LATE QUATERNARY PALAEOENVIRONMENTS OF THE MFABENI PEATLAND, NORTHERN KWAZULU-NATAL

by

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ABSTRACT

To assist in developing a more precise understanding of past climatic changes in southern Africa, further pollen analytical research is required. In the past, pollen sites in the subregion have been restricted to swampy areas such as permanent springs and peat deposits. While such sites are often rare as a consequence of the aridity of the country, rich polliniferous deposits can be found in the peatlands surrounding coastal lakes in the Maputaland Coastal Plain. The Mfabeni peatland, situated on the eastern shores of St. Lucia, contains relatively old sediments dating back to >45000 years bp at a depth of 7.80m. A multi-proxy approach, comprising radiocarbon, stable carbon isotope ($\delta^{13}C$) and palynological analysis, was applied in the investigation of Late Quaternary climatic conditions and vegetation changes along the Maputaland Coastal Plain. A single 10 m sediment core, dating back to >45000 years bp, was extracted from the Mfabeni Peatland. A detailed fossil pollen analysis of Mfabeni sediments indicated the existence of extensive *Podocarpus*-abundant coastal forests before *ca.* 44500 years bp. The onset of wetter local conditions after this time is inferred from forest retreat and the development of swampy conditions, which prevailed until *ca.* 25000 Cal years BP. Conditions during the Last Glacial Maximum (LGM; 18000 years BP) are inferred to have been generally colder and drier, as evidenced by forest retreat and replacement of swampy reed/sedge communities by dry grassland. A significant depletion in $\delta^{13}C$ values at *ca.* 18200 Cal years BP indicates the dominance of C_3 vegetation during the LGM, reflecting considerably colder conditions. This is in agreement with palaeoenvironmental indications from elsewhere in the Transvaalian Ecozone, although conditions at Mfabeni were more moderated in their manifestation, which can be attributed to the proximity of this site to the ocean. Cool, relatively moist conditions are inferred for the Holocene Altithermal (*ca.* 8000-6000 years BP), as evidenced by forest growth and expansion during this time. Warm, dry conditions are inferred for the Late Holocene, with the establishment of grassland/savanna type vegetation in the area after *ca.* 2000 Cal years BP.

PREFACE

The experimental work described in this dissertation was carried out in the School of Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, from January 2004 to December 2005, under the supervision of Prof T.R. Hill and Prof W.M. Ellery.

These studies represent original work by the author and have not otherwise been submitted in any form of degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.

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CHAPTER ONE
INTRODUCTION

A strong body of evidence in support of climate change[1] has become available in recent years, resulting in a global concensus amongst the scientific community that human activities are, whether directly or indirectly, responsible for altering the earth's climate (Peters and Lovejoy 1992; Hughes 2000; IPCC 2001). The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to draw together scientific research on the enhanced greenhouse effect, global warming and climate change. After more than a decade of research, the IPCC has confirmed the occurrence of significant global warming, using direct evidence from increased surface air temperatures, subsurface ocean temperatures and average sea levels, as well as the retreat of glaciers (IPCC 2001). In June 2005, the conclusions of the IPCC were endorsed by a joint statement issued by the science academies of all G8 countries together with the academies of Brazil, China and India. In response to the potential implications of these conclusions, research has been focussed on gauging the magnitude and extent of future climatic changes.

The only available means of predicting future climate change is through the use of well tested general circulation models (GCM's; COHMAP 1988). Independent data are required for the validation of any model, and thus climate model simulations can only be evaluated through the use of present and past (palaeo) climatic data (COHMAP 1988; Wright *et al.* 1993; Joubert and Hewitson 1997). It is now recognised that accurate predictions as to the nature of future environments depend on a sound understanding of past environmental changes (Birks and Birks 1980). Palaeoenvironmental studies make a significant contribution to climate model validation by providing: (i) insight into the causes and mechanisms of climatic change, thereby allowing for the fine-tuning of appropriate processes within climate models; and (ii) unique data sets for model validation purposes (Gates *et al.* 1990). In

[1] This refers to the UNFCCC definition (IPIECA 2001, p. 11), which states that climate change is 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to ntural climate variability observed over comparable time periods'.

addition, the palaeoenvironmental record provides a means of assessing the extent to which past climatic changes were human or natural induced (Huntley 1990).

Clearly, palaeoenvironmental research has much to contribute to our understanding of global environmental change (Delcourt and Delcourt 1991). Despite this, there is a distinct lack of high quality, long term records of both the recent past and palaeoclimates, limiting climate model validation, especially for the southern African subregion (Joubert and Hewitson 1997). Consequently, the last decade has witnessed a marked increase in the number of palaeoenvironmental reconstructions for southern Africa, with particular emphasis on the most recent period in geological history, the Quaternary (Meadows and Baxter 1999).

The most important palaeoenvironmental technique available to Quaternary researchers is that of palynology, or pollen analysis (Chambers 1993), which provides direct information relating to past vegetation reconstruction (Birks 1981). Faegri and Iverson (1989, p. 1) define pollen analysis as 'a technique for reconstructing former vegetation by means of the pollen grains it produced'. Pollen is of the most abundant of fossil types preserved in Quaternary deposits, which is one of the main reasons why pollen analysis dominates terrestrial palaeoecology (Birks 1981). Fossil pollen grains are particularly suitable for analysis as they are widely and evenly dispersed, and have highly resistant exines, permitting their survival in deposits where other fossil types have been diagenetically destroyed (Faegri and Iverson 1989). Stratified sequences of pollen, preserved in lake sediments, peats and mires, allow for the histories of individual plant taxa and even entire plant communities to be traced (Moore *et al.* 1991). This reconstruction of past vegetation using pollen analysis is reliant on the assumption that the pollen assemblage found at a particular time and space is representative of the regional vegetation present (Birks 1981). Climatic reconstructions are further dependent on the assumption that this vegetation is controlled by prevailing climate, such that there is an indirect association between pollen and climate (Birks 1981). Therefore, pollen data need to be interpreted in the context of past vegetation before climatic inferences are determined (Birks and Birks 2005).

There has been a strong call for further pollen analytical research in southern Africa, to assist in developing a more precise understanding of past climatic changes (Scott 1993). Historically, southern African palynological investigations have been disadvantaged by a lack of polliniferous deposits, owing to poor pollen preservation within the region's Quaternary age deposits (Scott 1984). As a result, few sites have exposed reliable pollen sequences for the Quaternary in relation to the regions large and diverse area (Meadows 2001). According to Scott (2000, p. 349), 'a much closer grid of sites is needed for successful modelling of environmental change'.

In the past, pollen sites in southern Africa have been restricted to swampy areas such as permanent springs and peat deposits (Scott 1984; Scott and Vogel 2000). While such sites are often rare as a consequence of the aridity of the country (Scott 1984), rich polliniferous deposits can be found in the peatlands surrounding coastal lakes in northern KwaZulu-Natal (Scott 2000). Approximately 270 peatlands have been identified within the Maputaland Coastal Plain (MCP) (Grundling and Mazus 1998), yet very little is known of the palynology of the area (Scott 2000). These peatlands can be geographically divided according to the age of their deposits (Grundling 2002). Those north of the Mkhuze River inflow into Lake St. Lucia are of Holocene age, while those south of this inflow are of Late Pleistocene age. The older deposits on the shores of Lake Sibayi and at Mbazwa have suffered weathering, resulting in poor pollen preservation (Scott 2000). However, those deposits associated with young estuarine lakes, such as St. Lucia, do demonstrate potential for palynological analysis (Scott 2000). The Mfabeni peatland, situated on the eastern shores of Lake St. Lucia, contains relatively old sediments dating back to 43 100 (+3 900, -2 600) years BP at a depth of 9.93m (Grundling *et al.* 1998). Although a limited number of studies have been carried out within this peatland, these have focussed on peat accumulation rates (Grundling 1996; Thamm *et al.* 1996) and peatland stratigraphy (Grundling *et al.* 2000) rather than vegetational or climatic reconstruction *per se*. Grundling *et al.* (2000) have used palynology to carry out a brief investigation of the vegetation history of Mfabeni, however no detailed palaeoenvironmental reconstructions have been undertaken to date. In the southern African context, where suitable sites for palynological investigations are limited, the Maputaland peat deposits, and Mfabeni in particular, represent a valuable opportunity for palaeoenvironmental research.

1.1. AIM AND OBJECTIVES

The aim of this research is to use palynology as an approach to the investigation of Late Quaternary climatic conditions and vegetation changes along the Maputaland coastal plain. Specific objectives are as follows:

(i) To expand on the existing pollen reference collection to include species from Maputaland, and furthermore, to convert these combined reference slides to digital format, thus setting up a digital image reference database.

(ii) To use a suitable coring methodology and sampling strategy to extract a minimally disturbed continuous sediment core from the Mfabeni peatland.

(iii) To obtain radiocarbon ages for a selection of subsamples, and to calibrate these ages using appropriate calibration datasets, such that independent chronological control is established for the length of the core.

(iv) To conduct a high resolution fossil pollen analysis of sediments preserved in the core, with the aim of reconstructing Late Quaternary vegetation history for the region.

(v) To conduct a stable carbon isotope ($\delta^{13}C$) analysis along the length of the core, as a complementary means of detecting changes in the relative composition of C_3 and C_4 plants though time.

(vi) To make inferences regarding the sequence of climatic and environmental changes that occurred in the region during the time of deposition, using an indicator species approach in the interpretation of pollen data.

(vii) To place this palaeoenvironmental reconstruction within the context of previous studies of the Late Quaternary in southern Africa, and assess the extent to which these data concur.

1.2. THESIS OUTLINE

The purpose of this chapter has been to introduce this research in terms of its palaeoenvironmental significance, particularly in the southern African context where Late Quaternary palaeoenvironments are so poorly understood. As Meadows argues (2001, p. 40), 'the most compelling reason for engaging in a study of the Quaternary in the region is that so little is know about it'. Secondly, this chapter has delineated the aim and objectives of the study, thereby providing the reader with a specific outline of the practical approaches adopted in this research. Chapter two provides a theoretical background, by summarising the advantages and limitations of the applied methodologies, *viz.* pollen, stable carbon isotope and radiocarbon analyses. A synthesis of previous palaeoecological studies of the Late Quaternary in southern Africa is provided in chapter three, thereby setting a context within which to interpret results. The results of previous palaeoecological studies are described according to ecozone, i.e. Basutolian, Cape, Kalaharian, Karoo/Namaqualian, Namib and Transvaalian (after Deacon and Lancaster 1988). Chapter four describes the specific methodologies applied in this research, providing justification for their selection. Results and descriptions thereof are presented in chapter five. Chapter six reconstructs the palaeoenvironmental history of Mfabeni, and places this reconstruction within the context of previous palaeoenvironmental research in southern Africa. In conclusion, chapter seven provides a synthesis of palaeoenvironmental changes at Mfabeni, and assesses the extent to which the initial aim and objectives of the research have been addressed.

CHAPTER TWO
THEORETICAL BACKGROUND

2.1. INTRODUCTION

This chapter will provide a theoretical background to the techniques that were applied in this research, including: (i) pollen; (ii) radiocarbon; and (iii) stable carbon isotope analysis. As pollen analysis is the major focus of this research, this technique will be discussed in the greatest detail, describing its applications, general principles, limitations and methodological considerations. Finally, this section will outline the approaches used in interpretating the palaeoenvironmental implications of pollen analytical data. Brief descriptions of the conceptual background of radiocarbon and stable carbon isotope analyses will be provided.

2.2. POLLEN ANALYSIS

2.2.1. Introduction and applications

Palynology is one of the most widely used research tools in Quaternary studies (Edwards 1983). Faegri and Iverson (1989, p. 1) define pollen analysis as 'a technique for reconstructing former vegetation by means of the pollen grains it produced'. While palynology technically refers to the study of both pollen grains and spores, these will be referred to collectively as 'pollen' for the sake of convenience. Pollen analysis has been used to document long-term vegetation dynamics ever since the success of von Post's pioneering experiments in 1916 (Birks 1993). The basic assumption of the technique is that the number of pollen grains deposited per unit time, at a given point, is directly related to the abundance of the associated species in the surrounding vegetation (Davis 1963). However, pollen data are presented as proportions of a total pollen sum, rather than as discrete numbers (Davis 1963). Therefore, difficulties with the representivity both between and within species are experienced, as some taxa produce far greater quantities of pollen, which are more widely dispersed than others (Birks and Birks 2005). In other words, pollen data require careful interpretation as the representivity of the pollen spectrum is shaped by differences in pollen productivity, dispersal and preservation (Faegri and Iverson 1989). Pollen grains are well suited to analysis for a number of reasons: (i) they have

extremely resilient exines, which allow for their survival in deposits where other fossil types have been destroyed; (ii) they are abundantly produced; (iii) they are widely and evenly dispersed; and (iv) pollen data are easily quantified (Faegri and Iverson 1989).

It is useful to think of pollen analysis as a remote sensing instrument, which records the past and present composition of vegetation (Webb *et al.* 1978). As with any sensing instrument, pollen analysis has certain response characteristics, which limit its application to certain contexts (Prentice 1988). Pollen data have been used in a wide variety of Quaternary applications including chronostratigraphic correlation, palaeoecology, palaeoclimatology and archaeology (Macdonald 1988). Data derived from pollen studies can be used to provide an indication as to the response of natural vegetation to human impacts through history, as well as to climatic and environmental change (Prentice 1988; Edwards and Macdonald 1991). Birks (1981) attributes the importance of the pollen record as a source of palaeoclimatic information to both its length (10^2 – 10^5 years) and sample resolution (10 – 1000 years). At the largest spatial scale, pollen data have been used to reconstruct past changes of biomes, using pollen records from entire modern biomes as a basis (e.g. Jolly *et al.* 1998; Elenga *et al.* 2000). In addition, Quaternary palynological data constitute a valuable quantitative record against which climatic models such as general circulation models (GCMs) can be validated, for studies of global change (Huntley 1990). These data strengthen predictions of how vegetation is likely to respond to future climatic conditions, thereby providing an indication of the future agricultural and silvicultural potential of various regions (Huntley 1990).

2.2.2. General principles

Birks and Birks (1980) have outlined the general principles of pollen analysis as follows:

(i) pollen grains are produced in large quantities during the natural reproductive cycles of many plants;

(ii) relative vegetation composition can therefore be inferred from the pollen grains released into the environment, as these are a function of the number of parent plants;

(iii) the majority of pollen grains produced by plants never fulfil their reproductive function, and when deposited within sediments they may be preserved as fossils;

(iv) fossil grains may be extracted from sediments and identified down to family/genus/species level; and

(v) the stratigraphic level at which grains are extracted corresponds with particular periods in the past.

While pollen analysis is based on sound principles, there are a number of limitations associated with the technique, as discussed below.

2.2.3. Limitations

Scott (1984) has noted a number of factors that complicate pollen analysis. These problems include the low taxonomic resolution of pollen studies, the difficulties associated with defining pollen source area and the representivity of pollen rain.

The wide range of size, shape and surficial sculpturing of pollen grains allow for their identification under light microscopy (Jacobson 1988). Unfortunately, pollen grain identification has a limited taxonomic resolution, which can often only be achieved down to the family/genus level, depending on variability within the taxonomic group (Scott 1984). There has been little or no progress in the identification of common pollen types such as Poaceae and Cyperaceae (Sëppa and Bennett 2003), which tends to limit interpretation in wetland and grassland systems. Scanning Electron Microscopy (SEM) techniques have greatly increased the taxonomic resolution of pollen identification (e.g. Hanks and Fairbrother 1970; Lynch and Webster 1975; Page 1978; Daghlian 1982; Vincent and Getliffe Norris 1989). However, SEM methods are simply not practical for the routine identification and counting of thousands of grains, as are required by the pollen analysis technique. Nevertheless, pollen-analytical precision has constantly improved and high-quality pollen identification guides with identification keys continue to be published (Sëppa and Bennett 2003). The development of digital photography has allowed for the creation of extensive pollen image databases (e.g. the African Pollen Database [APD]), which facilitate easy access of images from around the world (Sëppa and Bennett 2003).

It can be difficult to differentiate between allochthonous and autochthonous elements within a deposit i.e. whether the pollen was derived from regional fallout, or was of local origin (Janssen 1984). Pollen source area is defined as 'the area from which a fixed percentage (e.g. 70%) of the pollen sampled at a site is derived' (Jacobson *et al.* 1981, p. 80). The source area of a deposit is controlled by a number of factors as outlined by Jabobson and Bradshaw (1981). Pollen may arrive at a deposit through various processes including aerial fallout, surface wash or stream and river flow (Jacobson and Bradshaw 1981).

The representivity of different taxa is difficult to assess as pollen percentages are systematically altered by production bias and dispersal bias (Prentice 1985). Pollen analytical studies suffer from problems of representivity as it is difficult to quantify the relationships that exist between the: (i) pollen spectrum and pollen rain; (ii) pollen rain and vegetation; and (iii) vegetation and the potentialities of an area in terms of plant successional stages and climatic factors (Faegri 1966). Different modes of pollination between plant types has an important role to play in determining how evenly pollen is dispersed. Anemophilous (wind-pollinated) taxa produce pollen in large quantities, which tends to be widely and evenly sifted over the surroundings of the parent plant (Faegri 1966; Spieksma *et al.* 1994). Many zoophilous (animal pollinated) taxa, on the other hand, produce small quantities of pollen in sticky clumps, which are transported over shorter distances and do not separate out into individual grains (Faegri 1966). Thus, the number of grains belonging to zoophilous taxa that are counted during pollen analysis is a function of the size of the pollen clump rather than an accurate representation of the species (Faegri 1966). This leads to poor representation of zoophilous, and in particular entomophilous (insect pollinated) taxa in the pollen record (Jacobson and Bradshaw 1981; Macdonald 1993).

Differences in pollen productivity between species produce similarly disproportionate results (Faegri 1966). Pollen production of a species is controlled by a number of factors such as climate, exposure, competition, and cultivation measures (Faegri 1966). Pollen types also differ in transport effectivity; this is particularly evident when comparing arboreal and non-arboreal pollen (Faegri 1966). These complicating factors lead one to question the extent to which pollen rain is in fact representive of

the surrounding vegetation. Studies of modern pollen-vegetation relationships allow the pollen analyst to correct for discrepancies in representation by using R-values to calibrate pollen rain with vegetation composition (Prentice 1985). According to Prentice (1988, p. 17), the results of many modern pollen studies indicate that 'pollen assemblages are diagnostic for broadly defined vegetation types such as...forest-types'. Such studies demonstrate the quantitative relationship between vegetation composition and the pollen percentages of major plant taxa (Prentice 1988). Where modern pollen studies have not been undertaken, an intimate knowledge of the ecology and sociology of the concerned vegetation types is critical if meaningful conclusions are to be drawn from the pollen record (Faegri 1966). Faegri (1966, p. 140) argues that 'knowledge of a vegetation is a paramount demand for utilization of pollen-analytic data.'

2.2.4. Methodological considerations

2.2.4.1. Site selection

A range of sediment types including ice caps, deep-sea sediments and sediment exposures have been found to preserve Quaternary palynomorphs, yet non-oxidising environments such as lake and peat deposits remain the primary sources (Macdonald 1988). According to Jacobson and Bradshaw (1981, p. 93), 'peat deposits may contain the best pollen record for palaeoclimatic or palaeovegetational reconstructions'. When sampling peat deposits, consideration should be given to basin characteristics such as: (i) location; (ii) extent of tree canopy; (iii) extent of water movement; and (iv) basin morphometry (Jacobson and Bradshaw 1981). Sedimentation processes are equally important: (i) age of deposit; (ii) continuity of record-recurrence surfaces; (iii) human disturbance; (iv) postdepositional pollen movement; and (v) redeposition of peat that has broken loose from a floating mat (Jacobson and Bradshaw 1981). Finally, local environmental factors should be investigated: (i) present vegetation composition; (ii) pH and ionic content of percolating water; (iii) hydrology; (iv) fire frequency; and (v) prevailing winds (Jacobson and Bradshaw 1981). While vertical displacement of pollen grains within peat sediments have been a concern in the past, Birks and Birks (1980) demonstrate that the downward mixing of pollen is not a concern in pollen analytical studies due to the time scale involved.

2.2.4.2. Field sampling

Sediment cores are generally extracted from peats using chamber corers, which are directed into the sediment and then rotated to fill a sample chamber (Macdonald 1988). Both the Hiller and Russian samplers are commonly used, however the Russian sampler is advantageous in that it preserves stratigraphy (Macdonald 1988). The Russian corer consists of a semi-cylindrical barrel that is sharpened on one edge such that it cuts a segment of peat as the chamber is turned (Jacobson 1988). This instrument is recommended for peat stratigraphic work because of its clean action, and speed of operation and cleaning (Moore *et al.* 1991).

2.2.4.3. Laboratory processing

A standard laboratory processing sequence consists of the following stages: (i) subsampling; (ii) addition of exotic palynomorphs; (iii) chemical and physical processing; and (iv) staining and mounting (Macdonald 1988).

A standard volume of sediment is subsampled at regular intervals along the length of the core. Subsampling interval and subsample size are dependent on stratigraphic complexity and the degree of precision required for change detection (Moore *et al.* 1991). This interval is usually determined by beginning with a wide interval, such as 10 or 20cm, and then filling in the gaps where further detail is required. Where little or no change is detected between wide intervals, it can be concluded that further subsampling is unnecessary (Moore *et al.* 1991).

Where absolute pollen frequencies are to be calculated, a known quantity of exotic palynomorphs (spikes/marker grains), e.g. *Lycopodium clavatum*, is added to the sample. Exotic palynomorphs are added prior to chemical and physical processing so as to ensure even losses amongst fossil and exotic grains during processing (Stockmarr 1971). Experiments by Jemmett and Owen (1990) have shown that the pollen assemblage counted on the final slide is strongly influenced by differetial pollen loss during processing, which is in turn influenced by: pollen geometry, pollen type (exotic versus fossil) and tube substrate (glass versus plastic). Samples are chemically and physically processed to remove carbonates, humic acids, pyrite, silica and cellulose. Standard chemical processes include HCl, NaOH and HF digestion

(Faegri and Iverson 1989). Processed samples are stained and mounted to prepare for the counting procedure, which is carried out using light microscopy. Palynomorph identification is aided through the use of a pollen reference collection, which consists of pollen slides/reference cards/digital reference databases. These are assembled through the collection and identification of fresh and herbarium floral material, pollen concentration and microphotography.

2.2.4.4. Counting

Identification and counts of pollen grains are achieved using fixed traverses across the slide by means of an adjustable stage. It is essential that traverses across the slide are evenly spaced to obtain an accurate representation of the assemblage (Jemmett and Owen 1990). Where possible, it is recommended that full slides be counted (Gordon 1974), to avoid the possibility of non-random positioning of differently sized grains on the slide. Sample size and minimum pollen sum should be determined in such a way so as to obtain maximum resolution while maintaining adequate pollen assemblage representivity for each sample counted. Minimum pollen sum is usually determined by using standard counts of 250, 500 and 1000 and then statistically testing whether there is a significant difference between them, i.e. whether a smaller count would be representative (Hill 1996). Unidentified pollen grains should be classified as unidentified (unknown) or indeterminable (corroded/degraded/broken/ crumpled/concealed) (Berglund and Ralska-Jasiewiczowa 1986). Alternatively, counts may be adjusted to exclude poorly preserved specimens where grains are corroded, folded or damaged. Clusters of pollen grains of the same type should be grouped together as a single unit to avoid unrealistic overrepresentation (Faegri and Iverson 1989).

2.2.4.5. Data Presentation

Visual presentation of pollen data is an important means of facilitating palaeoenvironmental interpretation (De Vries and Wijmstra 1986). This can be facilitated by presenting pollen data as pollen diagrams, which plot chronostratigraphy (depth scale and radiocarbon ages) against biostratigraphy (pollen counts as influx figures or percentages) (Faegri and Iverson 1989). Pollen diagrams illustrate fluctuations in the abundance of taxa as new species are added to the

community, or are extirpated (Bennett 1988). They can be described as 'a record of changing realised niches in response to new competitors or the loss of old ones' (Bennett 1988, p. 718). De Vries and Wijmstra (1986) recommend that pollen diagrams satisfy the following criteria:

(i) provide a clear representation of regional and local developments (e.g. by excluding regional taxa from the pollen sum);

(ii) distinguish between different data types (e.g. pollen, macrofossils, stable carbon isotope data); and

(iii) indicate ecological groupings that reflect major changes in climatic parameters.

In order to accurately represent the composition of fossil plant communities in pollen diagrams, it is crucial that a suitable pollen sum be selected (Janssen 1970). The following considerations have been put forward to guide the selection process (Janssen 1970):

(i) any pollen sum assumes an ecological identity and thus reflects a vegetation type;

(ii) it is important to decide which vegetation type produced certain pollen types; and

(iii) the sum may be adjusted according to vegetation components that may be of particular interest.

Pollen diagrams are divided into zones that contain stratigraphically conterminous samples using a variety of numerical techniques (Birks and Gordon 1985). A pollen zone is defined as a body of sediment that can be differentiated from adjacent sediment bodies by differences in its contained fossil pollen grains and spores, which are derived from plants existing at the time of deposition of the sediment (Cushing 1964). In other words, pollen zones can be described as temporal entities of pollen samples with relatively uniform pollen composition (Ritchie 1995). Zones can be defined by visual inspection of a pollen diagram or through the application of various numerical techniques (Grimm 1988). Since the main purpose of pollen zonation is to simplify description, visual inspection is not necessarily inferior to the use of quantitative methods (Grimm 1988). However, numerical methods provide a

standardised procedure, which avoids any biases for particular pollen types that may arise when using the inspection method (Birks and Berglund 1979).

2.2.5. Interpretation

Pollen analytical data are directly relevant to palaeoclimatic reconstruction, due to the relationship that exists between modern vegetation and climate (Birks 1981). There are three dominant approaches to the quantitative reconstruction of past environments from pollen data, *viz.* (i) the indicator/floristic approach; (ii) the assemblage approach (or modern analogue technique); and (iii) the multivariate transfer function approach (Birks and Birks 1980; Birks 1981; 1998; 2003). These approaches rely on information regarding the modern environmental requirements of preserved indicator taxa (Birks 2005), and assume *methodological uniformitarianism* (Birks and Birks 1980; Birks 1981), *viz.* 'that modern-day observations and relationships can be used as a model for past conditions and, more specifically, that organism-environment relationships have not changed with time, at least in the Late Quaternary' (Birks 2005, p. 107).

Quantitative reconstruction of fossil data can only be achieved when large, high-quality, and taxonomically consistent modern data sets are available from comparable sedimentary environments as the fossil dataset (Birks 2005). Though the need for quantitative palaeoenvironmental reconstructions is increasing, the requirements detailed above are seldom met, especially in the African context. Such data do not exist for much of southern Africa (Scott 1984), preventing the use of complex quantitative approaches such as the modern analogue and multivariate transfer function techniques in palaeoenvironmental reconstruction. For this reason, the indicator/floristic approach was selected for use in this research.

2.2.5.1. Indicator species approach

The indicator (individualistic/floristic) approach uses the presence (or absence) of indicator taxa, whose modern ecological tolerances are well understood, as a basis for reconstructing palaeoenvironments (Birks 1981; Birks and Birks 2005; Birks 2005). The presence of indicator taxa at particular stages within the fossil record suggests that environmental conditions were within the range presently occupied by the taxon

in question (Birks 1981). Clearly, this requires insight into the present day climatic limits of indicator taxa (Birks 1981; Macdonald 1988), and assumes that the environmental preferences of these taxa have remained constant through time. The indicator approach not only assumes that each pollen type reveals something about the environment, but also suggests the possible presence of other ecologically related taxa (Janssen 1970). In general, indicator taxa are minor constituents of the vegetation and thus indicator pollen grains are unlikely to originate from the regional fallout (Birks 1981). This ensures that interpretation is not biased towards regional conditions, but remains focussed on the local signal. Ideal indicator taxa produce pollen grains that can be identified to the species level, and are rapidly dispersed (e.g by birds) over short distances (Birks 1981). The indicator approach is well suited to studies of the Late Holocene, where fossil flora do not differ considerably from those of the present day (Janssen 1970). Janssen (1970) warns that older sediments have a greater risk of revealing other ecotypes, for which we have no modern analogues. In no-analogue situations the principle of methodological uniformitarianism becomes difficult to implement. However, this is a generalised assumption, and the likelihood of a no-analogue situation occurring depends on the floristic diversity and marginality of the region in question. The limitation of these indicator species approaches is their assumption that plant distribution is only influenced by one (or two) climatic variables (Birks 1981). Moreover, only a few taxa are taken into account, and interpretations are based on presence/absence as opposed to numerical frequencies of pollen types in the fossil record (Birks 1981).

2.3. RADIOCARBON ANALYSIS

Within all living organisms, the radioactive carbon-14 isotope (^{14}C/radiocarbon) exists in dynamic equilibrium, continually decaying at an equal rate to its production (Pilcher 1991). Once an organism dies, however, radiocarbon production ceases while decay continues with a half-life ($T_{1/2}$) of 5568 ± 30 years (Saarnisto 1988). This negative exponential decay rate (figure 2.1) is known as Libby's conventional figure, and serves as the basis for all ages, unless otherwise stated (Saarnisto 1988).

Since the publication of the principles of radiocarbon dating by Libby *et al.* (1949), it has developed into the most widely applied and accepted means of establishing

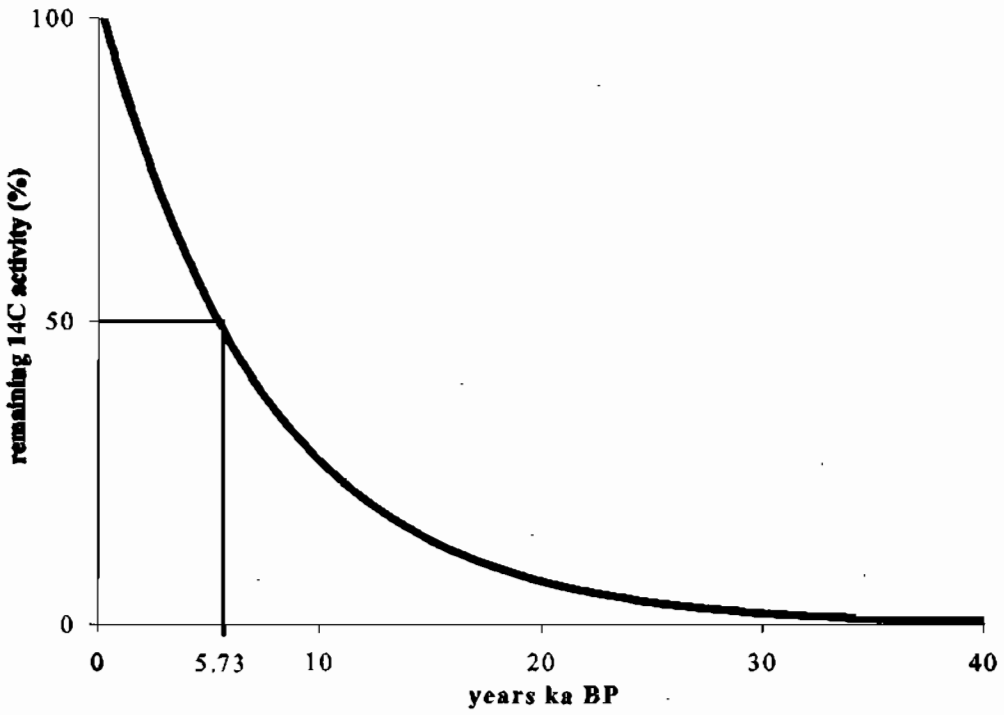


Figure 2.1 Radiocarbon decay curve (after Williams *et al.* 1995).

chronological control for the Late Quaternary (Williams *et al.* 1995). Radiocarbon ages are often used as a form of independent chronological control for pollen stratigraphic data (Macdonald 1988). The limitations of this technique for Quaternary scientists relate to the limited timescale and calibration curves, as well as the danger of contamination in peat sediments. However, as peat has a carbon content of approx. 50% and is entirely autogenic, it provides one of the best materials for radiocarbon dating (Barber and Charman 2005). The risk of contamination can be reduced and in some cases prevented through careful sample selection and handling during laboratory procedures (Williams *et al.* 1995). Pollen analytical studies are futher limited by the fact that suitable deposits for pollen analysis often provide poor material for dating (Scott 1989a). Of these, the biggest limitation of ^{14}C dating for Quaternary scientists is the fact that the ^{14}C timescale is effectively restricted to the last *ca.* 40 ka (Huntley 1996).

Recently, the importance of calibration of radiocarbon results has been emphasised, with increased effort to extend radiocarbon calibration curves to cover the entire radiocarbon timescale (Williams *et al.* 1995). The calibration process allows for the correction of fluctuations in ^{14}C production during the Earth's history (Pilcher 1991). At present, calibration curves are only available for the last 11 000 Cal yr BP for the Southern Hemisphere (SHCal04, McCormack *et al.* 2004) and 26 000 Cal yr BP internationally (INTCal04, Reimer *et al.* 2004). Differences in the atmospheric concentration of ^{14}C between the northern and southern hemispheres have necessitated the development of separate radiocarbon calibrations for each hemisphere (Pilcher 2005). Pilcher (1991) recommends that beyond the range of the calibration curve, ages should be left uncalibrated.

2.4. STABLE CARBON ISOTOPE ANALYSIS

During photosynthesis, most plants utilize one of two dominant metabolic pathways by producing initial molecules with either three or four carbon atoms (C_3 and C_4 plants, respectively) (Ehleringer *et al.* 1997). By analysing the stable carbon isotope ratio (i.e. $\delta^{13}C$, the $^{13}C/^{12}C$ ratio expressed as parts per thousand [‰] deviation from the international PDB [Peedee Belemnite Standard]) preserved in their organic components, it is possible to differentiate between plants utilising the C_3 and C_4 photosynthetic pathways (Wooller *et al.* 2003). Based on this principle, scientists have used stable isotopic analysis of plant organic remains in soils or peatbogs to investigate palaeoclimatic changes as well as the physiological responses of vegetation to these changes (Aucour *et al.* 1994; van der Water *et al.* 1994; Switsur and Waterhouse 1998; Conte and Weber 2002). The stable carbon isotope technique has been applied to a range of substrates, including fossil speleothems, palaeosols, antelope tooth collagen and tooth enamel, allowing for seasonal variations in moisture distribution to be reconstructed (Scott and Vogel 2000). Stable carbon isotope analyses offer a complementary source of information to pollen studies, by detecting changes in the relative composition of C_3 and C_4 plants though time (Aucour *et al.* 1994).

The distribution of C_3 and C_4 vegetation in southern Africa is controlled by growth season temperature (Vogel 1978; Vogel *et al.* 1978). C_3 plants predominantly woody vegetation in addition to grasses that experience a cool growing season, e.g. those growing within cool high altitude summer rainfall regions and those within the winter rainfall region of southern Africa (Killick 1978; Vogel *et al.* 1978; Cowling 1983; Acocks 1988; Smith *et al.* 2002). C_4 plants dominate the hot summer rainfall regions of southern Africa, and consist of grasses and cereal crops adapted to hot growing seasons (Bender 1968; Smith and Epstein 1971; Smith *et al.* 2002). The $\delta^{13}C$ values of C_3 plants range between -34‰ and -23‰, with a mean of -26‰, while those of C_4 plants range between –17‰ and -9‰, with a mean of -12‰ (Hatch *et al.* 1997; Calvin and Benson 1948; Bender 1968; Smith and Epstein 1971; Vogel *et al.* 1978; Smith *et al.* 2002). CAM (crassulacean acid metabolism) plants tend to produce isotopic values that range between those of C_3 and C_4 plants, making them difficult to distinguish using the $\delta^{13}C$ signal (Barbour *et al.* 1987).

2.5. CONCLUSION

This chapter has outlined the theory behind techniques that were applied in this research. The applications, general principles, limitations and methodological considerations of pollen analysis have been described in detail. In addition, the theoretical background of the radiocarbon and stable carbon isotope techniques have been explained. Finally, the interpretive approaches that can be used in palynological studies have been discussed. It is on the basis of theoretical considerations examined in this chapter, that specific methods were selected for use in this research.

CHAPTER THREE
LITERATURE REVIEW

3.1. INTRODUCTION

There has been a strong call for increased spatial and temporal pollen analytical research in southern Africa, to assist in developing a more precise understanding of past climatic changes (Scott 1993). Historically, southern Africa palynological investigations have been hindered by a lack of polliniferous deposits, owing to poor pollen preservation within the regions Quaternary age deposits (Scott 1984). As a result, few sites have exposed reliable pollen sequences for the Quaternary in relation to the regions large and diverse area (figure 3.1, Meadows 2001). This limited number of palynological studies has resulted in a paucity of data, which has prevented detailed palaeoenvironmental reconstructions (Scott 1984). According to Scott (2000, p. 349), 'a much closer grid of sites is needed for successful modelling

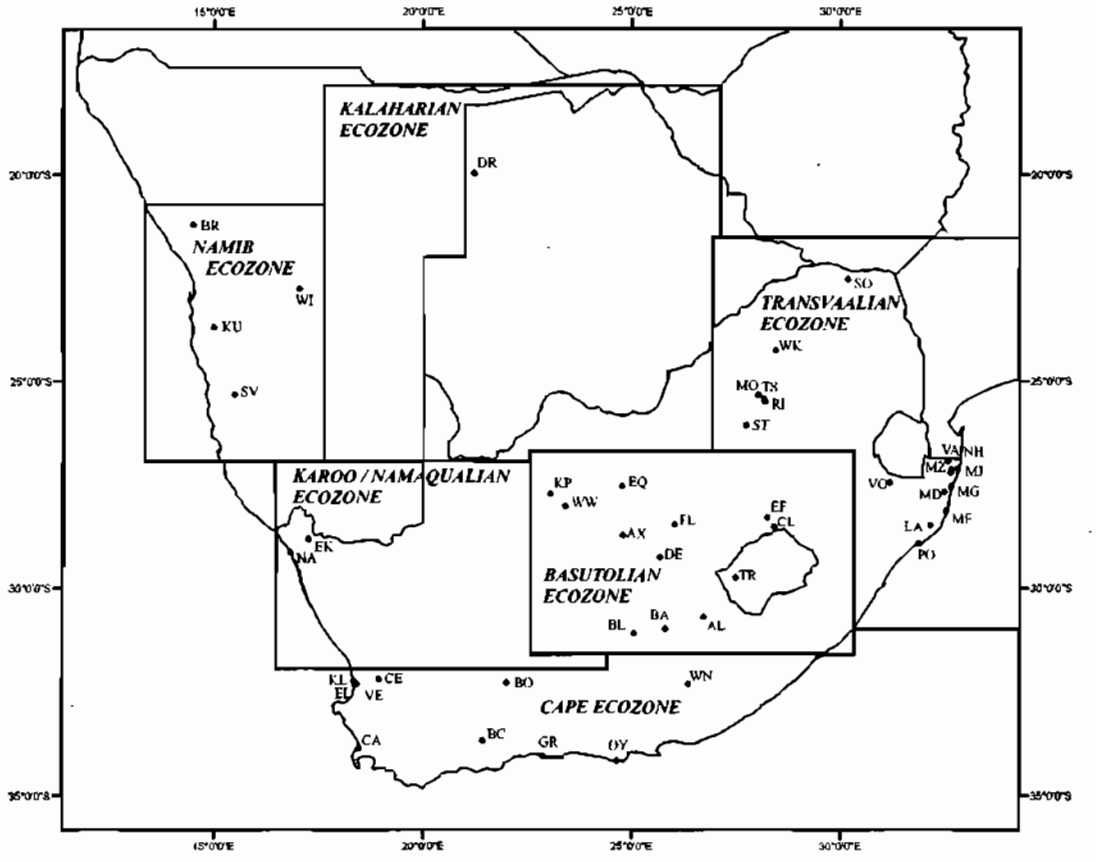


Figure 3.1. Geographic extent of ecozones for the southern African subregion (after Deacon and Lancaster 1988), indicating the location of palynological studies mentioned in the text. Codes associated with each site relate to the meta-data presented in table 3.1.

of environmental change'.

In the past, pollen sites in southern Africa have been restricted to swampy areas such as permanent springs and peat deposits (Scott 1984; Scott and Vogel 2000). Although such sites are often rare as a consequence of the aridity of the country (Scott 1984) a few reliable pollen records have been derived from the Cape and Transvaalian Ecozones. Pollen analytical research in southern Africa has moved away from traditional approaches, exploring the use of pollen preserved in speleothems (Burney *et al.* 1994), hyaena coprolites (Scott 1987b; Carrión *et al.* 2000; Carrión *et al.* 2001), cave sediments (Parkington *et al.* 2000) and, in particular, hyrax middens (Scott 1990a; Scott and Bousman 1990; Scott and Cooremans 1992; Scott and Vogel 1992; Hubbard and Sampson 1993; Scott 1994; 1996; Carrión *et al.* 1999; Scott and Vogel 2000; Scott 2005; Scott *et al.* 2005). This has allowed for the derivation of palaeoenvironmental records from data deficient arid regions, such as the semi arid Karoo and Kalahari (Meadows 2001).

This chapter will review the Late Quaternary pollen record for the southern African subregion, by summarising the results of previous pollen studies by ecozone (Deacon and Lancaster 1988). Ecozone subdivisions are appropriate to the description of palaeoenvironmental reconstructions, as they are based not only on climate but also on vegetation and flora (Deacon and Lancaster 1988). Pertinent results from other palaeoenvironmental studies will be drawn on, to strengthen the record of vegetational and climatic change, e.g. stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope records (Holmgren *et al.* 1999; Repinski *et al.* 1999; Holmgren *et al.* 2001; Lee-Thorp *et al.* 2001; Holmgren *et al.* 2003).

Table 3.1. Characteristics of the pollen sites from southern Africa mentioned in the text: details on location, dating range and principle analysts are provided. Where authors failed to include site coordinates and altitude, a 1:50000 map series was used to elicit this information.

Code	Name	Country	Ecozone	Latitude	Longitude	Altitude	Age range[2]	Site	Site Publication
AL	Aliwal North	South Africa	Basutolian	30°39'S	26°42'E	1370	undated	thermal spring	Coetzee 1967
AX	Alexandersfontein Basin	South Africa	Basutolian	28°40'S	24°44'E	1190	undated	basin	Scott 1976; Scott and Brink 1992
BA	Badsfontein	South Africa	Basutolian	30°57'S	25°49'E	1478	0-*ca.* 12500	spring deposits	Scott and Cooremans 1990
BL	Blydefontein Basin	South Africa	Basutolian	31°09'S	25°05'E	1700	0-*ca.* 11850	cave, swamp, hyrax middens	Bousman *et al.* 1988; Scott and Bousman 1990; Scott *et al.* 2005
CL	Clarens Area	South Africa	Basutolian	28°30'S	28°25'E	1270	0-*ca.* 23000	alluvial/ swamp/ stream deposits	Scott 1986a; 1986b; 1989b; Scott and Vogel 1992; Carrión *et al.* 1999
DE	Deelpan	South Africa	Basutolian	29°15'S	25°40'E	1321	0-*ca.* 4000	pan	Scott 1988a
EF	Elim Farm	South Africa	Basutolian	28°29'S	28°25'E	1890	0-*ca.* 4000	channel fills	Nyakale and Scott 2002
EQ	Equus Cave	South Africa	Basutolian	27°27'S	24°46'E	1250	undated	hyaena coprolites	Scott 1987b
FL	Florisbad Spring	South Africa	Basutolian	28°46'S	26°04'E	1270	0-*ca.* 8200	spring deposits	van Zinderen Bakker 1955; 1989; Scott and Nyakale 2002
KP	Kathu Pan	South Africa	Basutolian	27°42'S	23°02'E	1170	0-*ca* 32000	pan	Beaumont and van Zinderen Bakker 1983
TR	Tsoaing River Valley	Lesotho	Basutolian	29°45'S	27°30'E	1708	*ca.* 4000-*ca.* 12000	river basin	Grab *et al.* 2005
WW	Wonderwerk Cave	South Africa	Basutolian	27°59'S	23°24'E	1480	0-*ca.* 10000	cave	van Zinderen Bakker 1982
BO	Bokkraal Vlei	South Africa	Cape	32°17'S	21°59'E	1082	0-*ca.* 760	vlei	Sugden and Meadows 1989
BC	Boomplaas Cave	South Africa	Cape	33°41'S	21°23'E	646	0 –*ca.* 32000	cave	Deacon *et al.* 1983; Deacon and Lancaster 1988
CA	Cape Flats	South Africa	Cape	33°52'S	18°28'E	9	0-*ca.* 44000	borehole	Schalke 1973

[2] Due to discrepancies existing between chronological control measures used by different authors (e.g. ^{14}C and U-series dating techniques; calibrated versus uncalibrated ages), all ages provided have been stated as approximated ages (*ca.*) before present (BP).

