A palynological investigation of uMgeni Vlei Nature Reserve (Kwa-Zulu Natal) - late Quaternary vegetation and climate fluctuations in eastern South Africa

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Declaration

I hereby declare that the experimental work described in this dissertation is my own work, except otherwise acknowledged. It was conducted at the Evolutionary Studies Institute under the supervision of Prof. Marion Bamford, for the purpose of acquiring a degree of Master of Science at the University of the Witwatersrand. These studies represent my original work, and it has not been submitted previously to any University for the purpose of obtaining any degree.

17/01/2022

Kevwe Eweto Date

Abstract

The uMgeni Vlei Nature Reserve, an area located within the midlands of KwaZulu-Natal of South Africa, was investigated for palaeoenvironmental history and climatic change. Palynology, which is a popular technique to reconstruct southern African past environments, was utilized during this research, as it is directly a means of reconstructing vegetation histories which then can be used to infer changes in climate. A 300 cm sediment core, rich with organic content was obtained from the uMgeni Vlei wetland. Seven samples taken for radiocarbon dating indicated that the chronology is not reliable as the returned ages were not in chronological order and therefore indicates a great degree of disturbance to the sediment. What can be determined from the dating is that the sequence is of Holocene age as the oldest sediments at 141cm depth is dated to 10 680 cal yr BP. Pollen analysis reveals Poaceae, Asteraceae, Liliaceae and *Phragmites* as the dominant plant taxa during the Holocene within the uMgeni Vlei record. CONISS analysis separates the sequence into three zones of statistically significant similarities. Environmental conditions deduced from the pollen spectrum of Zone 3 is characterised by warmer conditions, and pollen of Asteraceae, Anacardiaceae and *Cerastium* dominate the bottom depth at 254cm. Zone 2 was marked with increased moisture availability where pollen taxa of Cyperaceae, Liliaceae, *Anthospermum* and *Phragmites* flourished in relatively warm conditions. Increased moisture availability continued to be detected in Zone 1 as water-loving plants such as *Podocarpus, Ascolepis and Aponogeton* dominated the top of the sequence. The palaeoclimatic trend comparison of palaeoenvironmental records from Mahwaqua, Ntsikeni, Braamhoek and Clarens reveal a palaeoclimatic trend similar to the uMgeni vlei.

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Table of Contents

Chapter 1

Introduction

1.1 Palaeoenvironmental Reconstruction Framework

The earth has contended with constant change of its environment from both naturally occurring and more recently human induced factors (Vogel, 1995). Evidence of these changes can be seen in many fossil records (Bell and Walker, 2014), and one way of understanding these changes is digging into the past environmental conditions and comparing them with the present. In this project, I will use pollen analysis as a method to investigate the vegetation and climate history of the most recent geological period, the Late Quaternary of the uMgeni Vlei Nature Reserve wetland in Kwa-Zulu Natal, South Africa.

Pollen analysis or palynology is essentially the analysis of pollen grains and spores. These grains are very small, averaging between 100 µm and 10 µm in diameter (Erdtman, 2013). These minute grains are easily transferred by wind currents into different regions and over great distances and are then deposited in a new site, distant from, or close to where the parent plant was growing. The "planktons of the sky" described by Erdtman (2013) with the right environmental conditions 'anaerobic condition' are preserved in peat, lake sediments and soils (Bell and Walker, 2014). Under normal circumstances, the composition of the pollen rain reflects the regional vegetation. Thus, if fossil pollen is obtained from sediments, records of the local and vegetational change through time can be deduced (Moore et al., 1991).

Repeated climatic fluctuations between cold or glacial stages, interspersed with episodes of warm conditions, have occurred throughout the Late Quaternary (Bell and Walker, 2014; Lowe and Walker, 2014). These repeated episodes have resulted in documentation of complex landforms and in remains and assemblages of biological forms (Lowe and Walker, 2014). Documentation and interpretation of the nature of these changes has thus been one of the greatest accomplishments in recent earth history. While the details of these changes have been extensively recorded and understood in most of Europe and North America, in Africa, with a focus on southern Africa, these documentations are very sparsely and poorly understood (Norström et al., 2009; Scott et al., 2004; Scott et al., 2012; Norström et al., 2014). The pioneering work of the southern African palaeoclimate studies done by Van Zinderen Bakker (1957) and Coetzee (1967), detailed the first spatial and temporal climatic change in the region, and since then interest in past climate change has grown considerably and extended to much longer time frames. This has contributed greatly to extensive past environmental data being collected to provide a better insight into the changing climate both on a regional and a global scale.

Variables such as landscape, people and climate are inextricably linked, and understanding their natural variability and responses to the changing environment is vital (Bell and Walker, 2014). This requires an analysis of not just the elements but also the way each influences the other. In southern Africa, these studies, although sparsely distributed, have contributed to the explanation of the evolution of the present biomes, past environmental change and how people have adapted to their changing climate (Scott et al., 2012). Past environmental reconstruction of this kind is possible because the environmental conditions are associated with the palaeogeography of a particular interval at a given time. The different stages (see flowchart, Fig 1) described by Lowe and Walker (2014) can be used to reach such reconstructions.

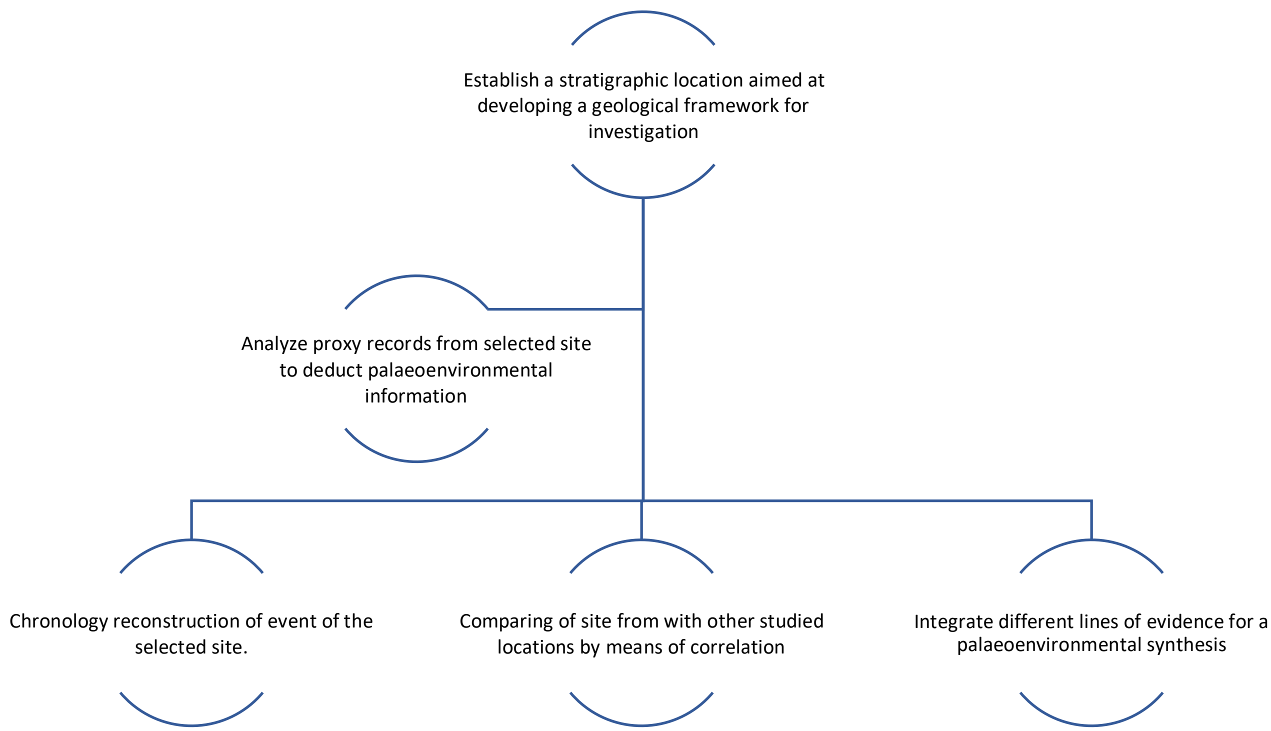

Figure 1: A summary of the various stages in reconstructing past environment. After Lowe and Walker, 2014

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Quaternary history in southern Africa covers a wide range of ongoing depositional, speciation and ecosystem change, hominin evolution and tectonic setting (McCarthy and Rubidge, 2005; Partridge et al., 1995). While its timeline given in (Fig 2) describes the sequence of events that characterises these periods, which includes not just the repeated warm and cold episodes that occurred throughout the Cenozoic Era, but also a combination of series of high amplitude and climatic oscillation coinciding with the intensity of the colder periods (Lowe and Walker, 2014).

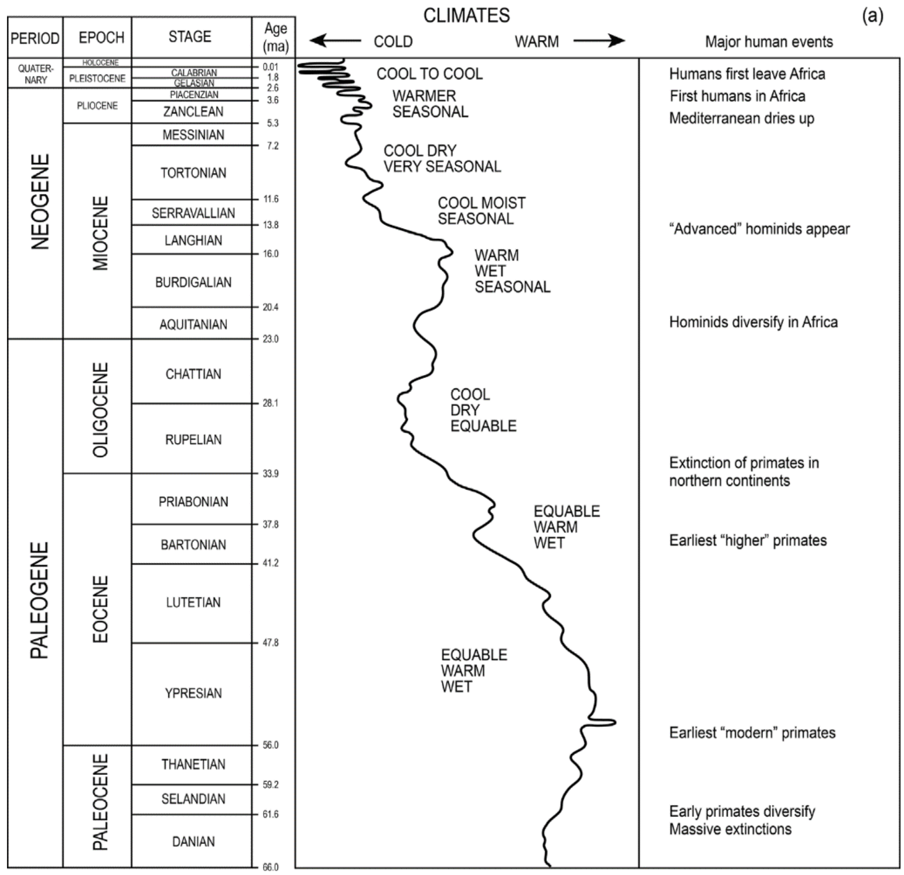

Figure 2: The Quaternary climate relative to the geological timescale. (After Partridge et al 1995)

Other African records in particular during the Pleistocene have reported on some climatic events that are mainly featured in the Northern Hemisphere such as Dansgaard- Oeschger cycles (D-O events) and the Heinrich events (Itambi et al, 2009). In southern Africa These events have in fact been identified in several records (Abell and Plug 2000, Thackeray and Scott 2006, Chase et al 2011, 2015, Quick et al 2021). According to Knight and Grab (2016), such reports only indicate that southern Africa is well placed to record such variation.

Considering the diverse nature of southern Africa's topography, past and present tectonic processes, the climate and climate changes have been the major regional-scale controls on southern Africa's recent geological history and has been recorded in the sediments (Knight and

Grab, 2016). Dating of these exposed and buried sediments can inform us on the sedimentation rates, although such dating studies are controversial, they are increasingly being explored (Portenga and Bierman, 2011). Results from such independent studies can be difficult to evaluate (de Wit, 2007). Hence, Lowe and Walker (2014) suggested that the application of a wide range of methods in Quaternary research is important and that both multidisciplinary and interdisciplinary approaches are required if a proper understanding of the complexities of the Quaternary environment is to be achieved.

In this study, the focus is to use palynological analysis to study core material from a wetland deposit from the uMgeni Vlei Nature Reserve as a step to add to and to investigate the potential of such deposits as reliable indicators of past climate and vegetation change. This is based on the premise that climate change is the principal component (Schulze, 1997; Meadows and Quick, 2016) shaping vegetation patterns, especially at the biome scale (Meadows and Quick, 2016; Bamford et al., 2016), as other factors such as fire and human interference may contribute to locally induced change (Neumann et al., 2014).

Palynology, a subfield in micropaleontology, investigates pollen and spores in order to reconstruct past climates regarding the plant community of the environment (Traverse, 2007). The guiding preface of investigation involves accumulating qualitative and quantitative data. These data include identifying and acquiring assemblages of pollen and spores. Although, there is a limitation in palynology in the precision of identification which often is to the family level and seldom genus or species level, nonetheless, it is possible to obtain evidence of obvious environmental trends based on these larger groupings that yield palaeoenvironmental information (e.g. Scott, 1982; 1999a, b; Neumann et al., 2014).

Palynology is employed in a range of disciplines (geology, archaeology, biology) all concerned with the environment and has proven to be an excellent tool in understanding southern African Quaternary climate fluctuations (Scott, 2012). The umgeni Vlei which is situated within the savanna biome is adjacent to two Quaternary sites Mahwaqa and Ntsikeni with long term palaeoenvironmental record. Other Quaternary sites across southern Africa, for example the Tswaing and Wonderkrater study sites, both located in the Savanna Biome, also have lengthy Quaternary land pollen records for this region (Scott, 1982, 1999a, b). With the later sites, the mid-late Pleistocene sections of the cores revealed some discontinuity (Scott, 1982, 1999a, b). In the core sequence, the older section had some interpretation constraints due to dating problems, thus leaving some gaps in the pollen records (Scott, 1999b). Other environmental studies within the Savanna Biome readily provide a summary of the missing records (Scott and Thackeray, 1987; Scott et al., 2012; Chase et al., 2010). In some cases, reinterpreting the palaeoclimate conditions and questioning previous interpretations of the environment, can contribute to and also improve the palaeo-vegetational history of the Savanna Biome. According to Bamford et al, (2016) such understanding can advance the Pleistocene section at Tswaing and other regions if the chronology is improved by these various independent studies at high resolution.

1.2 Study Aims and Objectives

To contribute to the regional paleoclimate history of the Quaternary with a focus on the Holocene environment, this study aims to utilize a palynological analysis to reconstruct the ancient environment of the present wetland site at uMgeni in Kwa-Zulu Natal. This will be done through the following objectives:

1. To explore literature of the modern vegetation surrounding the study site and its expanse.
2. To retrieve suitable sediments from the wetland for (a) radiocarbon dating (to establish a chronology) and (b) for pollen analysis
3. To extract and to concentrate fossil pollen and spores from the core material for identification and quantification of the content to detect regional vegetation changes over time.
4. To determine the relationship among plant communities and their associations with climate parameters. This will be done by visually and statistically exploring the total pollen count by utilizing clustering and ordination techniques (Principal Component techniques).
5. To compare findings from the study site to other palynological records within the same region.

1.3 Dissertation Outline

The Introduction Chapter presents the reader with the purpose and importance of the research undertaken in the palaeoenvironmental field. This chapter provides the framework on how palaeoenvironmental work was conducted.

Chapter Two presents the modern vegetation pattern in South Africa and is followed by a review of the postulated drivers responsible for environmental change and how they have contributed to the current biomes of South Africa. A summary of the South African palaeoenvironmental history is presented; this review highlights the key debates within the southern African palaeo-scientific community and from the synthesized literature, will present areas where this study can contribute to knowledge and to emphasize the need for such work to be conducted in the uMgeni wetland.

Chapter Three provides details of the regional setting of the uMgeni Vlei and insight into the geology, climate and current vegetation of the uMgeni Vlei and its surrounding region. An overview of the 'Drakensberg Foothill Moist Grassland' within the Savanna Biome where the wetland is currently situated is discussed

Chapter Four presents the theoretical background of the methods employed in conducting the palaeo-research. This will include a detailed description of the laboratory procedures employed in isolating pollen and preparation of pollen slides. This chapter will also discuss the statistical methods used to explore all retrieved pollen dataset. The statistical approach used for the radiocarbon dates will be discussed in this chapter.

Chapter Five presents the results derived from the pollen counts, and visual representation of the statistics explored in the dataset and a presentation of the changes detected.

Chapter Six is a discussion of the results presented in the preceding chapter; this includes change in vegetation detected from the wetland and with the environmental information inferred from the pollen analysis reconstructing the past environmental conditions of the uMgeni Vlei.

Chapter Seven provides detailed information of similar environmental reconstructions with which this study site can be compared. In conclusion, the final chapter provides a synthesis of the palaeoenvironmental changes at uMgeni Vlei, KwaZulu-Natal.

Chapter 2

Literature Review

2.1 Modern vegetation of southern Africa

Climate change remains one of the major contributors to shaping the current vegetation patterns of southern Africa. However, these changes in the Quaternary did not result in the current biomes but contributed to the partial migration of these biomes (Neumann and Bamford, 2015). This may result in individualised species being favoured over others or disadvantaged due to the changing climate within the biome level or at ecotonal boundaries over time (Neumann and Bamford, 2015). Hence, a consideration of the modern vegetation discussed below will provide insight into the climatic conditions that favoured the current vegetation and its geographical distribution.

The current vegetation of Southern Africa is known to have a rich variety of biomes that have been discussed extensively by Rutherford & Westfall (1994) and Rutherford and Powrie (2006). Their distribution stretches over three climatic zones: (1) the winter rainfall regions are known to support the Fynbos and the Succulent Karoo Biome in the west. (2) the summer rainfall region that comprises the Grassland Biome in the east, central interior and the southernmost part of the subcontinent, and (3) the all-year-round rainfall zone that comprises dry-adapted vegetation (e.g., Albany Thicket Biome) located within the southern coastal region of South Africa (Neumann and Bamford, 2015) (Fig 3).

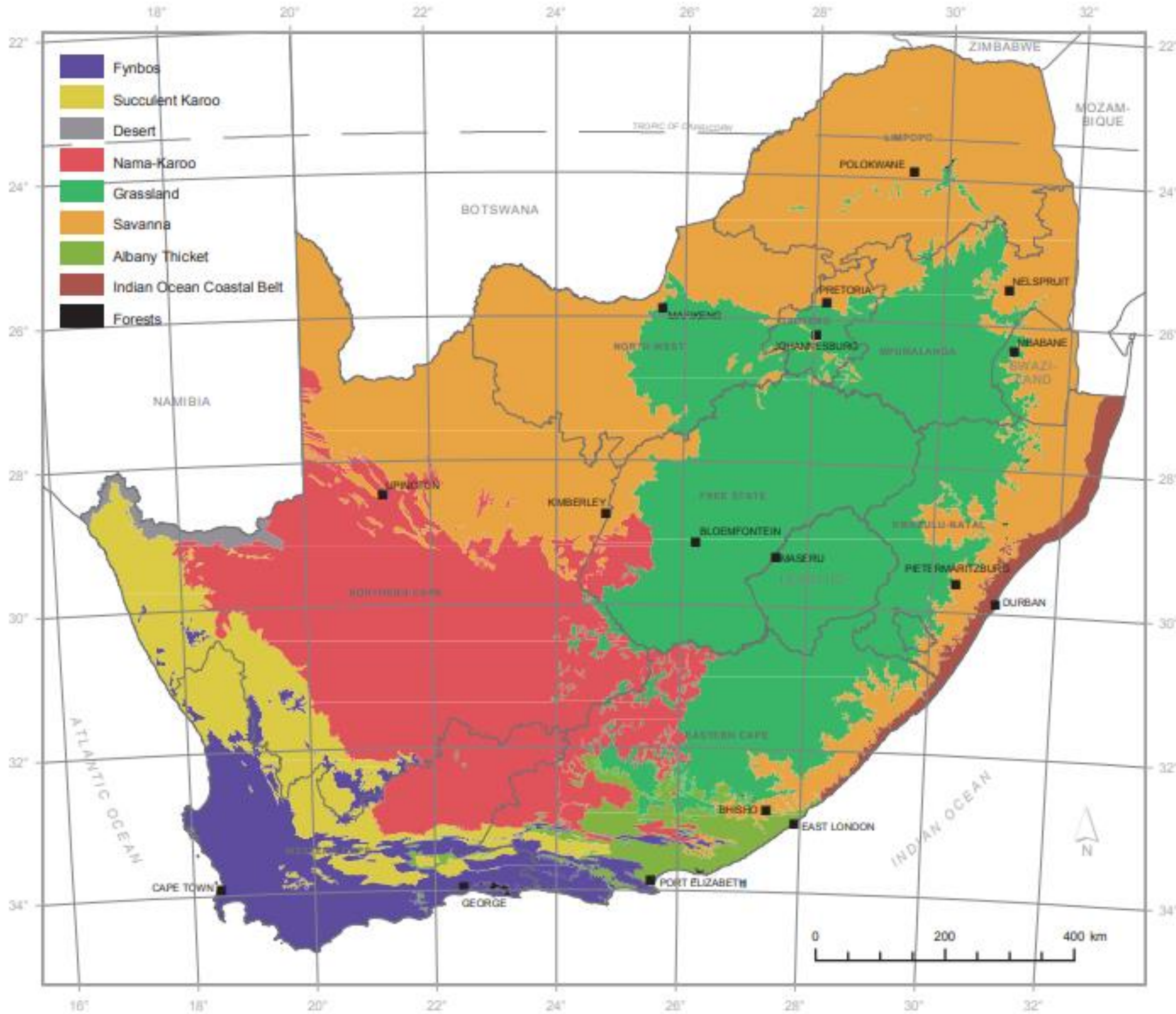

Figure 3: Current vegetation distribution map of South Africa (Rutherford et al., 2006; Meadows et al., 2016).

These climatic zones are distinguishable on the subcontinent by the patterns of topography, underlying geology and rainfall seasonality (Meadows and Quick, 2016). Although strong relationships between community biomes and climate are noteworthy, the climatic condition of the Quaternary did not lead to the current biomes (Neumann and Bamford, 2015). The origin was traced back to the Neogene with some biomes even suggested to have originated in the Paleogene (Cowling et al., 2005;(Neumann and Bamford, 2015). A description of the major biomes is presented in (table 1).

