The Quaternary pollen of Ntsikeni Wetland, KwaZulu-Natal, South Africa

Ntsikeni Wetland, KwaZulu-Natal. Photograph by M.K. Bamford

Dissertation submitted to the Faculty of Science in fulfilment of the requirements for the degree Master of Science.

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DECLARATION

I hereby declare that this dissertation is my own, unaided work, except where otherwise acknowledged. It is being submitted for the degree of Master of Science at the University of the Witwatersrand, Johannesburg. I have not submitted this work previously, for the purpose of obtaining any degree, qualification or otherwise, at this or any other university.

26/10/2017

_________________________ Maria Combrink

_________________ Date

“It is an important and popular fact that things are not always what they seem. For instance, on the planet Earth, man had always assumed that he was more intelligent than dolphins because he had achieved so much – the wheel, New York, wars and so on – whilst all the dolphins ever had done was muck about in the water having a good time. But conversely, the dolphins had always believed that they were far more intelligent than man – for precisely the same reasons.”

- *Douglas Adams; The Hitchhiker's Guide to the Galaxy, p119*

ABSTRACT

Ntsikeni wetland, one of the highest altitude wetlands (~1795 m.asl) in South Africa, is a Ramsar site. Data from Ntsikeni Wetland will add to the spatial and temporal palaeoclimate data for southern Africa. The CONISS analysis separates the sequence into four primary zones of statistically significant similarity: WNT4: 25,000-13,000 cal. yr BP; WNT3: 13,100-10,800 cal. yr BP; WNT2: 9,000-4,300 cal. yr BP; WNT1: 4,200-650 cal. yr BP. From 22,000-21,000 cal. yr BP an increase in temperature and moisture is observed, followed by an increase in temperature and a decrease in moisture from 21,000-18,750 cal. yr BP. At 17,000 cal. yr BP a short but sudden drop in temperature and moisture is recorded. The final two changes in Zone WNT1 are short and definitive shifts to colder temperatures; the first at 15,000-14,800 cal.yr BP, the second 14,000-13,200 cal. yr BP; at 13500 cal. yr BP it is possibly the coldest period. The entire Zone WNT1 points to an increase in precipitation during colder periods. The wetland continued to contract until 11,000 cal. yr BP. A hiatus in pollen 9,000-10,700 cal. yr BP is observed, followed by an increase in moisture 8,800-8,200 cal. yr BP, and a warm period, with a contraction of the wetland from 7,000-5,050 cal. yr BP. A very brief wet and warmer period from 4,300-4,100 cal. yr BP is recorded, as the wetland starts to expand. Temperatures continue to increase, with a short localised drying period (100 years) and evaporation.

ACKNOWLEDGMENTS

"There is a moment in every dawn when light floats; there is the possibility of magic. Creation holds its breath"

- ***Douglas Adams; Life, the universe and everything else, p.41***

My thanks must go firstly to my loving and supportive spouse - always ready to indulge my whims – Teresa Visser, without your constant voice of reason I will not be the person I am today. Thank you for being you and accepting me to be me.

A great big thank you to my supervisor, Prof Bamford and my co-supervisor, Dr Fitchett – you are two remarkable mentors, advisors and scientists. I must thank Dr Fitchett for also embracing my nature and allowing spontaneous communications and very inconvenient times. Thank you, Dr Fitchett for your guidance not only in the laboratory but also when running the administrative gauntlet.

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AMS:	Accelerator Mass Spectrometer
CONISS:	Constrained Incremental Sum of Squares
DAC:	Drakensberg Alpine Centre
DCA:	Detrended Correspondence Analysis
ITCZ:	Inter Tropical Convergence Zone
LGM:	Last Glacial Maximum
LIA:	Little Ice Age
PC:	Principal Component
PCA:	Principal Components Analysis
SRZ:	Summer Rainfall Zone
WRZ:	Winter Rainfall Zone
YRZ:	Year round Rainfall Zone
INSULATION:	Incoming solar radiation
RAMSAR:	A Ramsar Site is a wetland designated of international importance under the Ramsar Convention, with the mission to conserve wetlands through local, national and international cooperation, towards sustainable development.

CHAPTER 1 INTRODUCTION

[1]

1.1 Background to pollen-based palaeoclimatic reconstruction

Southern African regional climate is predominantly influenced by three key factors; 1) Latitude, 2) Coastal-continental location and 3) Altitude (Tyson and Preston-Whyte, 1972a; Carr *et al.,* 2006; Chase and Meadows, 2007). Latitude influences temperature with warmer climates toward the equator and colder climates toward the poles, coastal-continental location climate is influenced by the distance from an ocean as coastal locations will have lower variations in annual temperatures and greater humidity and precipitation than location further in-land, and finally the higher altitude locations will have cooler temperatures than locations closer to sea level due to environmental lapse rate (Tyson and Preston-Whyte, 1972b; Carr *et al.,* 2006; Chase and Meadows, 2007).

Over the past two million years there are immense environmental changes that have shaped and affected landscapes and life (Truc *et al.,* 2013; Metwally *et al.,* 2014; Neumann *et al.,* 2014). The Quaternary has been a period of ice sheets (Mills *et al.,* 2012), mountain ice caps (Elenga *et al.,* 2000), and lasting glacial stages (Holmgren *et al.,* 2003), interspersed with interglacial (Norström *et al.,* 2009), or warmer periods, of short duration. During this tumultuous time the global circulation patterns changed (Mills *et al.,* 2012; Truc *et al.,* 2013), which in turn changed the oceanic currents and this shifted the precipitation patterns (Holmgren *et al.,* 2003). Due to the change in temperature and precipitation rates (Neumann *et al.,* 2010; Neumann and Bamford, 2015), rates of weathering and erosion also changed and river regimes fluctuated (Norström *et al.,* 2009).

Since the global period of warming started after the Last Glacial Maximum (LGM), almost all components of the climate system underwent large-scale change (Clark *et al.,* 2012). In the Southern Hemisphere the most recognised climatic events since the LGM are: the African Humid Period (Chase *et al.,* 2009; Burrough and Thomas, 2013), the Younger Dryas (Peteet, 1995; Abell and Plug, 2000; Holmgren *et al.,* 2003; Thackeray and Scott, 2006; Truc *et al.,* 2013), the 8.2kyr (Smith *et al.,* 2002) event and the Little Ice Age (Matthes, 1939; Eddy, 1976; Herbert, 1987; Grove, 1988; Brook *et al.,* 1999; Tyson *et al.,* 2000; Holmgren *et al.,* 2003).

When using different proxies from archives, there is the assumption that processes and associations between modern environmental factors and ecological dynamics and palaeoenvironmental factors and palaeoecological dynamics are the same (Meadows, 2012). The assumption is that current processes function the same way that processes have functioned throughout geological time, as made popular by*Principles of Geology* (Lyell, 1830), or the present is the key to the past. Processes that happen today happen by the same natural principles that it has happened before (Meadows, 2012). Due to the dimension of geological time for idea of uniformitarianism (Lyell, 1830), Webb *et al.* (1993) offer a revised version of uniformitarianism to indicate that the past is *a* key to understanding the present, but not necessarily the *only* key. This revised version was further adapted by Roberts (2014) to included specific assumptions in the field of palaeoecology. The assumptions that must be met are:

1. An understanding of governing environmental factors of plant and animal distribution
2. Ecological affinities have not changed
3. Distributions (present and past) are in equilibrium
4. Modern analogues exist
5. The taphonomy of a fossil assemblage can be recognised
6. The assemblage is not biased due to contamination or variance in preservation
7. Fossils can be identified to a reasonable level of taxonomic resolution

[After Roberts, 2014 p32]

Palaeoenvironments and palaeoclimate, environmental proxies in archives including pollen (Van Zinderen Bakker and Butzer, 1973; Van Zinderen Bakker and Coetzee, 1988; Elenga *et al.,* 2000), diatoms (Grab *et al.,* 2005; Finné *et al.,* 2010; Fitchett *et al.,* 2016a), phytoliths (Scott, 2002; Finné *et al.,* 2010), speleothem isotopes (Scott, 2002; Holmgren *et al.,* 2003), charcoal (Chazan *et al.,* 2012), and sediment lithologies (Neumann *et al.,* 2010; Norström *et al.,* 2014); can be used to interpret long-term vegetation changes (Scott *et al.,* 2008) and the climatic drivers responsible (Scott *et al.,* 2012; Truc *et al.,* 2013). The changes and drivers can then be modelled using numerical methods (Truc *et al.,* 2013). By examining the changes during the Quaternary, the anthropogenic changes in vegetation can also be accounted for (Neumann *et al.,* 2008, 2010, 2014), such as the occurrence of pines due to European settler activity rather than climate change (Neumann *et al.,* 2014). Some proxies have more limiting factors than others and will only be useful in very specific conditions, for example phytoliths are mainly only suited for grasslands (Finné *et al.,* 2010), diatoms are aquatic and therefore only present in sediment from previous aquatic environments (Finné *et al.,* 2010; Fitchett *et al.,* 2016a) and speleothems are only available in caverns and caves (Holmgren *et al.,* 2003; Scott *et al.,* 2008).

Pollen is a very abundant palaeoenvironmental proxy as pollen grains are produced in great quantity by plants and distributed effectively by wind and animal vectors (Faegri *et al.,* 1989). Pollen grains are composed of cellulose and sporopollenin which are highly resistant organic compounds, this in conjunction with their small size make pollen grains remarkably resistant to morphological pressure changes due to burial (Faegri *et al.,* 1989). Due to the influence of wind as the primary vector, pollen therefore can reflect the local and regional vegetation (Scott *et al.,* 2012). Wetland areas are considered great palynological archives (Norström *et al.,* 2009) as pollen does not preserve well in dry oxidising conditions (Quick *et al.,* 2011) but preserve better in wetter climates (Finch and Hill, 2008; Neumann *et al.,* 2010; Scott *et al.,* 2012; Fitchett *et al.,* 2016a). Pollen is a well suited proxy for the reconstruction of wetland palaeoenvironments as it reflects the entire vegetation spectrum, rather than the more narrow representation of phytoliths or diatoms.

The palaeoclimates and palaeoenvironments of the Northern Hemisphere are documented much more in depth than the Southern Hemisphere. Southern Africa lacks in palaeoenvironmental data (Scott *et al.,* 2012; Neumann *et al.,* 2014), both spatially and temporally.

1.2 Contribution to Knowledge and Aims

1.2.1 Study Site

Ntsikeni wetland (Figure 1), one of the highest altitude wetlands, ~1795 meters above sea level (m.asl), in South Africa, was declared a Ramsar site on 2 February 2010, and is a wetland of natural origin (Kotze, 2003), and the pollen record has not been investigated previously. Data from Ntsikeni Wetland will add to transect of wetlands, north-west to south-east, that currently includes environmental reconstructions from Florisbad (Scott and Nyakale, 2002), Mafadi (Fitchett *et al.,* 2016a), Sekhokong (Fitchett *et al.,* 2016b) and Mahwaqa (Neumann *et al.,* 2014). This will assist in further determining the change in climate between the highly diverse bioregions in South Africa that currently cannot be sufficiently modelled due to the lack of spatial and temporal data (Scott *et al.,* 2012; Neumann *et al.,* 2014).

The western part of the country is in the winter rainfall zone (WRZ), with 66% of the precipitation from April to September, due to the frontal systems associated with Westerlies (Mills *et al.*, 2012; Fitchett and Bamford, 2017), and the eastern part in the summer rainfall zone (SRZ) with 80% of precipitation occurring from

October to April due to seasonal movement of high pressure cells (Mills *et al.,* 2012). There is a very narrow zone, part of the Eastern Cape Province, extending into Karoo and eastern parts of the Western Cape, which receive precipitation all year round (YRZ) (Mills *et al.*, 2012).

The Great Escarpment of southern Africa is the major moisture dispersal control across south-eastern Africa, as it blocks the inflow of moisture rich air from the Indian Ocean to the western interior (Mills *et al.*, 2012) .

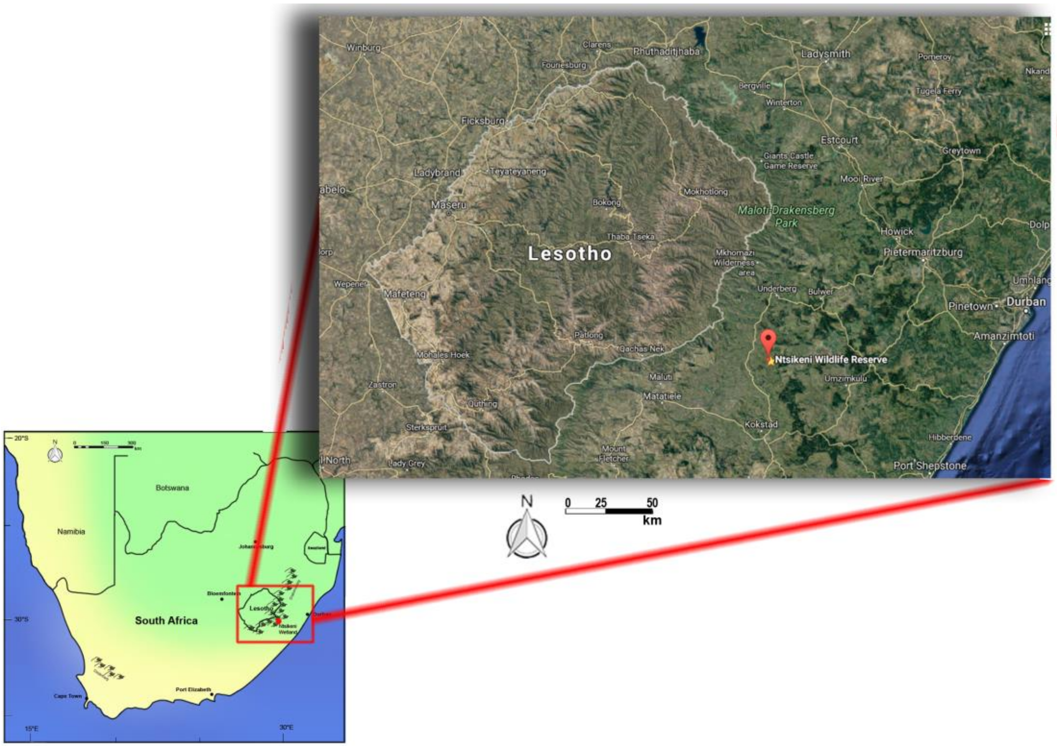


Figure 1: Locality map of Ntsikeni Wetland. After Google Maps.

Ntsikeni Wetland is situated in a summer rainfall zone (SRZ), has an annual precipitation of 1150mm, with occasional snow in winter (Kotze, 2003; Mills *et al.,* 2012). During 2002 an average daily maximum temperature of 21.5°C and an average daily minimum of 7.5°C were recorded in the area by Kotze (2003), which is typical for the Drakensberg region of KwaZulu-Natal.

According to Mucina and Rutherford (2006), Ntsikeni falls within the Drakensberg Foothill Moist Grassland, which is listed as least threatened and only has a national conservation target of 23%; however, the Ntsikeni wetland is relatively undisturbed. Current vegetation (Kotze, 2003) plant species lists (Appendix A), which include, but is not limited to some of the following species; *Carex*, *Cyperus*, *Erica, Kniphofia, Rununculus, Helichrysum* and *Crassula.* The aforementioned species are wetland species found in the Ntsikeni wetland and not only in the greater Ntiskeni Vlei. There are currently at least ten plant species listed as threatened that occur within the great Ntsikeni Nature Reserve (Scott-Shaw, 1999). According to Kotze (2003), the wetland provides a breeding site for two or three pairs of Wattled Crane. Burger (1996) recorded 5 species of amphibia and there is a likelihood that the threatened Long-toed tree frog (*Leptopelis xenodactylis*) may reside here as it is a suitable habitat. There are hummocked sedge meadow areas, normally associated with high altitude wetlands (Kotze and O'Connor, 2000).

The wetland is one of the largest at high altitude (>1700m.asl) that is still relatively undisturbed. Ntsikeni Vlei assists with streamflow regulation functions (Kotze, 2003). Furthermore it is entirely surrounded by a nature reserve with little or no alteration to its hydrological and ecological character (Kotze, 2003).

The Ntsikeni Vlei is situated high in the Mzimkhulu catchment, with little or no human activity upstream of the wetland, which gives it high water purification value (Kotze, 2003). With regards to water storage and streamflow, this catchment area drains 2.7% of South Africa's annual runoff (Basson, 1997).

1.2.2 Aims of the study

As previously mentioned, there is a shortfall of data when it comes to the palaeoclimate of the Southern Hemisphere, and specifically in South Africa. This study will add to the body of knowledge with the creation of a high resolution palaeoenvironmental record of Ntsikeni Wetland. The data is obtained from a sediment core that was extracted from Ntsikeni Wetland, then subsampled for pollen, and temporally constrained by Accelerator Mass Spectrometer (AMS) radiocarbon dating. Findings from this study will be compared to the existing records from wetland sites in close proximity, such as Mahwaqa Mountain (Neumann *et al.,* 2014) and Sekhokong (Fitchett *et al.,* 2016b); as well as to other sites that will assist with clarification of palaeoclimate fluctuations between sites orographically separate, such as Florisbad (Scott and Nyakale, 2012) and Tswaing Crater (Metwally *et al.,* 2014; Scott. 2016).

The specific objectives of this study are:

1. To determine the species composition based on fossil pollen to infer shifts in vegetation
2. To constrain the changes temporally through AMS dating of samples

3. To apply appropriate statistical methods to the pollen data in order to reconstruct the vegetation history of the site
4. To infer changes in the past environment
5. Investigate possible driver for inferred changes

1.3 Structure of the dissertation

The introductory chapter (*Chapter 1*) gives a brief overview of the different environmental proxies, as well as the aims and objectives of the study. This is followed by the L*iterature Review Chapter* (*Chapter2*) that scrutinises the development of palynological work in South Africa, as well as the emergence of multi proxy work. This is followed by brief highlights of palaeoclimatic events since the LGM.

The *Study Site Chapter* (*Chapter 3*) will give an overview of the regional setting, local geology, climate and vegetation of Ntsikeni Wetland. The *Materials and Methods Chapter* (*Chapter 4*) gives a detailed description of the methods used to perform the detailed palaeoenvironmental reconstruction. This includes the laboratory procedures to isolate the pollen grains, ASM dating, microscopy and statistical analyses performed on the data.

The R*esults Chapter* (*Chapter 5*) follows and offers the stratigraphic changes in pollen temporally constrained, as well as data derived from pollen counts. The *Environmental Reconstruction Chapter* (*Chapter 6*) takes the data presented in the results chapter and display and discusses the changes in vegetation within the wetland over the temporally constrained time period.

The *Discussion Chapter* (*Chapter 7*) compares this study to other study sites in close proximity and investigates possible drivers for the changes observed. This chapter also includes the limitations of this study as well as the scope for future studies.

The *Conclusion* (*Chapter 8*) will reveal the key findings of this study, as well as the extent to which the objectives were achieved.

CHAPTER 2 LITERATURE REVIEW

[2]

2.1 INTRODUCTION

Due to the geographical location of South Africa, it spans the temperate, subtropical and tropical belts (Preston-Whyte and Tyson, 1973; Tyson, *et al*., 1975; Carr *et al.*, 2006), which along with the oceanographic, topographic and latitudinal influences result in distinct rainfall zones and seasonality (Fitchett and Bamford, 2017). Due to the convergence of the Indian and Atlantic oceans and the associated warm and cold ocean currents respectively there is a longitudinal gradational effect – arid environments in the west of southern Africa to more humid environments in the east (Preston-Whyte and Tyson, 1973; Tyson, *et al*., 1975; Carr *et al.,* 2006; Chase and Meadows 2007).

Historically the past climates and environments of the Northern Hemisphere are documented at a greater resolution, while the Southern Hemisphere, more specifically South Africa, has great dearth in palaeoenvironmental data (Scott *et al.,* 2012; Neumann *et al.,* 2014; Meadows and Finch, 2016). This is especially challenging as modelling of the regional vegetation and climatic variability is difficult due to the sparsity of data. Highly diverse bioregions have likely undergone palaeoenvironmental shifts, but cannot be sufficiently modelled due to the lack of spatial and temporal data (Scott *et al.,* 2012; Neumann *et al.,* 2014).

Traditionally, the focus of palaeoenvironmental data has been on variability within datasets, but with little focus on the drivers of the variability (Fitchett, 2015). Many of the historic papers will therefore mention both temporal and spatial changes, in relation to other site within South Africa, but never considering the climatic drivers responsible for the similarity and differences between sites (Fitchett *et al*., 2017).

In this chapter the present literature on palaeoenvironmental change in southern Africa will be scrutinised. This chapter will be structured as follows; firstly the literature on different proxies that can be used to infer palaeoenvironmental information, then a summary, in table form, of the major contributors, highlighted proxies, study sites and climatic shifts.

The second part of the literature review will focus on previous work pertaining to South African palaeoenvironments and climate reconstructions, with pollen as the proxy for the study, with key findings in a chronological layout. Ntsikeni Wetland will form part of a transect of sites (Southeast to Northwest across the Drakensberg Mountain range and escarpment). The literature reviewed focus on either pollen, or are located in the area close to Ntsikeni Wetland. Lastly the focus will be on the Anthropocene in the South African context.

2.2 Southern African palaeoenvironmental work

The pioneering studies (Van Zinderen Bakker, 1955; cf. Coetzee, 1967; Martin, 1959, 1968; Scott, 1982) were not only limited by the want of accurate dating techniques but also by the absence of comparative pollen reference collection for the diverse flora of South Africa. Even though great advances have been made on precision dating and access to pollen collections, data is still lacking due to geographical and floristic diversity of the area (Neumann *et al.*, 2008; Fitchett *et al.*, 2017).

In terms of palynological studies South Africa has a very discontinuous record, as few well preserved polleniferous records exist (Scott 1982, 1987; Scott *et al.,* 2008; Neumann *et al.,* 2014). As the pollen record is spatially and temporally discontinuous other proxies are needed in environmental reconstruction studies (Scott 1982, 1987; Scott *et al.,* 2008; Neumann *et al.,* 2014). The difference in proxies used at different sites (Table 1) make comparison problematic. Literature pertaining to southern Africa was reviewed; the focus then shifted to palaeoenvironmental sites in South Africa, and finally the sites that are geographically close to Ntsikeni Wetland. Literature was examined and discussed based on proxies, location of the site, the geological time period spanned, as well as the inferred vegetation and environment. The information was used to compile Table 1.

Current pollen records are temporally discontinuous due to the poor preservation rate in the arid areas of South Africa (Scott and Bousman, 1990). The low concentration of fossil proxies do not allow for statistically significant analyses (Van Zinderen Bakker, 1955; Neumann *et al.*, 2008; Fitchett, 2015).

Palaeoenvironmental studies based on pollen and/or diatoms as proxies have been restricted to the humid areas, wetlands and springs in South Africa.

To study palaeoenvironments and palaeoclimates, different proxies such as pollen (Van Zinderen Bakker and Butzer, 1973; Van Zinderen Bakker and Coetzee, 1988; Elenga *et al.,* 2000; Finch and Hill, 2008; Quick *et al.,* 2011; Neumann *et al.,* 2014), diatoms (Grab *et al.,* 2005; Finné *et al.,* 2010; Fitchett *et al.,* 2016a, 2016b), phytoliths (Scott, 2002; Finné *et al.,* 2010), speleothem isotopes (Scott, 2002; Holmgren *et al.,* 2003), charcoal (Chazan *et al.,* 2012) and sedimentology and geomorphology (Neumann *et al.,* 2010; Norström *et al.,* 2014; Fitchett *et al.,* 2016a,b) can be used to interpret long-term vegetation changes (Scott *et al.,*, 2008) and the climatic drivers behind it (Scott *et al.,* 2012; Truc *et al.,* 2013). The changes and drivers can then be modelled using numerical methods (Truc *et al.,* 2013). By examining the changes during the Quaternary the anthropogenic changes in vegetation can also be accounted for (Neumann *et al.,* 2008, 2010, 2014), such as the occurrence of pines due to European settler activity rather than climate change (Neumann *et al.,* 2014). Some proxies have more limiting factors than others and will only be useful in very specific conditions, for example phytoliths are predominantly valuable for grasslands, diatoms are aquatic and therefore only present in sediment from previous aquatic environments (Finné *et al.,* 2010) and speleothems are only available in caverns and caves (Holmgren *et al.,* 2003; Scott *et al.,* 2008).

Table 1: Summary of literature reviewed.

Author/s	Year	Title	Time	Site	Proxies	Environment	Notes
Elenga, *et al.*	2000	Pollen-based biome reconstruction for Southern Europe and Africa 18,000 yr BP	Holocene	Numerous Southern Europe and Africa	Pollen	Vegetation reconstruction based on different studies	Decrease of rainforests, lowering of vegetation zones in mountainous areas, temperature shift between -8°C and -4°C, lower precipitation
Finch and Hill	2008	A late Quaternary pollen sequence from Mfabeni Peatland, South Africa: Reconstructing forest history in Maputaland.	Quaternary	Mfabeni Peatland, Maputaland	Pollen	44 000 cal yr BP cool and wet, 33 000 cal yr BP warm, wet local conditions 24 000 cal yr BP cool, dry might indicate onset of LGM cooler, drier towards end of Pleistocene	*Podocarpus* retreat to swampy expansion (Cyperaceae), to Poaceae grass, back to forest in early Holocene, Mid-Holocene back to drier grassland

							and burning
Finné *et al.*	2010	Siliceous microfossils late-Quaternary paleoenviron-mental indicators at Braamhoek wetland.	Quaternary	Braamhoek	Phytolith, diatom	13 600 - 10 400cal yr BP dry with one wet event 11300 cal yr BP, Wet from 10 400 - 10 000 cal yr BP, dry 8 000 - 2000 cal yr BP, wet 1 500 cal yr BP until present	
Fitchett *et al,*	2016c	Holocene climatic variability indicated by a multi-proxy record from southern Africa's highest wetland	Holocene	Mafadi Wetland	Pollen, diatom	Five zones; Fluctuations wet/dry throughout mid- to late-Holocene. Wet periods - ~8140 – 7580 cal. yr BP and ~5600 – 1100 cal. yr BP ., dry periods ~7520 – 6680 cal. yr BP , ~6160 – 5700 cal. yr BP and from ~1000 cal. yr BP , cold period at ~8140 cal. yr BP	High altitude wetland, close proximity to Ntsikeni Cold based on diatoms
Fitchett *et al.*	2016a	A multi-proxy analysis of late Quaternary palaeoenvironments, Sekhokong Range, eastern Lesotho	Late Pleistocene	alpine wetland located in the Sekhokong Mountain Range, Lesotho	Sedimentary characteristics, fossil pollen and diatoms	wet period from ~16 450 -14 440cal a BP, interrupted by dry conditions from ~16 350 - 15 870 cal a BP, drier ~14150-8560 cal a BP, warmer, dry conditions are inferred for ~8560–7430 cal a BP, followed by cold, wet conditions from ~7280-6560 cal a BP. A dry, warmer period ~6560-3640 cal a BP, followed by cool, wet conditions from ~3400-1200 cal a BP, from ~1110 cal a BP	

						– the present is characterized by progressive drying	
Grab *et al.*	2005	Holocene palaeoenvironments inferred from a sedimentary sequence in the Tsoaing River Basin, western Lesotho.	Holocene	Tsoaing River Basin, western Lesotho	Sediment, Pollen, phytoliths	12 200 - 9 000 cal yr BP wet, Dry 8600 - 8450 cal yr BP, wet events 7 000 mid-Holocene Altithermal and 4 500 cal yr BP	Warmer based on archaeological, Podocarpus, Olea. Colder based on geomorphological as pollen not preserved
Holmgren *et al.*	2003	Persistent millennial-scale climatic 300 variability over the past 25,000 years in Southern Africa.	Late Pleistocene and Holocene	Makapansgat Valley, South Africa	Speleothems, Stalagmite, Isotopes, groundwater	Little Ice Age 1300 - 1800 AD,13 000 cal yr BP wet, 8500 cal yr BP cool, 7 500 - 6500 cal yr BP warming	Increase of 5.7°C from terminal Pleistocene to Holocene
Metwally *et al.*	2014	Holocene palynology and palaeoenvironments in the Savanna Biome at Tswaing Crater, central South Africa.	Holocene	Tswaing Crater	Pollen, charcoal, alkanes	9400 - 7200 Dry, driest 7800 cal yr BP, 7000 - 6600 increase in moisture 6700 cal yr BP highest temp, 4900 - 3750 fluctuating moisture, 3750 dry event, until 1800 cal yr BP fluctuating moisture	
Neumann and Bamford	2015	A Shaping of modern	Neogene	numerous	Pollen, wood,		Vegetation history

		southern African biomes: Neogene vegetation and climate changes.		South Africa	charcoal, leaves, biomarkers		of biomes
Neumann *et al.*	2014	18,000 years of grassland evolution in the summer rainfall region of South Africa: evidence from Mahwaqa Mountain, KwaZulu-Natal.	Quaternary	Mahwaqa Mountain, KwaZulu-Natal	Pollen	1800 - 13500 cal yr BP cool then progressively warming 7500 cal yr BP warmest then cooling until 4600 cal yr BP, fluctuations in moisture driest 4600 - 3500, 3500 - 800 cal yr BP increased moisture, 1 000 cal yr BP wettest	Grassland/ wetland
Neumann *et al.*	2010	A Holocene sequence of vegetation change at Lake Eteza, coastal KwaZulu-Natal, South Africa.	Holocene	Lake Eteza, KwaZulu-Natal	Pollen, sediment molluscs, diatoms	10200 - 6800 cal yr BP from wetter woodland to drier grass, coolest 8200, 6800 - 3600 cal yr BP increased precipitation, high sedimentation rate 6500 and 4000 cal yr BP, dry 3600 - 2500 cal yr BP, 700 cal yr BP dramatic vegetation changes to grass (anthropogenic ?)	
Neumann *et al.*	2008	Holocene vegetation and climate records from Lake Sibaya, KwaZulu-Natal (South Africa).	Holocene	Lake Sibaya, KwaZulu-Natal	Pollen, brief lithological reference	10200 - 6800 cal yr BP from wetter woodland to drier grass, coolest 8200, 6800 - 3600 cal yr BP increased precipitation, high sedimentation rate	