Code	Name	Country	Ecozone	Lat	Long	Alt	Age range	Site	Site Publication
CE	Cederberg	South Africa	Cape	32°12'S	18°56'E	2026	0-*ca.* 19500	vlei/hyrax middens	Meadows and Sugden 1990; 1991a; 1991b; Scott 1994
EL	Elands Bay Cave	South Africa	Cape	32°14'S	18°21'E	37	0-*ca.* 20500	cave	Scott 1994; Parkington *et al.* 2000
GR	Groenvlei	South Africa	Cape	33°48'S	22°50'E	12	0-*ca.* 8000	fen	Martin 1955; 1968
KL	Klaarfontein Springs	South Africa	Cape	32°25'S	18°29'E	14	0-*ca.* 7000	artesian springs	Meadows and Baxter 2001
OY	Oyster Bay	South Africa	Cape	34°09'S	24°37'E	40	undated	hyaena coprolites	Carrión *et al.* 2000
VE	Verlorenvlei	South Africa	Cape	32°19'S	18°24'E	12	0-*ca.* 5000	estuarine lake	Baxter and Meadows 1994; Meadows *et al.* 1994; Meadows and Asmal 1996; Meadows *et al.* 1996; Baxter and Meadows 1999
WN	Winterberg	South Africa	Cape	32°18'S	26°20'E	1680	0-*ca.* 12500	vlei	Meadows *et al.* 1987; Meadows and Meadows 1988
DR	Drotsky's Cave	Botswana	Kalaharian	19°57'S	21°13'E	1100	0-*ca.* 12000	cave	Cooke 1984; Brook *et al.* 1990; Burney *et al.* 1994
EK	Eksteenfontein	South Africa	Karoo/ Namaqualian	28°49'S	17°14'E	1040	0-*ca* 11890	spring	Scott *et al.* 1995
NA	Namaqualand Mudbelt	South Africa	Karoo/ Namaqualian	29°08'S	15°50'E	30	0-*ca* 10000	mudbelt	Meadows *et al.* 1997; Gray *et al.* 2000; Meadows *et al.* 2002
BR	Brandberg	Namibia	Namib	21°08'S	14°35'E	2000	0-*ca.* 30000	hyrax middens	Scott *et al.* 2004
KU	Kuiseb River bed	Namibia	Namib	23°40'S	15°01'E	400	0-*ca.* 2000	hyrax middens	Scott 1996
SV	Sossus Vlei	Namibia	Namib	25°18'S	15°31'E	750	undated	vlei	van Zinderen Bakker 1983
WI	Windhoek	Namibia	Namib	22°44'S	13°03'E	1650	0- *ca.* 7000	spring deposits	Scott *et al.* 1991
LA	Lake Teza	South Africa	Transvaalian	28°28'S	32°08'E	63	0-*ca.* 8330	lake	Scott and Steenkamp 1996
MJ	Majiji	South Africa	Transvaalian	27°08'S	32°40'E	70	0-*ca.* 2140	peat deposit	Grundling *et al.* 1998; Mazus 2000

Code	Name	Country	Ecozone	Lat	Long	Alt	Age range	Site	Site Publication
MD	Mdlanzi	South Africa	Transvaalian	27°36'S	32°28'E	40	0-*ca.* 1450	peat deposit	Turner and Plater 2004
MF	Mfabeni	South Africa	Transvaalian	28°08'S	32°31'E	11	0-*ca.* 43100	peat deposit	Grundling *et al.* 1998; Mazus 2000
MG	Mgobezeleni	South Africa	Transvaalian	27°32'S	32°39'E	10	0-*ca.* 1100	peat deposit	Grundling *et al.* 1998
MO	Moreletta Stream	South Africa	Transvaalian	25°44'S	28°18'E	1310	0-*ca.* 5500	drainage line	Scott 1983
MZ	Muzi-Oos	South Africa	Transvaalian	26°55'S	32°35'E	40	0-*ca.* 4200	peat deposit	Grundling *et al.* 1998; Mazus 2000
NH	Nhlangu	South Africa	Transvaalian	27°06'S	32°49'E	15	0-*ca.* 6080	peat deposit	Mazus 1996; Grundling *et al.* 1998; Mazus 2000
PO	Port Durnford	South Africa	Transvaalian	28°55'S	31°55'E	30	undated	borehole	Scott *et al.* 1992; Oschadleus *et al.* 1996
RI	Rietvlei	South Africa	Transvaalian	25°50'S	28°20'E	1480	0-*ca.* 10500	peat deposit	Scott and Vogel 1983
ST	Sterkfontein Caves	South Africa	Transvaalian	26°04'S	27°44'E	1700	undated	cave	Horowitz 1975; Carrión and Scott 1999
SO	Soutpansberg	South Africa	Transvaalian	22°53'S	30°19'E	823	0-*ca.* 7000	peat deposit	Scott 1982a; 1987a
TS	Tswaing Crater	South Africa	Transvaalian	25°34'S	28°04'E	1100	0-*ca.* 190000	salt pan	Scott 1988b; Partridge *et al.* 1993; Scott 1999a; 1999b
VA	Vasi Pan	South Africa	Transvaalian	27°12'S	32°08'E	79	0-*ca.* 4500	pan	Grundling *et al.* 1998; Mazus 2000
VO	Voordrag Farm	South Africa	Transvaalian	27°44'S	31°19'E	940	0-*ca.* 36000	colluvial hollow	Botha *et al.* 1992
WK	Wonderkrater	South Africa	Transvaalian	24°26'S	28°45'E	1110	0-*ca.* 34500	thermal spring	Scott and Vogel 1978; Scott 1982b; Scott and Thackeray 1987; Scott 1990b; 1999b; Scott *et al.* 2003

3.2. BASUTOLIAN ECOZONE

The oldest pollen record for the Basutolian Ecozone was recovered from the Clarens area, and dates back to *ca.* 23000 years BP (Scott 1986a). Other important sites

include the *ca.* 12500 year old record from Badsfontein (Scott and Cooremans 1990), the *ca.* 11500 year old Blydefontein Basin (Bousman *et al.* 1988; Scott and Bousman 1990; Scott *et al.* 2005), and younger sequences from Wonderwerk Cave (van Zinderen Bakker 1982), Florisbad Spring (van Zinderen Bakker 1955; 1989; Scott and Nyakale 2002) and Deelpan (Scott 1988a).

The earliest palaeoenvironmental indications for this ecozone are of humid upland grassland with fynbos and local swamp development *ca.* 23000 years BP (Scott 1989b). This is followed by cold dry conditions *ca.* 19000 years BP, as indicated by increased fynbos development (Scott 1989b). A shift towards high-altitude grassland characterised by fynbos elements at *ca.* 18000 years BP reflects dry conditions, becoming more humid (Scott 1989b). Scott (1989b) suggests that the coldest part of the Last Glacial Maximum (LGM, *ca.* 18000 years BP) occurred after *ca.* 20000 years BP at *ca.* 18000 –17000 years BP. Temperature and moisture conditions became intermediate with relatively dry summers, as evidenced by grassland vegetation with characteristic fynbos elements at *ca.* 13000 years BP (Scott 1989b). An increase in *Podocarpus* pollen after *ca.* 13000 years BP reflects the establishment of forest stands in the area (Scott 1989b). However, *Podocarpus* forests, together with fynbos elements, declined within the next 2000 years, which may be attributed to warmer conditions, coupled with an increase in seasonal contrasts (Scott 1989b). After *ca.* 11850 years BP, shrubby vegetation becomes apparent in the record at Blydefontein, suggesting dry conditions (Scott *et al.* 2005). Towards the end of the Pleistocene (*ca.* 10700 years BP), fairly humid conditions were prevalent, with torrential summer rainfall and intermediate to warm temperatures indicated by Poaceae dominated vegetation (Scott 1989b).

According to van Zinderen Bakker (1982), the Early Holocene at Wonderwerk Cave was characterised by open savanna, signifying warm, humid conditions. A more recent investigation at Badsfontein (Scott and Cooremans 1990) found relatively high proportions of Chenopodiaceae/Amaranthaceae (>40%) and Asteraceae (>20%), and correspondingly low Poaceae percentages (15%), suggesting relatively dry conditions during the Early Holocene. This is in keeping with the Clarens record (Scott 1989b), which indicates relatively warm and dry conditions during the Early Holocene.

Conditions at *ca.* 7000 years BP were semi-arid, as evidenced by a high proportion of Chenopodiaceae/Amaranthaceae, with some grassland shrubs (Scott and Nyakale 2002). Low grass cover at *ca.* 6300 years BP reflects a shift towards more sub-humid conditions (Scott and Nyakale 2002). An increase in grassy elements after *ca.* 5400 years BP is indicative of dry subhumid conditions (Scott *et al.* 2005).

According to Bousman *et al.* (1988), conditions during the second half of the Holocene (*ca.* 5000-1000 years BP) were slightly wetter than those of the present day. The Late Holocene was characterised by grassland vegetation, suggesting sub-humid conditions experiencing summer rainfall as at present (Scott 1989b). In contrast, evidence of karroid vegetation at *ca.* 5000 years BP at Florisbad suggests dry summers (Scott and Nyakale 2002). As further evidence of intra-ecozone variation, van Zinderen Bakker (1982) describes the vegetation at *ca.* 5000 years BP as treeless dry grassveld, with an associated arid to semi-arid climate. At *ca.* 4600 years BP, Poaceae became dominant at Blydefontein, although shrub elements remained, signifying subhumid conditions with some drier variations (Scott *et al.* 2005). The Badsfontein Springs pollen record indicates a shift from Chenopodiaceae/Amaranthaceae/Asteraceae dominated to Poaceae dominated vegetation at *ca.* 4500 years BP, reflecting a change to moister conditions (Scott and Cooremans 1990). This is consistent with the Florisbad site, which records a similar trend at *ca.* 4200 years BP (Scott and Nyakale 2002). Drier conditions are recorded at Florisbad after *ca.* 4000 years BP (Nyakale 1999; Nyakale and Scott 2002; Scott and Nyakale 2002). These data do not concur with results from Blydefontein, which indicate a return to moderately dry conditions at *ca.* 4000 years BP, as reflected by shrub dominated vegetation recorded at this time (Scott *et al.* 2005). Blydefontein records the appearance of fynbos elements between *ca.* 4000 and 3000 years BP, along with varying grass cover, reflecting cool but variable moisture conditions (Scott *et al.* 2005). Between *ca.* 4000 and 2500 years BP, vegetation remained Poaceae dominated, although a slight increase in the proportion of shrubby elements is recorded, suggesting subhumid conditions with slight indications of drying (Scott and Nyakale 2002). The gradual development of drier conditions in indicated by the appearance of karroid elements at Deelpan from *ca.* 4000 years BP, although this vegetation only became fully established *ca.* 820 years BP (Scott 1988a). Subhumid

conditions are indicated by an increase in Poaceae composition at *ca.* 2500 years BP (Scott *et al.* 2005). This is followed by a short-lived dry event, marked by an increase in Asteraceae pollen at *ca.* 2000 years BP (Scott *et al.* 2005). Sub-humid conditions are once again prevalent between *ca.* 2000 and 1300 years BP, with a return to grassy vegetation evident in the pollen record (Scott *et al.* 2005). Moist conditions associated with Poaceae dominated spectra are indicated between *ca.* 1200 and 300 years BP (Scott and Bousman 1990). This is interrupted by a minor dry spell at *ca.* 1000 years BP, evidenced by slightly more shrubby karroid vegetation (Scott and Bousman 1990). Conditions after *ca.* 820 years BP became slightly moister, as suggested by the dominance of sedges in the pollen record at this time (Scott 1988a). A sharp increase in karroid shrub vegetation and a related decrease in grass elements at *ca.* 300 years BP are attributed to relatively dry conditions (Scott and Bousman 1990). Similarly, gradual drying is indicated by an increase in Asteraceae pollen after *ca.* 300 years BP (Scott *et al.* 2005). It is suggested that this drying trend was later (from *ca.* 150 years BP) exacerbated by overgrazing from European domestic stock (Scott and Bousman 1990).

3.3. CAPE ECOZONE

Although a wide range of palaeoenvironmental studies have been conducted within the Cape Ecozone, a clear picture of vegetation and climatic history for the Late Quaternary has yet to emerge (Meadows and Baxter 1999). This can be attributed to marked regional differences in the seasonality and quantity of rainfall experienced, resulting in an uneven response to climatic changes (Meadows and Baxter 1999). While the majority of pollen studies for the Cape Ecozone have focussed on the Holocene, a few records do extend into the Late Pleistocene (e.g. Schalke 1973; Meadows and Sugden 1991a; Meadows and Sugden 1991b).

The oldest pollen record from the Cape Flats (Schalke 1973) indicates intermittent wet and dry phases after *ca.* 45000 years BP, as reflected by swampy vegetation and the presence of *Podocarpus* forests. After *ca.* 40500 years BP, an increase in Asteraceae, Euphorbiaceae and Rosaceae is recorded, suggesting an unstable dune environment (Schalke 1973). The return of *Podocarpus* pollen to the record at *ca.*

36500 years BP reflects an increasingly stable dune vegetation (Schalke 1973). Instability returns after *ca.* 33000 years BP, as indicated by fynbos vegetation in the vicinity (Schalke 1973). A shift towards more open vegetation on the dunes and the re-establishment of *Podocarpus* forest is indicated between *ca.* 28500 years BP and the beginning of the Holocene (Schalke 1973). Evidence from hyrax middens in the Cederberg suggests the presence of fynbos elements from *ca.* 19700 years BP, with an altitudinal lowering of vegetation belts at the Last Glacial Maximum (LGM; *ca.* 18000 years BP) (Scott 1994). The pollen record from the Elands Bay Cave indicates that the LGM and Terminal Pleistocene were colder, wetter, cloudier and grassier (Scott 1994). This conforms with the southwestern Cape regional synthesis which describes cooler and wetter conditions during the LGM, in contrast with the summer rainfall region (Meadows and Baxter 1999). The Cango Caves $\delta^{18}O$ record for the LGM indicates temperatures on average 6°C lower than at present (Talma and Vogel 1992). After *ca.* 14600 years BP, conditions were moist, as reflected by restiod fynbos dominated vegetation (Meadows and Sugden 1991b). This was later replaced by proteoid and ericaceous fynbos communities with a greater proportion of cedar trees than exists at present, suggesting cooler, drier conditions (Meadows *et al.* 1987; Meadows and Meadows 1988).

The existence of dynamic plant communities, dominated by ericaceous fynbos during the Early Holocene reflects ameliorating climatic conditions (Meadows and Sugden 1991b). A shift towards drier conditions at *ca.* 8000 years BP is evidenced by retreating forest at Groenvlei, followed by climatic amelioration at *ca.* 7000 years BP (Martin 1968). Evidence from Verlorenvlei suggests mid-Holocene climate to be more arid than the present day (Meadows *et al.* 1996). A return to moister conditions is recorded at *ca.* 4000 years BP, with an increase in the proportion of restiod fynbos elements in the Cederberg pollen sequence (Meadows and Sugden 1991b). The last *ca.* 2000 years saw more xeric conditions which may be attributed to human disturbance, particularly as regards changes in fire regime (Meadows and Sugden 1991b).

3.4. KALAHARIAN ECOZONE

Palaeoenvironmental studies of the Kalahari Desert are limited by surface sediments that contain few fossils, including pollen, and provide little opportunity for dating (Burney *et al.* 1994). This problem is compounded by a lack of long-sequence sites, preventing the development of long records (Burney *et al.* 1994). As a consequence, primary sources of evidence in the Kalahari are usually limited to palaeogeomorphic and sedimentary evidence, together with isolated cave records (Thomas and Shaw 2002). Burney *et al.* (1994) have therefore made use of pollen preserved in speleothems to reconstruct Holocene environmental changes for the Kalahari.

Arid grassland is indicated at the beginning of the Holocene by pollen spectra reflecting dry adapted trees and shrubs such as *Acacia* and *Commiphora* (Burney *et al.* 1994). A shift towards wetter conditions is indicated at *ca.* 7000 years BP, by an increase in Combretaceae and Cyperaceae and the appearance of mesic savanna plants such as *Grewia* (Burney *et al.* 1994). After *ca.* 6000 years BP, mesic pollen types including Combretaceae continue to increase until *ca.* 3000 years BP, reflecting an increasingly moist climate (Burney *et al.* 1994). This trend was interrupted by a dry spell between *ca.* 5000 and *ca.* 4000 years BP (Burney *et al.* 1994). The remainder of the Holocene was characterised by variable climatic conditions (Burney *et al.* 1994).

3.5. KAROO / NAMAQUALIAN ECOZONE

The only reliably dated pollen record that exists for the Karoo/Namaqualian Ecozone is the 11890 year old sequence from Eksteenfontein (Scott *et al.* 2005). This can be attributed to the arid climate, which limits the availability of suitable pollen sites. Preliminary palynological investigations of this record have revealed a change from cool and dry to warm and dry conditions at *ca.* 10700 years BP (Scott *et al.* 2005). In addition, preliminary descriptions of pollen rich marine sediments derived from the Namaqualand mudbelt have been made (Gray *et al.* 2000), although final results have yet to be published. Difficulty in defining the pollen source / catchment area of these marine sediments poses a further limitation, as pollen may be contributed by reworking of floodplain deposits, runoff or atmospheric fallout (Scott 2000).

3.6. NAMIB ECOZONE

Evidence for Late Quaternary climate change in the Namib Desert has been described as 'geographically scattered and often poorly dated' (Lancaster 2002, p. 769). The Namib has experienced mostly arid to hyper-arid conditions throughout the Quaternary, with little or no evidence to indicate long periods of significantly increased precipitation (Lancaster 2002). Two reliably dated pollen records have been derived from the Namib Ecozone, *viz.* the spring deposits from Windhoek (Scott *et al.* 1991) and the hyrax middens from the Kuiseb River bed (Scott 1996). These sequences provide evidence for vegetation history and climatic change in the Namib for the past *ca.* 7000 years BP.

The record commences with moist conditions *ca.* 7000 years BP (Scott *et al.* 1991), which is consistent with results from other southern African pollen sequences (Scott 1989a; 1990c). Signs of drying are evident from *ca.* 6000 years BP although conditions remained favourable until *ca.* 5630 years BP (Scott *et al.* 1991). The pollen record for the next *ca.* 3000 years demonstrates an increase in weedy Asteraceae, suggesting local disturbance (Scott *et al.* 1991). Dry conditions, followed by a temporary wetter period, are indicated after *ca.* 3500 years BP by the record at Lake Otjikoto (Scott *et al.* 1991). Pollen data derived from hyrax middens in the Kuiseb River bed reflect moderately warm and dry conditions after *ca.* 600 years BP (Scott 1996). Scott (1996) further suggests that the Namib Desert, at least during the past 2000 years, has been characterised by 100-200 year cycles of vegetation change.

3.7. TRANSVAALIAN ECOZONE

According to Scott (1982c), the Transvaal[3] contains limited deposits with palynological potential that date beyond the Late Pleistocene. Important pollen records derived from the Transvaal include the Tswaing Crater (Partridge *et al.* 1993) and Wonderkrater (Scott 1999b), which date back to *ca.* 190000 and *ca.* 35000 years BP, respectively. The most important coastal sequence has been derived from the

[3] This terminology has been retained for the sake of convenience, as (i) much of Scott's work has been focussed on the former Transvaal province; and (ii) Deacon and Lancaster's (1988) Transvaalian Ecozone was delimited based on the former Transvaal province.

Port Durnford formation in northern KwaZulu-Natal, which dates back to *ca.* 70000 years BP (Scott *et al.* 1992). A detailed description of preliminary palaeoenvironmental investigations from Maputaland has been provided in section 3.7.1 (e.g. Grundling 1996; Mazus 1996; 1997; Grundling *et al.* 1998; Grundling *et al.* 2000; Mazus 2000).

The Late Pleistocene record for the Transvaalian Ecozone starts at *ca.* 60000 years BP, with moderately cool, wet grassland with fynbos and *Podocarpus* forest elements (Scott 1999a). After *ca.* 43500 years BP, wet, slightly warm grassland and savanna developed, becoming drier towards *ca.* 38200 years BP (Scott 1999a). The establishment of dry cool grassland with fynbos elements is indicated at *ca.* 38200 years BP, followed by local swamp development at *ca.* 34500 years BP (Scott 1999a). Cool, humid conditions are indicated by the Voordrag Farm site for 500 years after *ca.* 35000 years BP (Botha *et al.* 1992). This supports evidence from Wonderkrater, where mesic bushveld and expanded montane forest prevailed after *ca.* 35000 years BP, suggesting a moist cool environment at this time (Scott 1982b). Drier bushveld developed until *ca.* 25000 years BP, reflecting a shift towards drier conditions (Scott 1982b; 1983). Ericaceous vegetation, similar to that which characterises present day vegetation belts above the treeline, developed after *ca.* 25000 (Scott 1983). A high percentage of grasses and other non-arboreal pollen types including *Artemisia*, *Stoebe*, Ericaceae, *Passerina*, *Cliffortia*, and *Anthospermum* was recorded at Wonderkrater after *ca.* 24000 years BP (Scott and Vogel 1978). Arboreal pollen types associated with this assemblage, including *Podocarpus* and *Myrica* remained at low frequencies indicating long distance transport of these pollen types from other regions (Scott and Vogel 1978). This open grassland vegetation, which prevailed until *ca.* 11000 years BP, suggests cool temperate conditions towards the end of the Pleistocene (Scott and Vogel 1978). Temperatures during this period were believed to have been 5-6°C cooler than at present (Scott 1982c). An increase in shrubby karroid and ericoid fynbos species at *ca.* 20000 years BP reflects colder, more arid conditions, in addition to more seasonal rainfall distribution (Botha *et al.* 1992).

The Tswaing record suggests significantly reduced precipitation in the summer rainfall region during the LGM (Partridge 1997). An increase in Ericaceae and

Stoebe, coupled with the dominance of Asteraceae over Poaceae are recorded at Voordrag during the LGM (Botha *et al.* 1992). Climatic amelioration and a return to more humid conditions are recorded after *ca.* 18700 years BP (Botha *et al.* 1992). Coldest conditions at Wonderkrater are indicated later at *ca.* 17000 years BP (Scott *et al.* 2003). Slight warming is suggested by both the Tswaing and Wonderkrater pollen spectra at *ca.* 15000 years BP (Scott 1999b). Similarly, these records indicate cool conditions at *ca.* 14000 years BP (Scott 1999b). Evidence for increasing temperatures recorded in the Wonderkrater pollen record at *ca.* 13000 years BP (Scott *et al.* 2003) is supported by the Makapansgat $\delta^{18}O$ record (Holmgren *et al.* 2003). An increase in Chenopodiaceae/Amaranthaceae frequencies after *ca.* 12700 years BP suggests slightly cooler but evaporative conditions towards the end of the Pleistocene (Scott *et al.* 2003). After *ca.* 11000 years BP, Scott and Vogel (1978) record a decrease in Poaceae, and an increase in Chenopodiaceae and savanna elements including *Tarchonanthus*, *Boscia*, Combretaceae and Proteaceae. A decrease in fynbos elements and an increase in other Asteraceae are also recorded at this time. Conditions became drier towards the Pleistocene/Holocene boundary (Scott *et al.* 2003).

According to Scott (1982c), the Holocene was characterised by relatively warm, dry conditions with slightly more mesic types of woodland than was evident during the Late Pleistocene. Dry conditions, with warm temperatures prevailed during the Early Holocene (Scott 1990b), resulting in the expansion of warm, semi-arid savanna (Scott 1983). This is concurrent with pollen evidence from the Soutpansberg, which records an increase in savanna elements and local *Psoralea* pollen after *ca.* 10000 years BP (Scott 1987a). Warmer temperatures are indicated at Wonderkrater after *ca.* 9500 years BP (Scott *et al.* 2003), as reflected by high proportions of Combretaceae and Asteraceae (Scott and Vogel 1978). A sudden increase in Poaceae pollen is recorded at Wonderkrater at *ca.* 8500 years BP, corresponding with similar indications in the Makapansgat $\delta^{13}O$ record (Scott *et al.* 2003). After *ca.* 8000 years BP, dry, moderately warm conditions are indicated at Tswaing (Partridge *et al.* 1993). While temperatures remained warm, the environment became wetter after *ca.* 7000 years BP (Partridge *et al.* 1993). Bushveld elements expanded temporarily at *ca.* 6580 years BP, suggesting relatively warm temperatures and favourable moisture conditions

around this time (Scott and Vogel 1978). The development of warm savanna vegetation and reduction of fynbos elements in the Soutpansberg by *ca.* 6500 years BP, can be attributed to the attainment of optimal temperature conditions (Scott 1987a). Results from Wonderkrater indicate broad-leafed bushveld vegetation at *ca.* 6000 years BP, which is associated with slightly wetter conditions (Scott 1982b). A cooling trend is also evident in the Wonderkrater pollen record, between *ca.* 6000 years BP and the present (Scott *et al.* 2003).

While the mid-Holocene has been described as warm and wet, the Late Holocene was characterised by a cooling trend (Scott 1990b). During the second half of the Holocene, semi-arid savanna was replaced by a more broad-leafed woodland, probably as a result of wetter conditions (Scott 1983). Results from the Soutpansberg suggest that bushveld vegetation presently occupying the area has undergone little change since the mid-Holocene (Scott 1982a). After *ca.* 4000 years BP, conditions at Wonderwerk became cooler and wetter, as evidenced by the establishment of bushveld vegetation comparable with present open upland types (Scott 1982b). Evidence from Wonderkrater and Tswaing suggest very low temperatures in addition to dry conditions at *ca.* 3000 years BP (Scott 1990b; Scott *et al.* 2003). During the next *ca.* 1000 years, a more open type of woodland developed in the Soutpansberg (Scott 1982a). After *ca.* 2000 years BP, conditions became progressively warmer and relatively dry, as indicated by high percentages of Asteraceae and Chenopodiaceae as well as arboreal pollen types including Combretaceae, *Protea* and *Burkea* (Scott and Vogel 1978; Scott 1982b). A sharp decline in arboreal pollen types is recorded at *ca.* 1500 years BP in the Soutpansberg, perhaps as a consequence of human disturbances including burning and clearing of woody vegetation (Scott 1987a). Evidence from the Wonderkrater pollen record suggest that the modern climate of the central Transvaal bushveld originated *ca.* 1000 years ago (Scott 1982b). The $\delta^{18}O$ record from Cold Air Cave reflects more humid conditions *ca.* 800 years BP, followed by drier, cooler conditions after *ca.* 600 years BP (Repinski *et al.* 1999). Repinski *et al.* (1999) suggest this cool period at *ca.* 600 years BP to reflect the regional expression of the Little Ice Age.

3.7.1. Maputaland

A series of peatlands within the Maputaland Coastal Plain have been investigated by the Council for Geoscience, focussing primarily on peatland utilisation and stratigraphy, in addition to peat accumulation rates (e.g. Grundling 1996; Mazus 1996; Grundling *et al.* 1998; Grundling *et al.* 2000). Preliminary palynological investigations were conducted on a selection of peatlands (Mfabeni, Mgobezeleni, Majiji, Muzi-Oos, Nhlangu and Vasi Pan) running along a north-south transect up the coastline, the results of which have been published in Council for Geoscience Internal Reports (e.g. Grundling 1996; Mazus 1996; 1997; Grundling *et al.* 2000). Pollen analysis for these peatlands consisted of total counts of 300 grains per sample, except in cases with very low pollen content, and pollen diagrams for these records presented fluctuations in major pollen taxa only (Grundling *et al.* 1998). The results of these investigations, along with those from Lake Teza (Scott and Steenkamp 1996),

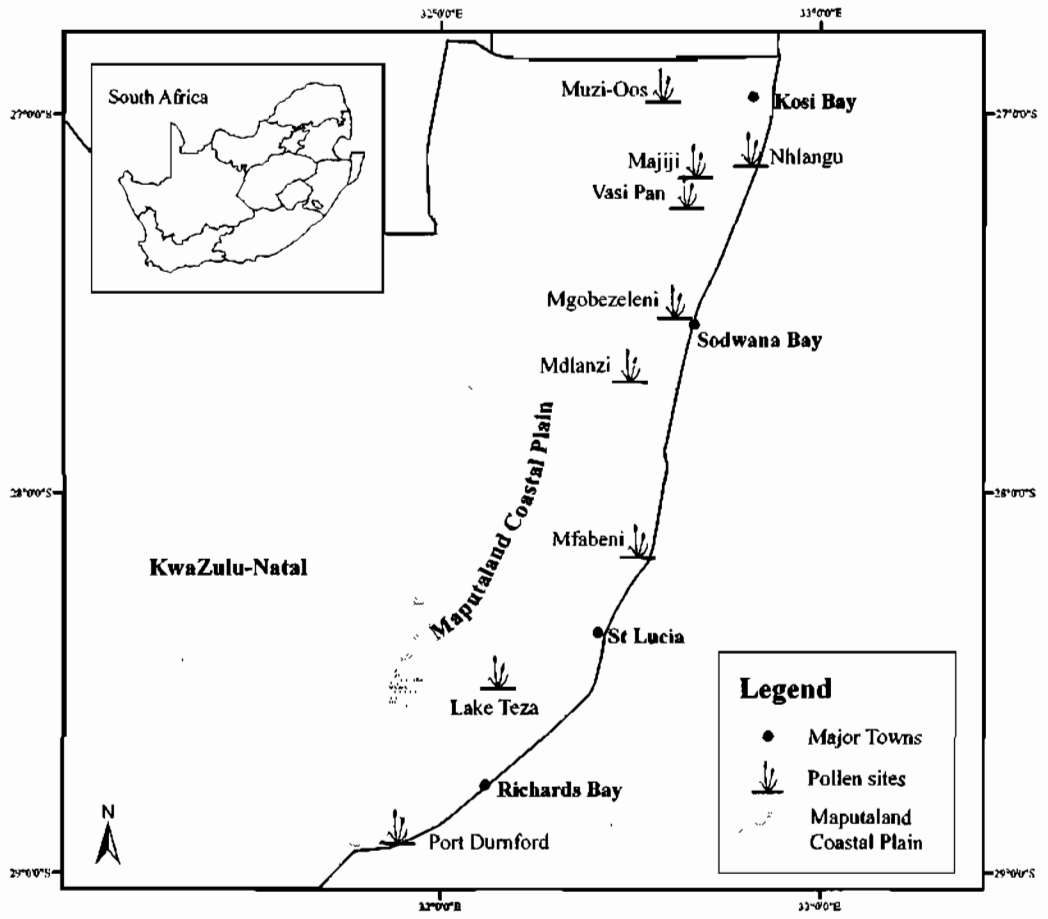


Figure 3.2 Map of the Maputaland Coastal Plain, along the north coast of KwaZulu-Natal, indicating important pollen sites.

Mdlanzi Swamp (Turner and Plater 2004) and the Port Durnford site (Scott *et al.* 1992; Oschadleus *et al.* 1996) are used here to describe Late Quaternary environmental changes along the Maputaland Coastal Plain (figure 3.2).

Although a detailed palynological record has been derived from a 33m borehole at Port Durnford (Scott *et al.* 1992; Oschadleus *et al.* 1996), this sequence remains undated, preventing accurate intercomparison with other records from Maputaland. A single $^{230Th}/^{234}U$ age was obtained from a nearby peat exposure indicating an age of *ca.* 70000±6000 years BP (Oschadleus *et al.* 1996). However, attempts to correlate this date with the borehole sequence using palynological composition were unsuccessful (Oschadleus *et al.* 1996). The general trend in vegetation change at Port Durnford suggests a shift from open grassland to terrestrial forest dominated by *Podocarpus* (Oschadleus *et al.* 1996).

Results from a study by Grundling *et al.* (1998) provides a 43000-year record of vegetation change from the Mfabeni peatland. A lack of pollen at *ca.* 43000 years BP, coupled with the presence of foraminifera suggests that this site may have been exposed to the open sea at this time (Grundling *et al.* 1998). After *ca.* 43000 years BP, dryland vegetation consisting of hydromorphous forest developed, as indicated by the presence of *Podocarpus*, *Celtis* and other arboreal pollen types (Grundling *et al.* 1998). The presence of *Typha* in the pollen record suggests the prevalence of fresh water conditions during this period (Grundling *et al.* 1998). The retreat of *Podocarpus* forest is recorded after *ca.* 33000 years BP with an associated increase in grassland vegetation (Grundling *et al.* 1998). A shift towards wetter conditions is recorded after *ca.* 20800 years BP, as indicated by an increase in aquatic elements (Grundling *et al.* 1998). After *ca.* 11570 years BP, an expansion in the hydromorphous forest is indicated by an increase in *Podocarpus*, *Olea*, *Syzigium*, *Myrica* and *Celtis* (Grundling *et al.* 1998). Further north at Nhlangu, Mazus (1996) records the existence of a similar swamp forest dominated by *Myrica* and *Syzigium* at *ca.* 6080 years BP. This was followed by a temporary increase in *Podocarpus* pollen, and finally by the retreat of forest elements from the site at *ca.* 5100 years BP (Mazus 1996). A similar trend is indicated at Mfabeni, with a decrease in *Podocarpus* pollen after the mid Holocene (Grundling *et al.* 1998). Dry grassland vegetation with high

percentages of *Anthospermum* and other Asteraceae are recorded at the Muzi-Oos site before *ca.* 4200 years BP (Grundling *et al.* 1998). Conditions later became drier as evidenced by the absence of *Podocarpus* pollen from the site (Grundling *et al.* 1998). Similarly, the retreat of *Podocarpus*-abundant forest is recorded at Lake Teza after *ca.* 3400 years BP (Scott and Steenkamp 1996). After *ca.* 2450 years BP, forest and dryland herbs were replaced by hydrophilous Poaceae and Cyperaceae at Mfabeni (Grundling *et al.* 1998). Arboreal pollen types including *Podocarpus*, *Celtis*, *Syzigium* and Oleaceae are evident in the Majiji pollen record at *ca.* 2140 years BP, suggesting the presence of hydromorphous forest at this site. This was followed by a decrease in the relative abundance of these elements, indicating the gradual migration of forest away from the site (Grundling *et al.* 1998). Wetter conditions after *ca.* 1390 years BP are reflected by an increase in Cyperaceae in the Nhlangu record (Mazus 1996). The Mgobezeleni site demonstrates an increase in swamp forest cover from after *ca.* 1300 years BP. This corresponds with data from the Mfabeni record, which indicates the establishment of *Syzigium*, *Myrica* and *Ficus* dominated swamp forest after *ca.* 600 years BP (Grundling *et al.* 1998).

The main trends evident in palynological analyses from Maputaland relate to the expansion and retreat of *Podocarpus* forest through the Late Quaternary. Results suggest a northward migration of these forests after the mid Holocene, with the last occurrences of *Podocarpus* pollen recorded at *ca.* 2140 years BP in the south (Mfabeni) and at *ca.* 1390 years BP in the north (Nhlangu and Majiji; Grundling *et al.* 1998).

3.8. CONCLUSION

The major climatic events recorded during the Late Quaternary in southern Africa include the LGM, between *ca.* 21000-18000 years BP, and the Holocene Altithermal, between *ca.* 8000-6000 years BP (Partridge 1997). While a degree of intra-ecozone variation is evidenced by conflicting results in more intensively studied ecozones, general temperature and moisture trends can be elucidated from within both the summer and winter rainfall regions. The winter rainfall region has experienced generally warmer temperatures and drier conditions than the remainder of southern

Africa throughout the Late Quaternary (Partridge *et al.* 1990). However, conditions during the LGM were cooler and wetter within the winter rainfall region, as opposed to cooler and drier conditions within the summer rainfall region (Meadows and Baxter 1999). The Holocene Altithermal saw temperature increases of 1-2°C in both the summer and winter rainfall regions (Partridge 1997).

It is clear from the syntheses presented above that the palaeoenvironmental records for the Namib, Kalaharian and Karoo/Namaqualian Ecozones require increased attention in the future, if a more comprehensive understanding of Late Quaternary changes in southern Africa is to be achieved. Conflicting palaeoenvironmental indications within the Cape Ecozone's record are as a result of marked regional differences in rainfall seasonality and quantity (Meadows and Baxter 1999), and it is therefore suggested that further subdivision of this broad ecozone be considered in the future. The Late Quaternary of the KwaZulu-Natal Province (Transvaalian Ecozone) remains poorly understood, with Voordrag (Botha *et al.* 1992) and Lake Teza (Scott and Steenkamp 1996) providing the only reliably dated, detailed pollen records. The regional syntheses presented in this chapter have provided a palaeoenvironmental context within which to place this research, whilst simultaneously allowing for the comparison and support of results obtained.

CHAPTER FOUR
METHODOLOGY

4.1. SITE DESCRIPTION

4.1.1. Physical description

The Maputaland Coastal Plain (MCP), which runs along the North Coast of KwaZulu-Natal into Mozambique, hosts the most well developed peat deposits in southern Africa (Grundling *et al.* 2000). The peat deposits of the MCP were formed in the extensive interdune wetlands of the Natal Mire Complex (Smuts 1992; 1997). From the 270 peatlands identified within the MCP (Grundling and Mazus 1998), the Mfabeni peatland on the eastern shores of Lake St. Lucia was selected as a research site because of its age and accessibility. Mfabeni is situated south of Lake Bhangazi South, in the Eastern Shores Nature Reserve at 28°08'55''S, 32°31'07''E (figure 4.1), and at a mean height of approximately 11m above sea level (Grundling *et al.* 2000). Radiocarbon ages obtained by Grundling, Mazus and Baartman (1998) indicate that sediments at a depth of 9.93m date back to 43 100 (+3 900, -2 600) years BP

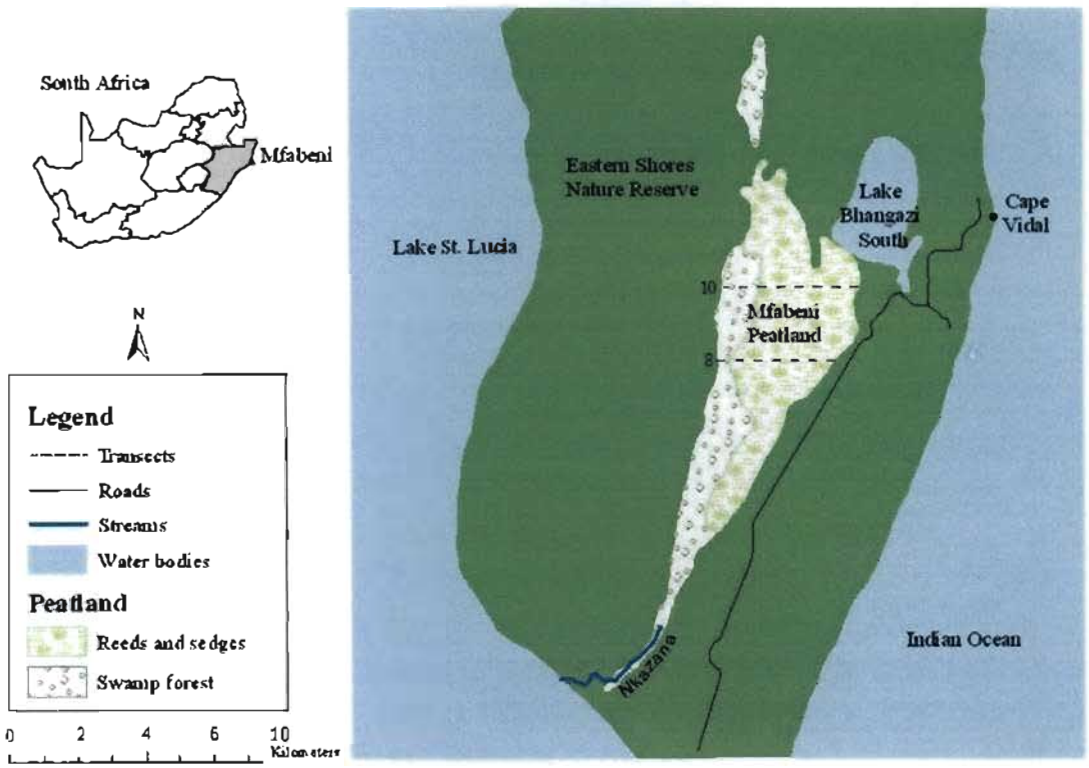


Figure 4.1. Location of the Mfabeni peatland on the eastern shores of Lake St. Lucia. Position of transects is relevant to core extraction (4.3.1).

(Grundling *et al.* 2000). The area has a mean annual precipitation of 1 000mm, 60% of which falls in the summer months (Grundling *et al.* 2000). Surface water draining off the eastern edge of the peatland flows north into Lake Bhangazi South, while that draining off the western edge flows south into Lake St. Lucia via the Nkazana Stream (Grundling *et al.* 2000). Groundwater flow into the peatland is derived predominantly from perched aquifers within the neighbouring coastal sand dunes (Grundling *et al.* 2000). There are no streams flowing into the peatland, keeping the influx of allochthonous material to a favourable minimum. The Eastern Shores nature reserve contains a diversity of habitats, including dune forest, grassland, and a mosaic of wetlands and swamp forest (Taylor 1991). The vegetation of Eastern Shores has been classified as *Coastal Bushveld/Grassland* and *Coastal Forest and Thornveld* (Acocks Veld Type No. 1) by Low and Rebelo (1996) and Acocks (1988), respectively. Within the peatland itself, only two vegetation types are found, *viz.* reed-sedge in the east and swamp forest in the western and southern parts (figure 4.2). A full species list for the Mfabeni peatland has been assembled using previous studies by Grewer (1997) and Venter (Venter 2003) (appendix A).

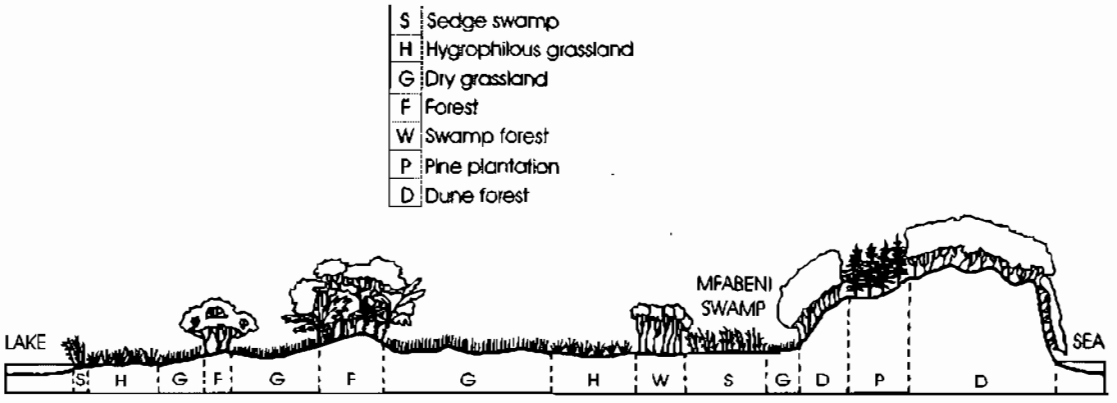


Figure 4.2 Transect from the coast to the shore of Lake St. Lucia, showing the plant communities of the Eastern Shores area (after Taylor 1991).

4.2. FIELD TECHNIQUES

4.2.1. Core extraction

A Russian peat corer was utilised in the extraction of a single continuous sediment core from the Mfabeni peat deposit to obtain a maximum length of core to a depth of 9.90m (figure 4.3). Following advice from Grundling (pers. comm.), the core was

extracted at the deepest point in the profile, between transects 8 and 10 (figures 4.2, 4.4) set out by Grundling *et al.* (2000) in a previous study. Extraction was carried out with minimal possible disturbance to the profile and least risk of contamination to the samples. Once extracted, the core was wrapped in heavy-duty aluminium foil (figure 4.3), labelled and transported back to the laboratory, where it was stored in a refrigerator at a temperature of 2 - 5°C.

4.2.2. Reference material

In order to aid in the identification of fossil pollen grains, a regional slide and digital microphotograph reference collection was built up (figure 4.5). This involved the collection of 38 flowering species, which were identified and used to improve upon the existing pollen reference collection. This existing reference collection consisting of 288 species was obtained from a previous study in the Drakensberg region (Hill 1992). In addition, reference slides from other reference collections, obtained by Hill (1992), were included, e.g. the Cederberg. This reference collection was analysed in conjunction with the Mfabeni plant species list (appendix A) to determine whether any important families were missing from the reference collection. Pollen samples for species belonging to missing families were obtained from herbarium specimens (23 species) at the Natal University Herbarium (NU). A full reference collection species list is included in appendix B. Finally, various pollen reference books/atlases were used to supplement the existing reference collection (e.g. Heusser 1971; Markgraf and D'Antoni 1978).

