HOLOCENE ENVIRONMENTAL CHANGE AND THE VEGETATION COMMUNITY DYNAMICS OF THE KYNSNA FOREST:

POLLEN AND CHARCOAL ANALYSIS OF SEDIMENTS FROM GROENVLEI, SOUTHERN CAPE, SOUTH AFRICA

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Submitted in partial fulfilment of academic requirements for the degree of
Master of Science
(By Coursework and Dissertation)

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September 2006

ABSTRACT

To establish an understanding of the long-term community dynamics of the Knysna forests, and gain a better understanding of the impacts of colonial exploitation of the forests against a background of environmental change, sediments were extracted from the lake shore of Groenvlei, an endorheic coastal vlei in the Wilderness Lake system on the southern Cape coast, some 10 km from the present-day forest core. These sediments were described, dated by radiocarbon means and subsampled for the analysis of fossil pollen and charcoal particles, environmental proxies used respectively to infer a vegetation and fire history for the region.

62 pollen taxa were identified and allocated to a habitat group [wet forest, moist-dry forest, dry forest to coastal scrub, forest margins, fynbos (heath elements) or wetland/local,] according to Geldenhuys (1993), and were presented in relative and absolute diagrams, to clarify the varying prominence of these ecological groups over time. Microscopic charcoal fragments present on the slides were counted alongside pollen grains, using Clark's (1982) Point-Count Method. Cluster analysis defined the pollen sequence into zones for descriptive purposes, while the provision of interpolated and calibrated ages, defined general time periods for these zones.

Description of the sediment core indicated that upper and lower sections of organics were separated by the substantial deposition of sand, imposing an effective hiatus on the derived pollen record, and therefore partitioning the core into two discrete units from ca. 8500 -8300 cal BP, and from ca.790 cal AD to present. Around 8500 calBP conditions at Groenvlei were inferred to be wetter, possibly owing to the maritime influence of warm sea surface temperatures associated with westerly-circulation. Hereafter, it is suggested that there was a transition to more easterly-dominated circulation, generally associated with Altithermal conditions. After the substantial sand section, the record resumes, indicating three further declines in the pollen spectra, separated by intervening mesic periods and the expansion of woodland and forest. The first, although correlating well

with the expression of the Medieval Warm Period, is suggested to be more likely an artefact of poor pollen preservation. The abruptness of the next decline in the late 1600s, in a generally more mesic period, and its temporal proximity to the extreme of the Little Ice Age, suggests this may be an expression of this global period of cold. The last decline can be dated by the appearance of Pine in the record to the late 19th century, a period that accords with a series of drought years, the most significant exploitation of the forest by woodcutters and merchants, and one of the greatest fires on record, that of 1869. It is difficult to resolve the individual contribution of these, although what is likely is that while the climatic dryness set the conditions for change, it was human disturbance, through both firing and logging that produced the decline, the effect of which is evident in the record as an event of similar magnitude to global climatic changes.

In general, pollen analysis has proved more successful in achieving the project objectives than the microscopic charcoal analysis. While the pollen record indicates the relationship between fynbos and forest margins, a relationship that is undoubtedly fire maintained, no clear evidence of this relationship could be found in the charcoal record. What was evident in the charcoal record, however, was the substantial rise in charcoal in upper sections which chronologically agrees with western discovery of the forest, suggesting that fire was applied by colonists most likely with intention to modify the landscape. The resultant diagrams showed very similar results to previous studies by Martin (1968); however, the interpretation of fluctuations occurring in coincident periods differed slightly owing to a higher resolution record for upper sections, as well as advances in palaeo-research subsequent to his investigation.

Acknowledgments

My particular thanks to my supervisor Professor Mike Meadow, for the constructive and valuable academic advice, continual encouragement as well as generous funding. My thanks to Cape Nature Conservation, the National Parks Board and the owners of the Lake Pleasant Holiday Resort, for bearing with the noisy coring procedure. To Brett Smith for the Vibracoring expertise, to Brian Chase for advice and guidance in the lab and in the field, Grant Cornish-Bowden, Kelly Kirsten, Arabel Shaw, Simon Charter, Charles van de Meden, Shannon Hampton and Catherine Duncan for being willing and enthusiastic participants during the coring field trips. I greatly appreciated the effort and assistance of Sayed Hess in the lab. This project was funded by the National Research Foundation (Grantholder Bursary), and the funding is greatly appreciated. Lastly, my thanks to my family and friends for their unflagging patience and support.

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Chapter 1:

INTRODUCTION AND BACKGROUND

1.1 Introduction

In a generally semi-arid country, the Knysna forests of the southern Cape (see Fig 1.1), provide an unusual aesthetic, steeped in a rich cultural history ensuring their status as significant natural assets from social, historical, economic and scientific points of view.

These forests are regarded as the largest block of forest in southern Africa, yet cover only 0.02% of South Africa's total land surface (Midgley *et al,* 1997). They are restricted to the area of high aseasonal rainfall (see Fig 1.1), on the seaward side of the Cape Fold range of Outeniqua Mountains, bordered by the Gouritz river to the west and the Kromme river to the east (Irving, 1998), with distributions outside of this area small and scattered, generally confined to protective kloofs. The vegetation in the area does not, however, consist of a homogenously forested stands, instead the forest forms part of a mosaic of both wet and dry Afromontane-type patches, interspersed with heath (fynbos) elements and bearing scrub components on coastal forelands (Martin, 1968).

This patchy distribution of the forests across the landscape has been subject to debate, particularly regarding the involvement of human disturbance in producing this pattern. Historical records indicate that during the colonial logging operations, carried out for near to two centuries, an estimated 3 million m^3 (Midgley *et al.*, 1997) of generally the largest and finest timber trees were removed from the forests (Phillips, 1931, van Daalen, 1980), a substantial statistic given the likelihood of attendant disturbances produced during the timber extraction. Therefore, fragmentation had been formerly ascribed to the ecosystem disruption and destruction wrought directly and indirectly by condoned forest clearance (Phillips, 1931). More recently, however, Geldenhuys (1994) has suggested

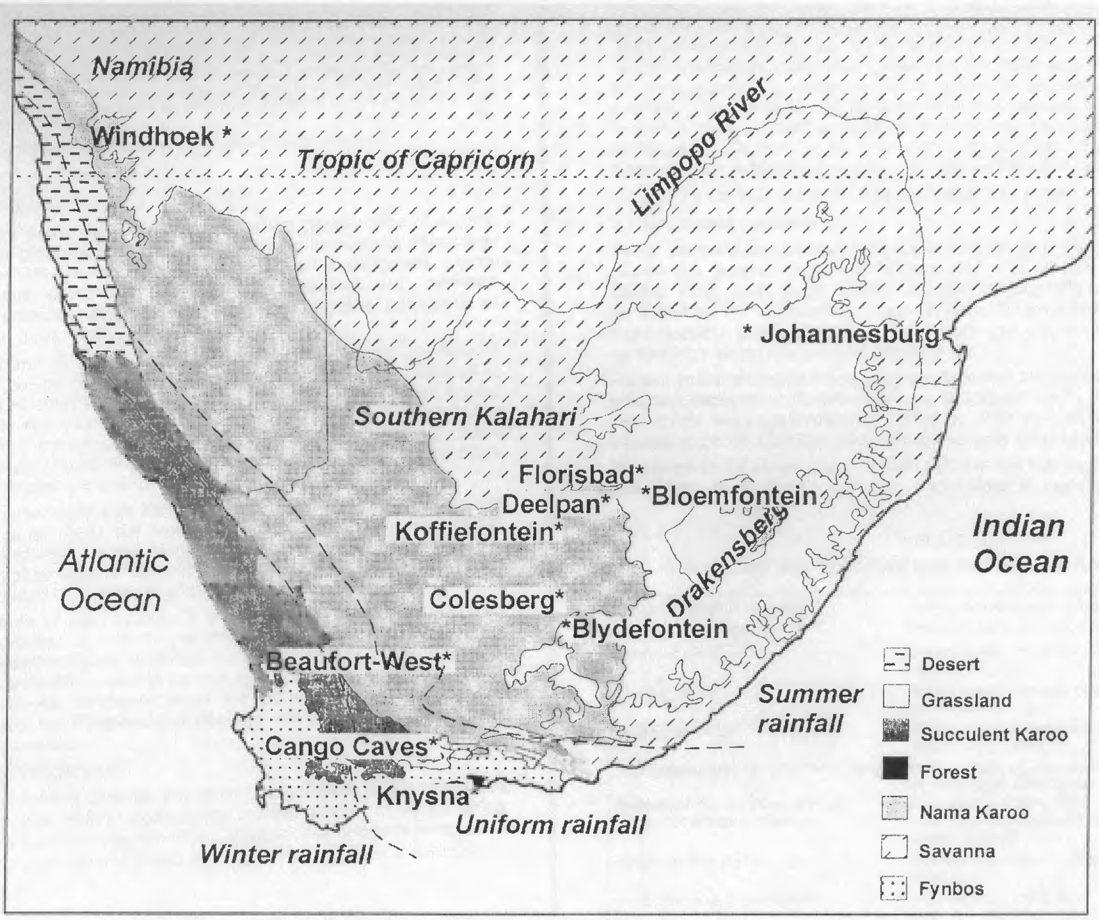


Figure 1.1: A map of southern Africa, indicating the boundaries of rainfall seasonality and vegetation types, with the Knysna forests situated within the uniform rainfall zone (SASQUA, 2005)

that colonial influence may have been overemphasized, given the late date of colonial entry and inaccessibility of some forest areas. Instead he suggests that the biogeographical controls of forest patches may instead be determined by the relation of forest to berg-wind channels. These warm, desiccating winds blowing from the arid interior, are capable of reducing even moist vegetation and forest litter to tinder, increasing the probability of a burn and, therefore, discouraging forest growth in these high fire frequency zones (Geldenhuys, 1994). Discounting the significance of the colonial impact on forest fragmentation, therefore, places the understanding of human influence in the environment in a confusing light, begging the question: what was the magnitude of colonial impact on the forest environment?

But setting the environmental history of forest fragmentation aside momentarily, this very pattern of fragmentation (natural or otherwise) bears significant consequences for the future. Peters (1991) indicates that given the likelihood of rapidly changing conditions of global warming, induced by higher atmospheric levels of greenhouses gases, small and fragmented populations such as these will shoulder higher levels of vulnerability. However, climates have never been static, with variation evident at every scale (Overpeck, 1995; Parrish, 1998; Bradley, 1999 as cited by Jackson and Overpeck, 2000). Although there is clear distinction between the climates of the past and those we anticipate in the future (Peters, 1991), it is suggested that built-in feedbacks ensure that climate will respond in a similar manner to how it did in the past (Peters, 1991) and, therefore, that 'palaeo-analogues' may provide, at the very least, "cautionary tales" (Jackson and Overpeck, 2000), but more likely useful insight into community response to environmental fluctuations (Huntley, 1990; Meadows *et al.*, 1993).

The most significant disparity, however, between the climates of the past and those of the next century, is the rapidity of change that is expected to take place (Peters, 1991). Researchers question the ability of species to adapt, citing their flexibility, efficacy of dispersal, and current size of base populations as features determining their survival (Peters, 1991,; Jacskon and Overpeck, 2000). Therefore, it is suggested that to ensure biodiversity, mitigation plans should be established now (Peters, 1991).

Significant conservation strategies should include an understanding of change, the timescales it acts on and its likely ecological expression, but all are difficult within the time confines of general ecological study (Delcourt and Delcourt, 1991). For this reason palaeoecological tools can provide a means of reconstructing the environments of the past and the conditions that shaped them, consequently providing a meaningful understanding of ecological relationships in the local and regional environment, thereby eliciting a clearer picture of long-term nature of environmental change, of both human and climatic origin

This project, therefore, proposes to investigate the Knysna forests, uniquely important natural assets, by palaeoecological means, in an effort to present an environmental history for the area. This would provide a long-term study, investigating the regional and local vegetation dynamics both before and after substantial human prominence in the environment, consequently allowing for degree of anthropogenic disturbance to be resolved, against a back-drop of naturally oscillating environments, an objective with latent significance for predicting the future of ecosystems given that "*The synergy between climate change and habitat destruction would threaten many more species than either factor alone.*" (Peters, 1991, p.113).

1.2 Methods Employed in Environmental Reconstruction

Based on the principles of Uniformitarianism, palaeoecological reconstruction relies considerably on a temporal continuum, and, therefore, on present-day communities to provide analogues for those in the past (Lowe and Walker, 1997). Any reconstruction, therefore, requires a thorough understanding of the environmental factors that influence vegetation dynamics, including the role of climatic, topographical, edaphic and ecological mechanisms in accounting for their presence, abundance and distribution. Furthermore, the contextual support that may be provided by previous palaeo-records assists substantially in establishing the likely changes that occurred in the long past, with comparison and corroboration of evidence from a wide range of proxies reinforcing the environmental reconstruction.

A variety of methods exist for determining the environments of the past, however, one of the most adaptable, widely implemented and successful environmental proxy tools (Bell and Walker, 1992; Lowe and Walker, 1997) is the study of fossil pollen and spores, a discipline known as palynology. The analysis requires the extraction of fossilized pollen grains from suitably organic, incremental and chronologically-resolved sediment deposits. These fossilized grains, at points through time, are identified and counted and taken to be representative of the presence and abundance of their parent plants, whose ecological affinity is assessed according to the modern analogues (Lowe and Walker, 1997), established in the theoretical part of the study. These counts are then expressed in diagram form and the vegetation community established through the time periods defined by the sediments extracted. These vegetation communities may then provide indirect evidence of the prevailing climatic conditions (Lowe and Walker, 1997). It is proposed that this form of evidence will provide insight into the nature of vegetation change of the Knysna forest.

Fire, as alluded to previously, may play a significant role in determining the distribution of forest patches (Geldenhuys, 1994). A naturally recurring ecological tool, but one discovered early on by humans for modifying their environment (Horne, 1981). Although the generally moist nature of the forest environment would be thought to prohibit fire from the region, it is shown that in extreme conditions, such as those set up by berg-winds, fires may occur, ignited intentionally or accidentally by humans, or by natural means (Horne, 1981). Although the recurrence of fire in the forest environment is thought to be at an interval of 100-200 years (Watson and Cameron, 2002), the return frequency of the interspersed fynbos, is a tenth of that (van Wilgen *et al.*, 1990). It is suggested that increased frequency of fire, owing to changes in climate or human influence, would bias succession towards fynbos at forest edges (Manders *et al.,* 1992), so eroding the forest core. A record of fire history, therefore, would provide an appreciation of the nature and prominence of fire in the forest environment, as well as the vegetative response over time. It is proposed that charcoal fragments, deposited in sediments in a similar manner to pollen, may provide such a fire history for the region.

1.3 Study Area

As pollen analysis is considered to be the foremost analytical technique with regards to assessing vegetation community change, depositional environments suitable to the preservation of pollen, generally of low-energy and anaerobic in nature, are required. The Wilderness lakes of the southern Cape (see Fig 1.1), provide such an environment; far enough away from the densely forested region so that environmental fluctuations occurring at forest margins (the effects of which are often dampened in the forest core) may be recognised, yet close enough for the forest to be represented in the pollen rain. Furthermore, these lakes are coastal, providing insight into lowland conditions, when pollen analyses are so often dominated by records from upland sites (Edwards, 1979 as cited by Moore, 2000).

Groenvlei, lying on the eastern extreme of the series, is an endorheic basin with no river inflow nor outlet to the sea, therefore, providing suitably low-energy conditions favourable to pollen preservation. The lake lies between fossilized barrier dunes (Bateman *et al.*, 2004), on the raised but narrow coastal platform (van Daalen, 1980; Geldenhuys, 1989), deeply incised by river gorges (van Daalen, 1980), fronted by abrupt cliff faces and backed by the foothills (Tyson, 1971 as cited by van Daalen, 1980), rising to the heights of the Cape Fold mountains, some 16-25 km from the coast (Martin, 1968). This topographical heterogeneity provides a diverse range of habitats and niches, allowing vegetation a degree of flexibility, and thus persistence, in the face of change.

Groenvlei was previously the site of a detailed palaeoecological analysis by Martin (1956, 1960, 1964, 1968) reviewing a range of environmental proxies including sediments, diatoms and pollen. His work is considered seminal to the understanding of the region's environmental development, although his words "*The formulation of the pollen diagrams...based on one site, and without antecedents in the same geographical area, is, of necessity, tentative and subject to later revision.*" (Martin, 1968, pp113) suggest the importance of further study, with his work providing an important measure of confirmation and comparison for current analysis. Martin's (1968) investigations revealed that this site provided a good record of the Holocene, the last major, globally-synchronous event and the epoch witness to the increasing prominence of humankind in the environment (Egan and Howell, 2001).