						6500 and 4000 cal yr BP, dry 3600 - 2500 cal yr BP, 700 cal yr BP dramatic vegetation changes to grass (anthropogenic)	
Norström *et al.*	2009	Reconstruction of environmental and climate changes at Braamhoek wetland, eastern escarpment South Africa, during the last 16 000 years with emphasis on the Pleistocene-Holocene transition.	Pleistocene/Holocene	Braamhoek	Pollen, Charcoal, isotopes	16 000 - 13 700 cal yr BP drier, 13 700 - 12 800 cal yr BP wetter, 12 800 - 10 500 cal yr BP dry, 10 500 - 9500 cal yr BP wet, 9500 - 8200 cal yr BP dry, 1500 - present wet	
Norström *et al.*	2014	Late Quaternary vegetation dynamics and hydro-climate in the Drakensberg, South Africa.	Quaternary	Braamhoek	Charcoal, pollen biomarkers, mineral magnetic properties	Increased wetness 13 800 - 12 00 cal yr BP and 10 200 - 8500 cal yr BP, one wet during Holocene 2000 cal yr BP until present. Drier conditions during Younger Dryas 12 600 - 11 300 cal yr BP, mid-Holocene, 7000 - 2000 cal yr BP, warmer temperatures from 8500 cal yr BP as fynbos declines	

Quick *et al.*	2011	A 19.5 kyr vegetation history from the central Cederberg Mountains, South Africa: Palynological evidence from rock hyrax middens.	Quaternary	De Rif, Cederberg Mountains, South Africa	Pollen, stable isotopes (hyrax middens)	fynbos vegetation throughout last 20 000 cal yr BP, decreased moisture 16 800, 13 000 and 11 500 cal yr BP.	Isotopes show changes, vegetation not change only relative proportions of fynbos
Roberts *et al.*	2013	Miocene fluvial systems and palynofloras at the southwestern tip of Africa: Implications for regional and global fluctuations in climate and ecosystems.	Miocene	Rondeberg clay pit, Cape Town	Pollen, Lignified wood, Biogeochemistry. palaeomagnetics		Depositional models (3) linked to biogeographics
Rosen *et al.*	1999	Palaeoclimatic and archaeological implications of organic-rich sediments at Tiffindell Ski Resort, near Rhodes, Eastern Cape Province, South	Holocene	Tiffindell Ski Resort Eastern Cape	Pollen, sediment	Fluctuating moisture, lower temperatures, not greatly varied	

		Africa.					
Scott	1993	Palynological evidence for late Quaternary warming episodes in Southern Africa.	Quaternary	numerous South Africa	Pollen	North of 28S, 7000 - 6500 yr BP, highest temps, South of 28 S difficult lack of record,	Difficult to preserve pollen in dry climates, development of SRZ, WRZ
Scott	2002	Grassland development under glacial and interglacial conditions in southern Africa: a review of pollen, phytolith and isotope evidence.	Quaternary	numerous South Africa	Pollen, Phytolith, isotope		ratio of Asteraceae to Poaceae pollen = strength of precipitation, more Poaceae, less precipitation
Scott *et al.*	2008	Reconciliation of vegetation and climatic interpretations of pollen and other regional records from the last 60 thousand years in the Savanna Biome of Southern Africa.	Pleistocene/Holocene	Tswaing Crater, Wonderkrater, Lobatse Cave (Botswana).	Pollen, sediment, isotopes in speleothem		Different proxies from different sites can overlap to confirm climate data.
Scott *et al.*	2012	Terrestrial fossil-pollen	Quaternary	numerous	Pollen	Coldest 24 000 cal yr BP, 17 000 cal yr	General trends and

		evidence of climate change during the last 26 thousand years in Southern Africa.	(Holocene)	South Africa		BP	discussion
Scott and Nyakale	2002	Pollen indications of Holocene palaeoenvironments at Florisbad spring in the central Free State, South Africa.	Holocene	Florisbad	Pollen	Number of moisture fluctuations, 6500 BP arid, moving to more moisture at 6300 BP and 4420 BP, dry episode 5500 - 4500 BP. After 4420 BP moisture gradually fluctuate until 2100 - 1700 BP (seasonality?) then strong evaporation	
Truc *et al.*	2013	Quantification of climate change for the last 20,000 years from Wonderkrater, South Africa: Implications for the long-term dynamics of the Intertropical Convergence Zone.	Holocene	Wonderkrater	Pollen, Speleothems	Great explanation - will summarise and fill in	Indicator species selection very important,
Van Zinderen Bakker and Butzer	1973	Quaternary environmental changes in southern Africa.	Quaternary	numerous South Africa	Pollen		

Van Zinderen Bakker and Coetzee	1988	A review of late Quaternary pollen studies in east, central and southern Africa.	Quaternary	Numerous, East, Central and southern Africa	Pollen	Warmer more humid period, 32 000 - 28 000 yr BP, 28 000 - 20 000 yr BP southern Africa colder episodes, higher precipitation in East Africa and Kalahari. LGM from 20 000 to 16 000 - 14 000 yr BP aridity over the entire region. Abrupt warmer and more humid conditions in East Africa from 12 000 yr BP. Great climate fluctuations during this period in South Africa, Holocene humid conditions continued in East Africa until 4 000 yr BP then started drying.	

Pollen is a very abundant palaeoenvironmental proxy as they are produced in great quantity by plants and distributed effectively by wind and animal vectors (Faegri *et al*., 1989). Pollen grains are composed of cellulose and sporopollenin which are highly chemically resistant organic compounds, this in conjunction with their small size make pollen grains remarkably resistant to morphological pressure changes due to burial (Faegri *et al.,* 1989). Due to the influence of wind as the primary vector, pollen therefore can reflect the local and regional vegetation (Scott *et al.,* 2012). Wetland areas are considered great palynological archives (Norström *et al.,* 2009) as pollen does not preserve well in dry oxidising conditions (Quick *et al.,* 2011) but preserve better in wetter climates (Finch and Hill, 2008; Neumann *et al.,* 2010; Scott *et al.,* 2012); initial pollen analysis work commenced upon Van Zinderen Bakker's arrival in South Africa. The initial site for pollen analysis was the eastern Lesotho highlands (Van Zinderen Bakker, 1955), followed by a pollen analysis of Florisbad (van Zinderen Bakker, 1957).

Due to the low preservation potential in South Africa's arid regions most studies focus on areas with greater preservation potential such as the eastern areas of South Africa (Van Zinderen Bakker 1955). As pollen has been used as a proxy in southern African palaeoenvironmental reconstructions since 1955 (Van Zinderen Bakker, 1955), there are numerous studies including all of the major shifts in palaeoenvironments – chronologically as well as longitudinally.

One of the first were by Van Zinderen Bakker and Butzer (1973) that investigated Quaternary environmental change in southern Africa, followed by climate change since the LGM (Scott, 1989; Neumann *et al.,* 2014; Fitchett *et al.,* 2016b), and then late Quaternary warming (Scott, 1993). There are also papers that focus only on the development and palaeoenvironmental history of specific biomes such as grassland development (Scott, 2002; Neumann *et al.*, 2014). Due to the historic focus of palaeoenvironmental investigation with pollen as a the only proxy a number of authors rely on previously published data such as Scott *et al.* (1995) with an analyses of the Pleistocene-Holocene transition in southern Africa and the past climates of the winter-rainfall region of the western Cape (Chase and Meadows, 2007).

As sampling, dating, and statistical tools improved, historic sites have been revisited or re-analysed (Thackeray and Scott, 2006). The three sites in the interior of South Africa are Florisbad, Wonderkrater and Tswaing Crater, and Braamhoek (Figure 2).

Florisbad is the first site that Van Zinderen Bakker investigated pollen for the purpose of reconstructing past climates (van Zinderen Bakker, 1957). During the first analysis of the site, Van Zinderen Bakker (1957) used sediment samples exposed from previous archaeological work; later new samples from newly exposed sediment were obtained (Van Zinderen Bakker, 1989, 1995).

Figure 2: Study sites reviewed in southern Africa.

Van Zinderen Bakker compared the earlier results with the newly obtained results and produced different records to highlight the methodology of sampling. Scott and Nyakale (2002) investigated the Holocene records of Florisbad, and Scott and Rossouw (2005) based a reconstruction on pollen as well as phytoliths.

Wonderkrater has also received a lot of attention, with the first investigation of the pollen record by Scott and Vogel (1978), followed by Scott (1982). Scott and Thackeray (1987) presented a statistically constrained analysis detailed analysis, then Scott *et al.* (2003) reported re-investigated age interpretations; this lead to renewed interest in the site as Scott and Thackeray collaborated again in 2006 to investigate the presence of the Younger Dryas. Truc *et al.* (2013) related the contemporary vegetation to the pollen record and Backwell *et al.* (2014) undertook a multi-proxy (pollen, charcoal, phytolith) investigation.

The third site, located in the interior of South Africa, is Tswaing Crater. Partridge *et al.* (1993) first investigated the pollen record, followed by very detailed analysis by Scott (1996) as he compared the Tswaing to Wonderkrater sites (Scott, 2016) using charred particle data as well as pollen data (Scott, 2002). Metwally *et al.* (2014) utilised pollen as well as charred particles to look at the Holocene portion of the sediment profile. Braamhoek wetland, located at 1700m.asl in the eastern part of the Free State, was investigated by Norström *et al.* (2009) utilising pollen, charcoal and stable isotopes as proxies, and again Finné *et al.* (2010) with phytoliths and diatoms as proxies. The two studies indicated some major environmental changes correlated, however the period between the late and middle Holocene raised more questions as proxies between the studies contradicted one another.

There are numerous sites in KwaZulu-Natal, where work is less than a decade old, such as Mfabeni peatland (Finch and Hill, 2008), Lake Sibaya (Neumann *et al.,* 2008) and Lake Eteza (Neuman *et al.*, 2010).

Neumann *et al.* (2014) completed a palaeoenvironmental reconstruction for South Africa based on pollen in the Mahwaqa Mountain, which is inland from the previously mentioned KwaZulu-Natal sites. The study investigates the dynamics of the development of grassland over the past 18,000 years utilising pollen and charcoal (Neumann *et al.*, 2014). Numerous vegetation changes are noted throughout the late Pleistocene and Holocene, with the occurrence of fynbos in the late Pleistocene outside current geographic fynbos biomes (Neumann *et al.*, 2014). The study also compares Mahwaqa to well-known sequences – Braamhoek (Norström *et al.*, 2009; Finné *et al.,* 2010), Florisbad (van Zinderen Bakker, 1957; Scott and Nyakale, 2002; Scott and Rossouw, 2005) , Craigrossie (Scott, 1986) – which will be deliberated more in depth in *Chapter 8 – Discussion*.

As stated previously, historical work focussed on the eastern region of southern Africa, due to the better pollen preservation; however since the use of hyrax middens to extract pollen the western, more arid regions are more represented (Scott *et al.,* 2004; Chase *et al.*, 2012; Meadows, 2014) and Verlorenvlei (Baxter and Meadows, 1994, 1999; Meadows *et al.* 1994, 1996).

2.3 Southern African palaeoenvironmental change

Over the past two million years, a tumultuous time, the global circulation patterns changed (Mills *et al.,* 2012; Truc *et al.,* 2013), which in turn changed the oceanic currents and this shifted the precipitation patterns (Holmgren *et al.,* 2003). Due to the change in temperature and precipitation rates (Neumann *et* *al.,* 2010; Neumann and Bamford, 2015) rates of weathering and erosion also changed and river regimes fluctuated (Norström *et al.,* 2009). The highly diverse faunal and floral areas of southern Africa have undergone great climatic fluctuations (Holmgren *et al.,* 2003; Scott *et al.,* 2012) during the Quaternary, and the climatic drivers behind it were initially the main focus of the body of work such as the shift of the Westerlies (Mills *et al.,* 2012), fluctuations in temperature (Scott, 1993) and moisture (Neumann *et al.,* 2014), the extent of glaciation during the LGM (Scott, 2002), the Younger Dryas (Thackeray and Scott, 2006; Norström *et al.,* 2014) and the Holocene Thermal Maximum (Neumann *et al.,* 2010).

This section will focus on the key palaeoenvironmental changes in a southern African context, starting with shifts in rainfall zone, then changes in sea level, and finally a summary of changes in temperature, moisture and glaciation during the late Pleistocene and Holocene

2.3.1 Shifts in the South African Rainfall Zones

The western part of the country is in the WRZ, with more than two thirds of precipitation from April to September, due to the frontal systems associated with Westerlies (Mills *et al.,* 2012), and the eastern part in the SRZ with 80% of precipitation occurring from October to April due to seasonal movement of high pressure cells (Mills *et al.,* 2012). There is a very narrow zone from the Eastern Cape Province, extending into Karoo and eastern parts of the Western Cape, which receive precipitation all year round (Chase and Meadows 2007; Mills *et al.,* 2012). According to Chase and Meadows (2007) the southern region of South Africa's climatic and accompanying floristic changes are due to a shift in the position and strength of the westerly belt. The WRZ has a high floristic diversity, which includes endemic Fynbos species (Chase and Meadows, 2007). Van Zinderen Bakker (1976) and Chase and Meadows (2007) contend that the westerlies shift northward during periods of glaciation as the area of the Antarctic sea ice increases. A northward shift in the westerlies results in an increase in the WRZ area and a southward shift results in a dryer WRZ (Stager *et al.,* 2012).

Van Zinderen Bakker (1976) initially suggested that the WRZ and associated Fynbos flora extended much further north (~24°S) during the LGM, but in 1983 he conceded that even though the vegetation associated with the WRZ might not have extended this far north, the westerlies during the LGM were considerably more robust than current. Later studies indicate that the WRZ extended more east (Fitchett and Bamford, 2017) as well as in a northern direction (Chase and Meadows, 2007; Stager *et al.,* 2012; Fitchett *et al.,* 2016a). The shift in position of the westerlies does not only influence the WRZ, but also the intensity and frequency of mid-latitude cyclones. The mid-latitude cyclones had a great influence on Braamhoek Wetland c.13.6 ka, 11.3 ka and 10.4–10.0 k, which is normally connected to the northern shift of the westerly belt (Finné *et al.,* 2010; Norström *et al.,* 2014). According to Mills *et al.* (2012) there exists palaeogeomorphological evidence that high intensity mid-latitude cyclones were active in the Lesotho highlands during the late Pleistocene.

2.3.2 Changes in sea level

Historic work on sea level change at the coast of South Africa relied greatly on geomorphological markers, such as wave-cut platforms, coastal dune complexes and marine sediments (Ramsay, 1995; Strachan *et al.*, 2014). Ramsay and Cooper (2002) questioned the exactness of such markers and dates; then developed a sea level curve based on other proxies that are currently the most recognised. Other individual studies at various sites (Meadows *et al.,* 1996; Baxter and Meadows, 1999; Carr *et al.,* 2015; Strachan *et al*., 2015) appear to follow this curve. Sea level change does not have a direct influence on Ntsikeni Wetlands climate but may assist in identifying possible drivers of climate change, further investigated in the *Discussion Chapter* (*Chapter 8*).

2.3.3 Changes in temperature, moisture and glaciation during the Quaternary

Climate during the late Quaternary was anything but stable, and an ongoing debate between the Northern Hemisphere and Southern Hemisphere shifts exists (Holmgren *et al.,* 2003; Truc *et al.,* 2013) not only on whether both hemispheres experienced the same climatic events, but also the chronology and extent of these events (Table 2). A number of climatic events already confirmed in the Northern Hemisphere still remains largely unconfirmed in the Southern Hemisphere such as; the African Humid Period (Chase *et al.,* 2009; Burrough and

Thomas, 2013), the Younger Dryas (Peteet, 1995; Abell and Plug, 2000; Holmgren *et al.,* 2003; Thackeray and Scott, 2006; Truc *et al.,* 2013), the 8.2kyr (Smith *et al.,* 2002) event and the Little Ice Age (Matthes, 1939; Eddy, 1976; Herbert, 1987; Grove, 1988; Brook *et al.,* 1999; Tyson *et al.,* 2000; Holmgren *et al.,* 2003).

Mayewski *et al.* (2004) and Wanner *et al.* (2015) both refer to two separate cold events – 4.1kyr and 2.8kyr. The Younger Dryas remains a contentious point in the debate between the climate shifts of the Northern and Southern hemispheres. The Younger Dryas, 13,000-11,500 cal. yr BP, is a cooler period following the warming period post-LGM (Abell and Plug, 2000), with abundant evidence in the Northern Hemisphere (Alley, 2000; Wang *et al.,* 2006), various sites with different proxies in South Africa indicate changes in climate; however these changes appear to not have an effect on the vegetation (Scott *et al.,* 2005). When analysing proxies other than pollen; oxygen isotope (Cohen *et al.,* 1992) and stable carbon and nitrogen isotopes (Quick *et al.,* 2011); there appears to be colder sea temperatures during this period. Thackeray and Scott (2006) investigated the pollen record at Wonderkrater, with an improved chronology, to find pollen samples that are contemporaneous with the Northern Hemisphere Younger Dryas. The pollen record from Braamhoek also displays evidence of the Younger Dryas (Norström *et al.,* 2014). The evidence for the concurrent occurrence of the Younger Dryas in southern Africa is growing as the resolution of data increases, Chase *et al.* (2011) indicates that the climate conditions may have varied regionally and further increase in data resolution is still needed.

Table 2: Summary of Quaternary palaeoclimate

Name	Approximate Age	South African Climate conditions	References
Holocene Stage	11.5 ka to present		
Neoglacial	5ka-AD 900		Porter and Denton, 1967
Medieval Warming Period (MWP)	AD 800–1500		Lamb, 1965
Little Ice Age (LIA)	1500 – 1900 A.D (Northern Hemisphere) AD 1300-1800 (South Africa)	Climatic conditions unclear, WRZ wet, SRZ dry	Matthes, 1939; Herbert, 1987; Grove, 1988; Brook *et al.,* 1999; Tyson *et al.,* 2000; Holmgren *et al.,* 2003; Fitchett *et al.,* 2016b
Maunder Minimum	AD 1645-1719	Coldest period during LIA	Eddy, 1976
Hypsithermal	Early to mid-Holocene		Deevey and Flint, 1957; Davis, 1984

Altithermal	Mid-Holocene		Meltzer, 1999
African Humid Period	~14,800 – 5,500 cal. yr BP	More moist than preceding period	Chase *et al.,* 2009; Burrough and Thomas, 2013; deMenocal, 2004
Younger Dryas	~13,000-11,500 cal. yr BP	Cooler after LGM warming event, conditions varied regionally (wet vs dry)	Abell and Plug, 2000; Peteet, 1995; Holmgren *et al.,* 2003; Thackeray and Scott, 2006; Truc *et al.,* 2013
8.2 kyr Event			Smith *et al.,* 2002; Fitchett *et al.,* 2016b
4.1 kyr Cold Event		Cooler temperatures	Mayewski *et al.,* 2004; Wanner *et al*., 2015
2.8 kyr Cold Event		Cooler temperatures	Mayewski *et al.,* 2004; Wanner *et al*., 2015
Last Glacial Maximum (LGM)	Still debated – broadly 24,000-17,000 cal. yr BP	Glaciation	Metcalfe, 1993; Partridge *et al.,* 1999; Scott, 1982, 2012 1999; Boelhouwers and Meiklejohn, 2002; Holmgren *et al.,* 2003; Carr *et al.,* 2006; Chase and Meadows, 2007; Thackeray and Scott, 2007; Mills *et al.,* 2012; Norström *et al.,* 2014; Neumann *et al.,*

			2014
Heinrich-2 (H-2)	26,000-24,000 cal. yr BP		Hemming, 2004; Wang *et al.,* 2006;
Heinrich-1 (H-1)	17,500-16,500 cal. yr BP		Hemming, 2004; Wang *et al.,* 2006
Daansgaard Oeschger cycles (D-O)	25 events, every 1-2kyr	Abrupt warming, drier conditions in Northern Hemisphere, wetter in Southern Hemisphere	Bond *et al.,* 1992; Benson *et al.,* 1996; Allen *et al.,* 1999; Wagner *et al.,* 2010; Wang *et al.,* 2001; Leduc *et al.,* 2007; Kanner *et al.,* 2012

During the early Holocene, 14,800-5,000 cal. yr BP, there is evidence for the African Humid Period in East Africa (Chase *et al.,* 2009; Burrough and Thomas, 2013). Further evidence for the African Humid Period on the western coast of Africa are contained in marine sediment that indicate an abrupt decline in vegetation ~5,000 cal. yr BP (deMenocal, 2004). There are contradictive data for southern Africa, with Chase *et al.* (2009) suggesting evidence for the period exists; and Burrough and Thomas (2013) suggesting that drier areas such as the Kalahari were fed by distant sources. Numerous publications (Meadows, 1988; Van Zinderen Bakker and Coetzee, 1988; Scott, 1993; Fitchett *et al.,* 2016a) refer periods of increased humidity postglacial warming, but refrain from naming it the African Humid Period.

The presence of the Little Ice Age, AD 1300-1800 (Matthes, 1939; Herbert, 1987; Grove, 1988; Brook *et al.,* 1999; Tyson *et al.,* 2000; Holmgren *et al.,* 2003), in southern African palaeoenvironmental records is mostly based on stable isotope analyses (Brook *et al.,* 1999; Tyson *et al.,* 2000; Holmgren *et al.,* 2003). The evidence indicates different climatic conditions between different rainfall zones. Holmgren *et al.* (1999), Lee-Thorpe (2001) and Neumann *et al.* (2010) suggest dry conditions in the SRZ and Stager *et al.* (2012) indicate wet conditions in the WRZ.

The LGM, ~24,000-17,000 cal. yr BP (Metcalfe, 1993; Partridge *et al.,* 1999; Scott, 1982, 2012 1999; Boelhouwers and Meiklejohn, 2002; Holmgren *et al.,* 2003;

Carr *et al.,* 2006; Thackeray and Scott, 2006; Chase and Meadows, 2007; Mills *et al.,* 2012; Norström *et al.,* 2014; Neumann *et al.,* 2014; Fitchett *et al.,* 2017), had a definitive influence on climate shifts in southern Africa, however, once again there appears to be a difference between rainfall zones (Chase and Meadows, 2007; Finch and Hill, 2008; Norström *et al.,* 2009; Mills *et al.,* 2012). The SRZ and YRZ had drier conditions than the WRZ, which experienced wetter conditions during the LGM (Partridge, 1999). The difference is also evident in Mfabeni Peatland (Finch and Hill; 2008), Tswaing Crater (Metcalfe, 1993), Wonderkrater and Boomplaas (Scott, 1989), and Braamhoek (Norström *et al.,* 2009), all in the SRZ, all suggesting drier conditions during the LGM. According to Chase and Meadows (2007) the YRZ was wetter than the SRZ, but drier than the WRZ. Carr *et al.* (2006) also present evidence of a wetter WRZ.

Temperatures during the LGM seems to have been cooler during the LGM (Scott and Vogel, 2000; Neumann *et al.,* 2014; Fitchett *et al.,* 2016a,b) however no reliable quantifiable definite is reported, as the quantified temperature is reflected between 5-10°C (Scott, 1982; Partridge, 1999; Lewis and Illinger, 2001; Boelhouwers and Meiklejohn, 2002). Thackeray and Scott (2006) once again used the chronologically improved record from Wonderkrater, and after statistical analysis reported a depression of 6 ±2°C during the LGM. Scott *et al.* (2012) suggest that the two coldest periods during the LGM in southern Africa was ~24,000 cal. yr BP and ~17,000 cal. yr BP.

There were numerous climatic events in the Holocene in both the Northern Hemisphere and Southern Hemisphere; post-glacial warming, the Younger Dryas cold period, the Medieval Warming Period, Holocene climatic optimum, and the Little Ice Age (Matthes, 1939; Herbert, 1987; Grove, 1988; Brook *et al.,* 1999; Tyson *et al.,* 2000; Holmgren *et al.,* 2003; Fitchett *et al.,* 2016b). In southern Africa there is evidence for the "8.2 kyr", "4.1 kyr", and "2,8 kyr" cold events, in the form of stable isotopes (Smith *et al.,* 2002; Chase *et al.,* 2015). Evidence for the Holocene Altithermal period is widespread (Scott, 1993; Partridge, 1999; Finch and Hill, 2008; Scott *et al.,* 2012; Chase *et al.,* 2013; Truc *et al.,* 2013). However, there is no consensus on the timing as yet.

2.4 CONCLUSION

It is evident that climate events that occurred in the Northern Hemisphere also occurred in the Southern Hemisphere or had an effect on the climate in the Southern Hemisphere. The dates for different climate events as well as exact temperature fluctuations are still debated. The southern African region has very varied climatic effects in different rainfall zones. The variation may be due to the geographical location of southern Africa and the effect of the westerlies and tropical easterlies on the climate; or it may be due to the paucity of palaeoenvironmental records for the southern African region. The Discussion Chapter (*Chapter 8*) will follow after, where possible drivers for climate changes as well as correlation of climatic events will be investigated.

CHAPTER 3 STUDY SITE

[3]

3.1 INTRODUCTION

The study of Quaternary pollen of southern Africa did not start until the early 1950s, when Eduard Meine van Zinderen Bakker (Van Zinderen Bakker, 1955) investigated the peat bogs of the alpine belt of what was previously northern Basutoland. The study was followed by others by van Zinderen Bakker (1957), Martin (1959, 1962) and by Coetzee (1967). However, these initial studies were not only hampered by a lack of reference pollen for the richly diverse floral species, but also by the lack of proper dating techniques (Fitchett 2015; Meadows 2015). Despite the interest and advances in the Quaternary pollen of southern Africa there still remain extensive gaps in the research (Fitchett *et al.*, 2017); however the number of palaeoenvironmental studies are increasing, but still remain sparse and variable in spatial and temporal climate change (Neumann *et al.*, 2014; Norström *et al.*, 2014).

Eastern South Africa is not only of interest due to possible past glaciation in the Drakensberg but also due to the unique location between various atmospheric and oceanic climatic influences (Norström *et al.*, 2014), such as the southern limits Inter Tropical Convergence one (ITCZ) and both the Agulhas and Benguela ocean currents. Currently there are not many studies focussing on the grassland of higher lying areas in KwaZulu-Natal (Fitchett *et al.*, 2017). This study site will add to the already existing body of knowledge.

This chapter will start with a discussion on the selection of the study site, then a brief description of the local geology, current vegetation and climate.

3.2 Selection of study site

Ntsikeni wetland, one of the highest altitude wetlands (~1795 m.asl) in South Africa, was declared a Ramsar site on 2 February 2010, and is a wetland of natural origin (Kotze, 2003). Ntsikeni Vlei falls within the Umzimkulu catchment on the Lubhukwini River (Kotze, 2003). Ntsikeni, situated in a year round wetland as part of a protected area, is undisturbed and therefore the sediment is expected to contain a decent fossil pollen record.

There currently only a few studies focussing on the grassland of higher lying areas in KwaZulu-Natal (Neumann *et al.,* 2014; Fitchett 2015). The sites closest to Ntsikeni Wetland are Mahwaqa Mountain (Neumann *et al.*, 2014) and Mafadi Wetland (Fitchett *et al.*, 2016a) (**Error! Reference source not found.**), which both fall within the grassland biome of southern Africa and are at a high altitude. Towards the east coast, in the Indian Ocean Coastal Belt Biome (IOCB), sites include Lake Eteza (Neumann *et al.*, 2010) and Lake Sibaya (Neumann *et al.*, 2008). The are other sites still located within the grassland biome; but on the escarpment on the northern side of the Drakensberg (from west to east); are Florisbad (Scott and Nyakale, 2002), Craigrossie (Scott, 1986) and Braamhoek wetland (Norström *et al.*, 2014). The eastern coast is well represented with data points but the immediate area close to Ntsikeni Wetland is not. The relatively undisturbed condition of Ntsikeni wetland makes it an exceptional opportunity to use pollen as a proxy for palaeoenvironmental reconstruction.