4.3. LABORATORY TECHNIQUES

4.3.1. Subsampling

The core was subsampled at fixed intervals to extract samples of approx. $2cm^3$ for pollen analysis. Subsampling interval was determined by beginning with a wide interval of 10cm and then filling in the gaps at a 5cm interval, such that further detail could be obtained where necessary. Where little or no change was detected between wide intervals, it was concluded that further subsampling was unnecessary (appendix C). Additional subsamples of approx. 50g each were extracted from suitable basal and intermediate layers for radiocarbon dating. A minimum of 1.5g of carbon is

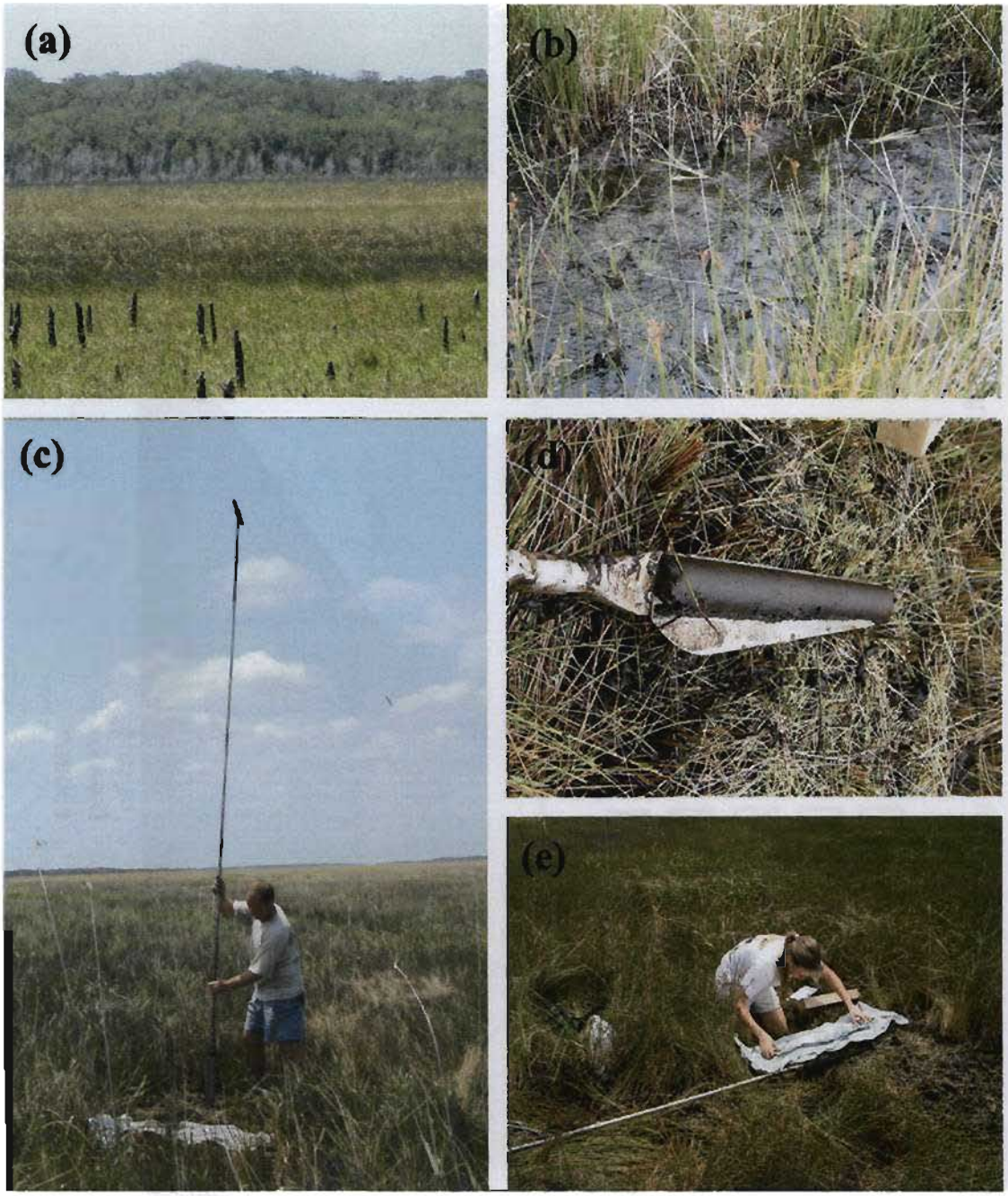


Figure 4.3 Coring procedure used in the extraction of the Mfabeni peat core: (a) the Mfabeni Peatland, indicating reed/sedge/hydrophilous grassland mosaic in the foreground and swamp forest in the background; (b) sedge dominated vegetation at the coring site, prior to core extraction; (c) the Russian peat corer was used to extract the core in segments; (d) semicylindrical core segment; and (e) core segments were labelled and wrapped in heavy duty aluminium foil for transport back to the laboratory.

recommended for radiocarbon dating and with peat having an estimated carbon content of 18%, it was calculated that a minimum of 9g of peat was required per sample. Finally, 33 subsamples of approx. 10g each were extracted at equal distances along the core for stable carbon isotope ($\delta^{13}C$) analysis.

4.3.2. Chemical processing

Subsamples were chemically processed using standard palynological methods of HCl, NaOH and HF digestion (Faegri and Iverson 1989). These processes serve to progressively remove all extraneous material such as $CaCO_3$, silica and cellulose (appendix D).

4.3.3. Reference collection

Pollen reference material was chemically processed using standard HCl and NaOH digestion (appendix E). Pollen reference slides were created and digitally photographed at 400X magnification. Digital photographs were used to compile a database of 350 reference slides (figure 4.5).

4.3.4. Pollen counts

Both absolute and relative pollen counts were calculated for all levels. Identification and counts of pollen grains were achieved using fixed traverses across the slide by means of an adjustable stage. Counts excluded unidentifiable (poorly preserved) specimens where grains were corroded, folded or damaged. Clusters of pollen grains of the same type were grouped together as a single unit to avoid unrealistic overrepresentation (Faegri and Iverson 1989).

Sample size and minimum pollen sum were determined to obtain maximum resolution while maintaining adequate pollen assemblage representivity for each sample counted. Initially, counts were performed at a 10cm resolution down the core. Later, gaps were filled in (i.e. at 5cm resolution) at levels where further detail was required. In a study conducted in the Natal Drakensberg, (Hill 1996) found that counts of 250 grains were representative at the 95% confidence level for most (10/13) vegetation communities. Based on this recommendation it was decided that counts of 250 and

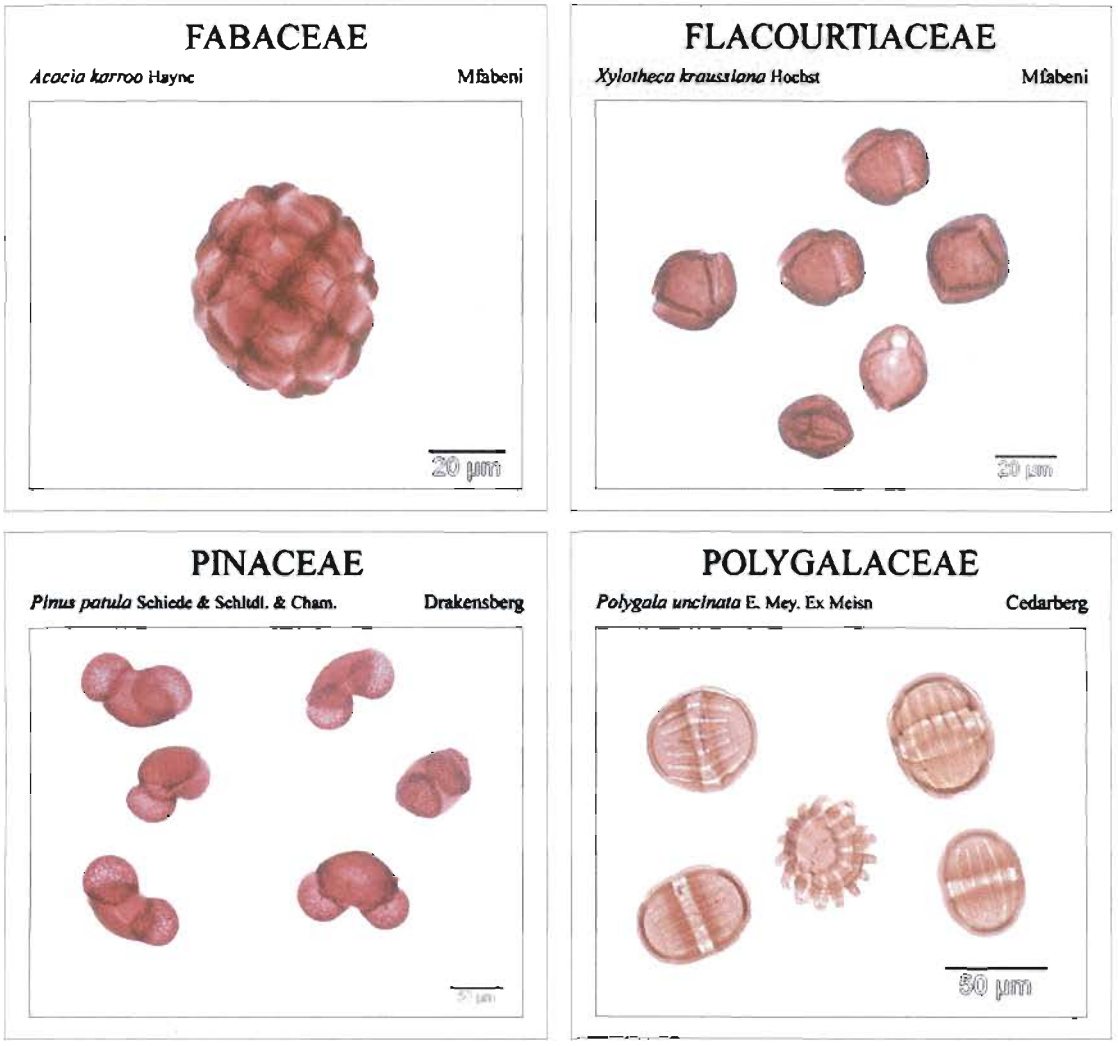


Figure 4.5. Examples of digital reference slides.

500 fossil pollen grains be used to determine relative pollen frequency. Statistical tests were performed to determine whether there was any significant difference in performing counts of 250 or 500 fossil pollen grains per sample. Count data constitute categorical rather than continuous data; therefore chi-squared (χ^2) statistical tests were selected for this purpose. As only two categories of data (i.e. counts of 250 and 500) were used for this test, there were only two degrees of freedom. Additionally, expected frequencies of less than 10 were anticipated for most taxa (approx. 75%). These limitations were corrected for by using Yates correction factor of 0.5 while performing the test (Yates 1934). The hypotheses tested were as follows:

H_0: There is no significant difference in the means of pollen counts (per taxa) from each depth sampled, with counts of 250 or 500 pollen grains and spores.

H_1: There is a significant difference in the means of pollen counts (per taxa) from each depth sampled, with counts of 250 or 500 pollen grains and spores.

Where absolute counts were used, a known number of exotic *Lycopodium clavatum* marker spores were added as markers to the sample such that all subsequent abundance determinations could be carried out in relation to counts of marker grains (Stockmarr 1971). Source details and statistics for *L. clavatum* spore tablets have been included in appendix F. The number of pollen grains in a sample is calculated using the following equation (Stockmarr 1971):

$$total\ pollen\ grains\ in\ sample = \frac{pollen\ grains\ counted \times L.clavatum\ spores\ added\ to\ sample}{L.clavatum\ spores\ counted}$$

Absolute pollen counts were determined using a minimum count of 50 *L. clavatum* spores. This was followed as long as the ratio of *L. clavatum* spores to fossil pollen grains remained greater than or equal to 0.05. In certain samples, however, where very high pollen influx values (ratio<0.05) were evident, a maximum of 1000 fossil grains were counted. This decision was made based on the trade off which exists between the number of grains counted for a single sample (to obtain a greater statistical reliability) versus the number of samples counted down a core (to obtain higher temporal resolution).

4.3.5. Pollen diagrams

To facilitate the visualisation of pollen data, they were presented as pollen diagrams, which plot chronostratigraphy (depth scale and radiocarbon ages) against biostratigraphy (pollen counts as influx figures or percentages) (Faegri and Iverson 1989). Separate pollen diagrams for absolute and relative pollen counts were plotted using the TGView 2.02 (Grimm 2004). The Constrained Incremental Sum of Squares (CONISS) cluster technique within TGView 2.02, was used to define boundaries between the most distinguishable pollen zones (Grimm 1987).

4.3.6. Radiocarbon dating

Subsamples from eight suitable basal and intermediate layers were selected for radiocarbon analysis. The Quaternary Dating Research Unit (QUADRU) at the Council for Scientific and Industrial Research (CSIR) determined all radiocarbon ages. Official Radiocarbon ages were calibrated using the Pretoria Calibration Program (CALP 1.02) in conjunction with the SH98 calibration dataset, adapted from the INTCAL98 dataset (Stuiver *et al.* 1998), which extends back to 39879 years bp (Talma pers. comm.).

4.3.7. Stable carbon isotope analysis

A stable carbon isotope ($\delta^{13}C$) analysis was conducted on 33 samples as an independent means of investigating palaeoenvironmental change. Delta notion, $\delta^{13}C$, is defined by the following equation:

$$\delta = \left[\frac{R_{sample}}{R_{standard}} - 1 \right] x\, 1000(‰)$$

where R_{sample} and $R_{standard}$ refer to the isotope ratios $^{13}C/^{12}C$ of the sample and the standard, respectively. Total organic carbon ($\delta^{13}C_{TOC}$) samples were analysed at the Stable Light Isotope Laboratory at the University of Cape Town using a Thermo Finnigan Delta Plus XP mass spectrometer coupled to a Thermo Flash EA 1112 via a Conflo III device (Lanham pers. comm.). An additional eight samples, those used for radiocarbon analysis, were analysed by the Quaternary Dating Research Unit (QUADRU) at the Council for Scientific and Industrial Research (CSIR).

4.4. PALAEOENVIRONMENTAL INTERPRETATION

An indicator species (individualistic) approach was used to interpret the palaeoenvironmental implications of trends evident in the pollen data. This approach compares the modern distributions of indicator taxa with contemporary climatic conditions, thus inferring which conditions are most likely to be associated with these taxa. Table 4.1, modified from Scott (1999a), provides a summary of important indicator taxa in the savanna biome of South Africa. The indicator taxa suggested in this table are appropriate for use in this research, since the Mfabeni site falls within

the savanna biome (Rutherford and Westfall 1986) albeit marginal/coastal. This indicator approach has been employed merely as a guideline, as the limitations of using this simplistic approach are acknowledged, e.g. at what threshold percentage do Podocarpaceae represent local or regional forest?

4.5. CONCLUSION

This chapter has provided an introduction to the study site, consisting of a physical description and a palaeoenvironmental history. A description is provided of the methodologies applied in this research, *viz.* pollen, stable carbon isotope and radiocarbon analyses. This was structured according to the field, laboratory and interpretive components of this research.

Table 4.1. Generalised environmental indicators of some fossil pollen taxa in the savanna biome (after Scott 1999a).

Pollen Type	Vegetation Type	Environmental Conditions
Podocarpaceae (*Podocarpus*)	forest	relatively moist conditions
Myricaceae (*Myrica*)	forest edge	subhumid conditions
Pteridophyta		
Flacourtiaceae (*Kiggelaria*)	woodland	
Proteaceae (*Protea*)	upland or mesic savanna	wide range of temperatures; subhumid conditions
Euphorbiaceae (*Spirostachys*)	microphyllous or plains	relatively warm conditions, wide range of moisture conditions; *Acacia* associated with relatively deep local soils
Anacardiaceae (*Sclerocarya*)	savanna	
Fabaceae (*Acacia*, *Dichrostachys*)		
Asteraceae (*Artemisia*)	shrubland	relatively even seasonal moisture distribution
Ericaceae	fynbos	cool subhumid conditions, relatively even seasonal moisture distribution
Thymeleaceae (*Passerina*)		
Rosaceae (*Cliffortia*)		
Chenopodiaceae	halophytes	dry conditions or local evaporation, salinity or disturbance under strong seasonality in climate
Cyperaceae	semi-aquatics	local swamp, shallow water or damp soil
Poaceae	grassland or savanna	generally indicative of summer rainfall

CHAPTER FIVE
RESULTS

5.1. INTRODUCTION

The aim of this chapter is to present and describe the results of the radiocarbon, stable carbon isotope and pollen analyses. The results of the radiocarbon analysis are evaluated and calibrated in order to provide suitable chronological control for stable carbon isotope and pollen analyses. Stable carbon isotope and pollen results are then described according to this chronological framework.

5.2. RADIOCARBON ANALYSIS

Radiocarbon (^{14}C) ages were determined for eight subsamples along the length of the Mfabeni core. Results of this analysis indicate an age of >44400 years bp at the base of the core (9.8m; table 5.1). Interpretation of these results is strongly dependent on the origin of the 'young' excursion / age reversal evident at a depth of approximately 9m (35100 ± 1200 years bp). Results have been compared with previous age determinations obtained from the Mfabeni Peatland by Grundling *et al.* (1998), which demonstrate a similar age reversal at approx. 9m (figure 5.1). These reversals are probably as a result of either (i) a reworking of older peat sediments, as interpreted by Grundling *et al.* (1998); or (ii) contamination of samples in lower strata. Alternatively, it is possible that these younger excursions occurred for entirely different reasons such that similar trends evident in the data of Grundling *et al.* (1998) and this study are purely coincidental. Discrepancies in accumulation rate are reflected between the two datasets prior to *ca.* 30000 years bp, suggesting spatial separation between the two cores. Thus, direct comparisons should not be drawn from the trends illustrated in figure 5.1, despite an apparently good match between these results (Woodbourne pers. comm.).

The origin of the age reversal will be discussed in terms of (i) the importance of finite and infinite results at the base of the core; and (ii) the results of the $\delta^{13}C$ analysis. The finite result on R_7 (35100 ± 1200; refer to table 5.1), in the context of infinite results obtained both above (R_5 >42800 years bp; R_6 >45000 years bp) and below (R_8 >44400 years bp), suggests that some form of contamination has taken place, e.g. by

tree roots (Woodbourne pers. comm.). This type of contamination occurs when a root grows through a deposit, introducing more recent carbon to an older sample. It is possible for contamination to make a deposit appear younger than its actual age, but not older. Potential contamination of R_7 is further supported by the large differences in age between this date and the ages above. This reasoning can also be applied to R_8, which is younger than R_6, despite being two metres deeper down the profile.

Table 5.1 Radiocarbon results for the Mfabeni Peatland, indicating calibrated (see 5.2.1) and uncalibrated ages.

Sample	Lab Codes	Depth (m)	^{14}C Age	Cal years BP[4]
Mfabeni Swamp R_1	Pta-9427	2.75	7630 ± 70	8443
Mfabeni Swamp R_2	Pta-9425	**4.55**	15100 ± 240	18055
Mfabeni Swamp R_3	Pta-9435	**4.70**	15300 ± 120	18285
Mfabeni Swamp R_4	Pta-9433	**5.82**	28900 ± 580	32827
Mfabeni Swamp R_5	Pta-9434	**6.40**	>42800	–
Mfabeni Swamp R_6	Pta-9426	**7.80**	>45000	–
Mfabeni Swamp R_7	Pta-9430	**9.20**	35100 ± 1200	41655
Mfabeni Swamp R_8	Pta-9436	**9.80**	>44400	–

Further evidence for tree root contamination is provided in the stable carbon isotope ($\delta^{13}C$) analysis (section 5.3), by a depletion in $\delta^{13}C_{TOC}$ values from *ca.* –18 to –21‰ between depths of approx. 8.5 and 9m. This reflects an increase in the proportion of C_3 plants (trees and shrubs) occupying the peatland at this time, which supports the argument that this was a layer in which tree roots concentrated, potentially contaminating strata directly below. Similarly, the pollen signal at this depth (approx. 8.5- 9m) indicates an increase in arboreal taxa associated with the expansion of forest vegetation, thus supporting tree root contamination in lower strata (refer to zone Z-1d in section 5.8.3). On the basis of recommendations from radiocarbon dating experts (Woodbourne pers. comm.) and of supporting evidence, including $\delta^{13}C$ and pollen data, ages R_7 and R_8 were rejected, due to possible contamination.

[4] Calibrated ages are stated as Cal years BP (Before Present) rather than Cal years BC (Before Christ) to aid in comparision of Mfabeni results with previous palaeoecological studies.

5.2.1. Radiocarbon calibration

Radiocarbon ages were calibrated using the Pretoria Calibration Program (CALP 1.02) in conjunction with the SH98 calibration dataset (Talma pers. comm.), adapted from the INTCAL98 dataset (Stuiver *et al.* 1998). The SH98 calibration dataset extends back to 39879 years bp, and was therefore suitable for use in calibrating five of the eight ^{14}C ages. Calibrated ages are provided in table 5.1, while calibration curves are provided in appendix G. Ages that fell outside of the range of the SH98 dataset were left uncalibrated, as recommended by Pilcher (1991). Once calibrated, ages R_2 (18055 Cal years BP) and R_3 (18285 Cal years BP) accurately pinpoint the position of the Last Glacial Maximum (LGM; *ca.* 18000 years BP) at approx. 4.6m, within a prominent sand lens. Accurate knowledge of the position of the LGM within the Mfabeni profile aided in palaeoclimatic interpretation of the pollen and $\delta^{13}C$ results, as it arguably constitutes the most important climatic event that occurred during the Late Quaternary.

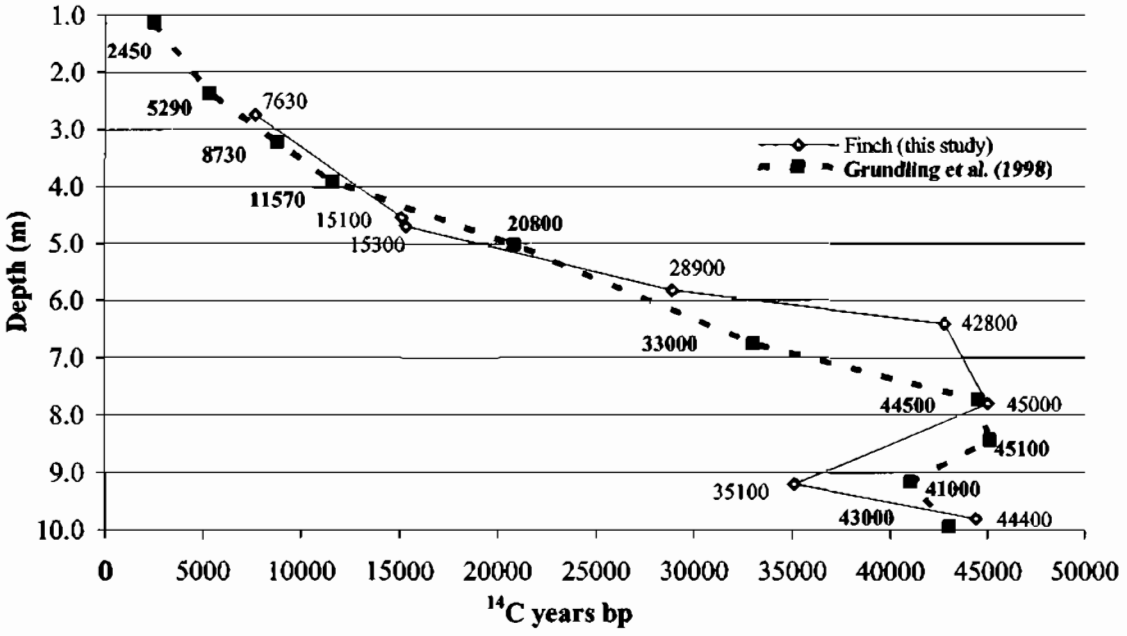


Figure 5.1 Comparison of radiocarbon datasets obtained by Finch (this study) and Grundling *et al.* (1998) for the Mfabeni Peatland.

As a consequence of the potential contamination of ages R_7 and R_8, these were excluded, leaving six remaining ages to provide chronological control for this study. Thus, ages provided by the calibrated age series R_1–R_4, together with the infinite ages R_5 and R_6, were considered in providing age estimates (figure 5.2).

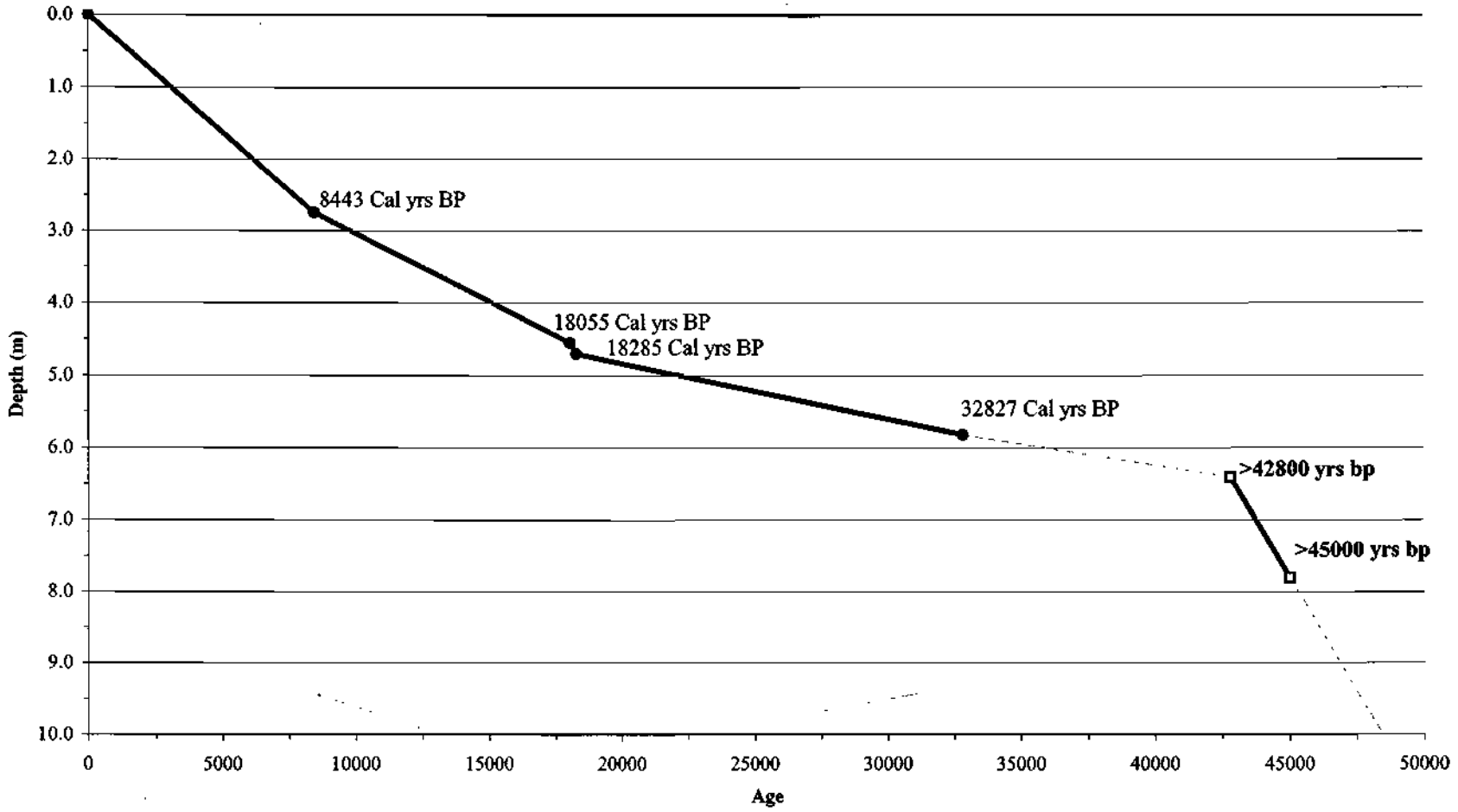


Figure 5.2 Sediment accumulation rate curve for the Mfabeni peat profile, constructed using selected radiocarbon dates. Data points in **bold** represent uncalibrated dates while the remainder are calibrated. Lines are interpolated for derivation of ages between radiocarbon samples.

Age estimates are based on interpolation between radiocarbon ages, as indicated in figure 5.2. Although the reliability of this method is reduced by differences in accumulation rate along the curve, this provided the only available means of determining intermediate age estimates. This places the Mfabeni peat core within the time frame 0 – *ca.* 48000 years bp, covering the Terminal Pleistocene and Holocene.

5.3. STABLE CARBON ISOTOPE ANALYSIS

The Mfabeni stable carbon isotope ($\delta^{13}C$) data (figure 5.3) demontrates variations in $\delta^{13}C_{TOC}$ with an amplitude of *ca.* 11‰ (raw data provided in appendix H). The pollen zones delineated in section 5.3 have been used in the description of $\delta^{13}C$ data to aid in the integration of these results with those of the pollen analysis during palaeoenvironmental reconstruction.

During zone Z-1a, the $\delta^{13}C_{TOC}$ values average at *ca.* –23‰, although they reach a minimum value of *ca.* –25‰. These light[5] values indicate a high proportion of C_3 plants (trees and shrubs) occupying the peatland at this time (*ca.* 48000 years bp), which in turn may reflect cooler conditions. By *ca.* 46500 years bp (zones Z-1b and Z-1c), $\delta^{13}C_{TOC}$ are enriched from *ca.* –23‰ to –18‰ by, indicating a shift towards C_4 dominated vegetation (Poaceae) and associated warmer conditions. $\delta^{13}C_{TOC}$ values are depleted in zone Z-1d, from *ca.* –18‰ to –21‰, reflecting an increase in C_3 plants by *ca.* 46000 years bp. A slight warming trend follows in zone Z-2, as reflected by a $\delta^{13}C_{TOC}$ enrichment of *ca.* 2‰. Zone Z-3a records fluctuations in $\delta^{13}C_{TOC}$ values, with an overall enrichment of *ca.* 1‰, potentially indicating the development of slightly warmer conditions by *ca.* 42800 years bp. During this zone, $\delta^{13}C_{TOC}$ values reach a maximum of *ca.* –16‰ at *ca.* 44500 years bp, indicating a high proportion of C_4 vegetation occupying the peatland, thus inferring a possible shift to warmer conditions. Zone Z-3b indicates minor fluctuations in $\delta^{13}C_{TOC}$ values, with an amplitude of *ca.* 0.96‰ during the period *ca.* 41500 – 25000 years bp. This is followed by a depletion in $\delta^{13}C_{TOC}$ values of *ca.* 3‰ after *ca.* 25000 years BP (Z-4a). During the LGM, a significant depletion of *ca.* 7‰ is recorded, indicating

[5] Low (depleted) $\delta^{13}C$ values are described as being *light*, while high (enriched) values are referred to as *heavy*.

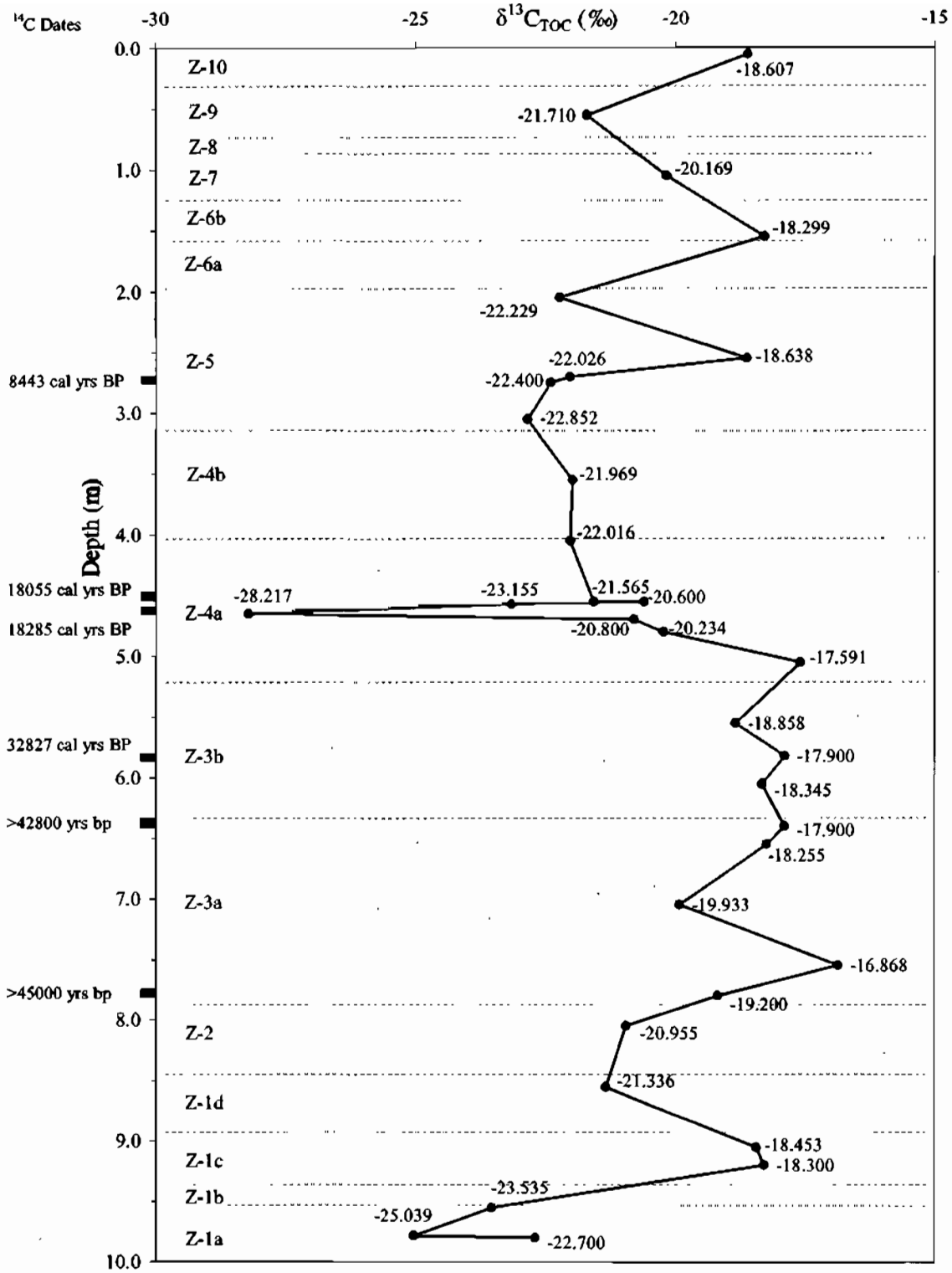


Figure 5.3 Stable carbon isotope ($\delta^{13}C$) results for the Mfabeni profile, indicating pollen zones and radiocarbon dates

the dominance of C_3 vegetation, which in turn reflects cooling within the profile. These observations are based on a single data point of *ca.* –28‰, and thus require verification through the analysis of additional subsamples. However, generally light values are indicated around this data point strengthening the probability of this cooling trend. A further consideration relates to the fact that this subsample (data point) fell within a prominent sand lens in the core, which may have influenced its $\delta^{13}C_{TOC}$ reading. Again, this justifies the need for analysis of additional subsamples. Zone Z-4b records a depletion in $\delta^{13}C_{TOC}$ values of *ca.* 0.7‰, reflecting a slight cooling trend towards the end of the Pleistocene.

After *ca.* 10000 years BP (zone Z-5), $\delta^{13}C_{TOC}$ values are enriched from *ca.* –22‰ to –18‰, reflecting an increase in C_4 vegetation. $\delta^{13}C_{TOC}$ values become depleted after *ca.* 7200 years BP, reaching *ca.* –22‰ within the next 1000 years. Zone Z-6a records an enrichment of *ca.* 4‰, indicating an increase in C_4 vegetation and associated warmer conditions. The period *ca.* 5000 – 2500 years BP (represented by zones Z-6b, Z-7 and Z-8) is suggestive of a progressive cooling trend (increase in C_3 plants), as indicated by a depletion of $\delta^{13}C_{TOC}$ values from *ca.* –18‰ to –21‰. The last *ca.* 2500 years record an enrichment in $\delta^{13}C_{TOC}$ values to *ca.* –18‰, reflecting an increase in C_4 vegetation and associated warming conditions.

In summary, $\delta^{13}C$ data indicate gradual fluctuations in the relative C_3:C_4 composition of vegetation occupying the Mfabeni Peatland over the past *ca.* 48000 years bp. Maximum cooling is recorded at the LGM, by a depleted $\delta^{13}C_{TOC}$ value of *ca.* –28‰, indicating the dominance of C_3 plants. These data are integrated with the results of the pollen analysis in chapter six, for the purpose of reconstructing a detailed account of the vegetation history at Mfabeni.

5.4. POLLEN ANALYSIS

5.4.1. Pollen counts

In order to select an appropriate minimum pollen count for Mfabeni, standard counts of 250 and 500 fossil pollen grains were conducted and compared (raw data provided in appendix I). A chi-squared statistical test was used to investigate whether there was a significant difference between counts of 250 and 500. This test does not

determine whether a particular count size is representative of the pollen assemblage, but rather establishes whether a large count of 500 could be substituted for a smaller count of 250, hence increasing the efficiency of the total pollen count. The hypothesis tested was that there was no significant difference in the means of pollen counts (per taxa) from each depth sampled, with counts of 250 or 500 pollen grains (at the 95% confidence interval). This test excludes very rare taxa, which are of lesser importance as they constitute a lesser proportion (less than 0.5%) of the total pollen assemblage. Although certain rare taxa, such as Proteaceae, constitute keystone or indicator species, low relative frequencies of these taxa implicate that minor changes in pollen count of these taxa represent major differences statistically. Thus, very rare taxa including Carryophyllaceae, Fagaceae-like, Geraniaceae, Myricaceae, Polygalaceae, Proteaceae, Rhamnaceae, Rosaceae and Thymeleaceae were excluded.

Table 5.2 Results of the chi-squared test for significant differences (at the 0.05 level) between counts of 250 and 500 pollen grains in peat samples.

Depth	Total Taxa	Accept H_0	Reject H_0	Rejected Taxa
0.10	15	15 (100%)	0 (0%)	
0.20	11	11 (100%)	0 (0%)	
0.30	14	13 (92%)	1 (7%)	Anacardiaceae*
0.35	13	13 (100%)	0 (0%)	
0.40	12	12 (100%)	0 (0%)	
0.45	11	11 (100%)	0 (0%)	
0.50	14	14 (100%)	0 (0%)	
0.60	15	15 (100%)	0 (0%)	
0.70	18	18 (100%)	0 (0%)	
0.75	7	7 (100%)	0 (0%)	
0.80	11	11 (100%)	0 (0%)	
0.85	14	14 (100%)	0 (0%)	
0.90	18	18 (100%)	0 (0%)	
1.00	16	15 (93%)	1 (6%)	Pteridophyta*
1.10	15	14 (93%)	1 (6%)	Celastraceae*
1.15	10	9 (90%)	1 (10%)	Pteridophyta*
1.20	17	17 (100%)	0 (0%)	
1.30	19	19 (100%)	0 (0%)	
1.40	20	20 (100%)	0 (0%)	
1.50	15	15 (100%)	0 (0%)	
1.60	18	18 (100%)	0 (0%)	
1.70	16	16 (100%)	0 (0%)	
1.80	14	12 (85%)	2 (14%)	Iridaceae*; Undetermined*
1.90	16	16 (100%)	0 (0%)	
1.95	13	13 (100%)	0 (0%)	
2.00	13	13 (100%)	0 (0%)	

* statistically significant at the 0.05 level

Depth	Total Taxa	Accept H_0	Reject H_0	Rejected Taxa
2.05	10	10 (100%)	0 (0%)	
2.10	17	17 (100%)	0 (0%)	
2.20	16	15 (93%)	1 (6%)	Pteridophyta*
2.30	13	13 (100%)	0 (0%)	
2.40	17	17 (100%)	0 (0%)	
2.50	14	14 (100%)	0 (0%)	
2.60	16	16 (100%)	0 (0%)	
2.70	15	15 (100%)	0 (0%)	
2.80	19	19 (100%)	0 (0%)	
2.90	14	14 (100%)	0 (0%)	
3.00	15	15 (100%)	0 (0%)	
3.10	13	13 (100%)	0 (0%)	
3.20	13	13 (100%)	0 (0%)	
3.30	14	14 (100%)	0 (0%)	
3.40	15	15 (100%)	0 (0%)	
3.50	13	13 (100%)	0 (0%)	
3.60	14	14 (100%)	0 (0%)	
3.70	14	14 (100%)	0 (0%)	
3.80	15	15 (100%)	0 (0%)	
3.90	15	15 (100%)	0 (0%)	
4.00	14	13 (92%)	1 (7%)	Liliaceae*
4.10	16	16 (100%)	0 (0%)	
4.20	16	16 (100%)	0 (0%)	
4.30	15	15 (100%)	0 (0%)	
4.40	14	14 (100%)	0 (0%)	
4.50	15	15 (100%)	0 (0%)	
4.60	13	13 (100%)	0 (0%)	
4.70	14	14 (100%)	0 (0%)	
4.80	12	12 (100%)	0 (0%)	
4.90	11	10 (90%)	1 (9%)	Poaceae*
5.00	13	13 (100%)	0 (0%)	
5.10	11	11 (100%)	0 (0%)	
5.20	7	7 (100%)	0 (0%)	
5.30	8	8 (100%)	0 (0%)	
5.40	8	8 (100%)	0 (0%)	
5.50	12	12 (100%)	0 (0%)	
5.60	12	12 (100%)	0 (0%)	
5.70	11	11 (100%)	0 (0%)	
5.80	11	10 (90%)	1 (9%)	Asteraceae*
5.90	12	11 (91%)	1 (8%)	Pteridophyta*
6.00	14	14 (100%)	0 (0%)	
6.10	12	12 (100%)	0 (0%)	
6.20	13	13 (100%)	0 (0%)	
6.30	11	11 (100%)	0 (0%)	
6.40	13	13 (100%)	0 (0%)	
6.50	14	14 (100%)	0 (0%)	
6.60	12	12 (100%)	0 (0%)	
6.70	12	12 (100%)	0 (0%)	
6.80	11	11 (100%)	0 (0%)	
6.90	14	14 (100%)	0 (0%)	
7.00	14	14 (100%)	0 (0%)	
7.05	6	6 (100%)	0 (0%)	

Depth	Total Taxa	Accept H_0	Reject H_0	Rejected Taxa
7.10	14	14 (100%)	0 (0%)	
7.20	12	12 (100%)	0 (0%)	
7.25	9	9 (100%)	0 (0%)	
7.30	14	14 (100%)	0 (0%)	
7.40	13	13 (100%)	0 (0%)	
7.50	14	14 (100%)	0 (0%)	
7.55	14	14 (100%)	0 (0%)	
7.60	13	13 (100%)	0 (0%)	
7.65	12	12 (100%)	0 (0%)	
7.70	15	15 (100%)	0 (0%)	
7.80	15	15 (100%)	0 (0%)	
7.90	10	10 (100%)	0 (0%)	
8.00	12	12 (100%)	0 (0%)	
8.10	10	9 (90%)	1 (10%)	Poaceae*
8.15	10	10 (100%)	0 (0%)	
8.20	14	14 (100%)	0 (0%)	
8.25	13	12 (92%)	1 (7%)	Poaceae**
8.30	15	15 (100%)	0 (0%)	
8.35	12	11 (91%)	1 (8%)	Poaceae**
8.40	11	11 (100%)	0 (0%)	
8.45	8	8 (100%)	0 (0%)	
8.50	11	11 (100%)	0 (0%)	
8.60	13	13 (100%)	0 (0%)	
8.70	12	12 (100%)	0 (0%)	
8.80	9	9 (100%)	0 (0%)	
8.90	9	9 (100%)	0 (0%)	
9.00	12	12 (100%)	0 (0%)	
9.10	9	9 (100%)	0 (0%)	
9.20	12	12 (100%)	0 (0%)	
9.30	13	13 (100%)	0 (0%)	
9.35	11	11 (100%)	0 (0%)	
9.40	5	5 (100%)	0 (0%)	
9.50	6	6 (100%)	0 (0%)	
9.60	8	8 (100%)	0 (0%)	
9.70	7	5 (71%)	2 (28%)	Asteraceae*; Poaceae***
9.80	10	9 (90%)	1 (10%)	Pteridophyta*

The results of the chi-squared analysis (table 5.2) indicate that a count of 250 was sufficient (at 99/114 depths), as there was no significant difference between counts of 250 and 500 pollen grains (full results provided in appendix J). In a few cases (at 15/114 depths), a single taxon (or in one case two taxa) showed a significant difference using counts of 250 and 500, and in these cases the null hypothesis was rejected. The most commonly rejected taxa were Poaceae and Pteridophyta, which can be attributed to the large counts achieved for both these taxa. Despite these

** statistically significant at the 0.01 level

*** statistically significant at the 0.001 level

anomalies, counts of 250 proved sufficient in representing the relative composition of the pollen spectrum throughout the profile. Nevertheless, the larger count was used in the construction of pollen diagrams, as it was available.

