ATTEMPTING PALAEOENVIRONMENTAL RECONSTRUCTIONS IN WAR-TORN ZONES: THE CASE OF THE OKAVANGO SOURCE WETLANDS IN ANGOLA

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DECLARATION

I hereby declare that this represents my own unaided work, except where otherwise acknowledged, and has not been submitted before for any degree or examination at any other University.

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Date

ABSTRACT

There are an increasing number of palaeoenvironmental reconstructions for southern Africa. Palaeoenvironmental reconstructions using pollen as a proxy tool are limited in southern Africa due to large areas of arid environments and the difficulty of accessing sites. The Okavango is an important biological region, and there have been a few studies done in the delta itself, but nothing in the source waters. In Angola, the absence of studies is mainly due to the civil war (1974-2002), which prevented access into the region and post-war as well due to the presence of landmines. Following this war remains an ongoing effort to demine the area. The National Geographic Okavango Wilderness Project is an initiative to protect the Okavango Delta as well as its source tributaries located in the Angolan Highlands. The goal is to study endemic species and inform conservation strategies. This is a pioneering attempt at a palaeoenvironmental reconstruction in this war-torn region. The sediment profile represents flora similar to the contemporary record with fluctuations with a depth that can broadly reveal changes in moisture dynamics. This would be useful in understanding the palaeo-hydro-climate of the broader Okavango system. However, radiocarbon AMS dates reveal that the material only spans the past 200 years with significant overturning. What was anticipated to be a Holocene core, turned out to be upturned material due to post-depositional disturbance. This reveals the long-lasting effects of the war due to landmines to the contemporary environment and the ability to reconstruct past environments from these sites.

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LIST OF ACRONYMS

AMS: Accelerator Mass Spectrometer

CONISS: Constrained Incremental Sum of Squares

IPCC: Intergovernmental Panel on Climate Change

ITCZ: Inter-Tropical Convergence Zone

LGM: Last Glacial Maximum

OWP: Okavango Wilderness Project

PC: Principal Component

PCA: Principal Components Analysis

LIST OF NAMING AND STYLE CONVENTIONS

± cal. yr BP: measured and calibrated AMS dates acquired from Beta Analytic; years before present

~ cal. yr BP: interpolated and calibrated AMS dates calculated using the BACON model; years before present

yr BP: un-calibrated age-dates presented in publications kyr: kiloyears, retained in the context of events by that name (eg. 8.2 kyr event)

m.a.s.l: meters above sea level

Cheno-Am: a group of ecologically similar pollen grains that are morphologically indistinguishable from one another. They belong to the Chenopodiaceae and Amaranthaceae families

GPS: Global Positioning System; this is often used to refer to a device which relies on GPS technology to determine ones location

CHAPTER 1: INTRODUCTION

1.1 Background study

Van Zinderen Bakker undertook the first palaeoenvironmental studies in southern Africa in Lesotho (Van Zinderen Bakker, 1955). There has since been tremendous growth in palaeoenvironmental science in the region with an increasing number of locations being studied (Fitchett et al., 2017). Early palynological work by Van Zinderen Bakker was very experimental in nature, attempting to understand and establish the fundamentals of pollen analysis (Fitchett et al., 2017). Joey Coetzee was a student of Van Zinderen Bakker who followed up on pollen analyses studies in a greater number of regions of southern and eastern Africa (Coetzee, 1964, 1967, 1978). Many of these studies by these scientists focused largely on east African mountains as they host environments that are very favourable for pollen preservation (Coetzee, 1967; Coetzee and Vogel, 1967; Van Zinderen Bakker, 1969; Van Zinderen Bakker and Coetzee, 1988). The contemporary spread of palaeoenvironmental research (Figure 1) is very dense over South Africa, but more sparse over the adjacent countries (Fitchett et al., 2017).

1.1.1 Development of Proxies

To validate environmental reconstructions from proxy evidence, it is wise to use multiple proxies (Meadows, 2014). An increasing range of proxies are being used in palaeoecological studies, these include but are not limited to fossil pollen, phytoliths, diatoms, charcoal, tree-rings, and corals (Battarbee, 2000; Armstrong and Brasier, 2005; Meadows,2014)

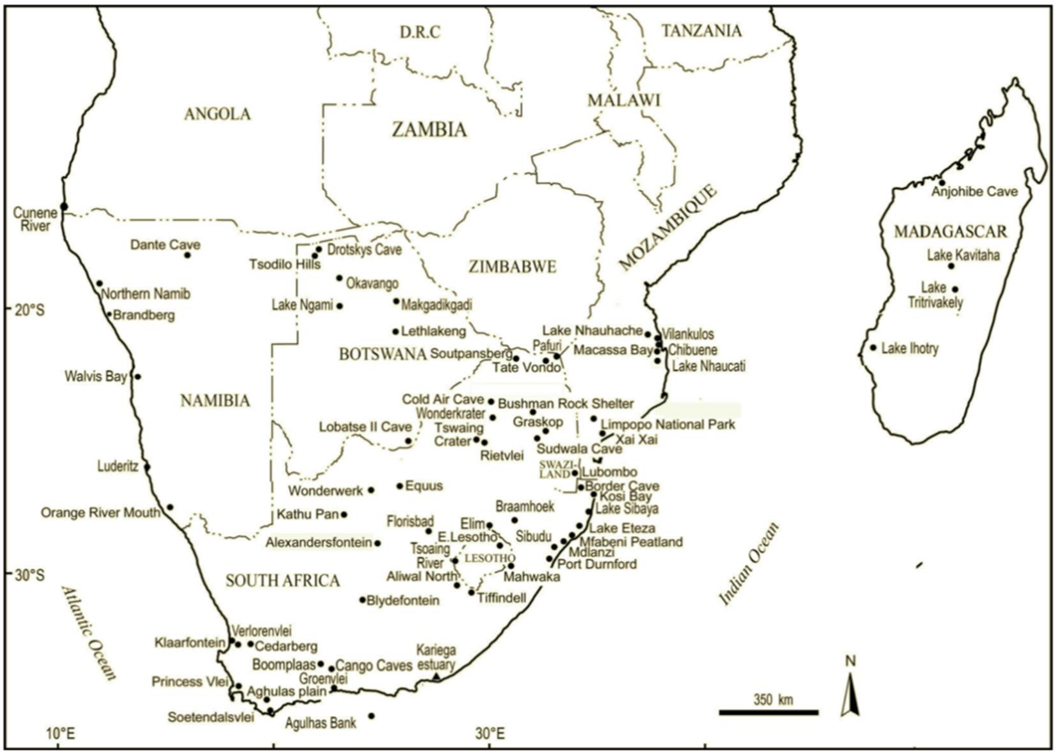

Figure 1: A map of southern Africa illustrating palaeoenvironmental work that has been done in southern Africa (Fitchett et al., 2017)

1.1.2 Development of New Archives

Certain environments do not preserve pollen in sediments, but there are other means of obtaining pollen such as hyrax middens (Fitchett et al., 2016). This is one of the greatest developments in southern Africa regarding the study of pollen, as most parts of Africa are dry and thus not many pollen archives are likely to exist. Pollen preserved in hyrax middens allow us to go ahead with pollen based environmental reconstructions in areas that are too arid to contain palynomorphs within sedimentary deposits (Scott et al., 2004, 2005; Scott and Bousman, 1990; Scott et al., 2004; Chase et al., 2012; Meadows, 2014). Recent work using hyrax middens as pollen archives has involved middens extracted from the Cederberg Mountains, southwestern Cape, South Africa, which helped improve the palaeoenvironmental reconstructions by doing high-resolution studies thus improving the climatic and environmental history (Scott and Woodborne, 2007; Meadows et al., 2010; Chase et al., 2011, 2013, 2015a,b; Quick et al., 2011).

1.1.3 Palaeoenvironmental Studies in Angola

There has been minimal work undertaken in Angola regarding palaeoenvironmental studies and scientific research in general (Huntley et al., 1974; Huntley, 2019; Rajmánek et al., 2017). This is a consequence of landmines in the area that significantly inhibit travel and access to certain parts of the country. Research in this area is very risky, and travelling in Angola is logistically and financially demanding as Angola is the costliest country in Africa (Rajmánek et al., 2017).

Present day biodiversity and environmental research are also at a minimum. Angola is among the most neglected countries when it comes to botanical research (Figure 2) (Rajmánek et al., 2017). Gossweiler (1948, 1949, 1950) have published on naturalized plants in *Flora Exotica de Angola*, but up to 90% of the species were found to not have naturalized or were invasive plant species.

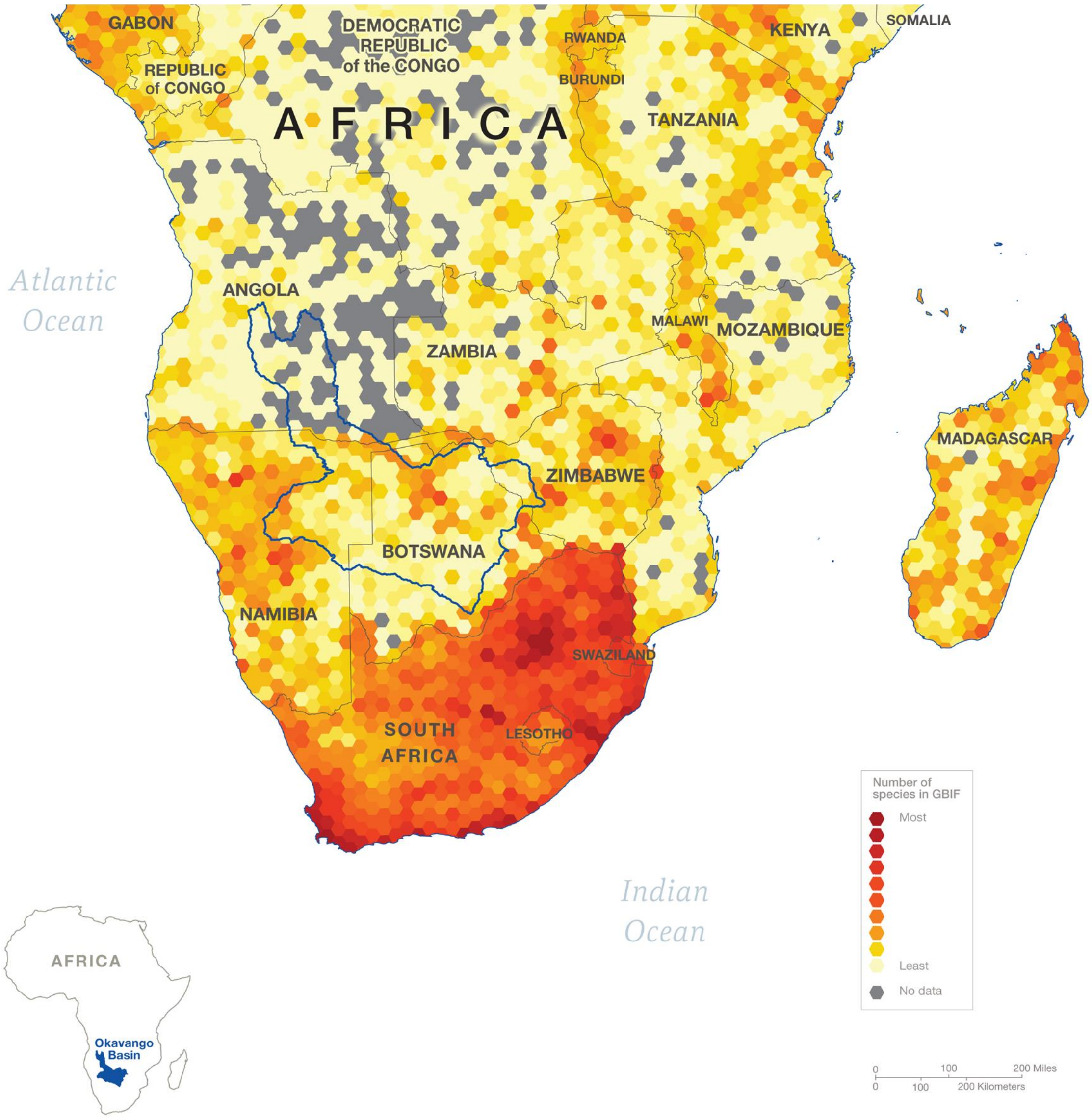

Figure 2: Map of southern Africa showing biodiversity data that has been published in Africa (National Geographic Okavango Wilderness Project)

Figueiredo and Smith (2008) have produced a checklist of Angolan vascular plants in *Plants of Angola*. Goyder (2016) has produced a survey on the habitats, vegetation, and plants in the Cuito and Cuanavale system óOkavango Wilderness Project, Angolan headwaters 2016 Botanical Reportô (Goyder, 2016). Studies like this are important for building reference collections that contributes to the growing archived data. Below is a map of Africa illustrating biodiversity studies that have been undertaken and published. In this map, there is a clear indication of a lack of data available in Angola and surrounding countries. There exists a paucity of plant distribution records in Angola (Figure 2), as well as much of southern Africa, with South Africa beign the exception as it has the most recorded plant diversity. On a visual representation of recorded plant biodiversity data in southern Africa (Figure 2), it is noted that there is an absebce of records in the Upper Cuito River which forms part of the Okavango Basin (outlined in Figure 2) (Goyder et al., 2018).

1.2 Historical context: the war in Angola

Angola was colonised by Portugal in the 19th century (Guimarães, 2001). From 1961 until 1974, the Angolan War of Independence took place, in an attempt to liberate itself from Portugal (Guimarães, 2001). Once Angola gained freedom, they were then faced with a civil war that lasted 22 years, from 1975-2002 (Tvedten, 1997). Two former liberation parties were fighting over controlling power (Tvedten, 1997), the Peopleôs Movement for the Liberation of Angola (MPLA) and the National Union for the Total Independence of Angola (UNITA) (Guimarães, 2001).

During the war, many landmines were placed around the country (which is discussed further in Chapter 2: Literature Review) (Landmine Monitor Report, 2009). Landmines are a type of ammunition that has severe direct consequences for civilians and the environment (Guimarães, 2001).

Apart from the apparent threat posed to civilians living in an area, as they are laid down sporadically and with sinister intention (Berhe, 2007; Gangwar, 2003). Landmines also wreak havoc on the environment, which in turn is detrimental to the biodiversity of the area and causes long-term harm to humans that live in the area (Berhe, 2007). A non-profit organization, the HALO Trust, has set out to demine the country. This is a demanding task, as landmines cost as little as $3 to purchase but are very costly and dangerous to remove (Gangwar, 2003).

1.3 Rationale

The National Geographic Okavango Wilderness Project (OWP) is the reason this project was possible. This is a group of dedicated scientists whose aim is to gain UNESCO WHS status for the headwaters to the Okavango Delta in the Angolan highlands. To accomplish this, biodiversity surveys are essential to record and track the wealth of species in Angola. The project reported here was commissioned as part of the broader OWP as a pilot study to determine the viability of reconstructing the Holocene palaeoenvironments from peat cores extracted from the wetland at Cuanavale and Cuito. A palaeoenvironmental reconstruction would allow the OWP and Angolan government to have a baseline against which to restore the war-damaged ecosystems and to track possible ecosystem responses under climate change. If the pilot study were found to be unsuccessful, this would inform the activities and initiatives of the OWP and provide a broader understanding of the impact of war and in particular how landmines cause environmental destruction and the destruction of palaeoenvironmental records. This study is the first attempt at reconstructing palaeoenvironments for the Okavango source waters in Angola. Pollen was used as the primary palaeoenvironmental proxy to reconstruct terrestrial vegetation which is the keystone of the contemporary ecosystem.

1.4 Aims and Objectives

The primary aim of this project is to assess the viability of reconstructing late Holocene palaeoenvironments from fossil pollen contained in peat wetlands in the war-torn source water region of the Okavango. This will be undertaken through the following objectives:

1. Extract two peat cores from Cuito and Cuito Cuanavale source lakes in Angola
2. Isolate and identify pollen assemblages at a 2cm resolution, by subsampling each core and determine the ages of the material through radiocarbon dating
3. Assess potential contamination of the cores from landmine activity through a critical analysis of sedimentation rate and contaminant pollen
4. Determine the palaeoenvironment through comparison to reference collections

1.5 Structure of the dissertation

Introduction ï the introduction chapter highlights the paucity of information available on scientific studies within Angola and surrounding regions in comparison to other parts of southern Africa. The aims and objectives on how to achieve the study goals of this project are defined in this chapter, and how they fit into the OWPôs main goal.

Literature review ï this chapter explores the development of palaeoecological work in southern Africa and the development of proxies and palaeoenvironmental archives, as well as examine the potential for additional sites with good proxies. This chapter also goes through previous studies on environmental reconstructions in war-torn regions, as well as a general history of the Angolan war to get a context of what is being dealt with.

Regional setting ï this chapter describes the geology, hydrology, climate, and vegetation of Angola, although records are sparse, a general understanding of the land can be attained.

Methods ï this chapter outlines the processes used in this study, from field work conducted in the landmine infested region of Angola, to the chemical preparation of the sediment to liberate the pollen grains. The statistical procedure is also explained as it is a vital part of interpreting the palaeoenvironment.

Results ï this chapter explains the graphs and tables that were produced from the statistical analyses. It also highlights the key trends that can be seen from these graphs by tracking the abundance of pollen grains, as well as identifying the traits associated to the families in which they belong.

Discussion ï this chapter compares results obtained from this study, to other work that has been conducted in surrounding regions, i.e. within southern Africa, as well as see how these results compare to the Northern Hemisphere.

Conclusion ï this chapter resolves the study and explains the results and how they add to our broader understanding of the Angolan highland region.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Historically, past climates have been more comprehensively documented for countries in the northern Hemisphere, while countries in the southern Hemisphere have received little attention (Scott et al., 2012; Neumann et al., 2014; Meadows and Finch, 2016). This is especially true for Angola. The twenty-seven year-long civil war in Angola hindered the ability of scientists to study the area (Huntley, 1978). Many other southern African countries lack palaeoecological data due to a lack of suitable sites containing well-preserved proxies (Neumann et al., 2008; Scott et al., 2012). Modelling regional the palaeovegetation becomes challenging when there is a scarcity of data available (Scott et al., 2012) and thus, regions with a high biodiversity may not be modelled to full potential due to a lack of spatial and temporal data (Scott et al., 2012; Neumann et al., 2014).

As mentioned, pollen analysis was initiated in the southern hemisphere by Van Zinderen Bakker (1955), and since then pollen has been the most widely used proxy in palynological studies (Faegri et al., 1989) but there is an increasing amount of other proxies being used for palaeoecological reconstructions (Faegri et al., 1989; Meadows, 2014). Incorporating multiple palaeoecological techniques provides a better resolution when reconstructing the palaeoenvironments (Meadows, 2014).

In this chapter, I explore the palynological and palaeoecological literature that explains the consequences of war on the environment and what implications this has for palaeoenvironmental reconstructions.

2.2 The development of palaeoenvironmental work in southern Africa

2.2.1 The introduction of palynology to southern Africa

Southern Africa will be defined on the basis of the Sahel and West Africa Club, in which the African continent is divided into six regions (Figure 3). These are the North, South, West, East, and Central (Sahel and West Africa Club Secretariat, 2017). For this study, southern Africa will be investigated which includes the countries Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe.

Palynological studies examining the Quaternary began in the Northern Hemisphere, where the temperate environments are favourable to pollen preservation (Meadows, 2015). The discipline was only introduced to southern Africa many years later by Van Zinderen Bakker (1955) and fellow pioneers (Coetzee, 1967; Martin, 1959, 1968; and Scott, 1982). Van Zinderen Bakker initiated the use of pollen as a palaeoenvironmental proxy in southern Africa, after he arrived in the country in 1947 where he instituted a pollen analysis laboratory at the Orange University of the Free State (now UFS) (Van Zinderen Bakker, 1955; Meadows, 2007).

These studies were hindered by the lack of precise dating techniques. Furthermore, the rich flora within the region did not have existing pollen reference collections which are needed to identify parent plants (Scott, 1989; Van Zinderen Bakker and Coetzee, 1988). Recent developments in more affordable high precision dating techniques and an increase in palynomorph collections (specifically pollen, diatom, and phytoliths) has been of great benefit to recent studies (Kristen et al., 2007).