The recent studies in the area (Neumann *et al.,* 2008, 2014; Norström *et al.,* 2014; Fitchett *et al.,* 2016a,b,c) have highlighted not only the lack in data available in the area, but also the need for greater investigation into the role that Westerlies and Indian Ocean moisture bearing Easterly winds play in the macro as well as microclimate of the Drakensberg Escarpment. Currently there is a need for higher spatial resolution of sites within the area that will assist in elucidating the discrepancies between site temperatures and precipitation rates. Ntsikeni Wetland study site will add to the growing body of data for the Drakensberg escarpment.

3.3 Local geography

Located in the foothills of the Drakensberg, 37.8 km south of Underberg, 17km North East of Swartberg and about 44.5 km SE of the Mahwaqa wetland and 173 km south of Braamhoek wetland (Neumann *et al.*, 2014), Ntsikeni is one of the largest wetlands at high altitude, 1,795m at its highest point to 1,752m at its lowest point (Kotze, 2003), that is still relatively undisturbed. It is entirely surrounded by a nature reserve that covers an area of approximately 1070ha, with little or no alteration to its hydrological and ecological character (Kotze, 2003). The Ntsikeni Vlei is situated high in the Mzimkhulu catchment, at 30° 08’S and 29°28’E and is drained by the Lubhukwini River, with little or no human activity upstream of the wetland, which gives it a high water purification value and Ntsikeni Vlei assists with streamflow regulation functions (Kotze, 2003). With regards to water storage and streamflow, this catchment area drains 2.7% of South Africa's annual runoff (Basson, 1997).

Ntsikeni Vlei wetland has been recognised as a “wetland of international importance” under the Ramsar Convention and was also proclaimed as part of the statutory protected area network within the Maloti Drakensberg Transfrontier Project. A Ramsar, wetland of international importance status is attributed to wetlands that are significant to humanity as a whole, and that the national government commits to take all the necessary steps to ensure that the ecological character is maintained (http://www.ramsar.org/). Ntsikeni wetland is situated close to the topographical boundary of the Drakensberg Alpine Centre (DAC) which is delimited by the 1,800m.asl contour, and is characterised by a high degree of plant endemism in the 40, 000km^2 (Carbutt and Edwards, 2006). The site is located in an approximate area of 100km^2 that is very rich in wetlands (Kotze, 2003). The relatively undisturbed nature of Ntsikeni Wetland will allow for an undisturbed pollen record which is also imperative for future management of the area.

3.4 Descriptive geology

The mountain on the eastern boundary of the reserve, Ntsikeni Mountain, is also the inspiration for the name Ntsikeni. The shape resembles that of a rondawel, which in the local language is “*intsika*” – which is the pillar that support the roof of a rondawel (Grieve, 2016), which is also the highest point – 2,214 m above sea level. The nature reserve is situated high on the plateau between Creighton and Franklin in the southern extents of KwaZulu-Natal and is underlain and surrounded by sandstones and mudstones of the Tarkastad Formation (Kotze, 2003) and dolerite sills capping peaks.

Figure 3: Ntsikeni Mountain, the eastern boundary of Ntsikeni Nature Reserve. (Photo: Graham Grieve).

Not only does the Karoo Supergroup boast vertebrate fossils and distinct plant assemblages, but also glacial deposits and dolerite dykes with extensive flood basalts (Groenewald, 1989). The Karoo Supergroup ranges from the Late Carboniferous to the Middle Jurassic (Stavrakis, 1980; Groenewald, 1989). The Beaufort Subgroup, consisting of a lower Adelaide Formation and an upper Tarkastad Subgroup (Figure 5), form part of the Main Karoo Basin (Groenewald, 1989). The Tarkastad Subgroup, deposited in the Early Triassic, is characterised by a great abundance of sandstone and red mudstone. It has a maximum thickness of almost 2000m in the south, declining to 800m in the middle area and is a mere 150m or less in the far north (Groenewald, 1989). There is a significant difference between the Katberg Formation, in the south, and the Burgersdorp Formation in the north (Groenewald, 1989). Towards the south the lithologies are more than 90% sandstone and there is a gradual increase of the mudstone:sandstone ratio towards the north; until it reaches about 20 – 30% or, or in some places, even less (Groenewald, 1989).

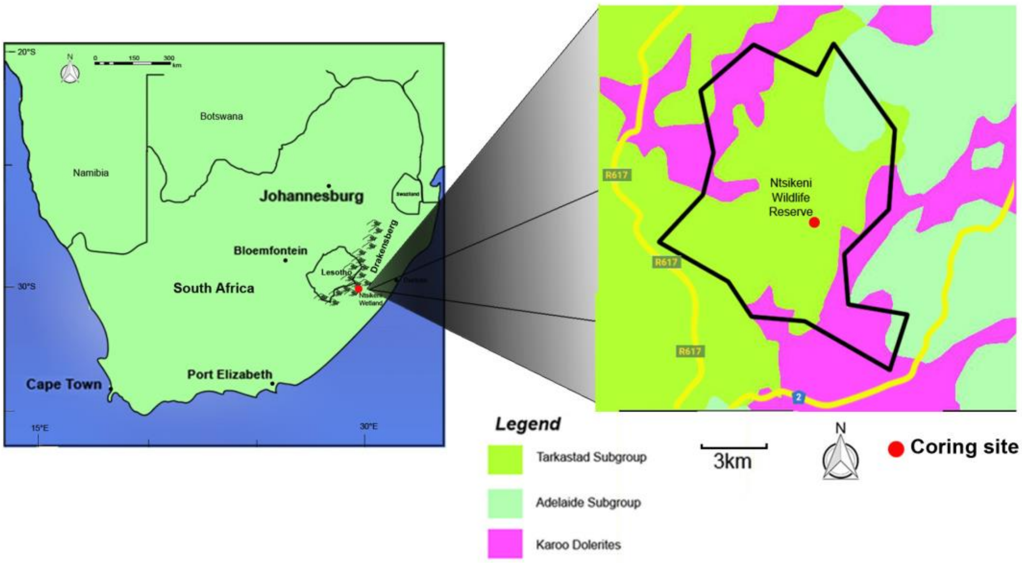


Figure 4: Geological map for Ntsikeni Wetland and surrounding area. After Council of Geosciences, http://www.geoscience.org.za/; 2017.

The rocks of the Beaufort Subgroup (Figure 4; Figure 5) were deposited by great braided rivers flowing from north to south (Stavrakis, 1980). This formation is particularly interesting and important as numerous fossils; vertebrate, invertebrate and plant; occur and shed light on the evolution of mammals

(Rubidge *et al.,* 1995). There are well developed Karoo dolerites, with the same composition as the Drakensberg lavas, criss-crossing the Beaufort Subgroup. According to Walker and Poldevant (1949) the intrusive dolerites represent a shallow feeder system to the flood basalt eruptions that is a network of interconnected sills, dykes, and saucer-shaped sheets (Chevallier and Woodford, 1999).

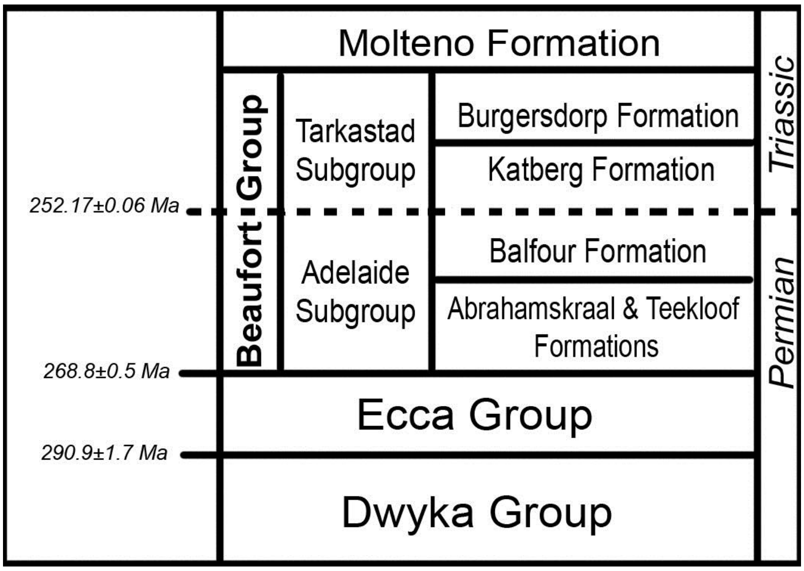


Figure 5: Stratigraphy of the area. After Johnson et al., 2006.

The soils in the wetland are primarily mineral, Katspruit form, which indicates an orthotic A-horizon of between 15cm and 30cm, overlying a thicker than 100cm G-horizon. The G-horizon develops where water saturation occurs for long periods and contributes to gleying with the reduction of hydrated oxides and ferric oxides; this horizon is normally dominated by grey, low chroma colours and demonstrates marked clay illuviation. This type of soil is associated with a seasonal to permanent wetland zone (Scotney and Wilby, 1983). There are also organic-rich soils of the Champagne form (Kotze, 2003), which also indicates permanent saturation of the soil. Both of the soil types have poor drainage with low erosion (Scotney and Wilby, 1983). Champagne soil may indicate extreme acidity – a pH of below 4 (Macvicar *et al.*, 1977) where the clay content is above 20% (Stratford Series in Champagne Form). The hydromorphic soil in the area is associated with water saturated areas such as marshes, wetlands and bogs (Scotney and Wilby, 1983), and tend to be high in clay content that demonstrates a high response to moisture changes; swell-shrink potential as the clayey element of the soil expands during high moisture periods and contract substantially when drier (Scotney and Wilby, 1983). According to Kotze (2003), there is hummocked sedge meadows present in the area. These landforms are generally associated with a periglacial environment (Grab, 2005).

3.5 Wetland properties and hydrology

A wetland is defined as "land, which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land that is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil" (National Water Act 36, 1998, p9). Wetlands attenuate the risk of floods, regulate water control and counter the effect of erosion (Mitchell, 2013) and also maintain biodiversity. The main body of Ntsikeni Wetland, a riverine wetland drained by the Lubhukwini River, is mostly permanently saturated and lacks a clearly defined stream channel towards the proximal side, whereas the distal portion of the main body has a clearly defined stream channel with permanent palustrine wetland patches (Kotze, 2003). There are also a number of tributaries branching from the main channel that feeds the extended wetland area (Kotze, 2003).

The basin is ringed by a number of small mountains and hills and the main vlei covers an area of approximately 1,200 hectares. The wetland drains towards the north into the Ngwagwane River (Begg and Carser, 1989). It lies at ~1,700m above sea level with a north-south alignment. The tributaries drain east and south, depositing clay and silt that form low alluvial fans extending into the basin.

3.6 Vegetation

According to the Vegetation Atlas of southern Africa (Mucina and Rutherford, 2006) Ntsikeni falls within the Drakensberg Foothill Moist Grassland. This vegetation group is listed as least threatened and only has a national conservation target of 23% (Kotze, 2003). The Grassland Biome is located mainly on the high, central plateau of South Africa with altitudes varying between 2,850m above sea level to sea level (Mucina *et al*., 2006). This type of biome, also known as Grassveld, is normally dominated by a single layer of grasses; trees are generally absent except in highly localised and isolated areas, and geophytes are often plentiful (Mucina *et al.*, 2006). The establishment of trees are normally hampered by frost, fire and grazing which preserve the dominance of grass (Mucina *et al.*, 2006; Neumann *et al.*, 2014).

The Grassland Biome has two greater categories of grass plants: sweet grasses and sour grasses. Sweet grasses are palatable, high in nutrients throughout the year and have a low fibre content; sour grasses are high in fibre, withdraw nutrients during winter and are unpalatable (Mucina *et al.*, 2006)

At higher rainfall and on more acidic soils, sour grasses prevail, with 625 mm per year taken as the level at which unpalatable grasses predominate. C4 grasses dominate throughout the biome, except at the highest altitudes where C3 grasses become prominent (Mucina *et al*., 2006)

The highland vegetation of the Ntsikeni Nature Reserve falls within the Drakensberg Foothill Moist Grassland (Mucina *et al.*, 2006) and is comparable to Acocks Veld Type 44(a) Highland Sourveld (Acocks, 1988). The vegetation context links the Ntsikeni, Mahwaqa and Umngeni wetlands in the Drakensberg foothills. Ntsikeni Nature Reserve has several important areas of indigenous forest in the surrounding regions. The Drakensberg Foothill Moist Grassland is forb-rich grassland, which is governed by short bunch grasses such as Red Grass (*Themeda triandra*) and Hairy Trident Grass (*Tristachya leucothrix*). Only 2-3% of this vegetation type is conserved in the uKhahlamba Drakensberg Park and other nature reserves in the region.

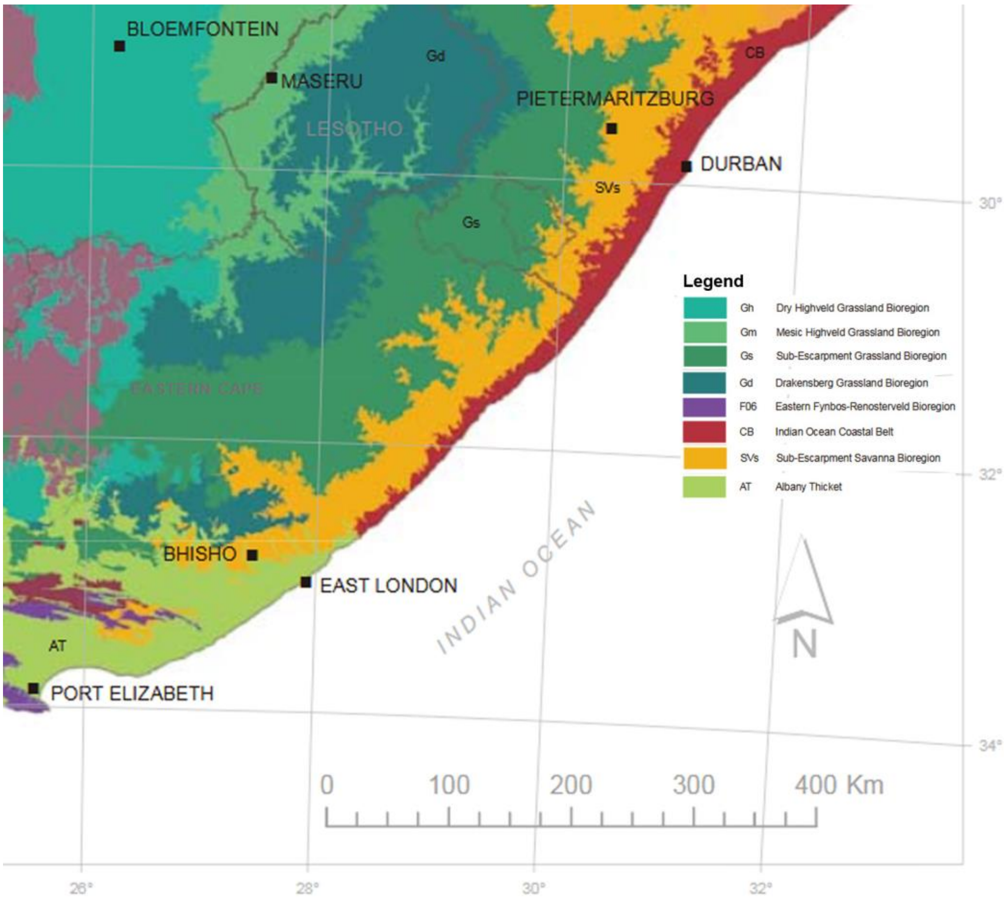


Figure 6: The vegetation biomes of South Africa (after Mucina and Rutherford, 2007).

The Drakensberg Mountain range and its outliers, which include enclaves such as the Impendle Plateau, have been identified as a biodiversity hotspot - an area of high endemism and species richness, which is under threat (Cowling and Hilton-Taylor, 1994). This is one of seven such areas on the subcontinent, known as the Eastern Mountain Hotspot (Cowling and Hilton-Taylor, 1994) or the Drakensberg Alpine Centre (DAC) (van Wyk and Smith, 2001; Carbutt and Edwards, 2004). The DAC is a composite of high-altitude enclaves centred within the greater Drakensberg Range, and has links to the Cape Floral Region. The wetland is considered Veld Type 44a, Highland Sourveld according to Acocks (1988), and is now named Drakensberg Foothill Moist Grassland (Ezemvelo KZN Wildlife Conservation Plan, 2008; Mucina and Rutherford, 2006). It was described by Begg and Carser (1989) as “Themeda-Trachypogon highland grassveld”, fire-maintained grassland dominated by short grasses, approximately 0.5 m high. In the absence of fire, *Podocarpus* forest develops, with grasses such as *Cymbopogon* spp. and tall *Hyparrhenia* spp.

Moreover, having been classified as a Ramsar Wetland for over a decade, the Ntiskeni wetland itself is highly undisturbed. Current vegetation is given as per Kotze's (2003) plant species lists (Appendix A), which include, but is not limited to some of the following genera; *Carex*, *Cyperus*, *Erica, Kniphofia, Rununculus, Helichrysum* and *Crassula.* All of the aforementioned species are wetland species found in the Ntsikeni wetland, there are currently at least ten plant species listed as threatened that occur within the great Ntsikeni Nature Reserve (Scott-Shaw 1999). Table 3 compares the plant species identified at Ntsikeni Wetland to the known species as illustrated by Kotze (2002) and Carbutt and Edwards (2004).

In terms of fauna, the wetland provides a breeding site for two or three pairs of Wattled Crane. Burger (1996) recorded five species of amphibia and there is a likelihood that the threatened Long-toed tree frog (*Leptopelis xenodactylis*) may reside here as it is a suitable habitat. The greatest threat to the Grassland Biome is grazing and human settlement development (Mucina *et al.*, 2006).

Table 3: Plant species identified at Ntsikeni Wetland and occurrence according to Carbutt and Edwards (2004) vs Kotze (2002)

	Carbutt & Edwards (2004)	Kotze (2002)
Acalypha sp	☑	☑
Apiaceae	☑	☑
Aponogenton sp	☑	☑
Artemisia sp	☑	
Asteraceae	☑	☑
Caryophylaceae	☑	☑
Celtis sp	☑	
Cheno/Am	☑	☑
Combretaceae	☑	
Crassulaceae	☑	☑
Croton sp		
Curtisia sp	☑	
Cyperaceae	☑	☑
Ericaceae	☑	☑
Fabaceae	☑	☑
Gentianaceae	☑	☑
Grewia sp		
Helichrysum sp	☑	☑
Hypoxidaceae	☑	☑
Juncaceae	☑	☑
Liliaceae		
Malvaceae	☑	
Mimosoideae		
Myrtaceae	☑	
Oleaceae	☑	
Orchidaceae	☑	☑
Phragmites sp	☑	☑
Poaceae	☑	☑
Podocarpus sp	☑	
Proteaceae	☑	☑
Rananculaceae	☑	☑
Stoebe sp	☑	
Typhaceae	☑	
Vernonia sp	☑	

3.7 Climate

Ntsikeni Wetland is located at latitude 30° 08′ 33′′S and longitude 29° 27′ 27′′E, which is within the Drakensberg Escarpment (located between latitude 28° 30′ S and 30° 30′ S and longitude 28° 30′ E and 29° 30′ E); typically with moderate temperatures that are heightened due to the longitudinal locational of the Drakensberg escarpment places it close to the east coast of South Africa, which is under great influence of the warm Agulhas current (Tyson *et al*., 1976). The eastward moving high pressure cells, especially over western South Africa, are associated with stable atmospheric conditions that inhibit rainfall-producing systems (Tyson *et al.*, 1976), the eastern half of South Africa, however, is penetrated more frequently by rainfall-producing systems due to South Africa's intermediate location between the tropical and middle latitude rainfall producing system, also known as the Westerlies (Tyson *et al.*, 1976; Stager *et al.*, 2012).

The onshore advection from the sea enriches the moisture content of the lower levels of the atmosphere, especially during summer months (McGee, 1974). The Great Escarpment of southern Africa is the major moisture dispersal control across south-eastern Africa, as it blocks the influx of moisture rich air from the Indian Ocean to the western interior (Mills *et al.,* 2012) and result in orographic rain at Ntsikeni. This roughly divides South Africa into a dry western and wet eastern half. The intermediate location between the tropical latitude and the Westerlies as well as a 4° seasonal displacement that the belt undergoes results in significant seasonality (Tyson and Preston-Whyte, 1972 ; Stager *et al.*, 2012). During winter it intensifies and migrates north while it weakens in summer and migrates southward (Tyson and Preston-Whyte, 1972a; Stager *et al.*, 2012), the movement of the pressure systems divide South Africa into Summer Rainfall (SRZ) – due to the weakening of the pressure system, Winter Rainfall (WRZ) – due to the intensification and All Year Rainfall Zones (YRZ) (Tyson and Preston-Whyte, 1972a; Stager *et al.*, 2012). Jackson (1952) and Taljaard (1953) describe a weak summer heat low pressure cell that exists over the plateau being replaced by a high pressure system; at approximately 2,000m; moving northwards and intensifies, relative to the summer pressure system, resulting in the Drakensberg experiencing winds which deflect counter clockwise (back) with increased height. To indicate the effect of the weather-producing systems on the Drakensberg the general circulation over South Africa will be discussed first.

The insolation (incoming solar radiation) over South Africa is at its maximum over the western interior and decreases eastward (Tyson *et al.*, 1976). The movement of the Westerlies influence insolation both spatially and temporally (Tyson and Preston-Whyte, 1972; Stager *et al.*, 2012). The Drakensberg is relatively cloud-free during winter and receive a high insolation rate (up to 80% of the possible winter sunshine), however the transition to spring is sudden and is accompanied with a drop in insolation rate to roughly 50-60% of possible summer sunshine (Tyson *et al.*, 1976).

Due to South Africa's topography a true mean temperature for the country cannot be illustrated, however it is evident that there is a difference in mean annual temperature based on latitude, longitude, altitude and the location in approximation to the coast lines (Tyson *et al.*, 1976). There appears to be a decline in temperature over the 13° latitude from north to south and an increase from the high-lying Lesotho Plateau to the low-lying Kalahari Basin (Tyson *et al.*, 1976).

There are two main rain-producing systems in South Africa; frontal (due to the movement of the Westerlies (Stager *et al.*, 2012) and thunderstorms (Preston-Whyte, 1971). Thunderstorms can be categorised as squall-line or orographically-induced thunderstorms (Preston-Whyte, 1971). Frontal weather patterns occur late autumn, winter and early spring (Taljaard and van Loon, 1963; Chase and Meadows, 2007) and due to the blocking effect of the high pressure cell over the subcontinent the low pressure cyclone cells move west-northwest to east-southeast, delineating the WRZ from the SRZ.

Thunderstorms that develop on large squall-lines in associated with the eastward passage of a trough, both in the upper air as well as close to the surface (Schulze, 1965). The regional wind system over KwaZulu-Natal, which consists of sea breezes, regional plain-mountain winds and north to northeast gradient winds, cause advection of warm moist air in the south-westerly air stream, creating storm cells as the unstable moist air is uplifted above a cool gust-front, creating a continuous convection process (Preston-Whyte, 1971). The squall-line thunderstorms in KwaZulu-Natal move in a northwest to southeast direction (Preston-Whyte, 1971). Orographically-induced thunderstorms are created when slope convection triggers the release of convective instability (Tyson *et al.*, 1976). These commonly occur in summer months, once again due to the movement of the Westerlies and the penetration of moisture from the east coast when the high pressure system weakens (Stager *et al.*, 2012). Thunderstorms are normally short-lived and intense.

The macroclimate of the region responds to controls on a large scale (the Westerlies), however the local microclimates are a feature of the individual valley geometry (Tyson *et al.*, 1976). Due to the paucity of temperature recording stations in the area (Fitchett, 2015; Tyson *et al.*, 1976) the regional temperature appears fairly uniform. The deeply dissected topography influences the regional temperature dramatically (Tyson *et al.*, 1976). The slope orientation, width, depth and shape of a valley as well as the occurrence of local winds all play a distinct role in the temperature of a site (Tyson and Preston-Whyte, 1972; Tyson *et al.*, 1976). During the day heat is trapped in the air amassed within the constraints of the valley ; U-Shaped valleys will contain more air and heat than V-Shaped valleys; and this occurs at a higher rate than heat trapped on plains, however the valley will cool faster at night due to the smaller air mass (Tyson *et al.*, 1976).

Frost in the winter is a common occurrence in the Drakensberg (Tyson *et al.*, 1976), due to the lack of general winds, clear skies and air dry air during large-scale drainage of cod air in valleys and hollows. The topography once again influences local distribution of frost (Tyson *et al.*, 1976). Frost generally occur on the Lesotho plateau from April to October, below the escarpment from May to September and on the lower lying foothills and river basins only from June and will only last until August (Tyson *et al.*, 1976).

According to (Tyson *et al.*, 1976) most of the Drakensberg receive maximum rainfall during January and February (SRZ) and a minimum from May to August. The mean annual rainfall varies significantly with altitude. With higher means toward the top of the escarpment and lower means towards the foothills; however the valley topography and geometry will also influence local variations due to the relief-effect and rain-shadows (Tyson *et al.*, 1976). Dyer (1975) and Tyson *et al.* (1975) discuss a quasi-20-year oscillation in rainfall that is more pronounced in the northern part of the Drakensberg but less clear towards Kokstad in the south. Other types of precipitation that occur within the Drakensberg region are hail, primarily during summer, fog and mist (Tyson *et al.*, 1976), the latter occur widely and can account for higher measured precipitation than actual rainfall, and lastly snow for which there is currently now systematic recordings.

Ntsikeni Wetland is situated in the southern part of the Drakensberg Escarpment Region, has a mean annual precipitation of 1150mm, with occasional snow in winter (Kotze, 2003; Mills *et al.,* 2012). An average daily maximum temperature of 21.5°C and an average daily minimum of 7.5°C in 2002 were recorded in the area by Kotze (2003), which is typical for the Drakensberg region of KwaZulu-Natal. The pressure systems discussed previously influence the gradient winds of general circulation at macroscale (Tyson and Preston-Whyte, 1972), and the occurrence of strong pressure gradients are normally a feature of frontal disturbances. In general, these winds are north-westerly and warm, when in front of a cold front (Berg winds) and when behind a front the gradient winds are strong, cold and south-westerly (Tyson *et al.*, 1976).

During high pressure systems the local topography will have a more significant impact on prevailing local winds, which occur at a variety of scales, such as anabatic winds during the day and katabatic winds during the night (Tyson *et al.*, 1976). There are three layers at which local winds occur; valley winds, mountain winds and mountain-plain/plain-mountain winds (Tyson and Preston-Whyte, 1972). These three winds may flow in contrasting directions to one another, for example; during the night a valley wind can flow up-valley, while the mountain wind drain down-valley and higher above the mountain wind the mountain-plain wind drain from the Drakensberg to the east coast (Tyson and Preston-Whyte, 1972). Due to the topography of the Drakensberg local winds need to be considered in detail, as well the valley topography itself, as cool air that flows down the mountain may be impeded by features in the valley, such a bend, creating higher velocities on or over the valley wall (Tyson *et al.*, 1976). The orientation of the slope of the valley will influence the onset of the valley wind and the dissipation of the mountain wind (Tyson *et al.*, 1976). According to Tyson *et al.* (1976), the maximum flow of the mountain wind occur at ~150m above the valley floor, anti-mountain winds occur with regularity at a height of half the depth of the valley and the maximum velocity of valley winds are at about a quarter of the depth of the valley. Strong gradient winds will eradicate the valley winds and in some cases even the mountain winds (Tyson and Preston-Whyte, 1972).

3.9 Conclusion

Ntsikeni Wetland is an undisturbed year-round wetland, located in an area that is one of the best watered and least drought-prone areas in South Africa; the preservation of fossil pollen in these conditions is historically excellent. The area currently lack spatial data pertaining to Quaternary pollen records and greater resolution is necessary in this region as the strong effect of the local relief is a controlling parameter in the frost, air movement, temperature and precipitation micro- and mesoclimate.

The effect of the macroclimate inducing systems also affect the study site and analysis of the pollen may answer some of the questions currently unanswered by other local studies.

CHAPTER 4 MATERIALS AND METHODS

[4]

4.1 INTRODUCTION

In this chapter the methods that were used for sample extraction, pollen preparation and statistical analyses are outlined. The reconstruction of palaeoenvironments from fossil plant evidence is not a new field; pollen has been used for more than a century as a valuable proxy (Erdtman, 1943; Faegri *et al*., 1989). Standardised methods were used to ensure reproducibility of all steps of sample preparation, and comparability of results with existing studies in the region. The chapter details the field work; laboratory work, which includes subsampling and laboratory pollen preparation, microscopy; dating and statistical analysis.

4.2 Field work

Fieldwork was performed by Greg Botha, Frank Neumann, Mawande Ncume and Marion Bamford in August 2015. The wetland is a RAMSAR site with Wattle Crane breeding pairs that cannot be disturbed and the coring trip occurred while the wetland was still wet in the middle of winter, and therefore a generator with a larger corer could not be used. An Eijkelkamp gouge auger with 1.2m extensions was used to core into the wetland. This corer was selected for the project as it is portable and results in low levels of compression. The coring site was chosen based on accessibility and drainage location within the wetland – towards the distal side of the wetland. Sub-sampling of the 300cm core was performed on site, from which 81 sediment sub-samples from Ntsikeni Wetland were isolated. The sediment was extracted; the core was photographed, and was immediately cut into 2.5 to 5cm segments. These segments were then bagged in labelled ziplock bags.