Table 1: The current southern African Biomes (After Neumann and Bamford, 2015)

Southern African Biomes	Location	Dominant vegetation types	Rainfall seasonality	Precipitation	Origin
Fynbos Biome	It occupies and is limited to the southwestern part of South Africa	Ericaceae, Restionaceae and Proteaceae are the main families characterising this biome	Winter rainfall	Differ between 210 to 800 mm/year	Early Pliocene
Succulent Karoo Biome	Some parts of the western and eastern region of southern Africa.	Characterised by a high diversity of succulent plants and semi-desert flora	Low	perennial or bimodal precipitation	Neogene
Nama-Karoo Biome	Northern to the south-eastern part of South Africa.	Has components of the six neighbouring biomes. Is less rich than the neighbouring succulent Karoo biome. Dominant families of this biome are Asteraceae, Fabaceae and Poaceae	Low	Depends on the location, In the north 70 mm, while records of about 500 mm in southeast	Neogene
Desert Biome	It spreads across the Orange River and extend toward the Namib Desert	It is characterised by ahighly diverse flora such as Crassulaceae, Asteraceae and Aizoaceae, among others	Summer rainfall	Annual precipitation ranges from 10 mm to 80 mm at different location	late Miocene
Albany Thicket Biome	Occupies the semi-arid area of South Africa between the Eastern and Western Cape region	The biome is characterised by a variety of semi-succulent vegetations as well as woody and dense vegetation	All-year-round rainfall	Precipitation is bimodal	Eocene

Grassland Biome	Occupies most of the highlands in the eastern part of South Africa	Dominant family is the Poaceae	Summer rainfall	400–2500 mm/year	Upper Cretaceous
Savanna Biome	Occupies most of the Congo Basin and stretches towards eastern Africa	Characterised by the dominance of C_4 grasses	Summer rainfall		Neogene
Forest Biome	They can be found between the eastern and southern parts of sub-continent as forest patches.	The forest patch characterising this biome are mostly evergreen and include, subtropical, azonal and afro-temperate forests in South Africa			Neogene
Indian Ocean Coastal Belt Biome	Vegetation characterising this biome are mostly found between the SA border with Mozambique on a coater strip and extends toward the mouth of the Great Kei River.		Summer rainfall	Average 819–1272 mm/ year	Neogene

In the southern African biome scale, longterm climate change contributed to the vegetation redistribution across the subcontinent (Scott and Bonnefille, 1986; Scott et al., 1997; Neumann and Bamford, 2015; Bamford et al., 2016). Its impact on the ecosystem is observed mostly in community dynamics within biomes where vegetation communities respond differently in accordance to the changing climate (Meadows and Quick, 2016). In determining the effect of climate changes on the ecosystem, an understand of the ecosystem drivers is considered necessary (Truc et al., 2013; Bamford et al., 2016). This is because recognised patterns are emerging from palaeoenvironmental records that are not in agreement (Chase et al., 2010), with arguments centring on different drivers as a possible explanation for the variability (Scott et al., 2012). Knowing the different ecosystem drivers is also important because of the sensitivity of ecosystems to climate (Meadows and Quick, 2016) which is affected by other environmental variables and by human activities (Daniau et al., 2013).

2.2 Drivers of Climate Change during the Quaternary

Southern Africa is bounded by two great oceans, the South Atlantic Ocean and the Indian Ocean (Fig 3). The position of the subcontinent, as well as the interface between climatic systems i.e., tropical, subtropical and temperate, greatly influences its atmospheric and oceanic systems across the landmass (Chase and Meadows, 2007). This is evident in the seasonal rainfall pattern of the subcontinent which is separated by regions into all-year rainfall zone, the winter rainfall zone and the summer rainfall zone (Tyson and Preston-Whyte, 2000). Areas situated along the northeast of South Africa experience much of their rainfall during the summer months of the year, while areas within the southern and western coast gets rainfall in the winter months. Between these rainfall regions is a narrow strip that receives rainfall throughout the year (Tyson and Preston-Whyte, 2000; Chase and Meadows, 2007). The climate of southern Africa is considered to be influenced by these seasonal interplays, owing much of its dynamics to the high-pressure cell, positioning of the intertropical convergence zone as well as the migration of wind (i.e., the easterly and the westerly wind) (ITCZ; Tyson, 1999; Chase and Meadows, 2007).

The milankovitch cycle provides an explanation for long term climate change, however this theory alone does not fully account for all aspects of the Quaternary climate record (Imbrie et al., 1993). This astronomical theory is one of the hypotheses that has gained attention and has provided a satisfactory explanation for climate change during the Quaternary. This theory presumes that the earth surface temperature would differ when responding to changes of the earth’s orbit and axis (Lowe and Walker, 2014). The proposal originally described by James Croll in the 1840s was later known as the Milankovitch theory as was further developed in the 1920s by the Serbian geophysicist Milutin Milankovitch. In his theory, he concluded that three different positional cycles influence the earth's climate, each with its cycle and length (1) the eccentricity of the orbit, (2) the obliquity of the ecliptic and (3) the precession of the equinoxes.

The eccentricity of the orbit describes earth as it orbits around the sun. The earth's orbit changes from circular to elliptical and vice versa due to earths gravitational influence. The timing of the orbit differs, although generally referred to as the 100ka eccentricity cycle, a higher range of values are also apparent (Lowe and Walker, 2014). *Obliquity of the earth's tilt*: Referred to as the angle of tilt, represents the plane of the ecliptic. It is considered an imaginary line that describes the earth's elliptical path around the sun. While t*he precession of the equinoxes* is the third variable that describes the influence on the earth, of the gravitational pull exerted by the sun and the moon that results in a wobbling of the earth, and this accounts for the change in the season of the earth (Lowe and Walker, 2014).

A combination of all these factors has a stronger impact on temperature on a global scale. The eccentricity of the earth's orbit accounts for radiation received on the earth (insolation), whereas other variables contribute to the redistribution of heat energy at different latitudes. Solar radiation received in regions situated between low to mid-latitude is mainly governed by the variation of precession and eccentricity, while the effect of obliquity cycles is mostly restricted to higher latitude regions (Lowe and Walker, 2014). Astronomical data produced from these variables aided Milankovitch to obtain estimates for radiation inputs at different latitudes which he then used to reconstruct long-term temperature changes (Lowe and Walker, 2014).

In general, all climate change can be explained through natural variability in the global weather system across the timescale. The increase in average global temperature since the mid-20s places the current environmental condition in a state referred to as global warming (Lowe and Walker, 2014). It is postulated to have resulted from increased greenhouse gasses from anthropogenic activities, and as described by Burrough (2009), this may set the climate into an unpredictable mode. Undoubtedly, a review of the Quaternary palaeoenvironmental research with more focus on South Africa can provide a historical perspective essential for long-term management (Lowe and Walker, 2014).

2.3 Southern Africa palaeoenvironmental history

In southern Africa, as in the rest of the world, at least 20 climatic cycles, each lasting several thousand years, have affected it, mirroring the series of expansion and contraction of glacier ice sheets (Preston-Whyte and Tyson, 1973; Tyson, 1986). The terms expansion and contraction are also readily used in a wetland setting to describe an environment experiencing drought (contraction) or flooding (expansion) (Scott, 2012; Vanderhoof et al., 2018) – but on a different scale. Evidence of climate change in southern Africa during the Quaternary is featured in various sources but remains patchy (Scott et al., 2012; Neumann et al., 2008). Many of these palaeoenvironmental works have been reviewed in detail (Scott, 1982a; Scott et al., 2003; Scott, 1999a, b; Neumann et al., 2008; Neumann et al., 2010; Meadows and Finch, 2016). Most of these works feature palynological data from core samples from various environment types that extend from the arid environment in the west to the humid environment in the east of South Africa (Scott et al., 2003). Various proxies (e.g., foraminifera, diatoms, charcoal and pollen) are available to researchers to aid palaeoenvironmental reconstruction. A review of the rich and diverse proxy records of the whole of the Quaternary is beyond the scope of this project. For a comparison of the palaeoenvironmental record, only the summer rainfall region which the current study site is located (Fig 4) will be used for the comparative study and reconstruction of the past environment.

Figure 4: Selected palynology sites within the Grassland Biome of South Africa

In selecting the proxy records and location, prominent Quaternary review papers from the Last Glacial Maximum (LGM) (ca 21 000 years BP) to the Present were selected from the resources available for review (in Chase and Meadows, 2007; Scott et al., 2012, Scott and Neumann, 2018). The list of selected sites for review is presented in Table 2. Palaeoenvironmental records in the summer rainfall region exceed the number listed here but it was decided to focus on the key, well-dated sites that are in close proximity, namely Mahwaqa Mountain, Nsikeni wetland, Braamhoek wetland and Clarens (Fig 1).

The discussion on the palaeoenvironmental records was based on evidence from proxy records and was not limited to just the listed sites. It includes other study sites with important climatic events (i.e., The Little Ice Age and the Holocene Altithermal) of the Quaternary that the listed sites lacked in providing sufficient evidence from their proxy records.

Table 2: Summary of Quaternary palaeoenvironments of selected site

Locality	Proxy type	Time covered	Summary of climatic inferences	Reference
Mahwaqa Mountain	Pollen	18,000 – 1,000 cal. BP	Vegetation response was highlighted in the following period: 18,000-13,500 cal. BP with cool conditions. 13,500-8,500 cal. BP with climate warming coupled with environmental wetness. A continuation of warm conditions extending to 4,600 cal. BP with some fluctuating moisture condition was inferred. The driest period recorded falls within 4,600 and 3,500 cal. BP. And a return of humid conditions from 3,500-800 cal. BP.	Neumann et al., 2014
Ntsikeni wetland	Pollen	25,000 – 4,900 cal. BP	Coldest condition was reported from the oldest period that coincides with the Last Glacial Maximum. A progessive warm, moist period reported from 7,500-5,500 cal. BP. Significant cold periods were also reported at 13,500 cal. BP, 8,500 cal. BP, and 4,000 cal. BP. While the driest period, two distinct periods were reported to occur. They spanned	Combrink et al., 2020

			from 19,600 -18,000 and 6,500 and 4,900 cal. BP.	
Braamhoek wetland	Pollen carbon and nitrogen content, isotope composition ($\delta^{13}C$, $\delta^{15}N$) and microscopic charcoal concentration	16,000-1,000 cal BP	Dry conditions were reported between the following periods: 16-13.7Ka, 12.8-10.5 ka, 9.5-8.2ka. while wet conditions were reported between 13.7-12.8ka and 10.5-9.5ka. within 8.2-7.5ka, moisture signal was reported but was suggested to be weak. Cool conditions were described throughout the late Pleistocene to early Holocene. And warmer conditions were suggested for 11- 8ka. At 1.5ka dry conditions were suggested. This period followed a humid condition at 0.5ka.	Norström et al., 2009
Clarens area (Claigrossie, Cornelia and Elim)	Pollen	23,000 cal. BP	At 23,000, humid grassland with strong fynbos and swampy conditions were the earliest paleoenvironmental records reported north of Clarens. Cooler, drier conditions followed from 22,600 -19,000 cal. BP. 18,000 and 17,000, grass vegetation became more prominent. At 13,000 cal. BP in Caledon Basin, shrubby grassland with fynbos element was reported in a slightly warmer and moist condition. And before 10,700 cal. BP decline in the fynbos element was reported.	Scott et al. 1989
Florisbad spring	Pollen	6,500 cal. BP	Arid conditions were prominent between 6,500 cal. BP, 6,300 cal. BP and 4,420 cal. BP. Within these dates were dry episodes with karroid shrubs between 5,500 and 4,500 cal. BP. After these periods, fluctuating moisture conditions were reported spanning 2,100-1,700 BP.	Scott and Nyakale, 2002
Rietvlei Dam	Pollen	6,500 cal. BP	This study suggests an inconspicuous date in the age profile. However, it reveals a temporary expansion of	Scott and Vogel, 1983

			bushveld elements over the highveld plateau with a relatively warm and moisture conditions at 6,580 cal. BP.	
Braamhoek	organic sediment fraction (fossil pollen, charcoal, n-alkane abundance, n-alkane d13C, TOC) and the inorganic fraction (mineral magnetic properties)	16,000 cal. BP	Two regional wetter phases were indicated in the Pleistocene to early Holocene phase: the first period spans from 13,800- 12,600 cal. BP and 10,200-8.500 cal. BP, while the second was at 2,000 cal. BP. Drier conditions coinciding with the Younger Dryas were reported on between 12,600-11,300 cal. BP and 7,000- 2,000 cal. BP. At 8500 cal. BP, warmer temperature with less pronounced winter rainfall was reported in the eastern region.	Norström et al., 2014

The literature presents some of the limitations associated with palynological studies in South Africa. This includes the discontinuity in polleniferous records (Scott et al., 2012). This has led researchers to use alternate methods such as hyrax-middens (Scott et al., 2004; Chase et al.,2012), and other proxies such as diatoms (Finné et al., 2010), phytoliths (Scott, 2002), charcoal (Chazan et al., 2012), among others to enhance the resolution in environmental reconstruction to interpret long-term vegetation change.

The Quaternary spans the last 2.6 million years and consists of the Pleistocene and the Holocene epochs (Anderson et al., 2013). Most of the Quaternary time is spanned by the Pleistocene, while from 11,700 years to the present is termed the Holocene and is mostly characterised by the development of agriculture and civilization (Anderson et al., 2013). The environmental conditions during the transition phase involve a shorter-term change that includes warm periods in the first decades of the twentieth century. This climatic transition, although better represented in palaeoenvironmental records, is far from smooth (Abell and Plug, 2000). The Pleistocene consists of major alternation between glacials and interglacial events that lasted over a longer period when compared to the Holocene (Anderson et al, 2013). In contrast, the changes with durations of hundreds of years during the Holocene include different phases of glacial advance and retreat, such as the Little Ice Age (1500 and 1850 AD) and the Holocene Altithermal (8,000- 4,000 years ago) among others (Anderson et al, 2013). An overview of the regional climatic change from comparisons drawn from multiple sites described by Scott et al (2012) and Engelbrecht et al., (2019) provides insight into the Quaternary of the savanna biome that will be briefly discussed.

Climatic conditions in South Africa during the Late Pleistocene: During the late Pleistocene, temperatures over the interior of southern Africa have fluctuated. Temperatures were significantly lower than the present-day temperature during the Last Glacial Maximum (LGM; about 26,000 to 18,000 years ago; Engelbrecht et al., 2019). Temperatures were estimated to have been around 2-6°C cooler based on pollen probability density functions in the northeastern part of South Africa (Truc et al., 2013). Pollen records from Ntsikeni reported a significantly reduced drier indicator such as Asteraceae coinciding with an increase in cold tolerant indicators such as Caryophyllaceae throughout the zone that accounted for the 25,100 - 12,800 cal yr BP (Combrink et al., 2020). Other sources report on fynbos pollen such as Ericaceae, *Passerina* and Restionaceae, suggestive of a cooler condition occurring during this timeline (Scott et al., 1989; 2012; Dupont and Kuhlmann, 2017), but where not conspicuous at Ntsikeni (Combrink et al., 2020). Some of the fluctuating climatic conditions from Ntsikeni that were associated within these periods include a slight increase in temperature that occurred from 22,000- 21,000 cal yr BP. The proposed rise in temperature was thought to represent either a migration of treeline upslope, due to the presence of *Podocarpus* or a change in wind strength direction (Combrink et al., 2020). Increased temperature as well as precipitation was reported for 21,000- 18000 cal yr BP with a return to cooler conditions reported on from 17,000 cal yr BP (Combrink et al., 2020). The coldest period for Ntsikeni was reported to be at 13,000 cal yr BP and from then on, increasing temperature preludes the rest of the periods (Combrink et al., 2020).

Pollen records from Clarens, a late Quaternary site from the eastern Orange Free State, describe the earliest paleoenvironmental conditions at 23,000 cal yr BP to be of humid grassland with strong fynbos and swampy condition (Scott, 1989). A cooler and drier condition progressively followed at 22,600 - 19,000 cal yr BP (Scott, 1989). This period was reported to hold the coldest condition and is reported to occur just after 20,000 cal yr BP and before 18,000 cal yr BP (Scott, 1989). At 18,000 - 17,000 cal yr BP, grass vegetation becomes prominent, it is unknown if the trend remains the same or changed before 13,000 cal yr BP as no environmental deduction was made due to poor resolution from the site (Scott, 1989). Shrub grassland accompanying fynbos element, in slightly warmer conditions in a relatively moist condition was described at 13,000 cal yr BP with a warmer condition described into the Holocene (Scott, 1989).

A multi- proxy study From Braamhoek wetland, situated within the Drakensberg region in South Africa, reported an increased regional wetness during the late Pleistocene to early Holocene (Norström et al., 2014). The study, which covers the last 16,000 cal yr BP reported an increase in fynbos element occurring from 15,400 - 13,900 cal yr BP. While no known inferred condition was given for that time period, it was reported that pollen from woodlands and marchlands accompanying a decrease in drier indicators coinciding with an increase in aquatic pollen representation, that occurred between 13,900- 11,600 cal yr BP was suggested to be linked with moisture availability in the region (Norström et al., 2014). This increase in wetness, saw a decline from 12,500 cal yr BP and reports on drier condition followed into the early Holocene (Norström et al., 2014).

Palynological records from Mahwaqa mountain in Kwazulu-Natal within the Drakensberg region also provide insight into the late Pleistocene. Covering the last 18,000 cal yr BP, described the vegetation between 18,000 - 13,000 cal yr BP to be dominant in fynbos elements, indicating a cooler condition (Neumann et al., 2014). A decline in fynbos element was reported from 13,500 into the early Holocene, were these elements where thought to be replace by grass pollen, signaling a warmer climate (Neumann et al., 2014).

The Holocene in South Africa (11.6 thousand years to the Present): This Period covers a time where many cultural and environmental changes took place, including activities from Iron Age people, European settlers, increased agriculture and herding together with a purposeful fire regime (Neumann et al., 2014). Pollen records from Ntsikeni at 12.6- 10.3 ka, reveal a contraction of the wetland indicating possibly reduced rainfall in a warmer climate at 10ka (Combrink et al., 2020). At Braamhoek, the Pleistocene/Holocene transition phase also recorded a return to dry conditions after 12.8ka (Norström et al. 2009). Prior to 12.8ka the vegetation associated with it were all favoured by relatively moister conditions that peaked at 12.8ka at Braamhoek wetland (Norström et al., 2009). This followed a return to drier conditions at 12.5ka in suggestively cooler climate at Braamhoek (Norström et al., 2009). The dry conditions must have prevailed until 10.5ka where a return to wetter and cooler conditions was suggested from pollen records from Braamhoek (Norström et al., 2009). Between 10.5 and 9ka, pollen record from Braamhoek continued to indicate a moister condition in a probably cooler climate due to the increase in fynbos vegetation and terrestrial taxa that were suggestive of a wetter environment (Norström et al., 2009). Records from Ntsikeni indicated that at 10.3-9ka terrestrial and aquatic plants were absent hence leaving a gap on the climatic event for that period (Combrink et al., 2020).

Pollen records from Mahwaqa however, describe the environmental trend of 12ka to have decreased in cooler indicators as well as decrease in moisture especially within the wetland (Neumann et al., 2014). Increase in temperature was suggested for Mahwaqa at 11 -10ka with no substantial inference for 9ka (Neumann et al., 2014). The Mid to late Holocene period have been reported by various sites as a period of slow drying and has low resolution probably due to low sedimentation rate (Norström et al., 2009; Scott et al., 2012; Neumann et al., 2014; Combrink et al., 2020).

The mid to early Holocene period covers the climatic event known as the Holocene Altithermal which is between 8-4ka. This climatic period is generally described as a period of warmth with a peak around 8ka (Anderson et al., 2013). Considering palaeoenvironmental records from within the Grassland Biome, the precipitation has been described to have reached a heightened moisture availability at 8ka from pollen records from Ntsikeni (Combrink et al., 2020). During this period moisture availability in cold conditions was inferred for Ntsikeni wetland (Combrink et al., 2020). An increase in temperature was however suggested to have peaked at 5.1ka, which was suggested to have resurfaced between (7-5ka) and was accompanied with dry conditions (Combrink et al., 2020). For Ntsikeni the warm conditions extended to 4ka after which regional moisture availability was described at 3ka with no records on the temperature and precipitation from Ntsikeni wetland thereafter.

Records from Braamhoek suggest that the regional conditions changed toward drier and warmer; however, a cool and wet spell was indicated around 8ka supporting records from Ntsikeni (Norström et al., 2009). A transition from C_3 environment to a higher C_4 observed from $\delta^{13}C$ records from Braamhoek later indicated a possibility of drier and warming conditions which could be related to a change in weather to drier condition between 9.7-7.5ka (Norström et al. 2009).

At 6ka warmer conditions were reported as developing at Mahwaqa (Neumann et al., 2014). The warming climate experienced an increase in charred particles as well as strong fungal occurrence (Neumann et al., 2014). The heavy presence of charred particles and fungal remains were thought to have resulted from the increasing temperature that may have favoured the growth of fungi in plants and soils (Neumann et al., 2014). Another possible explanation considered at Mahwaqa included an increase in dry season prompting the survival structure of the fungal species, presence of fungi growth in Poaceae and Asteraceae as discussed by White (1987) and a huge concentration of defecating and grass-grazing ungulate herbivores near a water source during dry season (Neumann et al., 2014). The conditions favouring charred particle and fungi remains were recorded into 3.5ka where the environment was inferred to be more humid due to the change in vegetation described from the pollen record from Mahwaqa (Neumann et al., 2014). Thereafter increasing fire intensity were reported from 2ka and Iron age farmers were detected in the region at 1.2ka in the Mahwaqa region (Neumann et al., 2014).

The late Holocene to Colonial period between 800-8 cal BP was described to be more humid from pollen records from Mahwaqa (Neumann et al., 2014). This period saw the arrival of European settlers (Neumann et al., 2014). Records from Mahwaqa indicated that modern plantations of pine pollen accompanied a decrease in *Podocarpus* forest, and that this reflected the destruction of the latter vegetation since their arrival (Neumann et al., 2014). Destruction of forest is sometimes linked to anthropogenic activities and induced fire (Scott, 2002b; Neumann., 2014), A comparison of the fire intensity, however, from the time of the European settlers revealed a more controlled fire regime that is thought to have begun since the arrival of the Iron Age settlers at 2ka (Neumann et al., 2014). Records from other sites revealed that these settlers have managed to gain control of wildfires interpreted from less charred particle recovery (Norström et al. 2009; Neumann et al., 2014). Another anthropogenic impact recorded includes recovery of increased dung probably due to large stock grazing (Neumann et al., 2014). Environmental conditions during much of the late Holocene to the colonial period between (800-8 cal year BP), have been suggested to be pointing to more humidity as indicated by pollen records from Mahwaqa (Neumann et al., 2014).

2.4 Key debates in the Quaternary palaeo-scientific community

In southern Africa, it is still unclear how vegetation responds to climate changes during the Quaternary (Meadows and Quick, 2016). Although past environments have been reconstructed, with attention to the temperature, precipitation, vegetation and the main drivers contributing to the change (e.g.Scott and Vogel, 1983; Scott et al. 1989; Norström et al., 2009; Neumann et al., 2014), but evidence from these studies still reveals a limitation on the ecosystem conditions (Meadow and Quick , 2016). Based on previous reconstructions, consistency tends to be more with temperature than precipitation and vegetation (Norström et al. 2009; Neumann et al., 2014; Combrink et al., 2020). Congruence in the climatic trend observed in southern Africa sometimes is derailed because of the unresolved key questions that are centred on the timing of these events, that is if the climatic event experienced both globally and regionally fits in chronologically and to what extent. For example, the issue of the last glacial period (LGM) discussed in the Biennial Conference of South Africa Society of Quaternary Research in (2017) highlights that the LGM from a global perspective corresponds to the coldest phase of the last glacial cycle (Fitchett et al., 2017). In southern Africa, the palaeoenvironmental evidence on the climatic conditions during that period vary (Meadow and Quick, 2016). Incongruence in the LGM is alluded to lack of sites (Fitchett et al 2017), and in comparison, with the Holocene, many more sites have been reconstructed (Meadows and Quick, 2016), however, the extent to which such evidence is translated into a clear picture of environmental change is limited. Some of the key global events of the Holocene includes:

1. The Medieval Warm Period (MWP) (800-1500 A.D) (Lamb, 1965)
2. The Little Ice Age (LIA) (1500-1900 A.D) (Tyson et al., 2000)
3. The mid Holocene Altithermal (HA) (5000 - 7000 cal yr BP) (Meltzer, 1999)
4. The 8.2Kyr BP Atlantic cold reversal (Smith et al., 2002)
5. The African Humid Period (AHP: 9-6 Kyr BP) (Chase et al., 2009)

Like the late Quaternary, debates in the Holocene still linger on the timing of these events across southern Africa (Meadows and Quick, 2016). Unlike the Holocene, Fitchett (2017) identifies the late Quaternary debates to be more centred on:

1. The fluctuations in the latitudinal extent of the westerly winds.
2. The correspondence of the southern Africa palaeoenvironmental records with the northern hemisphere.
3. The climatic events and the climatic conditions during the LGM.

2.5 Conclusion

This chapter provides the reader with an overview of the main drivers of climate change, and a review of the Quaternary environmental conditions of southern Africa. With palaeoenvironmental reviews limited to study sites from the grassland biome, it is clear that the climatic events from a local site can be seen in regional climatic patterns, but many of them are still debatable. This, however, highlights the importance of comparative study among other studied sites. Very notably is the way specific sites respond to the varied climate, and a lack of research areas that are within close proximity, so these have made regional comparison very problematic among the study sites. Ensuring a high resolution and chronological record to understand environmental change is vital in combating problematic correlation of climatic events. As other palaeoenvironmental studies have shown this research may be limited in establishing correlation of all known climatic events, however from retrieved data from the allocated site, the climatic events will be investigated and discussion on the climatic observations will be presented in the Results Chapter and will be elaborated on in the Discussion Chapter.