Having precise dates of samples studied enables a more accurate palaeoenvironmental reconstruction, and reference collections aid in the identification of proxies (Kristen et al., 2007).

Figure 3: Map illustrating the regional divisions in Africa (Sahel and West Africa Club Secretariat, 2017)

Many sites in southern Africa do not host fossil pollen deposits as they are too arid to preserve pollen, or host communities of aquatic microfossil proxies which could preserve diatoms, ostracods, and foraminifera (Livingstone, 1975; Scott, 1989; Chase and Meadows, 2007; Meadows, 2015). This is why much of the research conducted has been confined to wetlands found in humid regions, and isolated springs in the interior of the sub-continent (Scott, 1989; Neumann et al., 2008; Meadows, 2015). Figure 4 shows the main localities in southern Africa where palaeoenvironmental work has been undertaken (Fitchett et al., 2017).

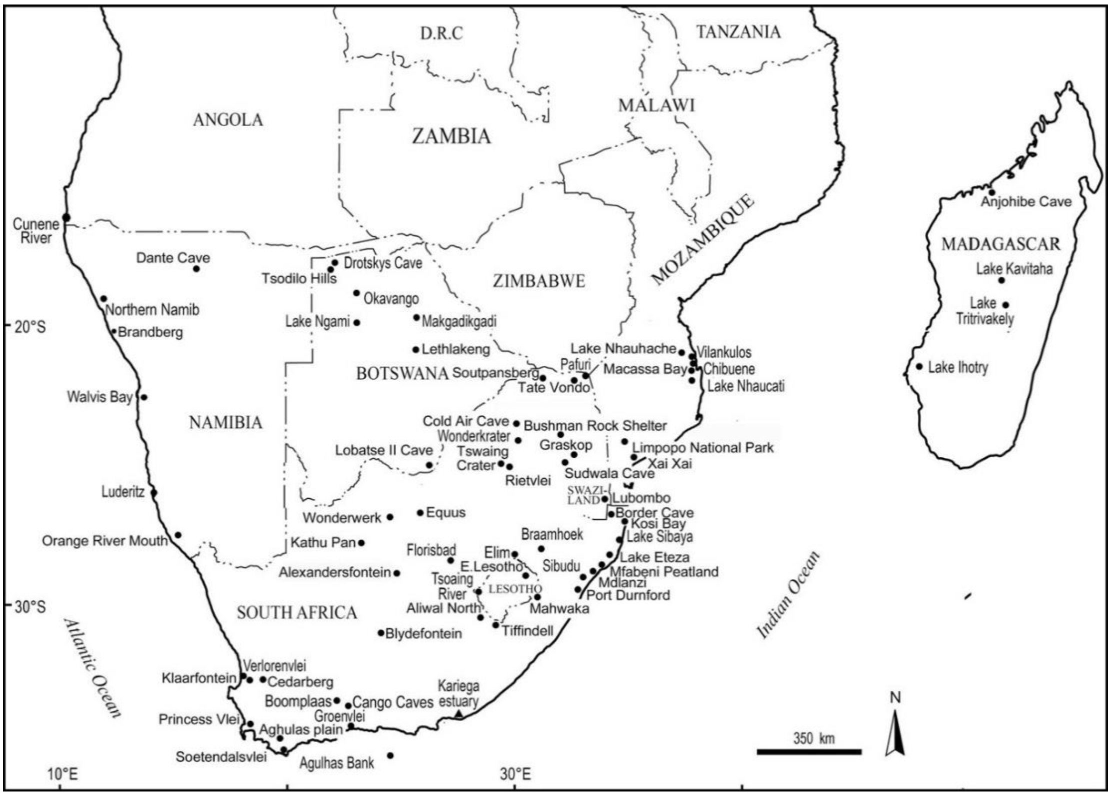

Figure 4: Map of southern Africa showing where known published palaeoenvironmental have been undertaken (Fitchett et al., 2017)

The East African Mountains were where the first major palynological studies were conducted in the 1950s and were aided by the improvements in radiocarbon dating techniques (Meadows, 2015). Much of central Africa lacks lake and wetland deposits, especially in the tropical equatorial regions (Meadows, 2015). It, therefore, possess few prospects for pollen studies (Meadows, 2015). Early in his career, Van Zinderen Bakker explored wetland and lakes in Congo, but many of these organic deposits were shallow due to peat fires (Meadows, 2015). This is a similar occurrence that peat deposits in the Okavango basin experience (Meadows, 2015), which is useful to note as the location of deposits for this study are part of the Okavango Basin.

The early work of Van Zinderen Bakker included low-resolution exploratory investigations from Florisbad and eastern Lesotho Highlands (Van Zinderen Bakker, 1955 and 1957). Recently, reanalyses using multiproxy palynological techniques on the eastern Lesotho Highlands flora were undertaken by Dr. Jennifer Fitchett (Fitchett, 2015; Fitchett et al., 2017). Most palynological work is focused on the East African Mountains as the environments found within those sites are more favourable for pollen preservation (Coetzee, 1967; Coetzee and Vogel, 1967; Van Zinderen Bakker, 1969, 1972; Van Zinderen Bakker and Coetzee, 1988).

Florisbad was the first southern African site that Van Zinderen Bakker studied to reconstruct past climates using pollen as a proxy. He used sediment samples that were left exposed from past archaeological work at the study site (Van Zinderen Bakker, 1957). Florisbad is located in the interior of South Africa (Van Zinderen Bakker, 1957). During re-analysis from exposed outcrops at the site many years later, Van Zinderen Bakker (1989, 1995) noticed methodological errors from the initial study, such as using samples that had been exposed for long periods. Over time as sampling, dating, and statistical tools improved, many of these historic sites have been revisited and investigated at a higher resolution (Scott and Thackeray, 2006). Scott and Rossouw (2005) did a re-analysis of botanical evidence at Florisbad looking at pollen and phytoliths. A detailed analysis of Holocene records was undertaken by Scott and Nyakale (2002) which improved the understanding of the palaeoenvironmental history of Florisbad.

With the focus on the interior of South Africa, Wonderkrater has also been a site of interest. The initial pollen results were published in 1978 (Scott and Vogel, 1978; Scott, 1982a). Scott and Thackeray (1987) then performed a more detailed pollen analysis five years later, as well as a re-investigation of the age interpretations by Scott and Vogel (Scott et al., 2003). Since the 2000s the Younger Dryas period has been investigated in this area by Thackeray and Scott (2006); an investigation into the geomorphology of the site with its implications on the validity of the palynological records (McCarthy et al., 2010); a study relating modern vegetation to pollen records (Truc et al., 2013); as well as a multi-proxy analysis of archaeological material that has been excavated from the site for archaeological studies such as the analysis of the pollen, charcoal and phytoliths within study samples (Backwell et al., 2014).

Another site within the interior of South Africa that researchers have displayed significant interest is the Tswaing Crater. The initial pollen sequence was relatively broad (Partridge et al., 1993), but a more detailed analysis was undertaken and produced by Louis Scott some years later (Scott, 1999b). Accompanying this was a comparison of the Tswaing Crater pollen records with that of Wonderkrater (Scott, 1999a). In his doctoral thesis, Metwally produced a high-resolution pollen analysis of the Holocene slice of the Tswaing Crater profile (Metwally et al., 2014). Other proxies have been studied at this site to re-investigate and gain clarity on palaeoenvironments and age determinations using diatoms (Metcalfe, 1993), geochemistry (Kristen et al., 2007), and biomarkers to determine biozones and correlate ages (Schmidt et al., 2014). Re-analysis of important sites which contain well-preserved archives is necessary as new techniques help improve the accuracy of results, as well as performing higher resolution reconstructions, but also prevents work undertaken in new locations (Fitchett, 2015).

Pollen has been the most commonly used proxy for palaeoenvironmental analysis in past investigations in southern Africa, and much of the literature published rely on results from pollen analyses results on the Pleistocene-Holocene transition in South Africa (Scott et al., 1995) as well as review papers on past climates of the Winter Rainfall Region of the

Western Cape (Meadows and Baxter, 1999; Chase and Meadows, 2007). Van Zinderen Bakker and Coetzee (1988) worked on the late quaternary studies of east, central and southern Africa. In this study, they stated that during the LGM, which occurred 20,000-16,000 yr. BP, the entire southern African region was arid, and from 32,000-28,000 yr. BP there was a cooler episode across southern Africa.

In addition to pollen as a proxy (Van Zinderen Bakker, 1955; Van Zinderen Bakker and Coetzee, 1988; Finch and Hill, 2008; Neumann et al., 2014), a variety of other proxies can be used to reconstruct palaeoenvironments including diatoms (Grab et al., 2005; Fitchett et al., 2016 a, b), phytoliths (Scott, 2002; Finne et al,. 2010), charcoal (Chazan et al., 2012; Bremen et al., 2011), sedimentology and geomorphology (Fitchett et al., 2016a, b; Huntsman-Mapila, 2006; Norström et al., 2014), to name a few. Using these proxies, one can deduce a palaeoenvironment from interpretation of long-term vegetation changes (Scott et al., 2008) as well as the climatic drivers behind these changes (Scott et al., 2012; Truc et al., 2013). There are also a few studies that use proxies such as foraminifera (Strachan et al., 2014, 2015), phytoliths (Burrough et al., 2012), dinoflagellates cysts (Dupont et al., 2004) and biomarkers (Norström et al., 2014; Carr et al., 2015), which further highlight that there is a variety of proxy data available in southern Africa that can be explored (Fitchett, 2015). Since the work of van Zinderen Bakker, there has been development in the sites explored and proxies used (Meadows, 2007, 2015). Louis Scott has done a significant amount of palynological investigations in southern Africa from 1981 (Scott, 1981, 1989, 1999, 2002, 2004, 2004, 2000, 2006). Scott (2002) worked on Florisbad Springs and also investigated pollen in hyrax middens in the Namib Desert and southern Africa (Scott, 2000, 2004). Scott also worked in the Karoo (2004), and faecal deposits in Cederberg (2006).

Palaeoenvironmental archives are those which preserve the various proxies that can be used in palaeoenvironmental reconstructions (Faegri et al., 1989). As previously mentioned, certain areas in southern Africa are too arid to enable the preservation of pollen in wetlands or peat bogs, as well as contain other communities of aquatic microfossils such as diatoms, ostracods, and foraminifera (Livingstone, 1975; Scott, 1989; Chase and Meadows, 2007; Meadows, 2015). To still study these proxies, other archives besides wetlands, peat bogs, and springs that also enable the preservation of palynomorphs can be studied (Meadows, 2015; Scott, 1989; Neumann et al., 2008). In recent years, there has been an increase in the quantity of archives studied such as hyrax middens, speleothems, and shells and bones at archaeological sites preserved in chronological order (Cohen et al., 1992; Cohen and Tyson, 1995; Johnson et al., 1997; Abell and Plug, 2000; Chase et al., 2012; Weldeab et al., 2013; Meadows, 2014).

Speleothems allow for a high-resolution isotope analysis with well-constrained chronologies (cf. Holmgren et al., 1995, 1999, 2001, 2003; Brook et al., 1999; Repenski et al., 1999; Finch et al., 2001; Lee-Thorp et al., 2001; Sundqvist et al., 2013; Green et al., 2015). Hyrax middens are a valuable palaeoenvironmental archive for facilitating pollen-based environmental reconstructions in areas that do not contain well-preserved pollen within the sedimentary records due to very arid conditions (Scott and Bousman, 1990; Scott et al., 2004; Chase et al., 2012; Meadows, 2014). Hyrax middens serve as archives for proxies such as pollen, preserved microcharcoal (Chase et al., 2015a), stable nitrogen and carbon isotopes (Scott and Vogel, 2000; Chase et al., 2011, 2013, 2015a), lipids, and ancient DNA (Chase et al., 2012). This array of proxies contained within these archives enables multiproxy analyses to take place and thereby refines palaeoenvironmental reconstructions (Chase et al., 2012; Meadows, 2015). Louis Scott initially investigated using this archive as a tool in palaeoenvironmental reconstructions in the 1990s (cf. Scott and Bousman, 1990; Scott and Vogel, 1992; Bousman and Scott, 1994; Scott, 1994, 1996). This was an attempt to reconstruct palaeoenvironments in regions where sedimentary records did not possess viable pollen records. Areas such as the Namib Desert (Scott et al., 2004; Gil-Romera et al., 2006, 2007) and the Karoo (Scott et al., 2005) which are some of the driest locations, and almost barren of proxies, were studied using hyrax middens as an archive. In recent years most work using hyrax middens has focused on high resolution analyses from hyrax middens that were extracted from the Cederberg Mountains, to improve the palaeoclimatic history of the southwestern Cape (Scott and Woodborne, 2007; Meadows et al., 2010; Chase et al., 2011, 2013, 2015a,b; Quick et al., 2011). Hyrax middens are limited to southern African sites, but the species is widely distributed, which points to the possibility of applications across much of the arid and semi-arid regions in Africa (Meadows, 2015).

2.2.2 Palaeoenvironmental reconstructions for the late Holocene/ Anthropocene:

Paralleled to the rest of the Quaternary, the Holocene period was a period of relative climatic stability from what scientists have discovered using palaeoenvironmental proxies (Hannah, 2010; Burrough and Thomas, 2013). There are key climatic events that have been identified to have occurred during the Holocene in the Northern Hemisphere but are still unconfirmed in the Southern Hemisphere (Holmgren et al., 2003; Truc et al., 2013), some of these events include: The Younger Dryas cold period (Abell and Plug, 2000; Holmgren et al., 2003; Peteet, 1995; Thackeray and Scott, 2006; Truc et al., 2013; Quick et al.,2011); the African Humid Period (Alley et al., 1997; Chase et al., 2009; Burrough and Thomas, 2013); the 8.2 kyr event (Smith et al., 2002) 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); post-glacial climate amelioration; the Holocene Climatic Optimum and Medieval Warm Period and the period of Anthropogenic influence (Hannah, 2010; Wanner et al., 2015).

As mentioned, not much work has been done in southern Africa due to a paucity of well-preserved proxies, which means records to prove the validity of certain climatic events is scarce as well. Within southern African palaeoenvironmental records, evidence from the 8.2 kyr event is contained within stable carbon and oxygen isotope records from western Lesotho in the Caledon River Valley (Smith et al., 2002), and hyrax midden archives from the Cederberg mountains (Chase et al., 2015b), these agree with the 8.2 kyr cold event that was identified in the Greenland Ice Cores in the Atlantic in the Northern Hemisphere (Alley et al., 1997; Alley and Ágústsdóttir, 2005). Evidence for the Holocene Altithermal event in southern African regions has been well studied except the timing and duration of this event is still uncertain (Scott, 1993). From these climatic events, the African Humid Period (Burrough and Thomas, 2013), the Younger Dryas (Peteet, 1995; Thackeray and Scott, 2006), the 8.2 kyr event (Smith et al., 2002) and the Little Ice Age (Tyson et al., 2000) area all confirmed in the Northern Hemisphere, however there remain unresolved questions such as whether these events occurred in southern Africa and specific environmental conditions as a result or by association with them.

The Winter Rainfall zone (WRZ) is a contemporary zone, currently located in the southwestern Cape, South Africa (Barrable et al., 1998), which during the late Quaternary was most likely affected by the shifts in position and strength of the westerly belt, impacting on the flora in the southern region of Africa (Barrable et al., 1998; Chase and

Meadows, 2007; Stager et al., 2012). Van Zinderen Bakker (1976), Tyson (1986), and Cockroft et al (1987) all initiated studies on the position of the westerly belt in southern Africa during the late Quaternary as a response to changes in sea level from melting ice caps. Initial suggestions were that the Mediterranean Cape flora and WRZ expanded north to ~24°S, which would have covered Namibia and the Free State in South Africa during the LGM (Van Zinderen Bakker, 1976). Van Zinderen Bakker then in 1983 still proposed that the westerlies were much stronger during the LGM with a significant influence on the WRZ, but the realms of the westerly belt did not go as far north as he had first suggested (Chase and Meadows, 2007). Recent studies have investigated the extent of the westerlies (Barrable et al., 1998; Chase and Meadows, 2007; Carr et al., 2006; Chase and Meadows, 2007), but exact geographical limits are still debated.

The Last Glacial Maximum event has been confirmed in the Northern Hemisphere, which influenced the Southern Hemisphere and the southern African palaeoenvironments (Chase and Meadows, 2007). For analytical purposes the period has been broadly defined as 24,000-17,000 cal. yr BP, even though the exact time period of the LGM in southern Africa is unclear (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).

A difference of climatic conditions was experienced by the Winter Rainfall Zone (WRZ), Summer Rainfall Zone (SRZ), and Year-round Rainfall Zone (YRZ) (Chase and Meadows, 2007; Finch and Hill, 2008; Norström et al., 2009; Mills et al., 2012). During this period, the WRZ experienced wetter conditions compared to the SRZ and YRZ which experienced much drier conditions (Partridge, 1999). Evidence from Mfabeni Peatland (Finch and Hill, 2008), the Tswaing Crater (Metcalfe, 1993), Braamhoek (Nörstrom et al, 2009), and Wonderkrater and Boomplaas (Scott, 1989) all suggest that the conditions in the SRZ were drier during the LGM, as these sites are all within the SRZ. The YRZ experienced wetter conditions compared to the SRZ, but drier conditions compared to the WRZ (Chase and Meadows, 2007, as also presented by Carr et al (2006).

Cooler temperatures seem to have been dominant during the LGM (Scott and Vogel, 2000; Neumann et al., 2014; Fitchett et al., 2016b). However, these studies do not quantify the temperature decline in comparison to contemporary conditions (Scott, 1982a; Shi et al., 1998; Scott and Vogel, 2000; Neumann et al., 2014; Nörstrom et al., 2014). From investigations of pollen in Wonderkrater (Scott, 1982a) data indicated temperature conditions to be 5-6°C cooler during the LGM, compared to current temperatures in the interior highveld. Thackeray and Scott (2006) suggest a temperature decline of 6±2°C during the LGM from data obtained from the reanalysis of the Wonderkrater.

The Younger Dryas cool period interrupted the warming period that followed the Last Glacial Maximum, between 13,000-11,500 cal. yr BP (Abell and Plug, 2000). The African Humid Period is believed to have also occurred in southern Africa from evidence recorded from East Africa that states this event occurred between approximately 14,800-5,500 cal. yr BP (Chase et al., 2009; Burrough and Thomas, 2013). The evidence has been obtained from hyrax middens located in Namibia (Chase et al., 2009). Evidence for the Little Ice Age cold period for southern Africa is marked from AD 1300-1800 (cf. Talma et al., 1974; Herbert, 1987; Talma and Vogel, 1992; Tyson and Lindesay, 1992; Brook et al., 1999; Holmgren et al., 2003; Sundqvist et al., 2013; Zinke et al., 2014).

Evidence for the Little Ice Age in southern Africa, from AD 1,300-1,800 is presented in many published works (Herbert, 1987; Talma and Vogel, 1992; Tyson and Lindesay, 1992; Brook et al., 1999; Holmgren et al., 2003; Sundqvist et al., 2013; Zinke et al., 2014). These studies primarily used proxies such as stable isotopes obtained from speleothems (Holmgren et al., 1999, 2001, 2003; Repinski et al., 1999; Tyson et al., 2000; Lee-Thorp et al., 2001; Sundqvist et al., 2013). The evidence suggests that the SRZ and WRZ experienced very different climatic conditions during this time, with dry conditions dominating the SRZ (Holmgren et al., 1999; Ekblom et al., 2008; Neumann et al., 2010) and wet conditions dominating the WRZ (Stager et al., 2012; Weldeab et al., 2013).