1.4 Aims and Objectives

The overarching aim of this project is, therefore, to establish an understanding, and account for the varying prominence, of the vegetation communities of the Knysna Forest region over the period defined by the extracted sediments. This is to be complemented by a number of secondary theoretical aims:

1. resolving the scale of perceptible human impacts in the region, within the context of macro-scale climatic changes,
2. understanding the long-term role of fire in southern Cape environments

These theoretical objectives of the project will be accomplished through a series of practical aims, which are methodologically-driven:

1. the extraction of stratigraphically-consistent sediment cores from appropriate locations,
2. the description of sediments and provision of chronological control through Radiocarbon (^{14}C) and Luminescence dating techniques,
3. the extraction of fossil pollen from organic sediments, and its counting, analysis and production of explanatory diagrams in an effort to understand and account for the dynamics and prominence of vegetation communities through time,
4. the counting and analysis of charcoal particles on pollen slides in an attempt to understand the long-term nature and prominence of fire in the environment
5. the comparison of resultant records with previous peer-reviewed records from the region, describing and accounting for divergent scenes.
6. the comparison of charcoal peaks with both individual pollen taxa as well as ecological groups, in an attempt to identify and assess the relationship between fire and vegetation.

1.5 Project Outline

The basis and motivation, methods and objectives of this project have been outlined in this chapter. Uniformitarian principles, adopted by this project, necessitate inclusion of a comprehensive account of the contemporary environment, and to this end, a discussion of the regional environmental characteristics including relief, climate and ecology, can be found in Chapter 2. A literature review, briefly outlining significant climatic fluctuations occurring through South Africa, in general, since the Last Glacial Maximum, and in the southern Cape region, in particular, is presented in Chapter 3. Chapter 4 then describes the study site more thoroughly, and outlines the theory and limitations of methods employed to produce the results, that are presented in Chapter 5. These results are interpreted and discussed in Chapter 6, and concluded in Chapter 7.

All specific radiocarbon dates in this project have been supplied with their equivalent calibrated ages, for more useful comparison. This calibration was performed using the online programme CALPAL (Weninger *et al.*, 2006), calibrating ages from 50 000 to 0 years BP according to CALPAL2005_SFCP curves (Weninger *et al.*,2006). Dates before 2000 years ago are quoted as Before Present (BP), with 'present' set at 1950. Dates after 2000 BP are quoted as AD, owing to the familiarity with the present day calendar.

Chapter 2:

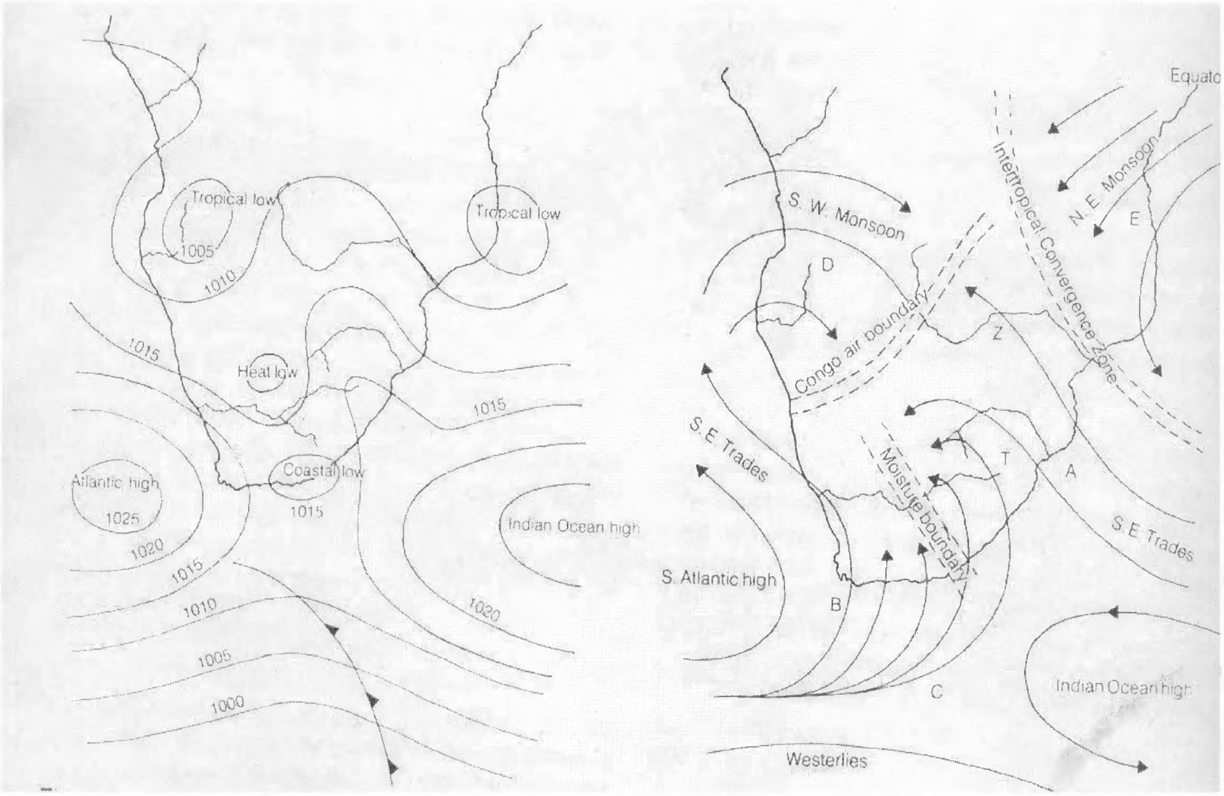
CONTEMPORARY ENVIRONMENT AND ECOLOGY

2.1. Introduction:

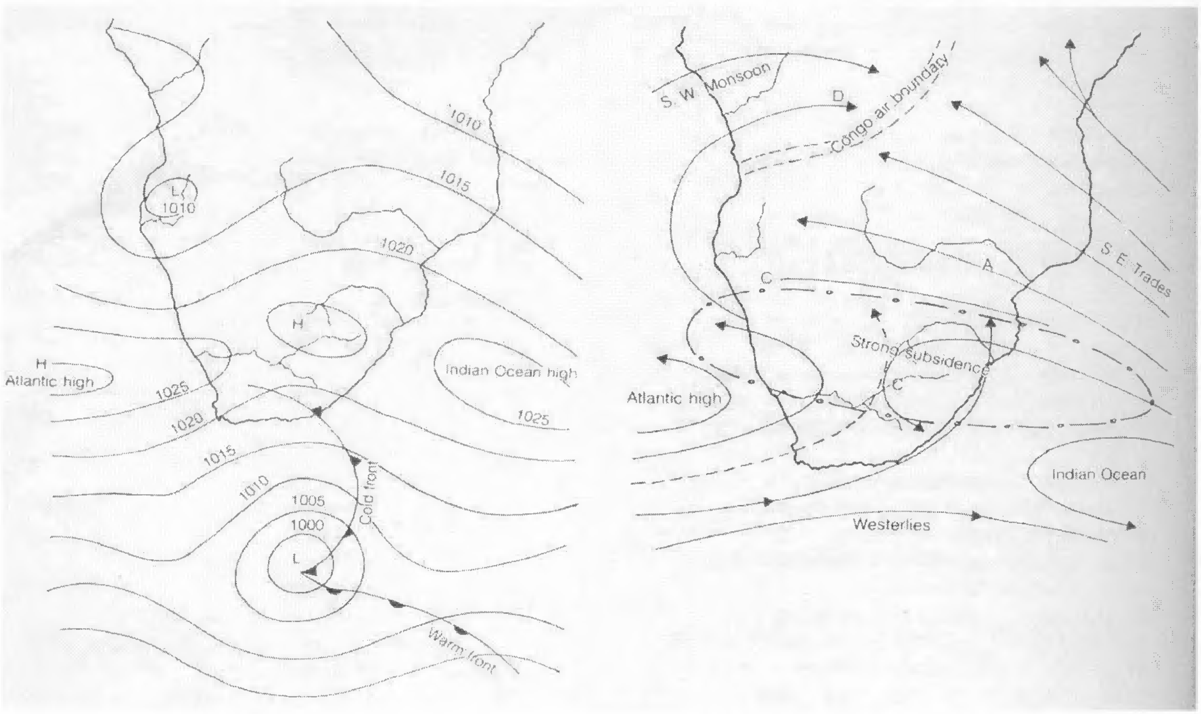
The Uniformitarian concept, of a continuum between past and present, rationalizes the importance of a working knowledge of modern conditions and influences. Contemporary landscapes are, in effect, historical archives; products of environmental changes operating over varying scales of space and time. An understanding of various aspects of the environment; the influence of climate, the regional relief, the nature of the vegetation and its ecology and, most significantly, the role of environmental factors in shaping vegetation type and distribution, is essential in providing an analogue community. Without this, studies into conditions of the past, where there is an inevitable decay further back into antiquity, would be impossible to critically assess.

2.2. Climate:

The southern Cape is geographically situated between the typically winter and summer rainfall areas, influenced by the easterly path of low-pressure systems, created by disturbances in the westerly waves, bringing frontal rain during winter and shoulder seasons (Geldenhuys, 1989) as well as the low pressure systems that may extend over the interior during summer that result in convective rain associated with troughs in the easterlies (Geldenhuys,1989). Being influenced by both regimes, the region receives aseasonally distributed rainfall, with slight peaks during the shoulder seasons, an annual average of 945 mm, and no month receiving less than 60mm (See Table 2.1, Tstistikamma data set, SAWS, 2006).



(a)



(b)

Figure 2.1: Map showing the seasonality of rainfall over southern Africa (a) summer pattern, (b) winter pattern (Schulze, 1997)

Topography, however, exerts a significant control over the regional climate of the southern Cape. Conditions are frequently cloudy, with high relative humidity and light rain and fog, the latter often of a highly localised nature (van Daalen, 1980). This is essentially caused by orographic uplift and atmospheric instability as maritime air masses, close to saturation point, are forced to rise on meeting the barrier of the Outeniqua Mountains, rising to 1500m near the coast (Martin, 1968). Most rainfall is light, however, thunderstorms (and other high intensity rainfall events) can take place, often occurring near the tops of mountains (Hurry and van Herden, 1982) and most frequently during summer months (van Daalen, 1980). Such events may be accompanied by lightning strikes, and are held, along with human incendiarists, as the major cause of fire ignition in the region (Granger, 1984, see section 2.4.4 d).

These mountains impose several steep climatic gradients in the area: In terms of altitude, upper slopes may receive more than twice the annual precipitation occurring at sea level (van Daalen, 1980), while a marked latitudinal variation is demonstrated by the position of the semi-arid Klein Karoo, lying in lee of these mountains, only 40 km inland. To the east and west of the region, precipitation varies markedly, trending towards seasonal aridity in both directions, with winter rainfall maxima to the west and summer rainfall maxima to the east. Drought conditions (of varying severity) have been reported to have a three year return interval (Geldenhuys, 1989). Severe rainfall deficits have been reported in the southern Cape in the years 1869 1881,1891,1895,1899 (Phillips, 1931, as cited by Geldenhuys, 1989)

The mountain barrier plays a further climatic role through the adiabatic transfer of heat that results in so-called *berg* winds. In winter, warm dry winds blowing from the interior can raise temperatures significantly. These conditions are set about by the concurrence of a low pressure system at the coast and a semi-permanent continental (Kalahari) high pressure system over the interior. This results in a coastward movement of air over the arid interior, and, on meeting the Cape Fold mountains, the air sinks towards the coast, warming adiabatically and producing strong, warm and desiccating winds (Geldenhuys, 1994). This climatic phenomenon has been shown to be an important control in the distribution of mountain forest patches (Geldenhuys, 1989), unfavourable to forest growth owing to the desiccating effects of the wind and its association with promotion of fire (Geldenhuys,1989 see section 2.4.4 d).

While the berg winds act towards moderating winter lows, the passage of cold fronts during spring and autumn, temper these seasonal highs (Geldenhuys, 1989). Annual average daily temperatures vary between 13 -20° C, and frost is a rare occurrence (Geldenhuys, 1989), with no temperatures below 4° C recorded for Tsitsikamma (1968-1990) (see Table 2.1, SAWS, 2006). Snow can occur, although it is restricted to high peaks over 1000 m.a.s.l. (van Daalen, 1980). Exceptions to the generally mild climate, therefore, occur on the upper end of the temperature spectrum, with highs of 38 °C recorded in climate data (SAWS, 2006, see Table 2.1 below), most likely the result of berg wind conditions (van Daalen, 1980).

Adjacency of coast and mountain range means that air movement in the region is subject to the combined forces of offshore land breezes and down-slope katabatic flow at night, and the relatively weaker onshore sea breezes and upslope anabatic flow during the day (van Daalen, 1980); the result being a diurnal and seasonal variation in wind patterns. During summer, the more pronounced variation between ocean and land temperatures during the day results in the combined onshore sea breezes and anabatic (upslope) flow picking up strength in a south easterly direction. The reverse occurs in winter with the nocturnal offshore/ katabatic component strengthened in a south westerly direction (van Daalen, 1980). The winter wind pattern also includes berg winds, blowing from a north-westerly direction (Geldenhuys, 1989), although their flow direction is complicated by topography, again highlighting the significance of this as an environmental determinant.

Table 2.1: Climate Data for Tsitsikamma (34° 02' S 23° 54' E) 1968-1990 (SAWS, 2006)

	Temperature (° C)				Precipitation		
Month	**Highest Recorded**	**Average Daily Max**	**Average Daily Min**	**Lowest Recorded**	**Average Monthly (mm)**	**Average Number of days with >= 1mm**	**Highest 24 Hour Rainfall (mm)**
January	32	23	17	10	77	8	70
February	35	22	17	11	70	7	71
March	31	21	16	10	81	8	88
April	38	20	14	8	80	6	214
May	35	19	12	7	86	7	107
June	29	18	10	4	75	7	63
July	31	17	10	4	78	7	47
August	31	17	10	5	111	9	89
September	30	17	11	5	66	7	50

October	30	19	13	7	83	9	108
November	32	20	14	7	78	8	55
December	29	22	16	10	60	8	66
Year	**38**	**20**	**13**	**4**	**945**	**91**	**214**

2.3. Topography, Geology and Drainage:

The landscape of the southern Cape is dominated by the East-West lying Cape Fold Belt, reaching heights of up to 1,500m, some 16-25 km from the coast (Martin, 1968). The landscape is best interpreted in terms of a series of plateaux, created during the region's complicated geomorphic past. From the Outeniqua range of the Cape Fold Belt, created around 120 MYA a region described as the foothill zone (Tyson, 1971 as cited by van Daalen, 1980) separates the mountains from the raised coastal platform, a product of Quaternary and Tertiary uplift (Geldenhuys, 1989, Martin, 1968; van Daalen, 1980). The platform, up to 16 km wide and extending up to 300 m.a.s.l. (van Daalen, 1980), rises steeply from sea level, with much of the seaward edge fronted by cliffed faces produced by wave erosion. Evidence of two previous high sea level stands are evident in the wave-cut platform at Gericke's Point and the terrace feature on which the town of Sedgefield stands (Martin, 1956). Characteristic of this platform are the deeply incised gorges, created by down-cutting of rivers running south from their mountain headwaters, subsequent to the various sea level transgressions, and evidence of a (geologically-speaking) recent sea level decline (van Daalen, 1980). Such rivers include the Brak, Kaaimans, Swart, Touw, Homtini, Goukama, Karatara, Knysna and Keurbooms (van Daalen, 1980). The last plateau of importance in the region is known as the Agulhas Bank, the shallowly submerged feature extending a few kilometres out to sea, and exposed during last glacial.

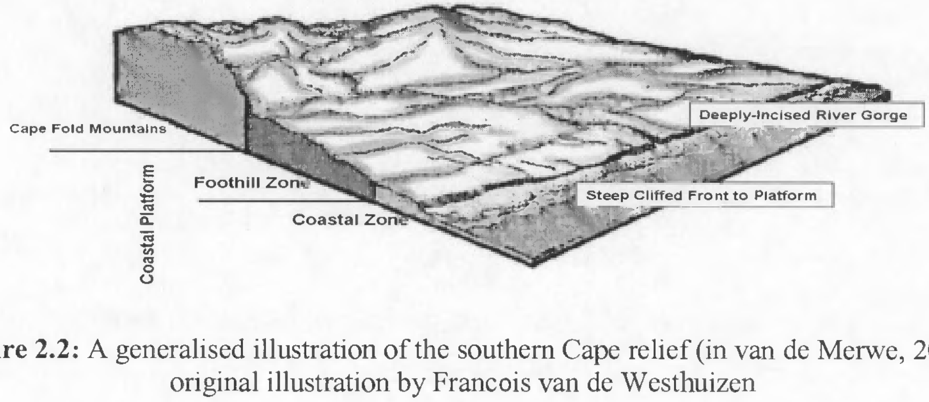


Figure 2.2: A generalised illustration of the southern Cape relief (in van de Merwe, 2002) original illustration by Francois van de Westhuizen

The majority of the region is underlain by rocks of the Cape Supergroup (Table Mountain Sandstones and Bokkeveld Shales) with a small region to the West, near Wilderness, underlain by igneous and metamorphic rocks of pre-Cape and Cretaceous ages (Martin, 1968; Torien, 1979 as cited by Geldenhuys, 1989). These are overlain by recent sediments of Pleistocene and Quaternary origins, of either unconsolidated sands, or variously cemented aeolinites (Martin, 1962). These surficial sediments have formed two ridges of stabilized parabolic dunes, their trailing arms aligned parallel to prevailing palaeo-wind direction (Bateman *et al.*, 2004). Older inland dunes trend ESE-WNW, while the more recent series run in an ENE- WSW direction (van Daalen, 1980). These start west of Wilderness (Martin, 1962), reaching heights of more than 100m between Gericke's Point and the Kaaimans river, but gradually lose height further west of Knysna (van Daalen, 1980).