Chapter 3

Study Location

3.1 Site Description

Figure 5: A topographic map of uMgeni Vlei showing the Impedle district of Kwa-Zulu Natal and the Maaloti Drakensberg Transfrontier Project Area (MDTA)

The uMgeni Vlei located within the Impendle District of KwaZulu-Natal, falls within the uMgeni Vlei Nature Reserve and expanding areas under the uMgungundlovu District Municipal Area. It is an internationally recognised area situated in the eastern fringes of the Maloti Drakensberg Transfrontier Project Area (MDTA) (Begg, 1989; Vrahimis and Visser, 2006) on the upper fringes of the Impendle Mnicipal District (Fig 5).

The KwaZulu-Natal Province is extensively covered by grassland, forests, thickets and woodlands but the main vegetation characterising this Vlei includes, Drakensberg Foothill Moist Grassland, the Eastern temperate Wetlands, Mooi River Highland Grassland and the Eastern Mist-belt Forest (Mucina and Rutherford, 2006) (Fig 6). This 9.58 square kilometre wetland is located at an altitude of 1767m within surrounding area restricted to the uMgeni River (Begg, 1989). The Vlei and its expanse fall within the summer rainfall region where its catchment receives about 600-1500mm average annual rainfall. This permanently waterlogged environment, in contrast with the Drakensberg known by tourists for its attractions like the uKhahlamba-Drakensberg Park, commonly is recognized as an agricultural area (Phillips, 1973; Camp, 1997).

Figure 6: Mosaic grassland and forest patch on top of the escarpment

The topographical feature of the nature reserve also includes the south-eastern face of the Drinkkop Mountain. It is a remnant of a Cainozoic landscape in the reserve (Carbutt and Edwards, 2003). At an altitude of about 2 081 m is the top of the Drinkkop, while the expanse of the Vlei (constituting the outlet and the head of the vlei) lies at an altitude of 1,840 m, and 1,828 m within the Drakensberg Alpine Centre (Begg, 1989). A part of the Impendle plateau is a remnant of a Cainozoic landscape (Carbutt and Edwards, 2003) which features some of the mountainous region. Carbutt and Edward (2003) describes this portion containing the wetland to have been formed in the two large basins that were fringed by series of Karoo dolerite ridges during the early Jurassic and were separated by a central ridge. Begg (1989) described the upper fringes of the Impendle Plateau, as a massive undulating sheet of fractured dolerite and that the basins in which the wetlands occur are a result of the natural shapes of the dolerite structures that were modified by weathering and erosion over time.

3.2 Geology and Geomorphology

The uMgeni Vlei is located within the Drakensberg Group rocks of the Karoo Supergroup in the ancient Gondwana supercontinent (Carbutt and Edwards, 2003; Rambarath et al., 2017). The main Karoo basin consists of a retro-arc foreland basin with a thickness of sedimentary successions ranging from over 10,000m in the foredeep part of the main basin, to less than 1000m in most subsidiary basins (Carbutt and Edwards, 2003). The rock of this supergroup covers about two-thirds of the land surface of South Africa and forms a huge layer of sedimentary rock that was deposited over the Late Carboniferous to the Middle Jurassic Period (Carbutt and Edwards, 2003; McCarthy and Rubidge, 2005). The supercontinent Gondwana at the end of that period was fragmented by rifting with a massive eruption of basaltic lava that formed what we know today as the Drakensberg volcanic group (McCarthy and Rubidge, 2005). Most of the magma that could not get through to the surface, due immense pressure seeped into horizontal sedimentary layers of the Karoo Supergroup forming dolerite sills while magma also solidified into fissures forming dolerite dykes which is one of the characteristics of this supergroup in the Karoo landscape (McCarthy and Rubidge, 2005).

The Drakensberg Group volcanic rocks today are only preserved in the high Drakensberg and Maloti Mountains and around Lesotho (McCarthy and Rubidge, 2005), and they boast not only diverse floral and faunal assemblages, but also dolerite dykes with extensive basalt (Groenewald, 1989). The mountainous region of the nature reserve (Fig 7) have a similar characteristics to the mountains of the Maloti Drakensberg (Brainbridge, 2004); in that the sedimentary outcrop underlying the Nature Reserve and its expansion areas, comprises a range of fine-grained doleritic structures (e.g., dykes and sills) with no visible crystals or amygdales that were formed during the extrusion of the magma (Norman and Whitfield, 2006; Rambarath et al., 2017).

Figure 7: uMgeni Vlei and its expanse

The outer boundaries of the Nature Reserve, within the surrounding areas lies a dolerite dyke known as the “keypoint”, it is known to prevent primary drainage lines and holds accumulating sedimentary material that sustains and maintains the wetland to its original state (Rambarath et al., 2017).

Other features in the uMgeni Vlei Nature Reserve include the Drinkkop Mountain, which lies at an altitude of 2081m (Rambarath et al., 2017). The soils of the slope of the mountain are described as shallow and highly weathered (Rambarath et al., 2017). The weathering is also notable with the dolerite ridges standing proud (Brainbridge, 2004; Rambarath et al., 2017). Although dolerite dykes are described as highly resistant to erosion (McCarthy and Rubidge, 2005), when they have been disturbed, they rapidly erode leaving a scar or scree on the mountain (Brainbridge., 2004; McCarthy and Rubidge, 2005). The uMgeni Vlei is not entirely free from human disturbance, as depressions filled with hydromorphic soils of the Katspruit form occur on the wetland in several locations (Scotney, 1970). The hydromorphic soil type mostly occurs in waterlogged areas and maintains stability under such conditions. The depression filled with these soil types in the Vlei are water yielding areas, and their water capacity impairs activities such as drainage and cultivation that could lead to a reduce organic matter through decay or oxidation and as such enhancing susceptibility to erosion (Rambarath et al., 2017).

3.3 Climate and Weather

The uMgeni Vlei can be found in the summer rainfall region in South Africa. This region is characterised by a warm wet summer and a cool dry winter. Its climate primarily is affected by Agulhas Current of the Indian Ocean (Fairbanks and Benn, 2000). The atmospheric system initiates a subtropical climate of high temperatures, humidity and rainfall in the coastal region (Fairbanks and Benn, 2000). Although the western border of the KwaZulu-Natal experiences a gradual climatic transition (Fairbanks and Benn, 2000), this transition is defined by a marked climatic gradient resulting from the physiographic relief and altitude of Drakensberg Escarpment on temperature and moisture (Fairbanks and Benn, 2000).

The weather pattern of the Nature Reserve itself is not known. Adjacent areas such as the Drakensberg hold an annual mean temperature record of about 16°C but vary considerably seasonally and diurnally (Tyson et al. 1976). On the average, temperature in the summer months from October -March is about 18°C, whereas the winter months are cold (from April -September), average temperature in July ranges between 0°C and 3.6°C (Tyson et al. 1976). The highest temperature records during summer on north-facing slopes are approximately 35°C, while the lowest temperatures are about -14°C (Tyson et al., 1976).

The region sometimes experiences air subsidence or inversions from the warm Indian ocean current in the form of south-easterly winds (Tyson et al., 1976). This causes stability in the atmosphere resulting in a distinct dry season from May until August in the region (Tyson et al., 1976). The uMgeni Vlei and the expansion areas are in one of the least drought-prone and well-watered areas in South Africa (Phillips., 1973; Camp., 1997). Both orographic induced rainfall and squall-line thunderstorms contribute significant precipitation that regularly occurs in the summer month, and an annual precipitation that varies between 980-1000 mm p.a in the nature reserve (Tyson et al., 1976; Schulze, 1982).

3.4 Vegetation

The study site is in the Grassland Biome in the central highveld of the Drakensberg (Mucina & Rutherford 2006). The southern African grassland biome has high biodiversity, community and ecosystem diversity (Cowling et al., 2004) that dominates the high central plateau in the Midlands of KwaZulu- Natal of South Africa where summer rainfall occurs (Neumann and Bamford, 2015). Based on altitude and rainfall gradient, four bioregions constitute the grassland biome (Mucina et al., 2006). They include (1) Dry Highveld Grassland Bioregion, (2) Mesic Highveld Grassland Bioregion, (3) Sub-Escarpment Grassland Bioregion and (4) Drakensberg Grassland Bioregion (Mucina et al., 2006). Considering the rainfall gradient of the bioregions, the Highveld Grassland and the Drakensberg Grassland are moist grasslands that receive rainfall that exceeds 600mm (Mucina et al., 2006). The bioregion where the Drakensberg Mountain range and its outliers are situated are in biodiversity hotspot, this area comprises of high species-richness endemic to the environment and are currently under threat (Myers, 1988). In South Africa it is described as the Drakensberg Alpine Centre (DAC) (Carbutt and Edwards, 2003) or the Eastern Mountain hotspot (Van Wyk and Smith, 2001). This region is linked to the Cape Floral Region, it also constitutes of high-altitude enclaves that is centred around the greater Drakensberg range (Carbutt and Edwards 2003). The diversity of the vegetation on a broad scale can be accounted for not only by topographic and edaphic gradients but also by climatic and altitudinal gradient (Bainbridge et al., 1991).

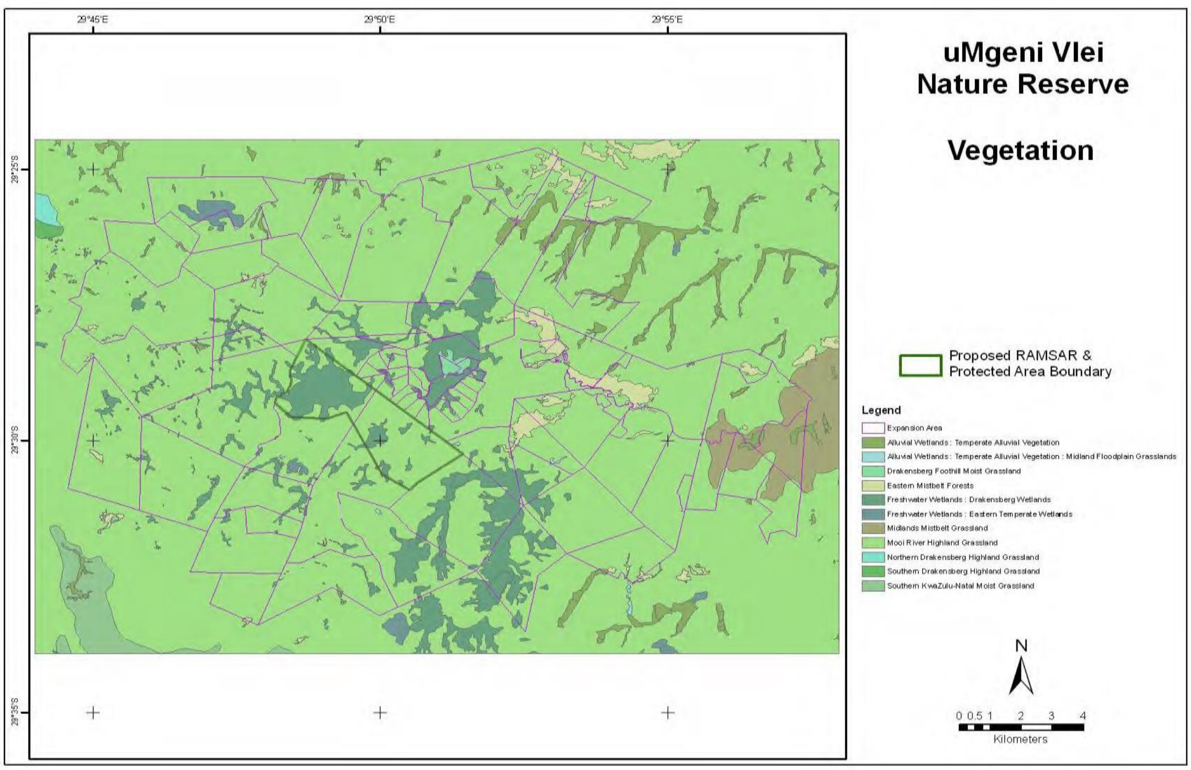

Figure 8: Vegetation map of uMgeni Vlei (Rambarath et al., 2017)

The vegetation of the uMgeni Vlei is classified under the Veld Type 44a which is the Mooi River Highland Grassland type according to the Ezemvelo KZN Wildlife Conservation Plan and the Highland Sourveld (Acocks, 1988) (Fig 8). Due to the varied classification system, the terminology has changed over time and presently it is now known as the Drakensberg Foothill Moist Grassland (Gs 10 of Mucina & Rutherford, 2006). The vegetation type is described as a fire-maintained grassland that is dominated by about 0.5m high bunch grasses (Begg and Carser, 1989). When there is reduced fire, *Podocarpus* forest is known to occur alongside grasses such as Hyparrhenia spp and *Cymbopogon* spp, trees *Buddleja salviifolia* and *Leucosidea sericea* which are considered as the first forest precursors (Begg and Carser, 1989). In the reserve, forest patches are restricted to the cooler and moister south-facing slope in the absence of fire. In such instances, trees such as *Rapanea melanophloeos, Kiggelaria africana and Halleria lucida* occurs in the first stages. A list of the primary vegetation present in the nature reserve as identified by Ezemvelo, K.Z.N. and CC, U.D.E.S (Rambarath et al., 2017) is listed in (Table 3), and its occurrence within the DAC as described by Scott-Shaw (1999) and Carbutt and Edward (2004).

Table 3: A list of plant species at the uMgeni Vlei nature reserve

Plant formation	Plant types	Rambarath et al. (2017)	Scott-Shaw (1999)	Carbutt and Edward (2004)
Herbs and shrubs	*Euphorbia clavariodes*	×	×	
	Rubus ludwigii	×		
	Searsia spp.	×	×	×
	Helichrysum spp.	×		
Forest Patch (small tree or shrubs)	*Leucosidea sericea*	×		
	Rapanea	×		
	Kiggelaria	×		
	Halleria	×		
Sedges of swampy communities	*Pycreus*	×		
	Scleria welwitschia	×		
	Festuca	×		
	Andropogon	×		
	appendicularis	×		

	Aristida junciformis	×		
Perennially wet communities	*Cyperus unioloides*	×		
	Pycreus cooperi	×		
	Juncus oxycarpus	×	×	
	Carex acutiformis	×		
	Lagarosiphon	×		
	Utricularia vulgaris	×		
	C. cognata	×		
Invasive species	*Rubus cuneifolius*	×		
Vulnerable species	*Dierama luteoalbidum*	×	×	
	Stachys rivularis	×		
	Calpurnia woodii	×		
	Kniphofia brachystachia	×		×
	Crocosmia pearsei	×		
	Sisyranthus fanniniae	×		
	Bowiea volubilis	×		
	Ocotea bullata	×		
	Kniphofia breviflora	×		×

The DAC vegetation is substantially diverse, it extends beyond the KwaZulu-Natal escarpment into the interior of Lesotho and the drier Eastern Cape Drakensberg region (Carbutt and Edward, 2004). It has patches of indigenous forest and the greatest number of grass species that occupies sheltered sites and steep gradients in south facing areas that are excluded from fire (Carbutt and Edward, 2004). The largest plant families dominating the DAC include the Asteraceae, Poaceae and Fabaceae (Carbutt and Edward, 2004). As noted from the list of identified species further work might reveal the presence of other plant species that are present within the nature reserve.

Chapter 4

Palaeoenvironmental Materials and Methods

4.1 Introduction to palynological methods

Palynology investigates vegetation through pollen grains and spores produced by plants (Lowe and Walker, 2014). The universally accepted methods of pollen analysis can be traced back to Von Post, who in 1916 published the first quantitative pollen diagram when reconstructing the past environment (Erdtman, 2013). The diagram gave a visual representation of the composition of fossil pollen flora at different levels of a deposit (Erdtman, 2013). The technique enhanced understanding of the relationships between vegetation and climate and provided valuable insight into how to predict future changes in plant migration, dynamics of plants within an ecosystem and the distribution of various biomes (Erdtman, 2013).

Alfred Traverse (2007) reveals that many Quaternary palynologists are mostly interested in sampling deposits such as bogs, lakes, marshes and swamps that reflect vegetation history. This is because such deposits are good for preservation. Ancient floras that can be traced back to their modern plant associations and their ecological requirements enable precise palaeoclimate deductions (Traverse, 2007; Lowe and Walker, 2014). The recommended or normal palynological approach used in the Quaternary as describe by Alfred Traverse (2007) involves: (1) a careful study of the pollen grain from the source plant communities and their ecological requirements; (2) precise counting of individual pollen grains of very closely spaced samples from a cored sediment; (3) visual representation of the pollen counts by plotting them in a standardised pollen diagram in conjunction with radiometric dating; and (4) based on modern analogues deduce temperature and precipitation at various levels of the core.

4.2 Materials and Methodological consideration

A 300cm core was retrieved from the uMgeni Vlei Nature Reserve in Kwa-Zulu Natal by Dr Frank Neumann, Dr Greg Botha and Prof Marion Bamford during a field trip in March 2016. In the field trip, a coring site was selected based on accessibility to the location within the wetland. After a suitable site selection, an Eijkelkamp gouge auger with 1.2m extensions was used to obtain the core sample from the wetland (Fig 9). On-site, the core was sub-sampled at a resolution of 5cm; each segment was placed in a labelled zip-lock bag and stored in a refrigerator at the Palynology Laboratory in the Evolutionary Studies Institute. For this study, 82 samples from the subsampled materials from the uMgeni Vlei were selected for pollen analysis.

Figure 9: Google earth photo of the coring site

4.3 Laboratory Processing

Sub-sampled core materials undergo chemical treatments in order to release the pollen and spores in the sediment (Traverse, 1999; Faegri and Iverson, 1989), and the extraction procedures are adaptable based on the rock type and composition (Aldridge, 1990). Many comprehensive accounts of procedures have been described (Sittler 1955, Philip and Playford 1984, Traverse, 1988; Faegri and Iverson, 1989), with all procedures involving the use of hydrofluoric acid (HF) that can be traced back to the technique of Assarsson and Granlund (1924). The generalized procedure ranges from the physical breakdown or crushing of the rock material to the removal of mineral constituents such as calcareous, siliceous and inorganic material, the latter part involves oxidation, sieving, cleaning, the concentration of organic-rich residue and preparation of slides (Green, 2001). Such work is recommended to be carried out in a controlled environment in order to prevent contamination of samples (Faegri and Iverson, 1989). As with all palynological work, care is required when handling chemicals used for treatment and also when quantitative work is the primary objective on the floral assemblage concentrated within a residue (Green, 2001). The main stages of palynological processes used for the uMgeni Vlei samples are described in Appendix 1, and they follow the format presented in the flow diagram in (Fig 10).

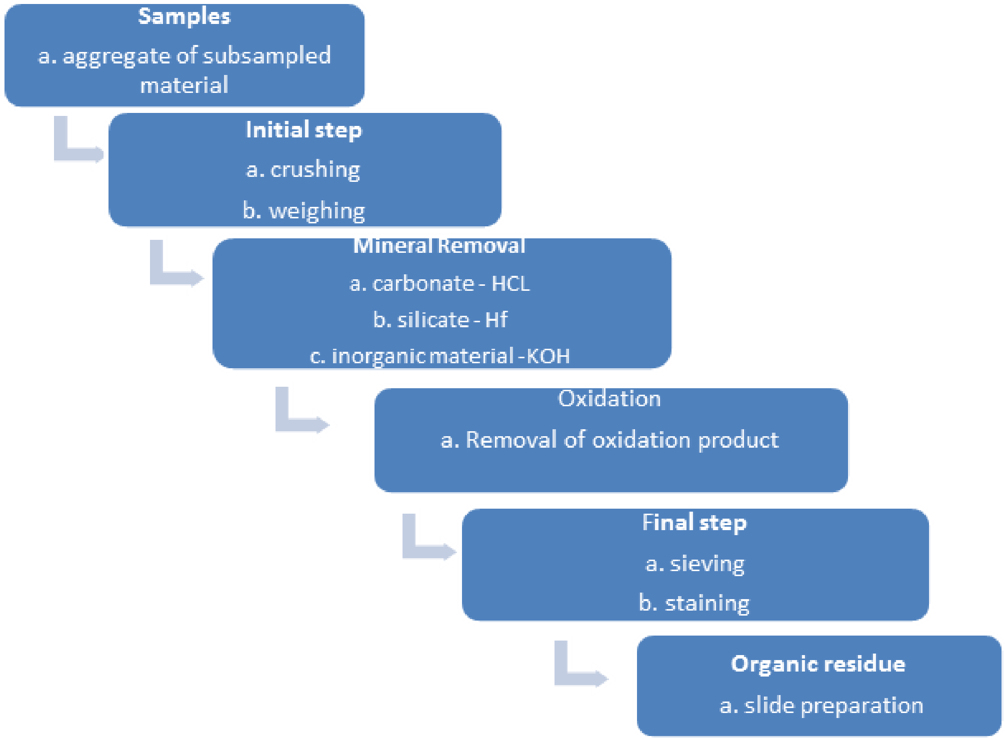

Figure 10: Stages of palynological processes

Since palynomorphs are dispersed in the sampled material the essence of mineral removal is to separate them from the mineral cast that is overwhelmingly predominant in sedimentary rocks. However, separating the minerals alone does not concentrate the palynomorphs. As advised by Traverse (2007) the needed treatment to release palynomorphs is the oxidation treatment. It breaks down organic matter described as nano-coals (e.g., wood and leaf cuticles). HF treatment sometimes preceded the oxidation treatment as it tackles any remaining mineral matter. To improve the concentration of pollen and spores, a gravity separation technique is employed (Traverse, 2007). This technique is also known as heavy liquid separation and is used to separate heavy minerals such as rutiles, tourmalines and zircons present in sediment samples (Traverse, 2007). Therefore, concentrating the palynomorphs in the suspension, and enabling the use of a pipette to retrieve it (Green, 2001). This separation technique is based on the principle that palynomorphs have a specific gravity of about 1.4 and lighter minerals have a specific gravity of about 2.5 (Traverse, 2007). The desired specific gravity is achieved by adding $ZnCl_2$ to the treated sample that is followed by centrifugation (Traverse, 2007). The centrifuging process thus allows the heavier minerals and the palynomorphs to work past each other in the traffic and causes the minerals to settle at the bottom while the palynomorphs are suspended in the solution, enabling easy extraction of the supernatant and mounting it on slides (Traverse, 2007).

4.4 Microscope Analysis

For pollen and spores to be analysed under a microscope, the residue (supernatant) needs to be mounted on a glass microscope slide (Green, 2001). This procedure like the other laboratory processes requires a careful and systematic approach to ensure that contamination is avoided. It involves the use of mounting aids (glycerol jelly, Canada balsam, epoxy resin or silicone oil), to mount a coverslip on the slide after the pollen and spore residues have been placed onto the slide (Faegri and Iverson, 1989). This enables analytical work to proceed under a light microscope for pollen and spore count or scanning electron microscope (SEM) for the study of individual pollen grains (Traverse, 2007).

4.5 Counting

After a slide is prepared, a count of all pollen and spores is made by traversing the slide from end to end of the cover slip at a magnification that is sufficient to recognise them (Traverse, 2007). Since most palynomorphs are flattened rather than three-dimensional, an accurate count is achieved when slides are not too densely filled as too many fossils will appear in each field which could lead to double counting (Faegri and Iverson, 1989). In such an instance, counting specimens that are only in the field of view or at the top or at the bottom may minimise such inaccurate counts (Traverse, 2007). This has left many palynologists with the question of how many counts are considered statistically reliable. Pollen analysis carried out in the 1930s and 1940s by Quaternary palynologists initially recommended 200 counts as satisfactory for reliable percentage calculations (Barkley, 1934). However, the recommended number was described as not statistically valid, firstly by Gordon Rittenhouse sometime around 1957 where he showed Alfred Transverse the statistical discrepancy of the 200 counts in use at that time. While some palynologists today have settled with the idea that the recommended number should be between 150-500 (Birks and Gordon, 1985; Erdtman, 2013). From a statistical evaluation by Traverse (2007) the recommended number can only be meaningful or satisfactory for the abundant palynomorphs but that larger total counts are necessary to achieve meaningful data for uncommon forms. However, for abundant forms large counts are not worth extra work. While the number of counts may vary with each palynologist, it is generally accepted that counts of any pollen and spore that comprises less than 1% of the palynoflora would not be statistically reliable, and for some they are exempted from further analytical work (Birks and Gordon, 1985).