The African Humid Period occurred at approximately 14,800-5,500 cal. yr BP during the early Holocene, as suggested by evidence from East Africa (Chase et al., 2009; Burrough and Thomas, 2013). An investigation by deMenocal (2004) of marine sediment from the western coast of southern Africa provides further evidence of an abrupt decline in vegetation ±5,000 cal. yr. BP. The data southern Africa during this period is contradictory, since some studies suggest that evidence for the period exists (Chase et al., 2009), while others suggest that dry areas of the region were fed by distant sources (Burrough and Thomas, 2013). Chase et al. (2009) investigated hyrax middens in Namibia and suggested that there was an early Holocene moist period, as the study infers that the African Humid Period extended to Namibia. Burrough and Thomas (2013) suggest an influence from a distant source due to the extensive aridity in the Kalahari Desert during the early Holocene, which may have fed into the Makgadikgadi (Burrough and Thomas, 2013). A lot of published research has made reference to periods of increased humidity which followed the postglacial warming but have not specifically named it the African Humid Period, these include analysis of the pollen across the interior of South Africa (Van Zinderen Bakker and Coetzee, 1988; Scott, 1993; Lewis, 2005), charcoal from the Caledon River (Esterhuysen and Mitchell, 1996; Esterhuysen et al., 1999), and evidence of peat development which only occurs in warm moist environments (Meadows, 1988).

2.2.3 Palaeoenvironmental reconstructions for the greater Okavango region

The first palaeoenvironmental Holocene record for the Okavango Delta was a study that used a variety of palynological proxies in Botswana with a date of 9 000 cal. yr BP (Nash et al., 2006). The cores were taken from the western margin of the Okavango Panhandle which is almost entirely the Okavango River (McCarthy and Ellery, 1998) and the point where the Okavango River (known as the Cubango in Angola) enters Botswana and then fans out into the alluvial plains of the Delta (McCarthy and Ellery, 1998). This study is one of few palaeoenvironmental work done in the Kalahari region and was initiated late compared to other studies in Southern Africa (Fitchett et al., 2017). Other work in this surrounding area includes pollen extracted from a single speleothem at Drotskyôs Cave in Botswana (Burney et al., 1994), and sediment submerged in a sinkhole at Lake Otjikoto in Namibia (Scott et al., 1991). Usually, detailed palynological work is restricted to sites around the southern rim of the Kalahari Basin in South Africa such as investigations done by Beaumont et al. (1984); Butzer (1984a, b); and Scott (1987).

A study conducted using cores from along the coast of Angola revealed the last 30 000 years of vegetation development and climate change in the region (Dupont et al., 2008). This is the first study that investigated the vegetation history in Angola during full glacial, deglacial, and interglacial conditions. From this study it was concluded that during the Holocene dry forests and Miombo Woodlands expanded in Angola, and the globally recognised climate change events that occurred 8000 and 4000 years ago did have an impact on the vegetation in Angola at the time. During the last 2000 years, Savanna vegetation became dominant, which is similar to present-day vegetation (Dupont et al., 2008; Dupont and Behling, 2006). Other proxies such as geomorphological and geochemical evidence have been undertaken in Botswana in the northern Makgadikgadi sub-basin to determine the formation of the basin (Ringrose et al., 2005; Huntsman- Mapila et al., 2005). The Congo fan has also been an area of interest and investigations looking at pollen assemblages from the Late Holocene haven been conducted (Vincens et al., 1997). For west equatorial Africa, the vegetation and climatic history for the late Pleistocene and Holocene are based on pollen extracted from marine sediments in the Congo (Jahns, 1996). Shi et al. (1998) used pollen obtained from marine records to reconstruct the past vegetation and climate in south-west Africa over the last 21,000 years. Marine records are consistent, and a regional palaeoenvironmental reconstruction can be inferred from results obtained by proxies found within the cores (Shi et al., 1998).

Brook et al. (1999) compared palaeoclimatic changes in eastern and southern Africa looking at multiple proxies (speleothems, tufa, sediment in rock shelters). Tufas and speleothems have also been used to provide evidence of palaeoclimates in Namibia (Brook et al., 1996; Brook et al., 1999) as well as sites in Botswana, which used U-series dating, within the preserved speleothems (Burney et al., 1994). Researchers have looked at the climate change experienced by the Kalahari by investigating geomorphological changes (Lawson et al., 2002; Lawson and Thomas, 2002; Eitel and Blümel, 1997; Blümel et al., 1998; Brook, 1995; Hein, 1982; Nash, 1996).

2.3 The Angolan Civil War

2.3.1 Overview of the history of the war

Angola has experienced 41 years of warfare (Guimarães, 2001). The country was first colonised by Portugal in the 19th century, until the Angolan War of Independence, where the people of Angola and various liberation movements fought so that the country was no longer ruled by Portugal (Guimarães, 2001). This war took place from 1961 till 1974 (Guimarães, 2001).

When Angola attained Independence in 1974, peace was still not achieved as a Civil War started between the various political parties (Guimarães, 2001; James, 2011). The parties involved were The People's Movement for the Liberation of Angola (MPLA) and the National Union for the Total Independence of Angola (UNITA) (Guimarães, 2001). This war began in 1975 and lasted 27 years until it ceased in 2002 (Tvedten, 1997; Guimarães, 2001; James, 2011).

Angola became a battleground for a proxy war because of international interference (Guimarães, 2001). Opposing powers such as the United States of America, Soviet Union, and South Africa instigated conflict in Angola and supported particular parties by funding them and supplying them with military equipment (Guimarães, 2001). UNITA received military support from anti-communist countries such as the USA, China, and the South African regime at the time, while the MPLA received support from the Soviet Union, Cuba, and other liberation movements from the African continent (Guimarães, 2001). Nearly 1.5 million Angolan civilians were killed and 4 million displaced as a result of the conflict, and many long-term effects of the war still prevail (Gangwar, 2003; Guimarães, 2001).

2.3.2 Environmental destruction caused during the war

During the Civil War, rebel parties sporadically placed landmines across the Angolan terrain (Guimarães, 2001; Landmine Monitor Report, 2009). According to the International Committee of the Red Cross (1963:3), a landmine is defined as ñammunition placed under, or near the ground or other surface area and designed to be exploded by the presence, or proximity of a person or vehicle.ò Landmines were mass produced and essentially operated by unwilling victims (Croll, 1998). Due to this mass production and affordability, they are used in abundance, but are very costly to get rid of (Croll, 1998).

There are two types of landmines that were used during the Angolan Civil War ï antipersonnel and antitank mines (Landmine Monitor Report, 2018). Antipersonnel land mines are detonated if a human or anything of similar weight steps on one (Croll, 1998; Landmine Monitor Report, 2018). The antitank mines are activated when a heavier military tank goes over them (Landmine Monitor Report, 2018). The antitank causes more damage than an antipersonnel mine and the uses for each are for different strategic purposes. However, there is no record or map of their placement (Berhe, 2007; Gangwar, 2003). For example, antipersonnel landmines are designed to maim the victim and ñweakenò the opposing army, while antitank mines can be used to disrupt vehicle routes to stop intrusion or to prevent the opposing side from using specific routes to distribute food and other supplies to specific areas (Gangwar, 2003). Angola has one of the most severe landmine impacts in Africa (Berhe, 2007; Landmine Monitor Report, 1999). There is an estimated 9-15 million antipersonnel landmines per square kilometre in Angola (US Department of State, 1998). The HALO Trust located in Angola works to demine areas and make them safe for people to inhabit once again (The HALO Trust, 2019).

Demining is a process in which landmines are located and removed from the ground, but this is a costly process, and they rely on funding which may not always be enough or consistent (Berhe, 2007; Gangwar, 2003). Unknown locations of the landmines in Angola contribute to the costs of removing them, as well as the safety of people in the country (Berhe, 2007; Gangwar, 2003). Studies as far back as the 1970s have indicated that landmines are environmentally destructive (Berhe, 2000; Newton, 1997; United Nations Environment Programme UNEP/IG.4/3, 1977; United Nations General Assembly, 1983). There are a wide range of environmental impacts that landmines have on the surrounding land, whether they are detonated or not (Berhe, 2007). Essentially landmines disrupt land stability, cause pollution, and loss of biodiversity (Berhe, 2007).

The presence of landmines, or the possibility of landmines in an area, has the following impacts:

- The destruction of infrastructure in a country such as bridges, roads, and water sources

- Access denial to vital resources as people are severely injured when stepping on unknown territory, or they are fearful of the possibility of landmines that they donât attempt farming on certain plots of land. As a result people and animals are restricted to limited arable lands, pastures, forests, and migratory paths.

- Landmines destroy and kill flora and fauna when they explode. In certain areas, where land is feared to contain landmines, certain ecosystems have had a chance to thrive due to the lack of human interference. This is only able to last as long as tree roots or animals do not detonate the mines.

- Landmines also disrupt the surrounding land and cause structural disturbance. A typical 250 gram antipersonnel landmine can create a crater with a diameter of up to 30cm when detonated (United Nations General Assembly, 1983; Troll, 2000). This can result in soil erosion, or compact the soil around the crater created.
- Harmful chemical contaminants are also released into the soil or ground water, and as the casing degrades the toxic waste is released. This decreases the productivity of the land.

[Berhe, 2007]

All of these factors add up and result in overuse of resources which are beyond the ecological carrying capacity, which then further results in famine, poverty, unemployment, and underdevelopment. A lot of pressure is placed on land that is safe to use because these areas become densely populated and natural resources are exploited (Berhe, 2007; Hooks and Smith, 2005).

These impacts vary depending on the size of the landmine and the number of landmines in close proximity to one another (Berhe, 2000). Antipersonnel mines contain 10-250g of explosives, while antitank mines contain 2-9kg of explosives (United Nations Department of Humanitarian Affairs, 1995).

Since landmines have such a severe impact on the surrounding land-cover, it is possible that in this study that they may have also had an impact on soil layers they exploded near. General stress on the soil from army tanks during battle may have also had a likely impact on the soil layers. Interestingly, the Battle of Cuito Cuanavale (1987-1988) was fought on the banks of the Lomba River, which is near the town of Cuito Cuanavale in Angola.

2.3.3 Long lasting effects of the war

The Angolan Civil War had devastating impacts on the country not only during warfare, but many years later, people are still dealing with the aftermath of the war (Landmine Monitor Report, 2009). Since the war ended there has been a variety of environmental problems such as a lack of water sanitation; rebuilding the infrastructure that was destroyed; strengthening technical and professional skills of the Angolan people so that the country can rebuild itself and its economy (Ó Dochartaigh et al., 2018). During the war, subsistence and agriculture were reduced, but there have been improvements since 2002 (Ó Dochartaigh et al., 2018). However, many innocent civilians fall victim to the landmines left behind from the war. Many amputees were seen while in the Kuito district as well as rural areas such as Lungué Bungo (NGOWP 2018 expedition).

2.4 Reconstructing Past Environments of War-torn Regions

When a country is dealing with war, many environmental issues take a backseat (Dudley et al., 2002). The war took priority and much needed resources from the country, resulting in a lack of ground surveys, monitoring stations, and measuring stations used to track past climate. There are currently no existing studies on reconstructing palaeoenvironments in war-torn regions, and more specifically regions disrupted by landmines.

Brian J. Huntley was the former director of the South African National Biodiversity Institute, before which he was the National Park Ecologist in Angola from 1971-1975 (Van Wilgen, 2017). In 1975 when the war began, Huntley had to leave as the danger increased. When the war ended, he then began contacting people in Angola to continue with his work (Van Wilgen, 2017). His paper óOutlines of Wildlife Conservation in Angolaô published in 1974 was his last published ecological work on Angola before the 27 year-long civil war had started (Huntley, 1974).

2.5 Conclusion

There exists a paucity of palaeoenvironmental data in southern African regions. Pollen analysis is the most common (Faegri et al., 1989), but other proxies are being explored at a higher rate than ever before. Using multiple proxies is a valuable tool, especially for regions that do not possess well-preserved pollen deposits, so another proxy that may have been preserved can be investigated to determine a palaeoenvironmental history of the area. The Civil War in Angola, apart from causing considerable damage to the civilians and surrounding environment, has also hampered ecological scientific advancements in the country in terms of environmental monitoring and modelling and palaeoenvironmental records (Huntley, 1974; Thomas and Shaw, 2002). Now that the 22 year-long war has ended, initiatives such as this study can be carried out to build up an archive of palaeoenvironmental information, which will be useful for understanding how past ecosystems worked and responded to climatic drivers, which in turn will aid future climatic models on climate change (Fitchett et al., 2017).

CHAPTER 3: REGIONAL SETTING

3.1 Introduction

This study presents a late Holocene palaeoenvironmental reconstruction for two source wetlands located in north-east Angola, which supply the Okavango Delta. Angola is one of the few countries in Africa with very little recorded biodiversity; an indirect consequence of the 27 year-long civil war that ceased in 2002 (Rejmànek et al., 2016; Huntley, 2017; Van Wilgen, 2017). The two study sites selected; the Cuito Cuanavale and the Cuanavale source lakes were strategically chosen, as wetlands and lakes often host well-preserved pollen rich deposits (Faegri et al., 1989; Twiddle, 2012). Accessing the two study sites posed as a challenge for the OWP team and required extensive fieldwork. The fieldwork carried on, despite a lack of seismic data for the region. The seismic data would have been helpful in indicating the depths of sedimentary deposits. This chapter provides a description of the contemporary geography of Angola, and the two mentioned study sites. A limited description is provided based on the interests of this study and does not delve deeper into the history, cultural, or social and economic standing of the country.

3.2 The Okavango Delta

The Okavango Delta is located in the north-western parts of Botswana (Kgathi et al., 2006). This river system is vital as it is the main water source for many locals in the area (Kgathi et al., 2006). Studying the regional palaeoenvironments around the Cuando River in Angola is of particular value as the locals are reliant on the river, and it is also a tributary into the main Okavango delta (McCarthy et al., 1998). Rivers from the Angolan highlands drain into the Okavango Delta which is a flood pulse hydrology system regulated by wet and dry seasons, and finally enters the Ntetwe and Sowa pans of the Makgadikgadi-Okavango-Zambezi rift depressions (Huntsman-Mapila et al., 2005; Marazzi et al., 2016). Local rainfall and inflow from the catchment in the Angolan highlands cause annual flooding in the Okavango Delta (McCarthy and Ellery, 1998; Steudel, 2013). This dynamic hydrological system is sensitive to change.

The main influences on the river system are climatic, geological, hydrological, vegetation, geomorphological, and anthropogenic (Kgathi et al., 2006). Current climatic conditions responsible for rainfall over the Okavango Delta are due to anti-cyclonic conditions that prevail over the interior of southern Africa, as well as rainfall patterns exhibiting an 18-year oscillation cycle (McCarthy et al., 1998).

Angola is the southernmost region that experiences rains from the West African monsoon (Dupont et al., 2008).The Angolan catchment which is dominantly influenced by the Inter-Tropical Convergence Zone (ITCZ) and the Congo Air Boundary. (McCarthy and Ellery, 1993; Gieske, 1996; McCarthy et al., 1998; Milzow et al., 2009, 2002; Ringrose et al., 2003). The Congo Air Boundary is a convergence zone, between the Indian Ocean air and the unstable air from the Congo Basin, that migrates over Angola annually (Dupont et al., 2008). This boundary moves from the southern parts of Angola in January (austral summer), to its northern position in July (austral winter) (Leroux, 1983)

3.3 Descriptive Geography

Angola is located on the west-coast of south-central Africa. It lies within latitudes 4°22ô and 18°02ô E, and longitudes 11°41ô and 24° 05ô S. Angola borders the Democratic Republic of Congo to the north; Zambia to the east; Namibia to the south; and the Atlantic Ocean to the west (Figure 5) (Kgathi et al., 2006). It covers a total surface area of 1,246,620km^2, and has a population of 27,145,526 people, with a population density of 21.77 people per square kilometer (Ó Dochartaigh et al., 2018). The country is divided into three main geographic areas; a coastal strip which is known as the littoral zone; highlands which are almost parallel to the coastline; and the central plateau (Pereira et al., 2003). The highest point in Angola is the Morro de Moco at an elevation of 2,m.asl and the lowest point is the Atlantic Ocean which lies at sea level. Approximately two-thirds of the country lying along the plateau land that reaches an average elevation of 1000-4000m.asl (Pereira et a., 2003). Along the Angolan coast, the elevation decreases substantially down to 200m at the highest point (Pereira et al., 2003). Of the 600 000 people inhabiting the basin, 58% are located in the Okavango Basin area in Angola, although this represents less than 3% of the total Angolan population.

Figure 5: Map of Angola, approximate location of Cuito study site indicated as CS and Cuanavale study site as CNV (Okavango Wilderness Project).

3.4 Geology and Geomorphology

Three main geological divisions of Angola are the Low Coastal Strip, the Highlands, and the Central Plateau. The Central Plateau, or óEastern Highlandsô is of a moderate topography and is comprised of ancient crystalline rocks with granite overlain by sandstones and conglomerates deposited during the Palaeozoic, which created the uplifted plateau resistant to erosion. This zone is underlain by Tertiary to recent deposits of the Kalahari Beds with small areas of Carboniferous and Jurassic age Karoo Supergroup units, mostly in the north-eastern part (Collelo, 1991). Precambrian units are also present in the far eastern border of the Central Plateau. This zone covers 75% of the country and extends from the eastern border to the mountainous coastal ridge in the Highland region (Collelo, 1991; Ó Dochartaigh et al., 2018). The highland region, also referred to as the óMedian Zoneô is formed by a series of hills and consists of crystalline rocks with granite and some Paleozoic age rocks. These mountain belts are parallel to the coastline, and underlain by predominantly Precambrian granites; as well as ultrabasic rocks, with lesser sedimentary units in the northwest region of the zone (Collelo, 1991; Ó Dochartaigh et al., 2018). The low coastal strip, also known as the óLittoral Zoneô hosts rocks of Tertiary age, and is the only zone that contains fossiliferous strata. It is underlain primarily by sedimentary deposits, which range from the Carboniferous period to Recent (Collelo, 1991). Continental sediments of the Kalahari Group are widespread in eastern Angola, and over 55% of Angolan land is covered by unconsolidated Kalahari sands (Haddon, 2005). The geology of the western parts of Angola is relatively well understood, but there is a paucity of geological studies done on the east of the country (Figure 6). There are eight key rock formations that exist in Angola, namely the crystalline basement, the Oendolongo System, the Bembé System, the Karoo Supergroup, the Kalahari Group, and finally Alluvium deposits which lie unconsolidated on the surface (Ó Dochartaigh et al., 2018). These key formations are summarized in a table below taken from Ó Dochartaigh et al (2018) describing their lithology and formation.

