecology: Celastraceae is commonly found in montante forests, woodlands, riverine forest, evergreen and coastal bushland as well as dry forest and savanna. Celastraceae is well adapted to arid conditions and thus indicative of drier conditions with lower precipitation (Gil-Romera *et al.,* 2007; Dupont *et al.,* 2008; Finch *et al.,* 2009).

Dispersal and preservation characteristics: This pollen is considered to be dispersed over long distances (Hamilton 1972).

Local / Regional: Regional
Arboreal / Non-Arboreal: Arboreal

CELTIDACEAE

Identified as: *Celtis*

Genus found at Mutale Wetland: *Celtis africana*

Likely parent taxa: *Celtis africana*

Pollen morphological characteristics (on Family level): Mostly tripolate, spheroidal and of equatorial diameter of 17 – 27 µm. Pores nearly circular in outline, membrane with a fleck orwith some granules (van Zinderen Bakker 1953).

Ecology: Occurs in various habitats. Usually associated with high rainfall area, but can be drought tolerant (Scott, 1982a).

Dispersal and preservation characteristics: Very well dispersed in East Africa, found in highnumbers in surface samples from mountainous slopes near Ladybrand (Scott, 1982a)

Local / Regional: Regional
Arboreal / Non-Arboreal: Arboreal

CHENOPODIACEAE

Identified as: Chenopodiaceae undifferentiated

Genera found at Mutale Wetland: *Chenopodium cristatum; Chenopodium carinatum; Chenopodium album*

Likely parent taxa: *Chenopodiumcristatum; Chenopodiumcarinatum; Chenopodium album*

Pollen morphological characteristics (on Genus 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: A widespread family of dry, halophytic habitats. They also favour saline conditions, summer rainfall and warmer evaporative conditions (Scott *et al*., 2005; Scott, 1993; Scott, 1982a).

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

Local / Regional: Regional
Arboreal / Non-Arboreal: Arboreal

COMBRETACEAE

Identified as: *Combretum*

Genera found at Mutale Wetland: *Combretum erythrophyllum; C. hereoense; C. collinum; C. molle; C. imberbe; C. paniculatum; C. kraussii; C. microphyllum*

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

COMMELINACEAE

Identified as: Undifferentiated

Genus found at Mutale Wetland: *Commelina erecta; Commelina benghalensis; Combretum africana; Aneile maaequinoctiale; Cyanotis speciosa*.

Likely parent taxa: *Commelina africana, Cyanotis speciosa*

Pollen morphological characteristics (on Family level): Grains are momosulcate, bean-shapedor ellipsoidal, 30 – 90 µm. Exine almost spilate, granulate, echinate, verrucate or areolate(van Zinderen Bakker 1953).

Ecology: Widespread herb with many species in South Africa, found in moist areas, grasslands, and forest margins (Pooley, 2005) and also recorded in open veld (Scott, 1982a).

Dispersal and preservation characteristics: Have been recorded in surface samples of the open bushveld conditions (Scott, 1982a).

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-arboreal

CORNACEAE

Identified as: *Cornus*

Genus found at Mutale Wetland: Unknown

Likely parent taxa: *Cornus*

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

Ecology: Occurs over a wide altitude range, in evergreen forests and on grassy mountainslopes (Palgrave, 2002)

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

Local / Regional: Regional
Arboreal / Non-Arboreal: Arboreal

CYPERACEAE
Identified as: *Ascolepis*

Genera found in Mutale Wetland: Large array of Cyperaceae genera and species occur

Likely parent taxa: *Ascolepis*

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

Ecology: *Ascolepis*-tribe is typically found in wetlands in aquatic (Scott 1982a), semi-aquaticand 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 welldispersed (Hamilton, 1972)

Local / Regional: Local
Arboreal / Non-Arboreal: Non-Arboreal

Identified as: Cyperaceae undifferentiated

Genera found at Mutale Wetland: Large array of Cyperaceae genera and species occur

Likely parent taxa: members of the Cyperaceae family

Ecology: Typically found in wetlands in aquatic (Scott, 1982a), semi aquaticand 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 welldispersed (Hamilton, 1972)

Local / Regional: Local
Arboreal / Non-Arboreal: Non-Arboreal

EBENACEAE

Identified as: *Euclea*

Genera found at Mutale Wetland: *Euclea divinorum*

Likely parent taxa: *Euclea divinorum*

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

ERICACEAE

Identified as: Undifferentiated

Genera found at Mutale Wetland: *Erica simii*

Likely parent taxa: *Erica simii*

Pollen morphological characteristics (on Genus level): An unmistakable palynomorph. Inaperturate, psilate, scabrate, fossulate, rugulate tetrad. 28-55 µm (Coetzee, 1955).