4.3 Laboratory Work

4.3.1 Laboratory samples

The sediment subsamples were further partitioned for pollen and AMS radiocarbon dating. Samples of 5-6g were partitioned for pollen preparation, and 8g were retained for AMS dating. A remaining 1g of sediment material per sample was retained for future microfossil analysis. Material initially sent for AMS radiocarbon dating was selected from five different intervals that span the entire transect of the core. Subsampling was conducted in a pressure controlled laboratory, in the Palynology Laboratory of the Evolutionary Studies Institute at the University of the Witwatersrand, to avoid contamination from native modern-day pollen (Faegri *et al.*, 1989). Samples were scooped with a stainless steel spatula from the sample bag into an appropriately labelled receptacle. The spatula was washed and rinsed with distilled water between samples.

4.3.2 Pollen Preparation

The objective of pollen preparation is the isolation of pollen grains present in the subsample (Faegri *et al.*, 1989; Scott, 1982). This objective is achieved by removing the unnecessary constituents from the sample. The methods used to isolate the pollen from the sediment are standard, as outlined by (Faegri *et al.*,

1989) and Fitchett (2015). A concise flow-chart of the technique is offered below in Figure 7, and the detailed technique is listed in Appendix B.

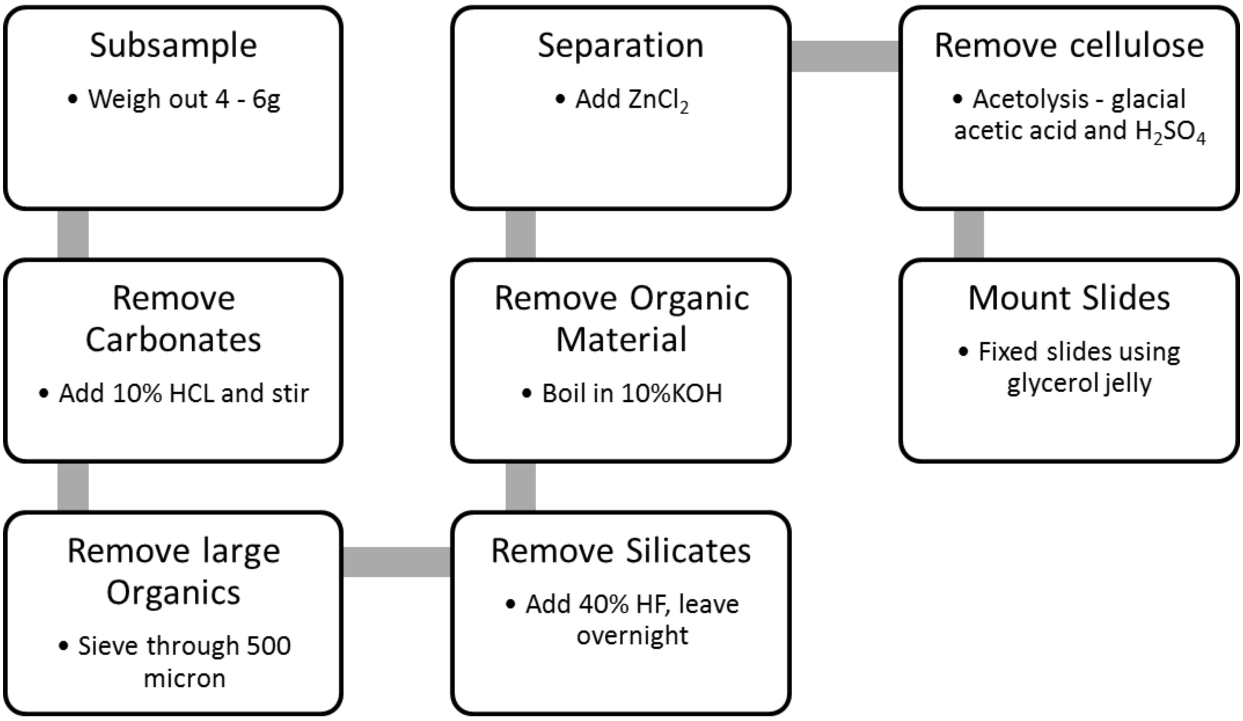


Figure 7: A flow diagram showing the laboratory steps for acid preparation of the samples.

The four main stages in the pollen preparation phase (Figure 7) are the removal of carbonates, removal of silicates, separation of suspended material under gravity and acetolysis to remove the cellulose. Hydrochloric acid (10% solution) is added to the sample to dissolve carbonates present, after dissolution of carbonates the sample is washed and prepared for hydrofluoric acid (HF) at 40% solution. The HF is added to the sample, left overnight, to remove silicates present in the sample; afterwards the sample is washed again in preparation for the next stage – separation of suspended material under gravity within sample with zinc chloride (super saturated mixture) to suspend pollen particles in supernatant. The last stage, before final rinsing, is acetolysis. Acetolysis is performed to remove cellulose from the sample. The advantages of acetolysis are that it expands the pollen grain and brings a degree of transparency which is helpful with pollen identification (Cushing, 1967).

The sediment samples for Ntsikeni Wetland were particularly clayey and the carbonate content was very low. To counter problems due to clayey particles; that resulted in stratification of the sediment; samples required further agitation. Additional agitation was applied during the HCl step, where the receptacle was placed on the shaker and the sample was agitated at 300rpm for 40 seconds and there after the sample was diluted with distilled water. The samples were also agitated before the addition of HF to prevent stratification of the sediment within the centrifuge tube and lastly before the KOH were added to the samples.

4.3.3 Microscope work

After the isolation of the pollen, two slides per subsample were prepared to ensure that there were sufficient pollen grains for counting. Fixed slides were made using glycerine jelly (Collinson, 1987; Fitchett, 2015), which allows for accurate counting as palynomorphs will not move around on the slide and ensure long term storage. According to Faegri and Deuse (1960) the glycerine jelly might cause the pollen grain to swell due to absorption of moisture, which will be deleterious if the main focus of the study was the size of pollen grains;

however in this case it was not. Once the slides were prepared, the glycerol jelly was fixed at low temperatures on a hot plate. The optical properties of glycerol (Batten and Morrison, 1983) ensures that the photography of the pollen grains is easy (Metwally, 2011). The residues from the samples were stored in a refrigerator in individually marked Eppendorf tubes to allow for additional slides to be prepared in future if needs be.

Pollen grains were identified based on the sculpting and morphology using a light microscope (Faegri *et al.*, 1989). General scanning and counting were undertaken at 400x magnification and each sample had at least two slides. The second slide was to ensure that, should there be less than 250 pollen grains on the first slide, counting can continue; as a sample is considered to be statistical robust, when at least 250 pollen grains were counted (Bradley, 1999). Photographs were taken at 400x magnification or, in the case of small grains, 1000x magnification under oil immersion. Pollen grains of each taxon were photographed to assist with identification through comparison with reference collections and through communication with pollen experts. The presence of phytoliths, spores, and where visible, types of degradation of pollen were also noted.

According to Delcourt and Delcourt (1980) pollen can deteriorate in four main ways: Corrosion, Degradation, Mechanical damage, and Obscured grains. During counting and identifying of pollen in samples, deterioration was dealt with in different ways. Corroded and degraded grains were only considered as

“Unknown” when deterioration rendered identification impossible. Mechanical damage (these included crumpled, bent or ruptured grains) for broken pollen grain only came in to play if more than 50% of the grain was intact and identifiable. If a grain was broken, and less than 50% was intact, the grain was not considered for identification or counting, the same held true for obscured grains where less than 40% was visible from behind amorphous organic material. Where less than 40% was obscured and identifying feature were not visible the grain was recorded as “Unknown”.

During counting and analysis each sample was treated individually; a tally per taxon per sample was created and was added to form the 250 grain count per sample. For the purpose of this study, pollen from the families Chenopodiaceae and Amaranthaceae were combined into the “Cheno/Am” group (Scott, 2002; Fitchett *et al.,* 2016a) due to the similarity in pollen morphology. Poaceae pollen grains were all identified only to family level as most grass taxa share a typical morphology; except for *Phragmites sp*, which was recorded separately. During counting the Asteraceae group was divided into “Asteraceae Unspecified”, *Vernonia sp*, *Helichrysum sp* and *Stoebe*-type.

During the identification of the pollen grains the following online reference collections were consulted;: the University of Arizona Geosciences’ African Pollen Database (http://www.geo.arizona.edu/palynology/apd.html); the Australian National University Pollen Database (http://apsa.anu.edu.au/); and the

University of Vienna, Austria, Department of Ultrastructure Research and Palynology (https://www.paldat.org/).

Counting and identifying of the pollen grains were completed from NT1 to NT82, in a sequential manner; however samples NT1 to NT6 were recounted after sample NT82 was counted. The recount and identification was completed to ensure that identification was correct and that a lack of sufficient knowledge did not compromise the results.

4.4 Statistical analyses

4.4.1 Age-depth modelling

The type of Bayesian age-depth model used in this study is the Bayesian accumulation models (BACON) as described by Blaauw and Christen (2011). This model is used as it is a simple autoregressive time series, which means that prior accumulation is based on previous sedimentation rates and therefore a more accurate display of natural changes in accumulation rates (Blaauw and Christen, 2011). The Bayesian model uses a Markov Chain Monte Carlo algorithm to address uncertainties and approximate sedimentation rates whilst accounting for sample depth spanned, depth of the sample and possible radiocarbon uncertainties (Parnell *et al.,* 2011).

Traditionally linear regression or linear interpolation methods have been used (Telford *et al.,* 2004) to generate age-depth models. These methods do have shortcomings; such as forcing the model to pass through radiocarbon dates

(Parnell *et al.,* 2011); using a central point from the calibrated radiocarbon dates and disregarding the probability of distribution for date ranges (Parnell *et al.,* 2011; Telford *et al.,* 2004) and not providing a statistical way to deal with outliers (Telford *et al.,* 2004) as sedimentary rate is considered as constant.

By using a Bayesian calibration of radiocarbon dates a number of variables are accounted for, for instance stratigraphy, other historical dates. According to Blaauw and Heegard (2012) the use of a Bayesian age-depth model holds a number of advantages which include, but is not limited to; a more refined date range; detection of outliers using a statistical basis and by accounting for errors and ambiguity in the calibration process one can compare dates between age-depth models. The most tangible advantage of a Bayesian age-depth model is that the model is sensitive to sedimentation rate changes (Telford *et al.,* 2004).

4.4.2 Statistical analysis of pollen data

The aim of analysing the data statistically is to determine if there are trends visible in which noticeable change has occurred (Rencher and Christensen, 2003; Fitchett, 2015). By using clustering and ordination such trends cannot only become visible, but can also be statistically investigated. This was done using ordination, performing Principal Component Analysis (PCA) (Austin, 1968; Fasham, 1977) and also classification using CONISS (Constrained Incremental Sum of Squares) (Grimm, 1987).

For statistical analysis the species that accounted for less than 2% of the average variability were excluded (MacKay *et al*., 2012. The Asteraceae group included all of the individual species, as individual species did not account for more than 2% of the average variability; therefore they would have been excluded. The individual Asteraceae species are considered separately within Chapter 6 (*Environmental Reconstruction*), as there were samples where identified Asteraceae species accounted for more than 2% of the variability within the sample.

Sample counts were recorded in *Microsoft Excel* and the count percentage per taxa per sample as well as average percentage occurrence within the sequence were determined. The data were compiled into a comma separated version (.csv) file that formed the basis of statistical analysis. The interpolated ages were added to the .csv file; this file was then used for ordination, PCA, clustering and graphical representation in C2.

4.4.3 AMS Dating

Five samples were selected for AMS dating. The samples were sent to *Beta Analytic* for radiocarbon AMS dating on bulk organic material. *Beta Analytic* is ISO/IEC 17025:2005 accredited, demonstrating technical competence in the measurement of natural levels of radiocarbon through Accelerated Mass Spectrometry (AMS), their quality management systems are also in line with ISO 9001:2008 (http://www.radiocarbon.com/iso-certified.htm).

There are different methods of dating that can be used for dating material with ages estimated to be younger than 50,000 cal yr. BP. AMS is used as a dating method when the sequence contain organic material in every sample and the expected age of the sediment is also less than 50,000 yr BP (Kolstrup, 2007). The Ntsikeni Wetland sequence contained organic material in all of the samples; therefore AMS dating was favoured (Kolstrup, 2007).

Three different isotopes of carbon are compared, the lighter ^{12}C and ^{13}C are stable; however the heaviest isotope, ^{14}C (radiocarbon) is radioactive (Bowman and Leese, 1995; Walker and Walker, 2005). In the upper atmosphere, as neutron producing cosmic rays react with ^{14}N atoms, ^{14}C is produced which then oxidises to create ^{14}CO (Walker and Walker, 2005). Throughout the atmosphere ^{12}CO, ^{13}CO and ^{14}CO is dispersed and used during photosynthesis by plants, the ratio of ^{14}C:^{12}C in plants to the atmosphere will comparable (Walker and Walker, 2005). When a plant dies the ^{14}C is no longer replaced and decay becomes apparent, once radioactive decay begins, the half-life of ^{14}C is 5 730 years ±40 years (Walker and Walker, 2005).

The amount of ^{14}C in the atmosphere is not stable and has varied throughout time due to solar activity, therefore a calibration is needed to ensure that the correct ratio is used (Walker and Walker, 2005). A calibration curve is constructed by using dendrochronology to ensure correct atmospheric ^{14}C data.

The data will then be calibrated to 1950 which gives a date reported as calibrated years before present (cal yr BP) (Walker and Walker, 2005). AMS counts the individual ^{12}C, ^{13}C and ^{14}C atoms in the sample and from these data the concentration ratio of isotopes can be used to calculate the level of decay (Brown *et al.*, 1992; Walker and Walker, 2005).

There is a difference in the ^{12}C, ^{13}C and ^{14}C ratios between the Northern and Southern hemispheres (Hogg *et al.*, 2013). The differences between the two hemispheres are thought to be due to the larger ocean to land ratio in the Southern Hemisphere, which translates into variable Southern Ocean wind strength and greater temporal alterations (Hogg *et al.*, 2013). Even though the calibration curves between the Northern and Southern hemispheres are broadly the same the synchronous Southern Hemisphere dates are found to be older by a few decades, compared to Northern Hemisphere dates (Hogg *et al.*, 2013). ShCal13, or Southern Hemisphere Calibration Curve 2013, is the internationally agreed radiocarbon calibration curve obtained by Bayesian models and methods (Niu *et al.*, 2013), this calibration curve's range is extended to 50,000 cal yr. BP from the ShCal04 model (Hogg *et al.*, 2013).

Ntsikeni Wetland, sited in the KwaZulu-Natal province of South Africa, is situated in the Southern Hemisphere and the sediment sequence's age was younger than 50,000 cal yr. BP; therefore the dates received were calibrated using ShCal13.

4.4.4 Ordination and Principal Component Analysis

Based on the similarity in environmental variable preference between species, samples are arranged linear relative to each other (Rencher and Christensen, 2003); in other words, the complex data patterns are summarised to a graphical representation to identify relationships between modern species assemblages and environmental variables (Legendre and Birks, 2012a)

Ordination is a statistical technique used in ecology to represent a number of large data points in a multi-dimensional space (Ter Braak and Prentice, 1988) ; all of the samples are plotted against each other in three-dimensional space. A set of axes produced through this three dimensional space to explore the variability in the dataset in one dimension (Rencher and Christensen, 2003). The first set of axes will account for the greatest variance in the variables (samples or species) and the second axes will account for the second greatest variance and the next set will be less significant in variance from the second axes but more so than the fourth until the maximum number of axes are reached (which will be no more than the number of samples) (Rencher and Christensen, 2003). Different ordination methods will be used for unimodal and linear data (Ter Braak and Prentice, 1988); therefore unimodal data need to be detrended first.

Unimodal data will display one clear peak (or most frequent value – mode) or a normal distribution of the data; this type of distribution normally indicates a low diversity within each sample; and a greater diversity between samples -

representing environmental change (Jain *et al.,* 1999; Fitchett *et al.*, 2016a); on the other hand linear data tends to display higher species diversity within each sample and less diversity between samples (environmental change gradient). To detrend unimodal data Detrended Correspondence Analysis (DCA) is used; detrending of data occurs by removing the aspect of the data that may cause a distortion and hide subtrends in the data (Rencher and Christensen, 2003). Linear data ordination will be completed using PCA. The principle component (PC) indicators (PC1 and PC2) were subjected to analysis using statistical coding interface R, this is to reduce the large number of interconnected variables into new sub-vectors on Y and X (Jolliffe, 2002). According to (Rencher and Christensen, 2003) the first principle component is the linear combination with the maximal variance and the second principle component is the linear combination with the maximal variance at 90° to the first component, which indicates no similarity between the linear combination of data. These values are represented in three-dimensional space on two different axes. The smaller numbers of variables are used for input in further analysis.

The eigenvalues of the covariance matrix (correlation matrix) were used to decide how many components were retained to effectively encapsulate the data. The principle components lack scale invariance; therefore the coefficients, allocated to the components by eigenvalues of covariance matrix, are used for interpretation (Rencher and Christensen, 2003); this results in one variable that may display a greater variance than the other variables, and will thus dominate the first component (Rencher and Christensen, 2003), therefore the greater the difference in score between the two variables on the linear combination's extremes the better illustration of the internal variation and covariation of the variables (Jolliffe, 2002; Rencher and Christensen, 2003). The species/taxon name was associated with a relative score to better aid in the visual representation of the data; a biplot was created displaying both PC1 and PC2 components. The PC1 and PC2 components were also plotted in C2 according to species/taxon scores to better visually represent the relationship.

4.4.5 Classification

Data can be grouped together or separated based on similarities to demonstrate period of environmental change. To group data in ordered groups data need to be classified first (Birks *et al.*, 2001). There are two types of data classification – unsupervised classification and supervised classification; unsupervised classification (clustering) is used in situations where little or no prior information about the group structure within the data is known (Birks *et al.*, 2001)

Palaeoecologists utilise clustering to reflect a segmented time series (core sediment samples) to a depositional temporal-series (Legendre and Birks, 2012b) . There are a number of different clustering methods available, however for this study hierarchical agglomerative clustering was used, whereby individual samples are merged to form small groups and the smaller groups are then fused in to larger groups (Legendre and Birks, 2012a).

The agglomerative clustering technique used for this study was CONISS (Constrained Incremental Sum of Squares) (Grimm, 1987; Legendre and Birks, 2012a) , as the data remain in the original order to reflect the depositional time-series with the clusters then at the true depth of the samples (Birks *et al.*, 2001; Fitchett, 2015). In conjunction with CONISS the Ward's minimum variance algorithm is used to measure the distance between samples (Fitchett 2015). The measurements are then plot as a silhouette plot to create all the possible group numbers where the sample has the least variance from the closest cluster; therefore a silhouette plot with values closest to 1 is optimal, a negative value indicates that samples are included within the wrong cluster and 0 that samples are between clusters (Legendre and Birks, 2012b). The clustering result are then graphically displayed as a dendrogram where the hierarchy of the different sample grouping, on different fusion levels are evident (Legendre and Birks, 2012b). The clusters are colour coded to indicate the statistically significant cluster structures. The clusters are used to indicate temporal zonation on the stratigraphic pollen diagram.

4.4.6 Graphical Representation

The first plot illustrates the groups the species/taxon based on plant type, the species/taxon were colour coded according to vegetation types; semi-aquatic, shrubs and herbs, trees, succulents and grasses; to enable environmental comparisons. The second arranges pollen taxa according to PC1 scores, and the third plots the species according to the PC2 scores. The pollen diagrams were plotted against the interpolated ages as estimated produced by the BACON model, and includes the zones as indicated from the results obtained from the CONISS cluster analysis.

4.5 CONCLUSION

The utilisation of standardised methods for pollen preparation as well as statistical analyses allow not only for reproducibility of the results, but also for future comparison of data obtained in this study to previous studies in close proximity to this site. Limitations, benefits and errors encounter while using standardise methods are better understood and accounted for.

CHAPTER 5 RESULTS

[5]

5.1 INTRODUCTION

This study utilises pollen as a palaeoenvironmental proxy to reconstruct the changes in climate and environment throughout the past ~25 000 cal. yr BP at Ntsikeni Wetland. A 300cm long sediment core was extracted from Ntsikeni Wetland, from which 81 subsamples were partitioned; five samples were used for AMS dating and all 81 samples were used for microscopy. The BACON v2.2 age-depth model was performed in R, using the conventional dates obtained from the AMS results received from *Beta Analytic*, to interpolate ages for all samples and sedimentary rates for the sediment profile. Dates, calibrated using ShCal13 and interpolated using BACON, are expressed as 'cal. yr BP'. This was followed by a CONISS cluster analysis, also in R, to identify zones within the data, which will be used in the discussion chapter to refer to statistically significant distinct intervals in the sediment. PCA was performed to explore trends in association between samples and the driving species vectors. Pollen diagrams were generated using C2; taxa were colour coded according to vegetation type and both PC1 and PC2 pollen are displayed with the zones as determined by CONISS.

This chapter will show the results as obtained from the above mentioned statistical analyses as well as additional information that were used to select the input values for the statistical analyses. The interpretation of the results will be discussed in Chapter 8 (*Discussion Chapter*), where the results will be used to reconstruct possible environments.

5.2 Stratigraphy and sediment properties

A sediment core was extracted from Ntsikeni wetland; a riverine wetland with palustrine areas; at GPS coordinates: 30° 08’ 33.3’’S 29° 27’ 27.3’’E, at the south eastern end of the wetland. The core site is positioned near but not at the water outflow of the wetland which allows for accretion of organics as well as clastic material.

The profile consists of light grey clay with a variation in the oxidation within the profile. No samples from 0cm to 24cm were used for analysis as they consist of compressed sedge roots; this is followed from 24cm to 38cm with a lower root zone rhizome zone. The sediment from 38cm to 100cm were not described by the field workers that collected the samples, but upon inspection in the laboratory it was described as light grey clay with silt, with some orange mottling present; however the percentage mottling could not be determined as sub-sampling already occurred. The sediment profile demonstrated varying degrees of oxidation, the largest percentage (50%) orange mottles occur from 200cm to 220cm and only 10% mottles from 115cm to 130cm and then again from 225cm to 270cm. The last 30cm of the profile is light grey with green, grey, blue and red mottles occurring. The samples within the last 50cm of the core had a greater sandy proportion than the preceding samples. Coring terminated at 300cm. Subsamples are numbered from the top (NT1) to the bottom (NT82). Samples NT1 to NT3 contained bulky root material and the samples became more clayey and large organic particles decreased from NT4. The entire sediment profile was clayey, however during sample preparation samples NT4 to NT10, NT28, NT30 – NT35 and NT63 – NT82 demonstrated to be extremely clayey. During sample preparation there were no samples that reacted with the hydrochloric acid due to possible lack of carbonate materials. Samples NT24, NT25, NT27, NT29 and NT36 had phytoliths and other siliceous material present even after treatment of hydrofluoric acid.

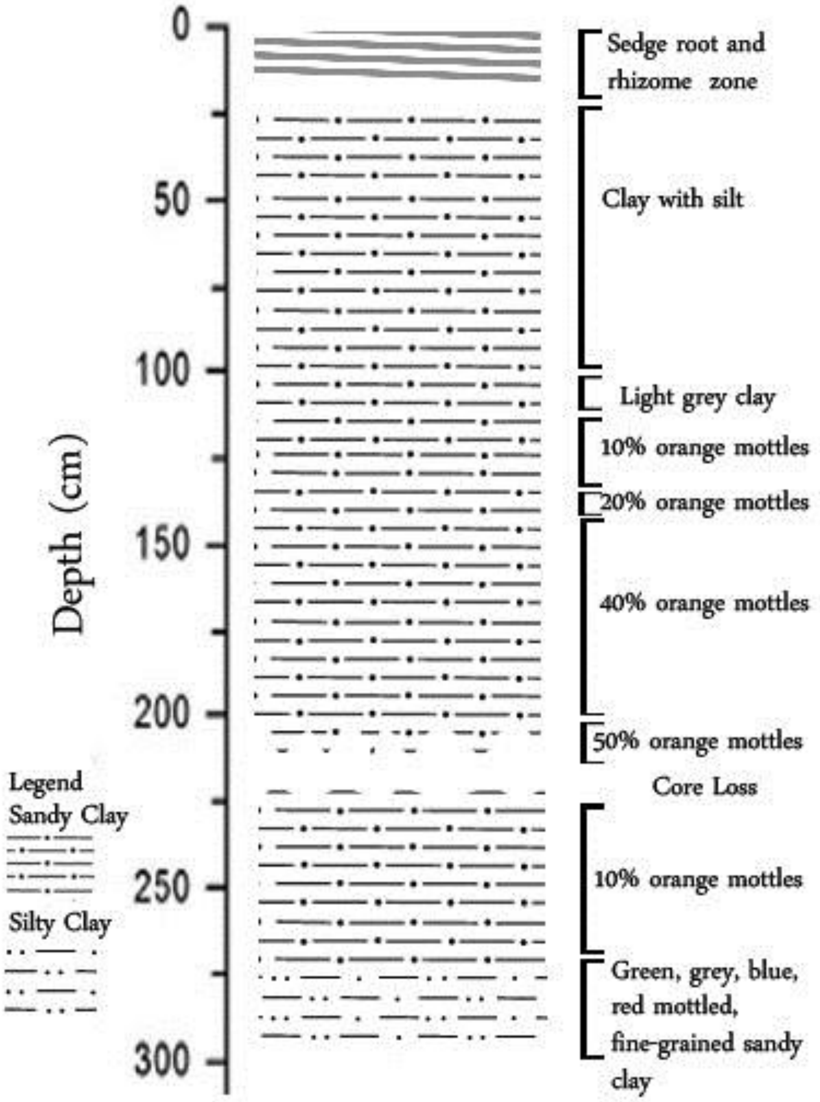


Figure 8: Stratigraphic log from the soil description of the Ntsikeni Wetland core

5.3 Chronology and sedimentation accumulation

Five AMS dates were obtained for Ntsikeni wetland (Table 4). Samples were selected to span the length of the core obtained. The dates obtained range from 5750 ±30 cal. yr BP at the mean depth of 111.75cm to 21190 ±70 cal. yr BP at a mean depth of 292.5cm. The date for Sample ID NT56 is incongruous due to possible bioturbation or contamination. However the data point was retained for input into the BACON model but was subsequently not regarded for statistical analysis. The dates indicate that the transect passes through the Holocene and past the Pleistocene-Holocene boundary to well into the Last Glacial Maximum.

Table 4: AMS radiocarbon dates acquired for Ntsikeni Wetland

Laboratory ID	Age (cal. Yr BP)	Uncertainty (yr)	Mean Depth (m)	Sample thickness (cm)	$\delta^{13}C$ (‰)
NT20	5750	30	111.75	2.5cm	-20.3
NTB	9440	30	157.5	5cm	-21.4
NT56	6390	30	203.75	2.5cm	-21.6
NTA	11150	40	234.25	5cm	-22.2
NT82	21190	70	292.5	2.5cm	-24

The BACON model approximations the mean accumulation rate throughout the Ntsikeni core sequence to 100yr.cm^{-1} (Figure 9). The BACON model also reveals a steady accumulation rate for the first ~15000cal yr. BP or to a depth of ~240cm at an accumulation rate of ~62yr.cm^{-1} and thereafter a considerably slower rate for the bottom 50cm; from ~15000cal yr. BP to until ~23000cal yr. BP at a rate of ~175yr.cm^{-1}.

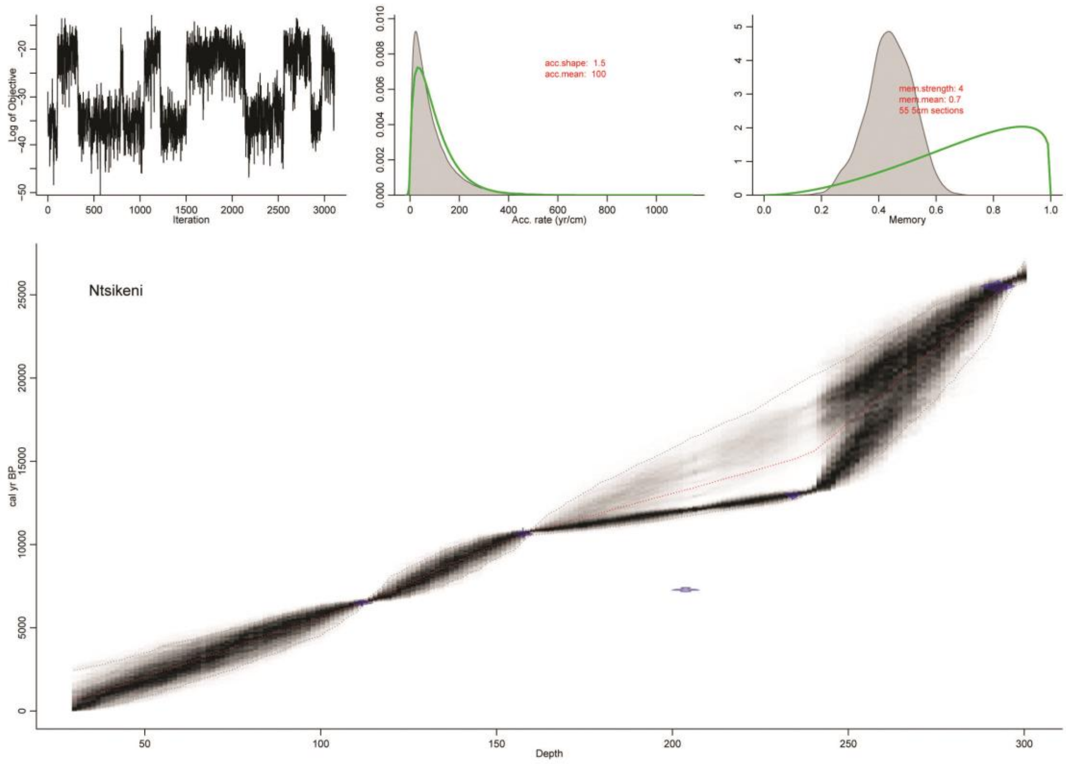


Figure 9: The BACON output for the Ntsikeni Wetland core, stating interpolated ages for depths throughout the core.