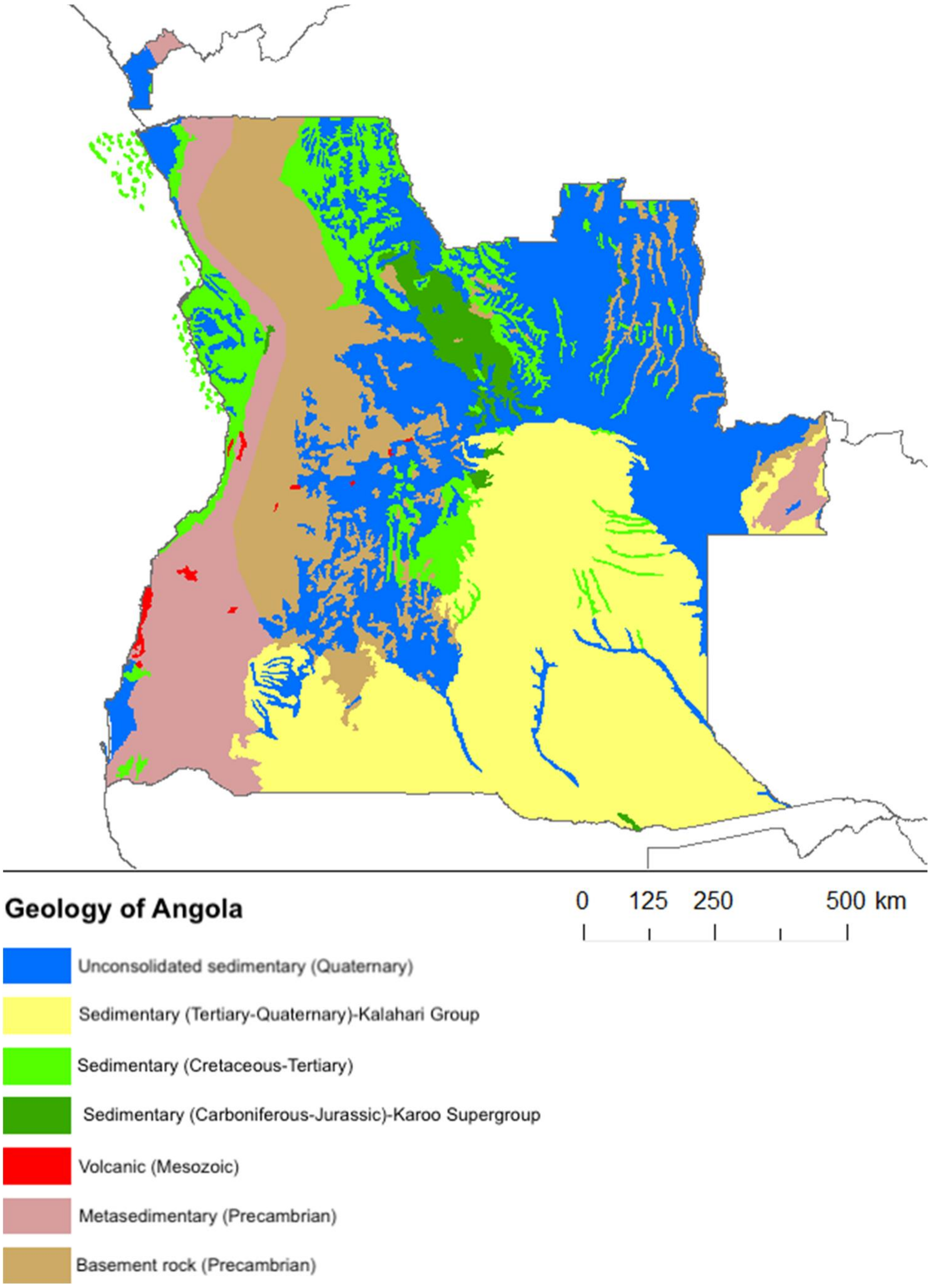

Figure 6: The geology of Angola (Ó Dochartaigh et al., 2018)

Table 1: Key geological formations in Angola (Ó Dochartaigh et al., 2018)

Geological environment		
Key formations	Period	Lithology
Unconsolidated/semi-consolidated		
Alluvium	Quaternary	Unconsolidated alluvial sediments infilling valleys. These are thickest below the floodplains and near-coast deltas of the large rivers-the Cuanza, Zaire and Cunene.
Kalahari Group	Tertiary-Quaternary	Loosely consolidated sandstones and unconsolidated sands and silts, covering much of the eastern part of the country. Up to 600 m thick.
	Cretaceous-Tertiary	Loosely consolidated sandstones and unconsolidated sands and silts, covering much of the eastern part of the country. Up to 600 m thick.
Consolidated sedimentary		
Karoo Supergroup	Carboniferous-Jurassic	Argillaceous limestones, sandstones and shales at the edge of Congo Basin. Up to 500 m thick. Intruded by dolerites.
Volcanic rocks		
	Mesozoic	
Precambrian		
Bembé System	Late Precambrian/ Lower Precambrian	Metasedimentary rocks: schist-limestones overlain by metasandstones, metaconglomerates and quartzites
Oendolongo System	Precambrian	Metasedimentary rocks: quartzitic metasandstones
Crystalline basement	Archean	Crystalline igneous and metamorphic rocks, largely granites, gneisses and gabbros, part of the African craton. Often with quartz veins. Except for the coastal area, Precambrian basement rocks are exposed in large parts of Angola (DNA, 2005).

3.5 Climate

The climate of Angola is largely influenced by the South Atlantic High Pressure Cell, which drives prevailing winds from the west and south-west, and the equatorward flowing Benguela Current (Tyson, 1986). The southward migration of ITCZ belt is limited by the South Atlantic high-pressure cell (Roffe et al., 2019). The cold Benguela Current creates a temperature inversion layer along the coast of Angola, which has a stabilizing effect on the lower atmosphere (Roffe et al., 2019). This encourages the upward movement of moist air along the Namibian and Angolan coastlines, creating a gradient of increasing precipitation north to south and west to east (USAID, 2013).

The country encounters distinct alternating wet and dry seasons, much like the rest of tropical Africa (Collelo, 1991). The northern parts of Angola have rainfall throughout the year receiving more than 1400mm.yr^{-1} of rainfall; while the southern and coastal regions are semi-arid and receive less than 400mm.yr^{-1} of rain. The dry season usually occurs from May to October, and the wet season occurs from February to April. Between Novembers to January, there are often transitional rains (Ó Dochartaigh et al., 2018). Towards the north, the wet season can sometimes last up to seven months, from September to April, briefly declining in January and February. During the dry season, there is often substantial mist in the early parts of the morning. Precipitation is generally higher in the north, but at any given latitude rainfall is greater in the interior than along the coast and increases with altitude. Temperature decreases with distance from the equator and altitude and generally tends to increase closer to the Atlantic Ocean (Collelo, 1991). In the southwest corner, part of the Namib Desert biome, the average rainfall is less than 100mm.yr^{-1}. Here, the endemic conifer Welwitschia mirabilis occurs. Moving north along the coast, the rainfall increases to more than 1,000mm per annum in Cabinda province. The increase in precipitation without changes in altitude is caused by changes in the trajectory of the cold, north-flowing Benguela current.

Moving inland, the effect of the Benguela current is attenuated, though topographic relief creates conditions that favour cloud formation and therefore increased precipitation. The topography-induced precipitation gradient is steepest in the transitional zone that separates the coastal area from the elevated inland.

In mountainous areas, moisture available to plants as the mist is a strong determinant of vegetation (Barbosa 1970). Hence, the elevated areas (Ó1,500m.asl) around Huambo receive more than 1,500mm of rainfall per annum. To the east and northeast, precipitation is more related to continental conditions and the movements of the inter-tropical convergence zone. In the extreme northeast, Angola receives more than 1,500 mm of rainfall. Temporal rainfall distribution is characterized by distinct wet (October-May) and dry (June-September) seasons. March and April are the wettest months; June and July are the driest. Mean annual temperatures range from 14°C at the highest elevations to more than 26°C in some low-lying north-western coastal areas. The cold season coincides with the dry season. (USAID, 2013)

3.6 Vegetation

Angola is one of the most neglected countries in terms of botanical research, both contemporary and past vegetation (Figueiredo et al., 2009; Huntley et al., 1974; Huntley, 2019; Revermann et al., 2017). According to a survey aimed at surveying Angolan flora, Angola is the only country in southern Africa for which plant inventory has not been produced to date (Figueiredo et al., 2009). Having a country-level floristic checklist enables scientists to determine the levels of diversity and endemism, so a lack thereof has hampered these as well as conservation-driven initiatives (Figueiredo et al., 2009).

There exists a paucity of well-preserved and accurately dated pollen profiles for central African regions, which impacts the ability to provide detailed reconstructions of past vegetation within the region (Scott, 1984). The most dominant plant species in Miombo systems are insect pollinated and do not produce large amounts of pollen and are thus likely to be under-represented in the pollen spectra. The Angolan Miombo woodlands in the southern part of Angola are dominated by Jubernardia paniculata and represents the southern limits of Miombo species Sensus stricto (Campbell, 1996; Finckh and Revermann, 2013). The south and south-west regions of Angola are covered in sparse Savanna grassland and desert, while the northern regions are covered in shrubland and deciduous forest (Ó Dochartaigh et al., 2018). Often the topographical positions and underlying geological substrate influence the vegetation such as in the Bié Plateau (Campbell, 1996; Finckh and Revermann, 2013).

3.5 Hydrology

Most of the rivers in Angola originate in the central Angolan highlands, although final outlets and flow regimes vary. Many of the rivers originate in the central highlands of the Bié Plateau, but take very different paths (Figure 7) (Ó Dochartaigh et al., 2018). Some flow due west while others flow in a westerly direction into the Atlantic Ocean, and in doing so provides water to the dry coastal strip, and also has potential for hydroelectric power schemes, which had only been considered by 1988 (Ó Dochartaigh et al., 2018).

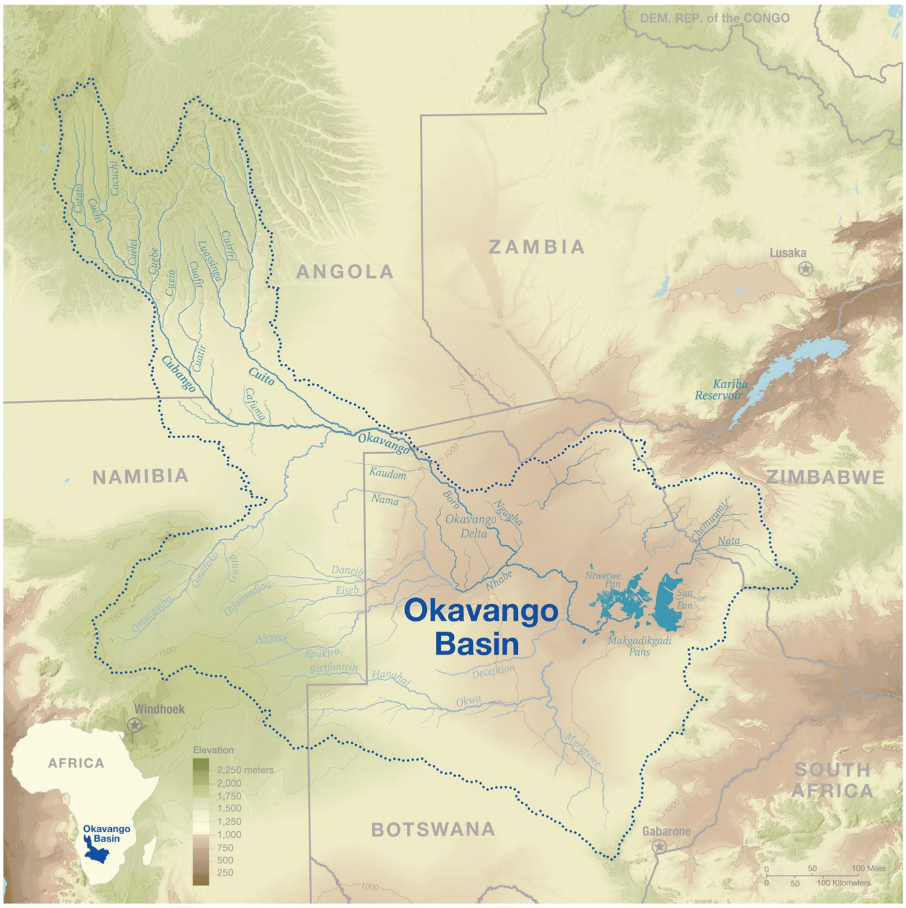

Figure 7: The Okavango Basin and it's two major tributaries, the Cuito and Cubango rivers (Okavango Wilderness Project; Goyder et al., 2018)

The north and central parts of Angola have a lot of perennial rivers, while the south only has three perennial rivers which are the Cunene, Kuando, and Cubango. This is the Angolan part of the Okavango River that leads into the Okavango Delta (Ó Dochartaigh et al., 2018). The Zambezi and Congo Rivers also have their sources in Angola, with the Congo River having several tributaries originating in Angola (Ó Dochartaigh et al., 2018). The Cuito and Cuanavale source lakes mentioned in this study form part of the river tributaries that lead into the Okavango Delta (Figure 8). Together this is all part of the Okavango River System. The headwaters of the Okavango River system originate in the Angolan Highlands.

The two main sources to the Okavango River are the Cuito and Cubango, located at 1800 m.a.s.l. in the Angolan Highlands, which contribute about 94% of the water influx into the Okavango system rainfall where these headwaters originate is usually 1300mm per year, between October and April. The Cuito headwaters begin in the eastern part of the country and drain into a flatter landscape, in which the water meanders through shallow valleys and floodplains. As previously mentioned, the Cubango River forms part of the Okavango River System. This river is located in the western region and follows a steep course of incised valleys, rapids, waterfalls, and well-weathered nutrient poor soils (Kgathi et al., 2006). The Cubango and Cuito rivers meet at an elevation of 950m and become the Okavango River (Figure 9). This area is flat due to the deposition of Kalahari sands over the last 65 million years. Due to geological faults within the underlying lithology, the waters of the two amalgamated flows to form the Okavango River are channelled into the panhandle where they seep into the swamps of the Okavango Delta (Steudel et al., 013).

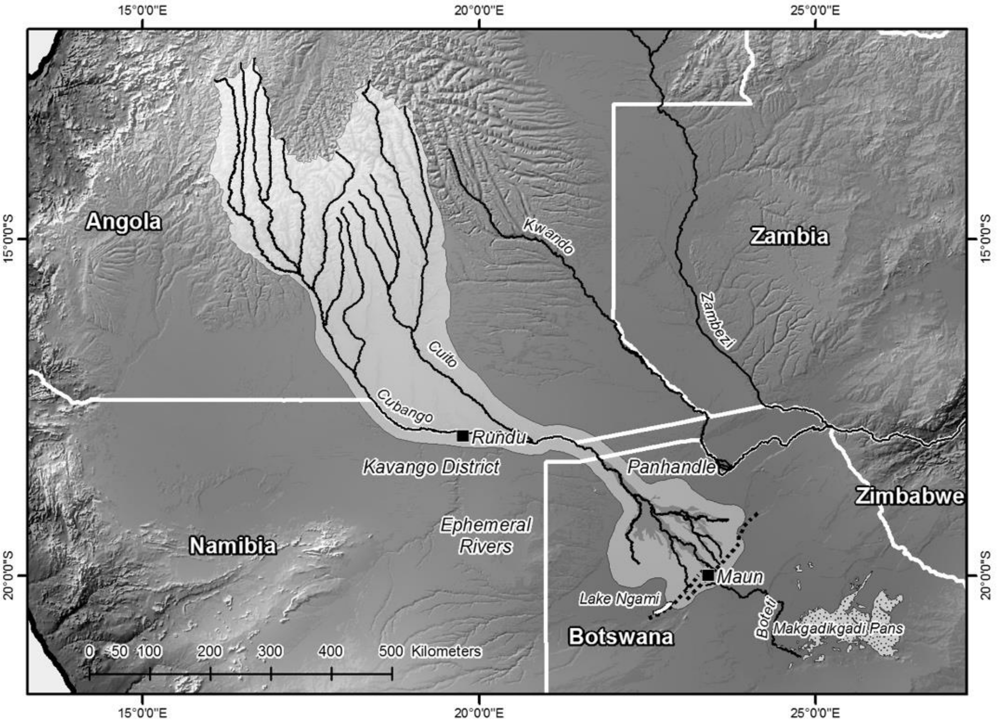

Figure 8: The active drainage basin of the Okavango River system (Okavango Wilderness Project).

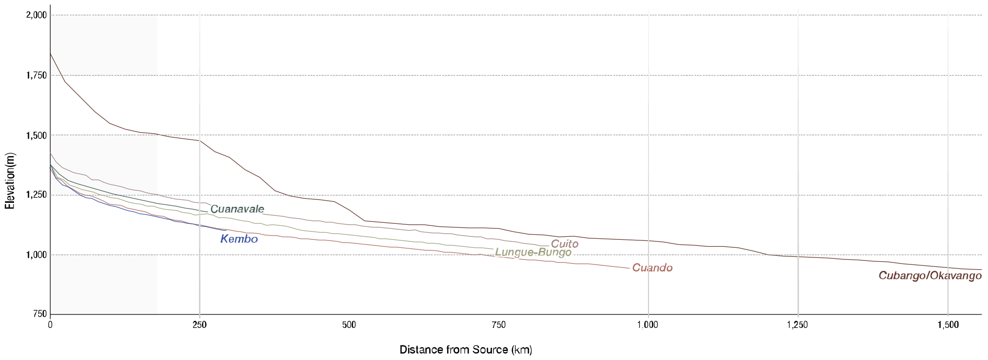

Figure 9: River profile comparison (Okavango Wilderness Project).

High flooding in the Cubango, due to the flood-pulse system of the Okavango River, are the primary water supply for the annual flooding of the Okavango Delta during the wet season. The Cuito river system maintains the permanent swamps in the basin as during the dry season when Cubango flows weaken, the Cuito flows into the lower Okavango to ensure that the core of the Delta is permanently inundated.

The Cuito River has not been investigated and is thus poorly known. This is due to inaccessibility due to landmines (Steudel et al., 2013). Limited research has been conducted with regards to groundwater in Angola, however it is assumed that only a small portion of the national groundwater reserves are used as there are limited levels of development in Angola (Ó Dochartaigh et al., 2018).

3.6 Environmental problems

Since the beginning of the Civil War in 1975 the country has had many challenges. These include the presence of landmines, many of which are still present and yet to be cleared. Also, water sanitation, in which large sums of funds have been invested in to create better water supply infrastructure (Ó Dochartaigh et al., 2018). Due to the presence of landmines, many areas remain inaccessible; this puts a break on agriculture, settlement, infrastructure, etc. (Ó Dochartaigh et al., 2018). This has also resulted in people overpopulating fragile strips of land that are known not to contain landmines. Research in the area is also hindered, and many species remain undiscovered, such as in the Cuito River (Steudal et al., 2013). Many natural resources in the region are over-exploited, and as a result, the environment is at risk of degradation due to unsustainable agricultural practices, deforestation, over-grazing, pollution, as well as human-induced factors (Angola: Biodiversity and Tropical

Forests, USAID, 2013). In addition to these factors, climate change and desertification add to environmental stressors, along with poverty and a fast-growing population (USAID, 2013).

3.7 Contemporary environments of the specific study sites

3.4.1 Cuanavale

The Cuito Cuanavale source lake is located at the lake edge at an altitude of 1,363m.asl and has GPS coordinates 12°41. 207ôS and 18° 21. 773ôE. This region contains typical wetland vegetation such as grasses and peat deposits. The core from this study site did not contain differentiated stratigraphic layers but instead dark organic peat matter, with roots from the present-day vegetation as well as decaying organic matter.

3.4.2 Cuito

The Cuito Source Lake is again located at a lake edge, with dense vegetation expected of wetlands. It lies at an elevation of 1,438m.asl, 75m higher than the Cuito Cuanavale source lake. This study site is located at 13° 04. 572ôS and 18° 53. 305ôE. The cores extracted from this site presented dark organic rich peat deposits with no stratification.

3.8 Conclusion

Angola provides an important environmental setting for palaeoenvironmental work to be conducted due to the network of peat-rich wetlands, which are an unlikely case for tropical African countries (Huntley, 1974; Goyder et al., 2018). A wealth of environmental proxies most likely exists in these peat bogs, and pollen preserves are known to be preserved in these anoxic environments. There are limitations to accessing particular study sites in Angola because of the presence of landmines. These war weapons were placed in various parts of the country during the 22-year civil war, and millions have still not been cleared. This is one of the primary threats Angola faces today (Landmine Monitor Report, 2009).

CHAPTER 4: STUDY METHODS

4.1 Introduction

The key methods used in this study to obtain and analyse data will be discussed in this chapter. The methods used in this study have been derived from similar palaeoenvironmental and palaeoecological studies done elsewhere around the world. The methods used in this study are divided into four key themes: fieldwork; laboratory work; microscope analysis; and statistical analysis. It is vital that the extraction process of the pollen and spore grains are carried out correctly to ensure the grains do not get destroyed, and a minimal amount of contamination occurs. Ideally, no contamination of modern pollen should occur, that would make for an uncluttered slide.

4.2. Study Site Selection

Gaining access into the country and exploring the unchartered territories of Angola was challenging. The OWP team provided the opportunity to access and obtain peat cores from these remote wetland regions.

The particular study sites were selected because areas were in anoxic environments, on a lake edge, and has little post-depositional disturbance. These factors are ideal for pollen preservation (Aaby, 1976; Langdon et al., 2003). Finding peat deposits in the equatorial tropical regions of the Southern Hemisphere is uncommon. Thus, access to these peat deposits was a rare opportunity. Both study sites are bog systems located near a lake.