5.4.2. Pollen zonation

The Constrained Incremental Sum of Squares (CONISS) program was used to divide pollen data into zones for descriptive purposes (Grimm 1987). This program uses an agglomerative and hierarchical approach to create clusters, which are plotted as a dendrogram alongside the pollen diagram (Grimm 1987). The dendrogram is then used to delineate appropriate zones according to the preferences of the analyst, such that pollen data can be described and interpreted in appropriate non-arbitrary strata (Grimm 1987). The CONISS algorithm was applied to relative pollen data (derived from counts of 500 pollen grains) to produce the dendrogram presented in figure 5.4.

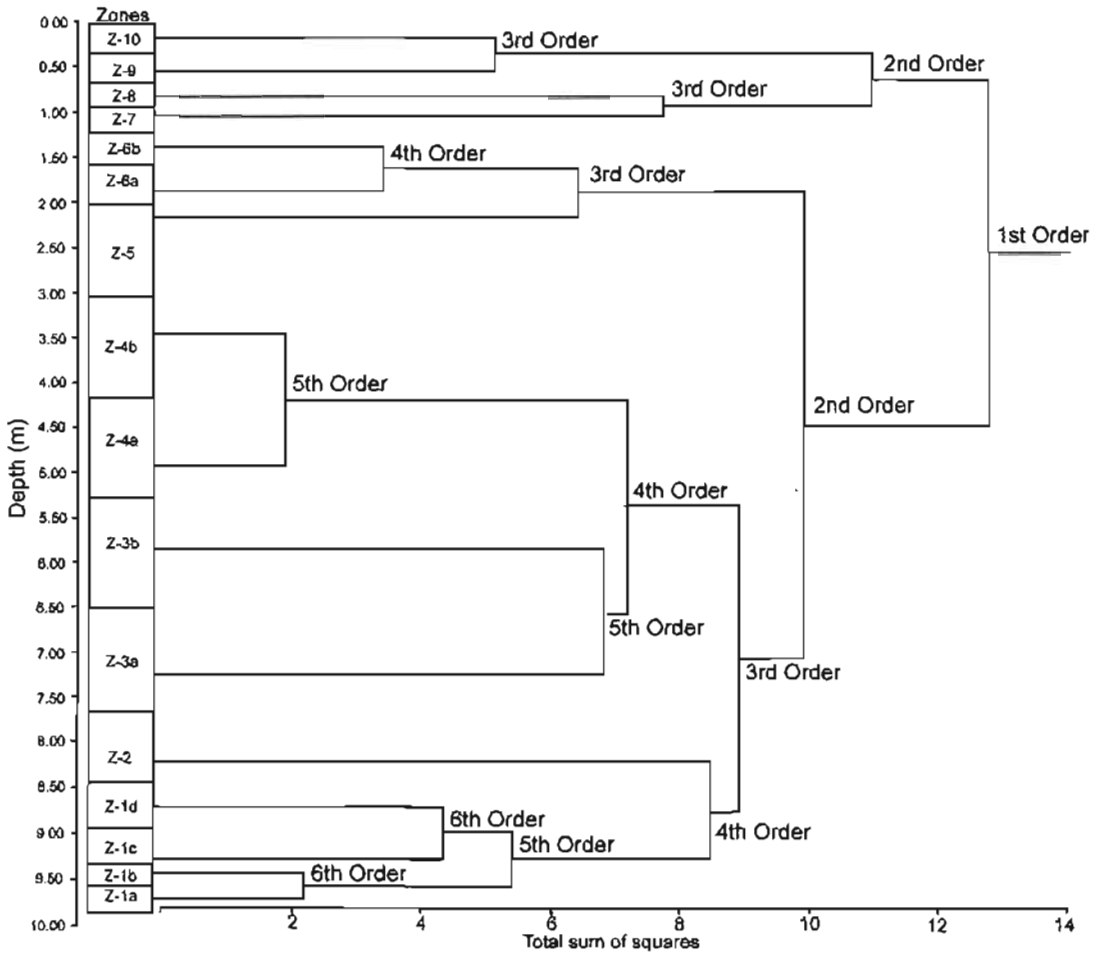


Figure 5.4 Derivation of pollen zones using CONISS dendrogram, indicating level of ordination used for delineation of respective zones.

The dendrogram presented above was used to divide the Mfabeni profile into ten zones, some of which were further divided into subzones. The zonation process was conducted according to the hierarchical structure of the dendrogram, such that third order splits were given priority over fourth order splits etc. While less variation is evident within the lower section of the profile (as indicated by the position of the first order split), the length of this section meant that it required lower order division than the remainder of the profile. This is apparent in the division of zones Z-1, Z-3 and Z-4 into subzones at the fifth and sixth order, while narrower zones at the third and fourth order are used higher up the profile. The zonation process is not entirely without subjectivity, as not all parts of the profile are divided uniformly. However, the zonation of biostratigraphical data is primarily for descriptive purposes.

5.4.3. Pollen diagrams

This section will present and discuss pollen diagrams for relative (counts of 500) and absolute (full-slide counts) pollen data (raw data provided in appendix I), constructed using TGView 2.02 (Grimm 2004). These data will be interpreted in light of modern surface samples collected at Mtunzini, approx. 100 km south of Mfabeni (Scott *et al.* 1992; figure 5.5), and generalised indicator taxa for the savanna biome (Scott 1999a; table 4.1). While major inferences will be drawn from relative data (figure 5.6), absolute data are provided (figure 5.7) as a means of verifying trends in the relative frequency of individual taxa, to provide an indication as to whether these trends are real, or the result of fluctuations in other taxa.

Additional diagrams, presenting relative pollen data in terms of indicator taxa, regional taxa (i.e. excluding aquatics), and as a summary pollen diagram (figure 5.8), are presented to aid in interpretation. The indicator approach, selected for use in evaluating changes in the Mfabeni pollen signal, has been facilitated using figure 5.9, which presents changes in selected indicator taxa (after Scott 1999a). The regional pollen diagram is provided on the recommendation of Scott and Vogel (1978), who emphasize the importance of separating local and regional pollen production when evaluating fossil spectra. According to Scott (2000, p. 343), local aquatic and semi-aquatic pollen types 'must be excluded to ensure successful interpretations of environmental change'. Vast differences in the local and regional signals within the

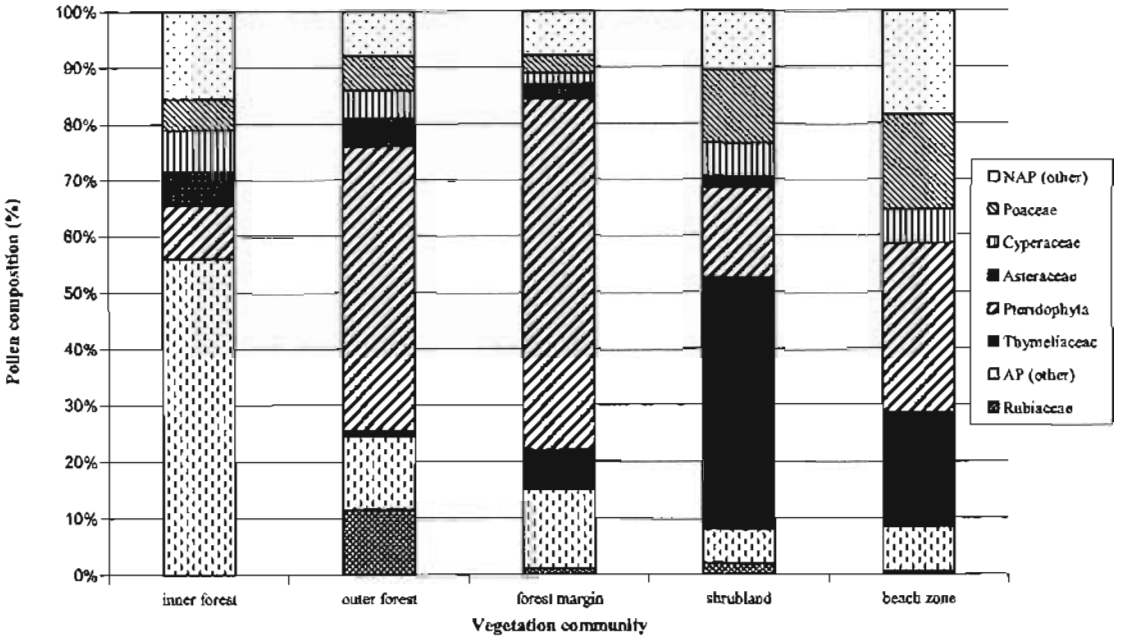
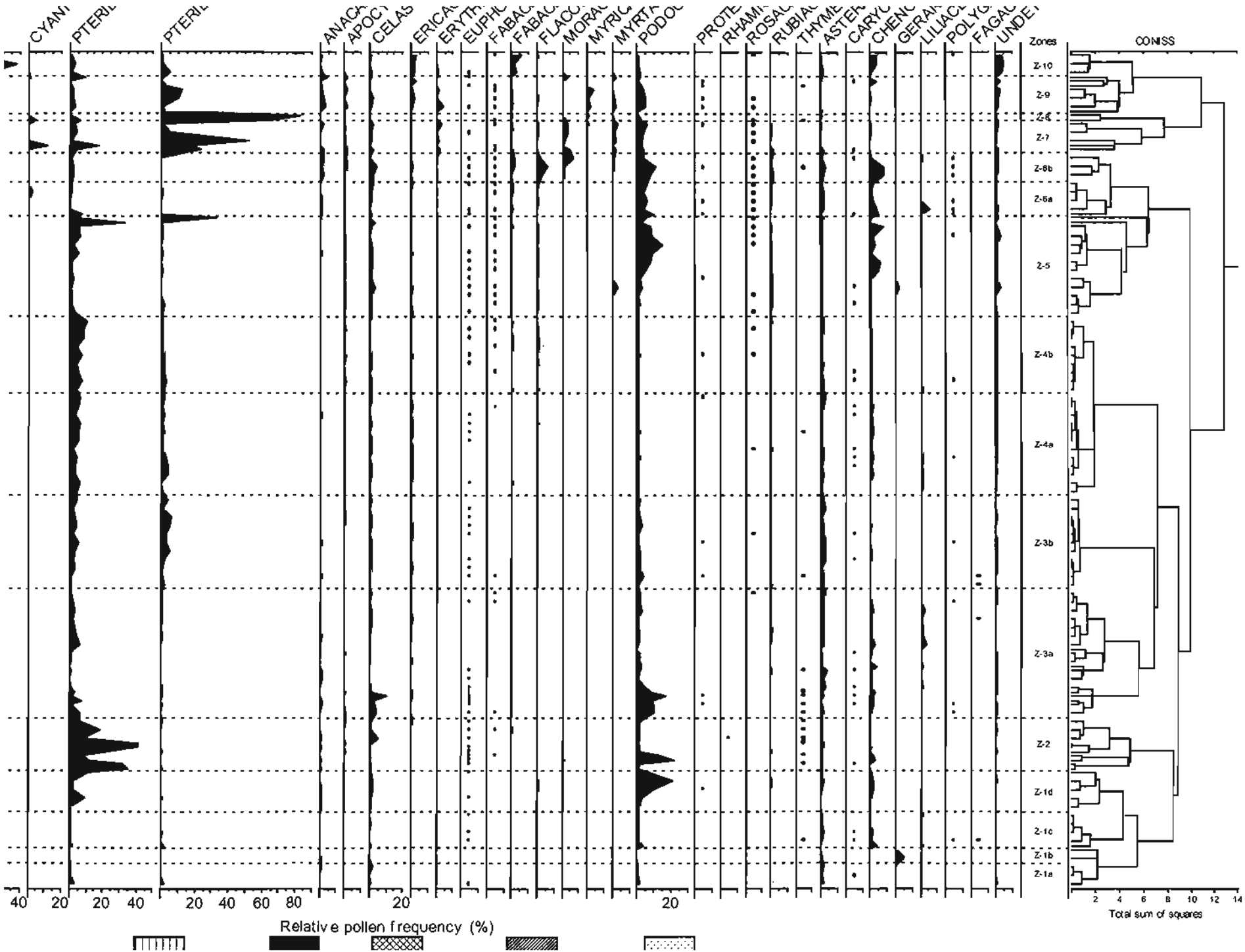


Figure 5.5 Percentage distribution of main pollen types in a transect of modern surface samples between the beach and coastal forest at Mtunzini, KwaZulu-Natal (after Scott *et al.* 1992). NAP refers to non-arboreal pollen while AP refers to arboreal pollen.

Mfabeni core, as are described later, validate this recommendation. While local successional processes are reflected by pollen production within the peatland itself, broad climatic changes are manifested in the regional vegetation (Scott and Vogel 1978). Thus, local pollen, including aquatic elements and pteridophytes, should be separated from the pollen sum to produce a regional pollen diagram. This approach has been implemented through figure 5.10. Pollen data are described using zones delineated in section 5.3.2, and approximate ages for pollen zones are derived from section 5.1.

ZONE Z-1a (>48000 years bp)

The pollen record commences with a signal dominated by Poaceae (75%) and, to a lesser degree, Cyperaceae (11%) (figure 5.6). This zone displays very low arboreal pollen frequencies (figure 5.7), with only 1% *Podocarpus* pollen. The dominance of Poaceae in relation to Cyperaceae, together with low arboreal pollen frequencies, suggests open grassland vegetation and relatively warm, dry conditions.


CYANI
PTERIL
PTERIL
ANACA
APOCY
CELAS
ERICA
ERYTH
EUPHO
FABAC
FABAC
FLACO
MORAC
MYRIC
MYRTA
PODOC
PROTE
RHAMN
ROSAC
RUBIA
THYME
ASTER
CARYO
CHENO
GERAN
LILIAC
POLYG
FAGAC
UNDET
Zones
Z-10
Z-9
Z-8
Z-7
Z-6b
Z-6a
Z-5
Z-4b
Z-4a
Z-3b
Z-3a
Z-2
Z-1d
Z-1c
Z-1b
Z-1a
CONISS
40 20 20 40
20 40 60 80
20
20
Relative pollen frequency (%)
2 4 6 8 10 12 14
Total sum of squares

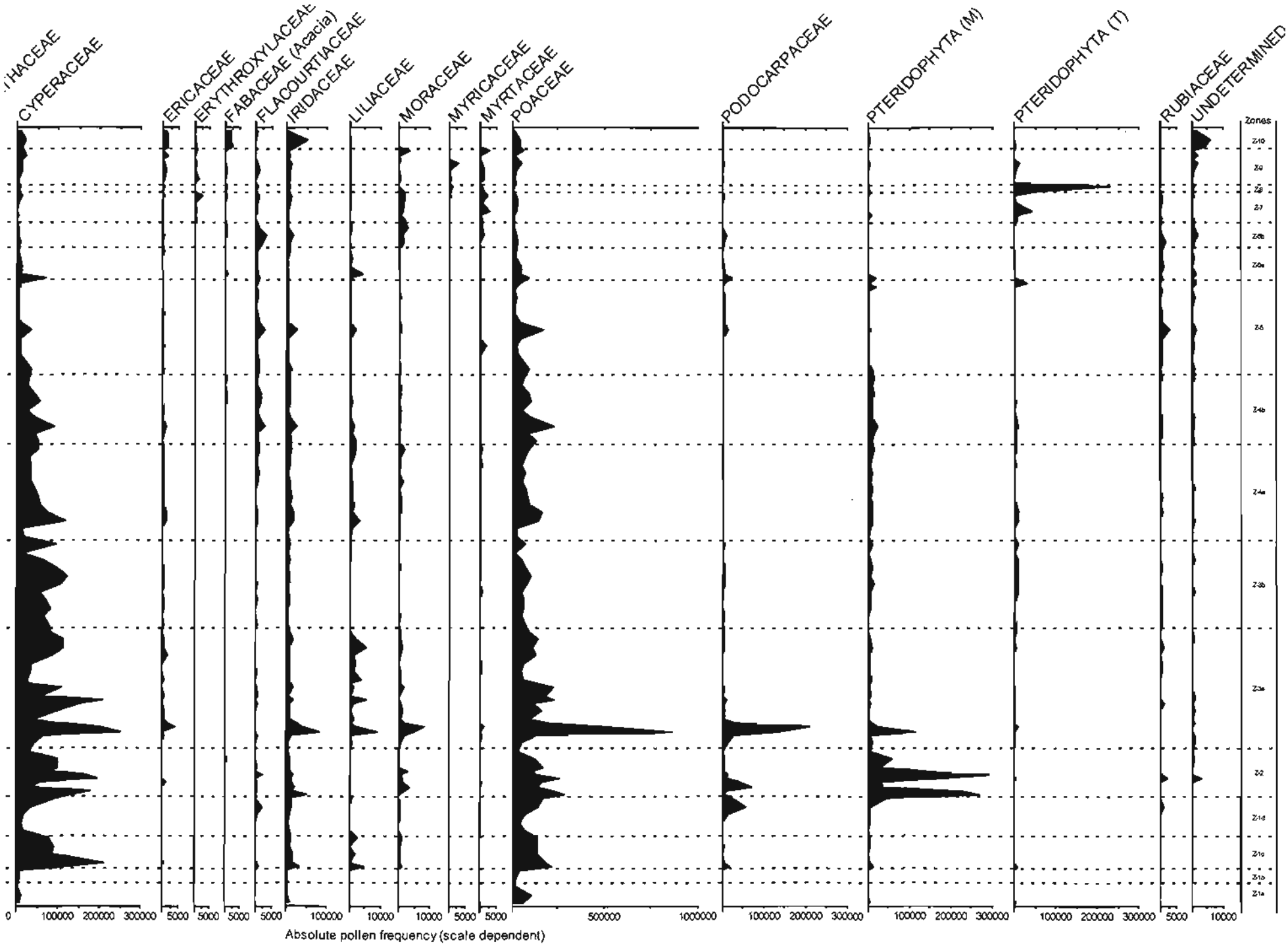
The absolute pollen data presented in figure 5.7 records very low pollen influx during zone Z-1a, which may be attributed to dry conditions. Within this zone, Poaceae progressively increase by approx. 10%, while the relative frequency of Cyperaceae pollen remains fairly constant.

ZONE Z-1b (*ca.* 48000 years bp – *ca.* 47500 years bp)

The start of zone Z-1b records an increase in Cyperaceae to approx. 26%, while Poaceae show an associated decrease by approx. 15%. This is followed by a decrease in Cyperaceae of approx. 10%, while Poaceae increase. These trends are clearly 'mirrored' in the diagram of relative pollen frequency (figure 5.6), which suggests that only one of these taxa is actually fluctuating, while the other is simply reflecting a proportionate increase/decrease according changes in the first taxon. This is confirmed by the diagram of absolute pollen frequency (figure 5.7), which demonstrates a gradual increase in Poaceae, but no change in Cyperaceae. The 'mirror effect' is one limitation in the use of relative pollen data, although, as demonstrated here, this can be overcome through the use of absolute and relative pollen data in conjunction with one another.

ZONE Z-1c (*ca.* 47500 years bp – *ca.* 46800 years bp)

This zone is characterised by a decrease in Poaceae to approx. 50 %, and an associated increase in other major plant taxa (figure 5.6). A slight increase in herbaceous taxa including Asteraceae, Caryophyllaceae, Chenopodiaceae, Liliaceae and Polygalaceae is recorded during this zone. The dominance of Poaceae, together with a diversity of herbaceous taxa in the pollen record, suggests the development of well established grasslands. An increase in both the absolute and relative frequencies of Cyperaceae does not support this inference. Cyperaceae are indicative of swampy local conditions and a generally wet climate. However, the pollen of Cyperaceae, which is a semi-aquatic, is generally restricted to the local signature, whereas herbaceous taxa may reflect regional conditions (figure 5.10). Thus, the signal for wetness may reflect the local water level while the herbaceous pollen is more likely to have originated from a greater distance. The proportion of pteridophytes and arboreal taxa remains very low, indicating the absence of forest from the area. After initial


HACEAE
CYPERACEAE
ERICACEAE
ERYTHROXYLACEAE
FABACEAE (Acacia)
FLACOURTIACEAE
IRIDACEAE
LILIACEAE
MORACEAE
MYRICACEAE
MYRTACEAE
POACEAE
PODOCARPACEAE
PTERIDOPHYTA (M)
PTERIDOPHYTA (T)
RUBIACEAE
UNDETERMINED
Zones
Z10
Z9
Z8
Z7
Z6b
Z6a
Z5
Z4b
Z4a
Z3b
Z3a
Z2
Z1d
Z1c
Z1b
Z1a
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100000
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5000
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10000
10000
5000
5000
500000
1000000
100000
200000
300000
100000
200000
300000
100000
200000
300000
5000
10000
Absolute pollen frequency (scale dependent)

increases in Cyperaceae, a decrease in this taxon is recorded from approx. 60% down to approx. 20%, reflecting a progressively drier local environment.

ZONE Z-1d (*ca.* 46800 years bp – *ca.* 46000 years bp)

An initial increase in pteridophytes, which characterise forest margin and understorey, was later succeeded by *Podocarpus*-abundant[6] forests, as recorded by a 20% increase in the relative frequency of Podocarpaceae pollen (figure 5.6). This observation is supported by an overall increase in arboreal pollen taxa (figure 5.8), including Anacardiaceae, Celastraceae, Euphorbiaceae, Flacourtiaceae and Proteaceae. The advancement of forest vegetation reflects a succession from grassland to forest vegetation, which in turn suggests the development of relatively cool, moist conditions in the area. A corresponding decrease in Poaceae pollen is indicated, reflecting the replacement of grassland by expanding forests via successional processes (figure 5.6). Arboreal taxa, including *Podocarpus*, show a decrease towards the end of this zone, and are replaced by a sharp increase in pteridophytes (approx. 20%), indicating a return to subhimud conditions. These observations reflect the retreat of forest species and the associated expansion of forest margin species (i.e. ferns) as a buffer to forest refuges.

ZONE Z-2 (*ca.* 46000 years bp – *ca.* 45000 years bp)

This zone records an initial decrease in pteridophytes by approx. 20%, accompanied by an increase in *Podocarpus* pollen by approx. 30%, suggesting the expansion of forest stands in the area and associated moist conditions (figure 5.6). This is supported by an increase in arboreal taxa, including Celastraceae, Euphorbiaceae, Moraceae and Rubiaceae, at this time. After *ca.* 45500 years bp, *Podocarpus* pollen is replaced by increasing pteridophytes, which reach a relative frequency of 45%. These changes reflect the retreat of forest stands and expansion of fern dominated forest margins, as a result of subhumid conditions. An overall increase of approx. 25% in Cyperaceae during this zone suggests a return to swampy vegetation and wetter local conditions by *ca.* 45000 years bp.

[6] Arboreal pollen assemblages containing high *Podocarpus* pollen frequencies are inferred to represent what are termed *Podocarpus-abundant forests*. This term is used to avoid misconception regarding the dominance of *Podocarpus* sp. in these forests, as *Podocarpus* pollen is dispersed over long distances and may therefore become overrepresented in the pollen record. This subject is considered in further detail in section 6.2.2.1.

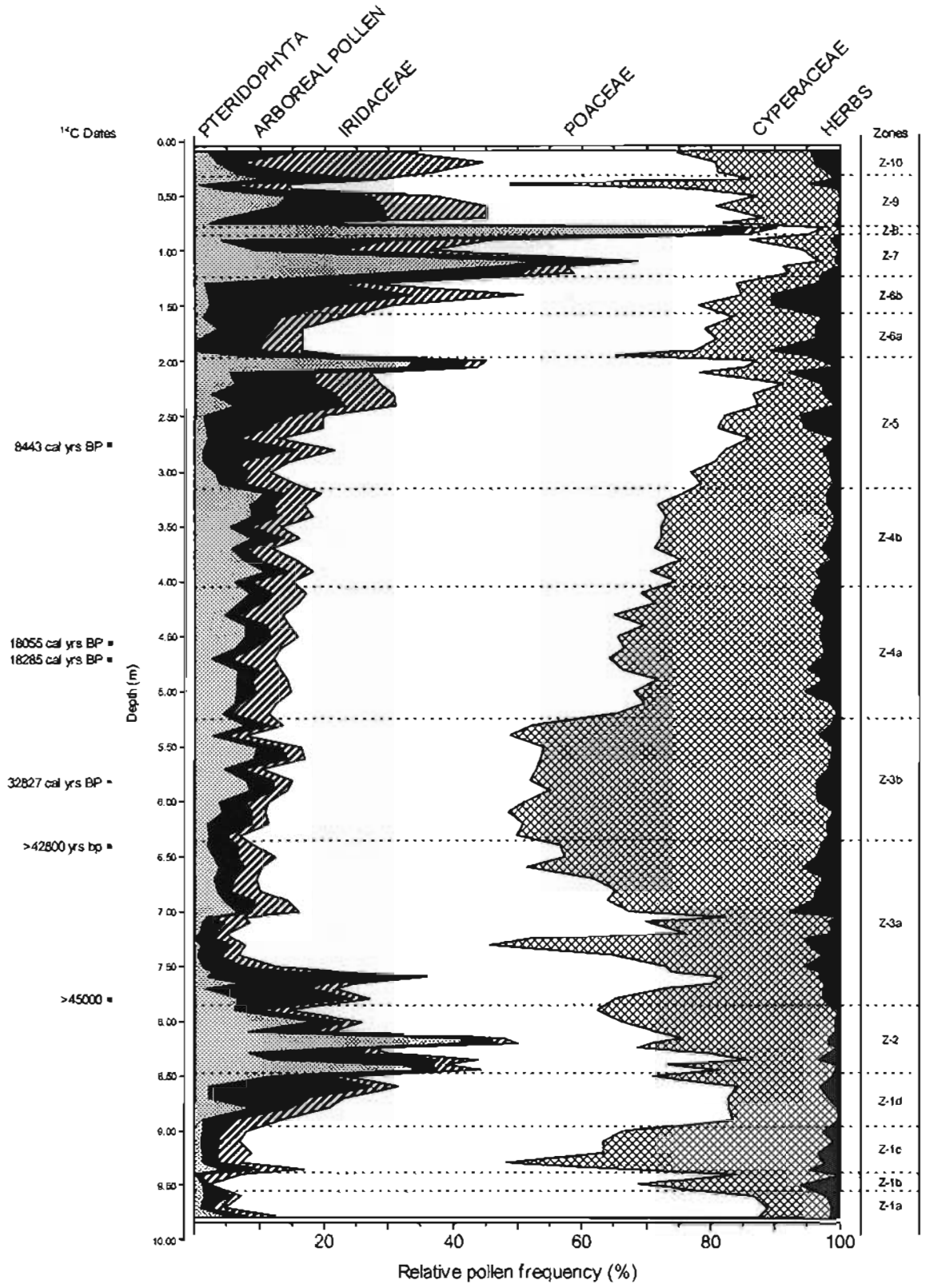

Figure 5.8 Summary pollen diagram for major plant taxa, based on relative pollen frequency.

ZONE Z-3a (*ca.* 45000 years bp – *ca.* 41000 years bp)

A 20% increase in the relative abundance of *Podocarpus* pollen, coupled with decreasing pteridophyte frequencies reflects an expansion in forested areas by *ca.* 45000 years bp (figure 5.6). An increase in Anacardiaceae, Celastraceae and Euphorbiaceae supports this observation, as does the expansion of arboreal taxa, clearly depicted in figure 5.7. After *ca.* 44000 years bp, arboreal taxa record a decrease, to be replaced by Cyperaceae, which show an increase of approx. 25%. This decrease in *Podocarpus* pollen reflects a retreat in this forest type from the area, which does not reappear in the pollen record (at frequencies >5%) for another *ca.* 35000 years. Wetter local conditions are indicated by increasing frequencies of Cyperaceae pollen, with sedge-dominated, swampy vegetation occupying the area. Cyperaceae continue to increase and dominate the pollen spectum throughout the remainder of zone Z-3a (figure 5.9).

ZONE Z-3b (*ca.* 41000 years bp – *ca.* 25500 Cal years BP)

Cyperaceae remain dominant throughout this zone, with very little change in the composition of the pollen spectrum (figure 5.6). Minor changes include a slight increase in the relative frequency of pteridophytes.

ZONE Z-4a (*ca.* 25000 Cal years BP – *ca.* 15000 Cal years BP)

The boundary between zones Z-3b and Z-4a indicates an abrupt change in the relative compositions of Poaceae and Cyperaceae (figure 5.6). After, *ca.* 25000 Cal years BP, Poaceae become dominant, increasing by approx. 20%, while Cyperaceae begin a steady decline. Stable grassland develops, as indicated by a diversity of herbaceous taxa including Asteraceae, Caryophyllaceae, Chenopodiaceae, Geraniaceae and Polygalaceae. Although this zone incorporates the LGM (*ca.* 18000 Cal years BP), the most significant climatic event during the Late Quaternary, very little change is indicated in the pollen record at this boundary.

ZONE Z-4b (*ca.* 15000 Cal years BP – *ca.* 10250 Cal years BP)

Zone Z-4b records fairly stable vegetation with little change in the pollen signal (figure 5.6). Cyperaceae continue to steadily decrease, indicating progressively drier

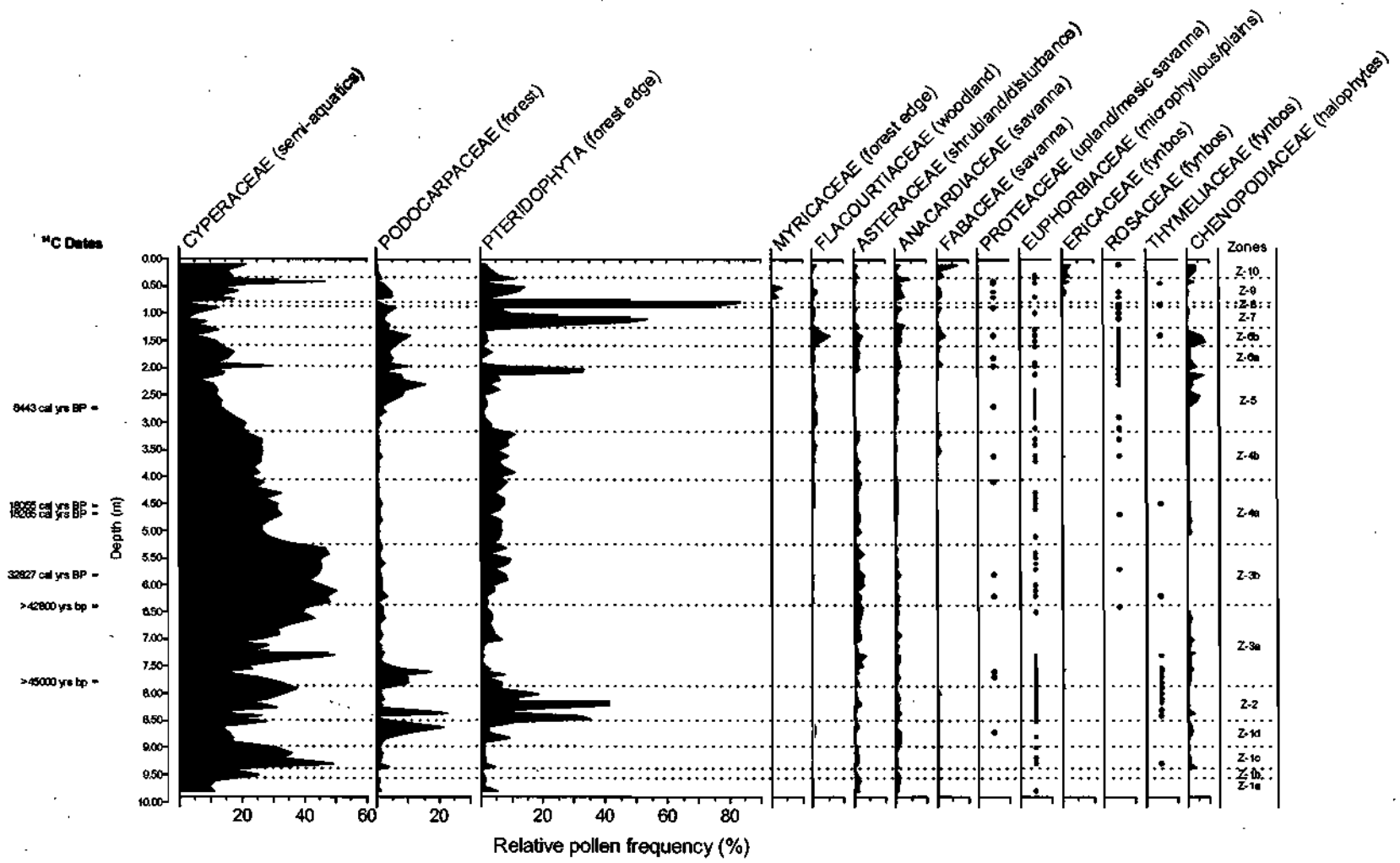

Figure 5.9 Relative pollen frequencies of selected indicator taxa (after Scott 1999a). *Rare taxa are presented as presence absence graphs.

local conditions. An increase in arboreal taxa such as Fabaceae, Euphorbiaceae and Flacourtiaceae, indicates the establishment of some canopy cover over the grassland, and a shift towards savanna-type vegetation[7].

ZONE Z-5 (*ca.* 10250 Cal years BP - *ca.* 5600 Cal years BP)

An initial increase in the relative frequency of Poaceae pollen to approx. 70% is followed by a sharp decrease after *ca.* 7500 Cal years BP (figure 5.6). This decline in Poaceae is accompanied by an increase in *Podocarpus* pollen to approx. 15%, indicating the reestablishment of *Podocarpus*-abundant forests in the area, potentially as a result of relatively cool, moist conditions. A marked increase in the relative frequency (figure 5.7) and diversity (figure 5.6) of arboreal taxa is recorded in this zone, including Anacardiaceae, Apocynaceae, Celastraceaea, Ericaceae, Erythroxylaceae, Euphorbiaceae, Fabaceae, Flacourtiaceae, Myrtaceae, Podocarpaceae, Proteaceae and Rosaceae. After *ca.* 6000 Cal years BP, arboreal pollen records a decrease, to be replaced by increasing pteridophytes (figure 5.8). This change reflects a retreat in forest stands together with an increase in fern-dominated forest margin, possibly as a result of drying. This is supported by a continous decline in Cyperaceae pollen frequencies thoughout this zone.

ZONE Z-6a (*ca.* 5600 Cal years BP – *ca.* 4500 Cal years BP)

After *ca.* 5600 Cal years BP, pteridophytes are replaced by increasing arboreal pollen, suggesting the reexpansion of forest stands (figure 5.8). Little other change in the pollen spectrum is recorded during this zone.

ZONE Z-6b (*ca.* 4500 Cal years BP – *ca.* 3500 Cal years BP)

Arboreal pollen continues to increase through zone Z-6b, with an associated decline in both Poaceae and Cyperaceae (figure 5.8). Flacourtiaceae and Moraceae in particular, record high relative pollen frequencies of 5% and 7%, respectively (figure 5.6). A diverse range of arboreal pollen taxa, together with *Podocarpus* pollen

[7] The intermediate seral stage between grassland and coastal forest is *Acacia karroo* woodland (Weisser and Marques 1979). However, poor production and preservation qualities of *Acacia*-type Fabaceae pollen prevented identification of this vegetation community in the pollen record (Coetzee 1955). Thus, the intermediate vegetation type is termed *savanna*.

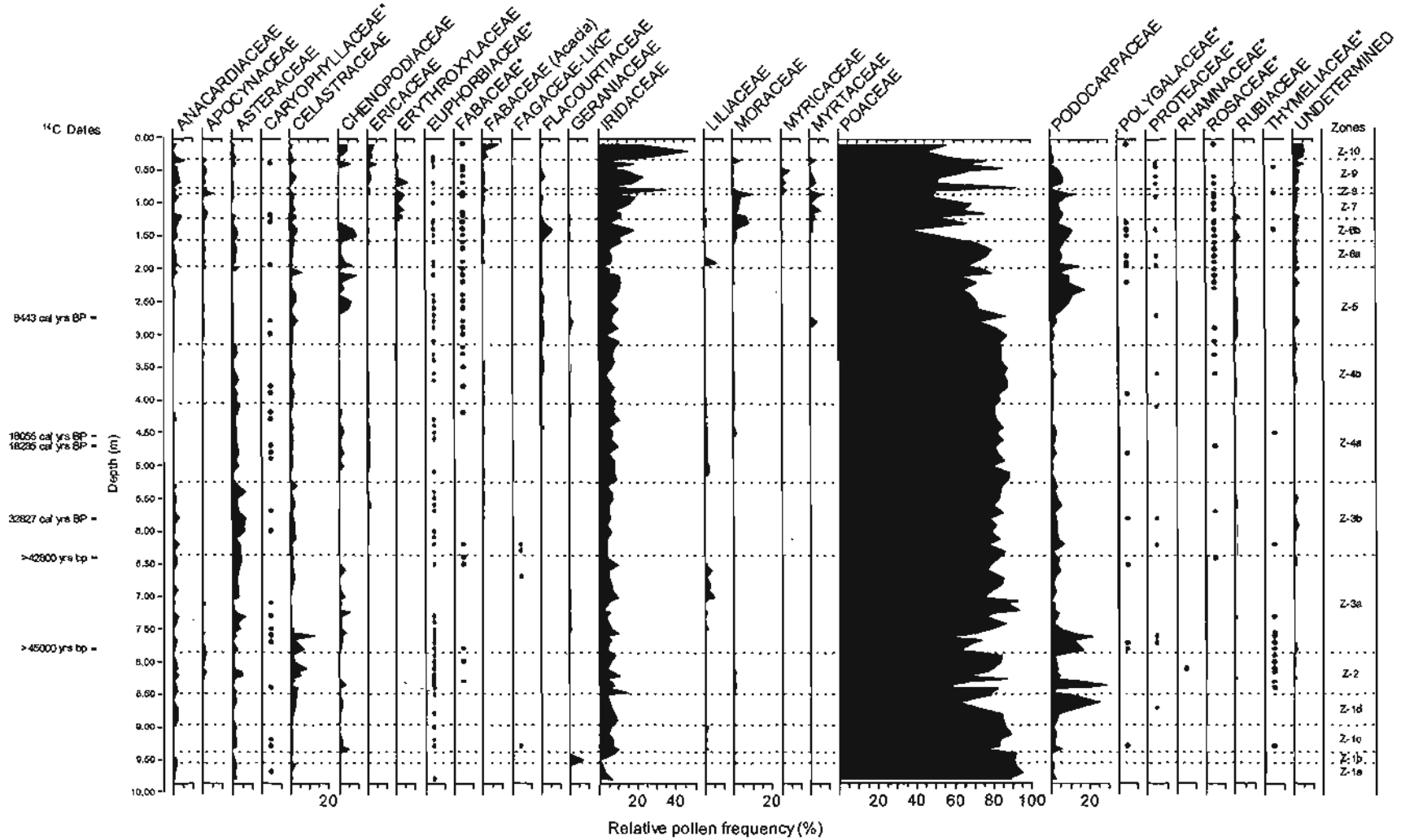

Figure 5.10 Regional pollen diagram (i.e. excluding aquatics) based on relative pollen frequency. *Rare taxa are presented as presence/absence graphs.

frequencies of approx. 10%, suggests that forest patches reached their maximum expansion during this time.

ZONE Z-7 (*ca.* 3500 Cal years BP – *ca.* 2300 Cal years BP)

A sharp decline in arboreal pollen is recorded at *ca.* 3500 Cal years BP, accompanied by a marked increase in pteridophytes of almost 60% (figure 5.8). Forest retreat during this time resulted in increasing diversity and abundance of pteridophytes, with high frequencies of both monolete and trilete spores, in addition to Cyanthaceae (tree fern) spores (figure 5.6). The expansion of this forests margin was, however, short-lived, with the replacement of pteridophytes by increasing Poaceae, Cyperaceae and arboreal pollen after *ca.* 3000 Cal years BP (figure 5.8). Alternatively, the dominance of the pollen spectrum by trilete spores may suggest overrepresentation as a result of selective preservation.

ZONE Z-8 (*ca.* 2300 Cal years BP – *ca.* 2000 Cal years BP)

Zone Z-8 represents a sudden, short-lived expansion of pteridophytes (trilete spores in particular) to 84% of the total pollen sum, suggesting an expansion in forest margin perhaps as a consequence of wet conditions (figure 5.6). Pteridophytes decrease back down to approx. 2% by the end of this zone. Again, this increase is predominantly comprised of trilete spores, which may be attributed to selective preservation, hence indicating the onset of adverse local conditions at this time.

ZONE Z-9 (*ca.* 2000 Cal years BP – *ca.* 1000 Cal years BP)

After *ca.* 2000 Cal years BP, an expansion in forests is recorded, as evidenced by increasing arboreal pollen, including *Podocarpus* (figure 5.6). Pteridophytes show an associated increase, possibly reflecting an increase in forest understorey vegetation. A decline in arboreal taxa is recorded before *ca.* 1000 Cal years BP, with increasing Cyperaceae suggesting wetter local conditions at this time (figure 5.8).

ZONE Z-10 (*ca.* 1000 Cal years BP – Present)

A decline in the relative frequency of Cyperaceae pollen, together with increasing Chenopodiaceae indicates a shift towards drier conditions during the last 1000 years (figure 5.9). *Podocarpus* pollen records a decrease from 5%, disappearing from the

record altogether within the past *ca.* 500 years (figure 5.6). Remaining arboreal pollen taxa include Rosaceae, Anacardiaceae and *Acacia* indicating the establishment of open savanna vegetation, similar to that which currently occupies the Mfabeni surrounds. No evidence of human impact, such as the presence of exotic pollen, was found in this zone.

5.5. CONCLUSION

The results presented and described in this chapter have provided a brief outline of the environmental trends evident in the pollen and stable carbon isotope records from Mfabeni. These results have been placed in the context of the chronological framework provided by the radiocarbon analysis, to allow for intercomparability with previous studies. The purpose of chapter six is firstly to integrate the results of the pollen and stable carbon isotope analyses, thereby reconstructing the palaeoenvironmental history of Maputaland, and secondly to place this reconstruction within the context of previous palaeoenvironmental investigations within the Transvaalian Ecozone, and southern Africa, respectively.

CHAPTER SIX
DISCUSSION AND PALAEORECONSTRUCTION

6.1. INTRODUCTION

A detailed palaeoreconstruction, derived from stable carbon isotope ($\delta^{13}C$) and palynological results, is presented in this chapter. Palaeoclimatic inferences are based on the $\delta^{13}C$ signal, in terms of the relative composition of C_3 and C_4 plants, and the pollen record, using generalised indicator taxa (Scott 1999a). Local and regional pollen signals are differentiated within the palaeoreconstruction. Furthermore, difficulties and considerations associated with the interpretation of these data sources are discussed. The palaeoreconstruction is compared with previous results from Mfabeni and Maputaland, in addition to the broader context of palaeoenvironmental research in the Transvaalian Ecozone and southern Africa[8].

6.2. LATE QUATERNARY PALAEORECONSTRUCTION

6.2.1. Vegetation and climatic history

Prior to *ca.* 48000 years bp, high relative frequencies of Poaceae are recorded, with low Cyperaceae and arboreal pollen frequencies (refer to figures 5.6–5.10), indicating the presence of open grassland vegetation (Z-1a). This vegetation composition suggests that the climate was warm and fairly dry. However, light $\delta^{13}C_{TOC}$ values during this period are indicative of a high relative proportion of C_3 plants occupying the peatland, which suggests cool conditions (refer to figure 5.3). This inconsistency may be explained by the fact that (i) the $\delta^{13}C$ record may only reflect vegetation growing within the peatland while most non-aquatic pollen taxa represent both local and regional fallout; and/or (ii) Cyperaceae consist of both C_3 and C_4 species thus complicating the interpretation of the $\delta^{13}C$ record. After *ca.* 48000 years bp, a gradual increase in Poaceae is recorded, suggesting warmer conditions (Z-1b). This is supported by the $\delta^{13}C$ record, which indicates an enrichment in $\delta^{13}C_{TOC}$ values, reflecting an increase in C_4 vegetation.