Soils in the region are commonly nutrient-poor and acidic with a poor buffering capacity (pers. comm. GN Schafer, 1988 as cited by Geldenhuys, 1989). Six soil types are present in the area as described by Geldenhuys(1989):

Table 2.2: Soil types of the southern Cape region, adapted from Geldenhuys (1989)

Soil Type	Location and Description
Unconsolidated soils and bedrock	Soils shallow and acidic, some organic accumulation. Widespread, but mostly on upper slopes.
Lithosols and lithocutanic soils:	Well drained soils, associated with slopes of mountain, foothills, valleys and coastal scarps
Duplex soils	Shale-derived soils, poorly drained owing to clay B Horizon. Soils occur on the coastal platform.
Podzols	Related to TMS colluvial material, Aeolian drift sands and disturbance of forest zone. Occurring principally in higher rainfall areas.
Red Apedal Soils	Well drained soils confined to a small area between George and Great Brak.
Regic Sands	Deep, unconsolidated sands with high calcium component.

Occurring parallel to the coast, between these stabilized barrier dunes (Bateman *et al.*, 2004), lie the Wilderness lakes. Groenvlei, the project study site, lies to the eastern extreme of this series and is effectively stranded between the dune ridges: sand severing any connection to neighbouring lakes; no river inflow, nor outlet to the sea (Martin, 1968). For further description of the project site, see Chapter 4.

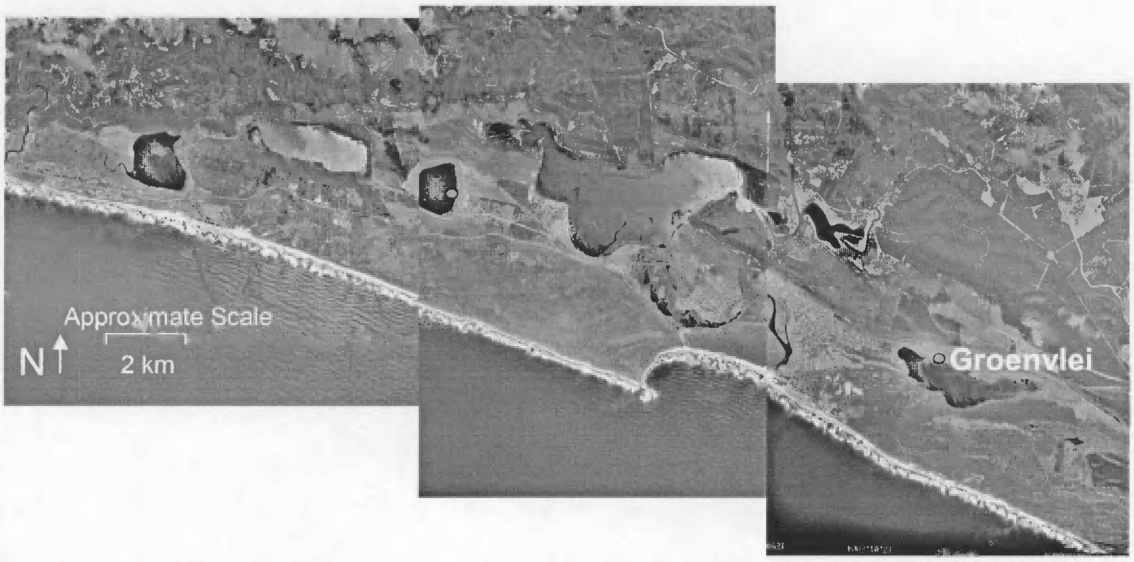


Figure 2.3 : A composite aerial photograph of the Wilderness Lakes 17.01.2004 (Job 1075 Oudtshoorn, Strip 014), showing the study area and study site (marked with a star)

2.4. Vegetation and Ecology of the Southern Cape

2.4.1 Introduction to Forest Distribution:

With both the afromontane-type and Indian Ocean coastal forests reaching their southerly limits here (Geldenhuys, 1988 b) the forests of the southern Cape have been designated as the country's largest forest block (Midgely *et al.,* 1997), and the continent's largest, most southerly, complex (Geldenhuys, 1993). These statistics unintentionally imply that the region consists, perhaps, of luxuriant and homogeneously forested stands. Instead, the forest forms part of a mosaic of both wet and dry afromontane types interspersed with often large heath (fynbos) stands and bearing scrub components on coastal forelands (Martin, 1968). Furthermore, these forests cover but 0.02% of the total land surface of South Africa and occur in a highly fragmented distribution, with only a few forest patches exceeding $1km^2$ (Geldenhuys, 1989) . In a generally semi-arid country, these forests are restricted to the area of high aseasonal rainfall, on the seaward side of the Cape Fold range of Outeniqua Mountains bordered by the Gouritz river to the west and the Kromme river to the east (Irving, 1998), with forests outside of this region, generally small and scattered and restricted to kloofs.

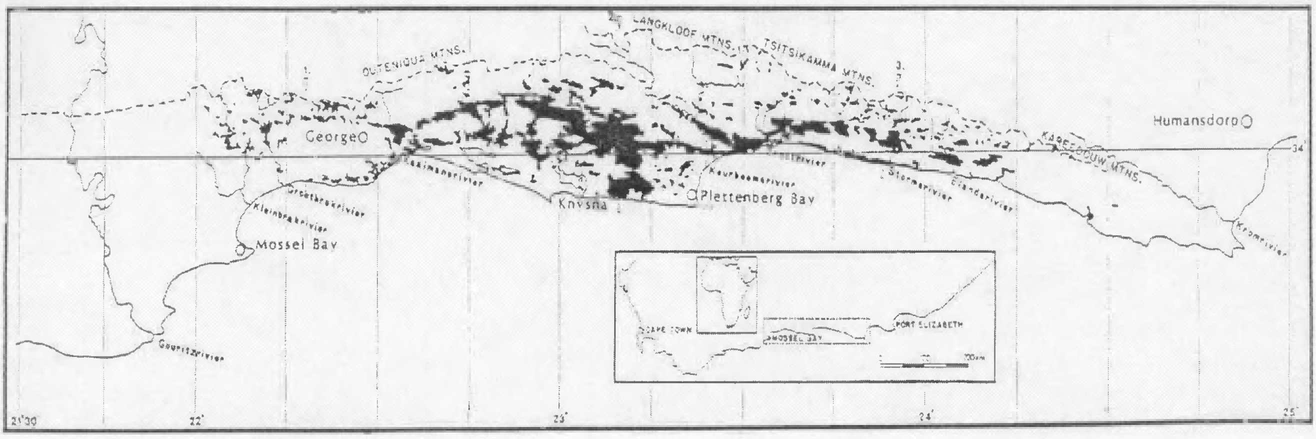


Figure 2.4: A diagram indicating forest distribution in the southern Cape (Geldenhuys, 1989)

2.4.2 Forests in Southern Africa:

Despite being heralded as the largest complex, it is by no means the only forested region on the sub-continent. Forests of varying type, size and fragmentation occur throughout southern Africa (see Fig. 2.6) with warm-temperate afromontane types occurring in the mountains and protected kloofs of the South-Western Cape, the Drakensberg escarpment, through the Kwazulu-Natal and Eastern Cape midlands (Geldenhuys, 1988a) and continuing north through the eastern African uplands (see Fig. 2.5), inheriting its standing as “the smallest and most widely dispersed biome” (Geldenhuys and Knight, 1988). The afromontane phytochorion is generally observed to be species-poor, dominated by shade tolerant species relative to Indian Ocean Coastal forests (Midgely *et al.,* 1997). The latter, as described by White (1983), are best represented in the Tongaland-Pondoland region, and include the sand forests of Kwazulu-Natal. White(1983) also mapped transitional forests between the regions, including the eastern cape’s subtropical thicket (Cowling, 1984) and valley bushveld types, occurring in drier low-lying regions (Geldenhuys, 1988a).

Figure 2.5: The distribution of afromontane environments across Africa (Meadows and Linder, 1993)

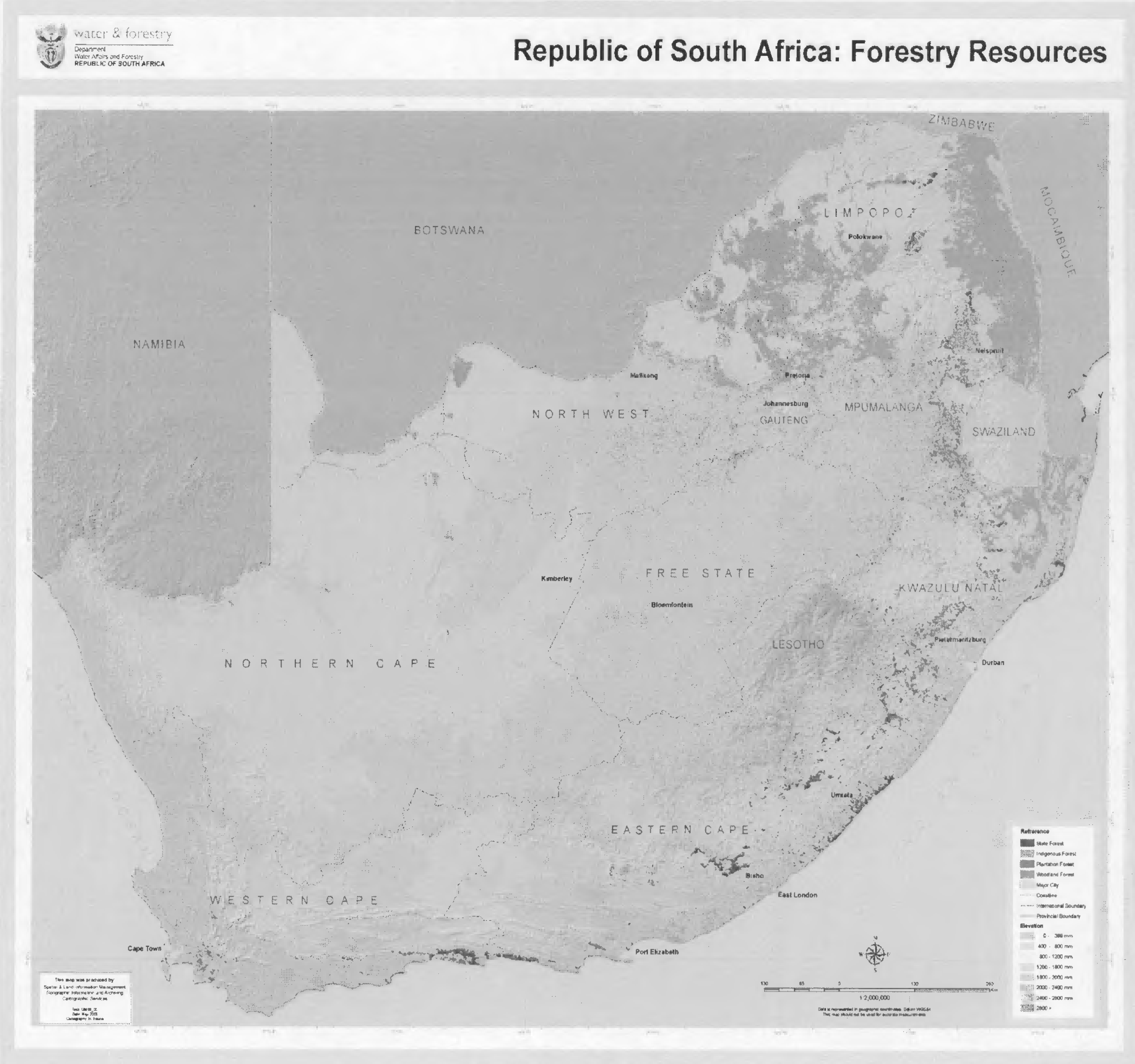


Figure 2.6: Indigenous forest and plantation distribution across South Africa (DWAF, 2006)

2.4.3 Habitat Diversity, Vegetation Type and Floristics:

These forest varieties, evidently a product of their environmental conditions, are all represented in the southern Cape forests: The high and wet forest is comprised mostly of trees common to afromontane vegetation, while dry high forest grading to scrub forest along the moisture gradient towards the coast, are made up of eastern cape transitional types and coastal forest (Geldenhuys, 1993). Various fynbos types [Mountain Fynbos (veld type 70) along uplands and forelands, Coastal Fynbos (Veld Type 47) and Coastal Renosterbos (Veld Type 46)] are representative of the south-western cape's winter rainfall and fire-prone conditions (Geldenhuys, 1993).

Endemicity is in the region is low, as is speciation (Geldenhuys, 1993). Most growth forms are monoecious (apart from woody shrubs) and are characteristic of closed, mixed tropical-subtropical forest (Hall and Swaine, 1981; Bullock 1985 as cited by Geldenhuys, 1993) and insect pollination is thought to predominate among trees (Phillips, 1931 as cited by Geldenhuys, 1993).

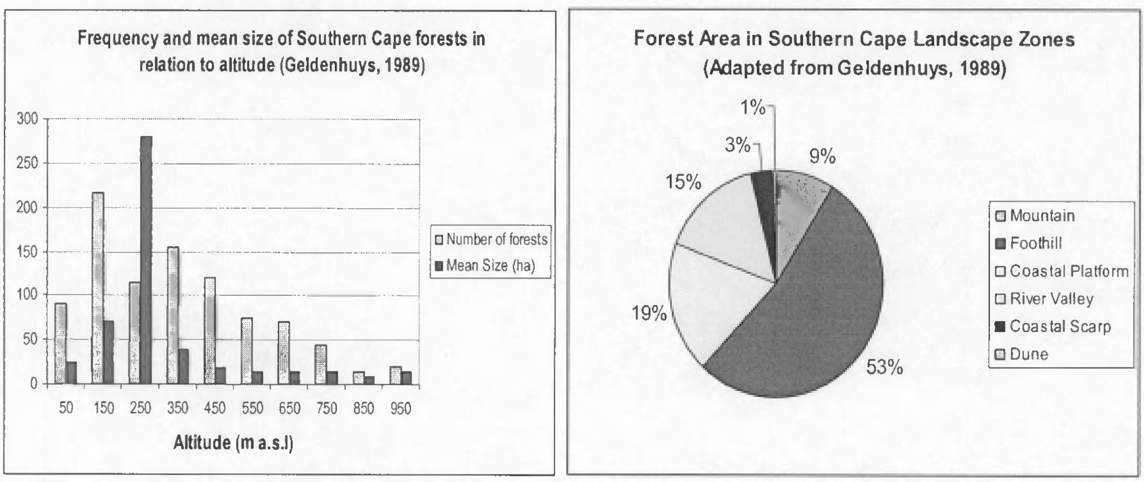
In the prevailing climate, that van Daalen (1980) suggests is more suited to the predominance of fynbos, it is therefore recognised that the diverse regional environment of the southern Cape is undoubtedly the most important reason for forest persistence: In a region subject to oscillating climates and sea levels, and saddled with a history of often-destructive human whims, environmental diversity has permitted the flora a degree of flexibility. The regional landscape provides a progression from low to high rainfall between coast and mountains, altitude range allowing for migration during climate change or sea level fluctuations, as well as topography providing sheltered niches for fire protection (Geldenhuys, 1988b). However, while these factors may explain the presence, abundance and type of forest communities occurring in the region, it does not entirely account for their location and discontinuous pattern in the landscape, arguably the most curious aspect of their distribution.