During the expedition, a limited number of peat cores could be extracted, and experimentation with a variety of field methods was not possible. this is because both study sites are difficult to access, and the number of field equipment taken along had to be kept to a minimum.

Present day research is also being undertaken at particular sites as well as many others around the region, so comparisons between palaeoecological works with contemporary work are possible once the ongoing research is published.

4.3. Field Work

A vital part of palaeoenvironmental studies is selecting the study site (2015). Several factors must be taken into consideration when doing so, such as ensuring peat preserves are present in the region, and cores of sufficient length can be extracted to represent a large timescale for palaeoenvironmental reconstruction.

Certain factors such as impermeable layers, shallow deposits, and bedrock will inhibit one from extracting the longest core possible. Obtaining a core that is too short will not represent a large timescale, thus the longer the core, the better to enable a palaeoclimatic study spanning thousands of years. This being said, the composition of peat does vary greatly (Clymo, 1983), depending on the type of wetland. Peat is usually composed of 65% organic matter, and 20-35% inorganic material (Clymo, 1983; Charman, 2000).

For palaeoenvironmental reconstructions, it is important to core from sediment that is undisturbed, to ensure an accurate depiction of the environment through time (Frew, 2014). Sites that are close to steep slopes or a visible mass movement such as across floodplains, where meandering has taken place are not ideal as they will contain disturbed sediment records (Frew, 2014).

Fieldwork for this study was conducted in November 2016. Cores were extracted by Goëtz Neef while on the National Geographic Okavango Wilderness Project expedition to the source wetlands to the Okavango Delta. Only one field trip was able to take place to reach the study sites. Coring was performed using a 75mm Russian corer, with 0.5m section pipes. The Russian corer also has the advantage of not disturbing the sediment that is being extracted, and it can expose a large surface of undisturbed sediment (Moore and Webb, 1978; Faegri et al., 1989).

A total of four cores were extracted, the two cores that were used for this study were 90cm and 30cm in length (Cuanavale and Cuito source lakes, respectively). These two cores held the best location and length for this study. The other two cores that were omitted from this study were either insufficient in length or the labels had been erased due to the extensive transportation of the cores. Sub-sampling was not performed in the field, as the collectors were not able to do so due to volatile conditions.

The Cuanavale and Cuito source lake cores can be located at 12°41.207ôS, 18°21.773ôE and 13°04.572ôS, 18°53.305ôE respectively. More detail about the study region is provided in the study region chapter. To extract the cores, the Russian corer was placed on the peat layers and pushed down into the sediment to the desired sampling depth, and then turned 180° which sliced the sediment into the half cylinder. The core sampler was then extracted out of the sediment and opened using the reverse procedure. After this, the core samples were transferred to a split plastic tube and covered in foil to prevent contamination of the samples. Contamination by modern day pollen can be disruptive to the study as it will not give an accurate palaeoenvironment (Moore and Webb, 1978). To prevent contamination or mixing of sediment, the fin of the Russian corer was wiped between the extractions of successive cores (Moore and Webb, 1978).

The cores were stored in a refrigerator at temperatures below 4°C once they were brought back to the laboratory. This is to prevent contamination and decay. In the field, the cores were stored in foil and kept in a cool environment as fieldwork was undertaken in the remote regions of Cuito Cuanavale and the cores could not be transported to the laboratory immediately (Haberyan, 1987; Stager et al., 2003). Decay often occurs in the form of mould, which then interferes with the identification of the fossil pollen as it obstructs the view (Faegri et al., 1989). Once samples are stored in temperatures below 4°C, ideally in a refrigerator, they can be kept for decades (Haberyan, 1987; Stager et al., 2003). The refrigerated cores were subsampled at a 2cm resolution, followed by the chemical maceration process.

4.4. Laboratory Preparation

4.4.1. Summary of techniques

Over the years there have been various adaptions to the chemical procedures used in pollen preparation, and preferred methods do vary among palynologists. For this study the techniques used to liberate the pollen grains were adapted from and described by Erdtman (1943), Moore and Webb (1978), Faegri et al., (1989) and Bradley (1999). Storage and preparation of the peat cores took place at the Evolutionary Studies Institute of the University of the Witwatersrand, Johannesburg, South Africa. All subsampling and preparation of the cores took place in a pressure-controlled laboratory at the Evolutionary

Studies Institute of the University of the Witwatersrand, where only filtered air is drawn in to prevent contamination from local modern pollen (Moore and Webb, 1978; Faegri et al., 1989).

The first step was to carefully measure out 7g of each subsample using a scalpel and place it into test tubes. After every sample was measured out, the scalpel was washed and rinsed with distilled water to prevent contamination (Renberg, 1990). A further 4g of the sample from particular depths in the core was set aside and sent to BETA Analytics to be dated using AMS radiocarbon dating techniques.

Before chemical preparation began, the samples were placed into polypropylene test tubes and refrigerated at 4°C to prevent decay and microbial activity (Haberyan, 1987; Faegri et al., 1989). Large organic material and silica compounds were removed by washing the sample through a 170-180 µm sieve. This allowed pollen and spore grains to pass through while trapping macro content which was then discarded (Faegri et al., 1989).

Once chemical treatment was complete (Figure 10), slides were made using glycerol jelly (Figure 10). Faegri and Iversen, (1989); and Moore et al., (1991) suggest using glycerol jelly to mount the float fraction onto slides, as it dries completely solid and does not allow for movement of the cover slip. This is especially useful if the samples are prepared in a warm climate. A cover slip staying in place allows for grains to be easily located if need be.

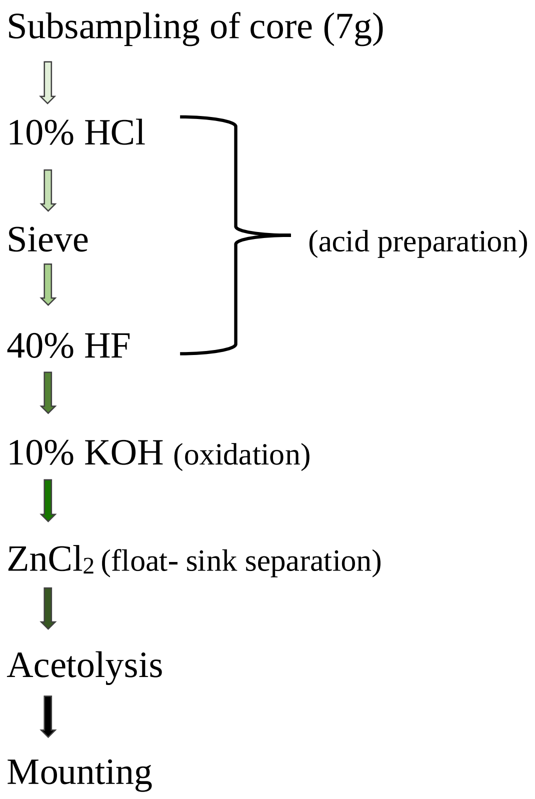

Figure 10: A summarized procedure of pollen preparation (after Faegri et al., 1989)

Accelerator Mass Spectrometry (AMS) Radiocarbon Dating

In order to provide a palaeoenvironmental reconstruction and situate it within ecological history, as well as compare the results with present studies, it is crucial to determine the chronology of the samples under investigation. AMS radiocarbon dating is used to determine the approximate age of the sediment in which the carbon isotopes are contained within (Kolstrup, 2007).

It is a dating method that is commonly used when the sample sequence contains only organic matter, and the expected age of the sediments is also less than 50,000 cal. yr BP (Kolstrup, 2007). This method of dating measures the concentration of C^{14} ions against the concentration of C12 and C13 ions (Walker and Walker, 2005). Between these three

Carbon isotopes, the lighter C^{12} and C^{13} are stable, however, the heaviest isotope C^{14} is radioactive (Bowman and Leese, 1995; Walker and Walker, 2005). Throughout a plantôs lifetime, the ratio of C14 absorbed, is in isotopic equilibrium with the percentage of C14 present in the atmosphere at the time, in relation to the other carbon isotopes (Bradley, 1999; Fairbanks et al., 2005; Walker, 2005). After the plant death, the C^{14} is no longer replaced and the existing C^{14} in the plant begins to decay to N^{14}. This radioactive decay has a half-life of 5,730±40years (Fairbanks et al., 2005; Walker, 2005).

The length of the period in which radioactive decay occurs can be calculated using a tendon accelerator system (Walker, 1999). This method is sufficient for Holocene research as the limit of routine measurements using carbon dating is ca. 45, 000 yr. BP (Hingham, 1999; Walker, 2005).

Vials that contained between 5-7g of subsampled sediment from selected depths in the core were sent to Beta Analytic which is based in Miami, Florida. Here the age of the cores was determined and calibrated using radiocarbon AMS dating. The samples were weighted to ensure there was enough sample for dating, as well as to measure pollen abundance and diversity.

4.5. Microscope Work

Once slides were prepared, the samples were then examined using an Olympus BX51 light microscope which is located at the Evolutionary Studies Institute of the University of the Witwatersrand. Pollen grains were identified using reference collections of both historic and contemporary pollen grains found on online databases. The African Pollen Database was an online source of modern pollen that was used in this study to aid with identification of the pollen grains; and the Atlas of tropical West African pollen flora (Gosling et al., 2013); as well as historical data from pollen assemblages worked on by Willard et al., (2004); Metwally (2011); and Scott (1982). A minimum of 300 grains was identified to family per slide, if there were fewer than 300 grains per slide, then a second slide was prepared from that sample, until the pollen count reached 300. As far as possible, pollen grains from each family were photographed to help with accurate identification. For the purpose of this study, pollen grains that were identified from the Chenopodiaceae and Amaranthaceae families were placed into the óCheno-Amô group due to similarities in morphological features (Scott, 2002; Fitchett et al., 2016a).

4.6. Statistical Analysis

Once all pollen grains from both peat cores were identified and recorded, a considerable matrix of data was generated. This data expressed general trends and a glance at the palaeoenvironment, but further statistical methods were required to fully make sense of the data and understand the ecological history of the data.

The collected data was first formulated into an age-depth model from AMS dates obtained from the Beta Analytics laboratory. To understand past climates in their entirety, it is crucial to quantify the dates of events in which changes in environmental proxies are observed, as well as the rates of such changes (Parnell et al., 2011). This is done using age-depth models. To perform age-depth modelling, measured ages of each sample are required. The relationship between the known ages and depths enable interpolation of ages for the remaining depths within the samples that have not been AMS dated. As AMS dating is and costly not all samples can be sent to the laboratory to be dated. Values for the missing dates were interpolated and account for errors in changing accumulation rates and the radiocarbon dating process itself (Blaauw and Christen, 2011; Parnell et al., 2011). A Bayesian technique referred to as BACON was used to model the age-depth data. This model, developed by Blaauw and Christen (2011) uses Markov Chain Montecarlo Simulations to produce a curve of best-fit, as well as a list of determined interpolated ages.

The next step of the statistical process entailed calculating the percentage of each pollen species represented in each sample and any pollen family that represented less than 2% throughout the entire sample was removed to eliminate outliers.

A Principle Component Analysis (PCA) was used to identify the key trends in the variability of the data. The stratigraphically coherent zones were determined using Constrained Incremental Sum of Squares clustering (CONISS) which deals with stratigraphic data.

4.7 Conclusion

Using standardised methods in fossil pollen preparation and analysis benefits scientific studies as it enables reproducibility of results. Errors are understood and accounted for which enables more accurate comparisons between sites. The difficulties faced during this methodological process is of value to future studies in the Angolan region.

CHAPTER 5: RESULTS

5.1 Introduction

This study used two cores from the Angolan highlands to reconstruct climate on the basis of pollen analysis. Chronology, pollen analysis and statistical analysis were all completed to obtain the end results. The initial step was recording all species/ families present in the slides by identifying and counting them.

Throughout the following chapter, pollen stratigraphic diagrams are presented with their species listed according to their species scores which were done using PCA and listing the first and second principle components. BACON describes mean accumulation rates. BACON is a Bayesian technique that uses Markov-Chain Montecarlo Simulations to produce a curve of best fit, and also a list of interpolated ages. A BACON model was used to interpolate ages for the rest of the core, as only a few samples could be sent for radiocarbon dating. Using a BACON model aided in interpolating the ages for the rest of the core by only sending in a few samples to date. CONISS cluster analysis was performed on results from both cores and zones. This is discussed further in this chapter.

Subsamples from each core are numbered as they were extracted consistently throughout these results. The stratigraphic diagrams are made based on subsample depth, as each sample number based on extraction would be consistent with the depth of each core.

The collected data was compiled into an age-depth model using AMS radiocarbon dates from the Beta Analytics Laboratory. In order to perform age-depth modelling, one needs to obtain a measured age for each sample by understanding the particular relationships between the known ages and depths to then be able to interpolate ages for remaining depths which have not been AMS dated. The dates are presented in Calibrated years before present (~ cal. yr BP).

As AMS dating is very costly, it is not possible to date all samples. To model this, a BACON model will be used. The next step was to produce a pollen stratigraphic diagram given the interpolated AMS dates as well as the species zonation present in each subsample.

5.2 Cuanavale Source Lake

5.2.1. Pollen analysis

Pollen grains from 24 pollen families were identified from a total of 45 samples, at a 2cm resolution. These samples provided a pollen sequence of the last ~2,500 years in the Cuanavale source lake region (Table 2). The Cuanavale sequence is dominated by Poaceae and Cyperaceae with relatively high proportions of Malvaceae, Asteraceae, and Fabaceae. The maximum counts for each of the pollen grains across the samples are generally higher than their average occurrence through the sequence. There are exceptions, such as Poaceae which has a higher occurrence in the sequence as a whole, and a small amount per individual sample. From the results obtained it is evident that the dominating pollen family is Poaceae, followed by significant portions of Cyperaceae, Oleaceae, Gentianaceae, and Malvaceae. None of the latter pollen families is as prominent as Poaceae.

Table 2: Frequency of occurrence of pollen identified from the CNV sequence

Pollen type (family)	% occurrence in CNV core	Maximum individual sample %
Cyperaceae	14.21	3.65
Asteraceae	4.93	7.19
Poaceae	27.99	3.31
Araceae	2.79	9.01
Arecaceae	2.79	8.36
Moraceae	0.81	24.47
Polygonaceae	0.24	21.43
Cheno-Am	1.14	9.85
Acanthaceae	0.35	36.59
Convolvulaceae	1.61	9.68
Cannabaceae	2.17	5.98
Proteaceae	0.53	16.39
Anacardiaceae	3.27	5.29
Fabaceae	5.56	5.45
Euphorbiaceae	1.25	13.10
Lycopodiaceae	0.96	9.01
Typha	7.48	4.86
Oleaceae	3.59	7.95
Nymphaceae	0.41	37.50
Gentianaceae	5.60	7.88
Malvaceae	9.18	4.43
Combretaceae	1.69	13.78
Taxodiaceae	0.09	40.00
Crassula	1.34	19.35

CONISS

The CONISS output plot for the Cuanavale sequence divides the profile into five statistically significant clusters. The division between Group 1 and Group 2 occurs at a mean depth of 32cm in the core, and Group 2 and 3 at 47cm. Group 1 and 5 both have multiple subdivisions. Group 4 contains only 2 samples, CNV1-30 and CNV1-31, at a depth range of 58-62cm. Group 1 consists of samples CNV1-1 to CNV1-16 (depth 0-32cm at ~606.1-1198.1 cal. yr BP); group 2 consists of cnv1-17 to cnv1-25 (depth 32-50cm at ~1198.1-1507.4 cal. yr BP); group 3 consists of cnv1-26 to cnv1-29 (depth 50-58cm at ~1507.4-1657.1 cal. yr BP); group 4 consists of cnv1-30 to cnv1-31 (depth 58-62cm at ~1657.1-1736.5 cal. yr BP); and lastly group 5 consists of cnv1-32 to cnv1-41 (depth 62-82cm at ~1736.5-2139.6 cal. yr BP). There is a sixth artificial cluster which includes the samples that were void of any pollen or spores, indicating a change in depositional environment or preservation conditions after the grains had been deposited.

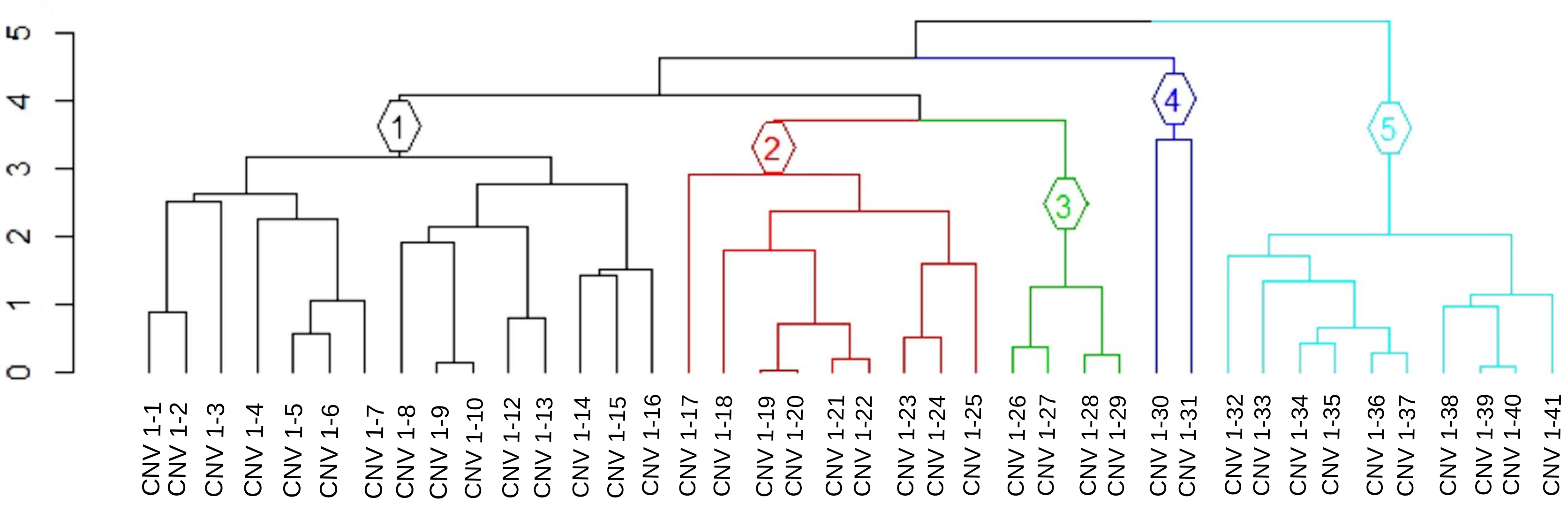

Figure 11: CONISS output for CNV pollen sequence

PRINCIPLE COMPONENT ANALYSIS

The PCA determines the main principle components of the data obtained from the CS core, namely PC1 and PC2 (Figure 12). These components illustrate the underlying components of the data that drive most of the variance, and in the directions illustrated on the PC plot will be those in which there is most variance in the data. The species-families that fall within PC1 and 2 are sensitive to a particular component which is influencing their abundance or lack of. For the Cuanavale core PC1 represents 23% of the variance, and PC2 represents 15% of the variance. These two values show the most variation within the dataset. PC1 scores are ordered at extremes from Gentianaceae which holds large negative PC1 scores, coupled with Anacardiaceae; Euphorbiaceae; and Moraceae, to Oleaceae and Poaceae which hold positive PC1 values. PC2 is dominated by Poaceae, Araceae, Moraceae, Crassula, and Euphorbiaceae. All these hold negative PC2 scores. This PC2 range extends to Typha, Fabaceae, Cyperaceae, Oleaceae, Gentianaceae, Convolvulaceae, and Anacardiaceae which are at the positive ends of the PC2 values. Fabaceae (6%), Poaceae (28%), Cyperaceae (14%), Typha (7%), Asteraceae (4.93%).