Ecology: Approximately 56 species of this family are present in the mountainous areas of Limpopo Province. An important fynbos element. At 23°S Ericaceae usually occurs up to 1000m (Scott, 1982a). It is often associated with fynbos environments that have cool, sub humid conditions with a relatively even seasonal moisture distribution (Scott, 1999).

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

Local / Regional: Regional
Arboreal / Non-Arboreal: Non-Arboreal

EUPHORBIACEAE

Identified as: *Acalypha*

Genera found in Mutale Wetland: *Acalypha glabrata; Acalypha villicaulis; Acalypha peduncularis*

Likely parent taxa: *Acalypha glabrata; Acalypha villicaulis; Acalypha peduncularis*

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: *Spirostachys africana*

Genera found in Mutale Wetland: Unknown

Likely parent taxa: *Spirostachys africana.*

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

Ecology: Present in low altitude bush, sometimes along rivers and streams (Scott, 1982a)

Dispersal and preservation characteristics: Pollen grains occur occasionally, in small numbers in samples from bushveld plains (Scott, 1982a)

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

FABACEAE

Identified as: *Burkea africana*

Genus found at Mutale Wetland: Unknown

Likely parent taxa: *Burkea africana*

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

Ecology: Second largest plant family. Found in grasslands, varying from damp to rocky habitats (Pooley, 2005). Also occurs in occurs in woodlands and bushvelds (Scott, 1982).

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

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-arboreal

Identified as: *Psoralea* type

Genus found at Mutale Wetland: *Psoralea latifolia; Psoralea arborea*

Likely parent taxa: *Psoralea latifolia; Psoralea arborea*

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

Ecology: Second largest plant family. This genus represents trees, herbs and shrubs (Scott, 1982). 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

HALORAGACEAE

Identified as: *Undifferentiated*

Genera found at Mutale Wetland: *Gunnera perpensa; Laurembergia repens*

Likely parent taxa: *Gunnera perpensa; Laurembergia repens*

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

Ecology: Found under aquatic conditions (Scott 1982a). *Gunnera* is a large semi-aquatic, perennial herb common in marshy environments up to 2400 m growing typically on the edge of wetlandsand in drier areas of the wetland. This species is thought to be highly responsive to changes inthe hydrological budget (Finch *et al.,* 2009).

Dispersal and preservation characteristics: Pollen is considered to be over-represented due toits local dominance at the swamp site (Finch *et al.,* 2009).

Local / Regional: Local
Arboreal / Non-Arboreal: Non-Arboreal

FLACOURTIACEAE
Identified as: *Kiggelaria africana*

Genus found at Mutale Wetland: *Kiggelaria africana*

Likely parent taxa: *Kiggelaria africana*

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 habitats. (Pooley, 2005). *Kiggelari africana* occurs in evergreen forests in mountains and protected areas in the moist eastern region of South Africa (Scott, 1982a).

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

Local / Regional: Regional
Arboreal / Non-Arboreal: Non-arboreal

LILIACEAE

Identified as: *Tulbhagia*

Genera found in Mutale Wetland: 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

MYRICACEAE

Identified as: *Myrica*

Genera found at Mutale Wetland: *Morella pilulifera* (Appendix L)

Likely parent taxa: *Unknown*

Pollen morphological characteristics (on Genus level): usually triporate, aspidate, oblate, with equatorial diameter 22-36 µm; 2,4, or 6 pores; ambit triangular with convex sides;

irregular arrangement pores; mostly circular, sometime elliptical; thickening of exine under aspis is of tarsus pattern or transition between this and club-shaped pattern; exine is two layers surface slightly roughened or minutely granulate (van Zinderen Bakker, 1953).

Ecology: *Myrica* occurs within and on the forest margins under sub-humid conditions (Scott 1982a, 1999).

Dispersal and preservation characteristics: This pollen is considered moderately welldispersed over long distances in East Africa (Hamilton, 1972; Scott, 1982a).

Local / Regional: Regional
Arboreal / Non-Arboreal: Non-Arboreal

MYRTACEAE

Identified as: Myrtaceae undifferentiated

Genera found at Mutale Wetland: *Syzygium cordatum; S. legatii; S. gerrardii; Eugenia woodii*

Likely parent taxa: *Syzigium* species

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

Ecology: According to Scott (1982a), pollen grains present in sediments from Limpopo Province most likely represent *Syzigium.* Although, in surface samples. These grains are may be representative of *Eucalyptus* (Scott, 1982a) is an exotic neophyte associated with human activity but also occurringwithin montane forest types (Finch *et al.,* 2009).