[8] Comparison with previous studies was in some cases limited by chronological differences.

A slight decrease in Poaceae, accompanied by an increase in Cyperaceae, is recorded after *ca.* 47000 years bp (Z-1c). A diversity of herbaceous taxa during this time suggests the establishment of stable grassland vegetation, whilst increased Cyperaceae indicate wetter local conditions. A further enrichment of $\delta^{13}C_{TOC}$ values indicates an increase in C_4 vegetation, which, together with the pollen signal, reflects warm, wet conditions.

A succession from grassland to *Podocarpus*-abundant forest is recorded after *ca.* 46800 years bp, with Poaceae being replaced initially by pteridophytes, and later by arboreal pollen taxa (Z-1d). This is supported by evidence from the $\delta^{13}C$ record, which indicates a depletion of $\delta^{13}C_{TOC}$ values during this period, suggesting an increase in C_3 vegetation. These data indicate the development of a cooler, wetter climate. A retreat in forest is recorded until *ca.* 46000 years bp, with an associated increase in pteridophyte-dominated forest margin species. Expanding *Podocarpus*-abundant forests is again recorded after *ca.* 46000 years bp, followed by forest retreat and an increase in pteridophytes (Z-2). A progressive increase in Cyperaceae suggests a shift towards wetter local conditions. Enriched $\delta^{13}C_{TOC}$ values indicate an increase in C_4 plants, with associated warmer conditions.

After *ca.* 45000 years bp, an initial expansion in *Podocarpus*-abundant forest is recorded, followed by forest retreat from the area (Z-3a). These forests do not reappear for the following 35500 years. Forest retreat, coupled with an increase in Cyperaceae, suggests the development of swampy vegetation as a result of wetter local conditions. An enrichment in $\delta^{13}C_{TOC}$ values reflects warmer conditions, with an increase in C_4 vegetation. These results are not concordant with those of Grundling *et al.* (1998), which record the development of *Podocarpus*-abundant forest after *ca.* 43000 years BP at Mfabeni. However, these discrepancies can probably be attributed to chronological errors resulting from the potential contamination of radiocarbon results. In other words, similar palaeoenvironmental histories are inferred from both records; these histories are, however, out of sequence as a result of chronological differences. Warm, wet conditions at Mfabeni are supported within the Transvaalian Ecozone by similar conditions recorded at Tswaing at *ca.* 43500 years BP (Scott 1999a).

It is evident from the pollen record that Cyperaceae remain prominent, with very little change in the pollen spectrum through the following *ca.* 15000 years. $\delta^{13}C_{TOC}$ values remain heavy at *ca.* -18‰ through this time, suggesting the dominance of C_4 vegetation. Warm, wet local conditions are inferred for the period *ca.* 41000-25500 years bp. The results of Grundling *et al.* (1998) indicate forest retreat after *ca.* 33000 years BP, with the development of grassland vegetation. While these results do not concur with those of this study, this can be attributed to chronological discrepancies, as this time period is characterised by age reversals in the case of both sets of cores.

There is an abrupt shift from Cyperaceae to Poaceae dominated pollen spectra at *ca.* 25500 Cal years BP (Z-4a). A diversity of herbaceous taxa during this period reflects the establishment of stable grassland, suggesting the development of drier local conditions. This is supported by a steady decline in Cyperaceae, which lasts until *ca.* 5500 Cal years BP. Very little change in the pollen signal is recorded at the Last Glacial Maximum (LGM, *ca.* 18000 years BP), although a significant depletion in $\delta^{13}C_{TOC}$ values at *ca.* 18100 Cal years BP indicates the dominance of C_3 vegetation during this event, reflecting considerably colder conditions. Although no sudden changes in vegetation composition are indicated at the LGM, the development of cold, dry conditions is in agreement with results from previous studies within the Transvaalian Ecozone (Botha *et al.* 1992; Partridge 1997; Scott *et al.* 2003). Alternatively, it could be argued that a shift towards drier conditions at Mfabeni after *ca.* 25500 Cal years BP reflects an early onset of the LGM. This is feasible since Mfabeni falls within a coastal zone, and the moderating effect of the ocean may have resulted in a gradual drying trend rather than a sudden very dry event. The results of Grundling *et al.* (1998) contrast with regional indications for the LGM, suggesting an increase in aquatic elements, with the development of wetter conditions at Mfabeni.

A slight increase in arboreal taxa is evident after *ca.* 15000 Cal years BP, suggesting the development of canopy cover as a result of succession from grassland to savanna (Z-4b). Besides a progressive decline in Cyperaceae, very little change in the pollen spectrum is recorded. Increases in arboreal pollen are supported by a slight depletion in $\delta^{13}C_{TOC}$ values, reflecting an increase in C_3 plants and an associated cooling trend. Similarly, an increase in arboreal taxa is recorded by Grundling *et al.* (1998) after *ca.*

11570 years BP. Evidence for the establishment of *Podocarpus* forest stands in the former Orange Free State after *ca.* 13000 supports indications of moist, cool climate at Mfabeni towards the Pleistocene/Holocene boundary. The development of savanna vegetation during the Terminal Pleistocene, coupled with a decrease in aquatics, reflects a drying trend, while the $\delta^{13}C_{TOC}$ record indicates cooling. These results are strengthened by the Tswaing (Scott 1999b) and Wonderkrater (Scott *et al.* 2003) records, which indicate cool, dry conditions during the Terminal Pleistocene.

The Early Holocene witnessed an initial increase in grassland, followed by the reestablishment of *Podocarpus*-abundant forests after *ca.* 7500 Cal years BP (Z-5). This trend is mirrored in the $\delta^{13}C_{TOC}$ record, with initial enrichment in $\delta^{13}C_{TOC}$ values followed by a depletion after *ca.* 7200 Cal years BP. Warm conditions during the Early Holocene are supported by data from the Transvaal (Scott 1990b; Scott *et al.* 2003), which record the expansion of warm, semi-arid savanna during this time (Scott 1983; 1987a). An increase in both the abundance and diversity of arboreal pollen taxa between *ca.* 7500 and 6000 Cal years BP is recorded. This is followed by a sharp decrease in arboreal pollen after *ca.* 6000 Cal years BP, with an increase in pteridophytes reflecting the expansion of forest margin, possibly as a result of seasonal flooding. Cyperaceae record a steady decrease through this time period, indicating continued local drying.

Forest expansion is recorded after *ca.* 5600 Cal years BP, by increasing arboreal pollen and decreasing pteridophytes (Z-6a). An enrichment in $\delta^{13}C_{TOC}$ values at this time reflects an increase in C_4 vegetation and associated warming. Once again, this discrepancy may be attributed to the fact that the $\delta^{13}C$ record reflects local vegetation, or to the existence of both C_3 and C_4 Cyperaceae.

After *ca.* 4500 Cal years BP, a further increase in arboreal pollen taxa, including Flacourtiaceae, Moraceae and Podocarpaceae, is recorded (Z-6b). An increase in arboreal taxa is supported by a gradual depletion in $\delta^{13}C_{TOC}$ values during this period, reflecting an increase in C_3 vegetation and related cooler conditions. Cool, wet indications at Mfabeni are in agreement with evidence from Wonderwerk, which

records the establishment of bushveld vegetation at *ca.* 4000 years BP, reflecting a cool, wet environment.

Forest retreat is recorded after *ca.* 3500 Cal years BP, with the replacement of arboreal pollen by trilete pteridophyte spores (Z-7). While this may relate to the expansion of pteridophyte dominated forest margin, it is more likely that the dominance of the pollen spectrum by trilete spores reflects selective preservation as a result of adverse climate. The onset of adverse climatic conditions at this time is similarly recorded at Wonderkrater and Tswaing, with evidence for very low temperatures and dry conditions at *ca.* 3000 years BP (Scott 1990b; Scott *et al.* 2003). Whether or not this increase in the relative frequency of trilete spores is related to selective preservation, forest retreat is recorded during this period, as evidenced by the lack of arboreal pollen taxa in later samples. Forest retreat is similarly recorded after the mid-Holocene at Mfabeni (Grundling *et al.* 1998) and further north at Nhlangu (Mazus 1996). Forest retreat at this time is further supported by the retreat of *Podocarpus*-abundant forest at Lake Teza after *ca.* 3400 years BP (Scott and Steenkamp 1996).

At *ca.* 2300 Cal years BP, a second major increase in trilete spores is recorded, once again suggesting the onset of adverse conditions (Z-8). Dry conditions are similarly recorded elsewhere in the Transvaalian Ecozone at *ca.* 2000 years BP (Scott and Vogel 1978; Scott 1982b).

A short cool, moist spell resulting in forest expansion, is recorded after *ca.* 2000 Cal years BP. This is followed by an increase in Cyperaceae, reflecting a shift towards wetter local conditions (Z-9). An overall enrichment in $\delta^{13}C_{TOC}$ values is indicated during this period, suggesting warmer conditions.

The last *ca.* 1000 years are characterised by the dominance of Poaceae, with low relative frequencies of arboreal taxa and Cyperaceae (Z-10). Warm temperatures are indicated by enriched $\delta^{13}C_{TOC}$ values, while a high proportion of Chenopodiaceae suggests a relatively dry climate. The pollen spectrum, together with the $\delta^{13}C_{TOC}$ record, indicates savanna type vegetation similar to that of the present. The

establishment of swamp forest vegetation at Mfabeni is indicated at *ca.* 600 Cal years BP, by Grundling *et al.* (1998). A summary of palaeoenvironmental indications from the Mfabeni record has been provided in table 6.1.

Table 6.1 Summary of vegetation history and inferred palaeoenvironmental changes at Mfabeni.

Time period (years BP)	Vegetation history	Inferred environmental conditions
ca. 2000-Present	Mosaic of reed/sedge and grassland/savanna type vegetation; establishment of swamp forest	warm and dry
ca. 3500-2000	Retreat of *Podocarpus*- abundant forest; expanded pteridophyte dominated forest margin	warm and locally wet
ca. 9000-3500	*Podocarpus* -abundant forest expansion	cool and relatively moist
ca. 25000-9000	Expansion of grassland component; reduced reed/sedge vegetation	cold and dry
ca. 44500-25000	*Podocarpus* -abundant forest retreat; local expansion of swampy reed/sedge elements	warm and locally wet
ca. 47500-44500	Succession from savanna/woodland to *Podocarpus* -abundant forest	cool and relatively moist
>47500	Grassland/savanna dominated	warm and dry

6.2.2. Forest history

6.2.2.1. Forest composition and the role of Podocarpus

Forest species composition, in particular with regards the importance of *Podocarpus*, is difficult to assess within the pollen record, and requires careful consideration in terms of the production and dispersal qualities of this taxon. *Podocarpus* pollen grains are very well dispersed, often leading to over-representation in the pollen record (Coetzee 1967; Hamilton 1972; Scott *et al.* 1992). Coetzee (1967) recommends that a presence of 10-20% indicates close proximity of the species, while frequencies greater than 20% indicate the presence of *Podocarpus* forest. Following this recommendation, the Mfabeni record indicates *Podocarpus* forest at depths of 8.35 and 8.6m (*ca.* 46000 years bp; figure 6.1). Forest vegetation inferred at depths of 7.6m (*ca.* 45000 years bp), 2.3m (*ca.* 7500 Cal years BP) and 1.4m (*ca.* 4000 Cal years BP) indicates *Podocarpus* species in close proximity (figure 6.1) and can therefore be termed *Podocarpus*-abundant forest. Forest composition inferred from Holocene spectra shows the dominance of other arboreal pollen types over

Podocarpus pollen, as compared with *Podocarpus* dominated forests in the Pleistocene (figure 6.1). This trend suggests a shift towards swamp forest vegetation during the Holocene, with *Podocarpus* comprising a lesser proportion of this forest type. This is concordant with the results of Mazus (2000), which record a northward migration of *Podocarpus* forests along the Maputaland Coastal Plain during the Holocene. The current distribution of the Podocarpaceae family along the Maputaland coast is mainly restricted to the Kosi Bay swamp forests, although it is found further south at very low frequencies (<1% of the vegetation composition; Scott *et al.* 1992).

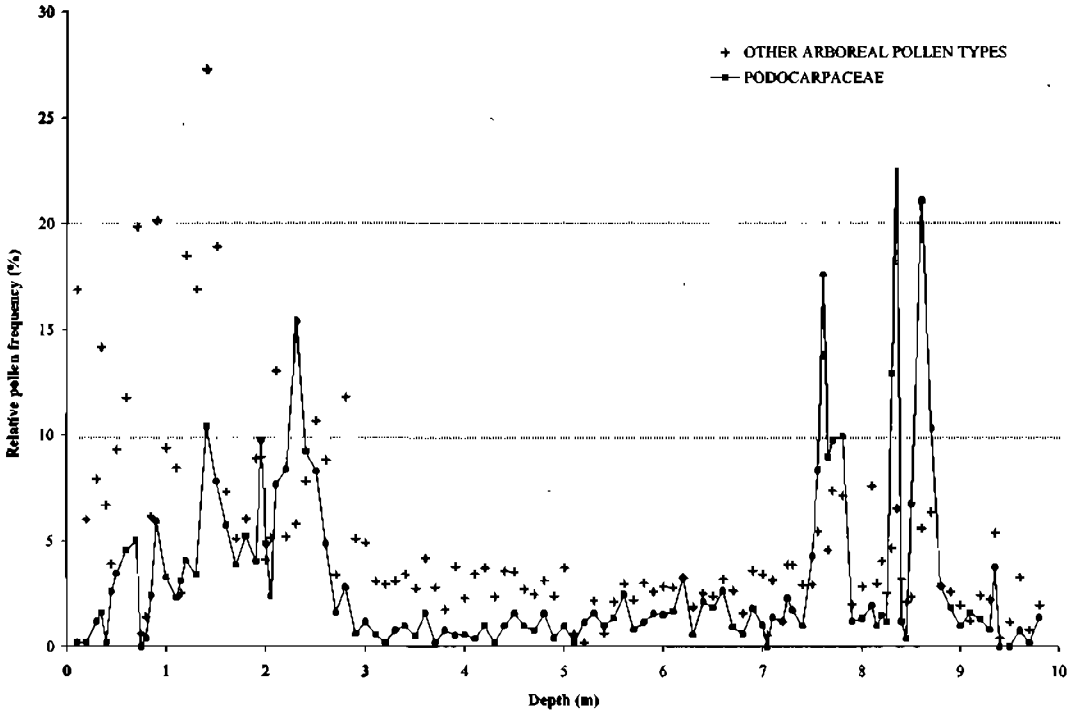

Figure 6.1 Relative frequencies of Podocarpus pollen in relation to other arboreal pollen types through the Mfabeni pollen profile. The presence of *Podocarpus* forest is indicated by *Podocarpus* frequencies >20%, while close proximity is indicated by frequencies of 10-20%.

6.2.2.2. Comparison with bioclimatic predictions

The Mfabeni pollen record displays marked changes in the composition and extent of forest vegetation over the past *ca.* 48000 years. Forest history at Mfabeni has been compared with predicted distributions of indigenous forest in KwaZulu-Natal, based on regional temperature indications for southern Africa (figure 6.2; Eeley *et al.* 1999). Predictions were made using a BIOCLIM-type modelling approach, which explored

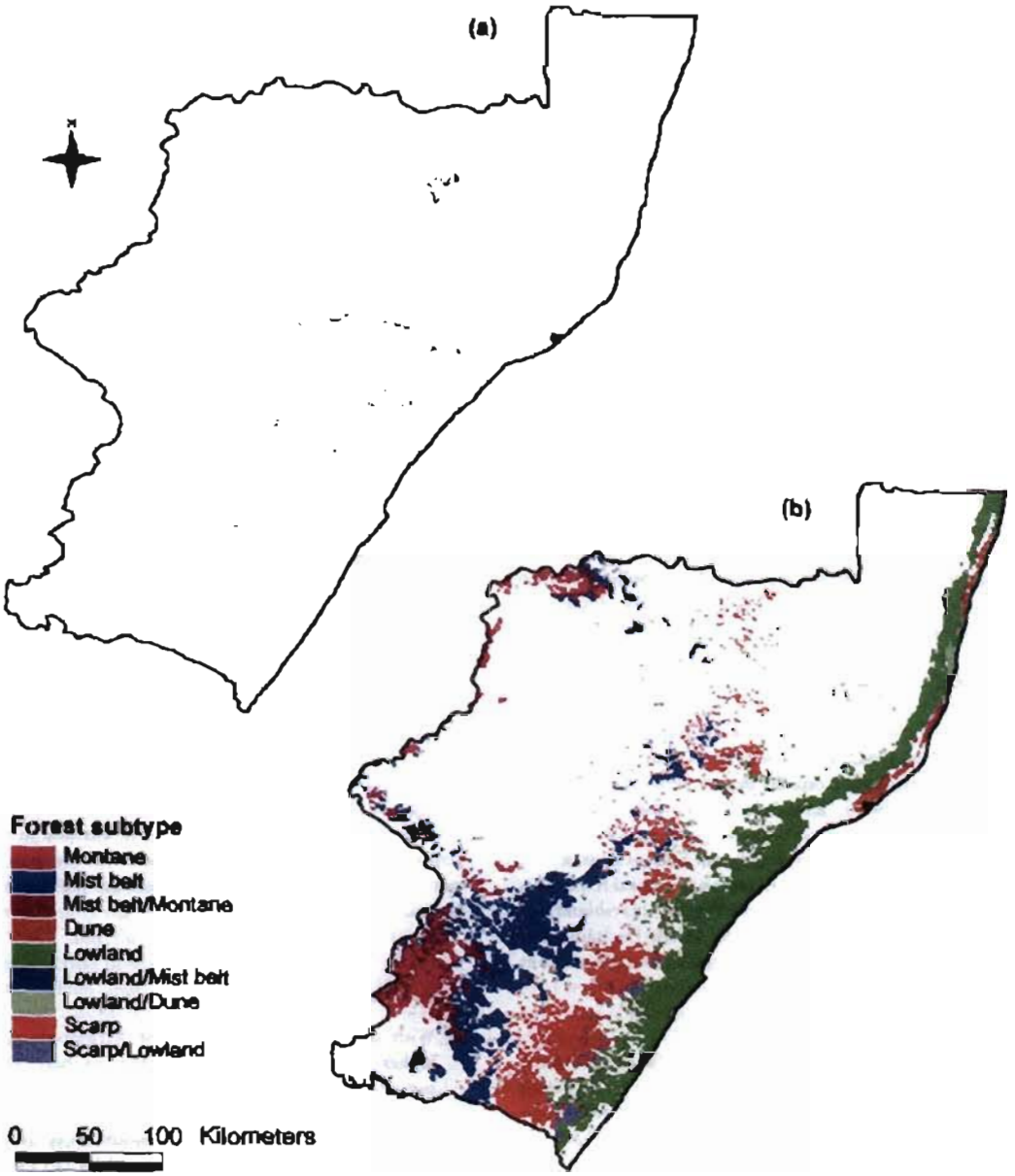

Figure 6.2 The predicted distribution of indigenous forest in KwaZulu-Natal under the climatic conditions of (a) the Last Glacial Maximum (LGM; *ca.* 18000 years BP), and (b) the Holocene Altithermal (*ca.* 8000-6000 years BP). Reprinted from Eeley *et al.* (1999) with kind permission from Blackwell Scientific Publishing.

the impact of palaeoclimatic change on forest distribution during the most extreme recent climatic events, *viz.* the LGM and the Holocene Altithermal (Eeley *et al.* 1999). Predictions for the LGM (*ca.* 18000 years BP) concur with the Mfabeni pollen record, which indicates contracted forest refugia as a result of significantly colder, drier conditions (Eeley *et al.* 1999). Predictions for the Holocene Altithermal (*ca.* 8000-6000 years BP) further support the Mfabeni pollen record by indicating forest growth and expansion as a result of warmer, wetter conditions (Eeley *et al.* 1999). As predicted distributions were made on a bioclimatic basis, and relied on regional indications of climatic conditions as derived from previous palaeoclimatic research, they provide a good indication of forest distribution patterns during these time periods. Thus, strong agreement between these predictions and the Mfabeni pollen record, which are derived from markedly different data sources, provides good support for the Mfabeni palaeoreconstruction.

6.2.3. Human impact

During the last *ca.* 2000 years, and particularly since the advent of European colonists, considerable impacts on the natural environment are recorded across southern Africa (Deacon and Lancaster 1988), for example at Verlorenvlei (Meadows *et al.* 1994). Along the Zululand coast in particular, Iron Age human settlements are recorded to have impacted upon dune vegetation through hunting, overgrazing, intentional fires, clearing of forest for ploughing and shifting cultivation (Hall and Vogel 1978; Hall 1981). Despite this, the Mfabeni pollen record contains no indications of anthropogenic impact, e.g. decreased arboreal pollen as a result of clearing and burning of woodland or increases in exotic pollen. While it may be argued that Podocarpaceae/Myrtaceae may have been mistaken for/include exotic species, e.g. *Pinus* and *Eucalyptus*, no significant increases in these families were indicated in the appropriate zone (Z-10). Furthermore, no traces of ash or charcoal, which provide evidence of burning, were recorded in the Mfabeni core. Certain weedy Asteraceae are used as indicators of disturbance (e.g. Scott *et al.* 1991), however, low Asteraceae frequencies are recorded throughout the Mfabeni record, inhibiting the use of this taxon as an indicator of human activity. This lack of evidence for human impact at Mfabeni is intriguing, and may be explained by possible loss of recent sediments from the record as a result of erosion.

6.3. INTERPRETIVE LIMITATIONS

While the results of both pollen and $\delta^{13}C$ analyses are quantitative, it is the interpretation of these results that is qualitative and thus subjective, requiring careful consideration. This section serves to discuss potential problems associated with the interpretation of the pollen and $\delta^{13}C$ records, while offering solutions to these limitations. Problems with representivity, selective preservation and the interpretation of conflicting indicators and data types are discussed. Moreover, the impact of chronological discrepancies on the intercomparison of palaeoenvironmental studies are examined.

6.3.1. Pollen record

6.3.1.1. Local versus regional pollen signal

Conflicting indications between local and regional pollen signals complicate interpretation of the pollen record. The importance of local moisture indicators, such as Cyperaceae, is difficult to gauge, as aquatic and semi-aquatic plants are strongly controlled by local water level fluctuations (Scott 1999a). As a consequence, aquatic and semi-aquatic pollen percentages should be interpreted as reflecting the relationship between water level and sediment surface, rather than water availability (Scott 1999a). For the purposes of this study, local and regional pollen signals were differentiated through the construction of a regional pollen diagram, which excluded local pollen taxa (Pteridophyta and Cyperaceae). This approach proved fairly successful in aiding interpretation, by focussing on regional pollen taxa, hence representing general environmental and climatic trends. One limitation of this approach is, however, the inability of the pollen analyst to distinguish between hydrophilous (aquatic; local) and non-hydrophilous grasses (non-aquatic; regional), although it is standard practice to classify all Poaceae within the regional signal (e.g. Scott and Vogel 1978).

6.3.1.2. Relative versus absolute pollen data

The representivity of relative versus absolute count data further complicates interpretation of the pollen record, as apparent fluctuations in the relative frequency of certain pollen taxa are sometimes only a product of changes in other taxa. Thus,

absolute and relative pollen data should be used in conjunction as a means of validating major changes in the relative composition of the pollen spectrum. This technique was successfully applied in investigating fluctuations in the dominance of Poaceae and Cyperaceae within the Mfabeni pollen record.

6.3.1.3. Selective preservation

Differential preservation of certain pollen taxa, according to grain structure/resilience, presented additional difficulties in interpreting pollen spectra. For example, short-lived dominance of the pollen spectrum by trilete pteridophyte spores at *ca.* 3500 Cal years BP and again at *ca.* 2300 Cal years BP, suggests differential preservation. It is likely that these changes indicate the survival of robust trilete spores during dry, aerobic or generally adverse pollen preservation conditions. Trilete pteridophyte spores are well represented relative to other palynomorphs in samples where the total number of fossil pollen grains is low, suggesting some degree of pollen destruction (Figure 6.3). Thus, during periods where pollen preservation was poor, a high proportion (up to approximately 85%) of surviving grains were trilete spores (figure 6.3). In contrast, where pollen preservation was high, a far lesser proportion of trilete spores was recorded (figure 6.3). This trend is indicative of selective preservation of trilete spores over other palynomorphs. Selective preservation under adverse (dry, aerobic) conditions has been previously recorded in the Tswaing Crater (Partridge *et al.* 1993; Scott 1999) and Blydefontein sequences (Scott *et al.* 2005).

6.3.2. $\delta^{13}C$ record

Difficulties in representivity are also experienced in interpreting the $\delta^{13}C$ record, which may only represent vegetation growing within the actual peatland, thereby reflecting only local vegetation. Interpretation of the $\delta^{13}C$ record within an often Cyperaceae dominated environment, such as Mfabeni, is further complicated by the existence of both C_3 and C_4 Cyperaceae. This limits the ability of the analyst to distinguish between arboreal and non-arboreal vegetation in the record. Despite these limitations, pollen and $\delta^{13}C$ data do provide an important means of reconstructing palaeoenvironments, especially when integrated, as demonstrated by the Mfabeni profile.

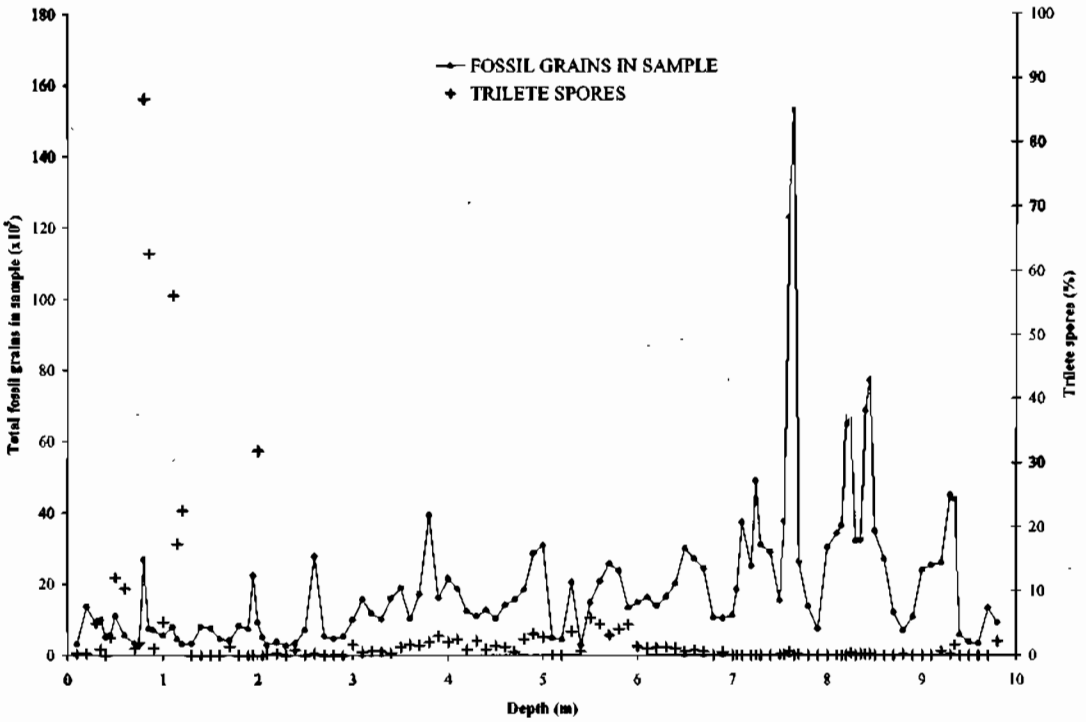

Figure 6.3 Total fossil grains per sample in the Mfabeni profile, compared with trilete pteridophyte spores.

6.3.3. Chronological control

Assessment of the Mfabeni palaeoenvironmental record, by comparison with records from Maputaland, the Transvaalian Ecozone and southern Africa has proven problematic in certain cases. This is attributed to differences in chronological control, especially as regards contaminated and calibrated versus uncalibrated radiocarbon ages. This limitation is best exemplified through comparison of this study with the record of Grundling *et al.* (1998), albeit less detailed. Both sets of results indicate a sequence of expansion and retreat of *Podocarpus*-abundant forest, amongst other similarities. However, there is an apparent mismatch between these records, which can be directly related to chronological discrepancies.

6.4. CONCLUSION

The Late Quaternary at Mfabeni was characterised by successional changes from grassland to savanna to *Podocarpus*-abundant forests, as a result of cyclical changes in local moisture conditions. The moderated nature of cooling and drying trends

experienced during the LGM can be probably be attributed to the proximity of the site to the ocean. Major environmental indications through the Mfabeni record are well supported by evidence from previous studies within the Transvaalian Ecozone and southern Africa. While a similar sequence of vegetational changes is evident from a previous Mfabeni record (Grundling *et al.* 1998), differences in the timing of these changes are probably as a result of chronological discrepancies.

CHAPTER SEVEN
SYNTHESIS AND CONCLUSIONS

7.1. INTRODUCTION

The purpose of this chapter is to provide a synthesis of palaeoenvironmental changes at Mfabeni, thus highlighting the most important results of this research. Based on these results, and the merits and limitations thereof, further research directions are suggested. Finally, the initial aim and objectives of the research are revisited, to assess the extent to which these have been addressed.

7.2. SYNTHESIS OF PALAEOENVIRONMENTAL CHANGES

A summary of the Late Quaternary palaeoreconstruction provided in section 6.2 is presented as figure 7.1. This diagram depicts a synopsis of major environmental changes at Mfabeni over the past *ca.* 48000 years, and is discussed below in terms of its vegetational and climatic implications.

Prior to *ca.* 47500 years bp, warm, fairly dry conditions are inferred, with the dominance of open grassland vegetation. Fynbos/dune elements, indicative of dry conditions, are present on coastal dune systems, while swampy vegetation is restricted to low lying areas. A succession from open grassland to savanna woodland to *Podocarpus*-abundant forests is recorded by *ca.* 47500 years bp, suggesting the development of moist, cool conditions. After *ca.* 44500 years bp, warm, wet local conditions are indicated, with the retreat of forests and expansion of swampy, Cyperaceae dominated vegetation. Cool, dry conditions are recorded after *ca.* 25000 Cal years BP, with a shift from Cyperaceae to Poaceae dominated vegetation. This change is likely to reflect an early onset of the LGM, with a steady shift towards cooler, drier conditions during the Terminal Pleistocene.

A succession from grassland to *Podocarpus*-abundant forest is indicated during the Early Holocene (*ca.* 9000 Cal years BP), reflecting moist, cool conditions. During the Late Holocene (*ca.* 3500 Cal years BP) warmer, wetter local conditions are inferred, with the expansion of pteridophyte dominated forest margin. The last *ca.* 2000 years

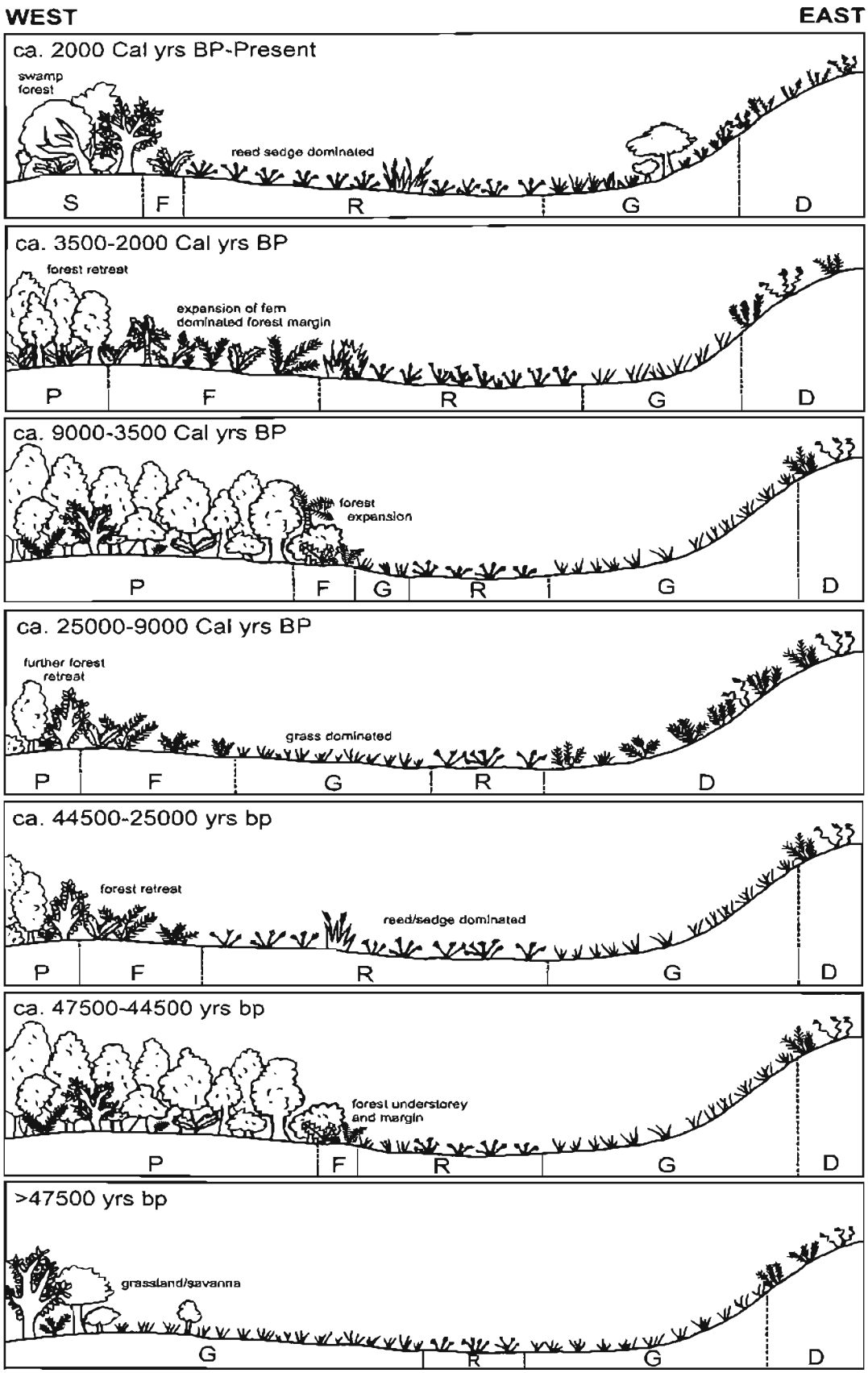

Figure 7.1 Schematic diagram indicating summarised palaeoenvironmental changes at Mfabeni over the past *ca.* 48000 years. Codes denote vegetation types where S=swamp forest; F=fern dominated forest margin and understorey; R=reed/sedge swamp; G=grassland; D=dune/fynbos elements; and P=Podocarpus-abundant forest.

records a steady shift towards drier conditions, with the expansion of grassland/savanna elements and establishment of swamp forest vegetation.

7.3. FUTURE RESEARCH DIRECTIONS

The results of this study are generally in agreement with palaeoenvironmental indications from previous studies in the Transvaalian Ecozone and southern Africa (refer to palaeoreconstruction; section 6.2.1), thus providing good support for the Mfabeni sequence. However, climatic conditions recorded at Mfabeni are noticeably moderated as compared with sites further inland, especially as regards the LGM. This can be attributed to the proximity of the site to the ocean, and provides support for division of the broad Transvaalian Ecozone into coastal and inland subzones. Future research into coastal palaeoenvironments within the Transvaalian Ecozone, as opposed to the comparatively well-studied inland areas, will shed further light on this subject.

The Mfabeni record falls within a largely understudied part of southern Africa, thus extending our knowledge of palaeoenvironments in the subregion. In addition, the Mfabeni palaeoreconstruction comprises a continuous record, covering a relatively long time span of almost 50000 years, thus making a significant contribution towards our limited understanding of the palaeenvironmental history of Maputaland, and of the KwaZulu-Natal province. High levels of pollen preservation within the Mfabeni record, together with its relatively old sediments, suggests potential for future palynological studies in the abundant peatlands of the Maputaland Coastal Plain. Improved understanding of environmental change within KwaZulu-Natal, as compared with the well studied former Transvaal, would provide a more balanced synthesis of Late Quaternary palaeoenvironments of the Transvaalian Ecozone.

7.4. REVIEW OF AIM AND OBJECTIVES

The aim of this research was to use palynology to investigate Late Quaternary climatic conditions and vegetation changes along the Maputaland coastal plain. This was achieved through the completion of several specific research objectives, the details of which are described below:

(i) **To expand on the existing pollen reference collection to include species from Maputaland, and furthermore, to convert these combined reference slides to digital format, thus setting up a digital image reference database.**

This objective involved creation of pollen reference slides from fresh and herbarium material to improve upon the existing pollen reference collection, which was obtained from a previous study in the Drakensberg region (Hill 1992). Pollen reference slides were digitally photographed at 400X magnification and used to compile a database of 350 digital reference slides. In addition, various pollen reference books/atlases were used to supplement the existing reference collection.

(ii) **To use a suitable coring methodology and sampling strategy to extract a minimally disturbed continuous sediment core from the Mfabeni peatland.**

Appropriate literature was consulted in order to select a suitable coring device, the Russian peat sampler, for the purpose of core extraction from the Mfabeni Peatland. Previous research on the stratigraphy of the peatland was used in the location of the deepest point in the Mfabeni peat profile, thus guiding the selection of an optimal coring site.

(iii) **To obtain radiocarbon ages for a selection of subsamples, and to calibrate these ages using appropriate calibration datasets, such that independent chronological control is established for the length of the core.**

Subsamples were extracted from suitable basal and intermediate layers for radiocarbon dating, such that the ages of important stratigraphical boundaries could be determined e.g. sand lenses. Each radiocarbon age was critically analysed for potential contamination by comparison with results in strata above and below, and using evidence in the pollen and $\delta^{13}C$ records. Results suspected of contamination were rejected, and remaining results were used to provide chronological control for the study. Where possible, radiocarbon ages were calibrated using the Pretoria Calibration Program (CALP 1.02) in conjunction

with the SH98 calibration dataset, which extends back to 39879 years bp (Talma pers. comm.).

(iv) **To conduct a high resolution fossil pollen analysis of sediments preserved in the core, with the aim of reconstructing Late Quaternary vegetation history for the region.**

Both relative and absolute pollen counts were conducted at a 10cm resolution along the Mfabeni profile. Where further detail was required, a 5cm resolution was used. An appropriate count size was determined by comparing total counts of 250 and 500 fossil grains and conduting a chi-squared statistical test to investigate whether there was any significant difference between the results of these counts. The results of this test indicated no significant differences between counts of 250 and 500 fossil grains, thus suggesting that a count of 250 was sufficient. Pollen diagrams were constructed for both relative and absolute count data and the Constrained Incremental Sum of Squares (CONISS) analysis was used in the zonation of relative pollen data. The pollen sum was adjusted to create (i) a summary pollen diagram; (ii) a regional pollen diagram; and (iii) an indicator taxon pollen diagram, to aid in interpretation. Finally, the pollen record was described according to the pollen assemblages indicated in each pollen zone.

(v) **To conduct a stable carbon isotope ($\delta^{13}C$) analysis along the length of the core, as a complementary means of detecting changes in the relative composition of C_3 and C_4 plants though time.**

A stable carbon isotope ($\delta^{13}C$) analysis was conducted on 41 samples along the length of the core. The $\delta^{13}C$ record provided information regarding the relative composition of C_3 and C_4 plants occupying the peatland, which in turn allowed for inferences to be made regarding climatic conditions through the past *ca.* 48000 years at Mfabeni.

(vi) To make inferences regarding the sequence of climatic and environmental changes that occurred in the region during the time of deposition, using an indicator species approach in the interpretation of pollen data.

Pollen data were interpreted using an indicator species approach, which uses the presence (or absence) of indicator taxa, whose modern ecological tolerances are well understood, as a basis for reconstructing palaeoenvironments. Environmental indications derived from the pollen record were integrated with those from the $\delta^{13}C$ record, such a that stronger palaeoreconstruction based on both proxies could be developed. The major advantage of multi-proxy approaches is the 'potentially independent lines of evidence they offer for environmental reconstruction' (Lotter 2005, p. 374). Each proxy is subject to its own advantages and limitations, as evidenced by differences in the Mfabeni pollen and $\delta^{13}C$ records. Thus, the advantage of a multi-proxy approach can be demonstrated in its ability to recognise proxy-specific weaknesses, with the objective of building on the consistencies and explaining the discrepancies between proxies (Lotter 2005).

(vii) To place this palaeoenvironmental reconstruction within the context of previous studies of the Late Quaternary in southern Africa, and assess the extent to which these data concur.

The Mfabeni palaeoreconstruction was compared with previous studies from Maputaland, the Transvaalian Ecozone and southern Africa respectively, in order to assess the degree of correspondence between these records. On the basis of these comparisons, further research directions were suggested.

7.5. CONCLUSION

This chapter has provided a synthesis of the major environmental changes indicated at the Mfabeni Peatland for the Late Quaternary period, thus highlighting the most important findings of this research. Through comparison with previous palaeoenvironmental research in southern Africa, future research directions have been

suggested. In conclusion, an assessment was made of the extent to which the initial aim and objectives of the research were addressed.

Further pollen analytical studies, covering a 'much closer grid of sites', are urgently required for successful modelling of environmental change in southern Africa (Scott 2000, p. 349). Moreover, extension of palaeoenvironmental research to poorly studied areas is necessary if we are to develop a more precise understanding of past climatic changes in the subregion. This research has provided a continuous palaeoenvironmental record for the past *ca.* 50000 years at the Mfabeni Peatland, thereby furthering palaeoenvironmental research in Maputaland, and making a significant contribution to our understanding of the Late Quaternary in the southern African subregion.