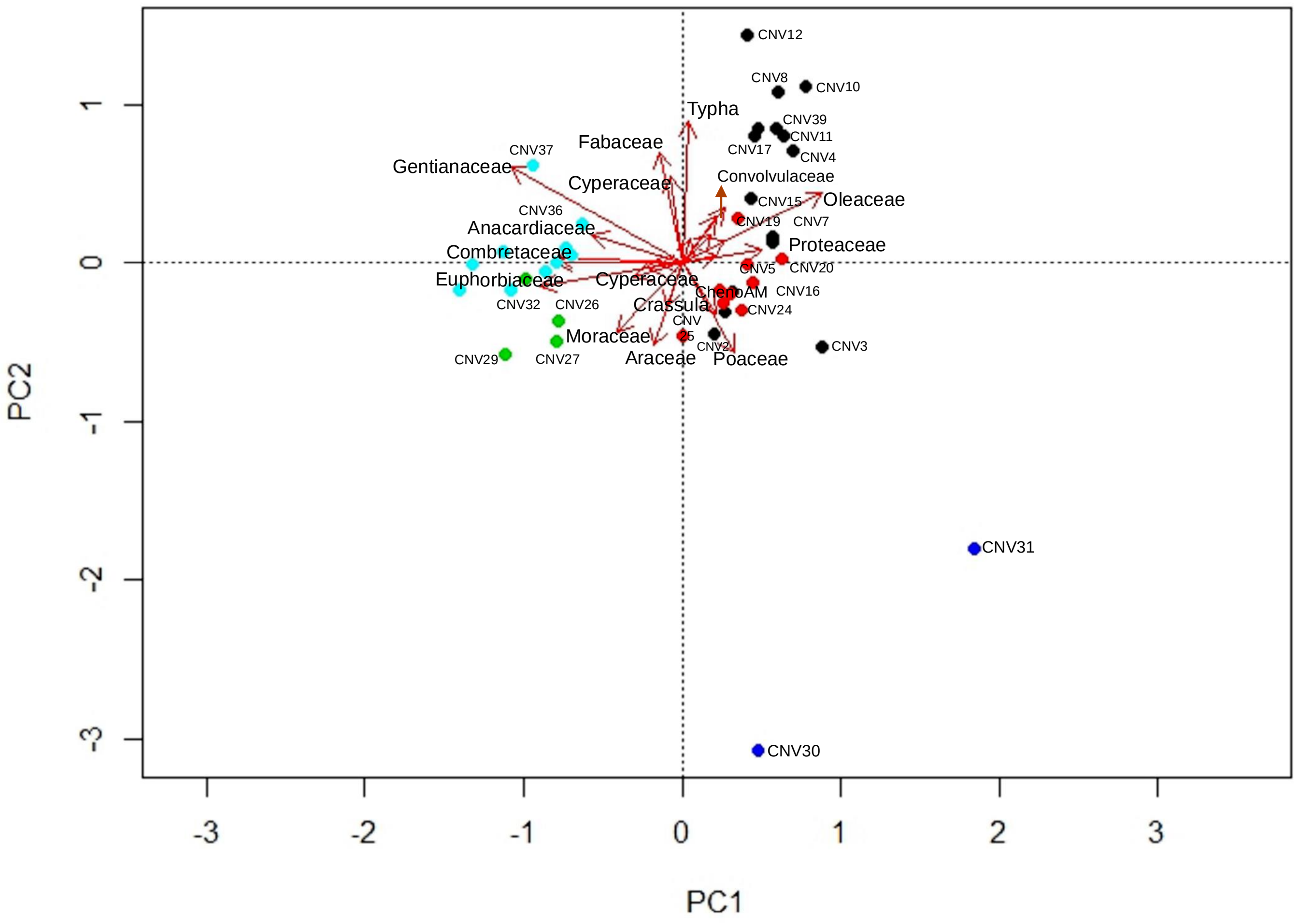

Figure 12: PCA biplot for CNV pollen sequence

5.2.2. Sediment Accumulation and Chronology

AMS DATING

Four dates were obtained from the Beta Analytics Laboratory for the Cuanavale site (Table 3). The selection of these samples was on the basis of notable changes in pollen abundances and PC 1 curves. Each date represents a conventional age, calendar calibration, sample thickness, sample depth, and the error that occurred during analysis. Sample CNV 1-14, the uppermost sample, lies at a mean depth of 27cm in the core and gives an age of ~1280 ±30 cal. yr BP. Sample CNV 1-25, at a mean depth of 49cm is 1650 cal. yr BP. Both having an error of 30 years. For samples CNV 1-33 (64-66cm) and CNV 1-44(86-88cm), contamination of the core sample yielded incorrect ages. Sample CNV 1-44 (86-88cm) was void of any pollen grains so the slide could not be counted. This is likely due to contamination from recent activity prior to field work or during extraction.

Table 3: AMS dates for CNV profile

Lab ID	Conventional age	Error	Calendar calibration	Delta 13 C (ppt)	Sample thickness (cm)	Sample depth (cm)
CNV 1-14	~1280 BP	30	~1189-1069	18.2	2	26-28
CNV 1-25	~1650 BP	30	~1568-1416	18.8	2	48-50
CNV 1-33	78% contamination ï post AD 1950				2	64-66
CNV 1-44	88.6% contamination ï 2000 Cal AD				2	86-88

BACON MODEL

The diagram below shows a BACON plot used to interpolate ages within the core. The BACON model estimates the mean accumulation rate throughout the core, using interpolated values from dates obtained at particular depths in the core. The contaminated dates have been excluded and therefore only two dates are used in this BACON model for the CNV core. These dates range from ~500 cal. yr BP to ~2500 cal. yr BP (Figure 13). Sediment accumulation rate was initially 50cm per year but peaked at around 20cm per year and eventually slowed down over the years. Due to insufficient sediment at the bottom of the core, no further dates could be obtained for AMS dating. Interpolated ages suggest an age of ~250 cal. yr BP for the bottom of the core. Slow and consistent sediment accumulation occurred throughout the core, with a notable change in sediment accumulation after ~1500 cal. yr BP.

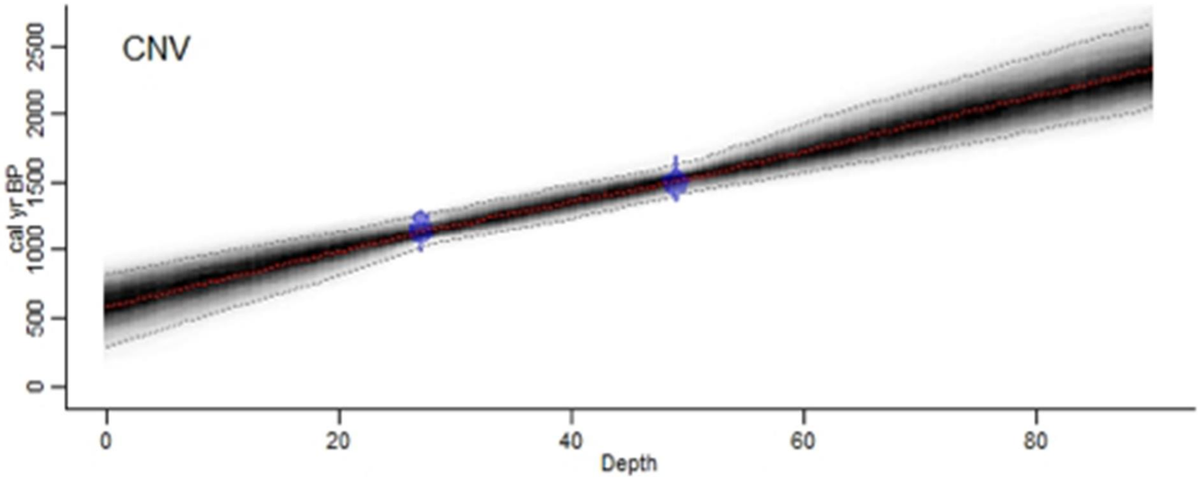

Figure 13: BACON output for the CNV profile, providing interpolated ages for depths throughout the core

5.2.3. Stratigraphy and sediment description

The contemporary environment consists of extensive peat bogs with an abundant wetland vegetation. Dark peat containing organic matter dominated the entirety of the CNV profile and showed no stratigraphic differentiation. The peat was very dense and easily decayed as observed with other cores that were not refrigerated as they were not used.

CNVZ6

Artificial zone (contains no pollen)

This represents a zone barren of pollen as less than five grains of pollen could be seen on the slides, at most. This could be due to contamination or poor preservation of the grains which may have been destroyed during the chemical preparation process.

CNVZ5 (depth 62- 82cm; age ~ 2097-1760 BP)

Zone 5 (62-64cm depth) ranges from ~2100 to ~1750 cal. yr BP. This zone has contaminated dates therefore the pollen and dates obtained must be treated with caution. Poaceae dominates this zone with 24% of the pollen at its highest peaks. The proportional representation of Poaceae is relatively low but remain fairly stable throughout Zone 5, with very shallow peaks. Cyperaceae at its highest peak makes up 18% of the pollen abundance, with a clear peak at ~1,995, ~2,000, and ~2,100, cal. yr BP. Gentianaceae is 20% of the pollen, and has a shallow peak that reaches its maximum count at ~1900 al yr BP at an average depth of 70cm in the core. Malvaceae and Typhaceae are both 10% at their highest and show an increase between ~2100-2000 cal. yr BP when Poaceae decreases. Towards the end of the zone at ~1800 cal. yr BP, the abundance of Cyperaceae increases to 20% but then proceeds to rapidly decrease in Zone 4 to 0% at ~1700 cal. yr BP. From ~1900-2000 cal. yr BP there is a decrease in Cyperaceae while a slight increase in Poaceae and Asteraceae. There is also a steady increase in Gentianaceae, Malvaceae, Typha, Fabaceae, and Proteaceae (although abundances are less than 3% for most).

CNVZ4 (depth 58-62cm; age ~1750-1645BP, ~ 200-305AD)

This zone ranges from ~1750 to ~1650 cal. yr BP. Zone 4 shows a very distinct clear layer of contamination, between ~1750 and ~1650 cal. yr BP, as there is an abnormal spike throughout the core. The Poaceae abundance peaks at 60% which indicates contamination from contemporary pollen as a likely cause.

CNVZ3 (depth 50-58cm; age ~ 1629-1500 BP, ~ 321-450 AD)

Zone 3 spans ~1650 to ~1500 cal. yr BP. Poaceae dominates this zone, with a 35-40% relatively stable pollen abundance. Cyperaceae consists of 20%, Asteraceae is less than 10%, Gentianacea7e is 10%, and Typha is 5%. Crassula has an initial rapid increase and then it decreases to zero in the zone, followed by another sharp increase. Euphorbiaceae also has a sharp increase only present in Zone 3, 4, and 5. After zone 3, there are no Euphorbiaceae pollen grains present at all.

CNVZ2 (depth 32-50cm; age ~ 1485-1185 BP, ~465-765 AD)

Zone 2 ranges from ~1500 to ~1150 cal. yr BP. This zone contains up to 40% Poaceae at certain peaks and has a relatively constant abundance of Poaceae pollen grains. Cyperaceae makes up 20% towards the upper edge of the zone, while Asteraceae represents less than 10%. Gentianaceae decreases significantly in this zone to values less than 2%, while in all other zones there is a much greater abundance of typically more than 10%. Araceae abundance increases in this zone to 10%. There is also a sharp increase in Moraceae, although at a value less than 5%, between ~1400 and ~1500 cal. yr BP.

CNVZ1 (depth 0-32cm; age ~ 1165-600 BP, ~785-1350 AD)

Zone 1 ranges from ~1200 to ~600 cal. yr BP. This zone is dominated by 40% Poaceae grains, and then followed by 10% Cyperaceae, 10% Asteraceae, 10% Cyperaceae, 10% Fabaceae, and 10% Oleaceae.

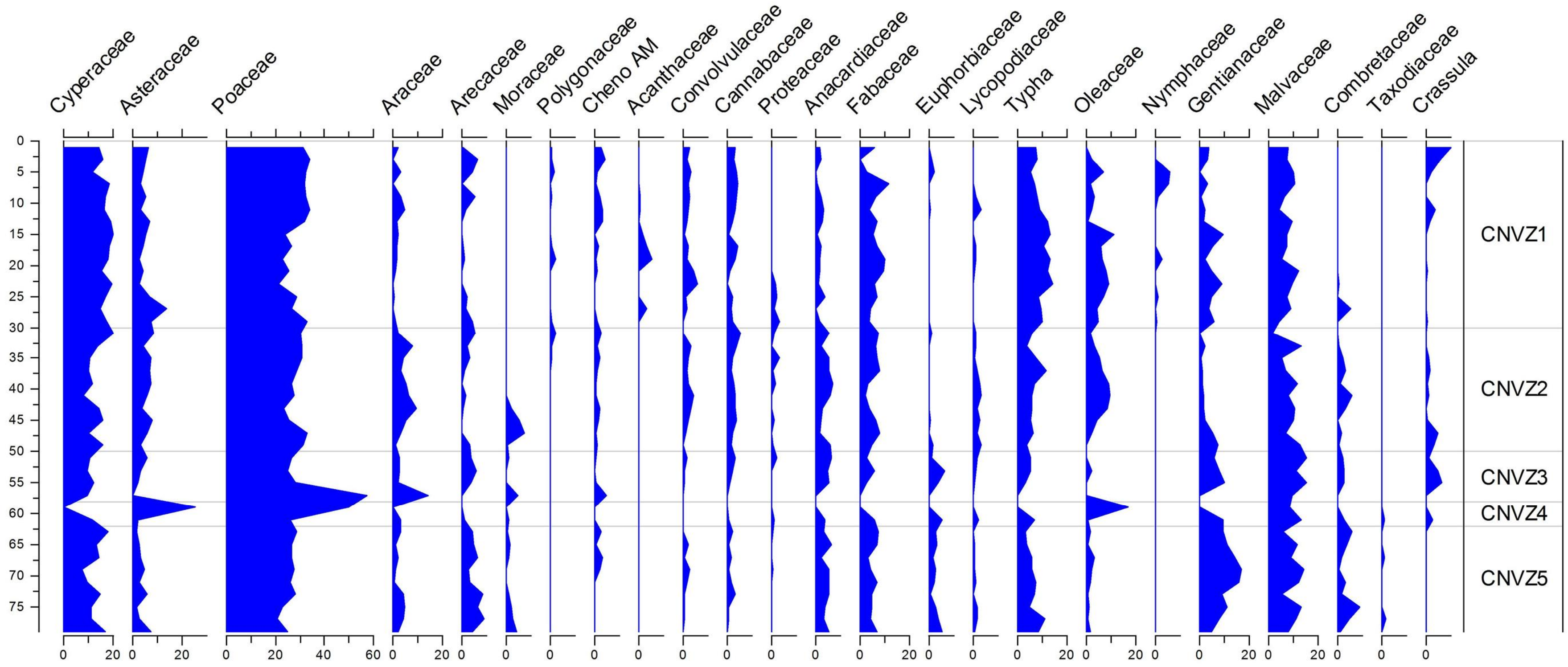

Figure 14: Pollen diagram for the CNV pollen sequence illustrating family abundance and zonation

5.3 Cuito source lake

5.3.1. Pollen analysis

Pollen grains from a total of 20 pollen families were identified from a total of 15 samples, at a 2cm resolution. These samples provided a pollen sequence of the last 150 years in the Cuito source lake region (table 5.4). The Cuito sequence is dominated by Poaceae with an average occurrence of 47% in the entire sequence. There are high portions of Cyperaceae and Typha too. The maximum counts for each of the pollen grains are much higher than their occurrence through the sequence for families that represent under 5% of the sequence. For families that dominate the sequence, there are fewer maximum counts per sample. From the results obtained, it is visible that Poaceae yet again dominates the core with a 45% abundance which is far more than the CNV core. This is followed by Cyperaceae, Typha, Combretaceae, and Anacardiaceae.

Table 4: Frequency of occurrence of pollen identified from the CS sequence

Pollen type (family)	% occurrence in CNV core	Maximum individual sample %
Cyperaceae	11.67	11.16
Asteraceae	1.28	22.22
Poaceae	45.56	8.44
Araceae	1.78	20.00
Arecaceae	3.55	13.33
Moraceae	1.89	22.50
Convolvulaceae	0.12	40.00
Cannabaceae	0.40	35.29
Proteaceae	0.88	24.32
Anacardiaceae	3.57	11.92
Fabaceae	3.62	12.42
Euphorbiaceae	2.84	15.83
Lycopodiaceae	1.09	23.91
Typha	11.76	11.07
Oleaceae	1.21	31.37
Gentianaceae	1.35	28.07
Malvaceae	1.78	18.67
Combretaceae	3.95	19.76
Taxodiaceae	0.12	100.00
Crassula	0.59	32.00

CONISS

The CONISS diagram divides the Cuito Source core into two major zones indicating that the pollen families that fall within each zone have particular traits that are similar and which would explain why changes in these species occur (Figure 15).

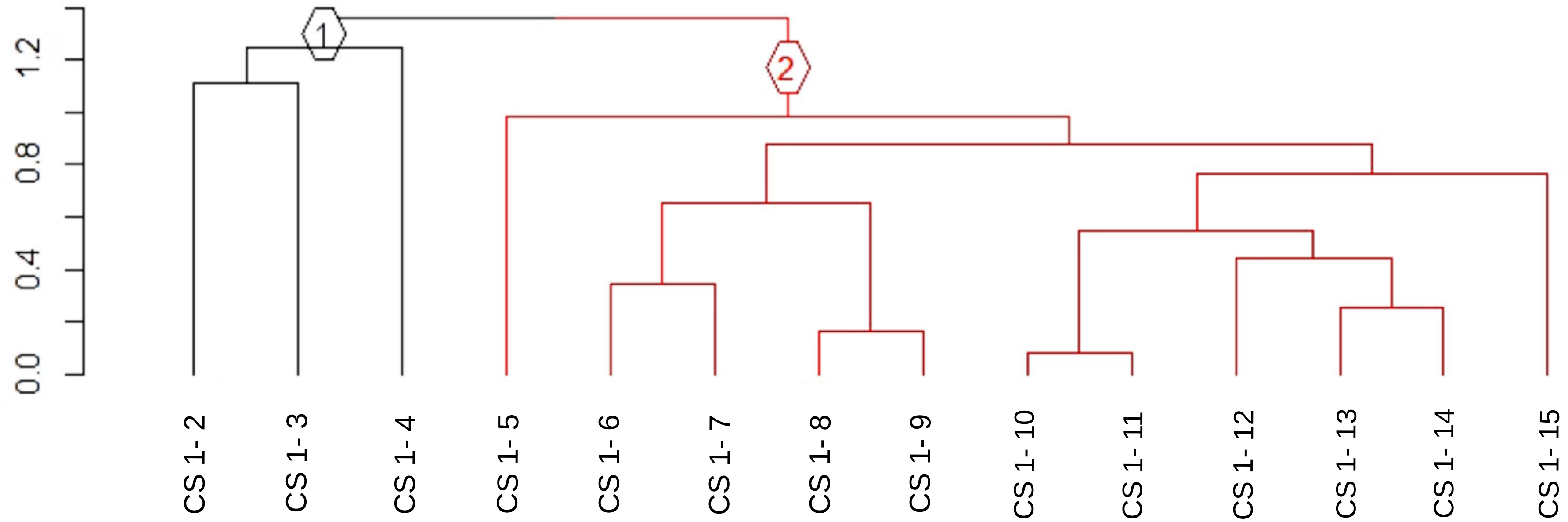

Figure 15: CONISS output for the CS pollen sequence

PRINCIPAL COMPONENT ANALYSIS

The PCA finds the main principal components of the data obtained from the CS core. In this case PC1 and 2. For the Cuito Source core, PC1 represents 19% of the variance, and PC2 represents 16% of the variance. These illustrate the underlying components of the data that drive most of the variance, and in the directions illustrated on the PC plot will be those in which there is most variance in the data. The species/ families that fall within PC 1 and 2 are all sensitive to a particular component which is influencing their abundance or lack of. Principle component 1 is mainly influenced by Asteraceae, Moraceae, and Proteaceae. Principle component 2 is influenced by Euphorbiaceae, Crassula, and Araceae families. Principle component 3, which has less influence than PC1 and PC2, consists of Cyperaceae, Moraceae, Oleaceae, and Taxodiaceae. PC1 scores are ordered at relative extremes from Euphorbiaceae, Moraceae, Asteraceae, and Proteaceae which all hold negative PC1 values, to Cyperaceae and Gentianaceae, which both hold positive PC1 values. PC2 is made up of Crassula; Moraceae; Combretaceae; and Cannabaceae which all hold negative PC2 values, to Euphorbiaceae, Oleaceae, and Lycopodiaceae which hold positive PC2 values. Asteraceae (1.28%), Poaceae (46%), Cyperaceae (12%), Typha (12%), Fabaceae (5.56%).