4.6 Data exploration

Pollen data obtained from counts are expressed in percentages and are statistically explored for overall observation of the palynoflora with the least counts. Pollen and spore species with the least count of 1% are considered statistically unreliable and can be excluded from further exploration (Birks and Gordon, 1985). Commonly used today to explore palynological dataset is an ordination technique called principal component analysis (PCA) (Rencher and Christensen, 2003; Fitchett, 2015; Combrink et al., 2020). The principle behind this analysis is to reduce the dimensionality of a large dataset made up of different variables while retaining valuable information about their variation (Fasham, 1977). After the variations have been deduced from PCA, Cluster Analysis is performed on the dataset. This separates the dataset by their nearest neighbours (Austin, 1968). Both analyses can be performed in software programs like R and RStudio. Such analysis is recommended to explore Quaternary palaeo-datasets in order to observe the visible trends and to be statistically reliable (Birks, 2003)

4.7 Data Presentation

Explored data that comprise the numbers of frequencies of the different pollen species in a sample, also called the pollen spectrum, can be visually represented in a pollen diagram. This diagram can be constructed with specialized programs such as Tillia (Grimm, 1992) and C2 (Juggins, 2003). It is simply a form of Cartesian coordinates, where the pollen frequencies are marked on the y-axis and the x-axis denotes the depths, and parallel with the diagram are columns representing the stratigraphy of the sediment (Erdtman, 2013). This diagram visually shows individual species or groups of species that represent a composition of the pollen flora and the oscillations in frequency during the deposition of the sediment (Erdtman, 2013). The illustration of frequency value by a pollen diagram renders the result particularly easy to analyse. It allows the examination of internal variation within and between groups of palynofloras by means of Zones into which pollen diagrams are further divided (Grimm, 1987). Zones can be derived from CONISS (Constrained Incremental Sums of Square), a function that can be performed on software programs, like R studio.

4.8 Palaeoenvironmental Reconstruction

Reconstruction of a Quaternary environment has followed three basic quantitative approaches listed by Birks (2003) as (1) the indicator species (individualistic) approach, (2) the assemblage's approach and (3) the multivariate indicator approach. They are all guided by the uniformitarianism assumption that presents the notion that modern-day observations and relationships can be used as a model for past conditions, and that organism-environment relationships have not changed over time (Birks, 2003).

The individualistic approach requires information about the modern environmental tolerance, distribution and abundance of the species concerned (Birks, 2003). Although this provides a basis for reconstructing a past environment, it is limited in its method as the fossil taxa need to be identifiable to species level which is not very applicable for fossil pollen analysis (Faegri and Iverson, 1989). Unlike the individualistic approach, the assemblage approach is more advantageous for pollen analysis as it considers the fossil assemblage as a whole and the numerical frequency of the different taxa (Birks, 2003). Moreover, it focuses on a quantitative-based modern analogue technique that makes its inferences on the present-day environment in which these vegetation types occur (Birks, 2003). Unlike the individualistic and the assemblage approach, the multivariate indicator approach involves a transfer of function of the environmental variables to be reconstructed from fossil assemblages (Birks, 2003). This approach is utilized to overcome common problems such as multiple analogues that may arise from fossil assemblages due to similar several modern samples that differ widely in climate (Birks, 2003).

4.9 Radiocarbon Analysis

Radiocarbon analysis is a method that is used to provide age estimates for carbon-based materials (Kolstrup, 2007). Two techniques known for measuring radiocarbon in samples are radiometric dating and Accelerator Mass Spectrometry. Although both techniques are based on different principles, they are used to determine the carbon-14 content in a sample (Bowman, 1990). The principle is based on the assimilation of carbon-14 by plants and animals from carbon dioxide throughout their lifetime (Bowman, 1990). The exchange of carbon with the biosphere stops at the point of death. This starts a decrease of their carbon-14 content at a rate that is determined by the law of radioactive decay (Bowman, 1990; Williams et al., 1998). In essence, this analysis measures the residual radioactivity.

Dating of core sediment allows for an age-depth model to be produced. This is described as the primary foundation in palaeo-environmental studies (Blaauw, 2010). These models are based on the theory that sediments are accumulated between samples of known calibrated age (Blaauw, 2010). Calibrated age is the conversion of the radiocarbon dates to calendar years (Blaauw, 2010) that allows accurate results to be achieved because of the natural fluxes in carbon-14 on a historical timescale (Saarnisto, 1988). Southern Hemisphere calibration curves are available for the Quaternary (McCormack et al., 2004). Calibrated dates for older dates are unknown (McCormack et al., 2004).

4.9.0 Conclusion

This chapter provides a general overview of the methods used for palynological analysis that were applied in this research. The materials discussed in this chapter highlight the specific location where the sample was retrieved and the number of samples considered for analytical work. However, the methods were discussed in a general application and theoretical background. From the theoretical background consideration, research methods were selected based on the merit of their application, the specific procedures used will be further discussed in Chapter Five.

Chapter 5

Applied Methods

5.0 Introduction

For analytical work to be carried on the studied material, pollen analysis as discussed in chapter four, utilizes a variety of tools. This chapter describes the methods employed in this research for retrieving pollen and spores from the sediment, identification of pollen, radiocarbon dating and data exploration.

5.1 Pollen Separation Technique

After HF treatment the heavy mineral separation technique was used to separate fossil pollen from the 82 samples selected from the uMgeni Vlei. $ZnCl_2$ solution with a specific gravity of 2.4 was added to the sample in a centrifuge tube, followed by centrifugation at 3000r/min for 5 min. The palynomorph content was retrieved and was mounted onto semi-permanent microscope slides with a glycerol jelly.

5.2 Pollen Counts and identification.

A minimum of 250 pollen grains was counted for each sample to represent the local vegetation of the uMgeni Vlei. This number was decided upon based on the number of identified taxa that reflects the general diversity of the environment (Birks and Gordon, 1985).

Pollen grains were first detected by their unique sculpture and morphology under a light microscope (Faegri and Iverson, 1989). To facilitate identification, images were taken and were compared to pollen reference collection from previous publications with pollen reference pictures centred around the KwaZulu Natal, and Scott (1982b) aided this. When forms were not easily recognised, photographs of the forms were compared to pollen references collections from larger databases such as (Paldat and the African Pollen Database). In addition, the location of the field of view on the slide was recorded for further referencing to aid identification from the pollen database.

All counts were done within a field of view, from end to end along a fixed transect on the slide (Faegri and Iverson, 1989). A complete transect was counted even when the minimum 250 pollen counts had already been reached. All counts were done at 40x magnification on an Olympus CX23 microscope and identification at 100x magnification under oil immersion on Olympus BX51. During counting, tallies of individual pollen grain were recorded, and total counts were transferred to Microsoft Excel where the data were further explored. In instances where clusters of pollen are observed in a field of view, counting was done on the top section of the slide to avoid double counting (Faegri and Iverson, 1989).

All grains were counted and were mostly identified to family level (Faegri and Iverson, 1989). For unidentified forms, these were badly damaged and could not be recognised; they were grouped and termed as *varia* and were excluded from further analysis

5.3 Radiocarbon dating

Accelerated Mass spectrometry (AMS) radiocarbon dates were conducted at the Beta Analytic (Florida) facility. This dating method was preferred for the following reasons:

1. **Sample amount**: The other dating method requires 10g of sample whereas the AMS dating method needs as little as 20-500 milligrams of sample. Considering the small samples obtained in the auger used for the uMgeni Vlei core the AMS method was more desirable.
2. **Processing Time:** The AMS dating method has a processing time of a few hours when compared to other dating methods that may take days and could lead to long delays for result production.
3. **Date Precision:** AMS measurements are widely used for palaeoenvironmental analysis due to their higher precision than other dating methods.

Three samples were sent off for AMS dating at the Beta Analytic (Florida) soon after extraction. However, during the course of this research, the need for more samples to be dated was recommended for quality control of the uMgeni Vlei date profile.

Four additional samples were selected based on their rich carbon content that was determined by the concentration of the palynomorphs contained in the samples. The samples were weighed to at least 2gram to ensure adequate carbon content. The following sample depths make up the selected samples for AMS dating (Table 4).

Table 4: Selected samples for AMS dating

Sample	Lab Codes	Depth (cm)
uM1	Beta-569037	78.75
uM2	Beta-569038	141.25
uM3	Beta-569039	246.25
uM4	Beta-569040	281.25
uM 5		116,25
uM6		198.5
uM7		297.5

Radiocarbon dates are calibrated due to the instability of Carbon-14 in the atmosphere (Walker and Walker, 2005). Calibration curves differ between the Southern and Northern Hemispheres due to the ocean and land ratio (Hogg et al., 2013). Hence, it is necessary for the International calibration curve to be corrected to the Southern Hemisphere by a factor of 56 ± 24 years (Blaauw, 2010; 2012). From the Southern Hemisphere Calibration Curve 2013 the calibration curve's range extends to 50,000 cal yr BP from the ShCal04 model that is internationally accepted and can be obtained by Bayesian models and methods (Niu et al., 2013; Hogg et al., 2013). Radiocarbon dates received for the uMgeni Vlei Nature Reserve were younger than 50,000 cal yr BP and were calibrated with the Southern Hemisphere calibration curve.

5.4 Age Depth Model

The Bayesian age-depth model was used to generate dates across the depth profile. This model assumes that prior sediment accumulation rates display a natural change in accumulation rates (Blaauw and Christen, 2011). The model uses an algorithm of Markov Chain Monte Carlo to address its uncertainties and accumulation rates while accounting for possible radiocarbon uncertainties across the depth profile (Parnell et al., 2011).

This method was chosen over the traditional linear regression method due to its limitation in dealing with sediment accumulation rate which is considered constant and its unsatisfactory ways of dealing with outliers (Parnell et al., 2011), as opposed to the Bayesian method which detects outliers by accounting for errors and ambiguity in the calibration process (Blaauw and Christen, 2011). The Bayesian method has a satisfactory approach when dealing with sedimentation rates (Blaauw and Christen, 2011).

5.5 Pollen Data Exploration and Representation

The aim of data exploration is to determine the visible trends within the dataset, but sometimes the data show noise that could hinder these visible trends (Birks, 2003). To achieve this all, pollen data were first explored on Microsoft Excel where the sample counts were recorded. The raw counts for individual taxa of each sample were converted into percentages as they are commonly expressed (Birks, 2003) and this allows the average percentage occurrence within the sequence to be determined.

Palynomorphs that were less than 1% were considered statistically unreliable and were exempted from further analysis (Traverse, 2007). Selected pollen taxa were further explored with clustering analysis using Constrained Incremental Sums of Squares (CONISS) (Grimm, 1987) and to detect the trends, Principal Component Analysis (PCA) was used (Austin, 1968; Fasham, 1977). The following analysis was conducted on R and RStudio software.

5.6 Conclusion

Standard methods maintained during the concentration of palynomorphs allowed pollen data to be obtained for the analytical work. Exploration of the pollen data allows for a statistically reliable palynomorph dataset that was selected for this study. Most of the analysis conducted produced a graphical representation of their result for virtual analysis. This will be presented in the Results section where a report of the analytical work will be presented either graphically or in tables where necessary.

Chapter 6

Environment and Vegetation Relationships

6.0 Introduction

Plant communities have boundaries in space and time and consist of complex aggregates of plants that are inseparable from their environment (Daubenmire, 1970). These communities consist of ecologically diverse groups of organisms superimposed on the same area, and although these organisms in the community are ecologically interrelated, they are not of equal sociological importance (Daubenmire, 1970).

Previous palynological studies have successfully used a habitat-type classification system to establish a relationship between vegetation and its environment (Scott and Vogel, 1978; Scott, 1982a). Considering that many plant families exhibit wide ecological amplitude over a wide range of habitats, a given type of species or a climax plant association may indicate a clear relationship (Scott, 1982a).

A better understanding of the environment to vegetation relationship is important in determining the vegetation potential and quantifying the natural range of variation. This chapter aims to explore the vegetation potential of the associated pollen grain from the uMgeni Vlei, from previous palynological interpretations for use in palaeoenvironmental reconstructions.

A list of the common pollen types encountered is presented in (Table 5). The pollen taxa were grouped into herbs/shrubland, fynbos, tree/woodland, grassland, aquatic and non-pollen palynomorphs types, to assess their value in palaeoecological interpretations.

Palaeoenvironmental reconstructions has been carried out successfully with reports on certain pollen species that have been used as indicators for climate inferences (Coetzee and Van Zinderen Bakker, 1957; Van Zinderen Bakker,1981; Cooremans, 1989; Scott,1982; 1987; 1988; 1999).

Among the list of pollen taxa based on the AP and NAP classification, the non-arboreal pollen (NAP) from the uMgeni vlei constituted most of the environment and includes both local and regional taxa.

Table 5: Classification of uMgeni Vlei pollen types according to arboreal and non-arboreal habits (* indicates pollen types < 1%).

Pollen Types	Classification types	vegetation types
POACEAE*	herbs/shrubland	grass
POACEAE *Phragmites**	herbs/shrubland	grass
ASTERACEAE undiff.*	herbs/ shrubland	herbs
ASTERACEAE *Liguliflora**	herbs/shrubland	herbs
ASTERACEAE *Artemisia**	herbs/shrubland	herbs
ASTERACEAE *Pentzia**	herbs/shrubland	herbs
ASTERACEAE *Stoebe**	herbs/shrubland	herbs
LILIACEAE*	herbs/shrubland	herbs
CARYOPHYLLACEAE undiff*	herbs/shrubland	herbs
EUPHORBIACEAE *Acalypha**	herbs/shrubland	herbs
AMARANTHACEAE*	herbs/shrubland	herbs
FABACEAE undiff*	herbs/shrubland	shrubs
CARYOPHYLLACEAE *Cerastium**	herbs/shrubland	herbs
THYMELAEACEAE undiff*	herbs/shrubland	herbs
MYRICACEAE *Morella**	herbs/shrubland	shrubs
RUBIACEAE *Anthospermum**	herbs/shrubland	shrubs
GENTIANACEAE *sebaea**	herbs/shrubland	herbs
EUPHORBIACEAE undiff*	herbs/shrubland	trees, herbs
ACANTHACEAE	herbs/shrubland	herbs
CRASSULACEAE*	herbs/shrubland	shrubs, herbs
XYRIDACEAE *Xyris**	herbs/shrubland	herbs

ERICACEAE*	fynbos taxa	shrubs (fynbos)
THYMELAEACEAE *Passerina**	fynbos taxa	shrubs
ARACEAE*	Aquatic	herbs
CYPERACEAE undiff.*	Aquatic	sedge
CYPERACEAE *Ascolepis**	Aquatic	sedge
RANUNCULACEAE	Aquatic	shrubs,herbs
Polygonum	Aquatic	herbs
Aponogeton	Aquatic	aquatic herb
TYPHACEAE *Typha**	Aquatic	aquatic
NYMPHAEACEAE *Nymphaea**	Aquatic	aquatic herb
ANACARDIACEAE	tree and woodland	tree
APIACEAE *Heteromorpha**	tree and woodland	tree
EUPHORBIACEAE *Spirostachys*	tree and woodland	tree
COMBRETACEAE *Combretum**	tree and woodland	tree
PODOCARPACEAE *Podocarpus**	tree and woodland	tree
OLEACEAE*	tree and woodland	tree
DIPSACACEAE *Scabiosa**	tree and woodland	tree
APIACEAE undiff.*	tree and woodland	trees, herbs
RHAMNACEAE *Ziziphus**	tree and woodland	tree
MYRTACEAE*	tree and woodland	tree
GREEN ALGAE *Zygnema* type*	non-pollen palynomorphs	algae
ALGAE undiff.*	non-pollen palynomorphs	algae
PSEUDOSCHIZAEA*	non-pollen palynomorphs	unknown form
SPORE undiff.*	non-pollen palynomorphs	spores
SCHIZAEACEAE *Mohria**	non-pollen palynomorphs	fern

6.1 Non-Arboreal pollen

Pollen grains and spores with aquatic affinity: These palynomorphs consist of Cyperaceae, some monocots and some dicots: Ascolepis, Aponogeton, Typhaceae, *Nymphaea, Polygonum* and some Ranunculaceae. Their modern vegetation types are all indicative of a wetland environment (Scott, 1982a; Lock, 1999). For example, Cyperaceae pollen grains have a wide distribution and are an important element in many peat samples that are locally formed (Scott, 1982a). Members of the Cyperaceae include perennial and annual herbs. According to Gordon et al. (2009), most of these annual herbs are found along watercourses in warmer parts of South Africa, on sandy alluvium, in dune slacks in dry areas, in poor soils on rock outcrops, on hilltops and where there maybe soil water seepages that are maintained by occasional rains. In contrast the perennial herbs are found in stands in permanently or periodically wet or damp areas where there is occasional flooding (Goetghebeur, 1998). The rest of the aquatic pollen types belonging to these groups are also mainly representative of local wetland elements (Scott, 1982a).

ARACEAE: This arum lily family is present in the uMgeni vlei pollen fossil record. It was utilised in South Africa for biological control of weeds and it is mostly found in water bodies (Cilliers, 1991). Currently no palynological significance is known to them.

Pollen taxa of herbs and shrubs: Palynomorphs associated with this group are dominant in the list of pollen taxa for the uMgeni vlei peat samples (Table 5).

AMARANTHACEAE: They are large and diverse families within the Order Caryophyllales (Dehghani and Akhani, 2009). The majority of their species are widely distributed occupying a wide range of habitats (Scott, 1982a). Some authors have demonstrated monophyly between the two families (Cuénod et al., 2002; Judd et al., 2008) and reports on their pollen records suggest that they are not very easily distinguishable and are sometimes termed Cheno-Ams (Scott, 1982; Combrink et al., 2020). Members from Chenopodiaceae are adapted to saline, hypersaline, xerophytic and xero-halophytic communities or ruderal habitats (Hedge et al., 1997; Kühn et al., 1993; Dehghani and Akhani, 2009; Scott, 1982; Finch and Hill 2008; Metwally et al., 2014). Pollen records of Amaranthaceae are not frequently recorded from deposits and only occasionally occur in surface samples from drier places (Scott, 1982).

ACANTHACEAE: A widely distributed family of herbs that is rarely aquatic (Scott, 1982a). Fossil pollen belonging to this family is widely distributed and can be suggestive of open veld (Scott, 1982a).

ASTERACEAE (*Liguliflorae*, *Artemisia*, *Pentzia, Stoebe)*: This group as a whole represents a wide variety of habitat and is substantially represented in the grassland community (Scott 1982a). A study of modern vegetation indicates that the ratio of Poaceae and Asteraceae can be used to assess the dryness of a veld (Scott, 1982a; Finch and Hill, 2008). Although this approach has been suggested not to show any clear relationship in locations that are between 28° and 32° S, it discriminates very clearly outside those restricted boundaries (Fitchett and Bamford, 2017).

CARYOPHYLLACEAE (*Cerastium)*: Is an annual or perennial herb that grows in the grassland biome (Pooley, 2003). In a study sample from Mahwaqa, *Cerastium* was observed to contrast between moisture demanding plants (*Phragmites* types) and were more closely associated with drought resistant elements such *Scabiosa* and *Pentzia*-type (Neumann, 2014). Study from the savanna biome at Tswaing Crater also showed Caryophyllaceae becoming prominent together with other arid indicators (Asteraceae and Chenopodiaceae) (Metwally et al., 2014). *Cerastium* generally grows in wetlands and their pollen sometimes can be confused with the Cheno-Ams (Scott, 1982).

CRASSULACEAE: Members of this group can be widespread, occurring in a variety of ecological conditions (Scott, 1982a). However, some palynological studies have suggested that they can be indicative of a dry environment (Pooley, 2005; Neumann et al., 2010; Valsecchi et al., 2013).

ERICACEAE: This family is an element of the fynbos vegetation found in the Cape region (Scott, 1982a). The species is also found mostly in the mountainous regions of Natal and Lesotho (Scott, 1982a), as they thrive in wetter and cooler habitats (Scott, 1982a: Neumann et al., 2014). A significant record of this family can be suggestive of cooler and sub humid condition (Scott, 1999; Neumann et al., 2008)

EUPHORBIACEAE (*Acalypha*): Some members of this genus represent herbs, shrubs, and trees (Pooley, 2005). They occupy a wide range of habitats (Scott, 1982; Finch and Hill, 2008), conspicuous in warmer regions (Scott, 1982; Pooley, 2005; Finch and Hill, 2008). Due to their diverse nature, they are sometimes removed from pollen sums due to their unrealistic overrepresentation (Scott, 1982).

FABACEAE: The family is listed among the plants commonly found in the moist grassland (Meter et al., 2002; Neumann et al., 2014), but there are a large number of trees and herbs. Its fossil record is not commonly emphasized in palynological records. Due to its cosmopolitan distribution (Combrick et al., 2020; Teale et al., 2021), It may be more common in warmer environments (Combrick et al., 2020; Finch and Hill, 2008) with a wide range of moisture conditions (Finch and Hill, 2008; Scott, 1999a).

LILIACEAE: Members belonging to this group may vary in habit types, however their pollen is not very distinguishable due to similar morphological features. They thrive mostly in the forest floor, at forest margins, in grassland or alpine meadow (Tamura, 1998). In South Africa, they commonly grow in peat deposits, grasslands and rocky outcrops (Scott, 1982); and are mostly indicative of surface moisture availability and in some cases may suggest cooler conditions (Scott, 1999).

MYRICACEAE *Morella*: This species occupies a wide range of moist forest habitats (Pooley 2003) and can be indicative of sub-humid conditions. Modern description of *Morella* indicates that it occupies a climatic niche that is low drought stress (Quick et al., 2016; 2018).

RUBIACEAE *Anthospermum*: This is known as a grassland element that mostly grows as a dune shrub (Scott, 1982; Neumann et al., 2014). Other members of the Rubiaceae family are commonly found along slopes of a rocky mountains, forests or woodland (Scott, 1982)

GENTIANACEAE S*ebaea*: This is an annual and perennial herbaceous plant (Pooley, 2005) that occurs in the grassland biome (Marais and Verdoom, 1963). It is present in the uMgeni fossil samples but generally no ecological interpretation is known for it.

POACEAE: Grass pollen is produeced in large quantities by the numerous species, but is indistinguishable to subfamily or generic level. Members belonging to this group are generally referred to as grasses or bamboo (Bouchenak-Khelladi et al. 2010). Their pollen comprises a large variety of grass taxa, however, the only distinguishable group is its perennial reed counterpart *Phragmites* that are of local origin (Scott, 1982; Neumann et al., 2010). This pollen type can be significantly represented in many peat samples (Scott 1982a). They are bigger in size when compared to Poaceae pollen that is smaller than 40µm (Scott 1982a). On a regional scale, grass pollen ratio is lower in dry bushveld where veld cover is poor, however, it is important to note that such interpretations may be affected by local elements (Scott 1982a). According to Hamilton (1972) all grass pollen grain larger than 60µm should be distinguishable.

THYMELAEACEAE (*Passerina*): This genus is well represented in South Africa in the Cape region and belongs to the Cape macchia (Scott 1982a) or fynbos. Reports on the modern vegetation suggests that this genus is mainly indicative of cool conditions and are most abundant when the arboreal pollen count is low (Scott 1982a; Brook et al 2010; Neumann et al., 2014)

XYRIDACEAE (*Xyris)*: This is a monocotyledonous terrestrial aquatic herb, which can be found sometimes occurring in acidic, sandy, rocky soils in medium to high elevations in the Pantropics (Kral, 1992). It is not known if this plant type is characteristic of local vegetation, but they are widespread and occur in permanently or seasonally wet places and very often on poor pale sandy soils (Pooley, 2005; Lock, 1999).