2.4.4 The Role of Environmental Factors in Forest Distribution:

In most environments, attempting to define the fundamental agent accountable for vegetation patterns and processes includes an attempt at disentangling the influences between the biotic and abiotic communities, often notoriously difficult pursuits. A variety of inter-dependent factors often explain the shape that communities assume, but clarifying the role each environmental factor plays is imperative for reconstructing environments of the past. The influence of various aspects of topography, soils and ecological factors such as vegetation succession and the influence of fire are considered below.

a. Altitude, Rainfall and Landscape Zones:

A generic boundary for forest development is that it requires upward of 625mm for development (Rutherford and Westfall, 1986), a condition that is met in the southern Cape, but is complicated by the presence of coastal mountains. A positive correlation between rainfall and altitude exists in the area (Grey, 1987 as cited by Geldenhuys, 1994) while Scriba (1984) showed that rainfall and forest cover are also positively correlated (as cited by Geldenhuys, 1994). These relationships therefore suggest that forest cover should be greatest at high altitudes. In fact, as illustrated by Fig. 2.7 below (adapted from Gelddenhuys, 1994), high altitudes support more forests but of a much smaller size, owing to the diversity of aspect, slope and protection provided by kloofs (Geldenhuys,1994), and that the largest forests occur at 250 m a.s.l (Geldenhuys, 1994, see Fig.2.7). This landscape zone provides mostly south facing, gently undulating slopes, while still receiving high rainfall (Geldenhuys, 1994). These foothill forests often join up with river valley forests that with steep slopes, low altitudes and receiving substantially less rainfall, providing a variety of habitat zones within a small geographical area. The restricted size of high mountain forests and kloofs in relation to larger foothill forests suggest that this pattern has little to do with human impacts, as colonial logging was focused more especially on these platform forests (Phillips, 1931) while high forests were largely inaccessible. It is therefore apparent that landscape diversity both ensures a variety of habitats, and partially explains the varying size of forest patches.



(a) (b)

Figure 2.7 : (a) a bar chart illustrating the frequency and mean size of forests in relation to altitude
(b) A pie chart indicating the percentage forest area belonging to different landscape zones (Geldenhuys, 1989)

b. Parent Material and Soils

Forest thrives on most soil types, with exceptions being those derived from granitic parent material (van Daalen, 1980), while soils derived from shale often support drier types of vegetation. This is caused by the high clay fraction in the soil's B horizon (van Daalen, 1980). Not only does this impede root growth, but also maintains vegetation at a greater water stress, more so than vegetation on well drained TMS soils, which supports wetter vegetation with quicker recovery post-disturbance (Phillips, 1931; van Daalen, 1980). Thus geology and soils may influence the type of forest that occurs in particular areas but they are not significant at landscape-scale distribution.

c. Vegetation Succession and its Influence on Soil Chemistry:

Studies have shown that over short distances (and therefore independent of the influences of parent material) soil moisture and chemistry varied remarkably under forest and fynbos stands (Manders *et al.,* 1992). Forest soils had a finer texture, were considerably richer in nutrients and less acidic (Manders *et al.,* 1992) than neighbouring fynbos soils. In forests, nutrients may enter the system through absorption by deep roots penetrating underlying bedrock, and then recycled through litter fall, providing a nutrient-rich humus layer (van Daalen, 1980) a system that is self-sustaining and holding a competitive advantage (unless disturbed) over fynbos, primarily by shading and low fire frequency (Manders *et al.,* 1992). Fynbos, on the other hand, exists on nutrient-poor, often acidic soils and the nutrient injection into the cycle is fundamentally related to fire. Should forests be substantially disturbed, the nutrient cycle would be truncated; litter fall would no longer occur and remaining nutrients would be quickly leached, with podzolization likely to occur (van Daalen, 1980). With the over-storey and litter layer removed, evaporation occurs more quickly, reducing soil moisture. Fynbos types, fast-growing and thriving on nutrient-deprived soils, profit in these disturbed conditions, and once established initiate their own self-sustaining system reinforcing the change in nutrient status and chemistry of the soil through acidification of their litter fall (van Daalen, 1980) while its more flammable nature increases the probability of more frequent fires, so "*...maintaining the identity of the developing community*" (Manders *et al.,* 1992, p. 97). This indicates that the vegetation itself may have a significant role in distribution, These salient differences in floristics, nutrient cycling and fire-adaptation between fynbos and forest provide a strikingly abrupt ecotone and have lead researchers to query the successional nature of these neighbouring vegetation types. Van Daalen (1980) suggests that fynbos should not be considered a seral stage of indigenous forest development as post-disturbance regimes alter conditions so markedly that it is unlikely that forest can recolonise over the short- to medium term. Manders *et al.,* (1992), contradict this finding noting succession to forest at Orange Kloof (Cape Town) after 50 years of fire exclusion, "*refut[ing] the concept that forest and fynbos are two distinct and mutually exclusive vegetation types.*" (Manders *et al.,* 1992 p. 98). Their study included a conceptual model (see Fig. 2.8 below) indicating the sequence of events at the forest-fynbos boundary after a disturbance. Given time and exclusion of disturbance, forests may encroach into neighbouring fynbos zones, seeded by avian vectors and sheltered by senescent fynbos stands, as is evident at Orange Kloof (Manders *et al.,* 1992).

It is apparent that vegetation itself has the ability to change its edaphic conditions, to the extent that it provides a competitive advantage over other vegetation types. This, however, is more a positive feedback factor than an actual distribution determinant, with disturbance a fundamental feature of any progression between states. Investigations show that soil moisture and nutrients affect the *rate* of forest development, but that the significant factor governing in the extent of forest development is the frequency of fire, as a disturbance regime that favours fire-prone fynbos over forest (Manders *et al.,* 1992).

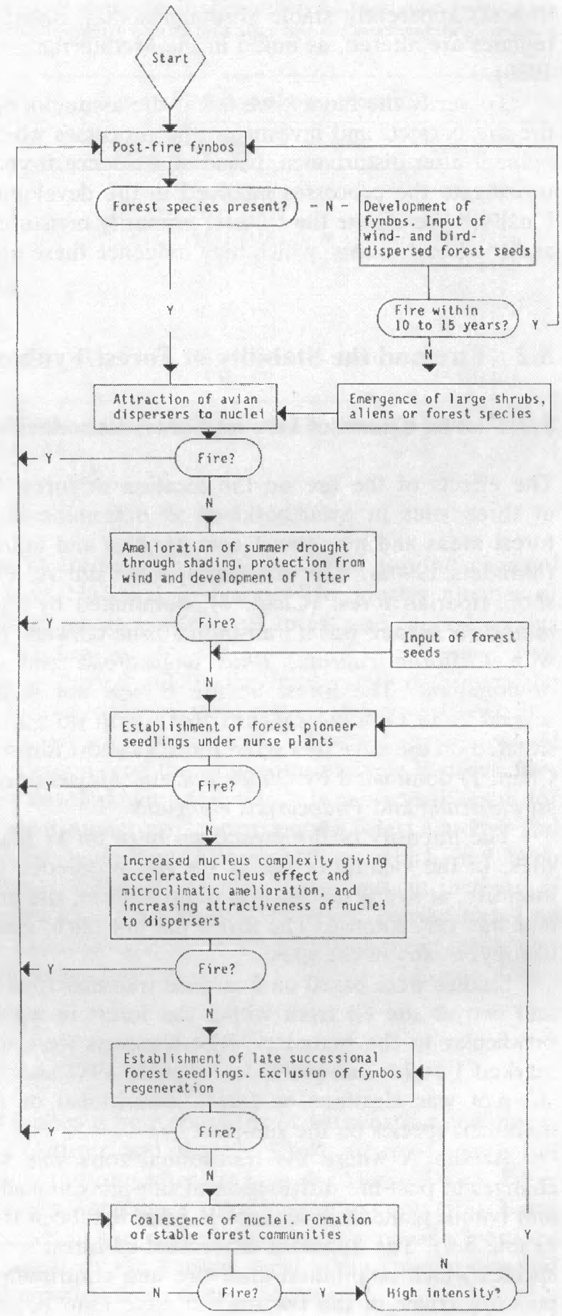


Figure 2. 8: A conceptual model of the succession between forest and fynbos (Manders *et al.*, 1992)

d. The Ecological and Biogeographical Significance of Fires in the Southern Cape:

Fire dynamics in fynbos and forest differ remarkably and, therefore, are an important consideration where the vegetation pattern consists of forest patches embedded in combustible fynbos. While fire is considered a common, and more importantly, necessary, ecological tool for regeneration and serotiny in the fynbos biome, forest rarely burns (van Wilgen *et al.,* 1990; Granger, 1984). Fynbos fires usually recur at least once every 20 years and their exclusion results in a build-up (van Wilgen *et al.,* 1990) of fuel load and a senescent population. Return frequency in forest is still uncertain, though presumed estimates appear to be around 100-200 years (Watson and Cameron, 2002) and more frequent fires (such as those occurring at forest margins) would stunt resprouting or sapling recruitment and prevent forest expansion into the marginal zone (van Wilgen *et al.,* 1990).

Van Wilgen *et al.,* (1990, p. 211) suggest that the disparity in fire dynamics between the vegetation type is likely to be caused by one or more of the following reasons:

1. *"A higher moisture content in the live foliage of forest trees when compared to fynbos and herbs.*
2. *A higher proportion of crude fats in fynbos compared to forest plants*
3. *higher heat yields in fynbos than forest plants*
4. *difference in packing ratios of plant (fuel) parts and the ratio of live to dead material"*

In southern African biomes, fires are related to seasonal dry periods which ensure high fuel availability. One could be mistaken in thinking that the aseasonal rainfall and generally evergreen nature of the forests in the southern Cape would preclude the region from this pattern. However, berg winds, most common in autumn and winter (but may occur at other times of the year), supply the necessary hot, dry and windy conditions (Geldenhuys, 1994) favourable to fire spread. The blustery weather has been reported to increase litter fall (Geldenhuys, 1994) and combined with the desiccating wind, reduces the litter to tinder, increasing flammability of formerly moist vegetation.

Anthropogenically-related ignition, either accidental or deliberate, is recognised as the most important ignition source of Berg wind fires (Sim, 1907, Phillips, 1931 as cited by Geldenhuys, 1994). This being said, Horne (1981) has shown that ignition of fire by lightening occurs more frequently in the southern Cape than in any other forested region, providing a natural ignition source. Lightening strikes occur chiefly in summer months, resulting in generally small burns as strikes occur most frequently at mountain ridges (Le Roux, 1979; Horne, 1981 as cited by Geldenhuys, 1994), where forests are small and scattered. Rockfall is another ignition source, but rarer still than lightening (Granger, 1984)

Given an ignition source and suitably extreme weather conditions, such as those specified above, forest may burn. Three types of fires may occur concurrently or apart; most common are the **flank fires** fed by flammable fuels in margins that advance on forest stands at a rapid rate (Granger, 1984). The flames of these fires may reach canopy height, igniting a second, and much rarer type of fire. **Canopy/Crown fires**, once started, may result in extensive burns, however, if limited to forest heights, may not damage young trees and soils (Phillips, 1931, as cited by Granger, 1984). Crown fires, however, often sustained by **ground fires** below, that burn at high intensities and through their measured advance, may cause substantial damage to soils, roots and even old and established trees (Granger, 1984). Sensitivity to fire and subsequent regeneration depends on a number of aspects including the moisture content and thickness of bark, root depth, nature of the seed coat, plant age and the ability to coppice (Granger, 1984). Many forest trees have the ability to resprout from dormant epicormic buds (Granger, 1984), including *Euclea, Cussonia, Illex mitis, Myrica sp., Ocotea bullata, Rhamnus and Olinia sp.,* whereas most *Podocarpus* species cannot resprout (Bond, 1997). Those species able to withstand fire most frequently dominate the forest margins, while the forest core, not often penetrated by fire, reflects a higher biodiversity (Watson and Cameron, 2002)

Geldenhuys (1994) theorises that it is the interplay of berg winds, topography and fire that has determined the disjointed location of forests in the region (see Fig. 2.9). Berg winds blow in a predominantly NW-NE direction from the arid interior, drying out the vegetation in its course, both discouraging its growth in wind channels as well as providing fuel potential, in the case of a fire (Geldenhuys, 1994). The flow direction is complicated by the topographical features of the southern Cape, redirecting the desiccating winds southwards down gorges and valleys, often increasing their velocity (Geldenhuys, 1994, see Fig 2.9). On the coastal platform, winds are directed in a south-easterly direction, accounting for pattern of forest presence west of a gorge, but absence on the easterly side (Geldenhuys, 1994). It is suggested that geology, soils, climate and the vegetation itself may contribute to the pattern, but that it is berg wind fires that ultimately determine the location of forest.

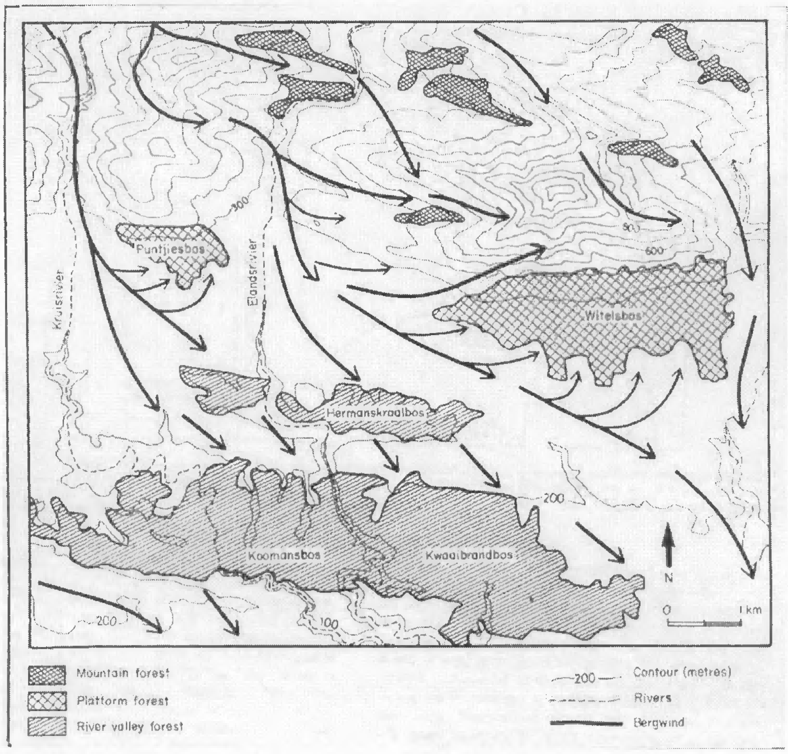


Figure 2.9: Location of forest patches in the shadow of berg winds (Geldenhuys, 1994)

2.5 Human Influence:

Tourists and investors attracted at first by aesthetics and then further encouraged by the increasingly wide range of affluent resorts and luxury real-estate developments are considered by environmentalists today as among the most significant threats to biodiversity and conservation in the region. Golf course development has been the particular bone of contention in the southern Cape, driven through bureaucratic barriers aided by "sweet-heart" environmental impact reports, to the detriment of the environment and developers alike. While most of these developments have been centred around Plettenberg Bay, the town of Knysna and near George, the Wilderness Lakes region has also recently been ear-marked for similar projects. These developments mean a seasonal influx of populations adding to the expanding base populations. Ribbon developments along the coast and burgeoning informal settlements have been seen to be impacting vegetation, particularly through clearing for development, fire-wood collection, solid waste pollution and soil erosion (Berry *et al.,* 1994).

Other substantial developments at the cost of forest were the clearing for the Garden Route extension of the N2. This required 50 hectares of medium to moist high forest to be felled to make way for the Tsitsikamma Toll Gate, the highway and its subsidiary roads (Mackay, 1997). Geldenhuys (1989) points out that the considerable effort it takes to clear forest today, suggests that perhaps clearing during colonial forestry was not as pervasive as it may have seemed. This is discussed further in Chapter 3.

Exotic plantations, established in the late 19th century to alleviate poverty among the woodcutters, are maintained for silviculture today. Some argue that the flammability of alien stands of Pine, Eucalyptus and Acacia, increase return interval and intensity of forest fire as well as alter the soil chemistry (through acidification through litter fall) and soil moisture (by high ground water usage). Geldenhuys *et al., (*1986) and Knight *et al.,* (1987) (in Geldenhuys, 1989) suggest, however, that as they provide nursery stands for forest expansion and alternative timber sources, these plantations therefore boost sustainability through employment, offsetting the potential environmental effects.

2.6 Conclusions:

The geographically confined forests of the southern Cape are notable for the diverse environmental influences in operation. Their location at the subcontinent scale is determined by the local topography that has allowed for vegetation flexibility through niche protection as well as landscape diversity. At a landscape scale, the obvious distribution pattern is that of the dislocation of forest patches, accounted for almost entirely by their position in relation to berg wind channels. On a finer scale still, disturbance by fire has the ability to alter succession paths, but exclusion of disturbance means that the vegetation itself would ensure boundaries between fynbos and forest. Soils and parent materials have a still more minor effect. What is difficult to determine from these short-term studies, however, is the longer term influences of climate change as well as the significance and scale of human influence in the region.