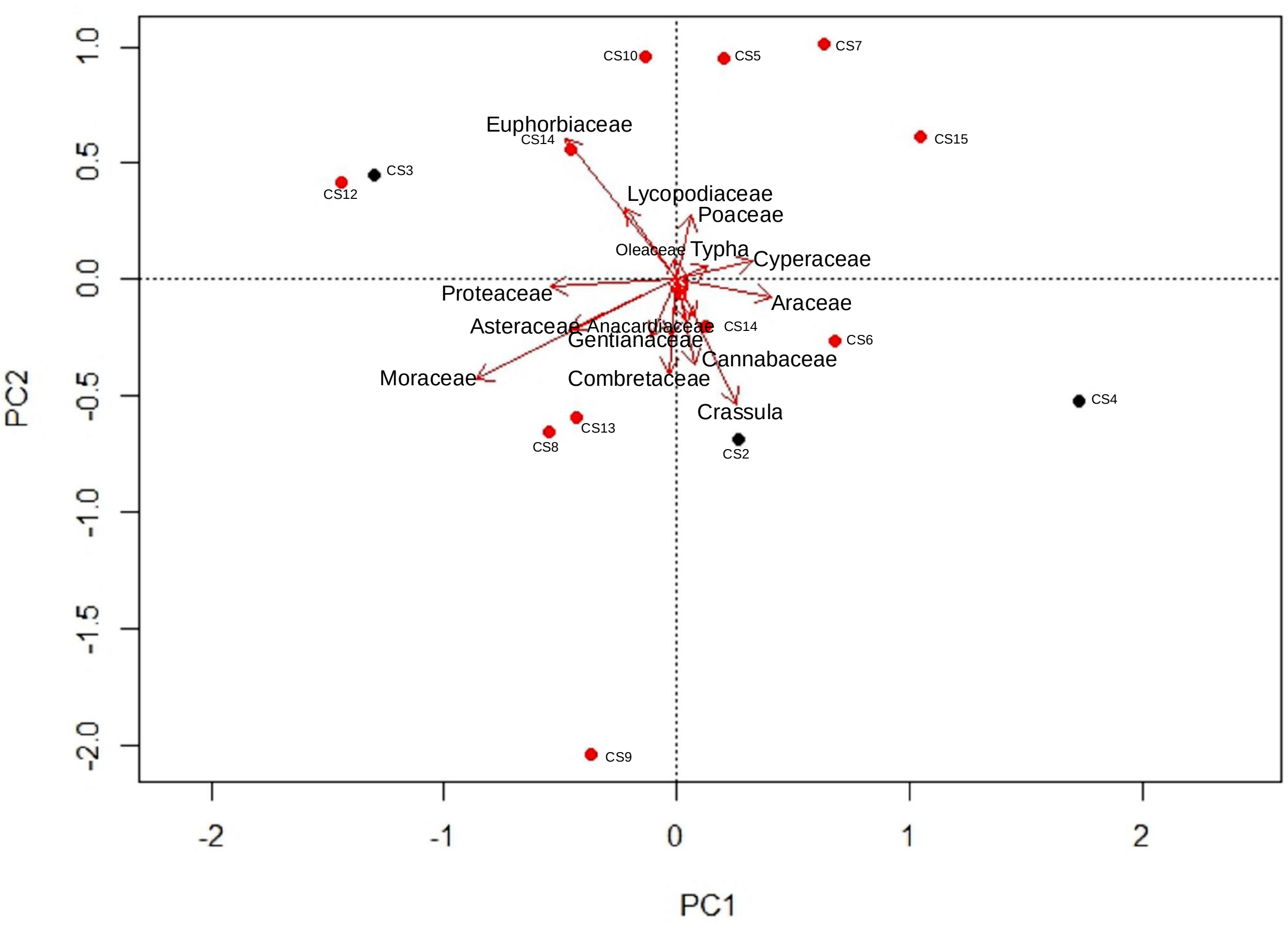

Figure 16: PCA biplot for the CS sequence

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5.3.2 Sediment accumulation and chronology

In the CS core, two AMS radiocarbon dates were obtained.

Table 5: AMS dates for CS profile

Lab ID	Conventional age	Error	Calendar calibration	Delta 13 C (ppt)	Sample thickness (cm)	Sample depth (cm)
CS 1-8	100.25 ± 0.37 pMC	30	~1990-1994	17.6	2	14-16
CS 1-3	101. 13 ± 0.38 pMC	30	~1955-1957	17.8	2	24-26
CS 1-14	114. 39 ± 0.43 pMC	30	~1954-1956	18.0	2	26-28

BACON Modelling

The BACON model provides mean accumulation rates for the CS core, which was 30cm long (Figure 16). There is a trend of overall slow and consistent sediment accumulation during the period for the entire core. There is uncertainty in accumulation rate from depths 7cm to 16cm (~ -39.1 - -12.2 BP) in which the period of sediment accumulation is not clearly displayed.

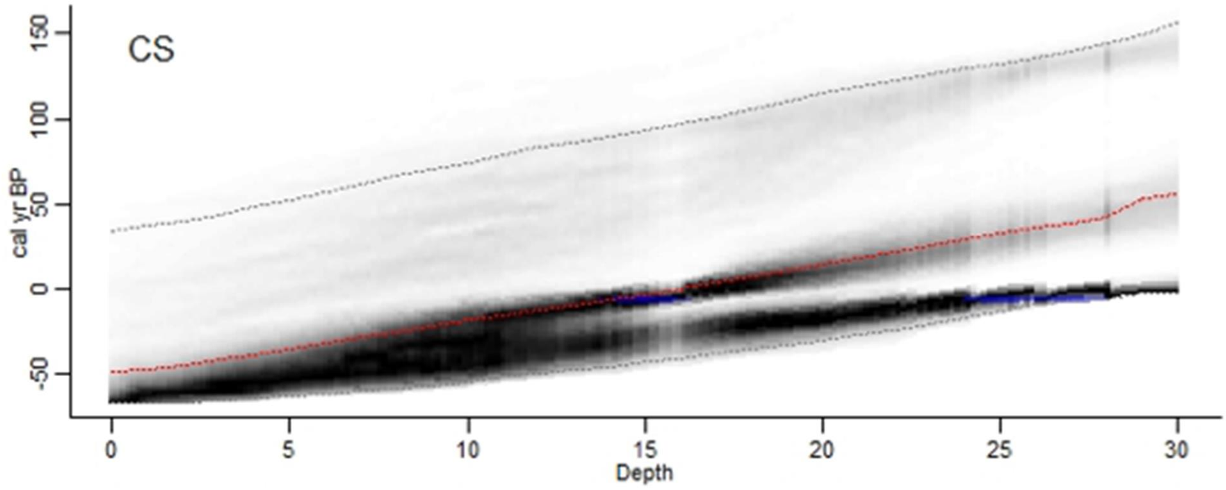

Figure 17: BACON output for the CS profile which provides interpolated ages and depths throughout the core

5.3.3. Stratigraphy and sediment description

The contemporary environment consists of extensive peat bogs with abundant wetland vegetation. Dark peat containing organic matter dominated the entirety of the CS profile and showed no stratigraphic differentiation. The peat was very dense and quickly decayed as observed with other cores that were not refrigerated. These cores were not used in this analysis.

CSZ2 (depth 8-30cm; age~ 39-24 BP, ~1895-1972 AD)

Zone 2 ranges from ~40 cal. yr BP to ~-45 cal. yr BP. Poaceae dominates this zone with a 55% abundance and decreases sharply at ~25 cal. yr BP, then increases sharply at 10 cal. yr BP, and finally decreases rapidly again at ~5 cal. yr BP. The remaining dominating proportions are 10% Cyperaceae, which shows an increase in abundance at ~25 cal. yr BP to about 12%, at the same time where there is a decrease in Poaceae abundance (from 50% to 40%). Typha make up 20% of the pollen grains in zone 2, and decrease in abundance at ~25 cal. yr BP but not significantly, and then increase at ~10 cal. yr BP from 10% to 20%. Combretaceae has a maximum of 10% at ~5 cal. yr BP and Anacardiaceae decreases to zero at ~10 cal. yr BP, with an overall abundance of less than 5%.

CSZ1 (depth 2-8cm; ~ -26 - -45 BP, ~ 1978-1992 AD)

Zone 1 ranges from ~-25 to ~-45 cal. yr BP. Poaceae dominates it at 55%, and the abundance remains stable for the entirety of the zone. Cyperaceae makes up 15% but decreases further up in the zone as it gets closer to present-day conditions. The rest of the abundances is 10% Typha, 3% Arecaceae, a sharp increase in Fabaceae at ~35 cal. yr BP but which only goes up to 3%

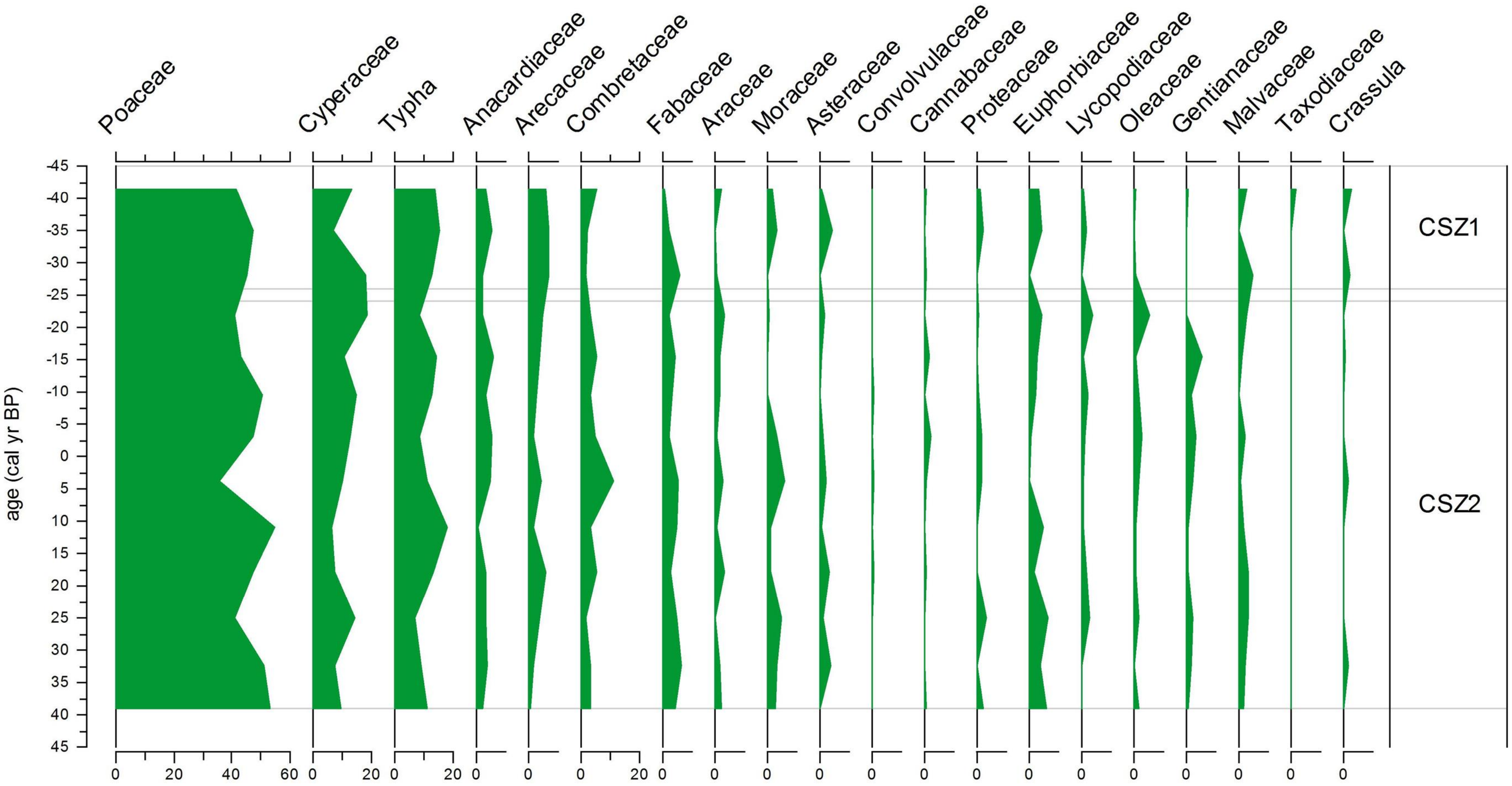

Figure 18: Pollen diagram for CS sequence illustrating family abundance and zonation

5.4 Conclusion

This chapter provides a summary of the pollen analysis of the peat cores obtained from the two study sites, namely the Cuito source lake and the Cuanavale source lake. Both pollen sequences span periods during the Late Holocene.

The 90cm peat core from the Cuanavale source lake is dominated by Poaceae, combined with a large abundance of Cyperaceae. In this core 24 pollen families were present. The lowermost portion of the core did not contain a statistically significant amount of pollen grains, suggesting an absence of vegetation or poor preservation conditions during that time.

The 30cm peat core from the Cuito source lake is significantly shorter than the Cuanavale core. In this core 20 pollen families were identified. The sequence is dominated by Poaceae, followed by large amounts of Cyperaceae and Typha.

CHAPTER 6: DISCUSSION

6.1 Palaeoenvironmental reconstruction

This study is a pioneering palynological investigation in this region and the diagenesis, to an extent, may be uncertain and analysis of samples can potentially be limited by the use of a broader regional pollen reference collection. For future work in this region, it would be beneficial to use multiple proxies and have more samples sent for radiocarbon dating. A palaeoenvironmental reconstruction is provided in this section for the Cuito and Cuito Cuanavale source lakes. The reconstruction is based on the fossil pollen evidence and sedimentation rates interpolated from the AMS dates obtained using the BACON model. The clustering used to divide the data into contemporarily constrained pollen assemblage zones is based on the output results on CONISS. First, the premises from which the pollen-derived reconstructions will be made, which outline the environmental variables that correlate with the key pollen taxa found in the cores used in this study. This will be followed by a reconstruction of each pollen assemblage zone and an overview of the sedimentation rate fluctuations.

6.1.1 Pollen indicators

Pollen has been reported as a useful proxy for palaeoenvironmental reconstructions (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). Local and regional climatic conditions can be inferred using a relative abundance of particular taxa.

6.1.2 Pollen types as indicators

From knowledge of present pollen families in the samples, the following table represents the associated environmental conditions with each pollen type.

Table 6: A summary of environmental conditions associated with certain pollen families

Family	**Vegetation type**	**Environmental conditions**	**Reference**
Asteraceae	Shrubland	Dry, decrease in the Summer rain, Winter rainfall	Scott and Nyakale, 2002; Carr et al., 2006; Neumann et al., 2014; Norström et al., 2014
Cyperaceae	Semi-aquatic	Shallow water, saturated soils	Scott and Nyakale, 2002; Carr et al., 2006; Neumann et al., 2014; Fitchett et al., 2016a
Poaceae	Grassland	Warm temperatures, damp air (regionally)	Scott and Nyakale, 2002; Neumann et al., 2014
Cheno-Am	Halophytes	Dry, saline, high evaporation rates	Scott and Nyakale, 2002; Fitchett et al., 2016a
Crassula	Succulents	Dry	
Combretaceae	Savanna	Warmer	Elenga et al., 2000
Proteaceae	Mesic Savanna	Sub-humid, large temperature range	Elenga et al., 2000; Scott and Nyakale, 2002
Typha	Aquatics	Shallow fresh water	
Gentianaceae	Alpine grassland	Increased sun influence, wind, high altitude grasslands	Ashwini et al., 2014
Malvaceae	Shrubland		Arnold, 2003
Oleaceae	Shrubland	Warm/ temperate	Elenga et al., 2000

6.1.3 Environmental Reconstruction

Environmental conditions that are associated with the occurrence of indicator pollen found within the two cores will be provided in this section. Sedimentation rates will also be discussed from the interpolated AMS dates provided on the BACON diagram.

General Abundance

CNV Core

In this core, the main components were Poaceae with an abundance of 58% at its highest peak, and then at 30% throughout the rest of the core. Cyperaceae was the second highest with an average abundance of 18%, followed by Typha with an abundance of 15% and then Malvaceae with an abundance of 10%. These particular families suggest that the common elements were that of Savanna grassland. Common environmental indicators from each of these dominating families indicate warmer temperatures prevailed with shallow water conditions and overall wetland elements located on a high altitude.

CS CORE

Not very dissimilar from the CNV Core, the CS Core was dominated by Poaceae, Cyperaceae, Typha, and Combretaceae. Poaceae represented 60% of pollen in the core, followed by Cyperaceae and Typha with an abundance of 20% each, and Combretaceae with a notably increased abundance of 10% at ~-5 cal. yr BP (noted at this period was a drastic decrease in Poaceae, which accompanied the increase in Combretaceae). These dominating elements indicate overall warmer temperatures and Savanna grassland vegetation. Cyperaceae and Typha suggest an increase in wetland conditions which host shallow saturated soils.

Principle Component Analysis

CNV Core

From this core, PC1 accounted for 23% of the variability within the dataset, and PC2 accounted for 15%. From the pollen families that dominated the PC1 and PC2 values, certain deductions can be made regarding the main components that influence the variation of the data. PC1 is likely caused by a change in temperature which drives the change in vegetation, as Gentianaceae which is commonly an indicator of high-altitude grassland was on the negative side of the PC1 scores, while Anacardiaceae, Euphorbiaceae, Moraceae, Oleaceae, and Poaceae all represented in the positive PC1 components. PC2 was dominated by negative scores of Poaceae, Asteraceae, Moraceae, Crassula, and Euphorbiaceae; while having positive scores of Typha, Fabaceae, Cyperaceae, Oleaceae, Gentianaceae, and Anacardiaceae influencing PC2. From the environmental indicators of these pollen families, it can be inferred that PC2 represents changes in moisture in the surrounding environment (Elenga et al., 2000).

CS Core

In this short core, PC1 represented 19% of the variability in the dataset while PC2 represented 16%. PC1 was influenced mostly by Asteraceae, Moraceae, and Proteaceae. PC2 was influenced by Euphorbiaceae, Crassula, and Araceae. From these, as environmental indicators, we can infer that PC1 is driven by changes in temperature while PC2 is driven by changes in moisture, much like in the CNV core.

Reconstruction of each zone

CNV Core

CNVZ6 (Artificial zone: contains no pollen)

This zone consisted of four samples which were all barren of any pollen. This suggests that during that phase of deposition, environmental conditions were not ideal for the preservation of pollen grains. Another possible cause for lack of pollen in these samples could be that the fossil pollen preserved during this period was more eroded than the pollen in the rest of the core, and the standard preparation techniques used to liberate pollen grains from the sediment they are within may have destroyed any preserved grains.

CNVZ5 (depth 62-82cm; age 2097-1760 BP)

This zone is located at the end of the core and is the oldest. Poaceae dominates this zone. At ~2020.2 cal. yr BP. Sharp increases in Gentianaceae, Malvaceae, Combretaceae, and Typha. Small amounts of Anacardiaceae, Arecaceae, Fabaceae, and Asteraceae are present. Combretaceae and Gentianaceae indicate warmer temperatures. There is a high abundance of Cyperaceae, which indicates semi-aquatic and generally wetter conditions. The sharp increase in Cyperaceae, Asteraceae and Poaceae, indicating common wetland elements (Scott and Nyakale, 2002; Carr et al., 2006; Neumann et al., 2014; Norström et al., 2014). At ~1939 cal. yr BP. Cyperaceae decreases drastically possibly indicating drier conditions and wetland reduction. The increase in Combretaceae and Gentianaceae at this depth further backs up the likelihood of drier conditions and expansion of grasslands at high altitudes. Cheno-Am first appears in this core at ~1776.6 cal. yr BP. Along with this is a sharp but small increase in Cyperaceae and small amounts of Asteraceae. Poaceae remains largely dominant and suggesting conditions were likely not as dry even with the presence of Crassula and Cheno-Am as these were in small amounts compared to the other indicator families. The relatively larger amounts of Combretaceae in this zone indicate warmer temperatures prevailing.