6.2 Arboreal pollen

Pollen taxa of tree/woodland

APIACEAE (*Heteromorpha*): This is an arboreal genus that usually occurs in montane woodland (Scott, 1982a). The plants are frost sensitive and might reflect temperature change when compared with cold tolerant indicators (Neumann et al., 2014). Palynological records of *Hydrocotyle* type belonging to the family of Apiaceae show that it can be difficult to distinguish from *Heteromorpha* (Scott, 1982b). The former is a wetland plant (Scott, 1982b; 2019).

ANACARDIACEAE: This family includes woody and shrub plants (Pooley, 2005), that occur regularly in fossil samples (Scott, 1982). Pollen records of them at Mfabeni peatland in Maputaland interpret them to be indicative of a relatively warm condition (Scott, 1999; Finch and Hill, 2008).

EUPHORBIACEAE (*Spirostachys*): This tree is a typical savanna woodland element that occurs in low altitude bush along rivers and streams (Scott, 1982a; Neumann et al., 2008). It grows in diverse environments (Metwally et al., 2014) that are associated with relatively local deep soil (Scott 1999). Its pollen type may be indicative of a warm woodland savanna environment (Scott, 1999).

COMBRETACEAE (*Combretum*): This tree pollen is known to occur particularly in bushveld in southern Africa (Pooley, 2005). The genus *Combretum,* which is the largest in the family, is reported to have a similar pollen morphology to *Dissotis* and *Memecylon* of the Melastomataceae

(Scott, 1982a). Differentiation of this family is highly recommended especially for *Dissotis* which represents four species of herbs that are associated with marshy places in the warmer parts of the country hence it is advisable to differentiate them from Combretaceae (Scott, 1982). Suggestions have been made that If the rest of a pollen assemblage indicates bushveld vegetation, it is likely that the pollen of this type will represent Combretaceae (Scott, 1982a).

DIPSACACEAE (*Scabiosa*): Palynological records from Portugal show that the genus *Scabiosa* is associated with dry-ground open vegetation (Fletcher and Boski, 2007). Pollen records from Mahwaqa KwaZulu-Natal, also detected that this genus contrasted between moisture demanding plants and drought-resistant elements, and its absence pointed to more humidity (Neumann et al., 2014).

MYRTACEAE: This predominantly woody family occurs mostly in tropical and subtropical climates (Pooley, 2005). Records of surface pollen samples from the Transvaal suggest that this vegetation occurs mostly in swamp forest (Scott, 1982). Pollen records from a winter rainfall zone from southern Africa described these pollen types as exotics that were introduced following European settlement (Carr et al., 2006). A similar description was used to describe these pollen types from Lake Sibaya, indicating that they are attributes of important neophytes relevant to their introduction and first extensive cultivation (Neumann et al 2008). Note, there are indigenous species and the common introduced Eucalyptus (gum) trees in this family.

OLEACEAE: Members of this family are relatively wide spread and are part of the bushveld trees (Scott, 1982). Pollen records from Cederberg suggest that it mostly represents a relatively moist condition (Scott and Woodborne, 2007).

PODOCARPACEAE (*Podocarpus*): This conifer is an Afromontane element that indicates moist but possibly cooler climatic conditions (Neumann et al., 2008; Pooley, 2003). Their pollen grains can be produced in large numbers that are readily transported by wind. For ecological interpretation, it has been proposed that a presence of up to 10% should represent absence of *Podocarpus* in the immediate environment, while 20% should represent close proximity of *Podocarpus* trees and presence of pollen >20% should represent *Podocarpus* forest. Other palynological records suggest that a substantial presence of *Podocarpus* may also be indicative of relatively moist condition (Finch and Hill, 2008; Scott 1999).

RHAMNACEAE (*Ziziphus*): This is a typical woody element, and widely dispersed (Scott 1982a). It occurs in low-altitude bushveld and often along river banks (Van Wyk, 2013). No palynological record with contrasting ecological significance is currently known to this group as they are rarely recorded (Scott 1982a)

6.3 Non-pollen palynomorphs and spores

PSEUDOSCHIZAEA and GREEN ALGAE (*Zygnema* type): Among the palynomorphs found in the uMgeni Vlei Nature Reserve are Zygnemataceae and an unknown form called *Pseudoschizaea* (Scott, 1982). Palynological records of *Pseudoschizaea* suggest that they are associated with moisture availability (Scot,1982; Carrión et al., 2000). While *Zygnema* type, a conjugating filamentous alga in the family of Zygnemataceae in Holocene sedimenst have been reported to be indicative of stagnant, shallow, and more or less mesotrophic freshwater habitats (Van Geel, 2002).

ANEMIACEAE (*Mohria*): The fern genus *Mohria* is exclusively restricted to southern Africa and Madagascar (Archangelsky, 2009). Pollen records of these spores reveal that they are mostly found in moist areas (Scott, 1982), and they can tolerate dry seasons (Scott, 1982; Farrant et al.2009; Neumann et al., 2014).

A summary of the palynomorph indicator values of the regional and total sum as described by various authors is presented in table 6.

Table 6: A list of palynomorphs indicators (* indicates pollen types <1% >1 × denotes level of recurrence, with more than one reference))

Pollen and classification type	Indicator value	level of recurrence
Arboreal		
ANACARDIACEAE	Warm condition	××
APIACEAE *Heteromorpha**	Warmer climate	×
EUPHORBIACEAE *Spirostachys*	Warm woodland	×
COMBRETACEAE *Combretum**	bushveld	×
PODOCARPACEAE *Podocarpus**	Moisture availability in a cooler environment	×××××
OLEACEAE*	Moist availability	×
DIPSACACEAE *Scabiosa**	Dry condition open vegetation	×
RHAMNACEAE *Ziziphus**	Wide-ranging	×
MYRTACEAE*	Neophyte	×
Non-Arboreal		
Herbs and shrubs		
POACEAE*	Moisture availability	×××
POACEAE *Phragmites**		
ASTERACEAE undiff. *	Dry environment	×××××
LILIACEAE*	Moisture availability	××
CARYOPHYLLACEAE *Cerastium* *	Dry and halophytic environment	×××××
THYMELAEACEAE *Passerina**	Cool conditions	×××××
EUPHORBIACEAE *Acalypha**	Wide-ranging	×××××
CHENO/ AMARANTHACEAE*	Dry and halophytic environment	×××××
FABACEAE undiff*		
ARACEAE*		
MYRICACEAE *Morella**	Sub-humid conditions	×××
RUBIACEAE *Anthospermum**		
GENTIANACEAE *sebaea**		
ACANTHACEAE	Open veld	×

ERICACEAE*	Wet and cool conditions	×××
CRASSULACEAE*	Widespread/Dry environment	×××
Aquatics		
CYPERACEAE *Ascolepis**	Moisture availability	×
XYRIDACEAE *Xyris**	Widespread/ Moisture availability	×
Polygonum	Moisture availability	×
Aponogeton	Moisture availability	×
TYPHACEAE *Typha**	Moisture availability	×
NYMPHAEACEAE *Nymphaea**	Moisture availability	×
RANUNCULACEAE	Moisture availability	×
Non-pollen palynomorphs		
GREEN ALGAE *Zygnema* type*	Moisture availability	×
ALGAE undiff. *	Moisture availability	×
PSEUDOSCHIZAEA*	Moisture availability	×
SPORE undiff. *	Moisture availability	×
SCHIZAEACEAE *Mohria*	Moisture availability	×

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Chapter 7

Results

7.1 Pollen analysis

A total of 45 pollen taxa were identified and were grouped according to the following: herbs and shrubs, fynbos taxa, aquatic, tree/woodland and non-pollen palynomorphs (Fig 11). Both local and regional pollen types were included in the pollen sum.

7.2 Relative abundances of pollen taxa within the record

The vegetation changes that occurred within the locality of the uMgeni Vlei Nature Reserve are reflected in the preservation of the fossil pollen. A list of the identified pollen and their average relative abundance is presented in (Table 7). The pollen data are arranged in the hierarchical order of their dominance (Table 7). The most dominant pollen types in the Vlei are those of Poaceae, Asteraceae, Liliaceae and *Phragmites.*

Table 7: Relative abundance of identified palynomorphs (The average of the relative percentage for the whole sequence)

Pollen types	Relative abundance	Pollen types	Relative abundance
Poaceae	24.16	Spore	0.34
Asteraceae	15.24	*Acalypha*	0.28
Liliaceae	10.01	*Mohria*	0.27
Phragmites	9.80	Amaranth	0.18
Cyperaceae	7.37	*Pentzia*-type	0.17
Heteromorpha	7.34	*Aponogeton*	0.15
Ascolepis	5.66	*Ziziphus*	0.14

Pseudoschizaea	4.25	*Stoebe*-type	0.10
Ericaceae	2.33	Fabaceae	0.09
Artemisia	1.35	Myricaceae	0.08
Xyris	1.28	Araceae	0.07
Crassula	1.23	*Cerastium*	0.06
Podocarpus	0.97	Thymelaeaceae	0.05
Euphorbiaceae	0.81	*Morella*	0.05
Oleaceae	0.79	*Nymphaea*	0.03
Zygnema type	0.79	*Anthospermum*	0.03
Caryophyllaceae	0.79	*Sebaea*	0.02
Passerina	0.71	Anacardiaceae	0.02
Algae	0.60	Ranunculaceae	0.02
Scabiosa	0.52	*Spirostachys*	0.01
Apiaceae	0.43	*Polygonum*	0.01
Combretum	0.39	Acanthaceae	0.01
Typha	0.38	*Liguliflora*	0.19

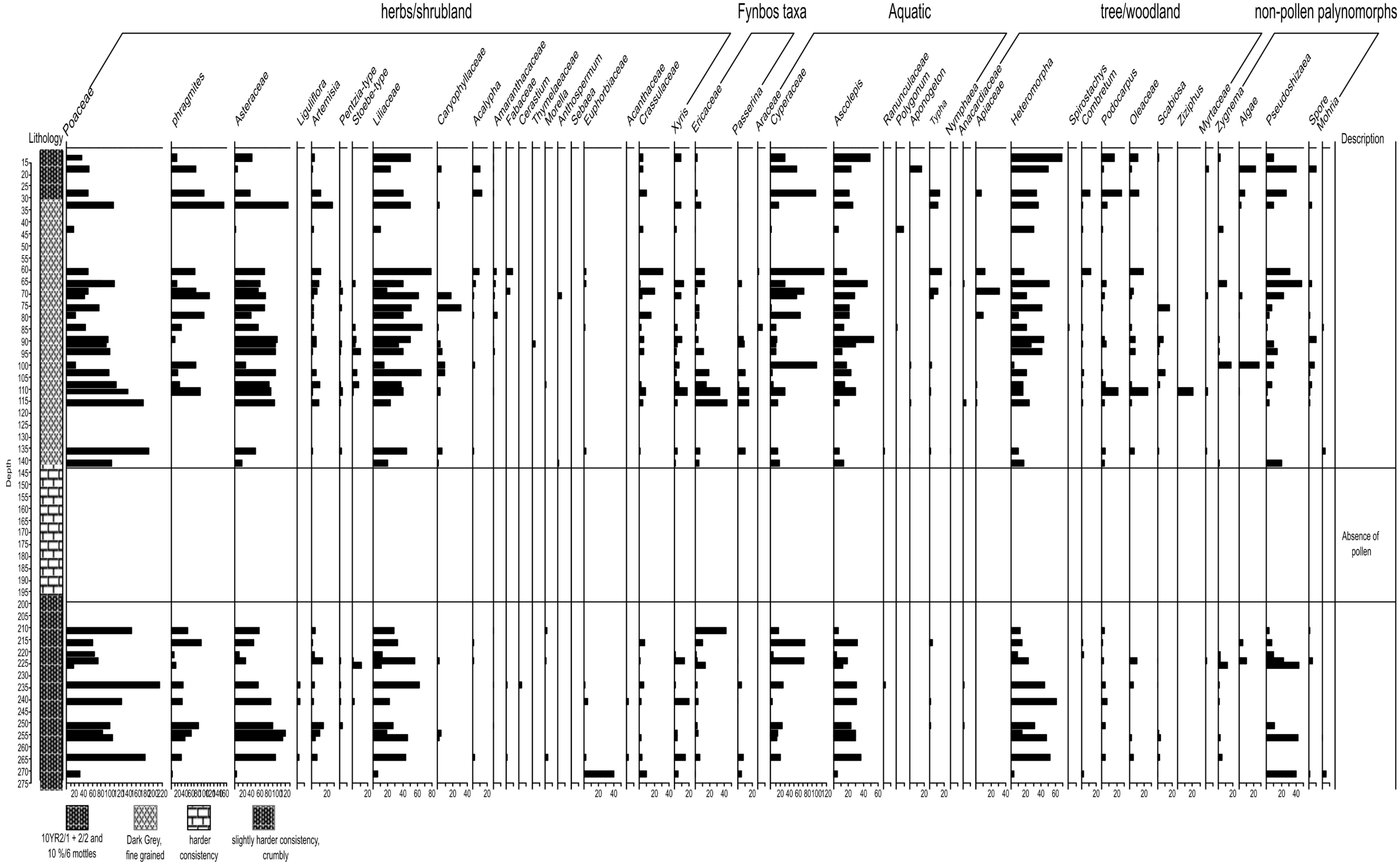

Figure 11: Pollen diagram of the identified pollen taxa from the uMgeni Vlei in their relative percentages

7.3 Radiocarbon Analysis

Seven bulk sediment samples from the 298cm core were dated for AMS radiocarbon measurement. The radiocarbon age is presented in (Table 8). The sedimentary profile of the selected dates consists of 10YR4/1 light brownish grey, coarse texture at 116 cm and a slightly hard consistency, crumbly at 246cm and 281cm respectively (Table 8).

The radiocarbon dates showed a discontinuous age across the depth profile. Perhaps this was due to contamination or bioturbation as variation of mottles (10YR 5/6) and root strains were noticeable across the profile. These radiocarbon dates indicate disturbance or reworking of sediments occurring at the uMgeni Vlei throughout the depths. It is evident that an age model is not applicable to this sequence, but from the collection of ages it is suggested that the material is derived from the Holocene.

Table 8: Radiocarbon dates

Sample	LabCodes	Depth (cm)	^{14}C yr BP	Cal yr BP Range	Sediment description
uM1	Beta-569037	79	8660+/-30	9669-9528 (95.4%)	finer texture, less root strains
uM5	Beta-438768	116	4280+/-30	4750 – 4725 (95%)	10YR4/1 light brownish grey, coarse texture
uM2	Beta-569038	141	10680+/-40	12700-12651 (93.7%)	softer pinkish grey harder zone
uM6	Beta-438769	199	9430+/-30	10710 -10515 (95%)	harder consistency
uM3	Beta-569039	246	5020+/-30	6755-5606 (84.4%)	slightly hard consistency, crumbly

uM4	Beta-569040	281	6000+/-30	6886-6678 (95.4%)	slightly hard consistency, crumbly
uM7	Beta-438770	298	4330+/-30	4870 – 4830 (95%)	slightly hard consistency, crumbly

7.4 Age model and sedimentation rate

A Bacon age model is used to depict the age-depth model for uMgeni Vlei. Three radiocarbon dates were selected for imputation into the Bacon model, as they revealed the best trend in the sequence. An attempt to impute all data points of all ages in Bacon is shown in (Appendix 2). A summary of the calibrated ages considered the best fit is presented in (Fig 12). The selected dates are 4280+/-30 cal yr. BP 5020+/-30 cal yr. BP and 6000+/-30 cal. Yr. BP at the mean depth of (116cm, 246cm and 281cm) respectively.

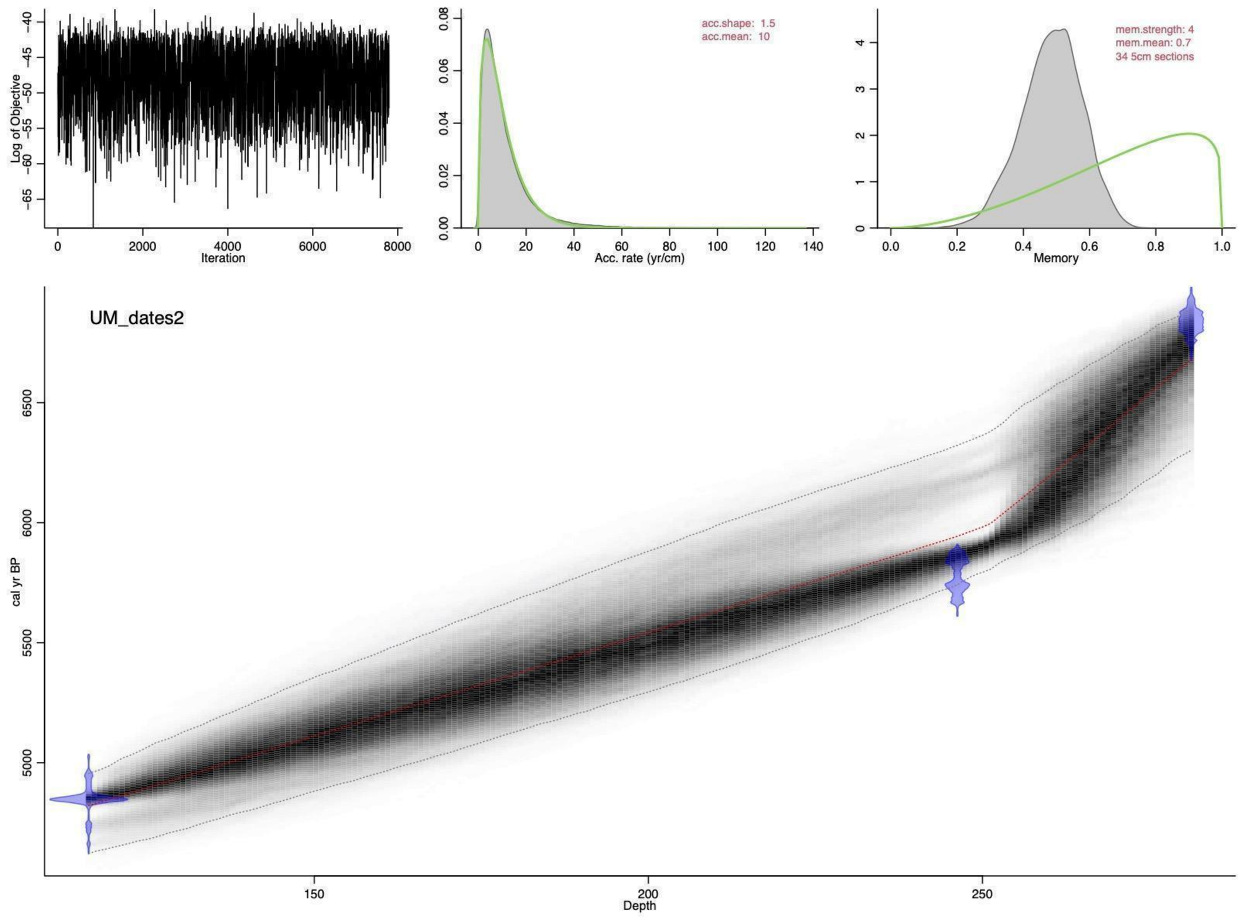

Figure 12: Calibrated Bacon age-depth interpolation from uMgeni Vlei

The radiocarbon dates indicate that the stratigraphic sequence of the uMgeni Vlei is Holocene in age. The mean accumulation rate throughout the sequence is approximately 10 yr. cm^{-1}. A steady accumulation rate at 4,622 cal. yr BP was recorded at a depth of 116cm to 4,808 cal. yr BP at an accumulation rate of 0.05 yr cm^{-1}. Thereafter, a decrease of about 0.02 yr cm^{-1} sedimentation rate was recorded from 4,808 cal. Yr BP at 144cm to 5,288 cal. yr BP at 199cm. This followed a considerably slower rate of 0.009 yr cm^{-1} for the rest of the section between (199- 281cm) from 5,288 cal yr. BP to 6,301 cal yr BP was recorded. However, due to the discrepancy in the age-depth profile across the sequence (Table 8), the interpolated ages will not be considered for statistical analysis.

7.5 Zonation

Three Zones were derived from Constrained Incremental Sum of Squares (CONISS, R studio: http://www.rstudio.com/). The results of the zonation are displayed on a dendrogram as shown in Fig. 13. The zones were derived accessing the fit of the individual pollen count on a silhouette plot (Appendix 3), consideration was also given to a possible disturbance of the sediments. The silhouette test in this study uses the generalised arithmetic mean of the individual species (Borcard et al. 2010; Lengyel and Botta-Dukát, 2019) to provide a pattern of recognition for the stratigraphic sequence.

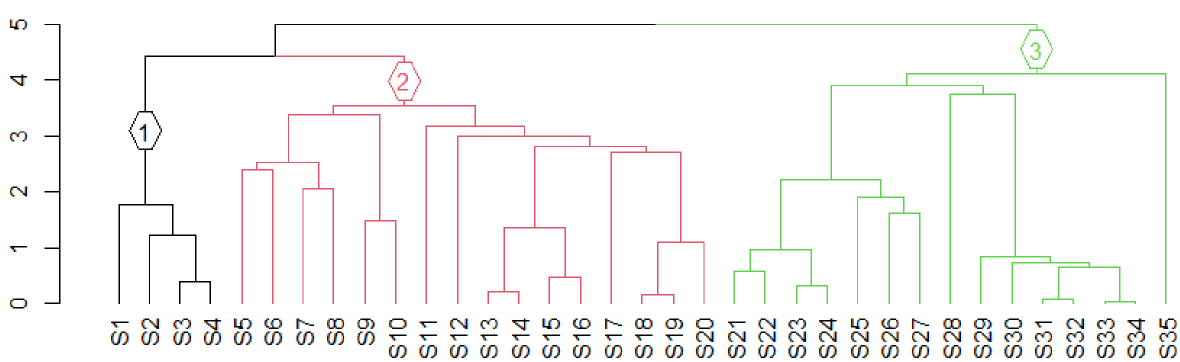

Figure 13: Coniss output of zones for the uMgeni Vlei pollen sequence

The zones are divided where minor stratigraphic intervals occur which are based on the total pollen sum. The following depths are associated with the zones, Zone 1 (13 – 33cm) Zone 2 (43 – 111cm) and Zone 3 (116 -271 cm). A large barren section at depth (199 – 144cm) was included in zone 2, this section lacked pollen data (Fig 14)

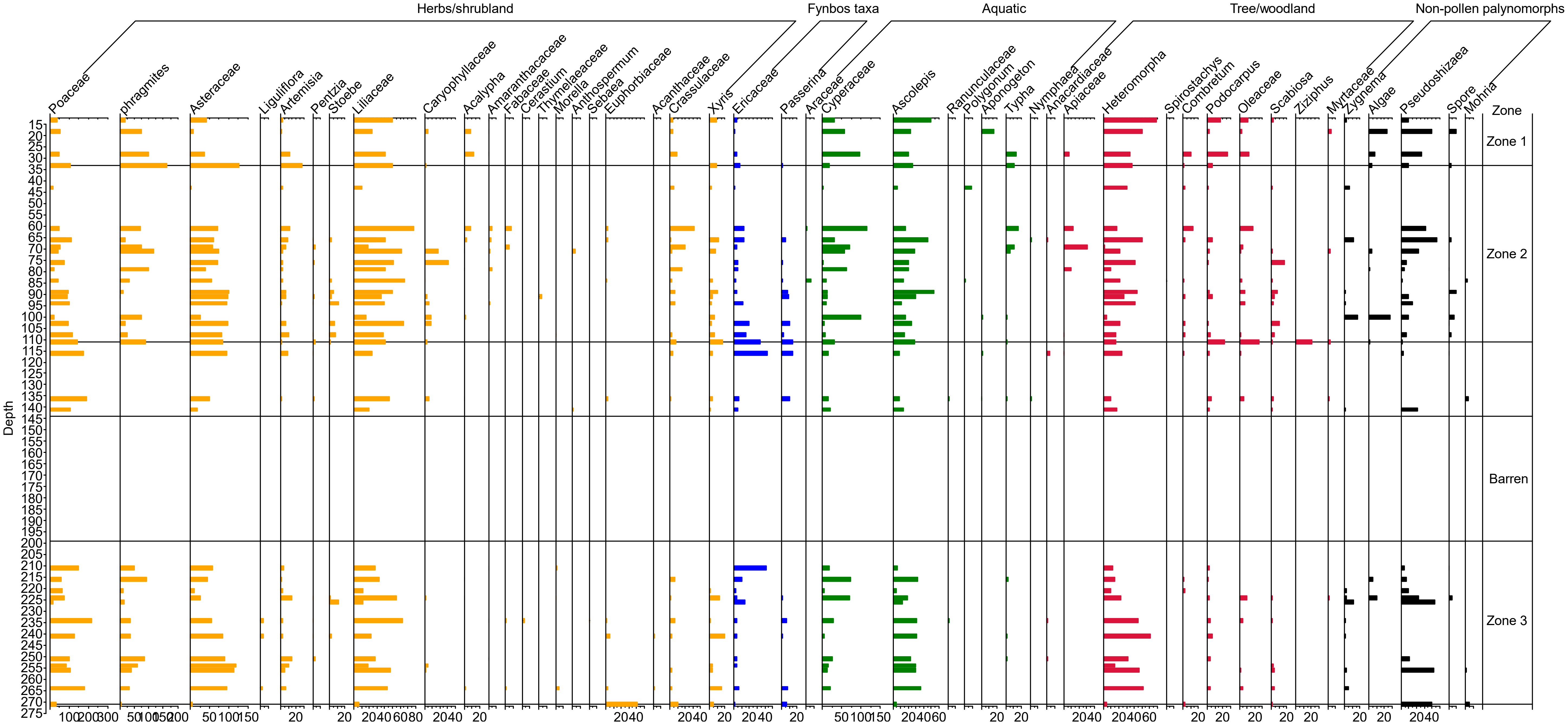

Figure 14: Zonation of pollen diagram

Palynomorphs were grouped according to their associated vegetation groups (herbs and shrubs, fynbos taxa, aquatic, tree/woodland and non-pollen palynomorphs) (Fig 14). The main vegetation characterizing the different zones is presented in (Table 9). A change in vegetation is observed within the zones as revealed in the palynomorph content associated with the different zones (Table 9).