5.4 Pollen analysis

The pollen counts for the 81 samples revealed a total of 31 identifiable taxa. A small group, comprising a maximum occurrence of 4% could not be identified due to damage to the pollen grain and/or its poor representation within African pollen databases. Samples for which less than 25 grains could be counted across two slides were excluded for statistical purposes. For 17 samples, 250 or more pollen grains were counted, with relatively even distribution throughout the length of the core. A further 40 samples yielded between 25 and 249 grains

counted. Of the original 81 subsamples, 24 samples yielded less than 24 pollen grains across two slides, and a further 12 samples were completely barren.
For the purpose of this study the pollen from the families Chenopodiaceae and Amaranthaceae were combined into the “Cheno/Am” group as is routine per previously published works (Scott 2002, Fitchett et al 2016b) due to the similarity in pollen morphology as well as similarities in ecologies.

Pollen grains that were obscured by amorphous organic matter (AOM) were recorded as “Unknown” as definite identification was not possible. “Unknown” is displayed in the stratigraphic pollen diagrams, but not included in any discussion. Taxa that accounted for less than 2% of the observed grains were removed.

Poaceae pollen grains were all identified only to family level as most grass taxa share a typical morphology: subspheroidal, monoporate, annulate and psilate to scabrate (Kapp, 1969); however the average diameter of Poaceae grains was 31.06µ which is likely to illustrate pollen grains of wild grasses and not of cereals (Joly *et al.*, 2007). The sediment sampling only started at 30cm below surface (~650 cal yr. BP), therefore a lack of domestic grains is not surprising.

The Asteraceae group includes *Vernonia sp*, *Helichrysum sp*, *Stoebe*-type with the unspecified Asteraceae to form “Asteraceae”. The individual species do not account for more than 2% of the average variability; therefore they would have been excluded; however there are samples where the identified Asteraceae species (*Vernonia sp* and *Helichrysum sp)* do account for more than 2% of the variability within the sample. These samples will be investigated and described in Chapter 6 (*Environmental Reconstruction*).

The dominant pollen taxa, which were observed more than 10% on average; included Cyperaceae (35.04%), Poaceae (18.65%), Asteraceae (13.86%) and Caryophyllaceae (9.31%) (Table 5). The taxa with the lowest occurrence were; *Artemisia* (0.01%), Euphorbiaceae (0.03%) and both *Celtis sp* and ChenoAm with 0.04%.This is consistent with pollen records of wetlands within southern Africa (Norström *et al*.,, 2009). The ChenoAm group was left in the dataset as ChenoAm are part of the pollen indicators for known conditions (Scott and Nyakale, 2002)

The CONISS analysis separates the sequence into four primary zones of statistically significant similarity (Figure 10), tested through a silhouette plot. Zone WNT4 spans from termination of the core at 300cm (~25 100 cal. yr BP) to 196cm (~12 800 cal. yr BP); that denotes the transition from Pleistocene to early Holocene. The next three zones all span depths less than 60cm. Zone WNT3 at 193cm (~12 600 cal. yr BP) follows to a depth of 155cm (~10300 cal. yr BP), then Zone WNT2 to 85cm (~4400 cal. yr BP) and finally Zone WNT1 terminating at sample NT1, which is 30cm below the surface, (~650 cal. Yr BP).

Table 5: The average percentage occurrence of pollen grains in the profile, as well as the highest percentage of occurrence of pollen grains throughout the Ntsikeni Wetland profile.

Species	Ave Percentage per sample	Highest percentage observed	Sample for highest percentage
Cyperaceae	35.04	60	NT9; NT66
Apiaceae	1.36	4	NT5; NT13; NT69
Juncaceae	1.34	8	NT1
Hypoxidaceae	0.22	4	NT1; NT23
Typhaceae	2.09	12	NT69
Aponogenton sp	1.48	8	NT28
Asteraceae	13.86	37	NT7
Artemisia sp	0.01	1	NT1
Liliaceae	2.31	11	NT11; NT13
ChenoAm	0.04	2	NT11
Caryophylaceae	9.31	49	NT61
Malvaceae	0.98	7	NT49
Crassulaceae	2.23	14	NT16
Proteaceae	0.05	1	NT1; NT43; NT47; NT65
Curtisia sp	0.04	2	NT13
Orchidaceae	0.66	5	NT26; NT30
Rananculaceae	0.28	2	NT26
Ericaceae	0.17	2	NT13; NT47
Grewia sp	0.27	4	NT48; NT73
Gentianaceae	0.13	4	NT78
Combretaceae	0.10	2	NT42; NT47
Olea sp	0.04	1	NT7; NT59
Myrtaceae	0.08	3	NT28
Mimosoideae	0.43	5	NT15
Celtis sp	0.04	1	NT42; NT52; NT77
Podocarpus sp	0.64	6	NT16
Fabaceae	0.15	7	NT45
Euphorbiaceae	0.03	2	NT12
Phyllanthus sp	0.25	4	NT49
Phragmites sp	0.40	8	NT19
Poaceae	18.90	49	NT16

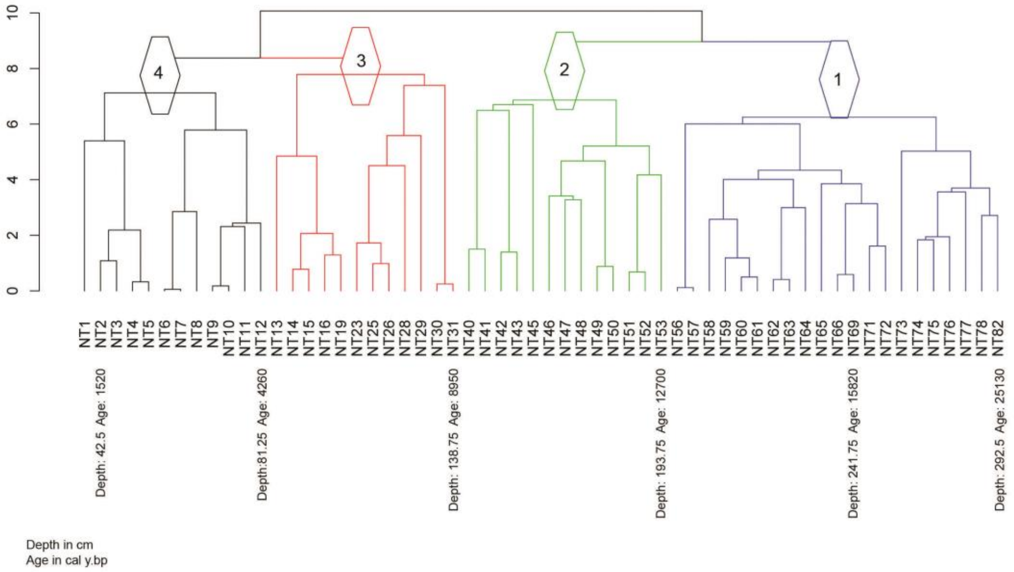


Figure 10: CONISS output showing four separate zones, centred on the relative distribution of pollen within the Ntsikeni profile.

Principle component analysis is the primary ordination method used in this study. Principle component 1 (PC1) accounts for 23.13% of the variability and principle component 2 (PC2) for 16.07% of variability observed, these descriptive tools are used to indicate main temperature (PC1) and moisture (PC2) trends. Together PC1 and PC2 account for a relatively low 39.20% of the variability. PC1 separates high negative values for Caryophyllaceae (-2.48), Typhaceae (-0.87) and Gentianaceae (-0.21), from Poaceae (1.19), Orchidaceae (0.36) and Malvaceae (0.30) with positive scores. Notably, the majority (18) of samples were clustered with PC1 scores between (value close to 0, value close to 0), with the majority of the plant taxa vectors PC2 distinctly separates semi-aquatic and wetland species with negative scores (Cyperaceae (-1.64), Apiaceae (-0.55) and

Hypoxidaceae (-014) from dry-climate taxa including grass and succulents with high positive scores (Poaceae (1.12), Caryophyllaceae (0.57) and *Podocarpus* (0.24). The "Unknown" group scored a high positive value (0.62), which indicates that the taxa included here, but not identified, will favour the same environment as the dry-climate species.

The PCA biplot (Figure 11) for PC1 and PC2 shows that the samples for WNT4 are centred on a PC2 score that is negative and PC2 score that is positive, placing it exclusively in quadrant 2. The similarity in samples is driven by the Cyperaceae and Apiaceae vectors. NT2 places mostly in quadrant 1, which shows positive values for both PC2 and PC1 and a strong similarity to Poaceae.

In the WNT2 zone sample NT28 has the greatest negative PC2 value and NT16 the greatest positive PC2 value as well as the greatest positive PC1 value. NT3 is associated with positive values for PC2, with values close to zero for PC1, which places this group into quadrant 4 and two data points in quadrant 1. NT4 plots in quadrant 3 and 4, where samples NT76, NT77, NT72, NT62 NT59, NT60, NT65 and NT78 appear to be more related to PC1 with strong negative values and values close to zero for PC2.

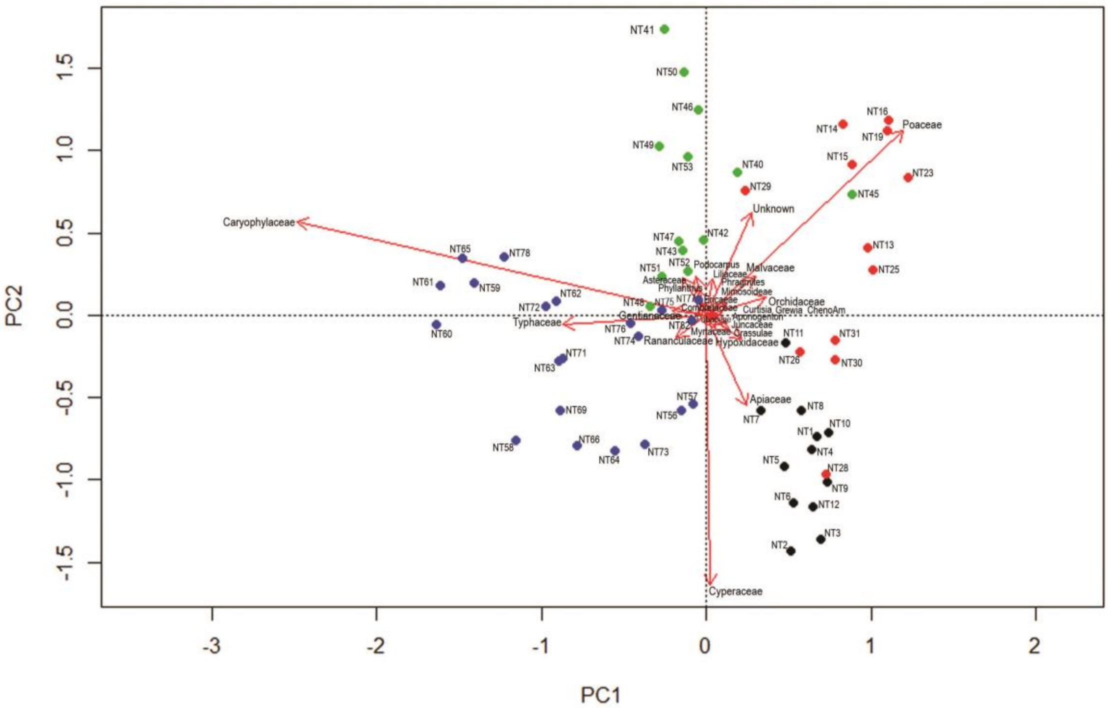


Figure 11: The PCA biplot for the Ntsikeni profile, illustrating samples and taxa along the PC1 and PC2 gradient.

From the stratigraphic pollen diagram by vegetation type (Figure 12), the relationship between different groups, and within groups, becomes evident. Throughout the stratigraphic sequence trees are present, however, Combretaceae and *Phyllanthus* are absent in zones WNT1 and WNT2. Myrtaceae is not present in Zone WNT1; however Mimosoideae and *Podocarpus* are present throughout the sequence. When the percentage composition of *Podocarpus* increases Mimosoideae decreases or is absent, Myrtaceae displays spikes in presence when *Podocarpus* and Mimosoideae decrease.

There is variance within the “Shrubs and Herbs” group: Liliaceae, Caryophyllaceae and Gentianaceae indicate marked increases of pollen presence where Asteraceae and Malvaceae decrease. ChenoAm is only present from the alteration between zones WNT2 to WNT1 with a spike at ~4,100 cal yr. BP. Fabaceae is absent in WNT2, and has a distinct incidence in WNT4, WNT3 and WNT1 which correlates closest to Typhaceae. The “Unknown” group of pollen grains reflect aspects of both Cyperaceae and Poaceae. Hypoxidaceae is not present from ~24,000 – 13,500 cal yr. BP, and from there indicates a simultaneous changes with Juncaceae and Apiaceae.

Where there is an increase in the percentage semi-aquatic pollen occurrence, there is a decline in the presence of grasses as well as some shrubs and herbs; such as Caryophyllaceae, Asteraceae and Gentianaceae. Cyperaceae exhibits a strong presence (average of 35%) throughout the sequence, only declining to less than 15% average occurrence between ~5,800 – 4,200 cal yr. BP, which inversely reflects the presence of Poaceae, which reaches highest average percentage occurrence (48%) in the same time frame. There is another decrease in Cyperaceae incidence between ~12, 100 – 11,000 cal yr. BP with an increase in Poaceae occurrence for the corresponding period. At ~6,000 cal. yr BP both Poaceae and Cyperaceae reflects a decrease in pollen present; however there is an increase of *Phragmites* average presence, which is also the time period where *Phragmites* demonstrates the highest average abundance for the entire sequence.

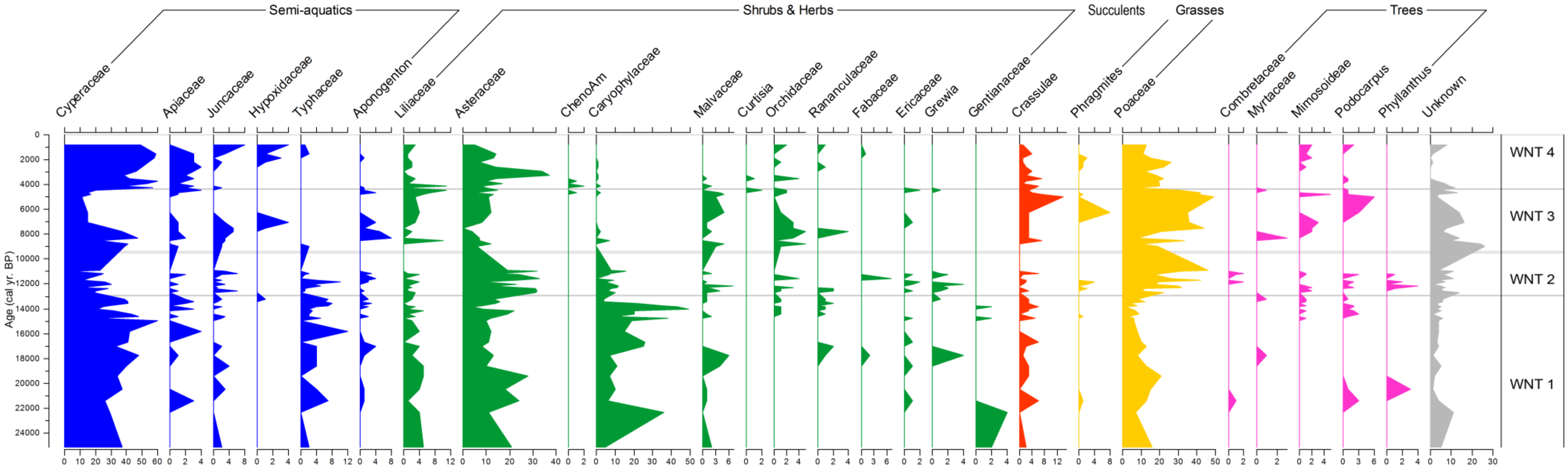


Figure 12: Stratigraphic diagram with palynomorphs grouped into types of vegetation.

Zone WNT4, 30cm – 82cm (~650 – 4,200 cal yr. BP) the average occurrence for Cyperaceae in this zone is at the highest for sample NT9 (~3,700 cal yr. BP), with an average abundance of 60%, and the lowest average occurrence for Poaceae at NT12 with an average abundance of 8% (~4,200 cal yr. BP). The lowest average occurrence for Cyperaceae is sample NT11 (~4,100 cal yr. BP) and the highest average occurrence for Poaceae within zone NT1 is sample NT4 (~2,200 cal yr. BP). Asteraceae reaches the highest average abundance of 37% at sample NT7 (~3,200 cal yr. BP) and a lowest average abundance of 5% in sample NT1. Crassulaceae peaks at NT8 (~3,500 cal yr. BP) with an average abundance of 7%. There was an absence of pollen from 140cm – 160cm (~9,100-10,700 cal yr. BP).

Zone WNT3, 84cm – 140cm (~9,000 – 4,300 cal yr. BP) the average occurrence for Cyperaceae in this zone is at the highest for sample NT28 (~8,200 cal yr. BP), with an average abundance of 47%, and the lowest average occurrence for Poaceae also at NT28 with an average abundance of 8%. The lowest average occurrence for Cyperaceae (11%) is sample NT16 (~5,000 cal yr. BP) which is where both Poaceae and Crassulaceae show the highest average occurrence within Zone WNT2, Poaceae with 49% and Crassulaceae with 14%. Asteraceae reaches the highest average abundance of 15% in sample NT13 (~4,500 cal yr. BP) and is not present at all in sample NT25 (~7,500 cal yr. BP). Caryophyllaceae reaches a highest average abundance of 7% at NT29 (~8,500 cal yr. BP).

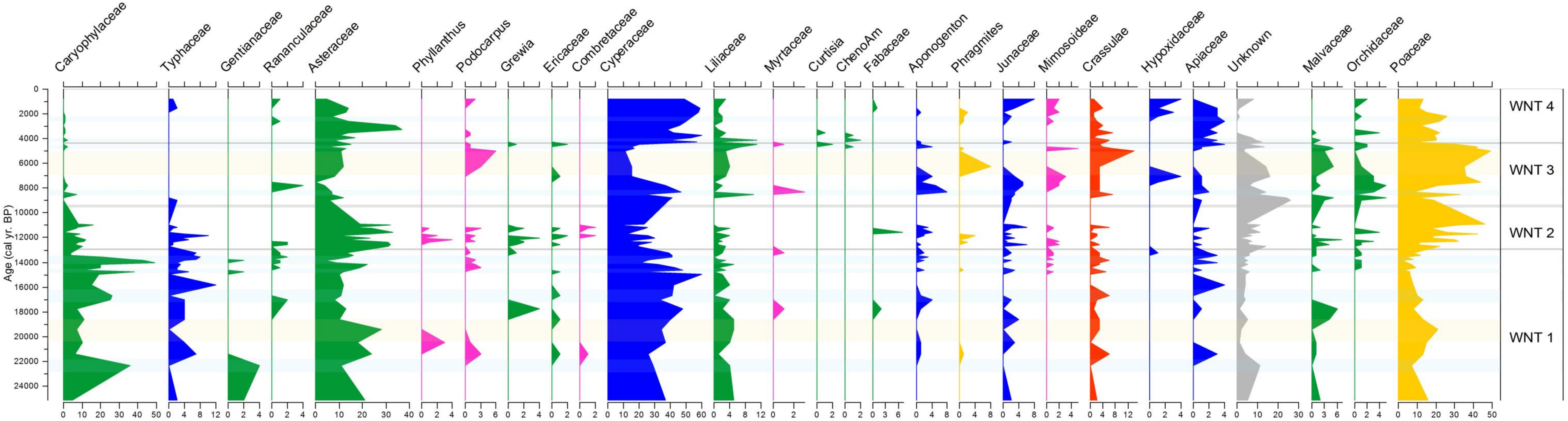


Figure 13: The stratigraphic pollen diagram for PC1

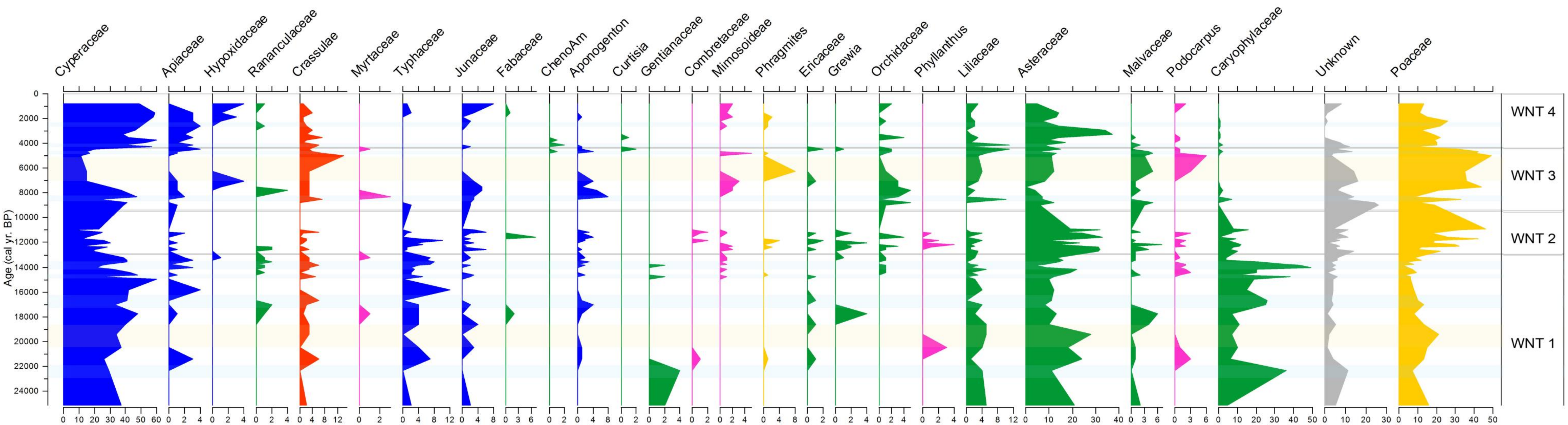


Figure 14: The stratigraphic pollen diagram for PC2.

Zone WNT2, 161cm – 192cm (~10,800 – 13,100 cal yr. BP) shows the highest occurrence of Cyperaceae (30%) at NT48 (~12,000 cal yr. BP) and the lowest occurrence of Poaceae at NT52 (~12,600 cal yr. BP) with 10% and the highest (46%) at NT40 (~10,900 cal yr. BP). Cyperaceae has the lowest abundance at NT41 (~11,000 cal yr. BP). Asteraceae is at the lowest abundance, 9%, at NT47 (~11,800 cal yr. BP) and reaches an abundance of 33% at NT45 (~11,400 cal yr. BP). Caryophyllaceae, reach the highest average abundance for this zone at NT41 (~11,000 cal yr. BP) with 16%.

The average pollen percentage is also illustrated stratigraphically by PC1 and PC2 scores (Figure 13 and Figure 14); the negative scoring taxa to the left and then grading towards the positive scoring taxa on the right. The Zone WNT1, 194cm – 300cm (~13,200 – 25,000 cal yr. BP) is the only zone where Gentianaceae is present and is at the highest average abundance at NT78 (~22,700 cal yr. BP). Caryophyllaceae is at its most prevalent in this zone and reaches a highest average abundance of 49% at NT 61 (~14,000 cal yr. BP) and occurs at an average abundance of 4% at NT56 and NT57 (~13,200 - 13,400 cal yr. BP). Cyperaceae has the highest average abundance of 60% at NT66 (~15,000 cal yr. BP) and the lowest abundance of 19% at NT53 (~12,700 cal yr. BP), which is where Poaceae has the highest relative abundance of 22%. Poaceae has the lowest relative abundance at NT60 (~13,800 cal yr. BP) with 2%.

The stratigraphic diagram, ordered by plant types, reveals interplay between the Cyperaceae and Apiaceae that have low PC2 scores, and grass and Caryophyllaceae which has high PC2 scores (Figure 14). When the stratigraphic plot is arranged by PC2 scores, the interchange between Cyperaceae, Apiaceae, and Hypoxidaceae on the one side and Poaceae, Caryophyllaceae and *Podocarpus* become evident. When the data are arranged by either PC1 or PC2 the types of vegetation are divided across the entire graph. It is apparent that all of the tree species occur intermittently. The stratigraphic plots demonstrate that all of the tree taxa peak at different times; with Mimosoideae only occurring from ~15,000 cal yr. BP, Combretaceae, with three distinct peaks, and *Phyllanthus* only occurring until ~11,000 cal yr. BP. *Podocarpus* pollen is present throughout the entire time period, but also with intermittent peaks. Myrtaceae is only present after ~19,000 cal yr. BP and only until ~4,000 cal yr. BP.

Once the data are arranged according to PC scores it is clear that the different tree taxa are spread across the scale, with *Phyllanthus* and *Podocarpus* demonstrating a closer score to Caryophyllaceae and Mimosoideae a closer affinity to Poaceae for PC1 scores. In the case of PC2 scores, Myrtaceae ranks closer to Cyperaceae and Apiaceae and *Podocarpus* ranking third on the opposite side of PC2's scale.

5.5 CONCLUSION

The data demonstrate the change in pollen assemblage, not only of specific taxa, but also the number of taxa during the temporal constraints of the samples. In the *Environmental Reconstruction Chapter* (*Chapter 6*), that follows, a possible interpretation of the data is used to reconstruct the environmental conditions. The *Discussion Chapter* (*Chapter 8*) will follow after, where possible drivers for changes in pollen abundance and taxa will be examined.

CHAPTER 6

ENVIRONMENTAL RECONSTRUCTION

[6]

6.1 INTRODUCTION

This chapter will present a palaeoenvironmental reconstruction of Ntsikeni Wetland. The reconstruction is based on the fossil pollen evidence as well as the interpretation of the sedimentation rates interpolated from the AMS dates using the BACON model. The clustering of used to divide the data into temporally constrained zones (pollen assemblage zones) is based on the output from CONISS. Firstly there will be discussion on the premises from which the pollen-derived reconstructions will be made, outlining the climatic variables most strongly aligned with key pollen taxa. This will be followed by an overview of the sedimentation rate fluctuations and a detailed reconstruction for each zone. Lastly there will be a stratigraphic pollen plot indicating the fluctuation in moisture and temperature based on different pollen types and the Principal Component (PC) score.

6.2 Pollen indicators

Coetzee and Van Zinderen Bakker (1957), Horowitz *et al.* (1978), van Zinderen Bakker (1981), Cooremans (1989), Scott (1982, 1987, 1988, 1999), and Scott and Nyakale (2002) all reported on pollen as a proxy for environmental reconstruction, and indicated that the relative abundance of certain species or taxa can be used to infer the local climatic conditions (Table 6).

According to Scott (1989), Caryophyllaceae are indicative of wet and cold environments, which are asserted by Thompson (1970), Davis (1995); Gianoli *et* *al. (*2004), and Kellmann-Sopyla and Gielwanowsk (2015). Davis (1995) states that the diversity of Caryophyllaceae results in ecological range of the taxon, especially pertaining to the precipitation range in which they can flourish, however all types are associated with colder temperatures. *Phyllanthus sp* occur in warmer areas with increased flooding in the riparian zone (Van Coller *et al.,* 1997), and *Podocarpus* is a cold-loving species (Chevalier and Chase, 2016). Ashwini *et al.* (2014) (Table 6) found that Gentianaceae are highly seasonal, demonstrating growth only during parts of the four divisions of the year with lower temperatures, and their distribution is restricted to a particular habitat - high altitude grasslands with ample sunlight and wind. The aforementioned taxa have a positive value as PC1 indicators, which reaffirms Principle Component 1 as driven by temperature (Table 6).