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APPENDIX A

FULL SPECIES LIST FOR THE MFABENI PEATLAND

FAMILY	SPECIES	SOURCE
ACANTHACEAE	*Chaetacanthus burchelli*	Grewer 1997
ACANTHACEAE	*Thunbergia atriplicifo*	Grewer 1997
ALLISMATACEAE	*Alisma plantago-aqu*	Venter 2003
ALOEACEAE	*Aloe myriacantha*	Grewer 1997
AMARANTHACEAE	*Amaranthus hybridus*	Venter 2003
APIACEAE	*Centella asiatica*	Grewer 1997
APOCYNACEAE	*Voacanga thoursii*	Grewer 1997
ARECACEAE	*Phoenix reclinata*	Grewer 1997
ASCLEPIADACEAE	*Schizoglossum hamatum*	Grewer 1997
ASTERACEAE	*Berkheya radula*	Venter 2003
ASTERACEAE	*Bidens pilosa*	Venter 2003
ASTERACEAE	*Cirsium vulgare*	Venter 2003
ASTERACEAE	*Cosmos bipinnatus*	Venter 2003
ASTERACEAE	*Gerbera ambigua*	Grewer 1997
ASTERACEAE	*Helichrysum sp.*	Venter 2003
ASTERACEAE	*Hypochaeris radicata*	Venter 2003
ASTERACEAE	*Pseudognaphalium luteo-album*	Grewer 1997
ASTERACEAE	*Pseudognaphalium sp.*	Venter 2003
ASTERACEAE	*Senecio adnatus*	Grewer 1997
ASTERACEAE	*Tagetes minuta*	Venter 2003
ASTERACEAE	*Vernonia oligocephala*	Grewer 1997
ASTERACEAE	*Xanthium strumarium*	Venter 2003
BRASSICACEAE	*Sisymbrium thellungii*	Venter 2003
CAMPANULACEAE	*Lobelia erinus*	Grewer 1997
CAMPANULACEAE	*Lobelia pinifolia*	Grewer 1997
CHENOPODIACEAE	*Chenopodium album*	Venter 2003
CHRYSOBALANACEAE	*Parinari capensis*	Grewer 1997
COMBRETACEAE	*Combretum sp.*	Grewer 1997
COMMELINACEAE	*Commelina africana*	Grewer 1997
COMMELINACEAE	*Commelina sp.*	Grewer 1997
CUSSONIACEAE	*Cussonia sp.*	Grewer 1997
CYPERACEAE	*Bulbostylis contexta*	Grewer 1997
CYPERACEAE	*Cladium mariscus*	Grewer 1997
CYPERACEAE	*Cyperus denudatus*	Grewer 1997
CYPERACEAE	*Cyperus eragrostis*	Venter 2003
CYPERACEAE	*Cyperus esculentus*	Venter 2003
CYPERACEAE	*Cyperus fastigiatus*	Venter 2003
CYPERACEAE	*Cyperus natalensis*	Grewer 1997

FAMILY	SPECIES	SOURCE
CYPERACEAE	*Cyperus prolifer*	Grewer 1997
CYPERACEAE	*Cyperus pulcher*	Venter 2003
CYPERACEAE	*Cyperus sp.*	Venter 2003
CYPERACEAE	*Fimbristylis complanat*	Grewer 1997
CYPERACEAE	*Fimbristylis microcary*	Grewer 1997
CYPERACEAE	*Fuirena hirsuta*	Grewer 1997
CYPERACEAE	*Fuirena pachyrrhiza*	Grewer 1997
CYPERACEAE	*Kyllinga erecta*	Grewer 1997
CYPERACEAE	*Schoenoplect corymbosu*	Venter 2003
CYPERACEAE	*Scleria sobolifer*	Grewer 1997
DROSERACEAE	*Drosera natalensis*	Grewer 1997
EBENACEAE	*Diospyros lycioides*	Grewer 1997
ERIOCAULACEAE	*Eriocaulon dregei*	Grewer 1997
EUPHORBIACEAE	*Acalypha segetalis*	Grewer 1997
EUPHORBIACEAE	*Antidesma venosum*	Grewer 1997
EUPHORBIACEAE	*Bridelia micracantha*	Grewer 1997
EUPHORBIACEAE	*Macaranga capensis*	Grewer 1997
EUPHORBIACEAE	*Sapium ellipticum*	Grewer 1997
FABACEAE	*Albizia adianthifolia*	Grewer 1997
FABACEAE	*Chaemaechrista mimosoide*	Grewer 1997
FABACEAE	*Desmodium dregeanum*	Grewer 1997
FABACEAE	*Desmodium setigerum*	Grewer 1997
FABACEAE	*Dichrostachys cinerea*	Grewer 1997
FABACEAE	*Elephantorrhrhiza elephantina*	Grewer 1997
FABACEAE	*Eriosema cordatum*	Grewer 1997
FABACEAE	*Eriosema salignum*	Grewer 1997
FABACEAE	*Rhynchosia totta*	Grewer 1997
FABACEAE	*Stylosanthes fruticosa*	Grewer 1997
FABACEAE	*Tephrosia multijuga*	Grewer 1997
FABACEAE	*Trifolium africanum*	Venter 2003
FABACEAE	*Zornia capensis*	Grewer 1997
GENTIANACEAE	*Sebaea sedoides*	Grewer 1997
ICACINACEAE	*Apodytes dimidiata*	Grewer 1997
IRIDACEAE	*Dierama igneum*	Grewer 1997
JUNCACEAE	*Juncus kraussii*	Grewer 1997
LAURACEAE	*Cassytha filliformis*	Grewer 1997
LECYTHIDACEAE	*Barringtonia racemosa*	Grewer 1997
LILIACEAE	*Scilla nervosa*	Grewer 1997
LORANTHACEAE	*Erianthemum dregei*	Grewer 1997
MALVACEAE	*Hibiscus trionum*	Venter 2003
MENASPERMACEAE	*Cissampelos hirta*	Grewer 1997
MORACEAE	*Ficus sur*	Grewer 1997
MORACEAE	*Ficus trichopoda*	Grewer 1997

FAMILY	SPECIES	SOURCE
MORACEAE	*Ficus verruculosa*	Grewer 1997
MYRICACEAE	*Morella serrata*	Grewer 1997
MYRSINACEAE	*Rapanea melanophloeos*	Grewer 1997
MYRTACEAE	*Eugenia albanensis*	Grewer 1997
MYRTACEAE	*Syzigium cordatum*	Grewer 1997
MYRTACEAE	*Syzigium guineense*	Grewer 1997
ONAGRACEAE	*Epilobium hirsutum*	Venter 2003
ONAGRACEAE	*Oenthera rosea*	Venter 2003
OXALIDACEAE	*Oxalis corniculata*	Venter 2003
PERIPLOCACEAE	*Petopentia natalensis*	Venter 2003
PERIPLOCACEAE	*Raphionacme elata*	Grewer 1997
PHYTOLACCACEAE	*Phytolacca octandra*	Venter 2003
POACEAE	*Agrostis eriantha*	Venter 2003
POACEAE	*Alloteropsis semialata*	Grewer 1997
POACEAE	*Andropogon appendicula*	Grewer 1997
POACEAE	*Andropogon festuciform*	Grewer 1997
POACEAE	*Andropogon gayanus*	Grewer 1997
POACEAE	*Andropogon schirensis*	Grewer 1997
POACEAE	*Cymbopogon validus*	Grewer 1997
POACEAE	*Cynodon dactylon*	Venter 2003
POACEAE	*Digitaria eriantha*	Grewer 1997
POACEAE	*Digitaria sanguinalis*	Venter 2003
POACEAE	*Diheteropogo filifoliu*	Grewer 1997
POACEAE	*Diheteropogon amplecten*	Grewer 1997
POACEAE	*Elionurus muticus*	Grewer 1997
POACEAE	*Eluesine coracana*	Venter 2003
POACEAE	*Eragrostis sp.*	Grewer 1997
POACEAE	*Hemarthria altissima*	Venter 2003
POACEAE	*Hemarthria altissima*	Grewer 1997
POACEAE	*Heteropogon sp.*	Grewer 1997
POACEAE	*Hyparrhenia hirta*	Venter 2003
POACEAE	*Imperata cylindrica*	Grewer 1997
POACEAE	*Ischaemum fasciculatum*	Grewer 1997
POACEAE	*Leersia hexandra*	Grewer 1997
POACEAE	*Panicum dregeanum*	Grewer 1997
POACEAE	*Panicum hymeniochilum*	Grewer 1997
POACEAE	*Panicum maximum*	Grewer 1997
POACEAE	*Panicum schinzii*	Venter 2003
POACEAE	*Paspalum dilatatum*	Venter 2003
POACEAE	*Paspalum scrobiculatum*	Grewer 1997
POACEAE	*Pennisetum clandestinu*	Venter 2003
POACEAE	*Phragmites australis*	Venter 2003
POACEAE	*Rhynchospora corymbosa*	Grewer 1997

FAMILY	SPECIES	SOURCE
POACEAE	*Rhynchospora holoschoe*	Grewer 1997
POACEAE	*Setaria pumila*	Venter 2003
POACEAE	*Setaria sphacelata*	Grewer 1997
POACEAE	*Setaria verticillata*	Venter 2003
POACEAE	*Sporobolus centrifugus*	Grewer 1997
POACEAE	*Themeda triandra*	Grewer 1997
POACEAE	*Trachypogon spicatus*	Grewer 1997
POACEAE	*Trichopteryx dregeana*	Grewer 1997
POACEAE	*Tristachya leucothrix*	Grewer 1997
POACEAE	*Urelytrum agropyroides*	Grewer 1997
POACEAE	*Urochloa panicoides*	Venter 2003
POLYGONACEAE	*Oxygonum dregeanum subsp. dregeanum*	Grewer 1997
POLYGONACEAE	*Persicaria lapathifoli*	Venter 2003
POLYGONACEAE	*Persicaria sp.*	Venter 2003
POLYGONACEAE	*Rumex crispus*	Venter 2003
PRIMULACEAE	*Samolus valerandi*	Venter 2003
RANUNCULACEAE	*Ranunculus multifidus*	Venter 2003
RESTIONACEAE	*Restio distichus*	Grewer 1997
RHIZOPHORACEAE	*Cassipourea gummiflua*	Grewer 1997
RUBIACEAE	*Burchelia bubalina*	Grewer 1997
RUBIACEAE	*Keetia gueinzii*	Grewer 1997
RUBIACEAE	*Pavetta natalensis*	Grewer 1997
RUBIACEAE	*Psychotria capensis*	Grewer 1997
RUBIACEAE	*Psydrax obovata*	Grewer 1997
RUBIACEAE	*Tarenna pavettoides*	Grewer 1997
RUBIACEAE	*Tricalysia sonderiana*	Grewer 1997
SANTALACEAE	*Thesium junceum*	Grewer 1997
SAPINDACEAE	*Allophylus dregeanus*	Grewer 1997
SAPOTACEAE	*Mimusops obovata*	Grewer 1997
SCROPHULARIACEAE	*Halleria lucida*	Grewer 1997
SCROPHULARIACEAE	*Veronica anagallis*	Venter 2003
SMILACACEAE	*Smilax anceps*	Grewer 1997
SOLANACEAE	*Datura stamonium*	Venter 2003
SOLANACEAE	*Physalis angulata*	Venter 2003
SOLANACEAE	*Solanum nigrum*	Venter 2003
SOLANACEAE	*Solanum sisymbrifolium*	Venter 2003
STRELITZIACEAE	*Strelitzia nicolai*	Grewer 1997
THYMELEACEAE	*Gnidia kraussiana*	Grewer 1997
THYMELEACEAE	*Peddiae africana*	Grewer 1997
TYPHACEAE	*Typha capensis*	Venter 2003
VERBENACEAE	*Verbena bonariensis*	Venter 2003
VERBENACEAE	*Verbena brasiliensis*	Venter 2003
XYRIDACEAE	*Xyris natalensis*	Grewer 1997

APPENDIX B

REFERENCE COLLECTION SPECIES LIST

FAMILY	SPECIES	SITE	SOURCE*
BRACHYTHECIACEAE	*Oxyrrhynchium sp.*	Drakenberg	Hill 1992
BRYACEAE	*Bryum sp.*	Drakenberg	Hill 1992
DITRICHACEAE	*Ditrichum brachypodium*	Drakenberg	Hill 1992
FISSIDENTACEAE	*Fissidens ovatus*	Drakenberg	Hill 1992
SEMATOPHYLLACEAE	*Sematophyllum subpinnatum*	Drakenberg	Hill 1992
ACANTHACEAE	*Monechma sp.*	Nuweveldberg	Hill 1992
ACANTHACEAE	*Peristrophe cernua*	Cederberg	Hill 1992
AMARANTHACEAE	*Achyropsis leptostachya*	Cederberg	Hill 1992
ANACARDIACEAE	*Rhus dentate*	Drakenberg	Hill 1992
ANACARDIACEAE	*Rhus discolor*	Drakenberg	Hill 1992
ANACARDIACEAE	*Rhus lucida*	Drakenberg	Hill 1992
ANACARDIACEAE	*Rhus natalensis*	Mfabeni	Finch 2005
ANACARDIACEAE	*Rhus nebulosa*	Mfabeni	Finch 2005
ANACARDIACEAE	*Rhus tomentosa*	Drakenberg	Hill 1992
APIACEAE	*Centella asiatica*	Pietermaritzburg	NU
APIACEAE	*Heteromorpha arborescens*	Drakenberg	Hill 1992
APOCYNACEAE	*Carissa bispinosa*	Drakenberg	Hill 1992
APOCYNACEAE	*Pachycarpus campanulatus*	Drakenberg	Hill 1992
APOCYNACEAE	*Voacanga thouarsii*	Amanzimtoti	NU
ARALIACEAE	*Cussonia paniculata*	Drakenberg	Hill 1992
ASCLEPIADACEAE	*Asclepias oreophila*	Cobham	NU
ASTERACEAE	*Artemisia afra*	Nuweveldberg	Hill 1992
ASTERACEAE	*Aster bakerianus*	Drakenberg	Hill 1992
ASTERACEAE	*Athrixia fontana*	Drakenberg	Hill 1992
ASTERACEAE	*Chromolaena odorata*	S. America	NU
ASTERACEAE	*Felicia filifolia*	Cederberg	Hill 1992
ASTERACEAE	*Gnaphalium declinatum*	Cederberg	Hill 1992
ASTERACEAE	*Helichrysum sp.*	Drakenberg	Hill 1992
ASTERACEAE	*Helichrysum appendiculatum*	Mfabeni	Finch 2005
ASTERACEAE	*Helichrysum herbaceum*	Drakenberg	Hill 1992
ASTERACEAE	*Helichrysum miconiifolium*	Drakenberg	Hill 1992
ASTERACEAE	*Helichrysum oreophilum*	Drakenberg	Hill 1992
ASTERACEAE	*Helichrysum rugulosum*	Mfabeni	Finch 2005
ASTERACEAE	*Helichrysum setosum*	Drakenberg	Hill 1992
ASTERACEAE	*Macowania glandulosa*	Drakenberg	Hill 1992

* NU refers to the University of KwaZulu-Natal Herbarium

FAMILY	SPECIES	SITE	SOURCE
ASTERACEAE	*Othonna sp.*	Nuweveldberg	Hill 1992
ASTERACEAE	*Phymaspermum parvifolium*	Cederberg	Hill 1992
ASTERACEAE	*Senecio brevidentatus*	Drakenberg	Hill 1992
ASTERACEAE	*Senecio bupleuroides*	Drakenberg	Hill 1992
ASTERACEAE	*Senecio speciosus*	Drakenberg	Hill 1992
BEGONIACEAE	*Begonia dregei*	Drakenberg	Hill 1992
BEGONIACEAE	*Begonia sutherlandii*	Drakenberg	Hill 1992
BORAGINACEAE	*Myosotis sylvatica*	Drakenberg	Hill 1992
BRASSICACEAE	*Heliophila coronopifolia*	Cederberg	Hill 1992
BRASSICACEAE	*Heliophila dregeana*	Cederberg	Hill 1992
BRASSICACEAE	*Heliophila sauvissima*	Cederberg	Hill 1992
BUDDLEJACEAE	*Buddleja auriculata*	Cederberg	Hill 1992
BUDDLEJACEAE	*Buddleja dysophylla*	Cederberg	Hill 1992
BUDDLEJACEAE	*Buddleja salviifolia*	Drakenberg	Hill 1992
CAMPANULACEAE	*Wahlenbergia undulata*	Drakenberg	Hill 1992
CAPPARACEAE	*Boscia oleodes*	Cederberg	Hill 1992
CARYOPHYLLACEAE	*Silene gallica*	Cederberg	Hill 1992
CARYOPHYLLACEAE	*Silene undulata*	Drakenberg	Hill 1992
CARYOPHYLLACEAE	*Silene zeyheri*	Drakenberg	Hill 1992
CASUARINACEAE	*Casuarina cunninghamii*	Pietermaritzburg	NU
CELASTRACEAE	*Allocassine laurofolia*	Mfabeni	Finch 2005
CELASTRACEAE	*Gymnosporia heterophylla*	Drakenberg	Hill 1992
CELASTRACEAE	*Gymnosporia mossambicensis*	Drakenberg	Hill 1992
CELASTRACEAE	*Lauridea tetragona*	Drakenberg	Hill 1992
CELASTRACEAE	*Maytenus undata*	Drakenberg	Hill 1992
CELASTRACEAE	*Pterocelastrus tricuspidatus*	Drakenberg	Hill 1992
CLUSIACEAE	*Hypericum lalandii*	Bulwer	NU
COMBRETACEAE	*Combretum celastroides*	Mfabeni	Finch 2005
CONVOLVULACEAE	*Ipomoea sp.*	Mfabeni	Finch 2005
CORNACEAE	*Curtisia dentata*	Drakenberg	Hill 1992
CRASSULACEAE	*Crassula obovata var. obovata*	Drakenberg	Hill 1992
CRASSULACEAE	*Crassula rupestris*	Cederberg	Hill 1992
CRASSULACEAE	*Crassula umbraticola*	Drakenberg	Hill 1992
CRASSULACEAE	*Kalanchoe rotundifolia*	Cederberg	Hill 1992
CRASSULACEAE	*Tylecodon reticulatus*	Cederberg	Hill 1992
CRASSULACEAE	*Tylecodon ventricosus*	Cederberg	Hill 1992
DIPSACACIAE	*Scabiosa columbaria*	Drakenberg	Hill 1992
DIPSACACIAE	*Scabiosa columbaria*	Mfabeni	Finch 2005
DIPSACACIAE	*Scabiosa drakensbergensis*	Drakenberg	Hill 1992
EBENACEAE	*Diospyros austro-africana*	Drakenberg	Hill 1992
EBENACEAE	*Diospyros lycioides*	Drakenberg	Hill 1992
EBENACEAE	*Diospyros scabrida*	Cederberg	Hill 1992
EBENACEAE	*Euclea divinorum*	Hluhluwe	NU

FAMILY	SPECIES	SITE	SOURCE
ERICACEAE	*Erica algida*	Drakenberg	Hill 1992
ERICACEAE	*Erica cerinthoides*	Drakenberg	Hill 1992
ERICACEAE	*Erica corifolia*	Drakenberg	Hill 1992
ERICACEAE	*Erica dracomontana*	Drakenberg	Hill 1992
ERICACEAE	*Erica straussiana*	Drakenberg	Hill 1992
ERYTHROXYLACEAE	*Erythroxylum delagoense*	Mfabeni	Finch 2005
ERYTHROXYLACEAE	*Erythroxylum pictum*	Mfabeni	Finch 2005
EUPHORBIACEAE	*Antidesma venosum*	Ngoye	NU
EUPHORBIACEAE	*Clutia sp.*	Cederberg	Hill 1992
EUPHORBIACEAE	*Euphorbia ericoides*	Drakenberg	Hill 1992
EUPHORBIACEAE	*Euphorbia erythrina*	Cederberg	Hill 1992
EUPHORBIACEAE	*Spirostachys africana*	Hluhluwe	NU
FABACEAE	*Acacia karroo*	Mfabeni	Finch 2005
FABACEAE	*Amphithalea villosa*	Cederberg	Hill 1992
FABACEAE	*Argyrolobium marginatum*	Drakenberg	Hill 1992
FABACEAE	*Argyrolobium sutherlandii*	Drakenberg	Hill 1992
FABACEAE	*Argyrolobium tuberosum*	Drakenberg	Hill 1992
FABACEAE	*Aspalanthus comptonii*	Cederberg	Hill 1992
FABACEAE	*Aspalanthus flexuosa*	Cederberg	Hill 1992
FABACEAE	*Aspalanthus linnearis*	Cederberg	Hill 1992
FABACEAE	*Aspalanthus polycephala*	Cederberg	Hill 1992
FABACEAE	*Aspalanthus villosa*	Cederberg	Hill 1992
FABACEAE	*Desmodium dregeana*	Ubombo	NU
FABACEAE	*Eriosema parviflorum*	Isipingo North	NU
FABACEAE	*Lessertia perennans*	Drakenberg	Hill 1992
FABACEAE	*Lotononis corymbosa*	Drakenberg	Hill 1992
FABACEAE	*Psoralea aphylla*	Cederberg	Hill 1992
FABACEAE	*Rafnia capensis subsp. dichotoma*	Cederberg	Hill 1992
FABACEAE	*Rafnia oppositia*	Cederberg	Hill 1992
FABACEAE	*Sesbania sesban*	Mfabeni	Finch 2005
FABACEAE	*Tephrosia marginella*	Drakenberg	Hill 1992
FABACEAE	*Wiborgia sericea*	Cederberg	Hill 1992
FLACOURTIACEAE	*Dovyalis zeyheri*	Drakenberg	Hill 1992
FLACOURTIACEAE	*Kiggelaria africana*	Drakenberg	Hill 1992
FLACOURTIACEAE	*Xylotheca kraussiana*	Mfabeni	Finch 2005
FUMARIACEAE	*Cysticapnos sp.*	Cederberg	Hill 1992
GENTIANACEAE	*Chironia krebsii*	Drakenberg	Hill 1992
GENTIANACEAE	*Sebaea natalensis*	Drakenberg	Hill 1992
GERANIACEAE	*Geranium ornithopodon*	Drakenberg	Hill 1992
GERANIACEAE	*Pelargonium caesipitosum*	Cederberg	Hill 1992
GERANIACEAE	*Pelargonium chamaedryfolium*	Cederberg	Hill 1992
GERANIACEAE	*Pelargonium coronopifolium*	Cederberg	Hill 1992
GERANIACEAE	*Pelargonium crispum*	Cederberg	Hill 1992

FAMILY	SPECIES	SITE	SOURCE
GERANIACEAE	*Pelargonium luridum*	Drakenberg	Hill 1992
GERANIACEAE	*Pelargonium zonale*	Drakenberg	Hill 1992
GESNERIACEAE	*Streptocarpus bolusii*	Drakenberg	Hill 1992
GESNERIACEAE	*Streptocarpus gardenii*	Drakenberg	Hill 1992
GREYIACEAE	*Greyia sutherlandii*	Drakenberg	Hill 1992
HALOPAGIDACEAE	*Laurembergia repens*	Zululand	NU
HYPERICACEAE	*Hypericum lalandii*	Drakenberg	Hill 1992
ICACINACEAE	*Apodytes dimidiata*	Drakenberg	Hill 1992
ICACINACEAE	*Apodytes dimidiata*	Tongaat	NU
ICACINACEAE	*Cassinopsis ilicifolia*	Drakenberg	Hill 1992
LAMIACEAE	*Becium obovatum*	Drakenberg	Hill 1992
LAMIACEAE	*Leonotis leonurus*	Drakenberg	Hill 1992
LAMIACEAE	*Leucas capensis*	Drakenberg	Hill 1992
LAMIACEAE	*Plectranthus grallatus*	Drakenberg	Hill 1992
LAMIACEAE	*Stachys aethiopica*	Drakenberg	Hill 1992
LAMIACEAE	*Stachys obtusifolia*	Drakenberg	Hill 1992
LAURACEAE	*Ocotea bullata*	Drakenberg	Hill 1992
LECYTHIDACEAE	*Barringtonia racemosa*	Ifafa	NU
LINACEAE	*Linum thunbergii*	Drakenberg	Hill 1992
LOBELIACEAE	*Cyphia sylvatica*	Drakenberg	Hill 1992
LOBELIACEAE	*Lobelia erinus*	Drakenberg	Hill 1992
LOBELIACEAE	*Monopsis decipiens*	Drakenberg	Hill 1992
LORANTHACEAE	*Moquiniella rubra*	Cederberg	Hill 1992
MALVACEAE	*Hibiscus sp.*	Mtunzini	Finch 2005
MALVACEAE	*Hibiscus trionum*	Drakenberg	Hill 1992
MELIACEAE	*Ekebergia capensis*	Drakenberg	Hill 1992
MESEMBRYANTHEMACEAE	*Mestoklema albanicum*	Cederberg	Hill 1992
MESEMBRYANTHEMACEAE	*Ruschia congesta*	Cederberg	Hill 1992
MOLLUGINACEAE	*Limeum aethiopicum*	Cederberg	Hill 1992
MOLLUGINACEAE	*Pharnaceum dichotomum*	Cederberg	Hill 1992
MONTINIACEAE	*Montinia sp.*	Cederberg	Hill 1992
MORACEAE	*Ficus cordata*	Cederberg	Hill 1992
MORACEAE	*Ficus ingens*	Drakenberg	Hill 1992
MYRICACEAE	*Morella integra*	Cederberg	Hill 1992
MYRICACEAE	*Morella pilulifera*	Drakenberg	Hill 1992
MYRTACEAE	*Eucalyptus camaldulensis*	Kimberley	NU
MYRTACEAE	*Eugenia natalia*	Inanda	NU
MYRTACEAE	*Syzigium cordatum*	Mfabeni	Finch 2005
MYRTACEAE	*Syzigium cordatum*	Kosi Bay	NU
NYMPHAEACEAE	*Nymphaea capensis*	Hluhluwe	NU
OLEACEAE	*Jasminum angulare*	Cederberg	Hill 1992
OLEACEAE	*Jasminum multipartitum*	Cederberg	Hill 1992
OLINEACEAE	*Olinia emarginatum*	Drakenberg	Hill 1992

FAMILY	SPECIES	SITE	SOURCE
OROBANCHACEAE	*Harveya laxiflora*	Drakenberg	Hill 1992
OROBANCHACEAE	*Sopubia cana*	Drakenberg	Hill 1992
OXALIDACEAE	*Oxalis obliquifolia*	Drakenberg	Hill 1992
OXALIDACEAE	*Oxalis smithiana*	Drakenberg	Hill 1992
PITTOSPORACEAE	*Pittosporum viridiflorum*	Drakenberg	Hill 1992
PLUMBAGINACEAE	*Plumbago auriculata*	Cederberg	Hill 1992
POLYGALACEAE	*Muraltia heisteria*	Cederberg	Hill 1992
POLYGALACEAE	*Polygala uncinata*	Cederberg	Hill 1992
POLYGALACEAE	*Polygala virgata*	Drakenberg	Hill 1992
PROTEACEAE	*Paranomus spicatus*	Cederberg	Hill 1992
PROTEACEAE	*Protea acuminata*	Cederberg	Hill 1992
PROTEACEAE	*Protea cryophila*	Cederberg	Hill 1992
PROTEACEAE	*Protea dracomontana*	Drakenberg	Hill 1992
PROTEACEAE	*Protea subvestita*	Drakenberg	Hill 1992
PROTEACEAE	*Serruria cygnea*	Cederberg	Hill 1992
RHAMNACEAE	*Phylica paniculata*	Drakenberg	Hill 1992
RHAMNACEAE	*Phylica thodei*	Drakenberg	Hill 1992
RHAMNACEAE	*Scutia myrtina*	Drakenberg	Hill 1992
ROSACEAE	*Cliffortia amplexistipula*	Cederberg	Hill 1992
ROSACEAE	*Cliffortia falcata*	Cederberg	Hill 1992
ROSACEAE	*Cliffortia linearifolia*	Drakenberg	Hill 1992
ROSACEAE	*Cliffortia paucistaminea*	Drakenberg	Hill 1992
ROSACEAE	*Cliffortia tuberculata*	Cederberg	Hill 1992
ROSACEAE	*Leucosidea sericea*	Drakenberg	Hill 1992
ROSACEAE	*Rubus rigidus*	Drakenberg	Hill 1992
RUBIACEAE	*Anthospermum galpinii*	Lusikisiki	NU
RUBIACEAE	*Burchelia bubalina*	Drakenberg	Hill 1992
RUBIACEAE	*Canthium ciliatum*	Drakenberg	Hill 1992
RUBIACEAE	*Canthium setiflorium*	Mfabeni	Finch 2005
RUBIACEAE	*Pentanisia prunelloides*	Drakenberg	Hill 1992
RUBIACEAE	*Tricalysia sonderiana*	Mfabeni	Finch 2005
RUTACEAE	*Agathosma divaricata*	Cederberg	Hill 1992
RUTACEAE	*Agathosma drageana*	Cederberg	Hill 1992
RUTACEAE	*Agathosma giftbergensis*	Cederberg	Hill 1992
RUTACEAE	*Calodendrum sapense*	Drakenberg	Hill 1992
RUTACEAE	*Clausena anisata*	Drakenberg	Hill 1992
SALICACEAE	*Salix mucronata subsp. hirsuta*	Cederberg	Hill 1992
SALICACEAE	*Salix mucronata subsp. woodii*	Drakenberg	Hill 1992
SANTALACEAE	*Thesium flexuosum*	Cederberg	Hill 1992
SANTALACEAE	*Thesium hispidulum*	Cederberg	Hill 1992
SANTALACEAE	*Thesium imbricatum*	Cederberg	Hill 1992
SCROPHULARIACEAE	*Aptosimum procumbens*	Cederberg	Hill 1992
SCROPHULARIACEAE	*Bowkeria verticillata*	Drakenberg	Hill 1992

FAMILY	SPECIES	SITE	SOURCE
SCROPHULARIACEAE	*Halleria lucida*	Drakenberg	Hill 1992
SCROPHULARIACEAE	*Pyhgelius capensis*	Drakenberg	Hill 1992
SCROPHULARIACEAE	*Selago albida*	Nuweveldberg	Hill 1992
SCROPHULARIACEAE	*Zaluzianskya maritima*	Drakenberg	Hill 1992
STERCULIACEAE	*Hermannia woodii*	Drakenberg	Hill 1992
THYMELEACEAE	*Dais cotinifolia*	Drakenberg	Hill 1992
THYMELEACEAE	*Gnidia cuneata*	Drakenberg	Hill 1992
THYMELEACEAE	*Passerina filiformis*	Drakenberg	Hill 1992
THYMELEACEAE	*Passerina montana*	Drakenberg	Hill 1992
ULMACEAE	*Celtis africana*	Ficksburg	NU
VERBENACEAE	*Avicennia marina*	The Haven	NU
CUPRESSACEAE	*Widdringtonia nodiflora*	Drakenberg	Hill 1992
PINACEAE	*Pinus patula*	Drakenberg	Hill 1992
PODOCARPACEAE	*Podocarpus falcatus*	Drakenberg	Hill 1992
PODOCARPACEAE	*Podocarpus latifolius*	Drakenberg	Hill 1992
AGAPANTHACEAE	*Agapanthus campanulatus*	Drakenberg	Hill 1992
ALLIACEAE	*Tulbaghia leucantha*	Drakenberg	Hill 1992
AMARYLLIDACEAE	*Cyrtanthus contractus*	Drakenberg	Hill 1992
AMARYLLIDACEAE	*Haemanthus sanguineus*	Cederberg	Hill 1992
AMARYLLIDACEAE	*Rhodohypoxis baurii*	Drakenberg	Hill 1992
ANTHERICACEAE	*Chlorophytum comosum*	Cederberg	Hill 1992
ANTHERICACEAE	*Chlorophytum cooperi*	Drakenberg	Hill 1992
APONOGETONACEAE	*Aponogeton junceus*	Cederberg	Hill 1992
ASPHODELACEAE	*Aloe claviflora*	Cederberg	Hill 1992
ASPHODELACEAE	*Bulbine minima*	Cederberg	Hill 1992
COLCHICACEAE	*Gloriosa superba*	Mfabeni	Finch 2005
COLCHICACEAE	*Sandersonia aurantiaca*	Drakenberg	Hill 1992
COMMELINACEAE	*Commelina africana*	Drakenberg	Hill 1992
COMMELINACEAE	*Commelina erecta*	Drakenberg	Hill 1992
COMMELINACEAE	*Cyanotis speciosa*	Drakenberg	Hill 1992
CYPERACEAE	*Cyperus compressus*	Mfabeni	Finch 2005
CYPERACEAE	*Cyperus obtusiflorus*	Drakenberg	Hill 1992
CYPERACEAE	*Cyperus rubicundus*	Cederberg	Hill 1992
CYPERACEAE	*Pycreus nitidus*	Cederberg	Hill 1992
CYPERACEAE	*Scleria poiformis*	Mfabeni	Finch 2005
DRACAENACEAE	*Sanseveria hyacinthoides*	Mfabeni	Finch 2005
HAEMODORACEAE	*Wachendorfia thyrsiflora*	Cederberg	Hill 1992
HYACINTHACEAE	*Dipcadi viride*	Drakenberg	Hill 1992
HYACINTHACEAE	*Drimia convallaroides*	Cederberg	Hill 1992
HYACINTHACEAE	*Galtonia candicans*	Drakenberg	Hill 1992
HYACINTHACEAE	*Ornithogalum maculatum*	Cederberg	Hill 1992
HYACINTHACEAE	*Schizocarpus nervosus*	Drakenberg	Hill 1992
HYPOXIDACEAE	*Spiloxene umbraticola*	Cederberg	Hill 1992

FAMILY	SPECIES	SITE	SOURCE
HYPOXIDEAE	*Hypoxis membranacea*	Drakenberg	Hill 1992
HYPOXIDEAE	*Hypoxis rigidula*	Drakenberg	Hill 1992
IRIDACEAE	*Aristea africana*	Cederberg	Hill 1992
IRIDACEAE	*Aristea cuspidata*	Cederberg	Hill 1992
IRIDACEAE	*Bobartia macrospatha*	Cederberg	Hill 1992
IRIDACEAE	*Dierama robustum*	Drakenberg	Hill 1992
IRIDACEAE	*Geissorhiza aspera*	Cederberg	Hill 1992
IRIDACEAE	*Geissorhiza cedarmontana*	Cederberg	Hill 1992
IRIDACEAE	*Geissorhiza juncea*	Cederberg	Hill 1992
IRIDACEAE	*Geissorhiza scillaris*	Cederberg	Hill 1992
IRIDACEAE	*Geissorhiza umbrosa*	Cederberg	Hill 1992
IRIDACEAE	*Gladiolus ecklonii*	Drakenberg	Hill 1992
IRIDACEAE	*Gladiolus guthriei*	Cederberg	Hill 1992
IRIDACEAE	*Gladiolus permeabilis*	Cederberg	Hill 1992
IRIDACEAE	*Ixia paucifolia*	Cederberg	Hill 1992
IRIDACEAE	*Moraea barkerae*	Cederberg	Hill 1992
IRIDACEAE	*Moraea cillata*	Cederberg	Hill 1992
IRIDACEAE	*Moraea cookii*	Cederberg	Hill 1992
IRIDACEAE	*Moraea simulans*	Cederberg	Hill 1992
IRIDACEAE	*Moraea trifida*	Drakenberg	Hill 1992
IRIDACEAE	*Romulea cruciata*	Cederberg	Hill 1992
IRIDACEAE	*Watsonia meriana*	Drakenberg	Hill 1992
ORCHIDACEAE	*Brachycorythis ovata*	Drakenberg	Hill 1992
ORCHIDACEAE	*Disa patula*	Drakenberg	Hill 1992
ORCHIDACEAE	*Disa stachyoides*	Drakenberg	Hill 1992
ORCHIDACEAE	*Eulophia aculeata*	Drakenberg	Hill 1992
ORCHIDACEAE	*Eulophia angolensis*	Mfabeni	Finch 2005
ORCHIDACEAE	*Eulophia calanthoides*	Drakenberg	Hill 1992
ORCHIDACEAE	*Eulophia foliosa*	Drakenberg	Hill 1992
ORCHIDACEAE	*Satyrium stenopetalum*	Cederberg	Hill 1992
PALMAE	*Phoenix reclinata*	The Haven	NU
POACEAE	*Bothriochloa sp.*	Mfabeni	Finch 2005
POACEAE	*Chloris virgata*	Cederberg	Hill 1992
POACEAE	*Cymbopogon sp.*	Mfabeni	Finch 2005
POACEAE	*Cynodon dactylon*	Cederberg	Hill 1992
POACEAE	*Dactyloctenium sp.*	Mfabeni	Finch 2005
POACEAE	*Digitaria eriantha*	Cederberg	Hill 1992
POACEAE	*Eragrostis sp.*	Mfabeni	Finch 2005
POACEAE	*Eragrostis ciliaris*	Mfabeni	Finch 2005
POACEAE	*Eragrostis obtusa*	Cederberg	Hill 1992
POACEAE	*Eragrostis racemosa*	Mfabeni	Finch 2005
POACEAE	*Imperata cylindrica*	Mfabeni	Finch 2005
POACEAE	*Melenis nerviglumis*	Cederberg	Hill 1992

FAMILY	SPECIES	SITE	SOURCE
POACEAE	*Melenis repens*	Mfabeni	Finch 2005
POACEAE	*Melica racemosa*	Cederberg	Hill 1992
POACEAE	*Miscanthus sp.*	Mfabeni	Finch 2005
POACEAE	*Panicum sp.*	Mfabeni	Finch 2005
POACEAE	*Panicum deustum*	Cederberg	Hill 1992
POACEAE	*Perotis patens*	Mfabeni	Finch 2005
POACEAE	*Setaria sphacelata*	Mfabeni	Finch 2005
POACEAE	*Stipa dregeana*	Cederberg	Hill 1992
POACEAE	*Themeda triandra*	Cederberg	Hill 1992
POACEAE	*Triraphis schinzii*	Mfabeni	Finch 2005
RESTIONACEAE	*Hypodiscus squamosus*	Cederberg	Hill 1992
RESTIONACEAE	*Thamnochortus bachmannii*	Cederberg	Hill 1992
RESTIONACEAE	*Thamnochortus erectus*	Cederberg	Hill 1992
RESTIONACEAE	*Willdenowia arescens*	Cederberg	Hill 1992
RESTIONACEAE	*Willdenowia stokoei*	Cederberg	Hill 1992
RESTIONACEAE	*Willdenowia sulcata*	Cederberg	Hill 1992
SMILACACEAE	*Smilax anceps*	Mfabeni	Finch 2005
SMILACACEAE	*Smilax anceps*	Sabie	NU
TECOPHILACEAE	*Cyanella alba*	Cederberg	Hill 1992
TECOPHILACEAE	*Cyanella orchidiformis*	Cederberg	Hill 1992
ANEMIACEAE	*Mohria caffrorum*	Drakenberg	Hill 1992
ASPLENIACEAE	*Asplenium aethiopicum*	Drakenberg	Hill 1992
ASPLENIACEAE	*Asplenium monanthes*	Drakenberg	Hill 1992
ASPLENIACEAE	*Asplenium stoloniferum*	Drakenberg	Hill 1992
ASPLENIACEAE	*Asplenium varians subsp. fimbriatum*	Drakenberg	Hill 1992
BLECHNACEAE	*Blechnum attenuatum*	Drakenberg	Hill 1992
BLECHNACEAE	*Blechnum australe*	Drakenberg	Hill 1992
BLECHNACEAE	*Blechnum inflexum*	Drakenberg	Hill 1992
BLECHNACEAE	*Blechnum punctulatum*	Drakenberg	Hill 1992
CYATHACEAE	*Cyathea dregei*	Drakenberg	Hill 1992
DENNSTAEDTACEAE	*Pteridium aquilinum subsp. aquilinum*	Drakenberg	Hill 1992
DRYOPTERIDACEAE	*Dryopteris inequalis*	Drakenberg	Hill 1992
DRYOPTERIDACEAE	*Polystichum luctuosum*	Drakenberg	Hill 1992
DRYOPTERIDACEAE	*Polystichum wilsonii*	Drakenberg	Hill 1992
DRYOPTERIDACEAE	*Rumohra adiantiformis*	Drakenberg	Hill 1992
GLEICHENIACEAE	*Gleichenia umbraculifera*	Drakenberg	Hill 1992
LOMARIOPSIDACEAE	*Elaphoglossum acrostichoides*	Drakenberg	Hill 1992
POLYPODIACEAE	*Lepisorus scraderi*	Drakenberg	Hill 1992
POLYPODIACEAE	*Microsorium scolopendria*	Mfabeni	Finch 2005
POLYPODIACEAE	*Pleopeitus macrocarpa*	Drakenberg	Hill 1992
POLYPODIACEAE	*Polypodium polypodioides*	Drakenberg	Hill 1992
POLYPODIACEAE	*Polypodium vulgare*	Drakenberg	Hill 1992
POLYTRICHACEAE	*Atrichum androgynum*	Drakenberg	Hill 1992

FAMILY	SPECIES	SITE	SOURCE
PTERIDACEAE	*Adiantum capillus-veneris*	Drakenberg	Hill 1992
PTERIDACEAE	*Adiantum poiretti*	Drakenberg	Hill 1992
PTERIDACEAE	*Cheilanthes ecklonia*	Drakenberg	Hill 1992
PTERIDACEAE	*Cheilanthes hirta*	Drakenberg	Hill 1992
PTERIDACEAE	*Cheilanthes inequalis var. inequalis*	Drakenberg	Hill 1992
PTERIDACEAE	*Cheilanthes multifida*	Drakenberg	Hill 1992
PTERIDACEAE	*Cheilanthes quadripinnata*	Drakenberg	Hill 1992
PTERIDACEAE	*Cheilanthes viridis var. viridis*	Drakenberg	Hill 1992
PTERIDACEAE	*Pteris cretica*	Drakenberg	Hill 1992
THELYPTERIDACEAE	*Christella gueinziana*	Drakenberg	Hill 1992
THELYPTERIDACEAE	*Cyclosorus interruptus*	Mfabeni	Finch 2005
WOODSIACEAE	*Athyrium schimperi*	Drakenberg	Hill 1992
WOODSIACEAE	*Woodsia montevidensis*	Drakenberg	Hill 1992

APPENDIX C

PROCEDURE FOR SUBSAMPLING

Source: revised from Faegri and Iverson (1989)

1. Use a clean, sharp scalpel to clean the entire surface of the core. Cut away superficial material using cleaning movements, which are parallel to the strata so as not to contaminate between strata.
2. Determine sampling interval by examining the stratigraphy, and considering the estimated depth of the core in relation to its length. For example, it is important to sample on either side of distinct chronological / stratigraphic boundaries. A wide sampling interval of 10cm was used to begin with and further, in-between samples (at a 5cm interval) were only used where greater detail was required.
3. Samples should consist of approx. 2 cm^3 of sediment situated at a depth of 1 cm beneath the wall of the core. Samples can be cut out using a scalpel or spatula where there is no need to determine exact volume.
4. Store each sample within an airtight plastic storage vial.
5. Samples for C^{14} dating need to represent the shortest possible period, i.e. should consist of a short slice across the whole core. These samples should consist of approx. 50g of peat and should be stored within ziploc bags and refrigerated.

APPENDIX D

PREPARATION PROCEDURE FOR FOSSIL POLLEN SAMPLES

Source: revised from Hill (1992) and Baxter (1996)

Note: - Centrifuge at 4000 rpm for 3 mins, unless otherwise specified.

- Use 100 ml sealable, polypropylene tubes in a swing-out centrifuge.

A. Addition of *Lycopodium* spore tablets

1. For each sample, dissolve two *Lycopodium* spore tablets in 20ml 10% HCl overnight in a 100ml sealable polypropylene tube.
2. Use a modified syringe to measure out $1cm^3$ of peat sample, which should be added to the *Lycopodium*/HCl mixture.
3. Stir, centrifuge and decant.
4. Rinse with distilled water, centrifuge and decant.

B. Sodium hydroxide digestion (removal of humic acids and clay minerals)

1. Add 20ml 15% NaOH and place in a heated water bath (50 - 60℃) for 10 mins, stirring occasionally.
2. Strain and wash through a 180μm sieve using distilled water.
3. Centrifuge and decant.
4. Wash four times with distilled water or until the supernatant becomes clear.

C. Hydrofluoric acid digestion / Bromoform flotation (removal of clastic material)

1. Add 20ml 10% HCl. Stir, centrifuge and decant.
2. Add 20ml 40% HF and place in a heated water bath (50 - 60℃) for 3 hrs, stirring occasionally.
3. Remove for the water bath, place airtight caps on centrifuge tubes, centrifuge for 5 mins and decant.
4. Add 20ml 10% HCl. Place in a heated water bath (50 - 60℃) for 20 mins, stirring occasionally.
5. Remove from water bath, stir, centrifuge and decant.
6. Rinse with distilled water, centrifuge and decant.

D. Acetolysis digestion of extraneous organic detritus

1. Add 20ml glacial acetic acid. Stir, centrifuge and decant. Pour off as much of the supernatant as possible as remaining acetic acid will react violently with the acetolysis mixture in the following step.
2. Add 20ml acetolysis mixture (comprising 9 parts acetic anhydride: 1 part sulphuric acid). Place in a heated water bath (50 – 60℃) for 10-15 mins, stirring occasionally.
3. Remove from water bath and place within cold water for a few seconds (this stops the reaction).
4. Stir, centrifuge and decant.
5. Add 20ml glacial acetic acid, stir, centrifuge and decant.
6. Add 9ml distilled water and 1ml NaOH to neutralise the sample.
7. Wash three times with distilled water, adding two drops of aqueous safranine stain on the last wash.
8. Add 5ml tertiary butyl alcohol (TBA). Stir, centrifuge and decant.
9. Add 5 ml TBA, using it to transfer the sample from the polypropylene tube into a labelled 30ml storage vial.
10. Place sealed vial within a clean polypropylene tube, centrifuge and decant.
11. Add glycerol in equal proportion to remaining TBA-pollen suspension.
12. Use a high frequency vibrator to suspend pollen evenly throughout the TBA-glycerol mixture.

E. Mounting

1. Place a single drop of glycerol a sterile glass microscope slide.
2. When the pollen is evenly suspended in the storage vial, use a blunt toothpick (or micropipette) to extract about three drops of the TBA-pollen suspension, which should be added to the glycerol. Use the toothpick to mix the TBA-pollen suspension with the glycerol.
3. Place a coverslip over the glycerol suspension and allow the mixture to spread to all the edges. Delicate pressure with a dissecting needle can aid this process.
4. Leave the slide to stand for at least 4 hours before counting to allow the pollen to settle out evenly. This ensures that all the grains are in the same focal plane and makes for easier microscopy.

APPENDIX E

PREPARATION PROCEDURE FOR REFERENCE MATERIAL

Source: revised from Hill (1992) and Baxter (1996)

Note: - Centrifuge at 4000 rpm for 3 mins, unless otherwise specified.

- Use 100 ml sealable, polypropylene tubes in a swing-out centrifuge.