CNVZ4 (depth 58-62cm; age 1750-1645BP, 200-305AD)

This zone is constrained to a short period and a sharp decrease in Cyperaceae, coupled with a relatively sharp increase in Poaceae and Asteraceae indicate prevailing warmer and drier conditions. A likely expansion of grassland elements and wetland retracting. Increased amounts of Oleaceae and Typha suggest warmer temperatures with more saturated soils.

CNVZ3 (depth 50-58cm; age 1629-1500 BP, 321-450 AD)

This zone begins at a depth of 58cm and sees a gradual increase in Cyperaceae and a drastic increase in Poaceae between Zone 3 and 4. Cheno-Am appears yet again after being absent in Zone 4, Malvaceae and Combretaceae also start to increase. Throughout this zone Crassula is present, reaching maximum abundance at ~1618.1 cal. yr BP, while Cheno-Am phases out. Typha remains constant during the entirety of this zone, and there is also an increase in Oleaceae, suggesting warmer conditions.

CNVZ2 (depth 32-50cm; age 1485-1185 BP, 465-765 AD)

Zone 2 can be characterized by an increase in Cyperaceae and a decrease in Asteraceae. With Poaceae remaining abundant. This indicated warmer and wetter conditions prevailing. Oleaceae is present in this zone and is at peak abundance between ~1438.0 ï 1336.2 cal. yr BP. So warmer conditions prevailed overall in this zone.

CNVZ1 (depth 0-32cm; age 1165-600 BP, 785-1350 AD)

This last zone which starts at ~1198 cal. yr BP and sees a decrease in Cyperaceae, while Asteraceae sharply increases at ~1776.6 cal. yr BP. Poaceae fluctuates a few times indicating changes in rainfall patterns. The decline in Cyperaceae, coupled with the increase of Asteraceae and Poaceae suggests wetland conditions reducing and grassland dominating the area once again. At ~1011.9 cal. yr BP Cheno-Am increases and is present in the core further validating dryer conditions. Combretaceae also suggests a temperature increase for a short period around ~1580 cal. yr BP.

CS Core

CSZ2 (depth 8-30cm; age 39-24 BP, 1895-1972 AD)

This zone, much like Zone 1, is dominated by Poaceae, indicating a dominant grassland environment over the given period (~ -58.6-42.9 cal. yr BP /~1985-1972 AD). Not much variation occurs in this zone. However there is an initial decrease in Cyperaceae and then a sharp increase at ~13.6 Cal yr. BP, with a decrease in Asteraceae and Poaceae. Typha increases and this coupled with Cyperaceae, indicate wetter conditions/ saturated soils. Combretaceae increases in abundance and is at a maximum at ~-5.0 cal. yr BP and suggests warmer temperatures, while Poaceae rapidly decreased during the same time.

CSZ1 (depth 2-8cm; -26 - -45 BP, 1978-1992 AD)

This zone is dominated by Poaceae and is relatively smaller than Zone 2 with fewer fluctuations in abundance of pollen families and environmental conditions. Dryer conditions dominated this zone shown by an increase in Asteraceae, and a constant abundance of Poaceae. Combretaceae suggests warmer temperatures.

Sedimentation rate:

The rate at which sediment was deposited at Cuito Cuanavale source lakes. Sedimentation rates are influenced by precipitation and erosion rates of the sediment (Peizhen et al., 2001). The amount of sediment accumulated depends on climatic fluctuations and percentage of overall vegetation cover (Langbein and Schumm, 1958). These factors are both a result of changes in precipitation and climate (Langbein and Schumm, 1958).

6.2 Palaeoenvironmental comparison

There still exists a paucity of Quaternary palaeoenvironmental data for southern Africa, especially in Angola. In order to address this gap, the results of this study have been presented in addition to a reconstruction of the palaeoenvironment based on the interpretation of the fossil pollen record. Previously published reconstructions of wetlands were used to aid in the interpretation of the past environment of the particular regions of this study (Finch and Hill, 2008; Norström et al., 2009; Finné et al., 2010; Truc et al., 2013; Neumann et al., 2014; Fitchett et al., 2016b). The first study looking at vegetation changes in Angola was conducted by Dupont et al (2008) by looking at marine sediment along the Angolan coast (Shi and Dupont, 1997; Dupont and Behling, 2006). The marine cores were extracted during the Ocean Drilling Program at site 1078. This study recorded the last 30 000 years of vegetation by looking at marine materials and comparing the pollen within the core with sea surface temperatures to enable land-sea correlations. Throughout most of the Holocene, dry forests and Miombo Woodlands dominated the landscape in Angola, with Savanna vegetation becoming the most dominant over the last 2 000 years. This positively correlated with the results from this study, as Poaceae and Asteraceae are very common elements throughout both cores. Poaceae makes up a total abundance of 45.56% in the CNV core, followed by 11.67% Cyperaceae, 11.76% Typha, and Gentianaceae with an overall abundance of 1.35%. Gentianaceae suggests high altitude grasslands which would correlate to the results from Dupont et al., (2008). During the last ~3700 years Savanna grasslands dominated at 3.7 ka and then again after 2 ka, while forest vegetation intermixed with the Savanna grassland probably became less frequent patchy fire-hardy trees that favoured sunlight (Dupont et al., 2008).

Western-central African studies for the late Holocene indicate that it was dominated by tropical seasonal forest, and tropical rain forests were minimized and instead more open landscapes consisting of evergreen vegetation such as *Podocarpus*, *Olea capensis*, and *Ilex mitis* were present (Maley and Brénac, 1987; Brénac, 1988; Maley, 1989, 1991;

Elenga et al., 1991; Giresse et al., 1994). In this study, there were no *Podocarpus* pollen grains that were found in either of the two cores, suggesting *Podocarpus* taxa were not present during this given time period. *Podocarpus* often represents Afromontane forests, which is known to have good pollen dispersal. Therefore, if *Podocarpus* was present in the environment during the period studied, the pollen grains would have been preserved in the sediment cores (Jahns, 1996). *Podocarpus* is typically found in Afromontane forests in Eastern and Southern Africa, but in south western Africa, they only occur on the Huambo Mountains located in Angola at altitudes higher than 1,700m.asl and in this study, both sites were below 1,700m,asl in altitude so *Podocarpus* would not be expected in the cores extracted for this study, unless they were deposited in the study area by wind (Huntley, 2019; Jahns, 1998, Shi et al., 1998).

The results of this study, in a broad scale, are similar to lowland tropical rainforests in Africa, which were laterally predominantly Savanna grassland elements (Hamilton, 1976). Marine cores from the coasts of western equatorial Africa that were investigated, show a decrease of rain forest taxa and an increase of Poaceae and *Podocarpus* (e.g. Caratini and Giresse, 1979; Bengo and Maley, 1991; Lézine and Vergnaud-Grazzini, 1993; Frédoux, 1994; Marret, 1994; Dupont, 1995; Jahns, 1996). No *Podocarpus* was present in this study but there was a large abundance of Poaceae.

A study which dated U-dated speleothems from the Kalahari Desert in Botswana, concluded that during the late Holocene (5000-4000 BP) conditions were drier than usual (Burney et al., 1993), which is in general agreement with the results of this study.

A study conducted in the Congo deep-sea fan, which is northeast to the Angolan Basin, revealed climatic conditions in equatorial Africa for the last 225 000 years using phytoliths and diatoms (Jansen et al., 1989). This study concludes that for the last 20 ka BP conditions agreed with those in western tropical Africa (Jansen et al., 1989). Between 90-30 ka BP, conditions were generally less humid, and between 30-17 ka BP, conditions were increasingly drier. (Jansen et al., 1989).

Jahns (1996) investigated west equatorial Africa during the Holocene, using marine pollen extracted from cores along the Congo fan. This study observed high values of lowland rainforest transitioning with dry forest. A high proportional abundance of Poaceae and Cyperaceae were also present during the Holocene which can be generally correlated with this study. Shi et al (1998) reported on vegetation and climate changes over the last 21 ka in south-west Africa, based off marine pollen records. The study dealt with environmental change that geographically included the northern Namibian Desert, the Angolan highlands, and the north-western Kalahari. In agreement with many other researchers, it was noted that there is a paucity in data on these regions during the Late Pleistocene and Holocene (Huntley et al., 1974; Rajmánek et al., 2017; Shi et al., 1998). Results of pollen records from the last 2000 years to present, were characterised by a decline in *Podocarpus*. Since *Podocarpus* is a cold-loving species (Chevalier and Chase, 2016), it is expected that temperatures increased hence the decline in *Podocarpus* from 2 ka to present. This very broadly correlates to the CS core at -5 cal. yr BP where warmer conditions prevailed.

6.3 Landmines in Angola

During the Civil War, many landmines were placed in Angola (Landmine Monitor Report, 2009). Their exact locations are unknown as landmine coverage was not mapped out or GPS coordinates were not taken for each landmine or even a group of landmines. The presence of these landmines has caused much disturbance to the country, and demining is essential even if it does disrupt the surrounding sediment when a mine is detonated (Berhe, 2007). Demining the land may render certain palaeoenvironmental research impossible. There are approximately 9-15 million land mines in Angola and navigating the region for ideal study sites is compromised (US Department of State, 1998). The impact of landmines on this study can be used to determine implications it may have on future studies conducted in war-torn regions.

6.4 The relevance of this record

If interpretations are correct for the sample records being disrupted by war activities; the results of this study are not to be disregarded. The results obtained in this study are useful for showing broad environmental conditions and overall pollen abundances over a larger scale of time. From the results obtained there has always been grass in the region and there have always been wetland taxa present. Results of this study also indicate that it is not beneficial for further investigations from this particular study site or any other known site where demining activity has taken place, or have been suspected detonations of landmines. However, cores taken from offshore deposits will be useful and can also be used to correlate with any reconstructions made from cores taken inland.

Landmines have an estimated life of 100 years or more (Gangwar, 2003). Demining the area is of great importance even though it disrupts soils. People are currently too scared to inhabit or farm on areas that possibly contain landmines and so the few areas that are free of landmines in rural areas of Angola are very highly populated. By demining and making more portions of land available, there can be an even distribution of people, which takes off less pressure on the land (Gangwar, 2003).

Samples for this study were taken from areas in the surrounding vicinity so it may be likely that the soil and palaeoenvironmental proxies have been disturbed post-deposition, especially from antipersonnel landmines. The results are able to provide a broader understanding of the vegetation over the last few thousand years, but high resolution results are not possible. Reconstructions using palynomorphs are not the only option; one may be able to look at other forms of data

6.5 Limitations of the study

Certain limitations do exist within the study of palynological assemblages. This section will focus on the limitations that were encountered during the preservation, preparation, and analysis of the palynomorphs.

6.5.1 The dating of samples

Due to financial constraints, samples were very carefully selected to be sent to Beta Analytics for radiocarbon dating. As a result, a total of seven samples, strategically chosen throughout the core were used to determine dates of the core. The more samples that are dated, the more accurate the data on the dates obtained. The small sample size for radiocarbon dating will impact the strength of the data set.

In this particular study, three dates showed contamination which inadvertently influenced the statistical analysis as there were only seven samples. Using the data obtained, a Bayesian age-depth (BACON) model was used to temporarily constrain data and establish a timeline. As the rate of sedimentation is determined using BACON models that are produced from radiocarbon dates of the samples; there will be greater variation in the data and climatic conditions inferred from this, resulting in over simplification of mentioned climatic conditions and sedimentation.

AMS dates were done with anticipated Holocene dates, however, if final results were known sooner, Pb^{210} dating on the whole of each core would have been more appropriate and should be done on future cores. This is not possible at this stage of the investigation because all sample material has been used in pollen preparation, and obtaining more samples is not possible as the study site is not easily accessible.

6.5.2 Identification of pollen

There is currently no simple online pollen reference database available for southern African pollen, or a consensus on identification of pollen grains into genus/ species. To identify the pollen grains from the two cores obtained, numerous online reference collections were used, containing pollen from different continents. The main source of identification was the Tropical West African Pollen Database, which is a valuable tool for environmental characterisation on a continental scale for Africa (Gajewski et al., 2002; Lézine et al., 2009).

Pictures of the pollen grains may not have resembled all possible angles as the slides are dry slides and so the position of the grain is fixed once the glue used to bond the cover slip dries up. This leads to a possibility of incorrect identification or compromised identification only down to Genus level instead of Species level. The vegetation of Angola is still relatively unknown and unexplored, and based on this there are no online databases.

The lack of identification or misidentification of the pollen grains can impact the statistical analysis since species with an abundance of less than 2% in the core are excluded from all statistical analysis to account for contamination. The Holocene had very complex flora, and so species were identified down to Family level and not species level, as there are no complete detailed reference collections down to species level for pollen in this region. This level of identification may influence the inferences made about the pollen present in the samples of this study. Different species have differences in environmental preferences and grouping them all into one family may result in a loss of specific environmental conditions experienced.

6.5.3 Preparation methods

The standard procedure for pollen preparation was used in this study (Faegri et al., 1989). No adaptions had to be made to this procedure but deposits are not all the same, and certain acid treatments do have a possibility of deteriorating some pollen grains which leads to obstructed identification.

6.5.4 Contamination of samples

Samples were prepared in the Acid laboratory at the Evolutionary Studies Institute, University of the Witwatersrand. This laboratory was also used by other palynologists, and there is a possibility that cross-contamination occurred. However samples with less than 2% abundance were removed to account for this. During the extraction of the peat cores, it is possible that contamination may have occurred from present-day pollen. As sample cores were already limited in length, terminating top and bottom layers of the core was not an option. The cores from Cuito Cuanavale were subsampled in the laboratory and not in the field to prevent contamination from present-day pollen.

6.5.5 Pollen as a single proxy

Using a variety of proxies often makes a study more reliable as different proxies provide information about very specific environments. Diatoms are aquatic and only contained within sediment deposits where previous aquatic environments existed (Finne et al., 2010). Phytoliths are useful for detailed information on grassland environments, and speleothems are only present in cave and cavern deposits (Finne et al., 2010; Holmgren et al., 2010). Charcoal can indicate a presence of fire in the record, and the occurrence of human activity can be inferred (Bremen et al., 2011).For this study, the only proxy used was pollen due to financial and time constraints, and for future work, it would be beneficial if samples from this region are investigated using multiple proxies to increase the validity of results and to build a more detailed environmental reconstruction (Fitchett, 2010).

6.5.6 Access to study site

Gaining access to Angola for scientific purposes is very difficult and very costly. Navigating through the region where samples were taken is also almost impossible. The presence of landmines coupled with permission to access certain sites makes field work very difficult. The National Geographic Okavango Wilderness Project team that collected these samples on the 2016 expedition were limited to areas where cores could be extracted. However some cores though ideal could not be extracted due to landmines.

6.5.7 Post-depositional disturbance

As mentioned earlier, the Civil war had a significant impact on the country and its people. The samples indicated some disturbance to the sediment deposits. The likely reason is the landmines, which were placed in areas of this region (Guimarães, 2001). It is impossible to tell where they were placed as they were placed sporadically and locations of mines were not mapped. Therefore, landmines that may have already detonated in the past will be unknown to us, and this could have occurred at the study site, which would disturb the sediment layers (Berhe, 2007). The Battle of Cuito Cuanavale, which took place in September 1987, was fought on the banks of the Lomba River in the vicinity of Cuito Cuanavale in south-east Angola (Breytenbach, 1997; Mills and Williams, 2006). The political part of this battle aside, there were also major impacts on the environment, which are known to occur as a result of battle (Gangwar, 2003). During this battle, the tanks, troop carriers, and logistical vehicles used would very likely disturb or compacted the underlying deposits or even the surrounding deposits. The impacts of landmines on the ground are mentioned in the literature review and if landmines did explode near the study site or if army tanks were rampant in the region during battle, this would disturb the sediment. Using multiple proxies to study ecological changes would help strengthen future palaeoenvironmental studies (Meadows, 2014). Any study would benefit from a multiproxy analysis, especially site-specific studies in regions that are affected by remnants of war activities, providing alternatives and increasing the number of available study sites.

6.6 Conclusion

This chapter provides a broad interpretation of the past environment of the Cuito Cuanavale, in which indicator pollen families suggest a predominantly grassland environment for the very end of the Quaternary, given the AMS dates are correct. The landmines throughout Angola and the battles during the Civil War that recently ended in 2002 have all had an impact on the surrounding environment and especially the sediment layers that have been deposited, such as those present in this study.

CHAPTER 7: CONCLUSION

7.1 Introduction

The headwaters to the Okavango Delta that are located in the Angolan Highlands are vital to the wellbeing of the Delta as well as the communities surrounding these tributaries. By understanding the way the climate has changed in this region and how it compares to surrounding regions, will assist in contemporary ecological management issues (Kruger, 2015). Due to the Civil War, only recently have scientists been able to attempt studying the ecology of Angola, both past and present. To be able to do this, multiple proxy investigations should be encouraged. Many regions in southern Africa have a sparse pollen record because many of these areas are too arid to enable pollen preservation (Elenga et al., 2000; Fitchett et al., 2016a, b). This study utilised pollen as a proxy to determine if using pollen as a palaeoenvironmental indicator will be useful in a war-torn region. This chapter outlines the extent to which the aims of the study were achieved and prospects for future work in the country to obtain good palynological records.

7.2 Achievement of Study Objectives

7.2.1 To extract two peat cores from Cuito and Cuito Cuanavale source lakes in Angola

The two cores used in this investigation were successfully extracted from the wetland deposits, despite the lack of sufficient equipment on hand. From the findings of this study, it is suggested that for further investigations marine cores should be used.

7.2.2 Isolate and identify pollen assemblages at a 2cm resolution, by subsampling each core and determine the ages of the material through radiocarbon dating

Palynomorph slides were prepared, and pollen grains were identified using reference collections such as the African Pollen Database. Ages were determined and taken to be true for this study, using AMS radiocarbon dates obtained from Beta Analytics Laboratory. The results were synthesised to reconstruct the dominant vegetation types and environments at the time.

7.2.3 Assess potential contamination of the cores from landmine activity through a critical analysis of sedimentation rate and contaminant pollen

Statistical analysis of the data is discussed in the Materials and Methods Chapter, and followed by graphical representation and discussion of the data in the Results Chapter. Despite post-depositional disturbances, a general idea of the climate conditions at the time can be deduced. During the Late Holocene, Savanna grassland conditions dominated with hardly any noticeable fluctuations, which is common for this period.

7.3 Future Possibilities

This project, is a pioneering study in the region, only utilized pollen as a palaeoenvironmental proxy. Using other proxies such as diatoms or hyrax middens investigate the palaeoenvironmental conditions during the late Holocene will strengthen the accuracy of future investigations.

The samples from Cuito Source Lake and Cuito Cuanavale are part of a pioneering study in the Angolan region and data obtained from this study will add to the archive of palaeoclimatic data, and help determine better methods for future palaeoecological investigations in the area. Future study sites should ideally focus on longer periods, which would require longer cores. Extraction of cores should be done in an area with knowledge of the underlying sediment layers and extent to which coring will be possible, as well as marine cores to enable both land and sea correlation over time.

7.4 Future Application of Findings

The outcomes of this project will be valuable for future studies in the area, specifically around the Cuito source lake region as it is poorly documented relative to other sites in Angola. Future studies in this region will benefit from determining locations beforehand that have not been affected by landmines, to prevent coming across sediment that has undergone major post-depositional disturbance. Pollen as a proxy for past environments can still be implemented using marine cores which also allow for land-sea linkages. Furthermore, using multiple proxies will make future studies more reliable and precise.

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