The seasonality of precipitation in the Drakensberg has been the point of much debate and discussion (Norström *et al.*, 2014; Fitchett *et al.*, 2016a,b; Mills *et al.*, 2017). The seasonality of precipitation in the Drakensberg mountain area will influence the type of flora; according to Carbutt and Edwards (2006), the frequent cold-season frost limits the vegetation to hardy species. Fitchett *et al.* (2016c) state that a small degree of climate change may lead to major change in vegetation composition at higher altitudes versus lower altitudes, this is due to elevation range shifts (Carbutt and Edwards, 2006). Therefore smaller climatic shifts will be more evident at high altitude sites than down-slope locations (Fitchett *et al.,* 2016b). The strength of seasonality for the eastern Lesotho highlands is driven by shifts in the Westerlies (Mills *et al*., 2012), where weakened Westerlies will result in warmer conditions due to the reduced frequency of incursion of mid-latitude cyclones. .

Seasonality of rainfall can be inferred on the basis on the ratio of Asteraceae to Poaceae pollen (Coetzee, 1967; Norström *et al.*, 2009; Fitchett and Bamford, 2017). The ratio of Asteraceae to Poaceae pollen was first proposed by Coetzee (1967), who stated a ratio score of <0.5 should be classified as SRZ and a ratio score of >0.5 as WRZ. Scott and Nyakale (2002) suggest a lower ratio score of 0.3 to distinguish between SRZ and WRZ. Fitchett and Bamford (2017) suggests that a more complex set of conditions need to be met for a region to be defined as exclusively SRZ or WRZ, from this basis they then propose the following ratio values be used as indicators of rainfall zones: ratio values >0.6 is deemed WRZ, and values <0.2 as SRZ. Fitchett and Bamford (2017) further sate that a ratio score that fall between 0.2 and 0.6 are indicative of conditions of reduced seasonal precipitation, possibly due to greater influence of the Westerlies.

Table 6: Summary of pollen type as environmental indicator.

Taxa/Species	Vegetation Type	Environmental Conditions	Reference
Poaceae	Grassland	Regional damp air, warm	Scott and Nyakale, 2002; Neumann *et al.,* 2014
Asteraceae	Shrubland	Dry, karroid, less summer rain, more likely winter rain	Scott and Nyakale, 2002; Carr *et al.,* 2006; Neumann *et al.,* 2014; Norström *et al.,* 2014
Artemisia	Shrub/Sandy	Local sub-humid conditions	Scott and Nyakale, 2002
Cyperaceae	Local semi-aquatic	Shallow water, damp soil	Scott and Nyakale, 2002; Carr *et al.,* 2006; Neumann *et al.,* 2014; Fitchett *et al.,* 2016a
Apiaceae	Local swamp (?)	Damp soil	Fitchett *et al.,* 2016a
ChenoAm	Halophytes	Dry/Saline, strong evaporation	Scott and Nyakale, 2002; Fitchett *et al.,* 2016a
Podocarpus	Forest	Relatively moist, warmer	Elenga *et al.,* 2000; Neumann *et al.,* 2014; Chevalier and Chase, 2016

Proteaceae	Mesic Savanna	Wide range temperatures, sub-humid	Elenga *et al.,* 2000; Scott and Nyakale, 2002,
Combretaceae	Plains/Savanna	Relatively warm	Elenga *et al.,* 2000,
Typhaceae	Aquatics	Shallow fresh water	
Crassulaceae	Succulent	Drier	
Hypoxidaceae	Semi-aquatic	Wet	
Caryophyllaceae	Diverse	Cold	Scott, 1989; Elenga *et al.,* 2000;
Phyllanthus	Grassland/riparian	Floodplains/warm	Van Coller *et al.,* 1997
Gentianaceae	Alpine Grassland	High sunlight and wind, high altitude grasslands	Ashwini *et al.,* 2014

The following equation was used by Fitchett and Bamford (2017) to calculate ratio scores for numerous palynological site in southern Africa:

$$Ratio_{seasonality} = \frac{Asteraceae}{Asteraceae + Poaceae}$$

This equation was also used to calculate ratio scores for Ntsikeni Wetland as part of this study.

6.3 Sedimentation rate

The rate at which sediment is deposited at Ntsikeni is not constant. The sedimentation rate from ~25,000 - 15,000 cal. yr BP is ~200yr/cm; the sedimentation rate then appears to be steady at ~60yr/cm for the remainder of the Holocene period as interpolated from BACON. Sedimentation rate will be influenced by precipitation and erosion rates (Peizhen *et al*., 2001). Langbein and Schumm (1958) suggest that sediment yield depends on fluctuations in climate and percentage vegetation cover, both due to an increase and decrease of precipitation, as well as the climate before the shift in precipitation.

6.4 Palaeoenvironmental Reconstruction

WNT1: ~25,000 - 13,000 cal. yr BP

Zone WNT1 begins with a low abundance of Asteraceae and a high abundance of Caryophyllaceae indicates cold temperatures, and the decrease in Cyperaceae, and all of the other semi-aquatics, indicate a contraction of the wetland (Figure

16). From ~22,000 - ~21,000 cal. yr BP there is a slight and sharp decrease in Caryophyllaceae and the presence of Ericaceae coupled with an expansion of the wetland as Apiaceae, Typhaceae and Aponogenton increases. The occurrence of *Podocarpus* pollen indicates a further increase in temperature as migration upslope allow for pollen to reach the high altitude wetland. During this period there is an inferred greater incidence of rainfall in winter, due to a ratio of Asteraceae to Poaceae pollen of >0.6. This is followed by a gradual increase in Poaceae, Crassulaceae and Liliaceae from ~21,000 - ~18,750 cal. yr BP indicating a further increase in temperature, *Phyllanthus* reaches a peak just as this period starts and gradually declines. The increase in the number of species further indicates the warming of temperature during this period, with a contraction of the wetland and an expansion of the grassland. Towards the end of this period it becomes wetter as the wetland gradually expands as Cyperaceae, Typhaceae and Juncaceae increase in abundance, coupled with a shift in rainfall regime as the Asteraceae to Poaceae ratio decreases. The wetland continued to expand until ~17,000 cal. yr BP when there was a short but sudden change in Cyperaceae as well as Poaceae, coupled with an increase in Caryophyllaceae indicating that there was most likely a drop in temperature as well as moisture. The decrease in species diversity during this same period supports a change in temperature.

The final two marked changes in zone WNT1 are not very prolonged but very definitive; the first of these two, at ~15,000 - 14,800 cal.yr. BP, the second, and last for Zone WNT1 ~14,000 - 13,200 cal. yr BP. Both of these events are marked with a sharp increase in Caryophyllaceae, Typhaceae and Gentianaceae; indicating a shift to colder temperatures. At ~13500 cal. yr BP possibly the coldest period, which is also supported by the decline in the species diversity for the same periods. After the last climatic shift the abundance of Caryophyllaceae continuous to decline and Gentianaceae is no longer present in the fossil record, indicating amelioration of the climate in the following three zones.

Based on the Asteraceae to Poaceae pollen ratio the entire Zone WNT1 points to an increase in precipitation during a colder season (Figure 15). This time period of increased cold and wet conditions from ~15,000-14,800 cal.yr BP, corresponds to a wet period evident at Sekhokong Range, eastern Lesotho (Fitchett *et al.,* 2016b) and a cool period from ~18,000-13,500 cal. yr BP. at Mahwaqa Mountain, KwaZulu-Natal (Neumann *et al.,* 2014).

WNT2: ~13,100 - 10,800 cal. yr BP

The wetland continued to contract until ~11,000 cal. yr BP, when Poaceae reaches a maximum abundance before starting to decline. During the same period Fabaceae and *Podocarpus* peak, about 500 years after an increase in Caryophyllaceae and Typhaceae, indicating a warmer period after a slight cooling (~10,900 - 10,700 cal. yr BP). *Podocarpus* prefer warmer climates, as the climate ameliorates slowly, tree species such as *Podocarpus* and Fabaceae can demonstrate shifts in elevation rang (Carbutt and Edwards, 2006), therefore occurring at altitudes higher than normally indicated (Carbutt and Edwards, 2006). The pollen that is indicative of more moist periods all demonstrate a decline during the entire time period for WNT2. These taxa only start to increase in abundance, along with species diversity towards the end of Zone WNT2 (~10,800 cal. yr BP) as the wetland started to expand again. The ratio scores of ratio of Asteraceae to Poaceae pollen still indicate that Zone WNT2 has increased precipitation during colder periods.

Hiatus in pollen ~9,000 - 10,700 cal. yr BP

During this time period there is a significant lack of pollen. Pollen that are present, are corroded and there is a marked increase in algal material. The state of preservation of the pollen, or lack thereof, indicates an increase in temperature during this time frame, as well as an oxidative environment that points to periodical drying (Delcourt and Delcourt, 1980; Campbell, 1999).

WNT3: ~9,000 - 4,300 cal. yr BP

There is a period of increased moisture and the expansion of the wetland from ~8,800 - 8,200 cal. yr BP. During this period there is an increase in Cyperaceae and inversely a decrease in Poaceae, however *Aponogenton*, Myrtaceae, Liliaceae and Orchidaceae reach a significant peak. *Aponogenton* is present in each zone, but reaches maximum abundance during this period before gradually decreasing. After this short wet period there is a gradual decline in Cyperaceae, a steady increase in Poaceae, but no increase in Caryophyllaceae, which indicates a decrease in moisture along with an increase in temperature as the

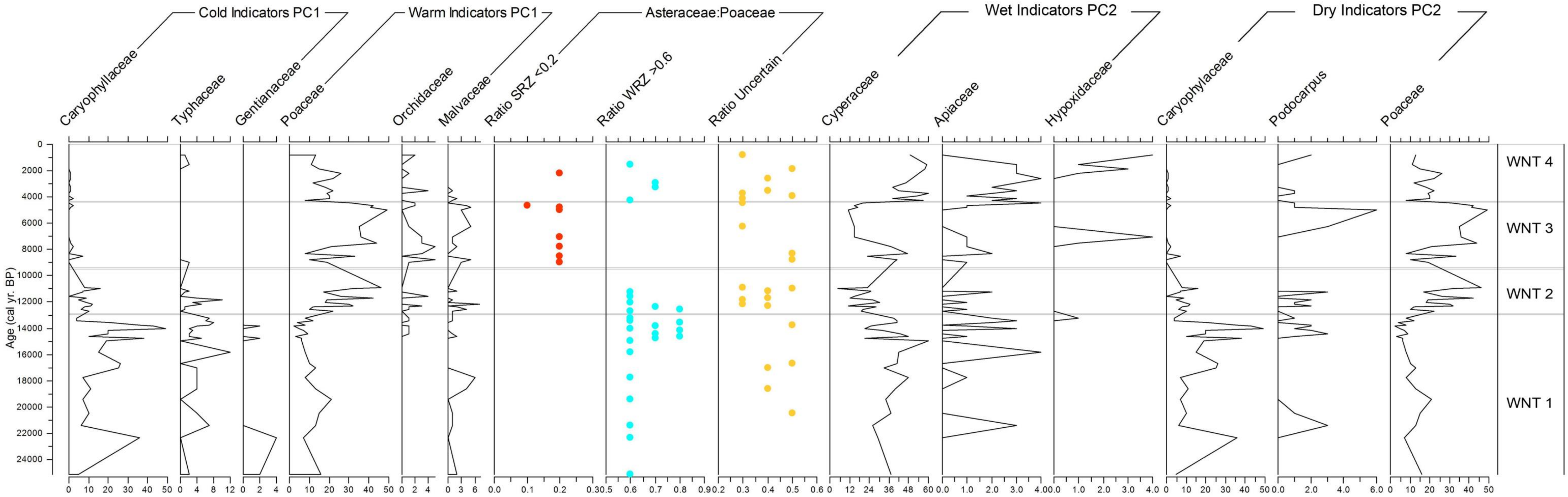


Figure 15: Stratigraphic pollen diagram by Principal Component 1 and 2, as well as the Asteraceae to Poaceae ratio to infer rainfall seasonality.

wetland contracts. An increase in Crassulaceae is observed, reaching the highest percentage abundance at ~5,100 cal. yr BP, the highest abundance of Phragmites come about in the middle of this warm period, further indicating a contraction of the wetland. The warm and drier period is lasts from ~7,000 - 5,050 cal. yr BP. Typhaceae is conspicuously absent during this zone. *Podocarpus* increase in abundance as the warmer temperatures allow for migration of the treeline upslope.

There is a very brief wet and warmer period from ~4,300 - 4,100 cal. yr BP , as the wetland starts to expand and this expansion continuing into the next zone. *Grewia* and Ericaceae are no longer present in the area after this shift. The entire Zone WNT3 display ratio scores of ratio of Asteraceae to Poaceae pollen that indicate that this zone had increased precipitation during warmer periods or undetermined seasonal rainfall, but not one sample displayed a ratio demonstrating Zone WNT3 to fall within the WRZ (Figure 15).

WNT4: ~4,200 - 650 cal. yr BP

The last zone, WNT4, demonstrates an increase in wet and warm temperatures. There are fluctuations between seasonality of rainfall, as the zone starts with increased precipitation during colder periods (Figure 15) and an increase in Apiaceae and Cyperaceae, indicating localised wet conditions. There is a short period of localised drying and evaporation as pollen representing Cheno/Am appears at low percentages. The winter rainfall continues until ~3,700 cal. yr BP, which is followed by summer rainfall, an increase temperature and a decrease in moisture as the wetland contracts and Poaceae increase along with Orchidaceae and Crassulaceae. At ~1,000 cal. yr BP there as a shift to winter rainfall, the wetland increases as the percentage abundance of Cyperaceae, Typhaceae, Juncaceae, Hypoxidaceae and Apiaceae increase.

6.5 Conclusion

This chapter provides a summary of the environmental conditions associated with the occurrence of indicator pollen. The rate of sedimentation was very slow initially and then increased, however the increased rate was still constant. The rainfall patterns based on the Asteraceae and Poaceae ratio indicates a shift in rainfall seasonality as well as changes in temperatures.

In the next chapter (*Discussion*) the environmental drivers possibly responsible for changes in the pollen assemblage will be reconnoitred. The *Discussion Chapter* will further interrogate the similarities and differences between Ntsikeni and Mahwaqa, Sekhokong and Braamhoek.

CHAPTER 7 DISCUSSION

[7]

7.1 INTRODUCTION

As pointed out in the *Literature Review* (*Chapter 2*), there still exist gaps in the Quaternary palaeoenvironmental data for southern Africa. Addressing this gap, the results of this study have been presented (*Results Chapter*) as well as a reconstruction of the palaeoenvironment based on the interpretation of the fossil pollen record (*Environmental Reconstruction Chapter*). The environmental interpretations made from fossil pollen are based on previously published reconstructions of wetlands Finch and Hill 2008; Norström *et al.,* 2009; Finné *et al.,* 2010; Truc *et al.,* 2013; Neumann *et al.,* 2014; Fitchett *et al.,* 2016a,b).

This chapter will compare the results and palaeoenvironmental inferences for Ntsikeni Wetland to those of other study sites regionally. The comparisons are to verify temporally synchronous climatic events, such as changes in seasonality, moisture and temperature.

7.2 Theoretical basis for pollen derived reconstruction

7.2.1. Pollen

The palaeoenvironmental reconstruction for Ntsikeni was based on pollen analysis, which remains the most widely used proxy in southern Africa (Fitchett et al., 2017). The dominant pollen taxa identified were Cyperaceae (35.04%), Poaceae (18.65%), Asteraceae (13.86%) and Caryophyllaceae (9.31%). Cyperaceae is a semi-aquatic plant family, and a change in Cyperaceae pollen abundance relative to non-aquatic-species pollen abundance reflect an increase in moisture (a wetter climate) and an expansion of the wetland (Norström *et al.*. 2009). The family of grass species, Poaceae, form part of the Drakensberg Alpine Centre grasslands (Carbutt and Edwards, 2004; Neumann *et al.,* 2014) and a relative increase of Poaceae pollen abundance is indicative of an increase of grassland extent within the wetland system (Neumann *et al.,* 2014) and coupled with a decrease in Cyperaceae indicates a contraction of the spatial extent of the wetland (Van Zinderen Bakker, 1955; Neumann *et al.,* 2014; Fitchett *et al.,* 2016a). The abundance of Asteraceae, as with Poaceae, is investigated in comparison to the abundance of other dominant species, as both Asteraceae and Poaceae occupy diverse ecological ranges (Chase *et al.,* 2009; Scott, 2012). However, seasonality of rainfall can be inferred on the basis on the ratio of abundance of Asteraceae pollen to Poaceae pollen (Coetzee, 1967; Norström *et al.,* 2009; Fitchett and Bamford, 2017).

The diversity of species was also taken into account, where a greater diversity of species was taken to indicate warmer periods (Fitchett *et al.,* 2016a). The rest of the pollen at Ntsikeni Wetland comprised of a number of different plant families in lower percentage abundance. Families such as Typhaceae, Hypoxidaceae, *Aponogenton* and Gentianaceae are also semi-aquatic, therefore an increase their abundance demonstrates an increase in moisture, which will be an expansion of the wetland and possibly shallow standing water (Scott and Nyakale, 2002; Fitchett *et al.,* 2016b). Cheno/Am (Chenopodiaceae and Amaranthaceae counts combined) is indicative of conditions with increased evaporation (Scott, 1999). There is no pine pollen present in the sequence, however the sequences terminates at ~650 cal. yr BP , and according to Van Wilgen and Richardson (2012) pine was introduced to southern Africa around 300 years ago. Pollen percentages were arranged according to broad ecological groups (Trees, Shrubs, Semi-Aquatics and Succulents) and abundance was plotted against age and not depth.

PCA offers an interpretation of the similarities between species, without human bias in pattern recognition (Stevenson and Pam, 2004). PC1 accounts for highest percentage of the variability and separates high negative values for Caryophyllaceae, Typhaceae and Gentianaceae from Poaceae, Orchidaceae and Malvaceae with positive scores. PC2 for 16.07% of variability observed and distinctly separates semi-aquatic and wetland species with negative scores (Cyperaceae, Apiaceae and Hypoxidaceae) from dry-climate taxa including grass and succulents with high positive scores (Poaceae, Caryophyllaceae and *Podocarpus*). The descriptive tools were interpreted to indicate main temperature (PC1) and moisture (PC2) trends.

The "Unknown" group scored a high positive value (0.62), which indicates that the taxa included here, but not identified, will favour the same environment as the dry-climate species.

7.2.2 Environmental reconstruction

The CONISS analysis separates the sequence into four primary zones of statistically significant similarity:

WNT1: ~25,000 - 13,000 cal. yr BP

WNT2: ~13,100 - 10,800 cal. yr BP

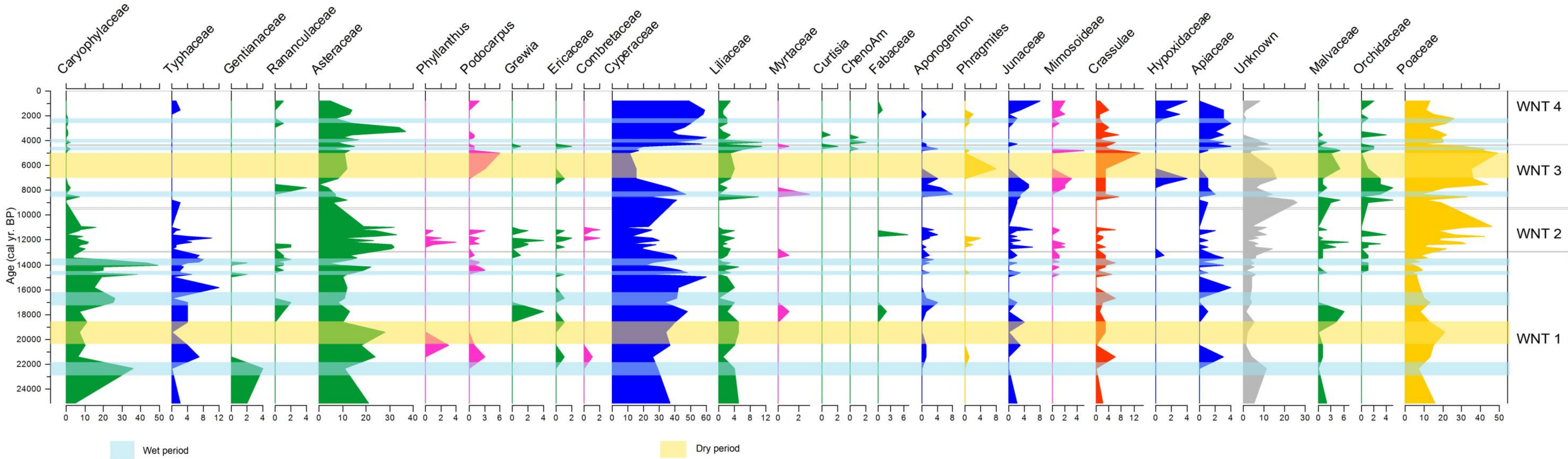
Hiatus in pollen ~10,700 - 9,000 cal. yr BP

WNT3: ~9,000 - 4,300 cal. yr BP

WNT4: ~4,200 - 650 cal. yr BP

Within these zones there are fluctuations of moisture and temperature (Figure 16). Figure 16 demonstrates the periods of fluctuations based on the changes in richness of pollen for species of PC1 and PC2. The blue lines indicate wetter periods and the yellow are indicative of drier time periods.

Figure 16: Pollen stratigraphic diagram indication periods of climate fluctuations.



7.3 Comparison with regional sites

There are a number of palaeoenvironmental sites in KwaZulu-Natal (Figure 17), including Mfabeni peatland (Finch and Hill, 2008), Lake Sibaya (Neumann *et al.,* 2008) and Lake Eteza (Neumann *et al.*, 2010). These sites are situated at 14m. asl and in close proximity to the Indian Ocean. The topographic differences between Ntsikeni and the aforementioned sites will greatly influence the pollen assemblage of the sites, and the therefore these sites will not form part of this discussion. The Drakensberg-Maloti wetland sites that will form part of the discussion are Mahwaqa (Neumann *et al.,* 2014), Sekhokong (Fitchett *et al.,* 2016b), Mafadi (Fitchett *et al.,* 2016a) and Braamhoek (Norström *et al.,* 2009, 2014; Finné *et al.,* 2013) (Figure 17).

These sites will be discussed in terms of the time frame the profiles span, the similarities between pollen identified and pollen used to infer the palaeoenvironmental changes, as well as the fluctuations in climate and the possible drivers for these changes (Table 7).

Each site will be discussed in relation to Ntsikeni and then the possible drivers of climatic fluctuations for all of the sites will be discussed as a separate combined impression.

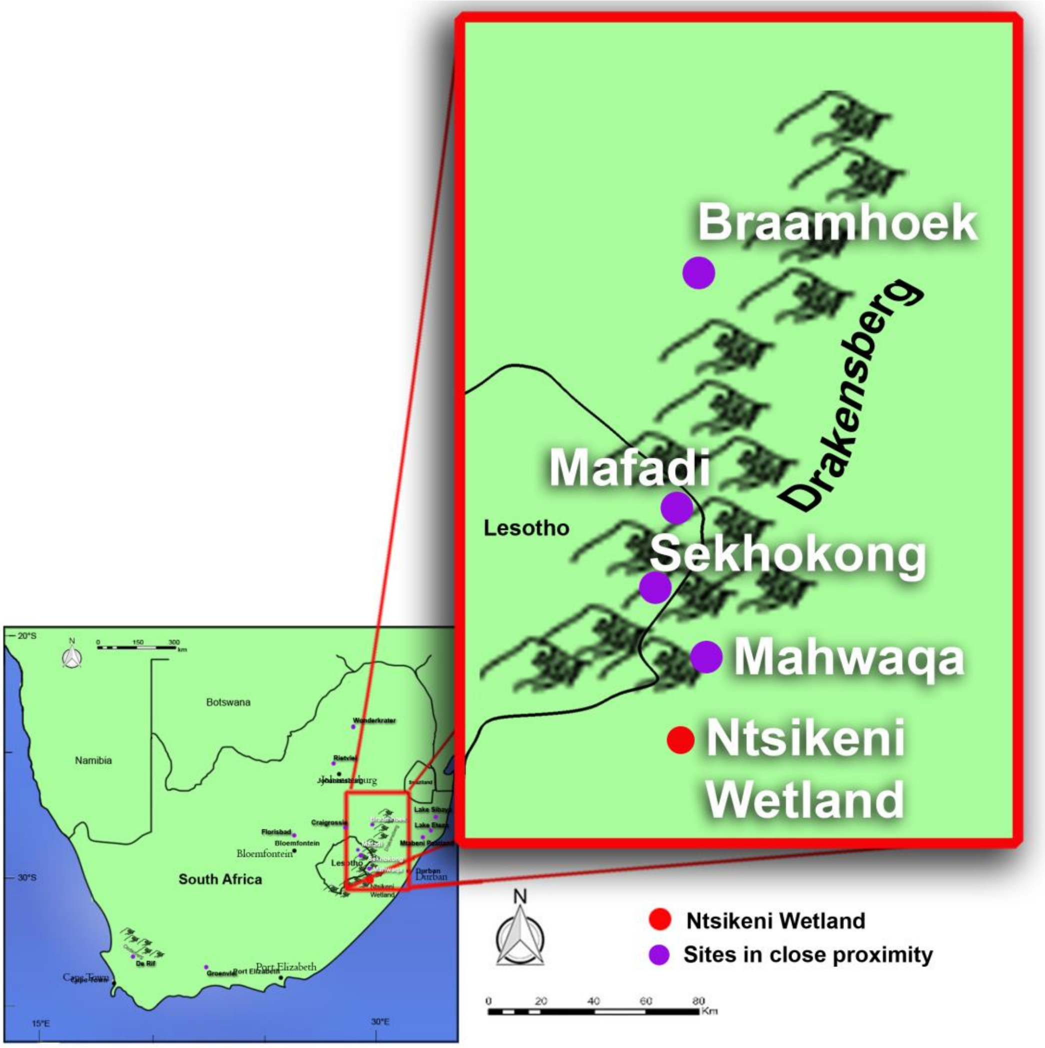


Figure 17: Well-known palaeoenvironmental study sites located close to Ntsikeni Wetland.

7.3.1 Mahwaqa Wetland

Neumann *et al.* (2014) undertook a palaeoenvironmental reconstruction based on pollen, charred particles and spores. Neumann *et al.* (2014) based temperature and moisture changes at Mahwaqa Mountain on the PCA scores for the pollen in the profile, fern spores were included with pollen to complete PCA at Mahwaqa Mountain (Neumann *et al.,* 2014), where it was excluded from

Ntsikeni Wetland PCA analyses due to errors arising from multivariate analysis incorporating multiple proxies (Juggins, 2013).

Many of the climatic inferences within each of the CONISS zones are based more on fungal remains and charred particles than the PC scores of the pollen in the record; however only the pollen will be used for the comparison and discussion of Ntsikeni Wetland and Mahwaqa Mountain.

As with Ntsikeni Wetland, Cyperaceae and Poaceae pollen dominate the pollen sum, and changes of relative abundance of these two pollen types are interpreted as changes in moisture (Neumann *et al.,* 2014). Changes in Poaceae pollen abundance at Ntsikeni also indicated a change in temperature, therefore a shift in abundance relative to Cyperaceae indicates changes in moisture, and a shift relative to Caryophyllaceae indicates a change in temperature. The profile for Mahwaqa contains a large fynbos constituent, which Neumann *et al.* (2014), interprets as periods of cooler temperatures. The time frame for Mahwaqa Mountain spans ~18,017-~8 cal. yr BP (Neumann *et al.,* 2014), whereas the profile for Ntsikeni spans from ~25,000-650 cal. yr BP.

Table 7: Comparison between regional sites.

cal. yr BP	Ntsikeni Wetland	Mahwaqa Mountain Neumann *et al.*, 2014	Sekhokong Fitchett *et al.*, 2016b	Mafadi Wetland Fitchett *et al.*, 2016a	Braamhoek Wetland			Global Climatic Events
					Norström *et al.*, 2009	Finné *et al.*, 2013	Norström *et al.*, 2014	
	No data	Dry, anthropogenic influence	Only 2 samples, anthropogenic influence	Fluctuating				
1,000	Wet & Warm period ~1000 wetter	1000 wetter			Wet	Wet	Wet	
2,000			Fluctuations between wet and dry	2000: SRZ, warm, dry				MWP LIA
3,000	2,800: decrease in temperature	Wet, warm	Dry: 3260, 2690, 1380 Wet: 3260 - 3190, 3050	Cooling post altithermal				2.8 KYR Cold Event
4,000		Dry, with a wet period 4000		1000: Wet, warm 4500: Dry 6500: Dry 6750: Dry		Dry	Dry	4.1 KYR Cold Event
5,000	4100: decrease in temperature	Warm, wet	Dry, cool					
6,000	4300 - 4100: wet, warm	5750: Dry 6750: Dry	⇧ Wet	7000: Warm				
7,000	7000 - 5500: warm, dry		8560 - 7280: warm	Wet/dry Possible ice				
8,000				Hiatus in pollen Wet, cold				Altithermal 8200 Event
9,000	*No WRZ				Dry	Wet		
10,000	Hiatus in pollen	11700 warm, SRZ	14150: Dry		Wet		Wet	
11,000	Wet, warm	Generally wet, seasonal dryness	15630 - 14440: wet				Dry	Holocene
12,000	⇧		16350 - 15870: Dry		Dry	Dry	Wet	Younger Dryas
13,000	13500: coldest Dry, cold *No SRZ				Wet	Wet		
14,000	15000 - 14800: cold, wet							African Humid Period
15,000		Wet, cool, WRZ			Dry			
16,000	Cold & dry; periods of fluctuations in moisture	Open landscape	Cool					
17,000								
18,000			No data					H-1
19,000	20500 - 18500: warm, wet	No data						
20,000								
21,000								
22,000	23000 - 22000: Cold							
23,000								
24,000	*No SRZ							H-2

The Mahwaqa Mountain record starts with a cool and wet period, with open landscapes and increased precipitation during colder periods from ~18,000-13,500 cal. yr BP based on the abundance of *Erica* and Restionaceae pollen (Neumann *et al.,* 2014). This same period at Ntsikeni Wetland is marked with fluctuations between wet and cool periods, and wet and warmer periods with an increase in precipitation during colder periods and three periods of non-seasonal rainfall. The sharp increase in abundance of Caryophyllaceae pollen indicates that ~13,500 cal. yr BP was possibly the coldest period at Ntsikeni Wetland.