A. Chemical preprocessing

1. Place specimen in a 100ml polypropylene tube.
2. Add 20ml 10% NaOH to the tube and stir.
3. Heat in a water bath (50 – 60℃) for 5 mins, stirring often.
4. Strain and wash through a clean 200 μm mesh sieve. Lightly crush the material on the screen and wash through with distilled water.
5. Centrifuge and decant
6. Transfer contents to a 10ml centrifuge tube using glacial acetic acid.
7. Stir, centrifuge and decant.
8. Add 20ml acetolysis mixture (comprising 9 parts acetic anhydride: 1 part sulphuric acid). Place in a heated water bath (50 – 60℃) for 5 mins, stirring occasionally.
9. Remove from water bath and place within cold water for a few seconds (this stops the reaction).
10. Stir, centrifuge and decant.
11. Wash 3-5 times with distilled water, adding 1-3 drops of aqueous safranine stain into the final wash.
12. Wash in a mild solution of phenol to prevent bacteriological and fungal spoilage.
13. Invert the tubes onto blotting paper and allow them to drain.

B. Mounting Slides

1. Clean and label the microscope slides (3 replicates for each specimen).
2. Cut tiny blocks of glycerine jelly (preferentially a brand which is phenol impregnated) and using a dissecting needle, pick up pollen grains/spores from the blotting paper. Wipe the glycerine around the inside of the centrifuge tube to pick up the pollen residue.

3. Place glycerine jelly on the centre of the slide and pass over a heating plate to melt the jelly. **Caution**: do not allow the jelly to boil as the texture of the jelly and the structure of the pollen will be damaged (heating plate must be approx. 40-45℃).
4. Carefully lower a coverslip over the jelly using a dissecting needle. While allowing the jelly to cool and set, invert the slide so that the pollen grains, suspended in the glycerine jelly, settle on the inside of the cover slip. This ensures that all the grains are in the same focal plane and makes for easier microscopy.
5. Once the jelly has set, scrape off any excess that may have extruded from the coverslip.
6. Paint a few coats of clear nail varnish around the edge of the coverslip to act as a sealant.

APPENDIX F

STATISTICS FOR LYCOPODIUM SPORE TABLETS
Source: Lund University (batch 124961)

N	X	SD	CV (%)
1	12542.4	930.7	7.4
2	25084.8	1316.1	5.2
3	37627.2	1611.9	4.3
4	50169.6	1861.3	3.7
5	62712.0	2081.0	3.3
10	125424.0	2943.0	2.3

where: N = *number of tablets*

X = *group mean*

SD = *group standard deviation*

$CV\ (\%)$ = *coefficient of variation*

Y = *mean number of grains per tablet*

$$X = N \times Y$$

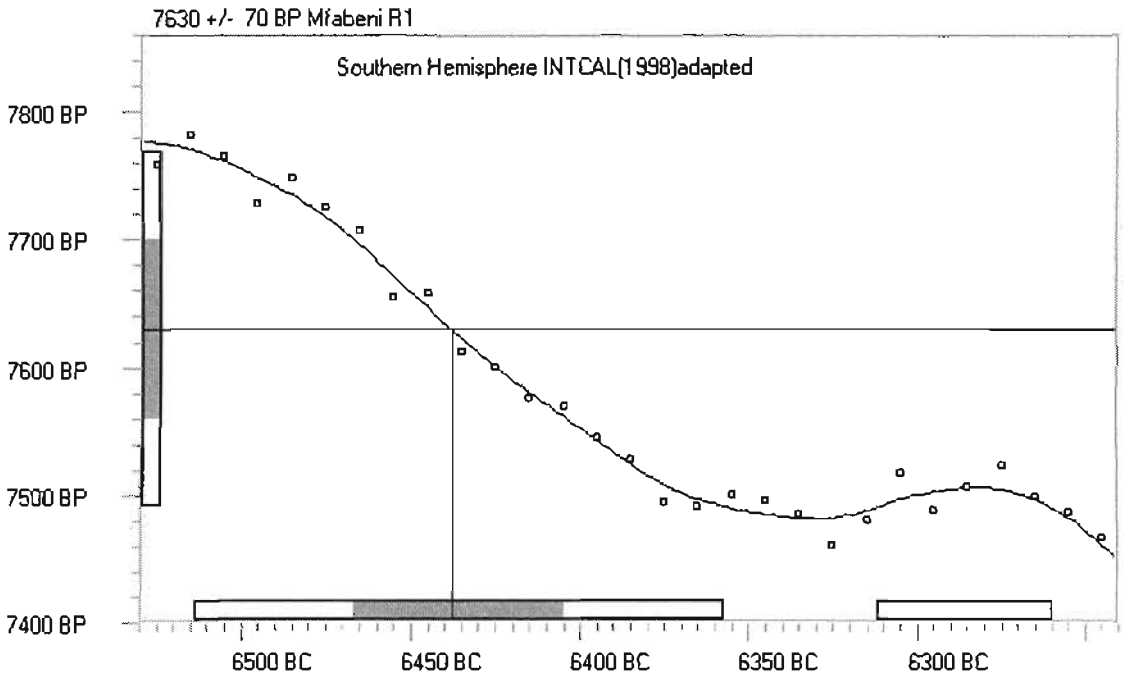
$$SD(\text{group of } N \text{ tablets}) = \sqrt{N} \times SD(\text{individual tablet})$$

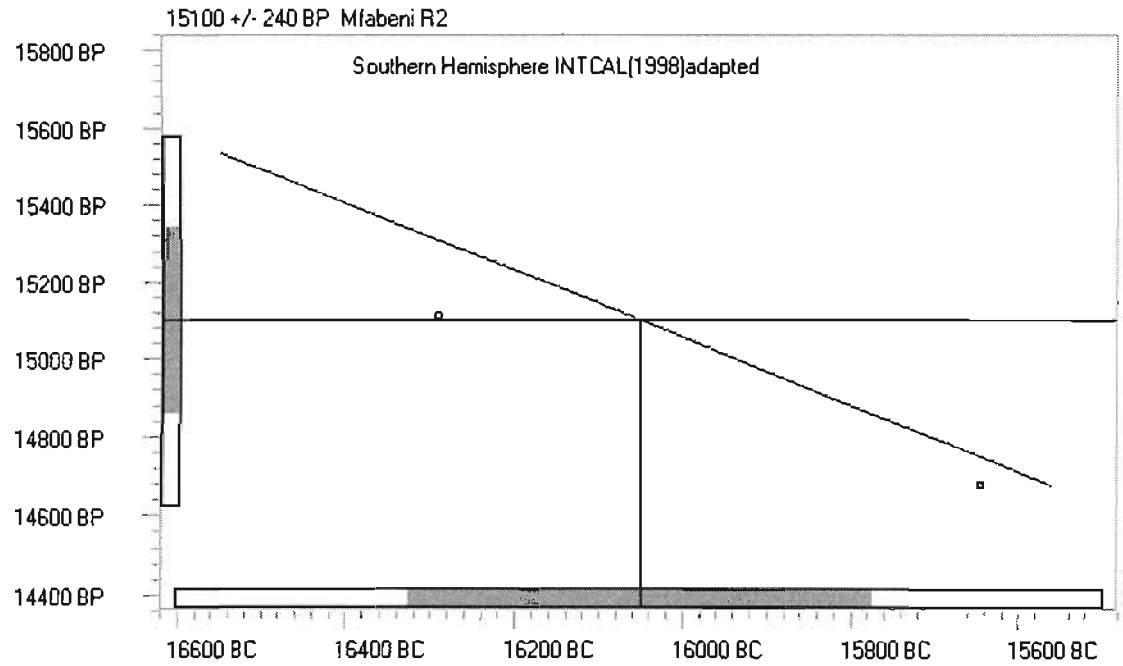
$$CV\% = \frac{SD}{X} \times 100$$

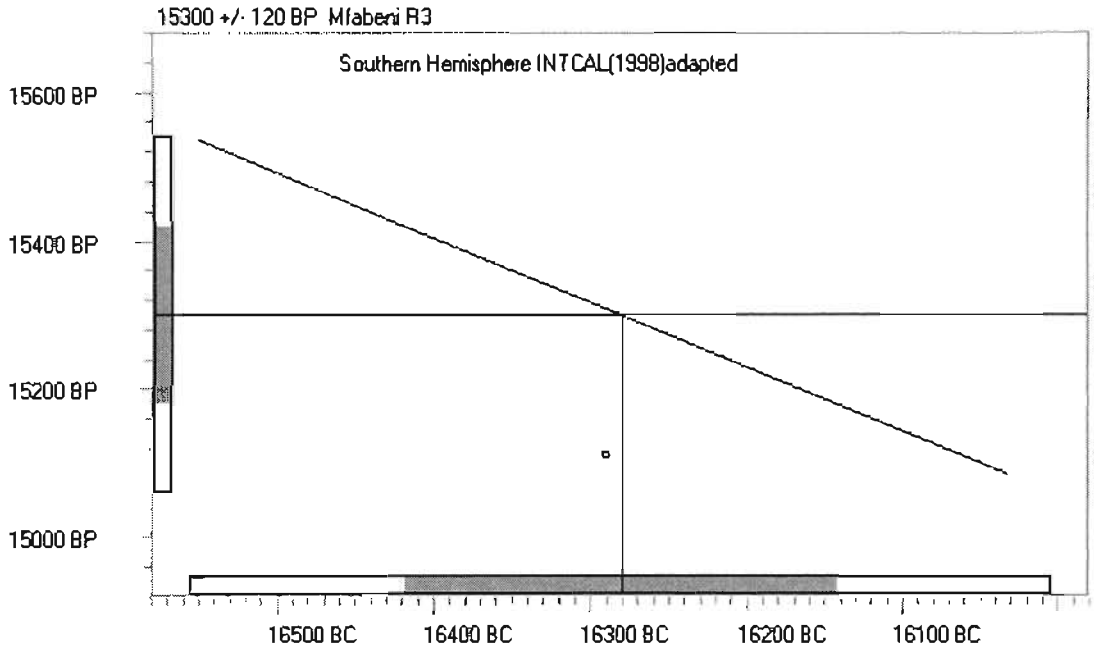
APPENDIX G

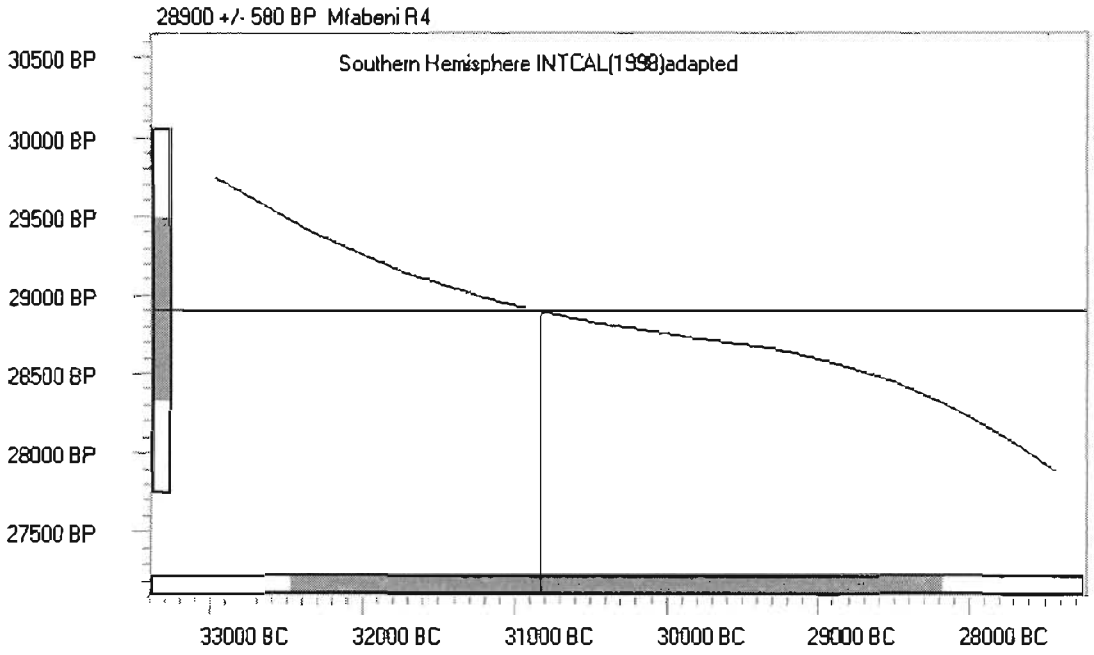
RADIOCARBON CALIBRATION CURVES

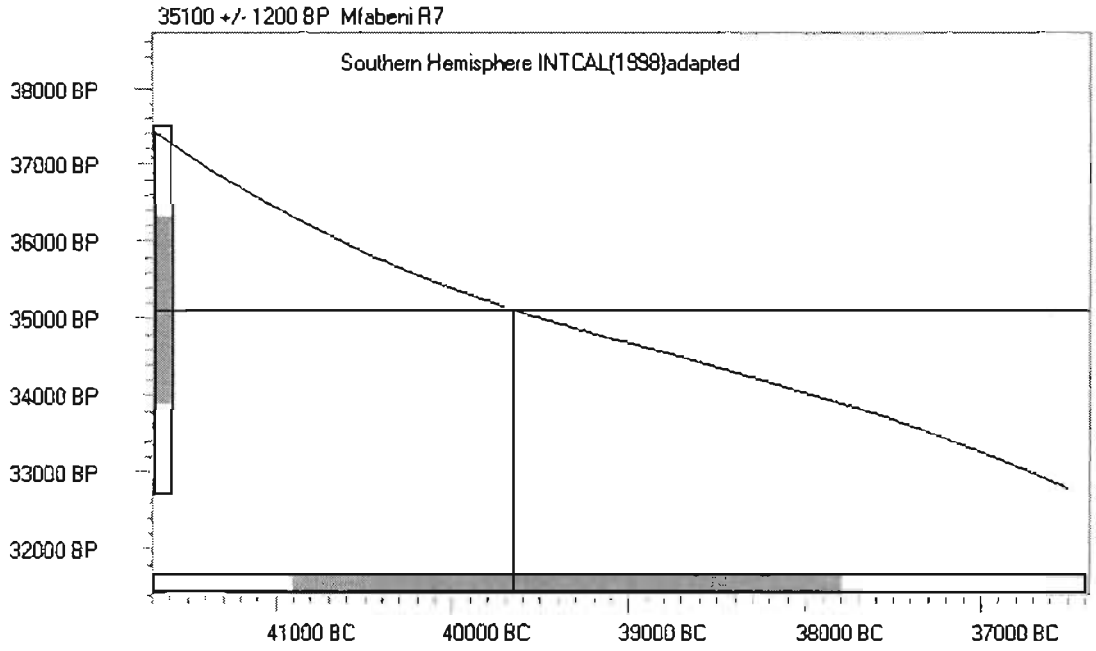
X-axes refer to uncalibrated ages (years BP), while *y*-axes refer to calibrated ages (Cal years BC). Square data points represent existing data points from which the calibration curve is derived; while lines intercepting calibration curves are used to read off calibrated radiocarbon ages in this study. For example, the uncalibrated age R_1 (7630±70 years BP) is calibrated at 6438 BC.






15300 +/- 120 BP Mfabeni R3
Southern Hemisphere INTCAL(1998)adapted
15600 BP
15400 BP
15200 BP
15000 BP
16500 BC
16400 BC
16300 BC
16200 BC
16100 BC


28900 +/- 580 BP Mfabeni R4
Southern Hemisphere INTCAL(1998)adapted
30500 BP
30000 BP
29500 BP
29000 BP
28500 BP
28000 BP
27500 BP
33000 BC
32000 BC
31000 BC
30000 BC
29000 BC
28000 BC


35100 +/- 1200 BP Mfabeni A7
Southern Hemisphere INTCAL(1998)adapted
38000 BP
37000 BP
36000 BP
35000 BP
34000 BP
33000 BP
32000 BP
41000 BC
40000 BC
39000 BC
38000 BC
37000 BC

APPENDIX H

RAW STABLE CARBON ISOTOPE DATA

STABLE CARBON ISOTOPE DATA - UCT & QUADRU

Sample	Depth	Analysis	Amount	Ampl 44	Area 44	d 13C/12C	Amount (%)	Corr 13C	Lab
Acacia		8912	0.077	2696	63.268	-28.318	53.50	-28.058	UCT
1	0.05	8913	0.056	2030	47.089	-18.867	54.75	-18.607	UCT
2	0.55	8914	0.048	1866	42.731	-21.970	57.96	-21.710	UCT
3	1.05	8915	0.044	1665	39.170	-20.429	57.96	-20.169	UCT
4	1.55	8916	0.049	1794	42.720	-18.559	56.77	-18.299	UCT
5	2.05	8917	0.048	1736	40.122	-22.489	54.43	-22.229	UCT
6	2.55	8918	0.063	2100	52.347	-18.898	54.10	-18.638	UCT
ANU Sucrose		8919	0.056	1793	40.299	-10.784	46.86	-10.524	UCT
7	2.70	8920	0.042	1511	37.641	-23.112	58.35	-22.852	UCT
8	3.05	8921	0.052	1886	45.527	-22.229	57.01	-21.969	UCT
9	3.55	8922	0.067	1660	41.282	-22.276	40.12	-22.016	UCT
10	4.05	8923	0.071	2451	56.432	-21.825	51.75	-21.565	UCT
11	4.55	8924	0.069	2590	62.570	-17.851	59.04	-17.591	UCT
12	4.57	8925	0.068	1748	52.446	-19.118	50.22	-18.858	UCT
Acacia		8926	0.050	1960	45.643	-27.928	59.44	-27.668	UCT
13	4.65	8927	0.067	2271	53.989	-18.605	52.47	-18.345	UCT
14	4.80	8928	0.062	1740	42.919	-18.515	45.07	-18.255	UCT
15	5.05	8929	0.078	2455	65.117	-20.193	54.36	-19.933	UCT
16	5.55	8930	0.068	2440	56.673	-17.128	54.27	-16.868	UCT
17	6.05	8931	0.044	1829	43.098	-21.215	63.78	-20.955	UCT
18	6.55	8932	0.069	2774	65.076	-21.596	61.41	-21.336	UCT
ANU Sucrose		8933	0.051	1850	40.836	-10.833	52.14	-10.573	UCT
19	7.05	8934	0.078	2766	62.661	-18.713	52.31	-18.453	UCT
20	7.55	8935	0.043	1564	38.565	-23.795	58.40	-23.535	UCT
21	8.05	8936	0.066	1532	34.673	-25.299	34.21	-25.039	UCT
22	8.55	8937	0.078	1300	28.923	-20.494	24.14	-20.234	UCT
23	9.05	8938	0.061	2204	56.173	-22.286	59.96	-22.026	UCT
24	9.55	8939	0.058	3052	67.483	-28.477	75.76	-28.217	UCT
25	9.78	8940	0.075	167	3.629	-23.415	3.15	-23.155	UCT
R1	2.75							-22.43	QUADRU
R2	4.55							-20.56	QUADRU
R3	4.7							-20.82	QUADRU
R4	5.82							-17.89	QUADRU
R5	6.4							-17.92	QUADRU
R6	7.8							-19.21	QUADRU
R7	9.2							-18.29	QUADRU
R8	9.8							-22.7	QUADRU

APPENDIX I

RAW POLLEN COUNT DATA

FULL SLIDE POLLEN COUNTS - MFABENI

Depth (m)	0.10	0.20	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.75	0.80	0.85	0.90	1.00	1.10	1.15	1.20	1.30	1.40	1.50	1.60	1.70
Lycopodiaceae	319	63	105	76	202	234	158	183	363	427	81	149	138	183	222	288	391	264	111	226	187	172
Anacardiaceae	7	0	2	15	1	10	9	7	15	2	1	1	9	3	3	0	14	10	7	12	1	1
Apocynaceae	0	0	0	5	0	5	11	1	7	0	1	5	3	0	3	6	7	1	3	0	0	2
Asteraceae	4	1	5	2	4	2	1	0	1	3	2	0	2	0	0	0	7	2	10	13	5	7
Caryophyllaceae	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0
Celastraceae	4	1	2	4	2	0	2	9	5	0	0	2	8	6	6	0	12	3	13	14	5	3
Chenopodiaceae	16	11	2	0	14	0	0	1	0	0	0	0	2	0	0	0	0	2	23	67	2	3
Cyanthaceae	0	0	0	3	0	2	1	0	0	0	0	23	0	0	0	59	0	0	0	0	0	7
Cyperaceae	81	54	61	47	179	119	91	77	57	89	24	25	58	25	14	45	25	47	16	68	38	43
Ericaceae	13	4	6	0	11	0	4	8	3	0	1	0	1	0	0	0	0	0	2	0	2	0
Erythroxylaceae	0	0	4	2	0	0	5	1	24	0	0	2	14	3	9	2	12	1	1	0	0	0
Euphorbiaceae	0	0	1	3	0	2	0	0	1	0	0	0	0	2	0	0	0	3	0	2	1	0
Fabaceae	2	0	0	0	0	1	7	1	2	0	0	1	2	0	1	2	2	1	7	3	1	1
Fabaceae (Acacia)	23	4	9	0	1	0	1	5	5	0	2	0	3	2	0	0	1	6	4	0	1	1
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	5	0	0	0	0	0	2	7	1	1	1	0	5	3	2	0	2	9	16	18	3	2
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
Iridaceae	57	124	81	5	43	22	62	58	73	27	26	6	62	53	22	26	39	12	64	56	38	10
Liliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	6	2	1	3	4
Moraceae	0	0	0	10	0	2	0	0	4	0	0	9	10	10	8	2	22	31	5	12	1	1
Myricaceae	1	0	0	0	0	0	19	2	11	0	4	0	2	0	0	0	0	0	0	0	0	0
Myrtaceae	1	0	0	8	0	0	1	7	12	0	1	5	12	4	23	1	10	6	4	0	0	0
Poaceae	157	112	163	190	135	337	327	142	210	371	46	44	144	233	187	172	161	179	119	321	212	185
Podocarpaceae	1	1	2	6	1	14	31	20	25	0	3	12	20	15	13	16	20	10	37	54	19	9
Polygalaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0
Proteaceae	0	0	0	0	1	1	3	1	4	0	0	0	1	0	0	0	0	0	2	1	0	0
Pteridophyta (M)	8	14	6	0	3	7	18	9	17	3	0	28	9	16	8	93	22	5	5	16	3	1
Pteridophyta (T)	1	1	19	3	0	15	84	42	5	10	748	277	4	21	396	89	111	0	0	0	0	4
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	1	0	0	0	0	0	0	1	4	0	0	1	2	5	2	0	0	1	1	1	2	1
Rubiaceae	0	0	0	0	0	0	0	0	1	0	0	0	3	2	1	0	9	1	2	17	2	2
Thymeliaceae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Undetermined	20	15	18	0	14	0	14	7	8	0	2	1	6	4	3	0	9	10	9	6	4	4
Total Count	403	342	381	303	411	539	693	406	495	506	862	443	382	407	705	513	492	349	354	685	343	291

FULL SLIDE POLLEN COUNTS - MFABENI

Depth (m)	1.80	1.90	1.95	2.00	2.05	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	3.90	4.00	4.10
Lycopodiaceae	95	167	61	139	268	461	304	377	366	171	66	220	242	215	186	159	168	85	84	135	167	95	42	115	67	115
Anacardiaceae	4	7	10	3	7	3	2	1	5	0	6	2	2	1	3	0	2	0	1	2	0	1	1	1	1	1
Apocynaceae	3	6	2	3	2	2	4	3	6	0	6	1	3	2	3	2	1	2	1	1	3	0	1	3	1	1
Asteraceae	5	7	0	9	2	1	0	1	1	2	3	2	3	2	3	9	10	5	2	4	7	11	3	11	8	19
Caryophyllaceae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0
Celastraceae	3	2	6	2	18	7	2	4	13	11	8	4	17	1	7	9	5	3	3	4	9	7	3	8	4	6
Chenopodiaceae	4	16	25	5	0	40	7	9	1	25	25	2	0	3	5	1	2	1	2	1	5	6	3	5	2	8
Cyanthaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	51	57	166	52	79	72	28	42	60	57	94	62	69	82	158	230	187	94	139	307	174	157	155	190	133	233
Ericaceae	0	0	0	0	0	0	0	0	3	0	0	0	3	0	0	2	1	0	0	0	3	0	2	3	0	1
Erythroxylaceae	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	1	2	0	0	1	0	0	2	2	4	1	4	0	0	4	2	1	1	1	2	2	0	0	0	0
Fabaceae	0	3	0	3	0	1	1	0	1	1	5	0	2	1	4	1	6	1	0	4	1	0	1	0	0	0
Fabaceae (Acacia)	0	5	0	0	0	1	0	0	0	0	0	0	0	0	1	0	3	0	3	4	2	0	0	0	1	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	3	2	2	2	0	4	5	1	4	6	7	2	5	5	8	7	5	2	6	9	3	4	5	2	3	5
Geraniaceae	0	0	0	0	0	0	0	0	0	1	0	0	8	1	0	1	0	0	0	1	0	0	0	0	0	1
Iridaceae	12	30	7	18	17	45	47	36	38	24	61	27	22	37	24	69	41	17	28	41	17	26	38	28	35	44
Liliaceae	1	29	0	0	0	0	3	0	1	0	5	0	1	0	2	2	0	0	0	3	1	1	2	4	5	8
Moraceae	0	0	0	0	0	1	2	0	0	1	1	0	1	0	0	1	0	2	1	0	1	1	0	2	0	8
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	0	0	1	15	0	0	0	0	0	0	0	0	0	0	0	0	1
Poaceae	207	297	228	214	228	266	276	204	274	294	441	342	272	304	466	600	434	183	290	555	373	390	384	392	336	429
Podocarpaceae	13	20	53	25	13	40	35	66	46	39	37	8	14	2	17	5	2	2	5	4	11	2	4	5	4	3
Polygalaceae	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0
Proteaceae	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	1
Pteridophyta (M)	1	1	39	5	179	27	20	13	27	5	12	9	4	7	13	42	74	28	45	55	50	27	40	55	27	57
Pteridophyta (T)	0	0	0	165	0	1	1	0	4	0	2	0	0	0	12	4	5	2	2	13	11	10	13	22	12	21
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	1	0	3	0	1	0	1	0	0	1	0	0	1	0	2	0	0	0	0	1	0	0	0	0	0
Rubiaceae	3	1	1	0	1	5	0	2	3	4	8	2	3	4	4	1	2	0	0	0	1	2	1	1	0	0
Thymeliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	1	10	1	8	0	1	11	3	2	1	4	4	10	0	1	5	6	1	1	3	3	4	1	2	3	2
Total Count	312	496	545	517	546	521	445	386	491	473	730	470	458	453	733	997	789	344	530	1012	680	651	658	737	575	849

FULL SLIDE POLLEN COUNTS - MFABENI

Depth (m)	4.20	4.30	4.40	4.50	4.60	4.70	4.80	4.90	5.00	5.10	5.20	5.30	5.40	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.30	6.40	6.50	6.60	6.70
Lycopodiaceae	141	155	109	84	113	86	94	77	60	139	150	96	427	101	102	96	94	134	90	100	109	83	45	60	61	55
Anacardiaceae	5	6	1	1	4	1	4	3	3	0	0	6	0	3	5	3	11	3	3	1	7	3	3	5	2	1
Apocynaceae	2	0	0	0	0	0	0	0	0	0	0	1	0	3	0	3	0	0	0	0	1	0	0	0	0	0
Asteraceae	11	7	6	4	10	9	12	21	12	0	1	13	16	7	10	11	19	18	16	10	13	10	11	16	10	8
Caryophyllaceae	1	3	0	0	0	1	1	1	0	0	0	0	0	0	1	2	0	0	1	0	0	0	0	0	0	0
Celastraceae	1	2	4	1	4	4	4	8	5	0	0	9	0	5	7	5	5	6	5	6	2	3	3	3	7	7
Chenopodiaceae	8	4	7	3	5	3	11	4	12	0	0	0	0	0	2	0	0	5	1	0	0	0	0	4	10	2
Cyanthaceae	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	171	212	147	111	196	175	212	228	278	75	97	368	227	258	394	457	406	294	241	321	284	261	150	267	275	189
Ericaceae	3	2	2	1	1	2	2	3	2	0	0	0	1	0	3	2	2	0	1	2	0	1	0	1	1	3
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	1	1	0	2	0	0	0	0	1	0	1	2	1	3	5	1	0	3	5	3	0	0	2	0	0
Fabaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
Flacourtiaceae	2	3	4	1	0	0	0	2	1	0	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0	0
Geraniaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	34	45	19	19	25	36	28	44	34	19	15	19	16	20	18	22	21	17	17	13	14	12	10	32	19	18
Liliaceae	7	1	3	2	3	2	5	2	8	3	0	1	0	0	0	1	0	1	0	0	0	0	0	5	13	3
Moraceae	2	1	0	3	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	3	1
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Poaceae	389	338	309	167	335	276	351	492	330	151	141	283	194	227	298	403	309	280	209	249	234	231	165	338	276	277
Podocarpaceae	6	4	5	6	7	4	10	4	6	1	3	16	5	7	20	14	14	12	8	9	19	3	7	15	14	5
Polygalaceae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0
Pteridophyta (M)	40	26	37	20	30	11	26	32	22	14	7	33	10	23	37	17	51	31	14	20	9	6	3	15	18	13
Pteridophyta (T)	6	15	5	5	8	3	17	29	21	0	0	29	3	35	41	31	36	34	7	7	7	7	4	4	5	3
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
Rubiaceae	0	1	0	0	0	2	0	1	0	0	0	0	0	0	2	0	0	2	1	1	1	2	0	0	2	0
Thymeliaceae	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Undetermined	2	1	1	1	3	1	1	1	2	1	0	1	0	3	0	0	1	5	2	1	0	0	1	2	0	0
Total Count	692	674	551	346	634	532	686	876	737	265	264	781	474	593	842	977	883	711	530	645	601	541	360	712	655	531

FULL SLIDE POLLEN COUNTS - MFABENI

Depth (m)	6.80	6.90	7.00	7.05	7.10	7.20	7.25	7.30	7.40	7.50	7.55	7.60	7.65	7.70	7.80	7.90	8.00	8.10	8.15	8.20	8.25	8.30	8.35	8.40	8.45	8.50	8.60
Lycopodiaceae	115	95	94	50	56	73	29	66	78	112	45	25	11	70	115	120	44	57	18	40	31	51	51	36	17	46	56
Anacardiaceae	0	7	1	0	5	1	0	8	7	1	1	10	5	7	2	0	4	10	1	13	3	4	10	7	5	2	0
Apocynaceae	0	0	0	0	4	0	0	0	0	0	4	0	0	2	5	2	1	0	2	2	2	1	1	0	0	0	1
Asteraceae	8	7	5	0	8	5	5	20	23	18	3	13	1	6	8	1	3	9	4	17	3	5	2	3	4	4	7
Caryophyllaceae	0	0	0	0	1	0	0	3	0	2	0	2	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0
Celastraceae	4	2	1	0	1	3	3	1	2	7	9	171	11	17	27	4	5	39	4	10	5	8	0	14	6	10	12
Chenopodiaceae	1	2	11	1	7	1	19	5	4	6	16	17	10	9	2	0	0	1	0	1	0	9	18	0	0	2	10
Cyanthaceae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	150	135	104	64	238	166	243	415	308	171	169	197	111	181	194	139	176	229	60	264	241	118	71	256	94	178	80
Ericaceae	0	0	1	0	0	2	0	0	1	2	3	4	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	0	0	0	0	0	0	4	6	4	2	4	1	8	4	1	1	6	0	4	2	2	5	4	0	1	0
Fabaceae	0	0	0	0	0	0	0	1	0	0	0	2	0	1	1	0	3	0	0	0	0	1	0	4	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	0	1	0	0	1	2	0	1	0	0	0	0	0	1	0	0	0	1	0	4	0	1	1	1	0	0	5
Geraniaceae	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	22	20	26	21	30	12	19	21	24	34	40	38	35	27	20	22	15	20	6	27	13	27	41	19	35	18	25
Liliaceae	9	5	15	0	3	1	6	3	0	6	0	2	4	0	3	0	0	0	0	0	0	0	0	0	0	1	0
Moraceae	0	1	1	1	3	0	0	1	3	1	3	8	2	4	1	0	0	0	2	1	1	2	7	2	0	0	1
Myricaceae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Poaceae	265	185	219	273	509	516	258	294	495	397	349	509	379	364	252	163	214	384	76	205	317	323	278	330	194	301	320
Podocarpaceae	3	8	5	0	8	6	13	16	15	28	52	209	60	78	62	3	7	14	3	19	13	85	146	15	2	43	123
Polygalaceae	0	0	0	0	0	0	0	0	1	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Pteridophyta (M)	18	15	30	6	11	10	0	15	3	6	18	21	50	14	42	22	97	61	101	464	202	62	73	326	182	76	12
Pteridophyta (T)	0	2	0	0	0	0	0	0	0	1	1	7	0	1	0	0	0	0	0	0	3	0	1	1	1	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubiaceae	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	2
Thymeliaceae	0	0	0	0	0	0	0	1	0	0	2	7	0	1	4	0	2	1	1	0	0	1	0	2	0	0	0
Undetermined	0	0	0	0	1	2	1	1	2	1	2	0	0	3	4	0	2	0	0	0	4	0	0	0	0	0	1
Total Count	483	393	419	367	830	727	567	813	895	686	674	1223	669	732	632	357	531	776	260	1032	812	652	654	985	523	636	599

FULL SLIDE POLLEN COUNTS - MFABENI

Depth (m)	8.70	8.80	8.90	9.00	9.10	9.20	9.30	9.35	9.40	9.50	9.60	9.70	9.80
Lycopodiaceae	90	173	125	60	50	44	43	21	216	368	232	73	139
Anacardiaceae	7	9	9	4	0	2	2	2	0	5	6	3	4
Apocynaceae	1	0	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	1	0	1	6	4	6	7	0	0	4	7	3	8
Caryophyllaceae	0	0	0	0	0	1	2	0	0	0	0	1	0
Celastraceae	7	4	4	3	5	2	5	4	2	0	6	0	4
Chenopodiaceae	6	1	0	2	0	4	7	14	0	0	0	0	0
Cyanthaceae	0	0	0	0	0	0	0	1	0	0	0	0	0
Cyperaceae	64	84	89	182	179	154	367	100	79	140	38	37	56
Ericaceae	0	0	0	0	0	0	1	0	0	0	0	0	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	1	0	1	0	1	1	0	0	0	0	0	2
Fabaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	1	0	0	0	0	0	0
Flacourtiaceae	1	0	1	0	0	0	1	1	0	1	0	0	0
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	28	28	42	22	16	24	27	26	33	29	6	9	27
Liliaceae	0	0	0	6	1	3	0	4	0	0	0	0	0
Moraceae	1	0	0	2	1	1	1	1	0	0	0	0	0
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	261	300	377	329	283	246	328	180	383	364	231	331	372
Podocarpaceae	48	14	10	5	8	4	7	15	0	0	2	1	7
Polygalaceae	0	0	0	0	0	0	1	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Pteridophyta (M)	10	43	7	6	5	3	11	11	1	8	5	3	17
Pteridophyta (T)	0	1	0	0	0	3	1	6	0	0	0	0	11
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubiaceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Thymeliaceae	0	0	0	0	0	0	1	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0	0	0	1
Total Count	435	485	540	568	502	454	771	365	498	551	301	388	509

POLLEN COUNTS (500) - MFABENI

Depth (m)	0.10	0.20	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.75	0.80	0.85	0.90	1.00	1.10	1.15	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	1.95	2.00
Lycopodiaceae	396	108	153	114	273	234	113	221	363	425	50	179	181	225	158	288	391	318	161	137	265	244	141	167	59	137
Anacardiaceae	7	0	5	24	1	10	8	9	15	2	1	1	11	3	2	0	14	11	7	9	1	3	6	7	9	3
Apocynaceae	1	0	0	8	0	5	7	1	7	0	1	5	4	0	3	6	7	2	7	0	3	5	3	6	2	3
Asteraceae	4	1	6	3	4	2	0	0	1	3	1	0	4	0	0	0	7	3	12	9	5	10	7	7	0	9
Caryophyllaceae	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0
Celastraceae	5	1	4	7	2	0	1	11	5	0	0	2	10	6	6	0	12	3	19	9	10	5	5	2	4	2
Chenopodiaceae	17	16	4	0	16	0	0	1	0	0	0	0	3	1	0	0	0	3	34	36	6	4	7	16	23	5
Cyanthaceae	0	0	0	5	0	0	0	0	0	0	0	26	0	0	0	59	0	0	0	0	0	10	0	0	0	0
Cyperaceae	103	71	82	67	224	119	63	90	57	89	12	26	63	27	13	45	25	62	22	52	69	84	77	57	146	51
Ericaceae	14	7	11	0	12	0	2	8	3	0	1	1	1	0	0	0	0	0	2	0	2	0	0	0	0	0
Erythroxylaceae	0	0	4	2	0	0	4	2	24	0	0	4	16	3	9	2	12	1	3	0	0	0	0	0	0	0
Euphorbiaceae	0	0	1	3	0	2	0	0	1	0	0	0	0	2	0	0	0	3	1	1	1	0	0	1	2	0
Fabaceae	2	0	0	0	0	1	3	1	2	0	0	1	3	0	0	2	2	1	8	1	3	1	0	3	0	3
Fabaceae (Acacia)	29	5	11	0	1	0	1	5	5	0	2	0	4	2	0	0	1	6	5	0	1	1	0	5	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	6	0	0	0	0	0	2	7	1	1	0	0	5	3	1	0	2	10	27	12	4	2	4	2	2	2
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0
Iridaceae	70	174	107	7	47	22	50	77	75	27	25	6	79	68	20	26	39	25	81	41	49	21	31	30	7	18
Liliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	7	3	0	3	4	1	29	0	0
Moraceae	0	0	0	16	0	2	0	0	4	0	0	11	18	15	7	2	22	34	7	7	2	1	0	0	0	0
Myricaceae	1	0	0	0	0	0	17	2	11	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	1	0	0	11	0	0	1	7	12	0	0	7	15	4	13	1	10	6	5	0	0	0	0	0	0	0
Poaceae	205	168	215	291	166	337	239	170	212	370	36	52	200	282	146	172	161	279	159	213	303	305	315	297	208	212
Podocarpaceae	1	1	6	8	1	14	17	22	25	0	2	13	30	16	12	16	20	17	50	35	29	19	26	20	48	25
Polygalaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	2	1	1	0
Proteaceae	0	0	0	0	1	1	0	2	4	0	0	0	1	0	0	0	0	0	2	0	0	0	1	0	1	0
Pteridophyta (M)	8	16	6	47	3	7	11	12	17	3	0	33	15	22	7	93	22	8	10	10	6	4	2	1	36	5
Pteridophyta (T)	2	1	24	3	0	15	58	48	5	9	416	347	5	25	273	89	111	0	0	0	0	4	0	0	0	164
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	1	0	0	0	0	0	0	1	4	0	0	1	6	5	2	0	0	1	2	1	2	1	1	1	0	3
Rubiaceae	0	0	0	0	0	0	0	0	1	0	0	0	3	2	1	0	9	3	2	9	2	2	3	1	1	0
Thymeliaceae	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Undetermined	20	22	20	0	15	0	11	8	8	0	2	1	8	5	2	0	9	10	10	2	5	4	5	10	1	8
Total Count	498	483	506	502	495	539	495	484	499	504	501	538	506	491	521	513	492	498	480	449	506	490	496	496	492	513

POLLEN COUNTS (500) - MFABENI

Depth (m)	2.05	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	3.90	4.00	4.10	4.20	4.30	4.40	4.50
Lycopodiaceae	268	461	315	500	379	175	38	230	266	244	109	88	121	115	84	69	109	80	70	78	64	55	96	115	92	115
Anacardiaceae	7	3	2	4	5	0	4	2	2	3	1	0	0	0	1	1	0	0	0	0	1	1	4	5	1	1
Apocynaceae	2	2	4	4	6	0	3	1	3	2	3	1	1	2	1	0	2	0	1	2	1	1	1	0	0	0
Asteraceae	2	1	1	1	1	2	2	2	3	2	2	4	10	8	2	2	5	10	3	10	8	13	9	6	6	5
Caryophyllaceae	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	1	0	0	1	3	0	0
Celastraceae	18	7	2	5	13	12	4	5	18	4	5	7	3	3	3	2	6	4	3	8	4	5	1	2	4	1
Chenopodiaceae	0	40	8	12	1	28	23	2	1	4	3	1	1	1	2	1	4	3	1	4	2	3	7	2	6	7
Cyanthaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	79	72	30	54	60	59	70	65	74	92	110	114	121	139	139	156	130	129	122	144	119	142	123	181	139	161
Ericaceae	0	0	0	0	3	0	0	0	3	0	0	2	0	0	0	0	3	0	1	2	0	1	2	1	2	2
Erythroxylaceae	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	1	0	0	2	2	2	1	4	1	0	2	0	2	1	0	1	1	0	0	0	0	0	1	1	2
Fabaceae	0	1	1	0	1	1	1	0	2	1	3	0	5	1	0	4	0	0	1	0	0	0	1	0	0	0
Fabaceae (Acacia)	0	1	0	0	0	0	0	0	0	0	0	0	2	0	3	3	0	0	0	0	1	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	0	4	5	1	5	6	3	2	6	6	6	2	2	3	6	5	2	4	1	2	3	2	2	1	4	1
Geraniaceae	0	0	0	0	0	1	0	0	8	1	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
Iridaceae	17	45	49	46	39	25	44	31	28	42	15	45	30	25	28	27	12	19	29	20	34	28	29	38	17	22
Liliaceae	0	0	3	0	1	0	2	0	1	0	1	0	0	0	0	2	0	1	1	3	5	3	4	1	2	3
Moraceae	0	1	2	0	0	1	0	0	1	0	0	0	0	3	1	0	0	1	0	2	0	3	1	0	0	4
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	1	0	0	0	0	1	15	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Poaceae	228	266	307	277	281	315	312	364	295	338	333	347	304	284	290	344	280	294	308	292	313	271	281	283	278	253
Podocarpaceae	13	40	42	77	46	42	25	8	14	3	6	3	1	4	5	3	8	1	4	3	3	2	5	1	5	8
Polygalaceae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Pteridophyta (M)	179	27	30	13	27	6	7	10	6	7	8	19	57	42	45	25	37	19	28	43	24	34	29	16	34	29
Pteridophyta (T)	0	1	1	0	4	0	2	0	0	0	8	2	2	2	2	7	7	9	11	18	9	11	5	9	5	10
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	1	1	1	0	0	0	0	0	1	0	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Rubiaceae	1	5	0	2	3	4	5	2	4	4	3	0	2	0	0	0	1	1	1	1	0	0	0	1	0	0
Thymeliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Undetermined	0	1	11	3	2	2	2	4	11	0	0	2	4	1	1	1	3	4	1	1	3	2	2	1	1	1
Total Count	546	521	501	500	500	506	511	501	500	511	509	553	545	521	530	584	503	500	517	558	530	525	508	552	505	511

XXX

POLLEN COUNTS (500) - MFABENI

Depth (m)	4.60	4.70	4.80	4.90	5.00	5.10	5.20	5.30	5.40	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.30	6.40	6.50	6.60	6.70	6.80	6.90	7.00	7.05
Lycopodiaceae	79	86	61	50	55	327	270	58	448	87	72	36	50	104	90	87	92	83	75	38	50	55	118	108	115	71
Anacardiaceae	3	1	3	2	3	0	0	3	0	3	3	2	8	3	3	1	7	3	4	4	1	1	0	7	1	0
Apocynaceae	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Asteraceae	6	9	10	6	11	1	2	7	16	6	7	8	17	17	16	5	11	10	14	12	10	8	8	10	10	0
Caryophyllaceae	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Celastraceae	4	4	3	5	4	0	1	8	0	4	6	2	4	5	5	6	2	3	4	3	4	7	4	3	1	0
Chenopodiaceae	4	3	8	2	9	0	0	0	0	0	1	0	0	3	1	0	0	0	0	3	9	2	1	3	11	1
Cyanthaceae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cyperaceae	160	175	148	132	135	149	180	237	242	233	258	226	236	239	241	272	245	261	210	213	229	189	159	160	123	98
Ericaceae	1	2	2	3	2	1	0	0	1	0	3	2	1	0	1	2	0	1	1	1	1	3	0	0	1	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	2	0	0	0	0	1	0	0	2	1	2	3	0	0	3	5	3	0	0	1	0	0	0	0	0	0
Fabaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0
Flacourtiaceae	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1	1	0
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	21	36	18	27	27	28	30	10	17	17	14	14	15	13	17	11	13	12	14	31	14	18	23	24	36	31
Liliaceae	2	2	5	2	7	7	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	3	9	8	18	0
Moraceae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	1	1	2
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	1	0	0
Poaceae	274	276	272	291	270	297	283	196	205	194	209	213	196	234	209	202	205	231	245	244	218	277	279	249	258	421
Podocarpaceae	5	4	8	2	5	1	6	8	5	7	14	4	6	9	8	9	17	3	11	10	14	5	3	9	5	0
Polygalaceae	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0
Pteridophyta (M)	26	11	22	15	15	32	21	21	11	18	25	9	26	20	14	18	5	6	5	13	16	13	18	21	33	10
Pteridophyta (T)	6	3	12	18	17	0	2	19	3	32	27	14	17	29	7	6	6	7	6	4	4	3	0	2	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Rubiaceae	0	2	0	0	0	0	0	0	0	1	2	0	0	2	1	1	1	2	0	0	1	0	2	2	1	0
Thymeliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Undetermined	3	1	1	0	2	1	0	0	0	3	0	0	1	5	2	1	0	0	1	2	0	0	0	0	0	0
Total Count	517	532	514	506	509	519	525	509	502	521	571	500	532	581	530	539	521	541	520	546	533	531	507	501	500	564