Table 9: A summary of the main pollen taxa characterising the zones

Zones	Depth (cm)	Chronology according to radiocarbon dates and age depth model	Main palynomorphs characterizing the zones in their highest abundance (%) are for when the whole core is considered)
Zone 1	0 -33	**Radiocarbon date**: No dates obtained for this section. **Age depth model:** undetermined	AP: *Podocarpus* (5%) and *Myrtaceae* (1%) NAP: *Ascolepis* (14%), *Artemisia* (5%) and *Aponogeton* (4%). NPP: Spores (2%).
Zone 2	33-111	**Radiocarbon date**: 8660 cal yr Bp; Depth 79cm **Age depth model**: undetermined	AP: *Heteromorpha* (32%), Oleaceae (4%), *Scabiosa* (5%), Apiaceae (9%), *Combretum* (2%) NAP: Cyperaceae (29%), Liliaceae (24%), *Phragmites* (29%), Caryophyllaceae (9%) Typha (3%), *Acalypha* (2%), *Cheno/Am* (1%), Pentzia (1%), *Stoebe* (4%), Fabaceae (1%), Araceae (2%), *Anthospermum* (1%) and *Polygonum* (<1%). NPP: Algae, *Mohria*
Zone 3	111-281	**Radiocarbon age**: 10680 cal yr Bp; Depth: 141cm. 9430 cal yr Bp; Depth: 199cm **Age depth model**: 4622 cal yr BP to 6301 cal yr BP; Depth: (116- 281) cm	AP: *Spirostachys* (<1%), Ziziphus (3%) and *Combretum* (2%), NAP: *Liguliflorae* (<1%), Ranunculaceae (1%), sebae (<1%), Thymelaeaceae (1%), Acanthaceae (<1%) , Anacardiaceae (<1%), *Cerastium* (1%), Euphorbiaceae (30%), *Xyris* (5%),, Asteraceae (33%), Ericaceae (11%), *Passerina* (4%) and Poaceae (51%). NPP: *Pseudoschizaea* (32%).

7.6 **Principal component Analysis**

Percentages of 21 pollen taxa were selected for principal component analysis. The selected taxa were considered the most ecologically sensitive ones that may reflect a clear distinction between the temperature and moisture gradient. A representation of the principal component analysis is shown in Fig, 15.

Principal components 1 and 2 make up 67% of the total variance and were selected as the descriptive tool to indicate the main climatic trend of the profile. PC1 (47%) reveals strong positive loadings Poaceae (0.94) and *Podocarpus* (0.28) and also indicated positive loading of >0.001 for *Cerastrum, Cheno/Am, Crassula, Typha and Stoebe.* High negative loadings for Asteraceae (-0.31) and Liliaceae (-0.29), and < -0.001 for Caryophyllaceae, *Passerina, Morella,* Ericaceae, Scabiosa, Apiaceae, *Artemisia*, Oleaceae, *Heteromorpha, Pentizia* and *Spirostachys*. In consideration of their ecological description of the species, PC 1 might be reflective of moisture change due to the separating of pollen indicators suggestive of drier condition (e.g., Asteraceae, *Heteromorpha*, Caryophyllaceae *and Scabiosa*), from moisture loving plants (e.g *Podocarpus*, Poaceae and *Typha*). Whereas, PC2 separates with positive loadings pollen taxa *Podocarpus* (0.24), Apiaceae (0.10), Cheno/Am (0.10) and *Petzia* type (0.07), and positive loading of >0.04 for Oleaceae, *Spirostachys, Typha, Crassula,* Caryophyllaceae*, Heteromorpha, Cerastrum,* Ericaceae Anacardiaceae and S*cabiosa*. It reveals negative loading for Liliaceae (- 0.56), Poaceae (-0.32), Asteraceae (-0.20) and *Passerina* (0.08) and > -0.06 for *Artemisia*, *Morella* and *Stoebe* type. PC1 also accounts for the separations of the stratigraphic sequence into the three different zones. From their ecological description PC2 accounts for the separation between cooler indicator Passerina and warm indicator *Heteromorpha*, Caryopyllacaea and *Spirostachys*, however no clear separation was suggested for other cooler indicators like (Ericaceae and *Podocarpus*) shown in Fig. 15.

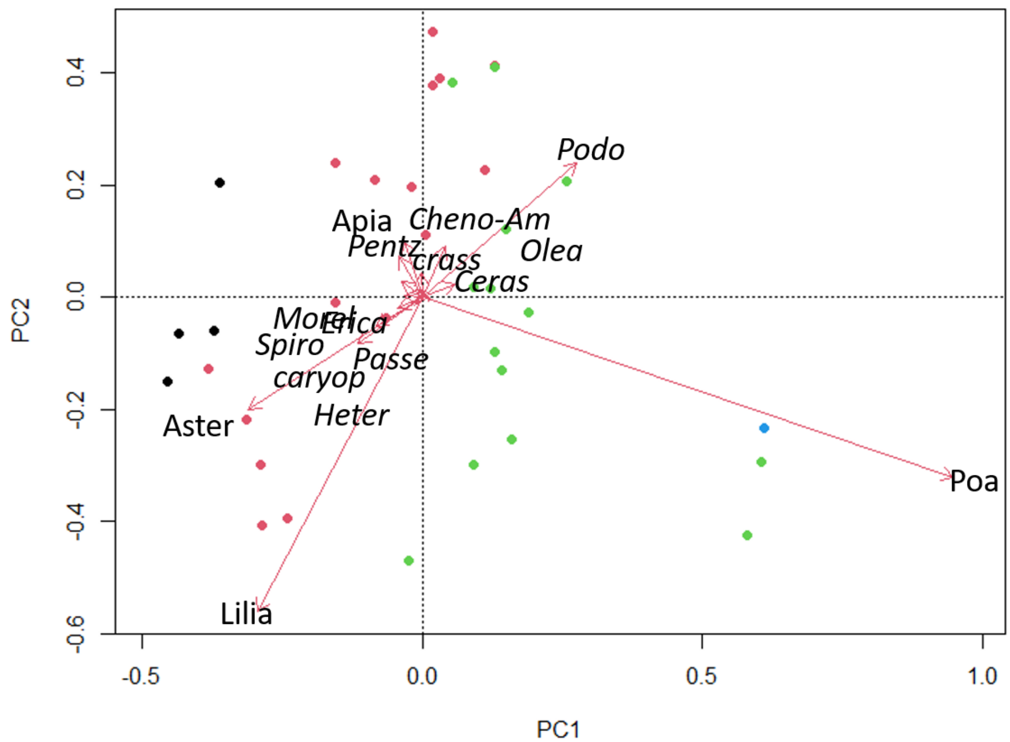

Figure 15: PCA biplot (● denotes samples grouped in zone 1, ● zone 2 and ● zone 3)

Chapter 8

Interpretation of Results and Discussion

8.1 Introduction

An interpretation of the change in vegetation revealed from the results will be provided in this chapter, as an indication of the palaeo-environmental conditions experienced at the uMgeni Vlei Nature Reserve. The interpretation will be deduced from the three zones determined from the uMgeni Vlei pollen records from and will be described and discussed based on ecological information composed for each pollen taxa discussed in Chapter 6. It will also incorporate previous palaeo-environmental research conducted within the grassland biome in the eastern part of South Africa discussed in Chapter 2. Where there is chronological correspondence, primary similarities and differences in climatic trends will be compared and discussed. The interpretation will be based on the environment to vegetation relationship summarized in (Table 7) of Chapter 6.

8.2 Interpretation of the vegetation Change at uMgeni Vlei

Zone 3: (111-281 cm); (RD: 10680; 9430 cal yr. BP) Early to Mid-Holocene?

Non-arboreal elements of herbs and shrubs vegetation dominate this zone (Fig. 14). Asteraceae at 254 cm reached its peak. The basal section can be described as an Asteraceae shrub land as the Asteraceae group in the profile represents a combination of the different Asteraceae pollen together, as forms like *Liguliflorae* were observed striving at their relative dominance at this level.

The basal depth reflects a warmer condition as Asteraceae and other vegetation that are frost sensitive such as Anacardiaceae and *Cerastium* dominate the depths (254- 241cm). The principal component analysis carried out on pollen data from the uMgeni Vlei, reveals a contrast between wet indicator Poaceae and drier indicator Asteraceae. In the basal depth, Asteraceae noticeably reached its peak at 254cm in a Poaceae dominated zone. The increase in Asterace indicates a possibility of a drier climate. The section must not have been completely dry, as moisture availability is inferred at 234cm from the presence of aquatic plant pollen of *Xyris* alongside Ranunculaceae. At 226cm, the non-pollen palynomorph *Pseudoschizaea* was more prominent, and its presence suggests increased moisture availability (Scott, 1982), or can indicate seasonal desiccation if its occurrence was with drier indicators (e.g., Asteraceae) (Neumann et al., 2014). Considering the depth profile, *Pseudoschizaea* increases from 4 - 32% at 226cm as Asteraceae declines from 32- 15%, pointing to a more humid condition. Drier conditions were probably short-lived, because the trend revealed a decrease in Asteraceae accompanying an increase in Poaceae, which appeared to reach its peak at 136cm. How humid was the environment? An indication of it being sub-humid is a possibility due to Stoebe type increasing from <1 - 4%, lingering at 111cm. While the Asteraceae group which includes strobe-type in general may reflect a drier climate caution is taken with this genus as it is more linked to cooler temperature (Scott 1982). The environment may have been a lot cooler as it transitioned into the sub-humid climate because fynbos vegetation pollen of Ericaceae increased from 3 – 11% at 211cm. The environmental setting cannot be described as an open veld due to the presence of arboreal pollen such as *Spirostachys*, *Ziziphus* and *Combretum* that were represented in the zone.

Zone 3 barren section (199-144cm): This section of the depth profile at the umgeni Vlei was marked with absence of palynomorphs. Pollen records from Ntsikeni wetland detect a barren section in its Early Holocene sequence (Combrink et al., 2020). It is uncertain whether the barren sequence at the uMgeni vlei is comparable to the pollen hiatus recorded at the Ntsikeni wetland as they are both situated in a similar timeframe (Table 10). The causes of absence of palynomorphs from Ntsikeni were considered taphonomical rather than a complete absence of terrestrial plants (Combrink et al., 2020); this was alluded to, in the concurrent pollen record from Mafedi which is situated in the mountainous region of Lesotho, suggests a similar hiatus but reveals an environment that may likely support plant preservation (Fitchett et al., 2016a). Considering the uMgeni vlei depth profile at (226cm) leading up to the barren section, there was a decline in drier indicator pollen (e.g., Asteraceae) accompanied an increase in moisture indicator dominating the zone that was pointing to a sub humid environment. The sediment profile within this zone predominantly consists of light brownish grey with coarse texture, softer pinkish grey with a harder consistency, grey with slightly hard consistency to very hard consistency, revealing an unfavourable soil condition for preservation (Erdtman, 2013).

Zone 2 (111-33cm); Probably Mid - Late Holocene (RD: 8660 cal yr. BP?)

This section continues to see flourishing aquatic vegetation. Cyperaceae which was represented throughout the profile increased from 7 – 30% indicating a continuation of moisture availability as suggested from Zone 3. Other water loving plants pollen (Liliaceae, *Anthospermum* and *Phragmites*) together with aquatic plants (*Typha* and *Polygonum*) and moisture demanding non-pollen palynomorphs (Algae and *Mohria*) become more prominent toward the top of the zone. The section can best be described as moderately humid. This is as a result of the presence of dry and halophytic pollen indicator Caryophyllaceae, increasing from 1 - 9% at 76cm, accompanying the increase of dry indicator pollen *Pentzia* type (<1 -1%). It may very likely be pointing to an increase in temperature and decreasing moisture, as warmer indicator arboreal pollen of Apiaceae, together with pollen of *Scabiosa,* both associated with drier conditions become better represented within 69 – 79cm. The warmer climate must have persisted to the top of the zone as *Heteromorpha,* a pollen mainly associated with a warmer climate, increases from 7 - 32% as it progresses toward the top of the zone. Considering how samples associated with Zone 2 were grouped in PC1, it supported the inferences for this zone. Some of the samples were surrounded in the quadrant that was driven by the water demanding tree of *Podocarpus*. While the rest of the samples are associated with the quadrant that is mostly driven by the drier indicator Asteraceae. Although Asteraceae were well represented in the group, *Heteromorpha* was at its climax pointing to a rather warmer condition and reduced moisture.

Zone 1 (0 -33cm); probably Late Holocene

This zone comprises pollen with the least percentage across the depth profile (Table 9) however some vegetational change could be detected. It started off with *Artemisia* (5%) reaching its climax at 33cm. *Artemisia*, which belongs to the Asteraceae family, is generally indicative of drier condition (Scott, 1982; Neumann et al 2014). The warming trend reflected in Zone 2 may have supported the growth of this vegetation. As it progressed toward the top of the zone, *Artemisia* started to be replaced with water loving plants. *Podocarpus*, at 28cm reaches its climax. *Aponogeton* and *Ascolepis,* successively increased and reached their climax at 18 and 13 cm, respectively in the zone: Indicating an increase in moisture for the rest of the zone.

8.3 Discussion and Comparison of Regional Palaeoenvironmental trends

Palynological records from Mahwaqa Mountain (Neumann et al., 2014) and Ntsikeni wetland (Combrink et al., 2020) are the closest palaeoenvironment sites, hence will start comparison with this site. The principal component analysis results from the uMgeni Vlei accounted for the separation of moisture indicators (Poaceae and *Podocarpus)* from drier indicators (Asteraceae and *Scabiosa)*. A similar distinction representing moisture availability is observed in both sites (Neumann et al., 2014; Combrink et al., 2020). The Holocene sequence discussed in the three different stages (Early, Middle and late) reveals the following regional trend:

Early Holocene (<9000 cal yr BP): *Fynbos vegetation retreat, warming conditions and pollen preservation hiatus*.

Pollen records from Mahwaqa at around 11,700 cal yr BP suggests that conditions started off dry but good enough to support the growth of fynbos vegetation (Neumann et al., 2014). Thereafter it became wetter at 10,300 following a decline in the fynbos element (Neumann et al., 2014). A possible explanation to the retreat of fynbos (Ericaceae) is thought to be linked with increasing temperatures, a shift to summer rainfall with winter droughts or more nutrient-rich soil favouring grassland elements (O'Connor and Bredenkamp, 2003; Neumann et al., 2014). Records from Ntsikeni indicated that conditions during the start of the Holocene were favourable for grassland conditions, no fynbos element were detected, however warm conditions prelude from 10900 to 10700 cal yr BP. Thereafter a gap in the pollen records due to a possible taphonomical cause, affecting the preservation of palynomorphs' limited climatic inferences for the period. Radiocarbon date from uMgeni vlei, at 141cm, was 10688 cal yr BP. Although the date remained unreliable as older depths were younger in age, the section (zone 3) remained the most closely linked with the early Holocene.

The uMgeni pollen records are quite comparable to Mahwaqa records in accounting for fynbos vegetation (Ericaceae), while the climatic conditions show a similar pattern with moisture and temperature change. The conditions at uMgeni Vlei favoured both grassland elements and fynbos element (Ericaceae), but at a lesser percentage when compared to the percentage of relative abundance at Mahwaqa (Neumann et al., 2014). A similar retreat of fynbos vegetation observed in Mahwaqa, is comparable to the declining trend of fynbos vegetation in Zones 2 and 1 of the uMgeni profile. This retreat in fynbos vegetation can also be compared to pollen records of the early Holocene section in Wonderkrater, Braamhoek and Clarens (Scott, 1989; 1999; Norström et al., 2009). At Wonderkrater, fynbos vegetation retreat was observed after 14,000 cal yr BP. while fynbos vegetation at Mahwaqa started retreating after 9,000 cal yr BP. At uMgeni Vlei, fynbos vegetation was prominent in the bottom section up to 211cm. With a radiocarbon date of 10,680 cal yr BP at 144cm, it is assumed that at 211cm the date could be much older and a parallel comparative site will be Mahwaqa rather than Wonderkrater due to geographical location and the altitudinal position of Wonderkrater (Scott, 1999).

Warming conditions were described as the main trigger in the retreat of fynbos vegetation (Scott, 1982). Mahwaqa, Ntsikeni and other early Holocene pollen records (Scott, 1989; 1999; Norström et al., 2009; Neumann et al., 2014; Combrink et al., 2020) suggest warming conditions during the early Holocene Period and this is comparable to the warming conditions at the uMgeni Vlei. At Mahwaqa, the warming period that coincides with the interval when fynbos vegetation was prominent, was characterised with moisture availability. Unlike Wonderkrater, where aridity of the environment corresponds with the decline of fynbos vegetation (Scott, 1999), that exact timing of event was not easy to estimate for Mahwaqa. Thus, a possible unrecognised hiatus indicated from slow sedimentation rate and low sample resolution detected between 16,000 and 8500 cal yr BP, was thought to have hindered the evidence of warming at Mahwaqa (Neumann et al., 2014). At uMgeni Vlei the interval during which Ericaceae was dominant, also was marked with moisture availability that are comparable to records from Mahwaqa. Like Mahwaqa this may have corroborated the evidence of aridity suggested at Wonderkrater to have triggered the decline of fynbos vegetation. Low sample resolution before 10,680 cal yr BP at 141 cm at uMgeni Vlei was recorded between 199--144 cm, because this section was marked with the absence of pollen and can be comparable to the missed hiatus suggested at Mahwaqa between 16,000 and 8,500 cal yr BP. Furthermore, this section of the uMgeni Vlei sequence can likewise be comparable to the pollen hiatus detected at the Ntsikeni wetland that occurred between 10,300-9,000 cal yr BP (Combrink et al., 2020).

Mid-Holocene (9,000- 6,000 cal yr BP): *Increase in temperature and decrease in moisture*.

Pollen records of the mid-Holocene suggest that conditions were much warmer and moisture availability was reduced (Norström et al., 2009; Neumann et al., 2014; Combrink et al., 2020). The regional trend of the Mid-Holocene is very comparable to the conditions reflected in Zone 2 of the uMgeni Vlei sequence. Radiocarbon date of 8,660 cal yr BP was established at a depth of 79cm. At Mahwaqa, decreases in moisture started around 8,500 cal yr BP and reached its minimum at about 6,500 cal yr BP (Neumann et al., 2014). The reduction of moisture content in Mahwaqa was as an effect of increasing temperature which was reflected in the change in pollen composition from the records. Frost tolerant pollen (Ericaceae and *Passerin*a) were replaced with drier indicators (Asteraceae) (Neumann et al., 2014). These conditions are comparable to the uMgeni Vlei Mid-Holocene sequence. At 8,660 cal yr BP (79cm) a decrease in moisture was detected. Frost tolerant pollen (Ericaceae and *Passerina*) which were prominent in the basal section of Zone 3, almost disappeared, and were replaced with drier indicators (*Heteromorpha* and Apiaceae) that are comparable to Asteraceae in Mahwaqa. This pattern, which reflects in other sites like Braamhoek (Norström et al., 2009), and Rietvlei (Scott and Vogel, 1983), might be correlated to the Holocene Thermal Maximum (Neumann et al., 2014; Renssen et al., 2012). This event is associated with orbital-force summer insolation maximum (Renssen et al., 2012), that suggests a phase of maximum warming over the Southern Hemisphere mid-latitudes during September to October (Neumann et al., 2014; Renssen et al., 2012) that the uMgeni Vlei environment might have experienced.

Late Holocene

The late Holocene is characterised by vegetation supportive of relatively humid conditions (Scott, 1989; Norström et al., 2009; Neumann et al., 2014; Combrink et al., 2020). Although in Mahwaqa mountains seasonal dryness occurring at 3,500 cal yr BP was detected (Neumann et al., 2014) and reduced humidity (Scott, 1999) in Tswaing Crater in Pretoria Saltpan, the altitudinal position of Mahwaqa is presumed to have ameliorated much of the regional trend during this period. The top zone of the uMgeni Vlei sequence cannot be compared to any of the regional trends due to the chronological limitations. However, its vegetation composition favoured much more humid conditions and suggests an increase in moisture starting at 28cm which progressively increased as water loving plants were seen dominating the top of the sequence.

8.4 Global comparison

Global palaeoenvironmental records during the Holocene, have described a widespread climatic trend that occurred during the early Holocene. Among these periods is the 9000- 8000 cal yr BP, where short-lived cooling (Alley et al., 1997) was detected in most parts of the Northern Hemisphere (Mayewski et al., 2004). In the southern Hemisphere, temperature change was described to be different in different regions (Ciais et al., 1994), with a prolonged increase in precipitation hypothesised across the subcontinent which may have resulted from the intensification of southern mid-latitude westerlies (Mayewski et al., 2004; Mills et al., 2012). Pollen records from the uMgeni Vlei between the late to mid- Holocene reveals an environment with moisture availability which parallels with records from Ntsikeni wetland (Combrink et al., 2020) and Braamhoek Wetland (Norström et al. 2009). At the interval between (211-136) cm, pollen indicators reflecting a cooler climate (e.g. *stoebe*-type) and Fynbos vegetation pollen (Ericaceae) become noticeable in the uMgeni profile. This climatic condition corresponds with other regional records, for example pollen record from Ntsikeni suggests of short-lived cold event occurring during the early Holocene (Combrink et al., 2020) and records from Mahwaqa reveal a change in fynbos vegetation outside the current fynbos biome to grassland during the late Pleistocene to early Holocene (Neumann et al., 2014). Following the short-lived cooler condition detected at the uMgeni vlei was a warmer climate in a moist environment. This pattern might be correlated to the broadly accepted Holocene Thermal Maximum, which occurred during the mid-Holocene between 7500 and 6500 cal BP (Neumann et al., 2014; Wanner et al., 2015) in southern Africa. This phace have been described to be associated with an increase in southern summer insolation (Ingolfsson et al., 1998), where climatic conditions were described as warmer than today (Mayewski et al., 2004). Other fluctuations such as the 4.1kyr cold event (Mayewski et al., 2004) and the little ice age, a period described in South Africa to occur between (AD 1300-1800) (Tyson et al., 2000; Wanner et al., 2008, 2015) in the late Holocene. Pollen records from the uMgeni vlei does not reveal evidence to support these climatic trends, however records from Mahwaqa after 4000 cal

BP described a warm condition with increase moisture (Neumann et al., 2014) which happens to correspond with records from Braamhoek (Norstrom et al. 2009) and Clarens (Scott,1989)

Chapter 9

Conclusion

9.1 Main findings from the study

- Pollen records from the uMgeni Vlei Nature Reserve accounts for fynbos vegetation (e.g. Ericaceae and *Passerina*) occupying the vlei during the early Holocene and was later displaced by grassland (Poaceae) as it progressed into the middle to late Holocene stage. This record is in accordance with the suggestion from Mahwaqa that postulated a similar widespread vegetation until 8,500 cal yr BP (Neumann et al., 2014).
- The relative abundance of the pollen types and the change in the pollen composition from the Early to the Mid-Holocene reveals changes in environmental conditions at uMgeni that are comparable to regional inferences.. This can be observed in the pollen types suggestive of warm conditions (e.g., *Heteromorpha,* Apiaceae and *Scabiosa*) increasing during the transition from the early to mid-Holocene.
- A possible pollen hiatus was also accounted for, from the pollen records of the uMgeni Vlei for the section that ranges from 144-199 cm of the early Holocene. This section which is comparable to the 10,300-9,000 cal yr BP section at Ntsikeni wetland (Combrink et al., 2020) as well as the unrecognised hiatus between 16,000 and 8,500 cal yr BP at Mahwaqa (Neumann et al., 2014), reduces insight into the evidence of warming / aridity, postulated by Scott (1999) as the contributing factor for the decline of fynbos vegetation.