The Mahwaqa profile indicates warming from ~13,500 cal. yr BP, with the warmest period at ~7,500 cal. yr BP; further indications are for generally wet conditions with periods of seasonal dryness (Neumann *et al.,* 2014). There is mention of shifts from WRZ to SRZ based on a decrease in Ericaceae pollen and established grassland at Mahwaqa; however there is mention of Cyperaceae and *Cliffortia* pollen that "spread in and around the wetland" (Neumann *et al.,* 2014), indicative of wetness. Mahwaqa stood out in Fitchett and Bamford (2017), as having a ratio of Asteraceae to Poaceae pollen much lower than any surrounding area, making WRZ conditions at any point during this time unlikely. During this time period Ntsikeni shifts from dry, warm conditions to wet, warm conditions from ~13,100-10,700 cal. yr BP. This period is followed by a hiatus in pollen from ~10,700-9,000 cal. yr BP, which indicates further warm and periodical drying. From ~8,500-4,600 cal. yr BP the Mahwaqa Mountain record proposes warm conditions, but fluctuations in moisture (Neumann *et al.,* 2014); this coincides with the record at Ntsikeni where the period from ~9,000-4,300 cal. yr BP is warm and wet, with SRZ conditions.

There is a period of warm and dry conditions from ~7,000-5,500 cal. yr BP at Ntsikeni wetland, which again corresponds to two warm periods at Mahwaqa Mountain - ~6,750 cal. yr BP and ~5,750 cal. yr BP. The driest period at Mahwaqa Mountain appears to be from ~4,600-3,500 cal. yr BP (Neumann *et al.,* 2014), during this period in the Ntsikeni record there are distinct cold and dry periods, with localised evaporation, followed directly by warm and wetter climates. Both the records indicate wet periods at ~4,000 cal. yr BP and ~1,000 cal. yr BP. The period from ~3,500-800 cal. yr BP at Mahwaqa Mountain is wet and warm, once again coinciding with the record at Ntsikeni. The Mahwaqa Mountain record terminates in a wet climate with indications of anthropogenic influences (Neumann *et al.,* 2014). However, the record at Ntsikeni Wetland terminates at ~650 cal. yr BP following a period of increasingly wetter conditions.

The consistent similarities between Mahwaqa Mountain and Ntsikeni Wetland may indicate that the local topography did not present such a great influence as the westerlies on a regional scale (Chase and Meadows, 2007). The differences in seasonality of rainfall between the sites maybe due to the different methods utilised to calculate the seasonality.

7.3.2 Braamhoek Wetland, Mafadi Wetland, Sekhokong

The palaeoenvironmental record for Braamhoek Wetland is investigated in three different papers, firstly Norström *et al.* (2009), using pollen, charcoal and isotope results as proxies; this is followed by diatom and phytolith analysis by Finné *et al.* (2010), and a re-examination of the pollen record, together with mineral magnetic properties and biomarkers (Norström *et al.* (2014). The three papers define different climatic periods and differ on the periods of decreased and increased moisture. All three records start toward the end of Zone WNT1 of Ntsikeni Wetland, and will be compared to Mafadi Wetland (Fitchett *et al.,* 2016a), Sekhokong (Fitchett *et al.,* 2016b), and Ntsikeni Wetland. It must be noted that not all the reconstructions utilise the same proxies, and some reconstructions uses multiple proxies, whereas Ntsikeni Wetland only uses pollen as a proxy.

The wealth of planktonic diatoms at ~13,600 cal. yr BP, 11,300 cal. yr BP, and 10,400 cal. yr BP at Braamhoek, indicates wet periods (Finné *et al.,* 2013), of which only one – ~13,600 cal. yr BP coincides with wet conditions at Sekhokong (Fitchett *et al.,* 2016b). During this time period Norström *et al.* (2009), indicates dry climate from ~16,000-13700 cal. yr BP, with a wet period from ~13,700-12,800 cal. yr BP followed by a dry period from ~12,800-10,500 cal. yr BP, the Sekhokong record indicates drier conditions until ~9,000 cl. yr BP (Fitchett *et al.,* 2016b); the Ntsikeni Wetland palynological record indicates cold and wet conditions at ~13,500 cal. yr BP, fluctuations, with a slight decrease in moisture with each cycle, between ~13,000-11,000 cal. yr BP. This shows similarities with the record by Norström *et al.* (2014), where there is wet period from ~13,500-12,600 cal. yr BP; followed by a dry period until ~11,300 cal. yr BP.

The wet event, 11,300 cal. yr BP, inferred from the diatoms at Braamhoek Wetland (Finné *et al.,* 2013) does not correspond to any of the other records discussed here (Norström *et al.,* 2009, 2014; Fitchett *et al.,* 2016a, 2016b). The pollen and charcoal record from Braamhoek (Norström *et al.,* 2009) indicate a wet period from ~10,500-9,500 cal. yr BP, with pollen, charcoal, mineral magnetic properties, and biomarkers (Norström *et al.,* 2014) indicating the wet period from ~10,200-8,500 cal. yr BP, which coincides with Finné *et al..* (2013). The pollen record for Ntsikeni Wetland has a hiatus in pollen from ~10,700-9,000 cal. yr BP which might be due to warm and wet conditions; there is a constant increase in moisture from ~9,100-8,700 cal. yr BP, with a short dry event from ~8,700-~8,200 cal. yr BP which directly followed by a wet event at ~8,000 cal. yr BP. The record for Mafadi Wetland (Fitchett *et al.,* 2016a) starts at ~8,200 cal. yr BP with wet and cold circumstances until ~7,250 cal. yr BP.

The record at Sekhokong indicates a dry period at ~7,460 cal. yr BP, but has many periods of fluctuating between wet and dry conditions until ~1,200 cal. yr BP (Fitchett *et al.,* 2016b). The dry periods are: ~3,260 cal. yr BP, ~2,690 cal. yr BP, ~1,380 cal. yr BP and the wet periods during the this period are: ~3,260-3,190 cal. yr BP and ~3,050 cal. yr BP (Fitchett *et al.,* 2016b). The diatom and pollen record at Mafadi Wetland also indicate periods of fluctuations between wet and dry until ~1,000 cal. yr BP (Fitchett *et al.,* 2016a). The Braamhoek record based on phytoliths and diatoms (Finné *et al.,* 2013) indicate a dry period from ~8,000-2,000 cal. yr BP, however the record based on pollen, charcoal, biomarkers and mineral magnetic markers (Norström *et al.,* 2014) reflects the dry period from ~7,000-2,000 cal. yr BP and the record based on pollen from Ntsikeni Wetland indicates a dry period from ~7,000-4,200 cal. yr BP.

The pollen record at Ntsikeni further indicate that the period from ~4,100-650 cal. yr BP is wet with short periods of dryer climates, not lasting more than ~100 years, which overlaps with the Mafadi Wetland record based on diatoms (Fitchett *et al.,* 2016a). Two records for Braamhoek (Norström *et al.,* 2014; Finné *et al.,* 2013) indicate a period of wet climate from ~1,000 until the present, however this is in contrast to the diatom record from Sekhokong that indicates a dry period (Fitchett *et al.,* 2016b) as well as the record from Mafadi Wetland (Fitchett *et al.,* 2016a) which also shows a dry record until ~250 cal. yr BP. The difference between the sites might be due the proxies used, where diatoms may respond more swiftly to a change in moisture than pollen. There are differences between the palaeoenvironmental reconstructions derived from different proxies at Braamhoek Wetland that raise concern as to the accuracy of the data presented.

7.4 Comparison of global climatic events

There are numerous factors that will influence the palaeoenvironmental and palaeoclimate conditions of an area, such as topography, altitude, and the modern environment (Scott, 2002; Chase and Meadows, 2007). Currently the climatic events of the Northern Hemisphere are well documented (Matthes, 1939; Herbert, 1987; Grove, 1988; Peteet, 1995; Brook *et al.,* 1999; Abell and Plug, 2000; Tyson *et al.,* 2000; Holmgren *et al.,* 2003; Mayewski *et al.,* 2004). The next step would be to investigate whether the climatic events illustrated in the pollen record of Ntsikeni Wetland reflect any, all or some of the global climatic events (Table 8).

The record for Ntsikeni Wetland commences at ~25,000 cal. yr BP in the LGM, with a cold period at ~22,500 cal. yr BP, and at ~ 13,500 cal. yr BP the coldest period for the entire record is reconstructed. The termination phase of the deglaciation following the LGM is at ~13,000 cal. yr BP (Holmgren *et al.,* 2003), which coincides with a new statistical zone, Zone WNT3, at Ntsikeni Wetland. This change is marked by a colder and drier climate until about ~11,000 cal. yr BP, as indicated by a marked increase in Caryophyllaceae pollen.

This time period overlaps with the Younger Dryas, which is typically described as cooler temperature after the LGM warming event driven by melt water pulses (Mayewski *et al.,* 1996; Abell and Plug, 2000) and was describe in South Africa by Thackeray and Scott (2006) after re-analysis of the Wonderkrater pollen data.

The Younger Dryas in South Africa is further supported by isotope records from hyrax middens in the Cederberg (Quick *et al.,* 2011; Chase *et al.,* 2015). Even though the event was positioned predominantly in the Northern Hemisphere, there is a growing body of evidence to support the synchronised depression in temperature in southern Africa.

The ‘8.2kyr’ event (Mayewski *et al.,* 2004), was also driven by melt water pulses in the Northern Hemisphere, and resulting in colder conditions with the freshening of the Thermohaline Circulation (Alley and Ágústsdóttir, 2005). Ntsikeni Wetland displays a short cold event at ~8,500 cal. yr BP, as Caryophyllaceae pollen spikes again. Holmgren *et al.* (2003), also provide evidence for the ‘8.2kyr’ event based on the speleothem record at Makapansgat.

The warming period connected to deglaciation endures until the Holocene Altithermal (Wanner *et al.,* 2015); however, the timing of the Holocene Altithermal is still not clear. The Altithermal is in the Mid-Holocene from ~7,500-6,500 cal. yr BP (Truc *et al.,* 2013; Neumann *et al.,* 2014; Wanner *et al.,* 2015). There is an increase in abundance of Poaceae and Crassulaceae pollen from ~7,000-5,500 cal. yr BP in the Ntsikeni Record. The absence of Caryophyllaceae, coupled with the increase in Poaceae pollen indicates warm conditions.

Table 8: Summary of global climatic events.

Name	Approximate Age	South African Climate conditions	References
Holocene Stage	11.5 ka to present		
Neoglacial	5ka-AD 900		Porter and Denton, 1967
Medieval Warming Period (MWP)	AD 800–1500		Lamb, 1965
Little Ice Age (LIA)	1500 – 1900 A.D (Northern Hemisphere) AD 1300-1800 (South Africa)	Climatic conditions unclear, WRZ wet, SRZ dry	Matthes, 1939; Herbert, 1987; Grove, 1988; Brook *et al.,* 1999; Tyson *et al.,* 2000; Holmgren *et al.,* 2003
Maunder Minimum	AD 1645-1719	Coldest period during LIA	Eddy, 1976
Hypsithermal	Early to mid-Holocene		Deevey and Flint, 1957; Davis, 1984
Altithermal	Mid-Holocene		Meltzer, 1999
African Humid Period	~14,800 – 5,500 cal. yr BP	More moist than preceding period	Chase *et al.,* 2009; Burrough and Thomas, 2013
Younger Dryas	~13,000 – 11,500 cal. yr BP	Cooler after LGM warming event, conditions varied regionally (wet vs dry)	Abell and Plug, 2000; Peteet, 1995; Holmgren *et al.,* 2003; Thackeray and Scott, 2006; Truc *et al.,* 2013
8.2 kyr Event			Smith *et al.,* 2002
4.1 kyr Cold Event		Cooler temperatures	Mayewski *et al.,* 2004; Wanner etal., 2015
2.8 kyr Cold Event		Cooler temperatures	Mayewski *et al.,* 2004; Wanner etal., 2015

Last Glacial Maximum (LGM)	Still debated – broadly 24,000-17,000 cal. yr BP	Glaciation	Metcalfe, 1993; Partridge *et al.,* 1999; Scott, 1982, 2012 1999; Boelhouwers and Meiklejohn, 2002; Holmgren *et al.,* 2003; Carr *et al.,* 2006; Chase and Meadows, 2007; Thackeray and Scott, 2007; Mills *et al.,* 2012; Nörtsrom *et al.,* 2014; Neumann *et al.,* 2014;
Daansgaard Oeschger cycles (D-O)	25 events, every 1-2kyr	Abrupt warming, drier conditions in Northern Hemisphere, wetter in Southern Hemisphere	Bond *et al.,* 1992; Benson *et al.,* 1996; Allen *et al.,* 1999; Wagner *et al.,* 2010; Wang *et al.,* 2001; Leduc *et al.,* 2007; Kanner *et al.,* 2012
Heinrich-2 (H-2)	26,000-24,000 cal. yr BP		Hemming, 2004; Wang *et al.,* 2006;
Heinrich-1 (H-1)	17,500-16,500 cal. yr BP		Hemming, 2004; Wang *et al.,* 2006

The ‘4.1kyr’ cold event (Mayewski *et al.,* 2004; Wanner *et al.,* 2015) resulted in colder and drier period identified arguably as one of the late Bond Cycles. Ntsikeni Wetland displays a short cold event at ~4,000 cal. yr BP, as Caryophyllaceae pollen spikes again, however ChenoAm spikes as well, and most of the pollen decreases bring the record to low species diversity.

The record for Ntsikeni Wetland does not indicate specific evidence to support the Little Ice Age - a very short cold period from ~1,300-1800 cal. yr BP (Eddy, 1976; Tyson *et al.,* 2000; Wanner *et al.,* 2008, 2015) - in South Africa; it does however appear to weakly resonate the Medieval Warming Period (MWP) from AD800-1500 (Wanner *et al.,* 2008). The warmer conditions are inferred from an increase in Apiaceae, Hypoxidaceae and Orchidaceae pollen; however the period is also very wet as Cyperaceae pollen also increases to the second highest point of abundance in the record.

7.5 Limitations of the study

There are a number of recurring limitations in the field of palynology. This section will focus on limitations – both encountered and preserved – of this study.

7.5.1 The dating of samples

The financial constraint placed on the number of samples that could be utilised for dating forces the samples to be spaced evenly throughout the core. This spacing may influence the robustness of the dating set. In the case of this study, a date was returned that indicated contamination of the sample that was sent for dating. The error created a gap in the data, which in turn may have had an influence on the statistical analysis as there were only five points to commence with. The data obtained from the five samples sent for AMS dating were utilised to generate a Bayesian age-depth model, which temporally constrained data. The lacks of sufficient AMS dated points create greater variation in the possibilities of sedimentation rate. Sedimentation rate is also used as an indicator of change in climatic conditions; hence the greater variance leads to the possibility of over simplification of data and the inferred conditions.

7.5.2 Identification of pollen

Currently there is no single online pollen reference database available in South Africa. Pollen grains were identified using numerous different databases, from different continents. The photographs used to identify the pollen at Ntsikeni Wetland may not have resembled all of the angles possible for a pollen grain, which may lead to erroneous identification. The sample core transects into very recent pollen, in an area close to the DAC, which has numerous endemic species that are not well represented on online databases. The endemic nature of the flora of the DAC also hampered identification as not many palynologists are familiar with the floristic region. The misidentification or lack of identification of certain species may have had an influence on statistical analysis, as species may have been disregarded due to an abundance of less than 2%, and therefore being excluded from all statistical analysis.

The identification of pollen only to genus or family levels may also influence the inferences made about the pollen present. At the DAC more than 430 species of Asteraceae have been identified (Carbutt and Edwards, 2003) with differences in ecological preferences between species of Asteraceae (Rosbakh and Poschlod, 2015). It becomes evident then, that identification should ideally occur to species level, for all pollen. However, this is not always possible and pollen is only identified to family level, creating a blanket effect that groups all of one family together, regardless of the differences in ecological preferences.

7.5.3 Preparation methods

Standardised laboratory methods for pollen extraction does exist (Faegri *et al.*, 1989), however these apply to samples that are not rich in clay. The samples from Ntsikeni Wetland were very rich in clay and silt, which initially hampered the effectiveness of the HF to remove silicates from the sample. Initially samples still contained high concentrations of silica rich elements, such as phytoliths and silicate minerals.

The standard preparation method was adapted, and samples were agitated for longer periods of time to allow better infiltration of chemicals during the process. This increased agitation may have led to the destruction or deterioration of pollen grains, which in turn would have hampered accurate identification.

7.5.4 Contamination of samples

The laboratory used for pollen preparation was also used by other palynologist at the same time that the samples for Ntsikeni were prepared. Cross contamination from different sites are very likely as space is sparse and the number of samples abundant; however the removal of pollen with an abundance of less than 2% should negate contamination. When the samples were collected at Ntsikeni Wetland there is a possibility for contamination of the terminating end of the core by sediment from the top of the core.

Possible contamination should not have a great influence on the high abundance species, however for arboreal species, occurring in low abundance, this may conceivably be a problem.

7.5.5 Use of a single proxy

Different proxies are useful in very specific conditions, for example phytoliths are predominantly valuable for grasslands and diatoms are aquatic and therefore only present in sediment from previous aquatic environments, and speleothems are only available in caverns and caves.

Pollen was used as a single proxy due to financial and time constraints. It would be ideal if the materials from Ntsikeni Wetland are further investigated using extra proxies, such as diatoms and sediment analysis. A multi proxy approach to the palaeoenvironmental reconstruction of Ntsikeni Wetland will ensure better interpretation of the pollen data.

CHAPTER 8 CONCLUSION

[8]

8.1 INTRODUCTION

The distinct geographical location of South Africa, that spans the temperate, subtropical and tropical belts (Carr *et al.*, 2006), as well as the oceanographic, topographic and latitudinal influences result in distinct rainfall zones and seasonality (Fitchett and Bamford, 2017). Understanding the rate at which climate is changing in southern Africa will assist in the way contemporary ecology is understood and managed (Kruger, 2015). Owing to a sparse palynological record, due to preservation difficulties, sites in the southern African region utilised multiple environmental proxies to investigate the long-term climatic record (Elenga *et al*., 2000; Scott 2002; Holmgren *et al*., 2003; Grab *et al*., 2005; Finch and Hill 2008; Finné *et al*., 2010; Neumann *et al*., 2014, 2015; Fitchett *et al*., 2016a,b), this study utilised pollen as a proxy to meet the first aim of the study - *To determine the species composition and to infer shifts in vegetation*.

This chapter outlines to which extent the aims of the study were achieved and prospects for future work.

8.2 Achievement of study objectives

8.2.1 To determine the species composition based on fossil pollen to infer shifts in vegetation

The result of the pollen analysis for Ntsikeni Wetland is discussed in the *Results Chapter* (*Chapter 5*), the results are then synthesised to reconstruct the dominant environments (*Environmental Reconstruction Chapter*), and then finally the possible drivers and regional comparisons are investigated in the *Discussion Chapter*. Different species were identified using online reference collections and consulting with other palynologists.

There were pronounced shifts in the conditions of the wetland, times when the wetland expanded or contracted based on the fluctuations of different species. The species richness also fluctuated, and changes in temperature were also inferred from these changes. Initially the species composition indicated cold conditions, based on the presence of Caryophyllaceae, which all but disappears from the contemporary pollen record.

8.2.2 To apply appropriate statistical methods to the pollen data in order to reconstruct the vegetation history of the site

The statistical analysis of the data is discussed in the *Materials and Methods Chapter*. The data were then graphically represented and discussed in the *Results Chapter*. The statistical analysis of the pollen results presented four main zones (WNT1 – WNT4). However, within these zones there were marked fluctuations in climate, highlighted by changes in pollen abundance of statistically significant species/family pollen. The sequence commences in the Pleistocene (~25,000 cal. yr BP) with a cold period, then entering a period of increased temperature and moisture from 20,500-18,500 cal. yr BP; the following period in cold and dry, with slight fluctuations in moisture, eventually becoming cold and wet from 15,000-14,800 cal. yr BP, reaching conceivably the coldest point at 13,500 cal. yr BP, and with no SRZ. From 13,200 cal. yr BP the climate indicates a gradual, but continuous shift from dry and cold to wetter and warmer, still no SRZ, until there is a hiatus in the pollen record between 10,700-9,000 cal. yr BP. The subsequent period commences with a warm, dry period and becoming wetter towards 4,300 cal. yr BP, there is a short but distinct decrease in temperature at 4,100 cal. yr BP; during this period there is no indication of an increase in precipitation during colder periods. The final zone continues to become wetter, with a small number of distinct cold events at 4,800, 4,100 and 2,100 cal. yr BP. The pollen record terminates at 600 cal. yr BP, with little or no indication of any anthropogenic influence in the vegetation of the area.

Utilising the data, different stratigraphic pollen diagrams were constructed to illustrate a number of different trends visible.

8.2.3 To constrain the changes temporally through AMS dating of samples

A total of five AMS dates were obtained to temporally restrain the pollen results of Ntsikeni Wetland. Utilising BACON, possible sedimentation rates and inferred dates were then assigned to depths. The initial period at Ntsikeni Wetland indicated slow sedimentation rates, which might be indicative of possible glaciation (~25,000-13,500 yr. cal BP) with an increase in sedimentation rates following this period, which may indicate post-glaciation warming and increase in moisture.

8.2.4 To infer changes in the past environment and establish possible driver for the changes

The comparison of this site to previously published palaeoenvironmental reconstructions in southern Africa indicates variations on a local scale, but more similarities on a regional scale. Some of the global climatic events are emanated at Ntsikeni Wetland; however there appears to be a slight delay of onset for most events. It is therefore evident that further investigation on a local scale is necessary to increase the resolution of data available, which in turn will enhance our understanding of local climatic variations due to topography, geography and micro-climates.

As stated above, the site appears to emulate global synchronous climatic events; there is relatively strong evidence for the H-1, H-2, and Younger Dryas, '8.2 kyr', and '4.1 kyr' and '2.8 kyr' cold events; however there appears to be a lag of ~ 1,000 years pertaining to the Younger Dryas at Ntsikeni Wetland. The broad inferences for the Holocene Altithermal exist, with the hiatus in pollen in the middle of this period.

8.3 Future possibilities

This project only utilised pollen as a proxy for palaeoenvironmental reconstruction, this creates the option for diatoms as another proxy to further investigate the results. The site at Mahwaqa Mountain (Neumann *et al*., 2014) is geographically the closest to Ntsikeni Wetland, however different pollen species were used as indicators for climatic change and that study also focussed a lot on spores, generating the possibility of a more in depth study and identification of the spores at Ntsikeni to be utilised as another proxy in a multi-proxy analysis of Ntsikeni Wetland.

After using standard laboratory preparation methods to extract the pollen from the sediment samples, there were a number of diatoms still present within the samples. This indicates that there are diatoms, possibly in large quantities, present at the study site. I have asked Dr J.M. Fitchett to investigate the diatoms at Ntsikeni Wetland to further increase the data resolution at this site.

This study produced five AMS dates, of which one was possibly contaminated, however greater precision on dates along the sediment core transect will be helpful to clarify if the global synchronous climatic events are in fact lagging at the site or if dating needs to be refined.

Ntsikeni Wetland samples are currently the only in the area that extends past ~20,000 cal. yr BP; this perhaps created more questions pertaining to the LGM and the effects locally. Future study sites should ideally focus only longer time periods.

8.4 Future applications of findings

The findings of this project will be valuable for the management of the Ntsikeni Wetland area, which is not only a RAMSAR site, but also part of an ecotourism initiative that is run and managed by the local community at Ntsikeni. Accessible data from this study will assist possible climate projection for the local area, which in turn will assist in the management of the remarkable birdlife in the area, as well as the protection of the wetland vegetation.

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APPENDIX A

Appendix 2: Plant species lists for Ntsikeni Nature Reserve (compiled by Tony Abbott, November 1999 and supplemented by D C Kotze, based on 2002 field visit)

Note: species marked with a “y” occur within the Ntsikeni wetland itself Status (IUCN categories) Lrlc=Lower risk (conservation dependent); Lrnt = Lower risk (Near threatened); VU= Vulnerable; DD=Data deficient

	Wetland	Status
ALGAE		
Nitella sp.	y	
BRYOPHYTA		
Braunia secunda		
Thuidium natarumense		
PTERIDOPHYTA		
Adiantum poiretii		
Cheilanthes quadripinnata	y	
Dryopteris athamantica		
Dryopteris inequalis		
Loxogramme lanceolata		
Mohria caffrorum var. caffrorum		
Polypodium polypodioides		
Polystichum pungens		
Polystichum transvaalense		
Thelypteris bergiana		
GYMNOSPERMAE		
Podocarpus henkelii		
Podocarpus latifolius		
MONOCOTYLEDONAE		
Agrostis eriantha var. eriantha	y	
Albuca fastigiata		
Albuca nelsonii		
Albuca setosa	y	
Albuca shawii		
Aloe pratensis		
Anemone fanninii		
Anthoxanthum ecklonii	y?	
Aponogeton junceus subsp. junceus	y	
Aponogeton junceus subsp. natalense	y	
Arundinella nepalensis	y	
Ascolepis capensis	y	
Asparagus microraphis		
Brownleea galpinii subsp. major		
Brownleea parviflora		
Bulbine abyssinica		
Bulbostylis humilis	y	
Bulbostylis oritrephes	y	
Bulbostylis schoenoides	y	
Bulbostylis scleropus	y?	
Carex acutiformis	y	
Carex austro-africanus	y	
Carex leporina	y?	
Chlorophytum comosum	y	
Chlorophytum sp.	y	
Corycium dracomontanum		
Crocosmia aurea var. aurea		
Cyperus denudatus	y	
Cyperus obtusiflorus var. sphaerocephalus	y?	
Cyperus rupestris var. rupestris	y?	
Cyperus sp.		
Cyrtanthus breviflorus	y	
Cyrtanthus epiphyticus	y	LRlc
Cyrtanthus mackenii var cooperi	y	
Cyrtanthus sp.		
Cyrtanthus stenanthus var. major		
Cyrtanthus tuckii	y	
Cyrtanthus tuckii var. transvaalensis	y	
Dierama argyreum		LRlc
Dierama dissimile		
Dierama igneum		
Dierama pauciflorum		

Dierama sp. cf. D. igneum		
Dierama trichorhizum		
Diheteropogon filifolius		
Disa cornuta		
Disa fragrans		
Disa versicolor	y	
Disperis stenoplectron	y	
Disperis tysonii		
Disperis wealii		
Eleocharis palustris	y	
Eragrostis planiculmis	y	
Eriocaulon dregei var. sonderianum	y	
Eucomis autumnalis ssp. autumnalis		VU
Eucomis bicolor	y	
Eucomis comosa var. striata	y	
Eulophia aculeata subsp. huttonii	y	
Eulophia clavicornis var. clavicornis		
Eulophia ovalis subsp. ovalis	y	
Eulophia zeyheriana		
Euplophia ovalis		
Festuca costata		
Festuca scabra		
Ficina cinnamomea	y?	
Gladiolus crassifolius		
Gladiolus dalenii		
Gladiolus ecklonii subsp. ecklonii		
Gladiolus longicollis var. longicollis		
Gladiolus ochroleucas var. ochroleucas	y	
Gladiolus oppositiflorus subsp. salmoneus		
Gladiolus papilio	y	
Gladiolus permeabilis subsp. wilsonii	y	
Habenaria cornuta		
Habenaria dives		
Habenaria laevigata		
Habenaria lithophila		
Habenaria malacophylla		
Habenaria schimperiana	y	
Habeneria dives		
Harpochloa falx		
Hesperantha baurii subsp. baurii	y	
Hesperantha candida	y	
Hesperantha sp.		
Hesperantha sp.		
Hesperantha tysonii		LRlc
Holothrix scopularia		
Isolepis costata var. macra	y	
Isolepis fluitans	y	
Juncus effusus	y	
Juncus oxycarpus	y	
Kniphofia caulescens	y	
Kniphofia laxiflora	y	
Kniphofia triangularis subsp. triangularis		
cf. Lagarosiphon verticillifolius	y	
Ledebouria cooperi	y	
Ledebouria ovatifolia		
Leersia hexandra	y	
Loudetia densispica	y?	
Luzula africana		
Mariscus congestus	y	
Massonia jasminiflora		
Monocymbium ceresiiforme	y	
Moraea brevistyla	y	
Moraea huttonii		
Moraea modesta		
Moraea stricta	y	
Moraea trifida	y	
Myrsiphyllum asparagoides		
Neobolusia tysonii		
Neobolusia virginea		
Nerine appendiculata	y	
Nerine pancratioides		
Osteospermum jucundum		
Panicum ecklonii		
Pennisetum thunbergii	y	
Poa binata	y	
Protasparagus virgatus	y	
Pterygodium cooperi		
Pterygodium hastatum		
Pterygodium magnum	y	
Pycreus macranthus	y	
Pycreus sp.	y	
Pycreus unioloides	y	
Rendlia altera		
Satyrium cristatum var. cristatum	y	
Satyrium hallackii subsp. ocellatum	y	
Satyrium longicauda var. longicauda	y	
Satyrium parviflorum		
Satyrium sphaerocarpum		
Satyrium trinerve	y	
Schizochilus angustifolius		
Schizochilus bulbinella	y	LRlc
Schizochilus flexuosus		
Schizoglossum nitidum+D208	y	
Schizostylis coccinea	y	
Schoenoplectus corymbosus	y	
Schoenoxiphium cf. ludwigii	y	
Scirpus falsus	y?	
Sporobolus centrifugus		
Stenoglottis fimbriata		
Stiburus conrathii	y	
Themeda triandra		
Trachypogon spicatus		