Dispersal and preservation characteristics: The pollen is moderately well dispersed (Scott, 1982a; Finch *et al.,* 2009).

Local / Regional: Regional

Arboreal / Non-Arboreal: Arboreal

OLEACEAE

Identified as: Undifferentiated

Genus found at Mutale Wetland: *Jasminum abyssinicum; J. fluminense; J. streptopus; Olea europaea; Schrebera alata; Chionanthus battiscombei*

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

PINACEAE

Identified as: *Pinus*

Genera found at Mutale Wetland: Not native, introduced

Likely parent taxa: *Pinus*

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

Ecology: Exotic neophyte associated with human activity (Finch *et al.* 2009).

Dispersal and preservation characteristic: *Pinus* is anemophilous and therefore extremely well dispersed, contributing to over-representation in the pollen signal (Finch *et al.* 2009).

Local / Regional: Regional (neophytes)
Arboreal / Non-Arboreal: Arboreal

POACEAE
Identified as: Undifferentiated

Genera found at Mutale Wetland: Large array of genera and species

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

PODOCARPACEAE
Identified as: *Podocarpus*

Genera found at Mutale Wetland: *Podocarpus falcatus, P. latifolius*

Likely parent taxa: *Podocarpus falcatus, P. latifolius*

Pollen morphological characteristics (on Genus level): Six species in South Africa occur inmountainous regions from the Cape Peninsula coastal belt to KwaZulu-Natal and into Mpumalanga; wind pollinated; grains: monosulcate, spherical to ellipsoidal, saccate, provided with 2,3 and exceptionally 4 air-sacs; 2 sac grains range 23-45µm diameter; proximal side arched; thick exine; sulcus on distal face, sharply defined, surrounded airsacs,; Bladders: atthe inside with reticulate thickenings, which merge with structure of proximal face; large, butmostly weak and flaccid (van Zinderen Bakker, 1953).

Ecology: *Podocarpus* are found in the woodland ravines in the Soutpansberg, Blaauberg and Waterberg (Scott, 1982a). It is often a forest-dweller (Scott, 1982a) favouring relatively moist conditions (Scott, 1999).

Dispersal and preservation characteristic: Pollen grains produced large numbers, each with airbladders making the grains very buoyant with the ability to be well dispersed by wind overlong distances (Scott, 1982a; Hamilton, 1972). As such they can be easily overrepresented inpollen sums (Scott, 1982a).

Local / Regional: Regional
Arboreal / Non-Arboreal: Arboreal

SAPOTACEAE

Identified as: *Englerophytum*

Genera found at Mutale Wetland: *Englerophytum magalismontanum*

Likely parent taxa: *Englerophytum magalismontanum*

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

Ecology: Occur on rocky outcrops and hills in the Sour Bushveld (Scott, 1982).

Dispersal and preservation characteristic: Present in low percentages in surface samples of this veld type (Scott, 1982a).

Local / Regional: Regional
Arboreal / Non-Arboreal: Arboreal

ROSACEAE

Identified as: *Cliffortia*

Genera found at Mutale Wetland: Unknown

Likely parent taxa: *Cliffortia*

Pollen morphological characteristics (on Genus level): grains 3-4 porate; spheroidal to suboblate; ambit circular; medium sized; pori: protruding; surrounded thick collar; often irregular outline; surrounded granules and small cracks in exine; exine: 2-3µm thick; nexine 0.5µm; baculate; crassitegillate; punctitegillate (van Zinderen Bakker and Coetzee, 1959).

Ecology: *Cliffortia* is an important fynbos constituent of the high mountainous areas of the escarpment (Scott, 1982), usually occurs under moist but also drier conditions (Scott, 1982a).

Dispersal and preservation characteristic: There are 78 species of *Cliffortia* occurring mostly in the southwest Cape but with a few species extending eastwards along the coastal belt (van Zinderen Bakker and Coetzee, 1959).

Local / Regional: Regional
Arboreal / Non-Arboreal: Non- Arboreal

THYMELEACEAE
Identified as: *Passerina*

Genera found at Mutale Wetland: *Passerina montana.*

Likely parent taxa: *Passerina montana.*

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

Ecology: Occurs in grasslands (Scott 1982a), also found in fynbos vegetation (Scott, 1991).

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

Local / Regional: Regional
Arboreal / Non-Arboreal: Non-Arboreal

TYPHACEAE

Identified as: *Typha*

Genera found at Mutale Wetland: Unknown

Likely parent taxa: *Typha*

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

Ecology: Found in aquatic habitats, often indicative of open water (Scott, 1987).

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

Local / Regional: Regional

Arboreal / Non-Arboreal: Non-Arboreal