A summary of the main climatic conditions in comparison to the conditions in some selected sites from the grassland biome is presented in Table 10.

Table 10: Comparison of palaeoenvironmental records from selected sites within the grassland biome

Epoch	Stages	uMgeni Wetland	Mahwaqua Mountain (Neumann et al., 2014)	Ntsikeni Wetland (Combrink et al., 2020)	Braamhoek Wetland (Norström et al. 2009)	Clarens (Scott, 1989)	Global climatic Event
Holocene	Late	Relatively humid conditions	800-8 cal BP more humidity 800- 3,500 cal. BP- more humid conditions 4,600- 3,500 cal. BP- drier conditions	4,200-650 cal BP- regional moisture availability	6,000-2,500 cal yr BP- relatively humid conditions	Sub- humid condition; agricultural disturbance	1300 - 18000 cal BP- Little Ice Age 4100 cal BP- cold event
	Middle	8,680 cal yr. BP- Moisture availability; warmer conditions *Stoebe*-type (111cm), signalling a cooler condition; moisture availability	8,500 - 4,600 cal. BP - warmer conditions	4,300- 4,100- warm period 7,000- 5,050 cal BP- warm and dry period 8,800- 8,200 cal BP- regional moisture availability; cold conditions	9,700-7,500 cal yr BP- drier and warmer 7,500-2,500 cal BP- warm and dry conditions		7500 and 6500 cal y BP- Holocene Thermal Maximum 9000-8000 cal yr BP- short cool event (8200)
	Early	Report on fynbos element (Ericaeae) at 136cm 10,680 cal yr BP- Pollen hiatus (199-144) (254cm)-warmer temperatures	11,700- 10,300 cal yr BP - increase in temperature 16-8500 cal yr. BP- possible unrecognized hiatuses	10,300- 9,000 cal yr. BP- pollen hiatus 12,600- 10,300 cal BP- warmer temperature	11,500-9,500 cal y. BP- initially wet and cool; dry conditions from 10,500 cal BP	Grassland with Fynbos. Relatively warm and dry	

9.2 Review of Study objectives

To explore literature for the modern vegetation of the study site and surrounding areas: Investigation into the modern vegetation of the uMgeni Vlei provided information about the climatic condition suitable for their growth. This study objective is discussed in Chapter 6 to establish the environment and vegetation relationship of the fossil pollen identified from the uMgeni Vlei. Forty-two pollen types were classified into their modern vegetative contemporaries (arboreal, non-arboreal and non-pollen palynomorphs), and based on their modern relationship, inferences on their climatic preference were established.

To retrieve core material from the current storage location and select samples from the middle to the bottom section of the core for AMS radiocarbon date: Seven AMS radiocarbon dates obtained for the uMgeni Vlei core sample, temporally constrained the pollen profile and chronologically controlled the sediment core. Initially three radiocarbon dates were obtained from the sediment core, however, due to the age reversal observed with the dates, an additional 4 samples were sent for radiocarbon dating to rule out all forms of contamination and biases that initial three dates were posing. Unfortunately, the four additional dates were no different from the initial set. The oldest radiocarbon date is 10,680 cal yr BP at 141cm with a reverse age of 4,330 cal yr BP at 298cm. Three dates from the seven were selected for Bacon analysis for a possible sedimentation rate and inferred dates were assigned. 6,301 cal yr. BP was the oldest date inferred, and slow sedimentation rates were indicated.

To extract and concentrate fossil pollen and spores from the core material for identification and quantification of the content to detect regional vegetation changes over time: Eighty-two samples were macerated using standard methods, and heavy mineral separation techniques were employed to concentrate the fossil pollen. A minimum of 250 pollen grains were counted to represent the regional vegetation, and identification was done using reference material from publication and online pollen databases.

To determine the relationship among plant communities: Presented in Chapter 7 (Results) are graphical representations of the pollen data highlighting the relationships within and between groups of the pollen grains. Based on the total pollen sum, 3 zones were determined where minor stratigraphic intervals occur. The zones highlighted statistically significant taxa that were prominent, and by utilizing the principal component analysis on selected taxa that were deemed ecologically sensitive, a clear distinction between the temperature and moisture gradient for each zone were established.

To compare findings from the study site to other palynological records: Climatic patterns were inferred from pollen records from the uMgeni Vlei. These recognised patterns point to some exceptional environmental conditions experienced during the Holocene that were discussed in Chapter 8. Palynological records from Mahwaqa Mountains (Neumann et al., 2014) Ntsikeni Wetland (Combrink et al., 2020), Braamhoek Wetland (Norström et al. 2009) and Clarens (Scott, 1989) all showed similar climatic conditions with uMgeni Vlei.

This core showed good correlation with cores from the other sites in the Grassland Biome so deeper cores and higher resolution sampling and dating are recommended for this site and to add the growing dataset for the South African Late Quaternary.

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Appendix 1

Extraction procedure for fossil pollen (Source: Faegri and Iverson,1989)

1 Weigh 5 -7g of sediment, crush weighed samples with a mortar and pestle, then transfer fragmented samples into a Teflon beaker.

2 **Add hydrochloric acid (HCl):** Hydrochloric acid is a strong corrosive acid used for removing carbonates from rock sediment. Working in a fume cupboard, in a large Teflon beaker, slowly add 40-50ml of 10% HCL into the fragmented samples and stir vigorously until all reaction ceases. Decant HCL and thoroughly wash samples with distilled water.

3 **Sieve washed sample:** Using a 500µm brass sieve, transfer washed residue into the sieve and hold the sieve containing the residue adding distilled water from within 1 cm of the top of the sieve into a large Teflon beaker. While adding distilled water, gently move the sieve up and down in the water without allowing the water to flow over the top of the sieve to allow fines to pass through. Continue this procedure, until no material passes through the sieve. Discard any remaining large plant materials from the sieve and transfer residue into a plastic centrifuge tube.

4 **Stir sieved residue:** Stir sieve residue and transfer into a centrifuge tube, centrifuge for 2minutes at 3000r/min, decant supernatant and add the remaining solution to the centrifuge tube, continue this process until all remaining solution have been centrifuge.

5 **Add hydrofluoric Acid (HF):** In a conventional pollen maceration process, HF is introduced to samples to remove silicate contained in sedimentary rocks.in a Teflon beaker add 30ml of a 40% HF to residue, leave overnight. The next day when the sample is no longer gritty, stir residue with a stirring rod, in a plastic tube centrifuge residue for 5 mins at 3000r/min.

Decant HF, add distilled water to residue for neutralisation and rinse with distilled water for at least 3 times.

6 **Add potassium hydroxide (KOH): In order** to remove humic acid as well as any other remaining organic materials, add 10ml of 10%KOH to residue in a centrifuge tube, stir and place centrifuge tubes in boiling water in a large Teflon beaker. Leave in a water bath until the beaker is hot (5mins or less), centrifuge (5mins at 3000r/min), decant KOH and water wash with distilled water, centrifuge 3 times until supernatant is clear. After final wash and centrifuge, thoroughly drain water out of the tube to prevent interference (such as diluting heavy liquid) with the next steps.

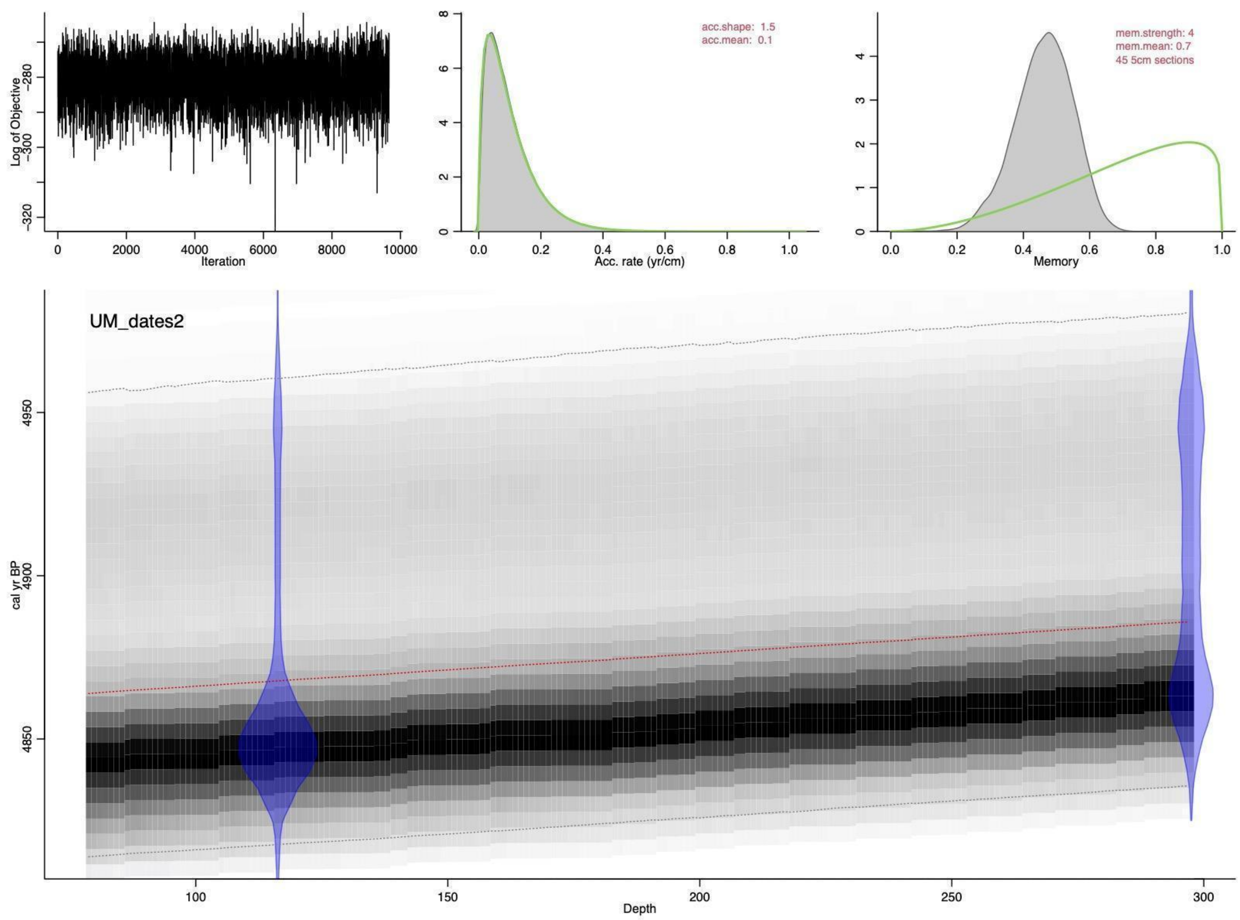
7 **Add zinc Chloride ($ZnCl_2$):** For heavy liquid separation, add 10ml of (250ml of 10%Hcl + 500g $ZnCl_2$ mix) to residue, shake on shake machine, transfer mixture into equal halves in a clear pipe tube, fitted into a centrifuge plastic tube. In a weight machine, balance the centrifuge tube with distilled water, and centrifuge (5min at 3000r/min). This allows the unwanted materials to settle down leaving the POM with pollen suspended in the supernatant. Decantation is carefully done by blocking off the unwanted material with a plier, and transferring the supernatant into a 250ml Teflon beaker rinsing the blocked part of the pile with distilled water and decant. Discard the settled residue in the pipe. Transfer residue in Teflon beaker into a centrifuge tube, add a little distilled water, shake with a shake machine, add more distilled water, balance, and centrifuge (5mins at 3000r/min). Water wash with distilled water 3 times until residue is clear, after final washing leave a bit of supernatant, mix with residue and mount slides.

8 **Preparing slides:** put glyceryl jelly and slide on a hot plate to heat up, label all slides according to the assigned sample depth. Place 2 to 4 drops of glycerine jelly on the slide

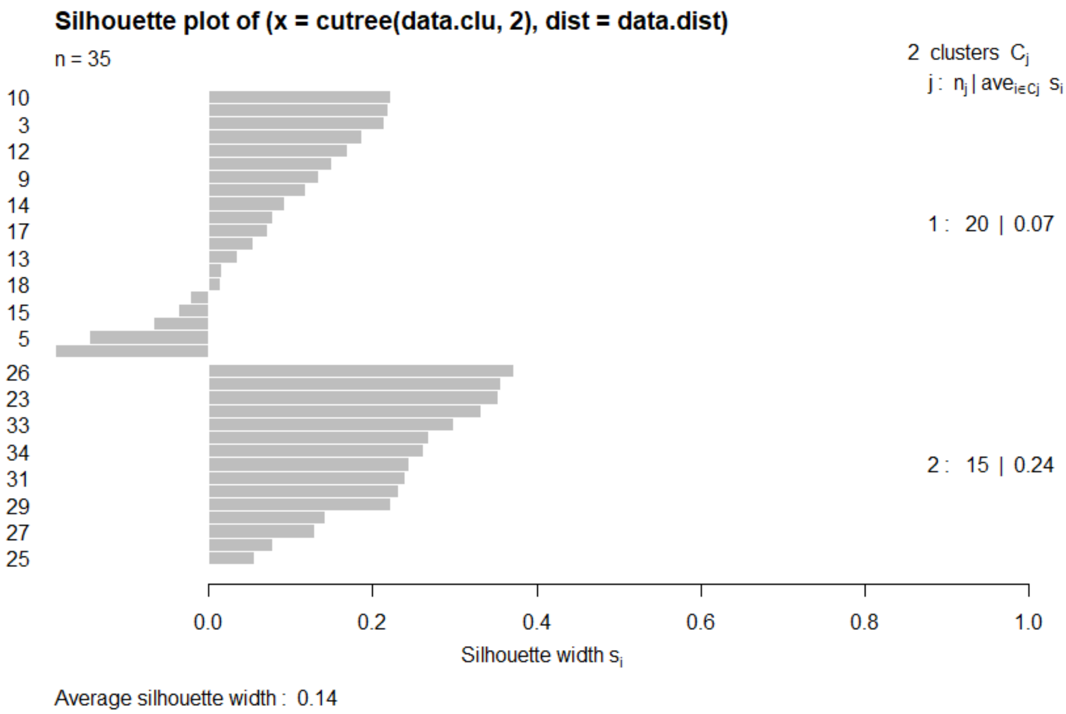
with a stirring rod, add 2 to 3 drops of sample mixture on slide with a disposable pipette, spread evenly and leave on hot plate to for 1minute to allow water from the sample to evaporate out, to check this, remove slide from hot plate and hold the cover slip very close to the slides, this will show a steam on the cover slip indicating presence of water on slide or stay clear that is complete evaporation, then cover slide.

Appendix 2

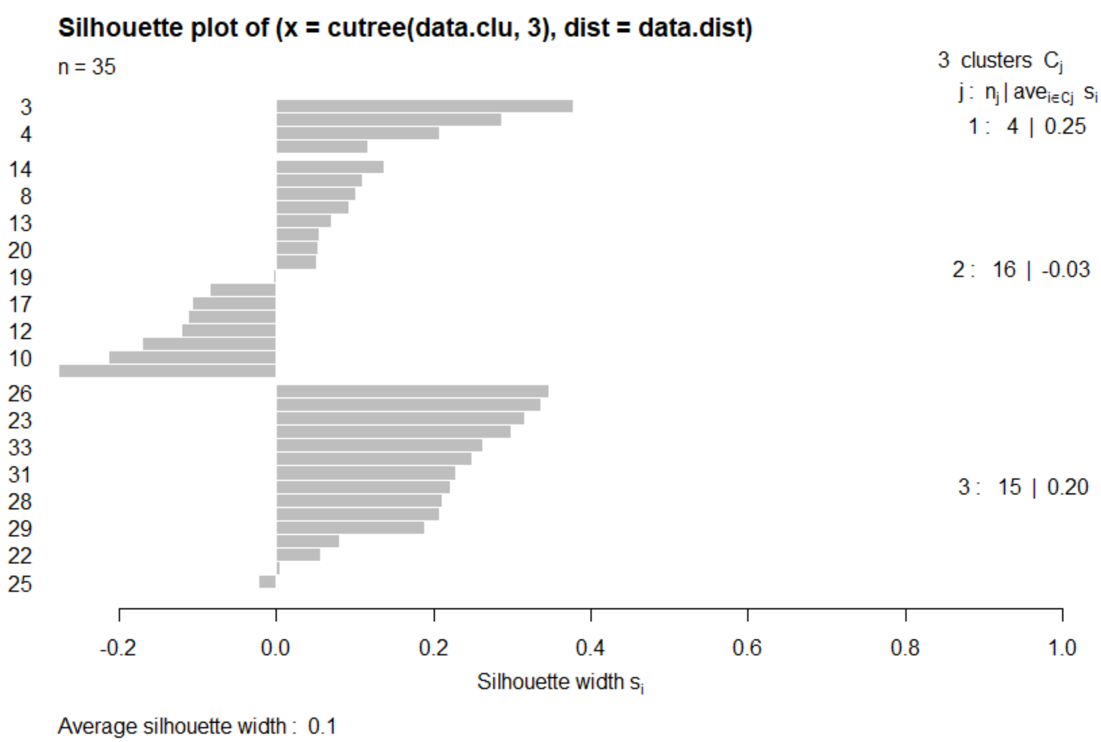
Calibrated Bacon age-depth model of all radiocarbon dates



Appendix 3



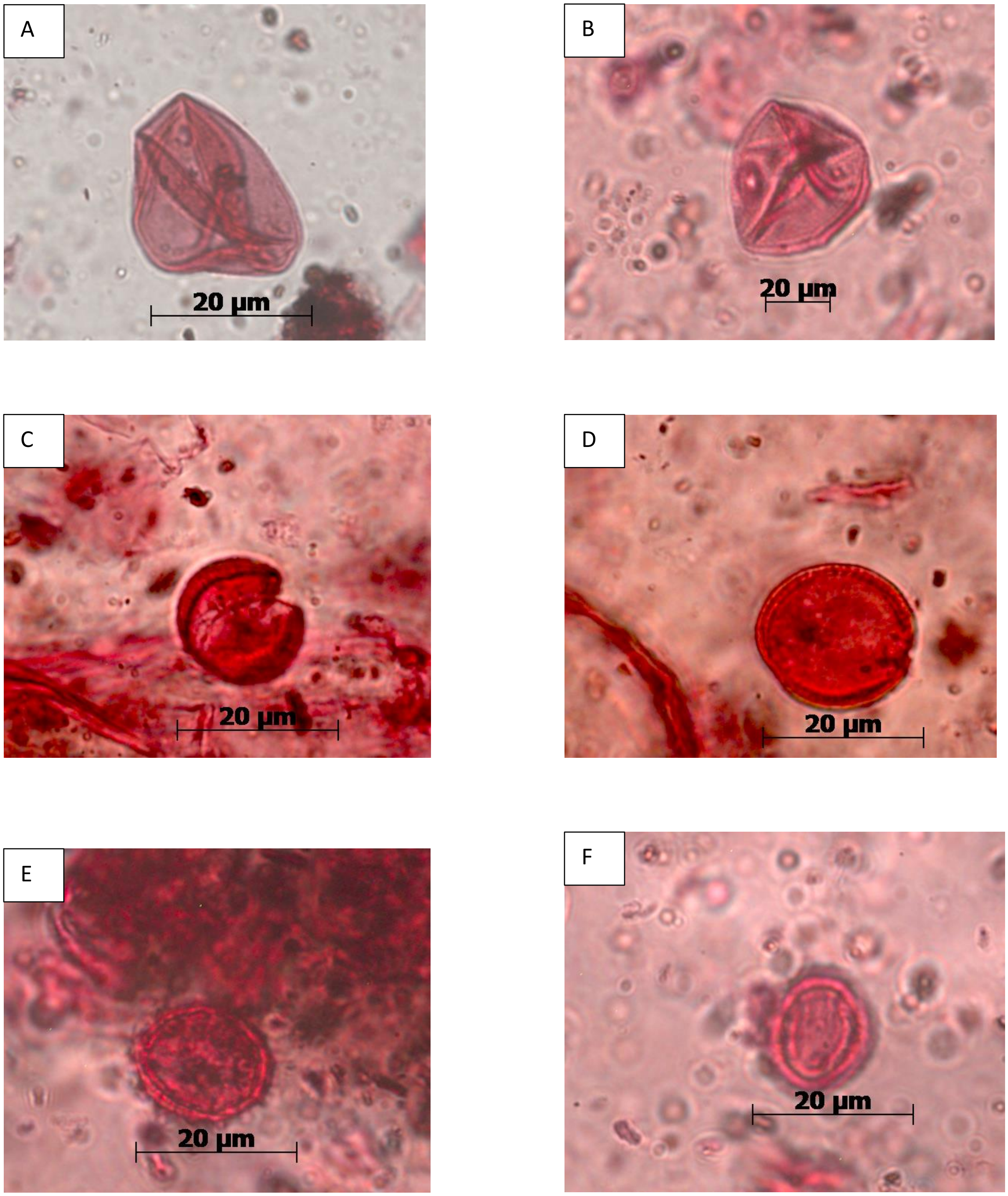
Silhouette plot of (x = cutree(data.clu, 2), dist = data.dist)
n = 35
2 clusters C_j
j : n_j | $ave_{i \in Cj}$ s_i
10
3
12
9
14
17
13
18
15
5
26
23
33
34
31
29
27
25
1 : 20 | 0.07
2 : 15 | 0.24
0.0
0.2
0.4
0.6
0.8
1.0
Silhouette width s_i
Average silhouette width : 0.14



Silhouette plot of (x = cutree(data.clu, 3), dist = data.dist)
n = 35
3 clusters C_j
j : n_j | $ave_{i \in Cj}$ s_i
1 : 4 | 0.25
3
4
14
8
13
20
19
17
12
10
26
23
33
31
28
29
22
25
2 : 16 | -0.03
3 : 15 | 0.20
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
Silhouette width s_i
Average silhouette width : 0.1