Chapter 3:

PAST ENVIRONMENTS OF THE SOUTHERN CAPE

3.1 Introduction:

As evidence of the nature of past environments (especially for earlier periods) is often difficult to come by, and often only exists in proxy form, studies into the history of the planet are, at times, beleaguered by contention, ambiguity and doubt. The inevitable perishing of evidence away from the present provides less than perfect conditions on which to base assumptions. This means that palaeoecology is beset by predicament: on the one side needing to appease the fastidiousness of science and on the other, actually being able to produce answers. Although dating precision has increased substantially, climate modelling is advancing rapidly and analysis methods have become more sophisticated allowing for high resolution studies (Tyson, 1999), there is very seldom agreement on synchronicity of events. A common occurrence has been to lengthen the boundaries of so called "global events" so that, for example, "cold" or "arid" phases, sometimes within millennia of each other, come to be lumped within a broader bracket that may, or may not, be representative of the event itself (Adam and Faure, 1997). Therefore, to offset the field's inherent limitations, the approach has been to provide multi-proxy and multi-scalar evidence that through the cross-reference of a number and variety of sites, provides credible and persuasive confirmation of past conditions (Egan and Howell, 2001).

A common statement in papers on southern African Quaternary palaeo-studies, is one bemoaning the relative paucity of these very sites. In the Cape, reconstructions are based on a handful of evidence, as appropriate sites are few owing to geomorphological activity, human interference and seasonal aridity (Meadows and Sugden, 1993), demonstrating both the precariousness of reconstruction and necessity for further investigation. This chapter starts with a summary-review of late Quaternary environmental changes in southern Africa and their correspondence with southern hemisphere and global events. The records from the southern Cape are then reviewed in greater detail. Finally, in recognition of the importance of multiple forms of evidence, historical records are reviewed accounting for human influences in the environment.

3.2 Late Quaternary Climates of Southern Africa

Although recognised as a global phenomenon, the clarity and timing of the so-called **Last Glacial Maximum** (LGM) expression across the subcontinent, is still elusive. To date, no single sequence is able to provide a continuous record of vegetation change since the LGM, necessitating a patch-working of various records from diverse forms of evidence (Scott *et al.,* 1997). In southern Africa, when northern hemisphere glaciation (18-20 ka BP) was at its greatest extent, speleotherms from the Cango Caves reveal an average reduction of 5 °C in temperature relative to today (Talma and Vogel, 1992). Precipitation values (relative to present) were reduced, resulting in increased aridity throughout much of the country. The exception is the south-western Cape where evidence from the Elands Bay Cave and the Cederberg suggest that the region was essentially out of phase with the rest of the country, in that wetter conditions prevailed during this period (Meadows and Baxter, 1999). Atmospheric modelling (Tyson, 1986 ; Cockcroft *et al.,* 1987 as cited by Tyson, 1999) suggests that, at the LGM, circulation was most likely dominated by the northward extension of westerly disturbances associated with winter frontal rain caused by the expansion of the circumpolar vortex (Tyson *et al.,* 2001). Evidence from the Vostok ice core and from offshore coring along the coast of southern Africa, indicate that the region's response corresponds with those of the rest of Africa and the Southern Hemisphere (Tyson, 1999).

Towards the present, the **Younger Dryas**,(YD) the next apparent and globally-synchronous event, occurred at the cusp of the Holocene (around 11 ka BP) as a sudden cooling event disrupting the fairly rapid warming after 16 ka BP (Tyson, 1999). Evidence of this has been found at Wonderkrater (Scott and Thackeray, 1987 as cited by Tyson, 1999), and by Cohen *et al.,* (1992 as cited by Tyson, 1999) in stable isotopes in molluscs on the west coast. This period (from 11-7.5ka BP) encountered relatively dry conditions, again excepting the south-western Cape, where apparently more mesic conditions prevailed (Scott and Lee-Thorp, 2004). More recent evidence from oxygen isotopes of shell fragments by Abell and Plug (2000) suggest that the YD event was very possibly predated by an earlier cooling event (Older Dryas), although the study can not confidently distinguish this from later-boundary Pleistocene glaciation (Abell and Plug, 2000).

Temperatures began to increase again, peaking towards the mid-Holocene, a period known as the **Altithermal** (8- 6 ka BP), evident shortly before 7.5ka BP (Scott and Lee-Thorp, 2004) in both summer and winter rainfall areas (Partridge *et al.,* 1999). By 7 ka BP, the ice volumes present today were reached (Lawes, 1990) and southern African biomes assumed their modern appearance (Scott *et al.,* 1997). Although temperature increases were spatially similar, rainfall patterns were somewhat more complicated (Partridge *et al.,* 1999). It is thought that during this period, the tropical easterlies expanded their influence (Tyson, 1999) with warming beginning in the northern regions and the expression of the climate changes gradually moving southwards (Scott, 1997), resulting in more mesic conditions finally reaching the southern coast around 3.5 ka BP (Tyson, 1999). Temperatures maxima reached at the Altithermal, are thought to have been higher than those today, unprecedented since the last interglacial (Tyson, 1999), and some 6-7 °C higher than at the LGM (Partridge *et al.,* 1999). Consequent sea level adjustments of +2m are evident along the coast (Scott and Lee-Thorp, 2004).

Two further cool periods from 4.7 -4.2 ka BP separated by a relatively mild period from the neo-glacial period 2.5 -3.2 ka BP are evident in the Cango Cave isotope record (Talma and Vogel, 1992). Scott and Lee-Thorp (2004) indicate the contradictory nature of evidence in the period 5.1- 2 ka BP, suggesting this to be caused by too subtle changes, poor chronology or the difficulties caused by proxy evidence (Scott and Lee-Thorp, 2004). However, by and large, evidence for conditions after the altithermal suggests aridity (Scott and Lee-Thorp, 2004).

Within the last millennium, two further climate oscillations are evident in palaeo-records, linked to the variable range of the circumpolar vortex (Tyson *et al.,* 2001). From 900-1300 AD, highly variable conditions occurred, with temperatures estimated to be 3-4 °C warmer and more mesic (relative to the present day) culminating at 1250 AD (Tyson *et al.,* 2001) and known as the **Medieval Warm Period**. This period has been correlated to a medieval maximum in solar activity (Tyson *et al.*, 2000). This was followed by a general cooling from 1300 AD to 1850 AD, with an intervening warmer episode from 1500-1675 AD (Tyson, 1999). This period of cooling, known as the **Little Ice Age,** a period of the most widespread cold and aridity since the Younger Dryas (Tyson *et al*, 2000) is associated with generally arid conditions, but also an increase in storminess (Scott and Lee-Thorp, 2004) and frequency of flood events (Hall, 1976; Dunwiddie and LaMarche, 1980; Thackeray, 1996 as cited by Tyson, 1999). High resolution studies of oxygen isotopes and colour banding in a speleotherm at Makapansgat (Holmgren *et al.,*1999) indicate that this event reached its maximum at 1700 AD, and accords well with regional, hemispheric and global accounts (Tyson *et al.*, 2000)

A number of climatic events have, therefore, punctuated the Holocene, with records illustrating fairly rapid fluctuations (O'Brien *et al*, 1995, as cited by Chen *et al*, 2006), in a period once thought to be relatively stable (Dansgaard *et al*, 1993). Most of these events show a degree of correspondence with global events, proposed to be connected to the changing range of the Antarctic circumpolar vortex (Scott and Lee-Thorp, 2004), that during periods of increased westerly influence produce conditions that are drier and cooler in the interior, whereas the influence of the easterlies produce warmer, more mesic conditions in the interior (Tyson, 1999).

Furthermore, southern Africa's position between the Indian and Atlantic and within influence of the Southern Ocean, means that oceanic circulations should not be disregarded in their influence on the climate and nature of the region. Cohen and Tyson (1995) suggest that during greater influence of the easterlies, ridging of the South Atlantic High Pressure south and east of the country produced easterly winds along the south coast, inducing upwelling off the eastern edge of the Agulhas Bank (Cohen and Tyson, 1995). This upwelling of cold water, close to the coast, results (Schumann *et al.*, 1982; Beckley, 1983 as cited by Cohen and Tyson, 1995) in cooler and drier local conditions, whereas in the interior, conditions would have been warmer and wetter owing to the easterly influence. During expansion of the circumpolar vortex and the expansion in range of the westerlies, upwelling would be reduced and instead the south westerly winds would blow plumes of warm Agulhas surface water towards the coast (Lutjeharms and van Ballengooyen, 1988; Beckley 1983, as cited by Cohen and Tyson, 1995), increasing sea surface temperatures and therefore local moisture availability. These currents, therefore, have particular influence over moisture supplies, significant in that Scott and Lee-Thorp (2004) suggest that fluctuating moisture levels were more important than temperature changes during the Holocene.

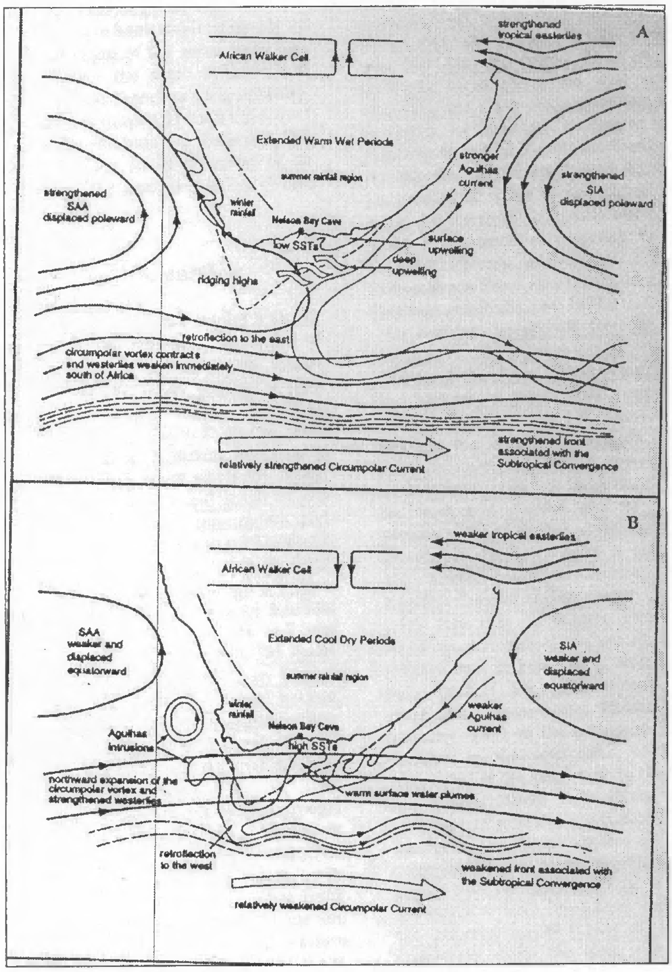


Figure 3.1: A diagram conceptualizing the atmospheric and oceanic circulations occurring over southern Africa and its adjacent ocean during periods of (A) extended warmth and (B) extended cold (Tyson, 1986; Cockroft et al, 1987 in Cohen and Tyson, 1995)

3.3 Late Quaternary Vegetation Communities of the Southern Cape

3.3.1 Late Quaternary Changes in the Forest Biome

The subject of Late Quaternary forest extent and distribution in southern Africa, is a contentious one. While certain evidence suggests that wetter phases of the mid to late Pleistocene were conducive to forest spread (Scott *et al.,* 1997), most researchers agree that the generally more widespread forest in the last interglacial (Lawes, 1990) suffered from overall decline and fragmentation since the Pliocene (Deacon, 1983, as cited by Geldenhuys, 1988b). In the south-western Cape, at 41.5 ka BP a 40% increase in *Podocarpus* pollen was recorded (Schalke, 1973, as cited by Scott *et al.,* 1997), and conditions suitable for forest were evident at 35 ka BP and in the interior at Wonderkrater (Scott, 1984 as cited by Lawes, 1990). However, it appears that by the LGM conditions were substantially drier and cooler, restricting forest to refuges in the interior, and excluding them from high altitudes (Lawes, 1990). Exposure to cold winds has been proposed to have a significant effect on forest, as this increases transpiration in unfavourable conditions, leading to physiological drought (Story, 1952 as cited by Lawes, 1990). During the early Holocene aridity, *Podocarpus* pollen in savanna regions was reduced, but spreading again during the mid to late-Holocene (Scott *et al.,* 1997). The responses of southern Cape forests to Late Quaternary fluctuations are considered in more detail below.

3.3.2 Vankervelsvlei (Irving, 1998)

A particularly long, organic sediment core was withdrawn from Vankervelsvlei, (Irving, 1998) the unique *schwingmoor* bog environment located near Knysna, inland from Groenvlei. Radiocarbon dating established that the sequence chronology spanned 45 ka to 3 ka BP. Pollen analysis provided evidence that, during the late Pleistocene and into the Holocene, fynbos elements were prevalent with fluctuating extents of forest suggested by Irving (1998) to be contingent on moisture variations. Periods of forest expansion were recorded as 43 -40 ka BP and 4-3 ka BP. Forest taxa were present (although restricted in extent) at the LGM, indicating that the area was possibly not as dry as other parts of the subcontinent, during what is generally perceived as an era of aridity. Irving (1998) shows that, in contrast to what was happening in other parts of the country, during the Holocene, the pollen assemblage of the southern Cape was generally suggests drier conditions with moisture increasing towards present day.

3.3.3 Groenvlei (Martin, 1968), and the Norga Peat (Scholtz, 1986)

The most recent palynological assessment performed at Groenvlei was undertaken some 30 years ago by Martin (1968), his objectives being to indicate (and attempt an account of) changes in forest, forest and heath, and the local vlei environment (Martin, 1968). The 650 cm retrieved core from the east fen spanned from the Altithermal period (8- 3 ka BP), and a post-Altithermal phase from 3 ka to present, and incorporating the Little Ice Age. Scholtz's later work at the Norga Peat near George, dates back approximately to 4 ka BP and palaeoecological interpretation was made on sediments from two locations. The peat bog under investigation was created in the bed of the Norga River by the accumulation of organic matter (Scholtz, 1986). The surrounding soils are of a duplex nature and the presence of a shallow clay layer (Scholtz, 1986), precluded the local development of forest. For this reason Scholtz (1986) suggests that even relatively low forest pollen counts may be an indication of optimal forestation (Scholtz, 1986).

In the earliest part of Martin's (1968) record, 8- 7 ka BP, Groenvlei was described as a freshwater mesotrophic lake and the assumed climatic state was that it was generally drier than today. Tree pollen was sparse and vegetation dry, with some presence of *Ericaceae,* but *Asteraceae* as the dominant group (Martin, 1968). It is suggested by Martin (1968) that these two groups are not common dune colonisers or stabilisers and it is therefore not probable that sand was an influencing factor during this early period. Martin(1986) suggested that the dry fynbos vegetation was much like that found further south near Riversdale, an area receiving substantially lower rainfall than that experienced in the Wilderness today. Martin's (1968) interpretation of the similarity was that the 400mm isohyet lay some 60-100km east of its present situation, resulting in lower (possibly more winter) rainfall than present (Martin, 1968).

At 7 ka BP, the record becomes more ambiguous and Martin presents two, differing hypotheses to explain the rest of the zone. The lowest pollen count was found in this section (zone B2, see Fig 3.2), but within this low count forest tree pollen (such as *Olea* – type and *Podocarpus*) is well represented while the previously high *Asteraceae* count declines (Martin, 1968). Either the local heath was deteriorating because of sand, reducing the masking effect of this local pollen, or else the climate was in fact moister allowing for the expansion of forest range. Martin (1968) believes that the latter conclusion is more likely, the low pollen number accounted for by a rapid peat build up such as that occurring 120 cm to the surface.

Between 7-3 ka BP the pollen (such as an increase in chenopods) and diatom evidence from Groenvlei suggests that the lake was under marine influence. Furthermore, evidence such as "*a relatively high silica-sand content of the sediment*", the closing of the mouth by dune sand dated at 3ka BP, and "*the calcareous nature of the lake*" suggests the influence of mobile sand dunes during this period (Martin, 1968 p. 131). These physiographic changes may have had a significant impact on local vegetation and in turn resulting in the appearance of a drier phase, when in fact regional climates may already have been trending towards the mesic (Martin, 1968). According to the Groenvlei pollen diagram it was either hot and dry during this period and conditions were not favourable to the spread of forest or else climate was wet enough to support forest but it was the movement of dunes that inhibited expansion (Martin, 1968, Scholtz 1986). Evidence from Norga Peat suggests a wetter local environment and increased forest extent (Scholtz 1986), although there were a number of uncertainties with this record. Both of Martin's arguments can be backed with possible explanation, but he could thoroughly verify neither and it is only with Scholtz's (1986) further evidence, that a clearer picture is established, again indicating the importance of confirmatory studies.