Tristachya leucothrix		
Tritonia lineata var. lineata		
Tulbaghia leucantha		
Urginea capitata		
Watsonia confusa		
Watsonia inclinata		LRnt
Watsonia lepida		
Watsonia pillansii		
Watsonia sp.		
Wurmbea kraussii		
Xyris gerrardii	y	
Zantedeschia aethiopica	y	
DICOTYLEDONAE		
Acalypha peduncularis		
Acalypha schinzii		
Agrimonia bracteata	y	
Agrimonia odorata		
Ajuga ophrydes		
Alchemilla incurvata		
Alectra sessiliflora var. sessiliflora		
Alectra thyrsoidea		
Alepidea amatymbica	y	LRnt
Alepidea longifolia ssp. longifolia	y	
Alepidea natalensis		
Alepidea woodii		
Alepidia sp.		
Anemone caffra		
Anemone fanninii		
Anisodontea julii subsp. julii		
Anthospermum herbaceum	y	
Aponogeton junceus subsp. junceus	y	
Argyrolobium marginatum		
Argyrolobium tomentosum		
Asclepias cucullata		
Asclepias multicaulis		
Asclepias stellifera		
Aspidoglossum fasciculare		
Aspidonepis flava		LRlc
Aster perfoliatus		
Athrixia fontana		
Begonia sutherlandii		
Berkheya cirsiifolia		
Berkheya multijuga	y	
Berkheya onopordifolia var. onopordifolia		
Berkheya rhapontica subsp. aristosa var. aristosa		
Berkheya rhapontica susbp. aristosa var. exaltata		
Brachystelma cordifolia		
Buddleja loricata		
Calpurnia sericea		
Carissa bispinosa var. bispinosa		
Cephalaria natalensis	y	
Cephalaria oblongifolia	y	
Cerastium arabidis		
Chironia krebsii	y	
Chrysocoma ciliata		
Cliffortia paucistaminea		
Clutia pulchella var. franksiae	y	
Conium chaerophylloides		
Convolvulus natalensis var. natalensis		
Convolvulus natalensis var. transvaalensis		
Conyza obscura	y	
Conyza pinnata	y	
Cotula hispida		
Crassula alba var. alba		
Crassula inanis	y	
Crassula lanceolata subsp. lanceolata		
Crassula languinosa var. pachystemon	y	
Crassula nudicaulis var. nudicaulis		
Crassula pellucida ssp. brachypetala		
Crassula sarcocaulis subsp. rupicola	y	
Crassula setulosa var. rubra		
Crassula setulosa var. setulosa		
Craterocapsa congesta		
Craterocapsa tarsodes		
Crepis hypochoeridea		
Cyathula uncinulata		
Cycnium racemosum		
Cyphia elata		
Cysticapnos pruinosus		
Cysticapnos sp.		
Delopserma caespitosum forma caespitosim		
Delosperma gracile		DD
Delosperma sp.		
Denekia capensis	y	
Desmodium repandum		
Dianthus basuticus subsp. basuticus		
Diclis reptans	y	
Dicoma sp.	y	
Dicoma anomala subsp. anomala		
Dierama trichorhizum		
Drosera natalensis	y	
Empodium elongatum		
Englerodaphne pilosa		LRlc
Epilobium capense		
Erica algida	y	
Erica caffrorum var. caffrorum		
Erica woodii		
Eriosema distinctum	y	
Eriosema kraussianum		
Euclea crispa var. crispa		
Eugenia zuluensis		
Euphorbia natalensis		

Euphorbia sp.		
Euphorbia striata var. striata		
Euryops laxus		
Euryops tysonii		
Felicia linearis		
Felicia rosulata		
Galium capense subsp. garipense		
Galium thunbergianum var. thunbergianum		
Galopina circaeoides	y	
Gazania krebsianan subsp. krebsiana		
Geranium pulchrum		
Geranium schlechteri		
Geranium wakkerstroomianum		
Gerbera ambigua		
Gerbera parva		
Gerbera viridifolia subsp. viridifolia	y	
Geum capense	y	
Gnaphalium filagopsis		
Gnaphalium griquense		
Gnidia baurii		
Gnidia kraussiana var. kraussiana		
Graderia scabra	y	
Gunnera perpensa	y	
Guthria capensis		
Hebenstretia dura		
Helichrysum adenocarpum	y	
Helichrysum adenocarpum subsp. adenocarpum		
Helichrysum argentissimum		
Helichrysum aureum var. monocephalum		
Helichrysum cephaloideum		
Helichrysum chionosphaerum		
Helichrysum cooperi		
Helichrysum ecklonis		
Helichrysum epapposum		
Helichrysum glomeratum		
Helichrysum grandibracteatum		
Helichrysum herbaceum	y	
Helichrysum heterolasium		
Helichrysum krookii		
Helichrysum melanacme		
Helichrysum mundtii		
Helichrysum nanum	y	
Helichrysum natalitium		
Helichrysum nudifolium		
Helichrysum odoratissimum		
Helichrysum pilosellum	y	
Helichrysum simillimum		
Helichrysum simulans	y	
Helichrysum spiralepis		
Helichrysum splendidum		
Helichrysum subfalcatum		
Helichrysum sutherlandii		
Helichrysum tenax var. tenax		
Helichrysum trilineatum		
Hemizygia stenophylla		
Hermannia depressa	y	
Hermannia schlechteriana		
Hermannia woodii		
Hirpicium ameroides	y	
Hypericum lalandii		
Hypoestes triflora		
Hypoxis argentea var. sericea		
Hypoxis filiformis		
Hypoxis galpinii		
Hypoxis multiceps		
Hypoxis rigidula var. pilosissima		
Hypoxis rigidula var. rigidula		
Indigofera dregeana		
Indigofera gerrardina		
Indigofera verrucosa		
Isoglossa cooperi		
Kiggelaria africana		
Kohautia amatymbica		
Lagarosiphon major	y	
Laportea peduncularis subsp. peduncularis	y	
Leucosidea sericea		
Limosella longiflora	y	
Linum thunbergii		
Lobelia angolensis		
Lobelia erinus	y	
Lobelia vanreenensis		
Lotononis biflora		
Lotononis laxa		
Lotononis puchella		
Lotononis sericophylla	y	
Luzula africana		
Manulea crassifolia subsp. crassifolia		
Manulea florifera	y	LRlc
Manulea paniculata		
Melasma scabrum	y	
Melolobium alpinum		
Melolobium microphyllum		
Mentha aquatica	y	
Mimulus gracilis	y	
Monopsis decipiens		
Monsonia brevirostrata	y	
Monsonia grandifolia		
Myosotis sylvatica		
Myrica sp. cf. M. brevifolia		
Nemesia caerulea		
Nemesia sylvatica	y	

Nidorella agria		
Nidorella undulata	y	
Osteospermum caulescens		
Osteospermum jucundum		
Otholobium polysticta		
Othonna natalensis		
Oxalis smithiana		
Papaver aculeatum		
Passerina filiformis		
Pelargonium alchemilloides		
Pelargonium inquinans		
Pelargonium luridum		
Pelargonium ranunculophyllum		
Pelargonium sp. cf. luridum		
Pelargonium zonale		
Peperomia retusa var. retusa	y	
Phytolacca octandra		
Pimpinella caffra		
Plantago lanceolata		
Plectranthus dolichopodus		
Plectranthus laxiflorus		
Polygala rehmannii		
Polygala rhinostigma		
Polygonum aviculare		
Protea subvestita		LRnt
Psammatrohpa sp.	y	
Psammotropha mucronata subsp.mucronata		
Pseudognaphalium luteo-album		
Ptaeroxylon obliquum		
Pygmaeothamnus chamaedendrum		
Pygmaeothamnus chamaedendrum var. setulosus	y	
Rabdosiella calycina	y	
Ranunculus meyeri	y	
Ranunculus multifidus	y	
Raphionacme hirsuta		
Rhamnus prinoides	y	
Rhodohypoxis baurii var. baurii		
Rhodohypoxis baurii var. platypetala		
Rhus discolor		
Rhus montana		
Rumex acetosella subsp. angiocarpus		
Scabiosa columbaria		
Schizoglossum bidens subsp. pachyglossum		
Schizoglossum flavum Schltr.		
Schizoglossum nitidum		
Scolopia mundii		
Sebaea bojeri		
Sebaea natalensis	y	
Sebaea sedoides var. confertiflora		
Sebaea sedoides var. schoenlandii		
Sebaea sedoides var. sedoides	y	

Sebaea spathulata	
Selago galpinii	
Senecio cathcartensis	y
Senecio erubescens var. crepidifolius	y
Senecio gregatus	
Senecio harveianus	y
Senecio inaequidens	
Senecio lygodes	
Senecio oxyodontus	y
Senecio polyodon var. subglaber	y
Senecio subcoriaceus	
Senecio subrubriflorus	
Silene bellidioides	y
Silene burchellii var. angustifolia	
Silene undulata	
Sonchus integrifolius var. schlechteri	
Stachys caffra	
Stachys grandifolia	
Stachys tubulosa	
Streptocarpus pusillus	
Striga bilabiata	
Sutera breviflora	
Sutera floribunda	
Tephrosia capensis	
Thalictrum rhynchocarpum	
Thesium orientale	
Trimeria grandifolia	
Ursinia alpina	
Ursinia tenuiloba	
Urtica urens	y

Utricularia gibba		
Utricularia livida	y	
Vepris lanceolata		
Wahlenbergia appressifolia		
Wahlenbergia cuspidata		
Wahlenbergia denudata		
Wahlenbergia huttonii		
Wahlenbergia lycopodioides		
Wahlenbergia paucidentata		
Wahlenbergia rivularis		
Wahlenbergia undulata		
Xysmalobium involucratum		
Xysmalobium parviflorum		
Xysmalobium tysonianum		LRlc
Zaluzianskya pulvinata		
Zaluzianskya glareosa		
Zaluzianskya microsiphon		
Zaluzianskya ovata		
Zaluzianskya pachyrrhiza		

APPENDIX B

Pollen preparation

1. Measure out 7g of each subsample into individual test tubes and label.

2. Add 45ml of 10% HCl to each of the samples and stir regularly in a beaker to dissolve carbonates.

3. Use a 500 micron sieve to remove roots and large organic particles. Add distilled water to the sieve to wash through small sized sediment and pollen. Sufficiently large spacing is required to prevent the removal of large pollen grains.

4. Sieved samples and distilled water stirred and placed in the centrifuge for 4 minutes at 3000rpm. Decant. Add remaining solution to centrifuge tubes and centrifuge, decant. Repeat until all of the solution has been centrifuged.

5. Add 30ml distilled water, agitate on shaker for 1 minute at varying speeds.

6. Add 30ml 40% HF to re-combine centrifuged sample and leave overnight to remove silicates. Stir using stirring rod. Centrifuge for 5 minutes at 3000rpm. Decant. Add distilled water, centrifuge and decant. Repeat until the supernatant rinses clean.

7. Add 30ml distilled water, agitate on shaker for 1 minute at varying speeds.

8. Add 30ml 10% KOH to remove remaining organic material. Stir with stirring rod, decant into crucibles. Heat on hot plate for approx. 5 minutes until boiling. Return liquid to the washed centrifuge tubes. Centrifuge for 5 minutes at

3000rpm. Decant. Add distilled water, centrifuge and decant. Repeat until supernatant rinses clean.

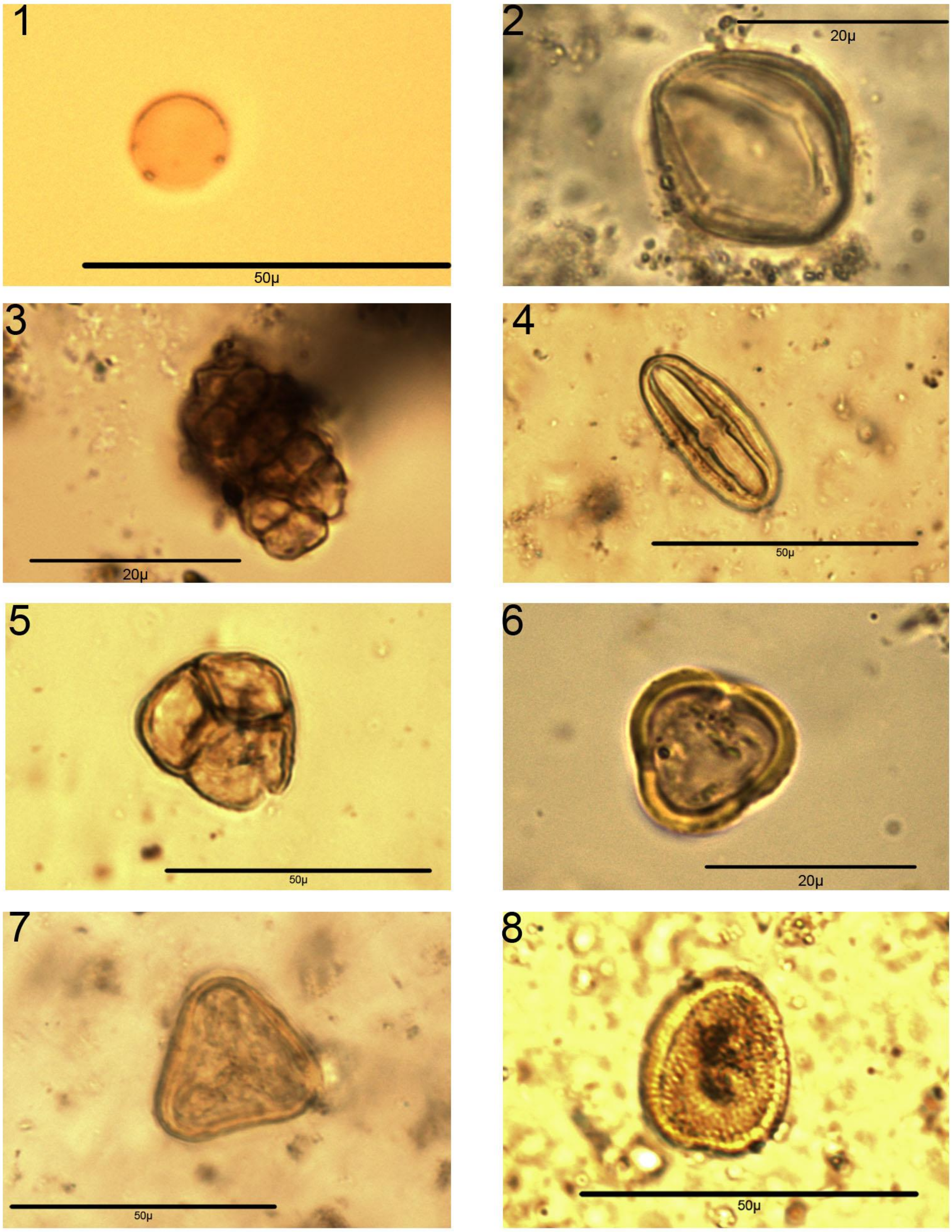
9. Place sample in beakers, add 30ml super-saturated $ZnCl_2$ solution (155ml 10% HCl + 500g $ZnCl_2$ mix) for mineral separation. Pour into a tube bent in half, placed inside the centrifuge tubes. Centrifuge for 5 minutes. Bend the top of the tube, pour into a second clean centrifuge tube. Rise out the bent section using distilled water to include any pollen grains stuck to the side of the tube. Add distilled water to the second centrifuge tube to 45ml. Shake on shake machine. Centrifuge for 5 minutes at 3000r/min. Decant. Rinse with distilled water until all of the $ZnCl_2$ has been removed.

10. Perform acetolysis to remove cellulose: Add 15ml glacial acetic acid to sample. Shake on shake machine. Add glacial acetic acid to fill to 25ml. Centrifuge for 5 minutes at 3000rpm. Decant. Add a small amount of a 9:1 mixture of acetic anhydride and H_2SO_4. Place centrifuge tubes in a beaker of 80°C water for 3 minutes for acetolysis to occur. Transfer the centrifuge tubes into a beaker of cold water to stop acetolysis. Centrifuge for 5 minutes at 3000rpm and decant. Add 15ml glacial acetic acid to sample. Shake on shake machine. Centrifuge for 5 minutes at 3000rpm and decant. Add distilled water to 45ml, shake. Centrifuge for 5 minutes at 3000rpm and decant. Repeat 3 times

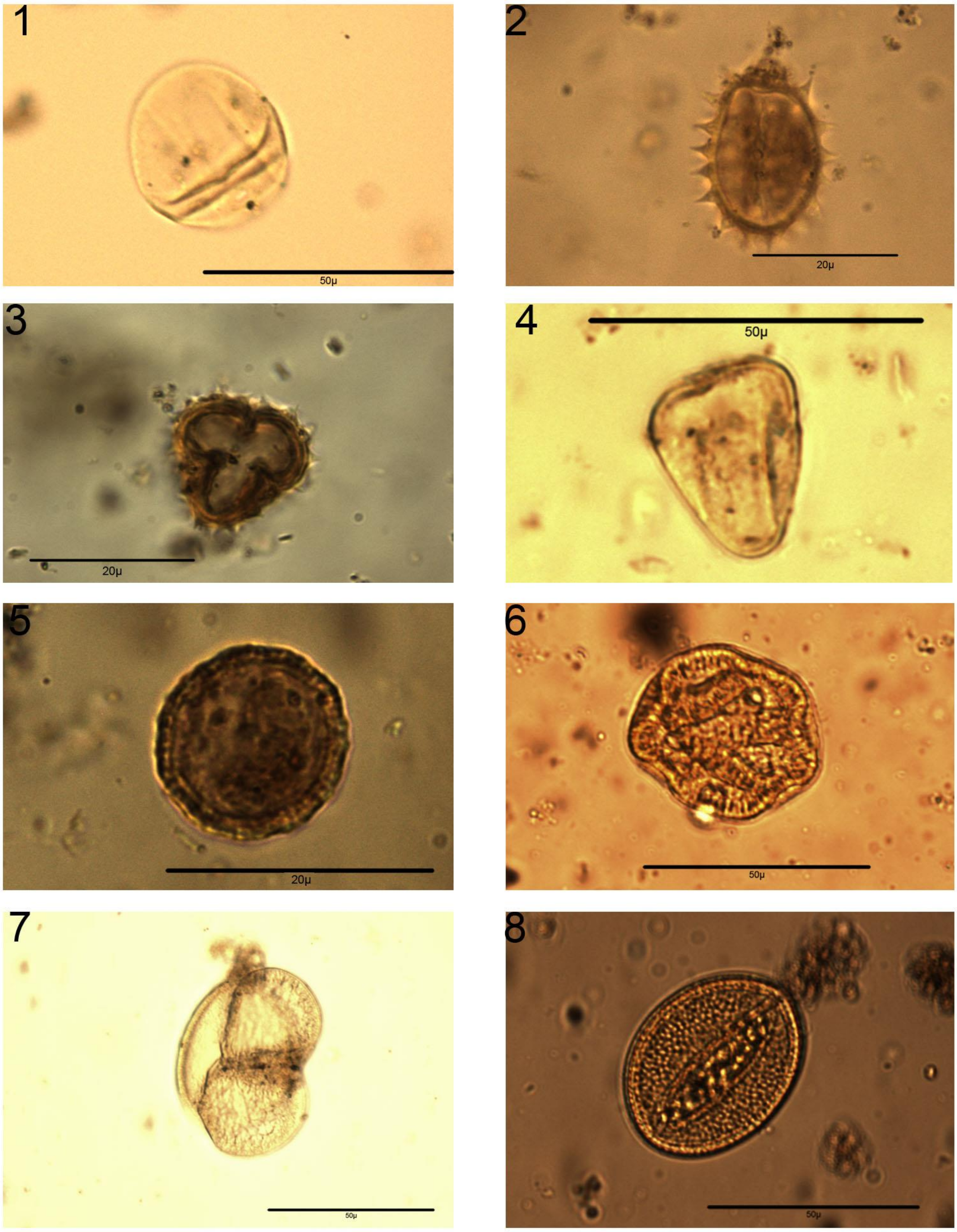
11. Preparing Slides: Heat glycerol jelly and slides. Number the slides according to the lab assigned sample numbers. Rinse sample (centrifuge) one last time, leaving behind some of the supernatant on decanting. Place 4 drops of glycerol jelly on a slide, followed by one drop of the corresponding sample mixture. Mix

and spread using mixing rod. Remove any large particles which would obstruct the coverslip. Place back on the hot plate for a few minutes to allow the excess water to evaporate. Place coverslip on. Leave to cool. Wash the slide and permanently label.

APPENDIX C



1. *Acylpha sp*	2. *Combretaceae*	3. *Mimosideae*	4. *Apiaceae*
6. Ericaceae	6. *Gentianaceae*	7. *Proteaceae*	8. Typhaceae



1. Poaceae 2. Asteraceae 3. *Stoebe-type* 4. Cyperaceae

6. Cheno/Am 6. Caryophyllaceae 7. *Proteaceae* 8. *Grewia*

APPENDIX D

Data used for statistical analyses

Sample	Cyperaceae	Apiaceae	Juncaceae	Hypoxidaceae	Typhaceae	Aponogenton	Asteraceae	Liliaceae	ChenoAm	Caryophyllaceae	Malvaceae	Crassulaceae	Curtisia	Orchidaceae	Rananculaceae	Ericaceae	Grewia	Gentianaceae	Combretaceae	Myrtaceae	Mimosoideae	Podocarpus	Fabaceae	Phyllanthus	Phragmites	Poaceae	Unknown
NT1	49	0	8	4	1	0	5	3	0	0	0	1	0	2	1	0	0	0	0	0	2	2	0	0	0	13	8
NT2	59	3	3	1	2	0	14	1	0	0	0	4	0	0	0	0	0	0	0	0	1	0	1	0	0	11	1
NT3	58	3	0	3	0	1	13	1	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	2	15	0
NT4	54	3	2	1	0	0	7	2	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	26	1
NT5	50	4	1	0	0	0	14	2	0	1	0	2	0	0	1	0	0	0	0	0	1	0	0	0	1	22	0
NT6	46	3	0	0	0	0	34	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0
NT7	38	2	0	0	0	0	37	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0
NT8	42	3	0	0	0	0	14	3	0	1	1	7	1	4	0	0	0	0	0	0	0	1	0	0	0	22	0
NT9	60	2	0	0	0	0	10	2	1	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	19	3
NT10	53	1	0	0	0	0	17	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	20	7
NT11	38	3	0	0	0	0	8	11	2	2	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	20	9
NT12	57	2	2	0	0	1	10	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	8	12
NT13	20	4	0	0	0	1	15	11	0	0	0	3	2	2	0	2	1	0	0	1	0	1	0	0	0	31	5
NT14	15	1	0	0	0	4	5	7	1	2	4	4	0	2	0	0	0	0	0	0	0	1	0	0	0	42	13
NT15	17	1	0	0	0	0	13	5	0	1	5	7	0	1	0	0	0	0	0	0	5	1	0	0	1	41	4
NT16	11	0	0	0	0	0	11	3	0	0	3	14	0	0	0	0	0	0	0	0	0	6	0	0	0	49	3
NT19	15	0	0	0	0	0	12	4	0	0	5	3	0	1	0	0	0	0	0	0	0	3	0	0	8	35	14
NT23	15	1	3	4	0	4	8	3	0	0	1	3	0	3	0	1	0	0	0	0	3	0	0	0	0	36	16
NT25	29	1	5	1	0	1	0	0	0	1	1	3	0	3	0	0	0	0	0	0	2	0	0	0	0	44	8
NT26	37	1	5	0	0	5	4	2	0	2	2	3	0	5	4	0	0	0	0	0	2	0	0	0	0	21	6
NT28	47	2	3	0	0	8	7	0	0	0	0	3	0	3	0	0	0	0	0	3	0	0	0	0	0	8	14
NT29	23	0	3	0	0	0	7	10	0	7	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	33	10
NT30	41	0	2	0	0	0	12	0	0	0	5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	10	24
NT31	39	1	2	0	2	0	6	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	19	26
NT40	23	0	0	0	0	0	19	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	4
NT41	5	0	3	0	0	0	32	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	11
NT42	25	0	6	0	2	3	15	1	0	7	2	6	0	0	0	0	1	0	2	0	1	0	0	0	0	21	8
NT43	24	2	2	0	1	1	24	4	0	7	0	1	0	0	0	1	2	0	1	0	1	3	0	1	0	17	6
NT45	15	0	0	0	0	4	33	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	7	0	0	26	11
NT46	12	0	2	0	4	2	23	2	0	9	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	42	4
NT47	26	0	0	0	10	2	9	4	0	5	1	2	0	0	0	2	0	0	2	0	0	2	0	2	4	19	7
NT48	30	1	3	0	3	0	23	2	0	9	0	1	0	0	0	1	4	0	0	0	0	1	0	0	2	18	1
NT49	20	0	0	0	5	0	13	1	0	12	7	0	0	0	0	0	1	0	0	0	1	1	0	4	0	30	5
NT50	11	0	1	0	2	0	25	2	0	11	0	0	0	3	0	0	2	0	0	0	2	2	0	2	1	32	7
NT51	28	0	0	0	1	0	31	1	0	8	2	1	0	1	2	0	2	0	0	0	1	0	0	1	2	12	5
NT52	20	1	6	0	1	1	32	1	0	6	4	3	0	1	2	1	1	0	0	0	2	0	0	0	0	10	6
NT53	19	0	0	0	0	0	31	3	0	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	14
NT56	39	2	2	1	7	2	13	2	0	4	1	3	0	1	1	0	1	0	0	1	1	1	0	0	0	8	6
NT57	41	3	1	0	6	0	16	1	0	4	1	3	0	1	1	0	0	0	0	0	1	0	0	0	0	12	6
NT58	41	2	0	0	8	3	14	0	0	21	0	3	0	0	2	0	0	0	0	0	0	0	0	0	0	4	3
NT59	28	0	0	0	7	0	8	1	0	36	0	5	0	0	0	0	0	0	0	0	1	2	0	0	0	8	4
NT60	25	1	2	0	4	2	4	3	0	43	0	6	0	1	1	0	0	2	0	0	0	2	0	0	0	2	5
NT61	21	3	0	0	2	0	9	1	0	49	0	3	0	1	1	0	0	0	0	0	0	1	0	0	0	5	3
NT62	32	0	0	0	3	0	22	5	0	20	0	3	0	1	0	0	0	0	0	0	1	2	0	0	0	7	5
NT63	43	0	0	0	2	0	19	1	0	20	1	0	0	1	1	0	0	0	0	0	0	3	0	0	0	9	1
NT64	48	1	3	0	2	2	15	3	0	10	2	3	0	0	0	0	0	0	0	0	0	1	0	0	1	3	4
NT65	21	0	2	0	5	0	12	0	0	38	0	5	0	0	0	1	0	2	0	0	1	0	0	0	0	6	6
NT66	60	0	0	0	0	0	10	2	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	4
NT69	42	4	0	0	12	0	12	4	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	4
NT71	41	0	0	0	0	1	11	0	0	26	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	10	3
NT72	33	0	2	0	4	4	8	4	0	25	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	13	4
NT73	48	1	0	0	4	1	13	2	0	7	6	1	0	0	1	0	4	0	0	1	0	0	2	0	0	8	1
NT74	40	0	4	0	4	0	10	5	0	11	4	3	0	0	0	1	0	0	0	0	0	0	0	0	0	13	5
NT75	34	0	0	0	0	0	28	5	0	7	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	21	2
NT76	37	0	3	0	4	1	18	4	0	10	1	0	0	0	0	0	0	0	0	0	0	1	0	3	0	15	1
NT77	26	3	0	0	7	1	24	1	0	6	1	6	0	0	0	1	0	0	1	0	0	3	0	0	1	13	4
NT78	29	0	0	0	0	0	11	4	0	36	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	7	11
NT82	37	0	2	0	2	0	21	5	0	5	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	16	5