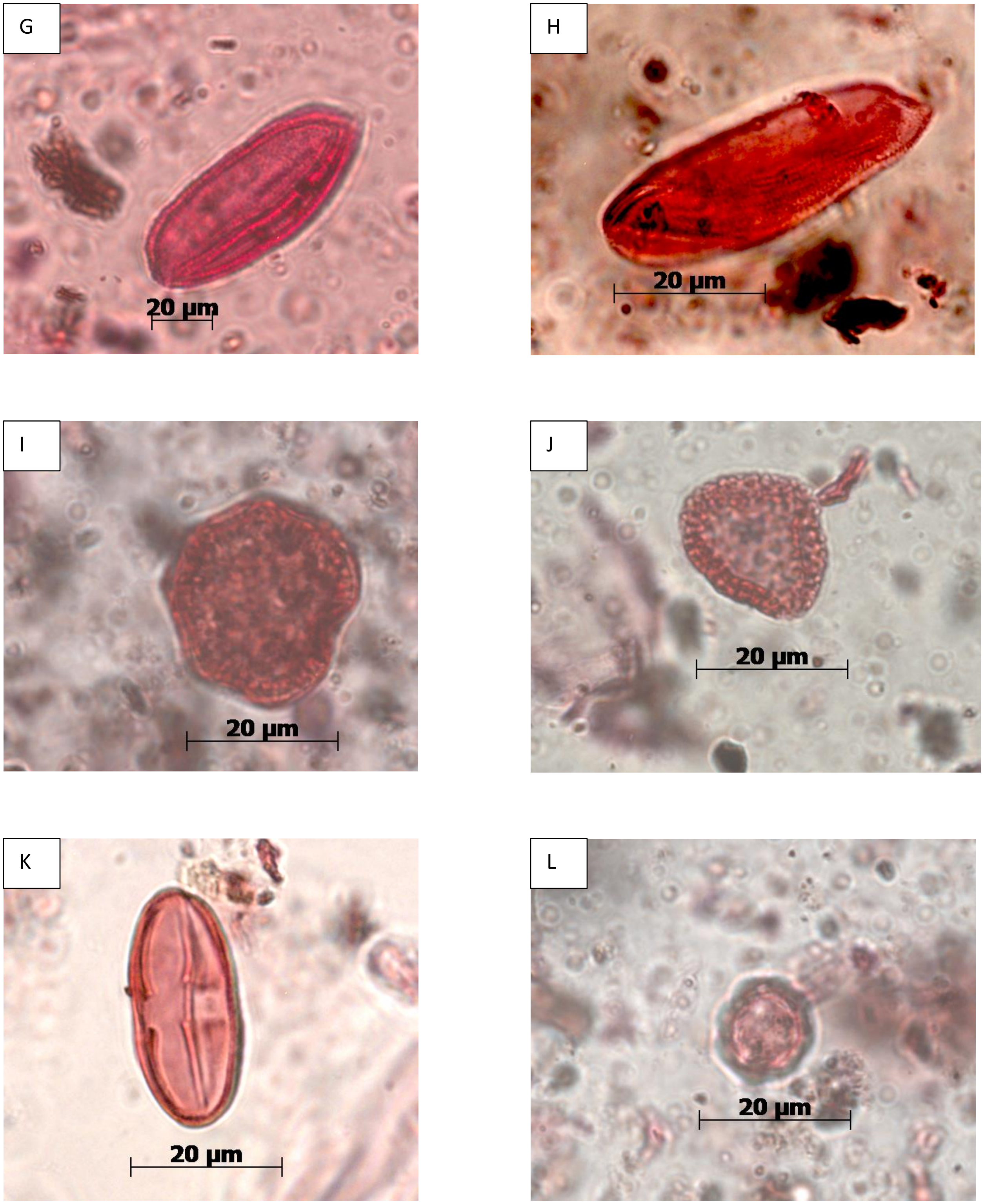
Appendix 4

Pollen Plates 1



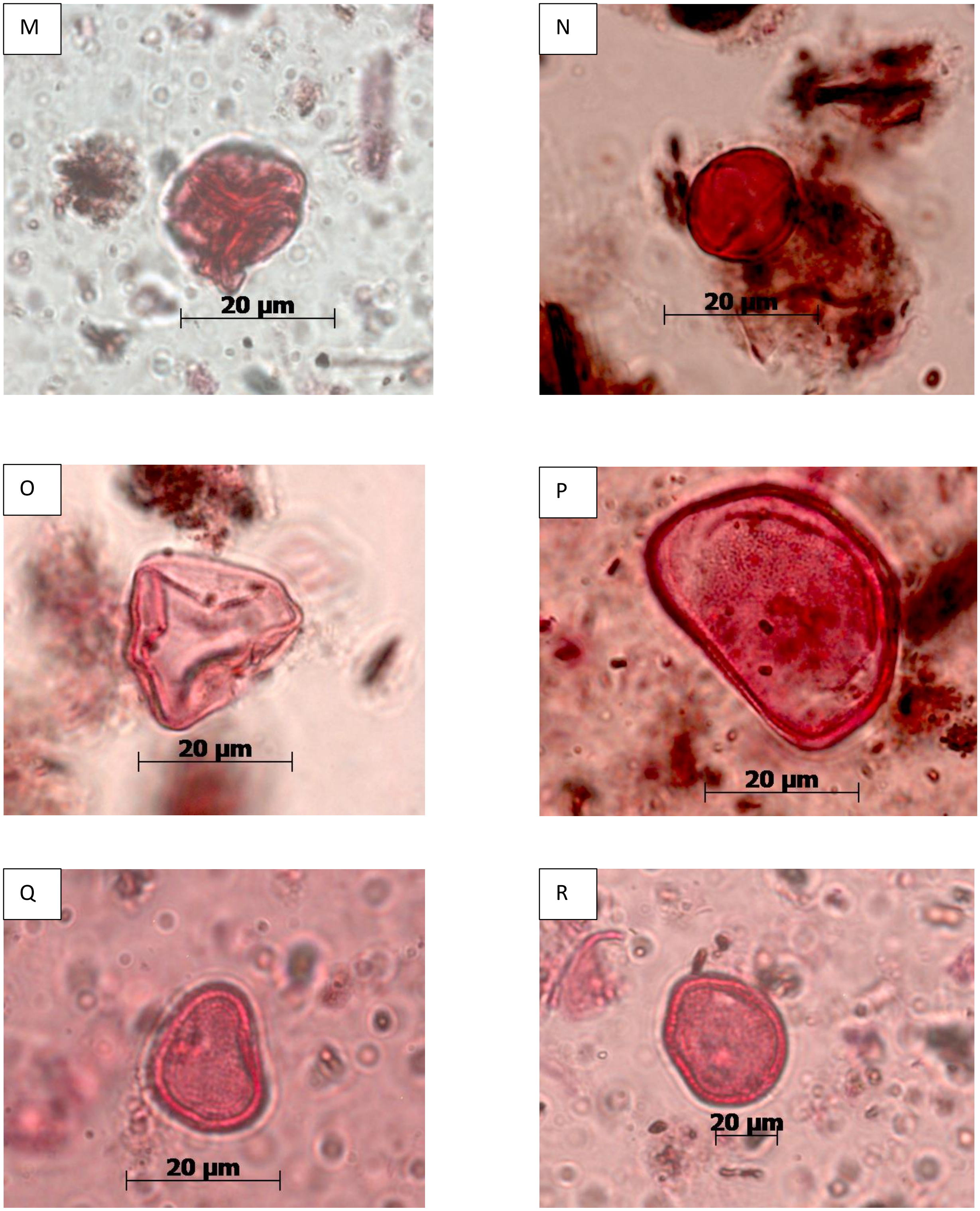
A and B- Poaceae; C and D- Asteraceae (*Artemisia*); E and F- Asteraceae (*Pentzia*).

Pollen Plates 2



G and H-Liliaceae; I- Caryophyllaceae; J- Thymelaeaceae (*Passerina*); Apiaceae (*Heteromorpha*); L-Chenopodiaceae/Amaranthaceae

Pollen Plates 3



M-Ericaceae; N-Crassulaceae; O-Cyperaceae; P-Xyridaceae, Q- Cyperaceae (*Ascolepis*); R- *Typha*

Appendix 5

Raw pollen count

Sample Nu	Midpoint D	Cyperacea	Poaceae >	Phragmites	Liliaceae	Asteraceae	Artemisia	Cheno-Am	Ascolepis
uM1	5								
uM2	1,5								
uM3	12,5	30	36	17	50	41	3	1	49
uM4	17,5	56	52	74	23	7	1	1	23
uM5	22,5								
uM6	27,5	97	50	100	41	36	12	1	21
uM7	32,5	16	108	161	50	127	28		26
uM8	37,5								
uM9	42,5	2	17		10	3	2		6
uM10	49								
uM11	52,5								
uM12	57,5								
uM13	61,25	115	50	71	78	70	12	4	17
uM14	63,75								
uM15	65,5								
uM16	66,25	30	110	16	41	61	9	3	46
uM17	68,75	71	51	75	18	57	7		
uM18	71,25	57	42	117	62	74	2	2	28
uM19	73,75								
uM20	76,25	1	76		51	71	2	1	21
uM21	78,75	63	21	100	41	40	2	5	21
uM22	81,25								
uM23	83,75	10	44	31	66	56	2		14
uM24	86,25								
uM25	88,75	12	96	11	50	100	6	1	54
uM26	91,25	11	91	1	35	97	6	1	30
uM27	92,5								
uM28	93,75	10	101		40	96	1	2	11
uM29	97,5								
uM30	99,5	100	22	75	15	26			17
uM31	102,5	4	98	19	65	97	6		24
uM32	107,5	6	115	25	38	81	11		15
uM33	111,25	30	141	88	41	85	1	1	29
uM34	112,5								
uM35	113,75								
uM36	116,25	14	177		23	95	9		8
uM37	115								
uM38	118,75								
uM39	121,25	1		4					2

uM40	123,75								
uM41	126,25	4	7			1			6
uM42	129,5								
uM43	128,75								
uM44	131,25								
uM45	133,75								
uM46	135,5	15	190		46	50	1		8
uM47	136,75								
uM48	142,75								
uM49	141,25	19	105		20	17			14
uM50	143,75								
uM51	146,25								
uM52	148,75								
uM53	151,25								
uM54	153,75								
uM55	156,25								
uM56	158,75								
uM57	160								
uM58	163,75								
uM59	166,25								
uM60	168,75								
uM61	171,25								
uM62	173,75								
uM63	176,25								
uM64	178,75								
uM65	181,25								
uM66	183,75								
uM67	186,25								
uM68	188,75								
uM69	191,25								
uM70	193,25								
uM71	195,5								
uM72	198,5								
uM73	211,25	16	150	50	28	59	4	1	6
uM74	213,75								
uM75	216,25	73	60	91	33	46	1		32
uM76	218,75								
uM77	221,25	5	64	9	12	11	3		4
uM78	223,75	71	74		56	26	14		19
uM79	226,25								
uM80	228,75								
uM81	231,25								
uM82	233,75	27	215	35	63	56	3	1	31
uM83	236,25								
uM84	238,75								
uM85	241,25	3	127	34	22	85	2		31
uM86	243,75								
uM87	246,25								

Sample Nu	Midpoint D	Heteromo	Podocarpu	Ericaceae	Crassula	Aponogetc	Pseudosch	Acalypha	Caryophyll
uM1	5								
uM2	1,5								
uM3	12,5	69	17	3	4		10		
uM4	17,5	50	2	1	4	16	40	9	5
uM5	22,5								
uM6	27,5	34	26	3	9		27	12	
uM7	32,5	37	7	8			9		2
uM8	37,5								
uM9	42,5	31	1	1	5				
uM10	49								
uM11	52,5								
uM12	57,5								
uM13	61,25	17		13	31		32	8	
uM14	63,75								
uM15	65,5								
uM16	66,25	51	6	1			47		
uM17	68,75	1		3	20				
uM18	71,25	21	3		3		23	1	18
uM19	73,75								
uM20	76,25	41	1	5			7		31
uM21	78,75	10		5	16		4	1	
uM22	81,25								
uM23	83,75	21		2	2		1		1
uM24	86,25								
uM25	88,75	44	3	4	6				
uM26	91,25	27	6				9		3
uM27	92,5								
uM28	93,75	41		11	6		15		6
uM29	97,5								
uM30	99,5	4				2	10	2	9
uM31	102,5	21	1	19					9
uM32	107,5	16	4	15	2		7		
uM33	111,25	16	22	34	8		1		3
uM34	112,5								
uM35	113,75								
uM36	116,25	24	3	43	4	2	3		
uM37	115								
uM38	118,75								
uM39	121,25			1					
uM40	123,75								
uM41	126,25	1	1				11		1
uM42	129,5								
uM43	128,75								
uM44	131,25								

uM45	133,75								
uM46	135,5	10	5	6	1	1		1	6
uM47	136,75								
uM48	142,75								
uM49	141,25	17	3	5			21		1
uM50	143,75								
uM51	146,25								
uM52	148,75								
uM53	151,25								
uM54	153,75								
uM55	156,25								
uM56	158,75								
uM57	160								
uM58	163,75								
uM59	166,25								
uM60	168,75								
uM61	171,25								
uM62	173,75								
uM63	176,25								
uM64	178,75								
uM65	181,25								
uM66	183,75								
uM67	186,25								
uM68	188,75								
uM69	191,25								
uM70	193,25								
uM71	195,5								
uM72	198,5								
uM73	211,25	12	3	42			4		
uM74	213,75								
uM75	216,25	15	1	10	7		7	1	
uM76	218,75								
uM77	221,25	9		2			9		
uM78	223,75	23	2	3	1		23	1	2
uM79	226,25								
uM80	228,75								
uM81	231,25								
uM82	233,75	45	4	3	6				
uM83	236,25								
uM84	238,75								
uM85	241,25	61	7	4	2				
uM86	243,75								
uM87	246,25								

uM88	248,75								
uM89	251,25								
uM90	253,75								
uM91	256,25	47			2		43		2
uM92	258,75	30	1	1	6		22		7
uM93	261,25								
uM94	263,75	52	4	6	3			2	
uM95	268,75								
uM96	271,25	4		1	10		40		
uM97	273,75								
uM98	276,25								
uM99	278,75								
uM100	281,25			1	1		1		
uM101	283,75								
uM102	288,75								
uM103	287,75								
uM104	292,5								
uM105	297,5								

Sample Nu	Midpoint D	Spores	Oleaceae	Rubiaceae	Apiaceae	Myrtaceae	Xyris	Combretac	Typha
uM1	5								
uM2	1,5								
uM3	12,5		11				9		
uM4	17,5	10	3			4			
uM5	22,5								
uM6	27,5		12	1	7			11	13
uM7	32,5	3					9	1	11
uM8	37,5								
uM9	42,5						2	2	
uM10	49								
uM11	52,5								
uM12	57,5								
uM13	61,25		18	3	12			13	16
uM14	63,75								
uM15	65,5								
uM16	66,25	3					12	2	
uM17	68,75		5		31				11
uM18	71,25		2			3	8		5
uM19	73,75								
uM20	76,25								
uM21	78,75	1		1	9				
uM22	81,25								
uM23	83,75		3				3	1	
uM24	86,25								
uM25	88,75	10	7				10		
uM26	91,25						3	2	
uM27	92,5								
uM28	93,75		7				2		
uM29	97,5								
uM30	99,5	7					6		2
uM31	102,5	1					2	3	
uM32	107,5	3	2		1		6	2	
uM33	111,25	1	25			3	17		1
uM34	112,5								
uM35	113,75								
uM36	116,25	1	2		1		3	1	
uM37	115								
uM38	118,75								
uM39	121,25								
uM40	123,75								
uM41	126,25								
uM42	129,5								
uM43	128,75								
uM44	131,25								

uM45	133,75								
uM46	135,5		6			2	4		1
uM47	136,75								
uM48	142,75								
uM49	141,25						1		
uM50	143,75								
uM51	146,25								
uM52	148,75								
uM53	151,25								
uM54	153,75								
uM55	156,25								
uM56	158,75								
uM57	160								
uM58	163,75								
uM59	166,25								
uM60	168,75								
uM61	171,25								
uM62	173,75								
uM63	176,25								
uM64	178,75								
uM65	181,25								
uM66	183,75								
uM67	186,25								
uM68	188,75								
uM69	191,25								
uM70	193,25								
uM71	195,5								
uM72	198,5								
uM73	211,25	1							
uM74	213,75								
uM75	216,25							1	3
uM76	218,75								
uM77	221,25						1	3	
uM78	223,75	5	10			1	13		
uM79	226,25								
uM80	228,75								
uM81	231,25								
uM82	233,75		5				1		
uM83	236,25								
uM84	238,75								
uM85	241,25						20		1
uM86	243,75								
uM87	246,25								
uM88	248,75								
uM89	251,25								
uM90	253,75								
uM91	256,25		2				3		
uM92	258,75	1	1					2	1

uM93	261,25								
uM94	263,75		5				15		
uM95	268,75								
uM96	271,25	1					5	3	
uM97	273,75								
uM98	276,25								
uM99	278,75								
uM100	281,25								
uM101	283,75								
uM102	288,75								
uM103	287,75								
uM104	292,5								
uM105	297,5								

Sample Nu	Midpoint D	Algae	Euphorbia	Fabaceae	Araceae	Pentzia-ty	Zygnema t	Anthosper	Scabiosa
uM1	5								
uM2	1,5								
uM3	12,5						2		2
uM4	17,5	23							
uM5	22,5								
uM6	27,5	8							
uM7	32,5	3							
uM8	37,5								
uM9	42,5						6		1
uM10	49								
uM11	52,5								
uM12	57,5								
uM13	61,25		3	8	1				
uM14	63,75								
uM15	65,5								
uM16	66,25		3				11		
uM17	68,75			5		3			
uM18	71,25	4						4	1
uM19	73,75								
uM20	76,25					2			17
uM21	78,75	1							
uM22	81,25								
uM23	83,75		1		6				1
uM24	86,25								
uM25	88,75						1		8
uM26	91,25					2			3
uM27	92,5								
uM28	93,75					1	1		2
uM29	97,5								
uM30	99,5	27					17		
uM31	102,5								10
uM32	107,5					1			3
uM33	111,25	1				3			1
uM34	112,5								
uM35	113,75								
uM36	116,25					1			
uM37	115								
uM38	118,75								
uM39	121,25								
uM40	123,75								
uM41	126,25								1
uM42	129,5								
uM43	128,75								
uM44	131,25								
uM45	133,75								

uM46	135,5		2			2			2
uM47	136,75								
uM48	142,75								
uM49	141,25						1	1	1
uM50	143,75								
uM51	146,25								
uM52	148,75								
uM53	151,25								
uM54	153,75								
uM55	156,25								
uM56	158,75								
uM57	160								
uM58	163,75								
uM59	166,25								
uM60	168,75								
uM61	171,25								
uM62	173,75								
uM63	176,25								
uM64	178,75								
uM65	181,25								
uM66	183,75								
uM67	186,25								
uM68	188,75								
uM69	191,25								
uM70	193,25								
uM71	195,5								
uM72	198,5								
uM73	211,25								
uM74	213,75								
uM75	216,25	5							
uM76	218,75								
uM77	221,25						2		
uM78	223,75	10				1	2		1
uM79	226,25								
uM80	228,75								
uM81	231,25								
uM82	233,75		1	1		1	1		1
uM83	236,25								
uM84	238,75								
uM85	241,25		5			1	1		
uM86	243,75								
uM87	246,25								
uM88	248,75								
uM89	251,25								
uM90	253,75								
uM91	256,25						2		4

uM92	258,75								1
uM93	261,25								
uM94	263,75		3	1			5		3
uM95	268,75								
uM96	271,25		41						1
uM97	273,75								
uM98	276,25								
uM99	278,75								
uM100	281,25								
uM101	283,75								
uM102	288,75								
uM103	287,75								
uM104	292,5								
uM105	297,5								

Sample Nu	Midpoint D	Passerina	Morella	Tubuliflora	steobe typ	Ziziphus	Mohria	Polygonum	Spirostach
uM1	5								
uM2	1,5								
uM3	12,5								
uM4	17,5								
uM5	22,5								
uM6	27,5								
uM7	32,5	1							
uM8	37,5								
uM9	42,5						9		
uM10	49								
uM11	52,5								
uM12	57,5								
uM13	61,25								
uM14	63,75								
uM15	65,5								
uM16	66,25	5		3					1
uM17	68,75								
uM18	71,25								
uM19	73,75								
uM20	76,25	1							
uM21	78,75								
uM22	81,25								
uM23	83,75	1		3		2	1	1	
uM24	86,25								
uM25	88,75	8		5					
uM26	91,25	9		3					
uM27	92,5								
uM28	93,75			11					
uM29	97,5								
uM30	99,5								
uM31	102,5	10		6					
uM32	107,5	2	1	8					
uM33	111,25	15		1	21				
uM34	112,5								
uM35	113,75								
uM36	116,25	15							
uM37	115								
uM38	118,75								
uM39	121,25	2							
uM40	123,75								
uM41	126,25								
uM42	129,5								
uM43	128,75								
uM44	131,25								
uM45	133,75								
uM46	135,5	10				4			1
uM47	136,75								

uM48	142,75								
uM49	141,25								
uM50	143,75								
uM51	146,25								
uM52	148,75								
uM53	151,25								
uM54	153,75								
uM55	156,25								
uM56	158,75								
uM57	160								
uM58	163,75								
uM59	166,25								
uM60	168,75								
uM61	171,25								
uM62	173,75								
uM63	176,25								
uM64	178,75								
uM65	181,25								
uM66	183,75								
uM67	186,25								
uM68	188,75								
uM69	191,25								
uM70	193,25								
uM71	195,5								
uM72	198,5								
uM73	211,25		2						
uM74	213,75								
uM75	216,25								
uM76	218,75								
uM77	221,25								
uM78	223,75	1	1	1					
uM79	226,25								
uM80	228,75								
uM81	231,25								
uM82	233,75	6							
uM83	236,25								
uM84	238,75								
uM85	241,25	1		2					
uM86	243,75								
uM87	246,25								
uM88	248,75								
uM89	251,25								
uM90	253,75								
uM91	256,25					1			
uM92	258,75			3					
uM93	261,25								
uM94	263,75	8	4						
uM95	268,75								

uM96	271,25	6				5			
uM97	273,75								
uM98	276,25								
uM99	278,75								
uM100	281,25			1					
uM101	283,75								
uM102	288,75								
uM103	287,75								
uM104	292,5								
uM105	297,5								

Sample Nu	Midpoint D	Nymphaea	Thymeleac	Anacardiac	Ranuncula	Cerastrum	Lugiluflora	Sebaea	Acantacea
uM1	5								
uM2	1,5								
uM3	12,5								
uM4	17,5								
uM5	22,5								
uM6	27,5								
uM7	32,5								
uM8	37,5								
uM9	42,5								
uM10	49								
uM11	52,5								
uM12	57,5								
uM13	61,25								
uM14	63,75								
uM15	65,5								
uM16	66,25								
uM17	68,75								
uM18	71,25								
uM19	73,75								
uM20	76,25								
uM21	78,75								
uM22	81,25								
uM23	83,75								
uM24	86,25								
uM25	88,75								
uM26	91,25	4							
uM27	92,5								
uM28	93,75								
uM29	97,5								
uM30	99,5								
uM31	102,5								
uM32	107,5								
uM33	111,25								
uM34	112,5								
uM35	113,75								
uM36	116,25		4						
uM37	115								
uM38	118,75								
uM39	121,25								
uM40	123,75								
uM41	126,25								
uM42	129,5								
uM43	128,75								
uM44	131,25								
uM45	133,75								

uM46	135,5			1					
uM47	136,75								
uM48	142,75								
uM49	141,25								
uM50	143,75								
uM51	146,25								
uM52	148,75								
uM53	151,25								
uM54	153,75								
uM55	156,25								
uM56	158,75								
uM57	160								
uM58	163,75								
uM59	166,25								
uM60	168,75								
uM61	171,25								
uM62	173,75								
uM63	176,25								
uM64	178,75								
uM65	181,25								
uM66	183,75								
uM67	186,25								
uM68	188,75								
uM69	191,25								
uM70	193,25								
uM71	195,5								
uM72	198,5								
uM73	211,25								
uM74	213,75								
uM75	216,25								
uM76	218,75								
uM77	221,25								
uM78	223,75								
uM79	226,25								
uM80	228,75								
uM81	231,25								
uM82	233,75		1	2	3	4	1		
uM83	236,25								
uM84	238,75								
uM85	241,25					4		2	1
uM86	243,75								
uM87	246,25								
uM88	248,75								
uM89	251,25								
uM90	253,75								
uM91	256,25								
uM92	258,75								

uM93	261,25								
uM94	263,75					2		2	
uM95	268,75								
uM96	271,25								
uM97	273,75								
uM98	276,25								
uM99	278,75								
uM100	281,25								
uM101	283,75								
uM102	288,75								
uM103	287,75								
uM104	292,5								
uM105	297,5								