From 3 ka to present the Groenvlei record seems to agree more closely with other records from the area (Scholtz, 1968). The period was generally more mesic, however, the timing of events is still uncertain. Conditions at Groenvlei were conducive to forest spread until a slight regression at about 1 ka BP while Scholtz's record indicates this regression from 2600 to 1400 years as pollen from forest types *Podocarpus, Olea, Cliffortia,* *Pteridophyta* as well as *Ilex mitis* (a more hygrophytic forest element) were reduced. Counts for Compositae (now termed Asteraceae, an element of dry heath) increase during this period, suggesting a decline in forest in favour of sub-karroid vegetation (Scholtz 1986). Martin (1968) uses this as an indicator that forests had already begun to fragment before the arrival of European colonists. This suggestion echoes one put forward by Phillips (1931) that the occurrence of heath stands in forest openings in many cases were "climax" vegetation, indicating longer disturbance cycles than those possibly produced during the 300 years of European influence. The final expansion of forests according Scholtz (1986) occurred from 1400 to 1000 yrs BP, Gramineae (Poaceae) and Compositae (Asteraceae) decrease with *Podocarpus, Olea* and *Ilex* increasing their representation. *Acacia* pollen occurs near the top of the sediments, testament to the influence of European occupation (Scholtz 1986).

3.4 The Afromontane Debate

The patchy nature of the afromontane forests, and particularly the pattern of forest islands surrounded by grasslands or heathlands, investigated with a north-west European experience, led to the early and somewhat persistent conclusion that recent distributions were relics of formerly unfragmented forests, holding *recent* human-induced fire regimes largely to blame. Acocks (1953) therefore supposed that these forests are southerly remnants of formerly more extensive African forests (Acocks, 1953; White, 1971), truncated from their northern relatives by the extensive use of fire in recent history. Their high floral similarity to other forests and few endemics, despite large distances between patches, suggest continuity, or at least connectedness by dispersal corridors now absent (Geldenhuys, 1988a). However, dismissing Acocks'(1953) premise of recent isolation, Geldenhuys (1988) suggests that southern Cape seclusion (for example) from its closest eastern neighbour of the Suurberg forests, east of the Sundays River Valley, occurred more likely by the late Pliocene as a result of differing uplift to the west and east of the valley resulting in river rejuvenation (Partridge and Maud, 1987 as cited by Geldenhuys, 1988a), with fragmentation advancing with increasingly more arid conditions since the Pliocene (Geldenhuys, 1988a). Furthermore, pollen analyses through a variety of afromontane regions (e.g. Tomlinson, 1973 as cited by Meadows and Linder, 1993; Meadows, 1984; Meadows and Meadows, 1988; Martin, 1968), have revealed that the pattern of forest patches in "seas" of heath or grassland had been well established by the Holocene. Despite admission that afromontane forest boundaries are fire maintained (Meadows and Linder, 1993; Midgley *et al.*, 1997) or that humans have the ability to seriously impact natural environments, it has therefore been suggested that human-induced fire and its influence in forest fragmentation has been overrepresented. While this largely exonerates recent human populations from Acocks' (1953) charge, it maintains and reinforces the importance of fire.

3.5 Historical Records and Human Influence

Ironically, a clear advantage of historical records is their subjectivity, as they provide researchers, interested in the human role in environments, with an idea of past perceptions. There is, however, a scarcity of these documents in South Africa, predating the 18^{th} century, although what records do exist provide some important insight into forest history preceding colonial arrival. In the late fifteenth century in their rounding of the Cape, Diaz and Da Gama logged the occurrence of dense smoke over the forests, licked by flames that were visible some kilometres off-shore (Phillips, 1931). This buttresses the idea that even prior to European colonisation, fires occurred in the region, although whether their origin was "natural" or not, is difficult to determine.

3.5.1 Pre-Colonial Period:

The mastery of fire is ancient, used globally for the last million years (Brain and Sillen, 1988 as cited by Bond and van Wilgen, 1996) with evidence from southern Africa revealing its employment since at least the last Interglacial, some ±150 ka BP (Hall, 1984). Similarly ancient is the presence of humans in the southern Cape. A treasure trove of archaeological evidence has been unearthed at the Klasies River complex indicating first habitation around the Last Interglacial (Deacon and Lancaster, 1988) by hunter-gather populations. Although it is recognised that until the arrival of the iron-age farmers by 2 ka BP (Henshilwood, 1995), indigenous population densities were low and migratory and the direct impacts of habitation were likely negligible, it would be imprudent to rule out the indirect effects such that accidental fire ignition would cause. As indicated in Chapter 2, the natural sources of fire ignition are lightning and rockfalls, that under hot, dry conditions such that berg winds induce, fires from entirely natural origins may spread. While conditions for overlap have been recorded (Geldenhuys, 1994) berg winds occur predominantly in winter, while lightning is most common in summer. Furthermore, lightning fires are generally restricted to upper slopes and small forests, and often do no more than scorch a restricted area (Phillps, 1931). Natural fires, as may be expected in a largely evergreen region (albeit interspersed with flammable fynbos) of all-year rainfall, are exceptional events. Fires started by early inhabitants, on the other hand, would have occurred at least daily for the last 150 000 years.

Phillips (1931) suggests that apart from fire for purely domestic purposes, the Khoi-San used it as a tool to flush out wounded game, smoke out bees for honey collection, as well as to produce a flush of palatable herbs that would attract large grazers (Hall, 1984). He also indicated that hunting pits were found under fynbos islands deep within forest (Phillips, 1931), the correspondence of fynbos and human invention forming tantalizing evidence for Phillips (1931) of early human influence on the vegetation pattern. Subsequent searches for these pits have, however, been unsuccessful (van Daalen, 1980).

While it is often possible to distinguish human influence in palaeoecological records, such as Baxter and Meadows (1994), this is only feasible for known events clarified through acknowledged historical records, and in southern African contexts, generally related to colonial arrival. Lack of written records prior to European colonial occupation, dating discrepancies and the relative paucity of coexisting palaeoecological and archaeological sites, means that it is impossible to assess the influence of early inhabitants in the same manner. For this reason, pre-colonial human involvement is difficult to resolve, and is often set aside or bracketed with climatic changes.

3.5.2 Post-Colonial Period:

European discovery of the forest occurred during a Dutch expedition in 1711, and a post set up between George and Knysna in 1777, for the woodcutter's, numbering only 15 at first. The Dutch entered the region the following year, with Governor Joachim van Plettenberg setting up a controlled system of contract exploitation, and the first timber load leaving by ship to Cape Town in 1788 (Phillips, 1963, von Breitenbach, 1974 as cited by van Daalen, 1980).

A second timber harbour was subsequently opened at Knysna in 1812, with concomitant increases in woodcutters' numbers and their exploitation. Demand increased as settlements along the southern Cape and inland came to be established, peaking in 1835 with the Great Trek (van Daalen, 1980). By 1847 government began to sell off deforested land on the coastal plateau for agricultural purposes, with areas in Tsitsikamma following suite (van Daalen, 1980).

The greatest fire on record occurred in 1869, after a spate of 3 dry months and 6 weeks of almost daily berg winds (Bond, 1997). A land-management fire started in scrub on Portland Estate, got out of control and joined up with other fires towards the east, burning thousands of hectares of forest between George and Humansdorp (Mackay, 1997). Following the devastation of this fire, some conservation efforts were made, beginning with the appointment of Captain Harison as forest conservator in 1874 (Phillips, 1963 as cited by van Daalen). His individual efforts were largely futile considering the pressure for timber from outside the forest, and the dire need for livelihoods from the woodcutters within the forest. The ill-fated "gold-rush" in Millwood 1876 gave teetering conservation efforts the final, fatal shove.

It is suggested that, at this point and up to 1882, trees were harvested in a fairly unregulated manner; that of removing single trees from various parts of the forest , but basically replicating natural processes of old-age, wind-fall or disease (Phillips, 1931). This method of timber removal allowed much greater chance of regeneration in a way that the systematic section exploitation, on a 40 year rotation, introduced by 1882 by Count Vasselot de Regne, could not (van Daalen, 1980). This system was poorly understood and quickly resulted in over-exploitation (Phillips, 1963).

Meanwhile, society in the southern Cape was becoming increasingly polarised, between the more affluent (generally English) town-dwelling tradesmen and the largely illiterate, poverty-stricken populations of woodcutters from the forests, who after just over 200 years since the forest opening, now numbered in their thousands (van Daalen, 1980), with both these groups depending on forest products, the former for continued affluence and the latter for meagre livelihoods. Woodcutters were registered in 1914, rationing 20 m^3 (over twice the sustainable allotment) to each woodcutter, amounting to an annual income of £25 (van Daalen, 1980). Afforestation with Pine and Eucalyptus plantations were began in 1917 in an attempt to alleviate the continuing poverty. However, forests were eventually closed in 1939 to all exploitation and the woodcutters, many of whom had been in the forests for generations, were evicted and provided with annuities (Mackay, 1997, van Daalen, 1980). It has been estimated that between 1776 and 1939, up to 3 million m^3 of timber was removed from the forests (Midgely *et al.*, 1997).

Phillips (1931) also points out some significant ecological occurrences, many caused by misguided and uninformed management approaches. Apart from section clearance, forest was further impacted by the market demands for only the largest and finest trees (substantially reducing gene and resource value) of particular tree species (*Podocarpus spp* and *Octea bullata*), with a further ill-advised measure, to ring-bark species deemed as "inferior" (such as *Olea*). A miscalculation of mature tree girths lead to the removal of immature trees and the decrease in canopy height resulting more sun reaching the seedling and sapling stages of growth (Phillips, 1931). Lastly the extensive use of fire on the fynbos margins of the forest, during their conversion to agricultural land, are said to have restricted and stunted seral succession (Phillips, 1931).

3.6 Conclusion

Although deemed to be a relatively stable period of earth history, the review of established work in the southern Cape and the rest of the subcontinent during the Holocene, suggest that variations in moisture and temperature were significant enough to result in changes to communities.

Palaeoecological reports from afromontane regions appear to placate earlier concerns as to the significance of recent anthropogenic disturbance in environments, particularly in the case of the fragmentation of afromontane forests and the derivation of grasslands/heathlands. Pollen analysis methods have indicated that grasslands/fynbos have long been associated with afromontane biomes and consequently fire, inherently associated with these vegetation components, is also a long-term ecological tool. While the possibility of fires lit by human sources, rather than rarer natural ones, is much more likely, human involvement is only clearly discernible where historical records exist. Phillips' historical account of ecological impacts provides an important insight into establishing recent influences on the forest ecology. It is evident that humans have been living in increasingly surplus cultures (Egan and Howell, 2001) since the beginning of the Holocene, but the extent to which this has changed the distribution and structure of communities in relation to natural fluctuations for the area, has yet to be established.

Chapter 4:

METHODOLOGY

4.1 Introduction:

To assess the changes to the vegetation community of the Knysna forest and environs through the Holocene, an indispensable palaeo-tool for this purpose is the analysis of pollen, trapped and preserved in incremental sediment layers, in depositional environments within the area. The Wilderness Lakes provide such an environment; close enough to the forest for its representation in the pollen rain, yet far enough away to be more sensitive to environmental changes that occur at forest margins. Their coastal position allows pollen-studies, often skewed towards upland sites, (Edwards, 1979, as cited by Moore, 2000) with insights into lowland conditions. Coastal processes, however, in particular the presence and potential mobility of dune sands (Martin, 1968), impose a certain drawback to such settings, as the mobility, abrasiveness and aeration of sand layers is not favourable to pollen preservation.

Although the region may be best known for forest, this forms only part of the vegetation mosaic, with fynbos patches forming prominent components of the landscape. It is apparent that this pattern is fire-maintained (Geldenhuys, 1994), although the degree to which this is entirely natural, is difficult to determine in a region whose environmental history is so steeped in human interference. In an attempt to understand the prominence of fire in the environment over the long term, charcoal analysis (following Clark's [1982] rapid Point-Count method), was undertaken as a secondary palaeo-tool.

It is often suggested that multiple sources of evidence of environmental change surpass single proxies (Lowe and Walker, 1997) in that it is possible to `triangulate' a more precise and accurate signal of change. The purpose of this chapter is to describe the practical applications necessary for multi-proxy research, and the methods applied during this project. This chapter opens with an account of the study site selection, determined by the suitability of retrieved sediments. The study site of Groenvlei is then described, followed by the sediment sampling procedures. Subsequently, sediment description and dating methods are outlined, followed by explanations of sampling strategy and laboratory procedures, and the subsequent procedures necessary for pollen and charcoal analysis. While methods particular to this project are provided in this chapter, a step-by-step description of the laboratory procedures followed may be found in Appendix B. The theoretical considerations that underpin (and often limit) the particular methods are discussed briefly, with reference made to key texts for further information.

4.2 Site Selection

Coring took place in March 2005, with cores retrieved from four locations in the Wilderness Lakes (see Fig. 4.1). A long core (GK1) and a surface sample (GKS2) were retrieved from the north shore of Groenvlei, with a second retrieved from the north-western shore (GK2). A core was recovered from the eastern shore of Rondevlei (RV), a lake under National Parks Board jurisdiction, while the last core was obtained from the north shore of Langvlei (BLV). The Rondevlei core was not considered for further investigation, as it was evident that the majority of the fairly short core consisted of wet sand (much of which slumped out on retrieval) and was, therefore, inappropriate for the purposes of this project. The BLV core was abandoned much later (post-pollen extraction phase) when it became clear that the organic content was too low, and clay content too high, for satisfactory pollen analysis. Therefore, only the Groenvlei cores provided sediments suitable for pollen analysis purposes, consequently defining this vlei as the study site for the project. As the scope of the project and the time period available limited analysis to a single core, GK1 was selected in preference to GK2, in that there was a greater availability of organic material, and a thinner sandy layer than in GK1 (see Fig 4.2 below); furthermore this core was better chronologically resolved.

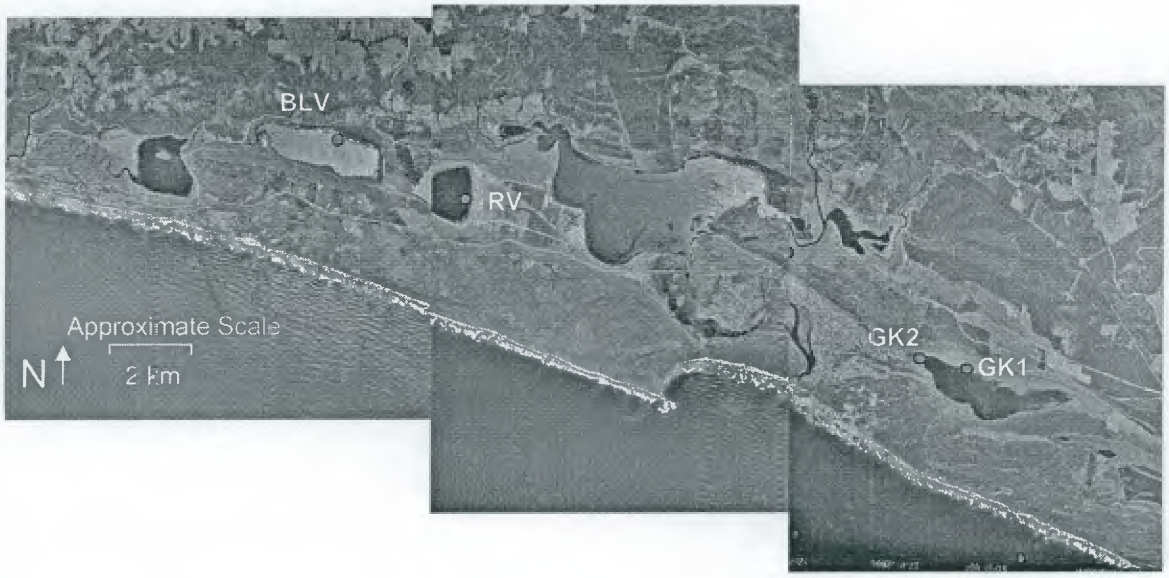
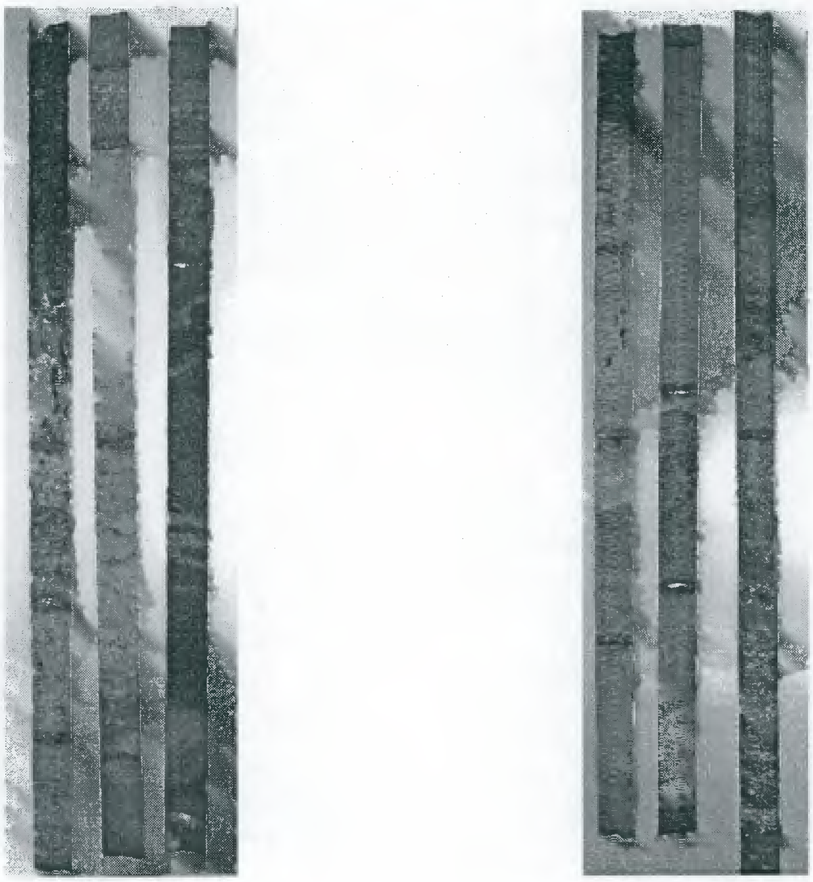


Figure 4.1 : A composite aerial photograph of the Wilderness Lakes 17.01.2004 (Job 1075 Oudtshoorn, Strip 014), showing the coring sites (marked with a dot)



GK1 **GK 2**

Figure 4.2: Photographs of the cores retrieved from Groenvlei, indicating the significantly larger sand section of GK2, in comparison to GK1

4.3 Site Description

4.3.1 Introduction:

Groenvlei is situated on the south-east coast of South Africa, ensconced in an inter-dunal depression lying parallel to the coast, east of the town of Sedgefield. It is one in a series of warm-temperate coastal vleis (Randall, 1990) (from west to east: Eilandvlei, Langvlei, Rondevlei, Swartvlei and Groenvlei), known collectively as the Wilderness Lakes (see Fig. 4.1, above). While the other vleis in the series are connected either directly or indirectly (via channels) to the sea, Groenvlei, on the eastern extreme of the series, is isolated by dune ridges from its neighbour Swartvlei, with neither river inflow, nor an outlet to the sea; this provides a suitable situation for palaeoecological pursuits (Delcourt and Delcourt, 1991).