POLLEN COUNTS (500) - MFABENI

Depth (m)	7.10	7.20	7.25	7.30	7.40	7.50	7.55	7.60	7.65	7.70	7.80	7.90	8.00	8.10	8.15	8.20	8.25	8.30	8.35	8.40	8.45	8.50	8.60	8.70	8.80	8.90
Lycopodiaceae	32	50	29	50	55	78	32	16	9	50	84	182	44	50	33	29	18	41	50	20	17	46	50	110	198	125
Anacardiaceae	3	1	0	7	5	1	1	2	5	6	2	0	4	8	2	5	3	4	9	4	5	2	0	9	9	9
Apocynaceae	4	0	0	0	0	0	3	0	0	1	5	3	1	0	4	1	2	1	1	0	0	0	1	1	0	0
Asteraceae	2	4	5	18	9	15	2	7	1	3	7	1	3	5	9	9	2	4	2	1	4	4	7	1	0	1
Caryophyllaceae	1	0	0	1	0	1	0	1	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Celastraceae	1	2	3	1	1	4	5	54	9	15	21	4	5	33	7	9	3	7	0	8	6	10	12	9	4	4
Chenopodiaceae	5	0	19	5	4	5	14	7	7	7	2	0	0	0	0	1	0	6	18	0	0	2	9	8	1	0
Cyanthaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	144	115	243	256	169	110	119	80	93	134	162	189	176	172	114	149	158	104	70	132	94	178	70	79	88	89
Ericaceae	0	2	0	0	1	1	3	2	0	1	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	0	0	3	3	3	1	2	1	5	4	1	1	5	0	3	2	2	5	2	0	1	0	0	1	0
Fabaceae	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	0	0	5	3	0	1
Geraniaceae	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	19	9	19	10	17	26	38	19	26	22	14	26	15	19	13	19	9	26	38	11	35	18	23	28	32	42
Liliaceae	1	1	6	0	0	6	0	1	4	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Moraceae	2	0	0	1	1	1	1	4	2	3	1	0	0	0	2	1	1	2	7	1	0	0	1	1	0	0
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	311	358	258	195	297	308	267	239	291	275	190	241	214	310	139	113	206	278	263	172	194	301	280	300	324	377
Podocarpaceae	7	6	13	9	5	22	43	92	47	53	50	6	7	12	5	8	6	72	141	6	2	43	113	52	15	10
Polygalaceae	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Pteridophyta (M)	6	4	0	5	2	6	14	6	39	9	33	30	97	52	206	223	111	47	72	160	182	76	12	12	47	7
Pteridophyta (T)	0	0	0	0	0	1	1	5	0	1	0	1	0	0	0	0	2	0	1	0	1	0	0	0	1	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubiaceae	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	2	0	0	0
Thymeliaceae	0	0	0	1	0	0	1	2	0	1	4	1	2	1	1	0	0	1	0	2	0	0	0	0	0	0
Undetermined	1	2	1	1	1	1	2	0	0	2	4	0	2	0	0	0	3	0	0	0	0	0	1	0	0	0
Total Count	508	505	567	517	515	512	515	524	525	544	503	505	531	618	502	543	510	558	628	501	523	636	536	504	522	540

POLLEN COUNTS (500) - MFABENI

Depth (m)	9.00	9.10	9.20	9.30	9.35	9.40	9.50	9.60	9.70	9.80
Lycopodiaceae	52	50	50	37	34	216	339	404	92	139
Anacardiaceae	4	0	2	1	3	0	5	7	4	4
Apocynaceae	0	0	0	0	0	0	0	0	0	0
Asteraceae	6	4	7	6	0	0	4	9	5	8
Caryophyllaceae	0	0	1	2	0	0	0	0	1	0
Celastraceae	2	5	2	4	5	2	0	10	0	4
Chenopodiaceae	1	0	7	5	20	0	0	0	0	0
Cyanthaceae	0	0	0	0	1	0	0	0	0	0
Cyperaceae	161	179	179	310	161	79	129	59	50	56
Ericaceae	0	0	0	1	0	0	0	0	0	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	1	0	1	1	0	0	0	0	0	2
Fabaceae	0	0	0	0	0	0	0	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	1	0	0	0	0	0	0
Flacourtiaceae	0	0	0	1	1	0	1	0	0	0
Geraniaceae	0	0	0	0	0	0	26	0	0	0
Iridaceae	21	16	27	23	38	33	0	9	13	27
Liliaceae	6	1	3	0	6	0	0	0	0	0
Moraceae	2	1	1	1	1	0	0	0	0	0
Myricaceae	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	0
Poaceae	301	281	293	256	276	383	340	412	429	372
Podocarpaceae	5	8	7	5	21	0	0	4	1	7
Polygalaceae	0	0	0	1	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0
Pteridophyta (M)	6	5	4	8	14	1	6	8	5	17
Pteridophyta (T)	0	0	3	0	10	0	0	0	0	11
Rhamnaceae	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	0	0	0	0	0	0
Rubiaceae	0	0	0	0	0	0	0	0	0	0
Thymeliaceae	0	0	0	1	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	1
Total Count	516	500	537	627	557	498	511	518	508	509

POLLEN COUNTS (250) - MFABENI

Depth (m)	0.10	0.20	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.75	0.80	0.85	0.90	1.00	1.10	1.15	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	1.95	2.00
Lycopodiaceae	196	48	78	69	122	119	74	112	216	218	18	95	81	106	86	83	184	211	74	66	130	146	74	77	36	66
Anacardiaceae	5	0	0	10	1	6	4	6	12	1	0	0	5	1	1	0	9	9	6	6	1	1	4	4	3	2
Apocynaceae	0	0	0	4	0	1	2	1	5	0	0	3	2	0	1	3	7	0	2	0	0	1	3	3	1	2
Asteraceae	3	1	3	0	4	2	0	0	0	2	0	0	1	0	0	0	1	1	6	3	4	6	3	2	0	4
Caryophyllaceae	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0
Celastraceae	3	1	1	1	2	0	0	8	4	0	0	2	5	5	0	0	3	3	8	4	3	3	2	1	2	1
Chenopodiaceae	11	8	1	0	8	0	0	1	0	0	0	0	2	0	0	0	0	2	21	16	1	3	4	8	12	1
Cyanthaceae	0	0	0	3	0	0	0	0	0	0	0	11	0	0	0	32	0	0	0	0	0	7	0	0	0	0
Cyperaceae	53	41	41	32	100	65	34	45	36	42	7	12	39	18	8	27	13	36	12	25	25	39	42	22	84	26
Ericaceae	10	3	5	0	3	0	1	6	2	0	0	0	1	0	0	0	0	0	2	0	1	0	0	0	0	0
Erythroxylaceae	0	0	2	1	0	0	1	1	21	0	0	2	14	3	7	2	10	1	1	0	0	0	0	0	0	0
Euphorbiaceae	0	0	1	3	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0	1	0	0
Fabaceae	1	0	0	0	0	0	0	0	2	0	0	1	2	0	0	2	0	0	5	0	1	1	0	0	0	3
Fabaceae (Acacia)	15	1	6	0	1	0	0	1	2	0	0	0	2	1	0	0	0	5	1	0	1	1	0	3	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	2	0	0	0	0	0	0	4	1	1	0	0	4	3	1	0	0	8	9	4	2	2	2	0	1	2
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Iridaceae	33	88	58	4	30	13	29	33	30	16	12	5	35	39	19	19	14	7	43	14	27	10	6	14	6	14
Liliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	2	4	1	14	0	0
Moraceae	0	0	0	9	0	1	0	0	0	0	0	6	10	5	2	1	12	23	4	4	0	0	0	0	0	0
Myricaceae	0	0	0	0	0	0	10	1	10	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	1	0	0	6	0	0	0	3	9	0	0	3	7	2	9	0	5	6	4	0	0	0	0	0	0	0
Poaceae	94	87	108	145	86	162	140	104	85	193	22	30	97	150	78	96	90	120	89	117	158	150	160	152	112	98
Podocarpaceae	1	1	1	4	1	8	9	13	16	0	1	7	11	10	3	10	11	8	24	15	14	6	10	9	30	9
Polygalaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0
Proteaceae	0	0	0	0	1	0	0	1	4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
Pteridophyta (M)	6	9	4	26	3	5	5	7	13	2	0	21	6	4	4	62	11	4	5	6	1	1	1	0	22	3
Pteridophyta (T)	1	1	10	3	0	7	40	31	4	4	209	164	2	9	118	60	50	0	0	0	0	4	0	0	0	73
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	1	0	0	0	0	0	0	1	1	0	0	0	2	5	2	0	0	1	0	1	2	0	0	0	0	2
Rubiaceae	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	7	1	1	6	2	2	3	1	0	0
Thymeliaceae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Undetermined	15	14	8	0	9	0	8	6	6	0	1	1	4	2	1	0	3	7	8	0	3	3	0	5	1	6
Total Count	256	255	249	251	251	270	283	273	263	261	253	269	255	260	255	314	248	251	256	224	249	244	241	240	277	246

POLLEN COUNTS (250) - MFABENI

Depth (m)	2.05	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	3.90	4.00	4.10	4.20	4.30	4.40	4.50
Lycopodiaceae	116	276	157	244	214	78	15	135	156	127	65	46	65	60	36	27	57	34	33	38	29	31	43	51	50	58
Anacardiaceae	5	2	1	1	3	0	3	2	1	1	0	0	0	0	1	0	0	0	0	0	1	0	4	4	0	1
Apocynaceae	1	0	3	1	4	0	0	1	1	2	2	1	1	2	1	0	2	0	1	2	0	1	1	0	0	0
Asteraceae	2	0	0	0	1	2	0	1	1	1	2	0	6	3	1	2	2	7	1	5	6	5	5	3	2	3
Caryophyllaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
Celastraceae	11	4	2	2	7	11	2	3	9	0	4	5	2	2	2	2	3	2	2	3	3	3	1	1	2	1
Chenopodiaceae	0	25	2	6	1	16	11	1	0	3	2	1	0	0	1	0	3	2	1	4	2	2	5	1	4	1
Cyanthaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	32	47	14	31	24	38	34	37	37	49	55	56	67	74	73	68	70	61	51	71	63	82	63	75	75	88
Ericaceae	0	0	0	0	2	0	0	0	3	0	0	0	0	0	0	0	2	0	1	0	0	1	1	1	1	1
Erythroxylaceae	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	0	0	0	2	1	1	1	3	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0
Fabaceae	0	1	1	0	0	0	0	0	1	1	3	0	3	1	0	3	0	0	0	0	0	0	1	0	0	0
Fabaceae (Acacia)	0	1	0	0	0	0	0	0	0	0	0	0	2	0	1	2	0	0	0	0	1	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	0	4	4	1	3	3	0	2	2	4	4	0	2	1	2	2	1	2	0	1	1	1	0	0	1	1
Geraniaceae	0	0	0	0	0	1	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	13	21	16	18	26	11	22	21	15	21	7	18	15	13	13	15	4	13	18	13	16	14	21	21	10	10
Liliaceae	0	0	3	0	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1	3	0	3	3	0	1	2
Moraceae	0	0	2	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1	0	0	0	2
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	1	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	103	143	161	137	138	145	165	179	144	167	172	161	160	139	150	162	138	148	158	136	155	139	155	129	155	122
Podocarpaceae	7	26	20	35	29	18	8	4	10	1	5	2	1	2	1	3	4	1	1	2	1	1	2	1	3	6
Polygalaceae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Pteridophyta (M)	79	16	5	12	12	2	2	7	2	4	5	7	37	15	29	13	19	12	9	19	12	18	11	7	15	15
Pteridophyta (T)	0	1	1	0	2	0	0	0	0	0	4	1	1	1	1	3	2	2	4	7	2	5	4	6	4	4
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Rubiaceae	1	5	0	2	3	1	3	1	2	4	2	0	1	0	0	0	0	1	1	1	0	0	0	1	0	0
Thymeliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Undetermined	0	1	7	3	2	1	0	4	4	0	0	0	2	1	1	1	2	3	1	0	3	2	2	0	1	0
Total Count	254	299	243	250	260	251	251	266	257	260	267	253	300	256	279	277	253	257	250	269	266	279	280	251	274	258

POLLEN COUNTS (250) - MFABENI

Depth (m)	4.60	4.70	4.80	4.90	5.00	5.10	5.20	5.30	5.40	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.30	6.40	6.50	6.60	6.70	6.80	6.90	7.00	7.05
Lycopodiaceae	45	46	37	24	22	131	150	31	248	41	41	20	25	53	38	44	48	35	36	13	30	26	52	71	72	32
Anacardiaceae	3	1	2	1	1	0	0	2	0	2	1	2	4	2	1	1	3	2	3	0	1	0	0	5	1	0
Apocynaceae	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	5	3	6	3	6	0	1	2	9	5	2	3	2	9	9	1	6	5	7	5	4	4	6	6	4	0
Caryophyllaceae	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Celastraceae	4	3	2	4	1	0	0	4	0	2	2	0	2	2	3	2	0	1	3	3	2	1	2	0	1	0
Chenopodiaceae	3	0	5	0	7	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	4	1	1	2	8	0
Cyanthaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	97	87	86	81	66	72	97	125	114	121	145	121	104	104	120	128	129	133	118	109	138	96	76	95	72	42
Ericaceae	1	2	2	3	2	0	0	0	1	0	2	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	2	0	0	0	0	1	0	0	1	0	1	1	0	0	1	2	1	0	0	1	0	0	0	0	0	0
Fabaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Flacourtiaceae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Geraniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	13	18	12	17	18	17	15	3	7	9	9	7	7	4	10	5	3	7	8	18	8	13	7	14	21	16
Liliaceae	1	2	3	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	5	4	12	0
Moraceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Poaceae	160	133	147	189	129	145	141	118	108	106	114	124	98	110	94	106	93	115	126	120	134	127	145	124	148	191
Podocarpaceae	3	2	3	2	3	1	3	4	4	4	10	1	4	4	6	2	4	2	7	3	9	1	0	6	5	0
Polygalaceae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pteridophyta (M)	15	4	15	11	9	13	7	14	5	10	14	8	17	6	5	8	3	4	3	4	9	5	8	10	23	2
Pteridophyta (T)	3	2	7	12	11	0	0	7	1	19	14	8	8	7	5	4	4	5	1	3	3	3	0	1	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubiaceae	0	1	0	0	0	0	0	0	0	1	2	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0
Thymeliaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undetermined	3	1	1	0	1	0	0	0	0	1	0	0	1	3	2	0	0	0	1	1	0	0	0	0	0	0
Total Count	313	260	291	325	258	251	264	279	250	282	317	278	250	254	258	259	250	275	279	268	323	252	250	269	295	252

POLLEN COUNTS (250) - MFABENI

Depth (m)	7.10	7.20	7.25	7.30	7.40	7.50	7.55	7.60	7.65	7.70	7.80	7.90	8.00	8.10	8.15	8.20	8.25	8.30	8.35	8.40	8.45	8.50	8.60	8.70	8.80	8.90
Lycopodiaceae	18	21	10	32	28	41	20	9	4	22	44	82	25	25	18	13	12	18	23	6	8	17	20	50	123	70
Anacardiaceae	3	1	0	3	1	0	1	2	2	4	1	0	2	5	1	3	1	3	5	1	1	1	0	5	6	4
Apocynaceae	3	0	0	0	0	0	2	0	0	0	1	2	0	0	2	1	0	1	1	0	0	0	1	1	0	0
Asteraceae	2	2	2	11	4	5	2	6	1	1	3	1	1	2	4	5	1	2	1	1	3	3	4	1	0	0
Caryophyllaceae	1	0	0	0	0	1	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Celastraceae	0	0	0	1	0	2	2	25	4	8	10	3	2	11	4	6	3	1	0	5	2	6	5	4	3	2
Chenopodiaceae	3	0	10	3	2	4	7	4	3	4	2	0	0	0	0	0	0	2	5	0	0	2	5	3	0	0
Cyanthaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	56	65	109	128	79	50	78	44	37	63	85	95	82	78	60	68	93	57	35	69	45	70	32	44	53	43
Ericaceae	0	0	0	0	1	0	1	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	0	0	2	3	2	0	2	0	4	4	1	1	2	0	2	1	0	1	1	0	1	0	0	0	0
Fabaceae	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flacourtiaceae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	1
Geraniaceae	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	13	4	10	7	9	11	21	13	17	9	8	16	7	5	6	8	7	15	16	8	18	12	9	14	17	20
Liliaceae	0	1	3	0	0	1	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moraceae	1	0	0	1	0	0	1	1	1	0	0	0	0	0	2	1	1	1	3	1	0	0	1	1	0	0
Myricaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	161	171	121	103	152	169	154	128	143	135	100	115	99	121	76	53	139	133	96	93	104	126	125	159	168	177
Podocarpaceae	2	4	8	4	2	7	29	46	21	22	28	3	3	4	3	4	2	40	59	4	1	25	60	27	14	4
Polygalaceae	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pteridophyta (M)	4	1	0	3	2	3	9	4	18	5	18	14	49	27	101	99	54	19	27	68	87	29	5	6	33	6
Pteridophyta (T)	0	0	0	0	0	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubiaceae	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Thymeliaceae	0	0	0	0	0	0	1	1	0	0	4	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
Undetermined	0	2	1	0	0	0	1	0	0	0	1	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Count	250	251	264	269	255	257	310	284	249	260	269	250	251	255	260	250	303	277	250	251	262	275	250	265	294	257

POLLEN COUNTS (250) - MFABENI

Depth (m)	9.00	9.10	9.20	9.30	9.35	9.40	9.50	9.60	9.70	9.80
Lycopodiaceae	29	27	31	18	16	118	163	192	50	62
Anacardiaceae	2	0	1	0	2	0	4	4	3	3
Apocynaceae	0	0	0	0	0	0	0	0	0	0
Asteraceae	4	1	2	3	0	0	3	7	0	6
Caryophyllaceae	0	0	1	1	0	0	0	0	0	0
Celastraceae	1	3	2	2	3	1	0	5	0	4
Chenopodiaceae	0	0	2	2	13	0	0	0	0	0
Cyanthaceae	0	0	0	0	0	0	0	0	0	0
Cyperaceae	78	90	87	145	71	45	66	32	29	27
Ericaceae	0	0	0	0	0	0	0	0	0	0
Erythroxylaceae	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	1	0	1	1	0	0	0	0	0	2
Fabaceae	0	0	0	0	0	0	0	0	0	0
Fabaceae (Acacia)	0	0	0	0	0	0	0	0	0	0
Fagaceae-like	0	0	0	1	0	0	0	0	0	0
Flacourtiaceae	0	0	0	0	1	0	1	0	0	0
Geraniaceae	0	0	0	0	0	0	12	0	0	0
Iridaceae	13	7	12	12	18	15	0	3	4	17
Liliaceae	3	1	2	0	3	0	0	0	0	0
Moraceae	2	1	1	1	0	0	0	0	0	0
Myricaceae	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	0	0	0	0	0	0
Poaceae	150	139	140	120	131	204	172	205	293	190
Podocarpaceae	3	5	4	2	11	0	0	0	0	6
Polygalaceae	0	0	0	1	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0
Pteridophyta (M)	3	3	1	4	8	1	2	5	2	17
Pteridophyta (T)	0	0	2	0	5	0	0	0	0	11
Rhamnaceae	0	0	0	0	0	0	0	0	0	0
Rosaceae	0	0	0	0	0	0	0	0	0	0
Rubiaceae	0	0	0	0	0	0	0	0	0	0
Thymelliaceae	0	0	0	1	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	1
Total Count	260	250	258	296	266	266	260	261	331	284

APPENDIX J

FULL CHI-SQUARED RESULTS

Depth	Anacardiaceae	Apocynaceae	Asteraceae	Celastraceae	Chenopodiaceae	Cyperaceae	Ericaceae	Erythroxylaceae	Euphorbiaceae	Fabaceae	Flacourtiaceae	Iridaceae	Liliaceae	Moraceae	Myrtaceae	Poaceae	Podocarpaceae	Pteridophyta	Rubiaceae	Undetermined
0.10	0.094	3.125	0.018	0.016	0.219	0.007	0.422	0.000	0.000	0.003	0.766	0.147	0.000	0.000	0.063	0.572	0.063	0.184	0.000	1.032
0.20	0.000	0.000	0.063	0.063	0.047	0.403	0.313	0.000	0.000	1.688	0.000	0.000	0.000	0.000	0.000	0.040	0.063	0.042	0.000	0.281
0.30	4.225*	0.000	0.125	1.225	1.225	0.009	0.195	0.168	0.063	0.007	0.000	0.170	0.000	0.000	0.000	0.000	2.161	0.139	0.000	0.540
0.35	0.445	0.094	3.375	2.641	0.000	0.102	0.000	0.375	0.188	0.000	0.000	0.011	0.000	0.005	0.007	0.007	0.094	0.323	0.000	0.000
0.40	0.063	0.000	0.391	0.031	0.047	1.003	1.875	0.000	0.000	0.063	0.000	0.859	0.000	0.000	0.000	0.040	0.063	0.188	0.000	0.047
0.45	0.008	1.688	0.031	0.000	0.000	0.245	0.000	0.000	3.063	3.125	0.000	0.089	0.000	0.375	0.000	0.211	0.006	0.004	0.000	0.000
0.50	0.094	1.125	0.000	3.125	0.000	0.063	0.375	1.225	0.000	3.781	3.063	0.267	0.000	0.000	3.125	2.058	0.005	1.668	0.000	0.322
0.60	0.075	0.063	0.000	0.322	0.063	0.008	0.223	0.375	0.000	2.161	0.011	0.710	0.000	0.000	0.313	2.431	0.089	1.073	0.000	0.223
0.70	1.042	0.094	3.125	0.125	0.000	0.980	0.025	3.025	3.125	0.011	0.063	1.296	0.000	3.781	0.482	3.186	0.369	1.413	3.125	0.223
0.75	0.375	0.000	0.025	0.000	0.000	0.161	0.000	0.000	0.000	0.000	0.063	0.142	0.000	0.000	0.000	0.187	0.000	0.063	0.000	0.000
0.80	3.125	3.125	3.125	0.000	0.000	0.007	3.125	0.000	0.000	3.063	0.000	0.084	0.000	0.000	0.000	0.364	0.375	0.000	0.000	0.375
0.85	3.125	0.016	0.000	0.031	0.000	0.161	3.125	0.188	0.000	0.063	0.000	0.284	0.000	0.007	0.313	0.258	0.006	0.200	0.000	0.063
0.90	0.195	0.168	1.225	0.075	0.025	0.893	0.063	1.838	0.000	0.031	0.125	0.484	0.000	0.004	0.142	0.095	1.101	0.540	0.025	0.094
1.00	0.781	0.000	0.000	0.284	3.125	0.625	0.000	0.188	0.375	0.375	0.188	0.338	0.000	1.056	0.188	0.315	0.120	4.218*	0.031	0.446
1.10	0.375	0.781	0.000	4.687*	0.000	0.054	0.000	0.383	0.000	0.000	0.063	3.490	3.781	1.125	0.278	0.161	1.875	1.749	0.063	0.375
1.15	0.000	0.125	0.000	0.000	0.000	0.391	0.000	0.031	0.000	0.031	0.000	1.225	0.000	0.375	3.125	0.639	0.120	5.430*	0.000	0.000
1.20	0.136	1.080	2.641	1.875	0.000	0.003	0.000	0.960	0.000	3.375	3.063	1.474	3.781	0.004	0.075	0.610	0.004	0.403	0.383	0.844
1.30	0.756	3.063	0.781	0.188	0.025	0.369	0.000	0.063	0.781	0.094	0.563	2.441	0.094	0.967	0.844	2.055	0.125	0.094	0.781	0.184
1.40	0.471	1.125	0.063	0.375	0.384	0.004	0.031	0.781	3.125	0.164	1.531	0.049	0.025	0.011	0.125	0.617	0.083	0.075	0.375	0.563
1.50	0.075	0.000	0.844	0.240	0.291	0.080	0.000	0.000	0.063	3.125	0.945	1.911	0.000	0.011	0.000	0.576	0.423	0.008	0.075	3.063
1.60	0.063	3.375	0.125	1.163	2.161	2.235	0.375	0.000	0.063	0.188	0.188	0.081	0.025	3.063	0.000	0.143	0.073	2.161	0.031	0.016
1.70	0.781	1.688	0.008	0.016	0.018	0.229	0.000	0.000	0.000	0.031	0.031	0.101	0.391	3.125	0.000	0.046	1.445	0.338	0.031	0.018
1.80	0.013	0.188	0.313	0.446	0.011	0.127	0.000	0.000	0.000	0.000	0.188	5.679*	0.063	0.000	0.000	0.013	0.781	0.375	0.188	4.225*
1.90	0.011	0.125	1.125	0.375	0.047	1.331	0.000	0.000	0.063	0.557	3.063	0.139	0.073	0.000	0.000	0.034	0.211	3.125	0.063	0.075
1.95	0.844	0.375	0.000	0.188	0.004	0.914	0.000	0.000	3.063	0.000	0.375	0.471	0.000	0.000	0.000	0.329	0.707	0.364	3.125	0.063
2.00	0.025	0.025	0.240	0.375	1.688	0.002	0.000	0.000	0.000	0.188	0.031	1.129	0.000	0.000	0.000	0.494	1.063	0.698	0.000	0.223
2.05	0.094	0.375	0.031	0.108	0.000	1.226	0.000	0.000	0.000	0.000	0.000	0.938	0.000	0.000	0.000	0.834	0.006	0.981	0.063	0.000
2.10	0.025	3.063	3.125	0.011	0.556	1.766	0.000	0.031	3.125	0.031	0.391	0.153	0.000	3.125	0.000	0.418	0.835	0.225	0.613	0.063
2.20	0.375	0.018	3.125	0.031	1.513	0.139	0.000	0.000	0.000	0.063	0.125	2.633	0.188	0.031	3.125	0.195	0.099	5.679*	0.000	0.063
2.30	1.225	1.225	3.125	0.446	0.063	0.249	0.000	0.000	0.000	0.000	0.063	1.033	0.000	0.000	0.000	0.024	0.323	1.805	0.031	0.188
2.40	0.016	0.013	0.063	0.006	0.063	1.085	0.025	0.000	0.031	3.125	0.016	1.017	0.063	0.000	0.000	0.050	0.735	0.225	0.188	0.031
2.50	0.000	0.000	0.031	1.571	0.071	1.238	0.000	0.000	0.375	3.125	0.125	0.281	0.000	0.063	0.000	0.763	0.469	0.766	1.225	0.375
2.60	0.018	3.375	3.063	0.188	0.092	0.059	0.000	0.000	0.375	3.125	3.375	0.017	3.063	0.000	0.000	0.285	1.670	1.920	0.016	3.063
2.70	0.031	0.063	0.375	0.016	0.375	0.276	0.000	0.000	0.063	0.000	0.031	0.868	0.000	0.000	0.063	0.052	0.094	0.184	0.375	0.391
2.80	0.375	0.781	0.781	0.042	3.125	0.010	0.188	0.000	0.018	0.375	0.766	0.003	0.063	3.125	3.038	0.082	0.422	0.766	0.188	0.675
2.90	0.781	0.031	0.375	3.781	0.018	0.072	0.000	0.000	3.125	0.063	0.013	0.018	0.000	0.000	0.000	0.030	0.781	0.011	0.391	0.000
3.00	3.125	0.025	0.031	0.125	0.025	0.007	0.000	3.125	0.000	0.188	0.013	0.142	3.125	0.000	0.000	0.089	0.284	0.005	0.025	0.000
3.10	0.000	0.063	3.781	0.094	0.063	0.036	3.063	0.000	0.375	0.000	3.063	0.875	0.000	0.000	0.000	0.691	0.025	0.728	0.000	3.063
3.20	0.000	0.063	0.008	0.025	3.125	0.352	0.000	0.000	0.000	0.094	0.031	0.025	0.000	0.000	0.000	0.227	0.063	1.238	0.375	0.188
3.30	0.000	0.031	0.557	0.025	3.125	0.132	0.000	0.000	0.375	0.063	0.781	0.003	0.000	0.781	0.000	0.066	0.188	1.519	0.000	0.063
3.40	0.063	0.063	0.375	0.025	0.375	0.071	0.000	0.000	0.063	0.781	0.766	0.149	0.000	0.063	0.000	0.082	1.688	0.859	0.000	0.063
3.50	3.125	0.000	0.031	0.031	3.125	1.032	0.000	0.000	0.000	0.094	0.446	0.027	0.375	0.000	0.000	0.457	0.188	0.023	0.000	0.063
3.60	0.000	0.031	0.446	0.125	0.018	0.181	0.025	0.000	3.125	0.000	0.375	0.945	0.000	0.000	0.000	0.036	0.094	0.094	3.125	0.025
3.70	0.000	0.000	0.184	0.188	0.025	0.190	0.000	0.000	0.063	0.000	0.188	0.473	0.063	0.063	0.000	0.000	0.063	0.027	0.063	0.018
3.80	0.000	0.063	0.781	0.025	0.063	1.336	0.063	0.000	0.000	3.125	3.125	0.322	0.063	0.000	0.000	0.045	1.225	2.022	0.063	0.063
3.90	0.000	0.031	0.075	0.557	0.391	0.028	3.063	0.000	0.000	0.000	0.375	0.307	0.188	0.375	0.000	0.540	0.025	0.634	0.063	3.125
4.00	0.063	3.125	0.223	0.018	0.031	0.083	0.000	0.000	0.000	0.063	0.781	0.123	4.225*	0.000	0.000	0.022	0.781	0.449	0.000	0.188
4.10	3.125	0.063	0.563	0.016	0.025	0.938	0.063	0.000	0.000	0.000	0.375	0.027	0.188	0.781	3.125	0.037	0.375	0.002	0.000	0.031

* statistically significant at the 0.05 level

Depth	Anacardiaceae	Apocynaceae	Asteraceae	Celastraceae	Chenopodiaceae	Cyperaceae	Ericaceae	Erythroxylaceae	Euphobiaceae	Fabaceae	Flacourtiaceae	Iridaceae	Liliaceae	Moraceae	Myrtaceae	Poaceae	Podocarpaceae	Pteridophyta	Rubiaceae	Undetermined
4.20	0.391	0.063	0.009	0.063	0.094	0.006	0.375	0.000	0.000	0.063	3.063	1.323	0.018	3.125	0.000	0.867	0.446	0.309	0.000	0.031
4.30	0.125	0.000	0.125	0.375	0.375	2.063	0.063	0.000	3.125	0.000	3.125	0.053	3.125	0.000	0.000	0.852	0.063	0.003	0.063	3.125
4.40	3.125	0.000	0.766	0.188	0.013	0.211	0.375	0.000	3.125	0.000	1.225	0.042	0.375	0.000	0.000	1.074	0.016	0.054	0.000	0.063
4.50	0.063	0.000	0.016	0.063	2.641	0.366	0.375	0.000	3.063	0.000	0.063	0.191	0.025	0.188	0.000	0.147	0.223	0.054	0.000	3.125
4.60	0.188	0.000	0.284	0.391	0.018	2.055	0.063	0.000	0.031	0.000	0.000	0.180	0.375	0.000	0.000	2.281	0.016	0.063	0.000	0.188
4.70	0.063	0.000	0.844	0.018	3.375	0.012	0.031	0.000	0.000	0.000	0.000	0.021	0.031	3.125	0.000	0.162	0.188	0.306	0.375	0.063
4.80	0.025	0.000	0.008	0.025	0.010	1.082	0.031	0.000	0.000	0.000	0.000	0.338	0.016	0.000	0.000	0.501	0.557	0.645	0.000	0.063
4.90	0.375	0.000	0.125	0.125	3.063	1.907	0.188	0.000	0.000	0.000	0.000	0.344	0.031	0.000	0.000	7.614*	0.031	1.181	0.000	0.000
5.00	0.781	0.000	0.007	1.225	0.383	0.050	0.031	0.000	0.000	0.000	3.125	0.625	0.011	0.000	0.000	0.228	0.016	0.285	0.000	0.375
5.10	0.000	0.000	3.125	0.000	0.000	0.096	3.125	0.000	0.063	3.125	0.000	0.225	1.125	0.000	0.000	0.082	0.063	0.625	0.000	3.125
5.20	0.000	0.000	0.375	3.125	0.000	0.282	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.007	0.125	1.838	0.000	0.000
5.30	0.025	0.000	1.125	0.094	0.000	0.183	0.000	0.000	0.000	0.000	0.000	1.163	0.000	0.000	0.000	2.360	0.094	0.002	0.000	0.000
5.40	0.000	0.000	0.005	0.000	0.000	0.337	0.063	0.000	0.375	0.000	0.000	0.422	0.000	0.000	0.000	0.144	0.125	0.306	0.000	0.000
5.50	0.025	0.031	0.284	0.188	0.000	0.079	0.000	0.000	3.125	0.000	0.000	0.005	0.000	0.000	0.000	0.454	0.011	0.267	0.063	0.781
5.60	0.781	0.000	1.125	0.766	0.063	1.154	0.025	0.000	0.375	0.000	0.000	0.136	0.000	0.000	0.000	0.474	0.422	0.039	0.031	0.000
5.70	0.031	3.125	0.557	3.063	0.000	0.303	0.375	0.000	0.781	0.000	0.000	0.054	0.000	0.000	0.000	1.665	1.225	0.721	0.000	0.000
5.80	0.094	0.000	5.532*	0.188	0.000	1.280	0.063	0.000	0.000	0.000	0.063	0.142	0.000	0.000	0.000	0.004	0.013	0.222	0.000	0.063
5.90	0.025	0.000	0.005	0.446	0.781	1.540	0.000	0.000	0.000	0.000	0.000	1.243	0.000	0.000	0.375	0.349	0.240	4.840*	0.375	0.016
6.00	0.781	0.000	0.005	0.016	3.125	0.009	3.125	0.000	0.781	0.000	3.125	0.042	0.000	0.000	0.000	0.835	0.223	0.101	0.063	0.031
6.10	0.063	0.000	1.688	0.766	0.000	0.383	3.063	0.000	0.446	0.000	0.000	0.195	0.000	0.000	0.000	0.117	1.920	0.031	3.125	3.125
6.20	0.313	3.125	0.007	3.063	0.000	0.177	0.000	0.000	0.781	0.063	0.000	2.258	0.000	3.125	0.000	0.705	2.625	0.063	0.063	0.000
6.30	0.025	0.000	0.075	0.781	0.000	0.016	3.125	0.000	0.000	0.000	3.125	0.007	0.000	0.000	0.000	0.009	0.025	0.278	0.375	0.000
6.40	0.018	0.000	0.054	0.018	0.000	0.915	3.125	0.000	0.000	0.031	0.000	0.006	3.125	3.125	0.000	0.041	0.063	0.675	0.000	0.063
6.50	3.781	0.000	0.360	0.188	0.781	0.019	3.125	0.000	0.063	3.125	0.000	0.125	3.375	0.000	0.000	0.042	1.163	0.422	0.000	0.375
6.60	0.063	0.000	0.438	0.188	0.240	2.821	0.063	0.000	0.000	0.000	0.000	0.006	0.756	0.063	0.000	3.341	0.136	0.098	3.125	0.000
6.70	3.125	0.000	0.094	2.641	0.375	0.004	3.375	0.000	0.000	0.000	0.000	0.681	3.375	3.125	0.000	0.743	1.688	0.047	0.000	0.000
6.80	0.000	0.000	0.223	0.188	0.063	0.154	0.000	0.000	0.000	0.000	0.000	1.838	0.009	0.000	3.125	0.106	3.375	0.236	3.063	0.000
6.90	0.094	0.000	0.008	3.375	0.025	1.593	0.000	0.000	0.000	0.000	0.063	0.082	0.094	3.125	0.063	0.008	0.075	0.092	3.063	0.000
7.00	0.063	0.000	0.438	0.063	0.322	0.975	3.125	0.000	0.000	0.000	3.125	0.178	0.338	3.125	0.000	1.641	0.613	1.181	3.125	0.000
7.05	0.000	0.000	0.000	0.000	3.125	0.858	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.375	0.000	1.340	0.000	2.779	0.000	0.000
7.10	0.188	0.018	0.031	3.125	0.016	2.806	0.000	0.000	0.000	0.000	0.063	0.473	3.125	0.375	0.000	0.096	1.125	0.013	0.000	3.125
7.20	0.063	0.000	0.188	3.063	0.000	0.506	3.063	0.000	0.000	0.000	3.125	0.240	0.063	0.000	0.000	0.289	0.013	1.225	0.000	0.031
7.25	0.000	0.000	0.446	3.375	0.004	0.998	0.000	0.000	0.000	0.000	0.000	0.004	0.125	0.000	0.000	0.404	0.054	0.000	0.000	0.063
7.30	0.313	0.000	0.108	0.063	0.016	0.003	0.000	0.000	0.025	0.000	3.125	0.184	0.000	0.063	0.000	0.151	0.240	0.016	0.031	3.125
7.40	1.688	0.000	0.240	3.125	0.188	0.315	0.063	0.000	0.188	0.000	0.000	0.005	0.000	3.125	0.000	0.034	0.446	0.031	0.000	3.125
7.50	3.125	0.000	1.056	0.188	0.125	0.413	3.125	0.000	0.025	0.000	0.000	0.409	2.161	3.125	0.000	0.851	1.556	0.011	0.000	3.125
7.55	0.063	0.025	0.031	0.446	0.054	3.199	0.781	0.000	3.125	0.000	0.000	0.053	0.000	0.063	0.000	1.853	1.266	0.245	0.000	0.375
7.60	0.031	0.000	0.471	0.191	0.011	0.170	0.031	0.000	0.031	0.000	0.000	0.473	3.125	1.225	0.000	0.327	0.008	0.322	0.000	0.000
7.65	0.446	0.000	0.063	0.240	0.313	1.616	0.000	0.000	3.125	0.000	0.000	0.491	0.188	0.375	0.000	0.049	0.311	0.178	0.000	0.000
7.70	0.013	3.125	0.781	0.005	0.011	0.229	0.063	0.000	0.125	0.000	0.000	0.488	0.000	3.375	3.125	0.052	0.735	0.075	0.000	3.063
7.80	0.375	1.688	0.313	0.101	0.031	0.086	0.000	0.000	0.391	0.063	0.000	0.006	0.031	3.125	0.000	0.125	0.130	0.022	0.000	1.225
7.90	0.000	0.025	0.063	0.018	0.000	0.000	3.063	0.000	0.063	0.000	0.000	0.241	0.000	0.000	0.000	0.219	0.125	0.225	0.000	0.000
8.00	0.188	3.125	0.781	0.446	0.000	0.353	0.000	0.000	0.063	0.188	0.000	0.142	0.000	0.000	0.000	0.489	0.313	0.001	0.000	0.031
8.10	0.010	0.000	0.446	1.776	0.000	0.613	0.000	0.000	0.446	0.000	3.125	2.297	0.000	0.000	0.000	5.603*	0.945	0.002	0.000	0.000

Depth	Anacardiaceae	Apocynaceae	Asteraceae	Celastraceae	Chenopodiaceae	Cyperaceae	Ericaceae	Erythroxylaceae	Euphobiaceae	Fabaceae	Flacourtiaceae	Iridaceae	Liliaceae	Moraceae	Myrtaceae	Poaceae	Podocarpaceae	Pteridophyta	Rubiaceae	Undetermined
8.15	0.375	0.188	0.240	0.011	0.000	0.058	0.000	0.000	0.000	0.000	0.000	0.164	0.000	0.031	0.000	0.308	0.016	0.049	0.000	0.000
8.20	0.016	0.063	0.009	0.075	3.125	0.484	0.000	0.000	0.825	0.000	3.125	0.375	0.000	0.063	0.000	0.218	0.094	1.090	3.125	0.000
8.25	0.781	3.063	0.375	0.188	0.000	1.399	0.000	0.000	0.375	0.000	0.000	0.383	0.000	0.063	0.000	7.203**	0.766	0.126	3.063	0.781
8.30	0.018	0.063	0.188	2.641	0.766	0.224	0.375	0.000	3.063	0.063	3.125	0.076	0.000	0.375	0.000	0.222	0.189	0.835	0.000	0.000
8.35	0.009	0.063	0.375	0.000	1.962	0.011	0.000	0.000	1.688	0.000	0.063	0.521	0.000	0.313	0.000	7.320**	1.501	2.101	0.000	0.000
8.40	1.225	0.000	0.063	0.010	0.000	0.050	0.000	0.000	0.375	0.000	3.125	0.322	0.000	0.063	0.000	0.295	0.013	1.426	0.000	0.000
8.45	1.688	0.000	0.018	0.766	0.000	0.109	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.262	0.375	0.133	0.000	0.000
8.50	0.375	0.000	0.018	0.008	0.031	3.146	0.000	0.000	0.063	0.000	0.000	0.338	3.125	0.000	0.000	2.986	0.222	1.811	0.000	0.000
8.60	0.000	0.063	0.011	0.360	0.009	0.276	0.000	0.000	0.000	0.000	0.446	0.660	0.000	0.063	0.000	1.225	0.087	0.360	0.375	3.125
8.70	0.009	0.063	0.063	0.240	0.557	0.229	0.000	0.000	0.000	0.000	3.375	0.027	0.000	0.063	0.000	0.297	0.002	0.063	0.000	0.000
8.80	0.075	0.000	0.000	0.018	3.125	0.945	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.112	2.280	1.681	0.000	0.000
8.90	0.240	0.000	3.125	0.188	0.000	0.077	0.000	0.000	3.125	0.000	0.063	0.099	0.000	0.000	0.000	0.542	0.438	0.471	0.000	0.000
9.00	0.188	0.000	0.013	0.375	3.125	0.088	0.000	0.000	0.063	0.000	0.000	0.180	0.125	0.063	0.000	0.007	0.016	0.125	0.000	0.000
9.10	0.600	0.000	1.225	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.266	0.063	0.063	0.000	0.024	0.010	0.016	0.000	0.000
9.20	0.375	0.000	1.125	0.031	1.125	0.079	0.000	0.000	0.063	0.000	0.000	0.260	0.025	0.063	0.000	0.243	0.011	0.313	0.000	0.000
9.30	3.125	0.000	0.125	0.188	0.446	0.508	3.125	0.000	0.063	0.000	3.125	0.004	0.000	0.063	0.000	0.407	0.446	0.094	0.000	0.000
9.35	0.025	0.000	0.000	0.016	0.307	0.906	0.000	0.000	0.000	0.000	0.063	0.109	0.125	3.125	0.000	0.295	0.004	0.063	0.000	0.000
9.40	0.000	0.000	0.000	0.375	0.000	0.364	0.000	0.000	0.000	0.000	0.000	0.211	0.000	0.000	0.000	0.470	0.000	0.063	0.000	0.000
9.50	0.125	0.000	0.018	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.063	0.000	0.000	0.000	0.000	0.006	0.000	0.766	0.000	0.000
9.60	0.011	0.000	0.383	0.075	0.000	0.067	0.000	0.000	0.000	0.000	0.000	0.844	0.000	0.000	0.000	0.010	3.781	0.010	0.000	0.000
9.70	0.018	0.000	4.220*	0.000	0.000	0.267	0.000	0.000	0.000	0.000	0.000	1.243	0.000	0.000	0.000	16.740***	3.125	0.446	0.000	0.000
9.80	0.018	0.000	0.223	0.391	0.000	0.074	0.000	0.000	0.031	0.000	0.000	0.344	0.000	0.000	0.000	0.038	0.471	6.270*	0.000	0.063

** statistically significant at the 0.01 level; *** statistically significant at the 0.001 level