4.3.2 Physical and Chemical Properties of Groenvlei

Groenvlei, so named for the persistent green taint to its waters, created by generally eutrophic conditions, lies 2.2 m above sea level as a shallow depression of Pleistocene origin (Martin, 1968), approximately 4 km long and 1 km wide (Martin, 1960). As it has no riverine freshwater source, water levels fluctuate according to rainfall, spring-flow and seepage (Martin, 1956) with levels highest during winter when evaporation rates are low (Martin, 1956). Groenvlei has a maximum water depth of 5.5 m, easily mixed by wind (mostly in a westerly direction) and thus preventing any extended periods of oxygen, carbon dioxide or thermal stratification (Martin, 1960). It has a surface area of 248 hectares and a catchment area, consisting almost exclusively of dune sands, of 956 hectares (Martin, 1956). This catchment type is reflected in the calcareous nature of the water, providing alkaline conditions suitable for the formation of peat (Martin, 1956), and consequently suitable for the trapping and preservation of pollen, the major analytical component of this study. Furthermore, Groenvlei is brackish: although the source of salinity is difficult to define, it is possible that the saline conditions may be derived from salt particles entrained in sea-spray, salt concentration during summer months, the result of former sea inundation, or seepage from saline springs (Martin, 1960).

4.3.3 Description of the Vlei and Vegetation Communities

Below a shallow peat layer, a sand lens between 1 and 2m blankets the northern shore (Martin, 1960), forming a discontinuity in any record extracted from this side (GK1: GK1: 34°01'507S 22°51'069E). The northern shelf of the lake falls away rapidly under water to 2.5 m and then slopes more gradually to the vlei's maximum depth, rising symmetrically towards the southern shore (Martin, 1960), inhabited by a narrow reedbed and backed by the abruptly rising dunes separating Groenvlei from the coast. These slopes are inhabited by low dune forest, with *Sideroxylon inerme* prominent, and coastal scrub and fynbos on the forelands. Apart from the fringing reedbed, the western shore is occupied by a hotel and caravan park. Martin (1968) obtained cores from the eastern edge of the vlei which, immediately adjacent to the current lake shoreline, is continuous with the northern shore, in that the fen overlies the sand bar. This sand lens is apparently absent further away from the lake, with fen deposits directly overlying lake sediments (Martin, 1960). Although this shore would, therefore, provide the most continuous record, it was inaccessible at the time of sampling.

As outlined by Martin (1960), in his comprehensive study of the vlei and its primary communities, Groenvlei is roughly encompassed by a number of vegetation zones. Aquatic communities consist of benthic algae, including bottom-living diatoms, as well as blue-green algae (Martin, 1960). *Chara macropogon* forms a prominent lake floor cover, and may occur down to maximum depth, while *Potamageton* commonly forms a dense blanket on the deeper edge of the reedbank (Martin, 1960). Shallower zones are inhabited by *Scirpus littoralis,* shifting to *Typha capensis* reedbeds (Martin, 1960). *Phragmites australis* may occur intermingled with the *Typha*, but generally forms a boundary between the semi-aquatic *Typha* and the more terrestrial *Cladium mariscus* (often interspersed with *Cyperus papyrus*) (Martin, 1960). The boundary between the reedbeds and the surrounding marginal thicket is clearly defined, with this latter zone capable of supporting some fairly large vegetation such as *Clausena inaqualis, Myrica sp., Fagara capensis, Sideroxylon inerme*, with *Rhus*-type and *Rubus fructicosus* occurring on sandy substrates (Martin, 1960). Fynbos elements are also prominent, particularly restioids and asteraceaous types (e.g. *Metalasia sp.).* On the northern shore, it would appear that, if not dissected by cultivation and the N2 freeway, the marginal thicket surrounding the vlei, would fuse with woodland communities (Martin, 1960), inhabiting dunes to the north.

The environmental heterogeneity of the southern Cape in general, and the area surrounding Groenvlei in particular, means that vegetation communities inhabiting the region are similarly diverse. To acquire a working understanding of the dynamics, and varying prominence, of these different types of vegetation over time, a number of groups were defined in line with their ecological affinities (according to Geldenhuys, 1993; Martin 1968) . These were designated as the following:

- **Wetland/Local:** aquatic, semi-aquatic and local terrestrial groups
- **Fynbos:** heath-associated elements inhabiting nutrient-poor soils, or fire prone areas;
- **Forest Margins:** generally pioneering or fire prone types
- **Dry Forest to Coastal Scrub**: inhabiting dry sands, dune and lee slopes; (Geldenhuys, 1993)
- **Moist to Dry Forest**: inhabiting well-drained sites, generally foothill and platform forests (Geldenhuys, 1993)
- **Wet Forest**: generally restricted to moist areas of high mountains (Geldenhuys, 1993)

The contemporary heart of the Knysna forest lies some 10 km away from Groenvlei, and therefore, a greater representation of more local groups (such as wetland/local, dry forest-coastal scrub and fynbos) is likely. Furthermore, as indicated in Chapter 2, many forest species are insect pollinated, potentially further reducing their prominence in the pollen record. Species lists, adapted from Geldenhuys (1993) and Martin (1960, 1968), indicating their ecological grouping are provided in Appendix A. The premise underlying their designation into these ecological groups is that as the group shares similar growing affinities, the prominence of the group in the record will reveal insight into prevailing conditions. Certain taxa, however, may provide more specific information on prevailing conditions, than is merely denoted by their presence as part of a group. Such taxa can be found in Table 4.1 below.

Table 4.1: Ecological indicators of environmental conditions derived from: Martin (1968), Scholtz, (1986), Finch (2005), [modified from Scott(1999)], and www.plantzafrica.com

Name	Vegetation Type	Ecological Indicator
Cyperus	Semi-aquatic (Wetland/Local)	Swamp/marshy conditions or damp soil
Poaceae	Grassland (many genera)	Generally an indicator of summer-rainfall
Podocarpus	Moist-dry forest	Major wet and dry forest tree. Important timber tree.
Euphorbiaceae	Dry forest/Coastal scrub	Relatively warm conditions
Amaranthaceace/ Chenopodiaceae	Dry forest/coastal scrub/wetland	Dry conditions, open places in dunes, salt marshes
Acanthaceae	Forest margins	Widely tolerant, usually under-storey component. Sun and frost tolerant.
Aquifoliaceace	Wet forest	Stream banks and other moist areas
Pinaceae	Exotic	Human disturbance
Oxalidaceae	Moist-dry forest/heath	Mainly confined to winter rainfall, also found in disturbed places.
Pteridophyta	Moist forest/margins	Wet sites. Common pioneer.
Asteraceae	Fynbos	Mainly dry heath
Restionaceae	Fynbos	Mainly wet heath

4.4 Sediment Extraction

Sediment cores examined in this project were obtained both by hand (in the case of GKS2) by driving a short section of aluminium tubing into the ground, and with the aid of a mechanical device (in the case of GK1) known as a Vibracorer (see Fig 4.4, below). This device produces high frequency, low amplitude vibrations which are translated through the core tube, setting up a standing wave which liquefies and dislodges sediments on the outer side of the tube, allowing for decreased resistance and therefore increased ease of downward movement through the sediments (Baxter, 1996). The current Vibracorer, belonging to the University of Cape Town, is derived from the original design by Lanesky *et al.*(1979 as cited by Baxter, 1996) and subsequently adapted by Smith (1984) and Baxter (1996), and is a useful extraction device in a range of depositional environments (Baxter, 1996). The Vibracorer is essentially used in two phases (see Fig 4.3): the first involves the sinking of the core tube, 6m lengths of aluminium irrigation tubing (diameter = 7.8cm), into the substrate, followed by its extraction using a winch-and pulley system attached to a stainless steel frame. For the extraction of GK1, the vibracorer was set up about 3 meters to the west of the access road, within the north shore reedbed (34° 01'507S 22 ° 51'069E), about 50 meters from the shoreline.

The bottom edge of the core tube was bevelled using a metal file, to cut through the root mat, and was then pushed into the ground by hand, until stabilized in the sediments. The depth of this depends on the texture, type and sorting of the sediments and sank to approximately 50 cm (a process that was repeated for the collection of the short core GKS2). The handle and Poker-Vibrator were then clamped onto the core (see Fig 4.3.1) tube, the latter (adapted from construction equipment, designed to consolidate liquid concrete) consists of a flexible transmission shaft housed in a steel and rubber liner, and powered by a portable 3.7kW Yanmar GE 50 generator (Baxter, 1996). The vibrator is capable of establishing amplitudes of 1.0 mm at a frequency of 1200 vibrations per minute (Baxter, 1996). Once assembled, the generator was switched on and core began to sink through combined force of vibration and downward pressure exerted on the handle (see Fig 4.3.2). Once the handle had sunk to ground level, the generator was switched off and the handle and vibrator re-clamped higher up, and the process was repeated until it was impossible to sink the core any deeper. Cores of greater than 6m are possible to retrieve by joining tubes. For GK1 coring proceeded adequately until approximately 5m down, when the core tube resonance suggested that there was too much vibration, and the tube sheared before the motor could be turned off. This resulted in coring being halted, and the tripod was assembled.

Extraction of the cores from sediment requires the assembly of stainless steel tripod (see Fig 4.3.3), consisting of three 4m cylindrical legs. These were bolted together at their apex and manoeuvred into position over the core tube. One of the legs may extend to 5m, which aids stability during winching. The winch rope is fed through a pulley attached to the linchpin at the tripod's apex and then tightly secured to the handle on the core tube (Baxter, 1996). The GK1 core tube was then winched out of the ground (see Fig 4.3.4), losing 50 cm of sediment, owing to shearing, in the process. A final length of 4.30 m was noted with sediment compaction of 0.70m (14%) occurring in GK1 (see Table 4.2). The core was cut into three sections, carefully labelled, and sealed for transport back to the laboratory at the University of Cape Town.

The surface sample (GKS2) was retrieved manually in July 2005, during a subsequent field excursion, from the north shore of Groenvlei, some 20m east of the GK1 coring site, in order to provide a greater sampling resolution in upper sections (see Table 4.2).

Figure 4.3: 1. Attaching the handle and Poker-Vibrator. 2. Coring begun, placing a firm downward pressure on the handle. 3. Assembling the tripod. 4. Extraction

Table 4.2: Summary of Groenvlei coring information, indicating site position, core length, compaction and anticipated analyses

	GK1	GKS2
Grid Reference	34°01'507S 22°51'069E	34°01' 440S 22° 51'090E
Final Core Length	430 cm	42 cm
Compaction	0.70 cm	0 cm
Analysis to be performed	Radiocarbon Dating, Pollen and Charcoal Analysis	Pollen, Charcoal

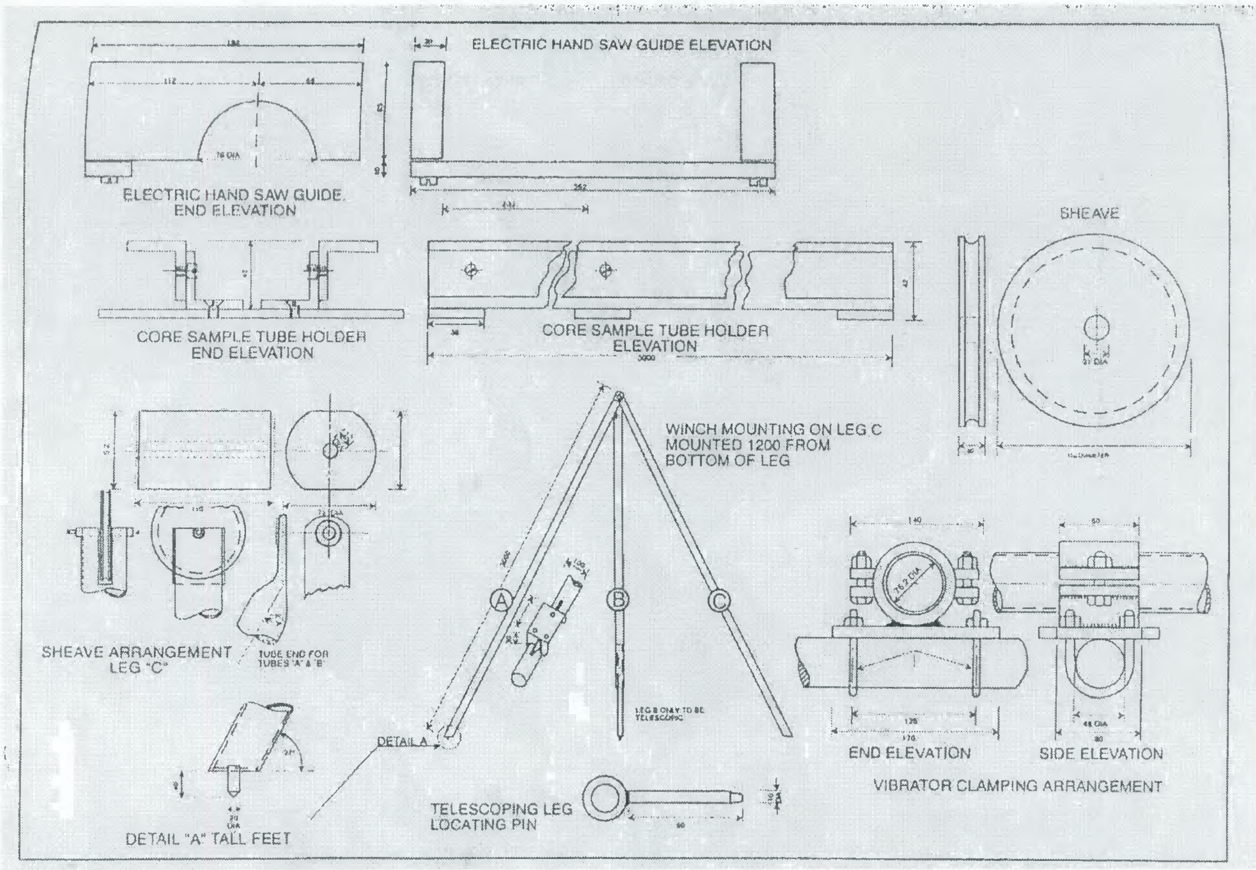


Figure 4.4: A schematic of the Vibracorer design (Baxter, 1996)

4.5 Sediment Description and Dating

To access the sediments, the aluminium core tube was divided, using a circular saw, and the sediments separated by drawing wire down through the central split. The tubes were then opened under dark-room conditions, and sand samples extracted at this point for luminescence dating (see Table 4.3, below for sampling depths), to be performed by Dr. B Chase at the Centre for the Environment, Oxford University. For further dating control, bulk peat samples were extracted from organic-rich layers for radiocarbon (^{14}C) dating (see Table 4.3, below) which were sent to the Quaternary Dating Research Unit (QUADRU) at the Council for Scientific and Industrial Research (CSIR) for analysis. These samples were pretreated with 1% hydrochloric acid to remove any carbonate inclusions, the carbon was extracted in gaseous form, counted on gas proportional counters, and the results were calibrated according to the terrestrial ^{14}C curve (Pers. Comm S. Woodborne, 2006). By plotting this resolved chronology against depth, an estimated sedimentation rate for the cores can then be established (Berglund and Ralska-Jasiewiczowa, 1986). The cores were described by colour (according to Munsell colour notation), texture and organic/inorganic content and a stratigraphic diagram was drawn up. The GK1 and GKS 2 cores were then compared according to similarity of lithology and alignment of strata, in order to determine the appropriateness of combining pollen sequences extracted from these cores.

Table 4.3: Indicating the levels at which samples for Luminescence and Radiocarbon dating were extracted from GK1

Depth GK1 (cm)	Dating Technique
31-36	^{14}C
73	Luminescence
84	Luminescence
100	Luminescence
123	Luminescence
156	Luminescence
158-163	^{14}C
168	Luminescence
220	Luminescence
274	Luminescence
303	Luminescence
335	Luminescence
381	Luminescence
400-405	^{14}C
428	Luminescence

4.6 Pollen Analysis

4.6.1 Introduction:

A range of different methods is used in determining past environmental conditions, however, the prevailing method for determining late Quaternary environments since the 1920's (Faegri and Iversen, 1950) and thus arguably one of the most adaptable, widely implemented and successful environmental proxy tools (Bell and Walker, 1992; Lowe and Walker, 1997), is the study of pollen and spores, a discipline known as palynology. While the function of pollen from a biological perspective is reproduction, its purpose in palaeoecological research is in supplying the means to analyse and understand the dynamic relationship between plant communities and their environments. Essentially the procedure requires the extraction of fossilized pollen grains from suitably organic incremental sediment deposits. These fossilized grains, at points through time, are identified and counted and taken to be representative of the presence and abundance of their parent plants, whose ecological affinity is assessed according to modern analogues. The theory, principles and limitations of this method are discussed briefly below. For further detail see reference texts such as Faegri and Iversen, (1989); Moore *et al.*, (1991).

4.6.2 Theoretical Considerations

Pollen is the male gamete, produced on the anthers of both angio-and gymnosperms (Bell and Walker, 1992; Lowe and Walker, 1997) and distributed by various means (by wind or animal vectors) to the female plant. Pollen grains are extremely small (most 25-35μm) and consist of three concentric layers (Faegri and Iversen, 1950). The living cell is contained in the inner layer, enclosed by the middle layer or *intine* consisting of the easily-decaying cellulose that makes up ordinary plant cell-walls (Lowe and Walker, 1997). The third layer or *exine* is made up of a highly-resistant substance sporopollenin (Faegri and Iversen, 1950) the purpose of which is to protect the grain from desiccation and microbial attack (Lowe and Walker, 1997) and allows for the pollen grain to resist decay for millennia. This external coating is sculptured, as, depending on its method of dispersal, pollen grains develop morphological differences allowing for taxonomic identification to be made. Groups that use wind dispersal (anemophily) produce pollen that is commonly small and smooth, with low specific gravity and occasionally bearing features such as air sacs (Lowe and Walker, 1997). Zoomophilous taxa, those that rely on animal or insect vectors, produce substantially fewer pollen grains than wind-pollination and this pollen is typically more hardy, generally large (or very small) and may bear features such as a sticky or armoured coating (Lowe and Walker, 1997).

The principle that effectively underpins analysis of fossil pollen, is that of Uniformitarianism. Proposed in the 18th century by James Hutton, Uniformitarianism can be clarified by the adage "the present as the key to the past". The theory proposes that the biological, chemical and physical processes that control interactions today are the same as those that occurred in the long past, requiring a dependence on the interpretive argument of analogy (Bell and Walker, 1992) and the number of assumptions that underpin it. These assumptions, which are the same for any palaeoecological investigation, are summarised as the following from (Roberts, 1998)

"1. *The environmental factors governing present day plant and animal distributions*

2. Their ecological affinities have not changed through time

3. Present (and past) distributions are (and were) in equilibrium

4. Modern analogues exist.

5. The origin (taphonomy) of a fossil assemblage can be established, and that...

6....this assemblage is not biased by contamination or differential preservation.

7. Fossils can be identified to a meaningful level of taxonomic resolution "

Evidently, fully satisfying each of these assumptions, is often difficult, and as Bell and Walker (1992) put it, "*...every context is unique and no analogy exact and therefore no argument made from analogy is certain*" (p.15). This is mostly counteracted by the use of relatively short geological time periods and few taxomic differences between the fossil and modern analogue (Dodd and Stanton, 1990). Moreover, without the assumptions, that appear inherent in the theory, understanding and reconstructing past environments would be virtually impossible (Bell and Walker, 1992, Delcourt and Delcourt, 1991), and the various applications of palaeoecological research would be vastly reduced.

Over and above these suppositions, that appear to both support and limit palaeo-investigations, are a number of principles that determine the availability of a pollen assemblage and therefore govern the procedure of pollen analysis. These principles summarised from Moore *et al.*, (1991), Birks and Birks, (1980), Faegri and Iversen, 1989), Irving (1997) follow:

1. Pollen is produced in vast quantities by parent plants, with only a small percentage fulfilling a reproductive role.
2. The predominant dispersal mechanism is wind, which mixes the air-borne pollen to a fairly uniform blend.
3. Pollen is then deposited, and may be preserved given suitable conditions
4. The proportion of each pollen type is related to number of parent plants in the vicinity
5. Pollen that is preserved in dateable, stratified sediment can provide an indication of vegetation communities occurring in that area at time of deposition and their changes over time
6. Pollen taxa have different morphologies and exine sculpturing that enables

their identification to family for herbs/grasses and to genus/species level for trees and shrubs.

7. Abundance and small size of pollen means that only small samples (±1 cm^3) are required for analysis

As with most tools, there are limitations to its use, not least of which is the amount evidence and research time available. However, the fundamental shortcoming of pollen analysis is the assumption of equal representation of major taxa, presuming a similarity in production, dispersal and preservation (Lowe and Walker, 1997). Production and dispersal may differ perceptibly between taxa, particularly those using insect/animal vectors, (which require only small quantities of pollen) versus those using wind-dispersal (which require large quantities to ensure reproductive viability), while preservation demands anaerobic conditions, in generally low energy environments, as oxygen and abrasion result in damage and consequently difficulty in identification. During the analysis phase these limitations may be added to through the extraction process (which may bias the results owing to the harshness of chemical and mechanical procedures), slide preparation (where grains disperse in the mounting media according to size (Moore *et al.,* 1991), with smaller grains jetted to the periphery, where they may be overlooked) and identification and counting phase (where hardier grains may be better represented and more easily identifiable than the more fragile, or where differences in exine sculpturing, size or shape may make it easier to distinguish the pollen taxon). Furthermore, pollen representation in any fossil assemblage is affected by the environmental factors specific to that site, including the position of plants in vegetation, the prevailing wind direction, vegetation proximity to the depositional basin as well as the size of that basin (Delcourt and Delcourt, 1991). While some of these biases may be impossible to amend, a meticulousness in the sampling, extraction and counting phases described below, may go some way to producing a reliable palaeoecological record.

4.6.3 Sediment Sampling Phase:

Owing to the poor preservation capacity of sand, samples for pollen analysis purposes were extracted from organic strata in GK1 and GKS2, as close to a regular sampling interval as these organic inclusions would allow. In peaty, upper layers in GK1 and through the short core of GKS2 this meant a ±5 cm sampling interval was employed, while in lower layers of GK1, below a substantial sand lens (between 42 and 295 cm) a roughly 10 cm sampling interval was assumed. The presence of this substantial sand layer imposes a discontinuity on the record, while the uneven sampling strategy means that any pollen records produced for this site will more likely present community snapshots through time, rather than a continuous record of change.

Samples of $3cm^3$ were extracted from the cleaned face of the GK1 and GKS2 sediment cores, using an adapted syringe (Baxter, 1996). $1cm^3$ of this was destined for pollen extraction procedures (see section 4.6.4), while the other 2 cm^3 was stored in carefully-labelled airtight vials for reference and as a back-up.

4.6.4 Reference Collection:

The first step towards creating the reference collection for this project, was assembling a thorough species list. This was based primarily on the detailed, annotated checklist produced by Geldenhuys (1993) with additional information sought in Von Breitenbach (1985) for tree species and by Martin (1968) from his list of species found during his palaeoecological investigation at Groenvlei. Thereafter, representative pollen images were sourced by genus, when specific pollen reference material was not available. The primary resource used in establishing the collection was the Cape Town Collection of Pollen (CTCP), housed in the Environmental and Geographical Science department at UCT, as reference slides for the region had been previously prepared by Irving (1998). These slides were digitally photographed and supplemented, where necessary, with photographs from the African Pollen Database (APD). Grains were classified by morphometric properties and divided into aperture classes (Porate, Colpate, Colporate, Other) with grains within these classes grouped according to structural similarity so that taxonomic differences may be more carefully defined and mistakes in identification minimised. During compilation of this list, ecological affinities and boundaries were noted, and the list was divided into representative ecological groups (as specified in 4.3.3 above). In a case where members of the same genus may occupy different habitat zones, the more common member's ecological affinity was designated.

4.6.5 Pollen Concentration Phase:

Techniques employed were adapted from Faegri and Iversen (1989), Moore *et al.* (1991), Baxter (1996) and Irving (1998). Despite an initial attempt to adhere to the methods set out in these texts, trial and error soon established which treatments required adaptation (detailed below at the appropriate step) to the specific requirements of the sediments and the laboratory. Essentially, treatments are applied sequentially to remove unwanted or obscuring materials from the sample, ultimately to produce a slide consisting principally of the palynomorphs to be studied (Horowitz, 1992). As the sediments obtained contained a substantial portion of sand, the following chemical treatment was employed:

1. A *Lycopodium* tablet was added in a distilled water solution to each sample, for absolute counting procedures. This was added before any chemical treatment began so that both the fossil pollen and counting spores would undergo similar conditions and therefore maintain the counting relationship.

2. Samples were initially digested in 10% Potassium Hydroxide (KOH) to dissolve the humic acids and break up (but not remove) the matrix (Moore *et al.*, 1991; Faegri and Iversen, 1989). The samples were then wet sieved to remove any coarse sand or detritus and the <106 μm portion was then decanted from the samples and if still dirty (such as the case with GK 1.1 to 1.4) they were rewashed in 10% NAOH, to which they responded better.

3. The samples were then treated with 10% cold Hydrochloric Acid (HCl), to remove the Calcium Carbonate and colloidal silicates (Irving, 1997) from the matrix (Moore *et al.*, 1991) a step necessary before treatment with Hydrofluoric acid (Moore *et al.*, 1991).

4. A cold 48 hour Hydrofluoric acid (HF) treatment followed to remove the silica content (Moore *et al.*, 1991; Faegri and Iversen, 1989) of the sample. While considerably corrosive, it has been shown that even prolonged treatment with concentrated HF (0.4-0.6 M) does not damage organics, although it may result in size variation of grains (Faegri and Iversen, 1989). While warm treatments are preferable in that they are much more efficient, at time of treatment the water bath was being repaired.

5. The samples then underwent a final resuspension in 10% HCl to remove the silico fluorides produced during HF treatment (Moore *et al.*, 1991)

6. Acetolysis was then carried out to eliminate excess cellulose, increasing the prominence of pollen in the organic portion of the sample (Horowitz, 1992). This requires the sample to be dehydrated with glacial acetic acid followed by a three-minute exposure to cellulose digestion by boiling the sample in Actetolysis mixture (consisting of nine parts Acetic Anhydride to one part Sulphuric Acid). It has been argued by Brown (1960) that this aggressive acid treatment acts to enlarge and darken the pollen grains as well as improve the clarity of sculpturing, through partial dissolution of the exine (Horowitz, 1992). While this may aid general identification, again identification based on grain size statistics becomes more difficult (Faegri and Iversen, 1989).

7. The pollen grains were then stained with safranin to improve their structural clarity and aid identification.

8. Samples were stored in Tert-Butanol Alcohol (TBA) and 0.02 ml portions were mounted in glycerine, a fluid mounting media that improves diagnostic capabilities in that it is possible to rotate grains to different views with slight pressure from a dissecting needle (Baxter, 1996). The slide was then sealed with a line of glycerol-jelly, impregnated with an anti-bacterial agent (phenol).

4.6.6 Identification and Counting Phase:

The accepted identification practise involves examining the prepared slides at 400x magnification, identifying taxa present across the slide, and recording this on a count sheet (Traverse, 1988; Moore *et al.*, 1991, Horowitz, 1992). As it has been noted that pollen grains disperse under the cover slip according to size (Moore *et al.*, 1991) counting took place by starting in the top left hand corner and progressing in linear traverses from left to right and then moving down two fields of view and counting from right to left. This zigzag fashion, leaving a field of view between transects, both decreases the chance of recounting (as the grains are in a fluid medium and likely to move) while allowing for a representative assessment to be made of the slide. If a representative count had not been made by the last transect, it was then possible to return to `between' transects.

An absolute counting procedure was employed in this project to identify the total number of pollen grains in the sediment. Developed by Stockmarr (1971), the technique involves the addition of a known number of exotic markers, in the form of *Lycopodium clavatum* spores, to a known amount of sample. Exotic markers were then counted along with fossil grains, using a minimum count of 120 *Lycopodium* spores per slide.

The final pollen sum was also noted, allowing for the presentation of data in relative frequency form as well. While absolute frequency graphs represent taxa independent of one another, relative frequency graphs present data as a percentage contribution to the whole. An artefact of presenting data in percentage form, however, is that when one taxon (or group) increases, others appear to decrease in proportion (Birks and Gordon, 1985), but not necessarily in reality. The benefit of relative counts, however, is that they eliminate the effects of the varying totals of grains for each sample as occurs with absolute counts (Birks and Gordon, 1985), thereby standardizing data and smoothing the sequence curves in relation to absolute frequency forms. It is intended that, in using both forms of data presentation, the drawbacks of each may be accommodated, thereby converging on a more reliable signal of change within the sequences.

Moore *et al.*, (1991) advise that exotic maker addition (in the form of a tablet) be applied prior to the commencement of any chemical treatments. This provides a control measure to ensure similar conditions for both fossil grains and markers, thereby preventing the numerical relationship between them from being compromised (Moore *et al.*, 1991). Faegri and Iversen, (1989) advise that markers should form no less than 20% of the expected total fossil pollen count, while Berglund and Ralska-Jasiewiczowa, (1986) suggest that a ratio of 1:1 (exotic marker: fossil pollen) should be assumed, recommending the use of 1-4 tablets with each tablet containing approximately 10 000 spores (Berglund and Ralska-Jasiewiczowa, 1986). During laboratory procedures, 1 tablet containing *Lycopodium clavatum* (Batch No. 483216) with approximately 18 583 spores in each tablet (Berglund, 2004) was added to $1cm^3$ of sediment (See Appendix C).

Total pollen can be determined by the following equation (Faegri and Iversen, 1989):

$$\textbf{Total Fossil Pollen (TFP)} = \frac{\textbf{Fossil Pollen Counted x Total No. Markers}}{\textbf{Exotic Markers Counted}}$$

To acquire the pollen concentration, the TFP is divided by the sample volume (Faegri and Iversen, 1989). As samples of $1cm^3$ were used, the above equation provides the pollen concentration as well.

Identification was made according to the compiled reference collection, based primarily on the number and arrangement of apertures, and then by shape and exine sculpturing. There is a certain amount of subjectivity involved in identification as there may often be a high degree of similarity between grains, particularly between those of afromontane arboreal types (Irving, 1998). Despite the inherent possibility of inaccuracies, an honest and careful attempt was made to identify pollen types..

4.7 Charred Particle Analysis

4.7.1 Introduction

During a fire, the combustion of organic matter results in the production of charcoal, a chemically inert carbon (Clark, 1984), appearing in pollen slides as black, opaque, angular fragments (Swain, 1978; Head and Stewart, 1980; Battson and Cawker, 1983; Edney *et al.*, 1990; Clark *et al.*,1984 as cited by Rhodes, 1998). Microscopic fragments carried by the wind, or by stream or sheetwash, (Whitlock, 2001) may be conveyed far from the source of the fire before being deposited in suitable preservation environments, in a similar manner to pollen. Theoretically this provides a record of regional fire history, as it is proposed that so-called peaks in the record may be assumed to be an expression of high intensity or frequency of fires in the region, although the intricacies of the relationship are still to be ascertained (Singh *et al.*, 1981, as cited by Tolonen, 1986).

4.7.2 Methods, Theory and Limitations

The potential for investigating long term fire records from quantifying microscopic fossilised charred particulates on pollen slides was first tested by Iversen (1941). Subsequently, the number of applications and the number of methods employed has increased, but to variable effect, with no common agreement on a single superior method (Rhodes, 1998), each bearing a set of limitations. It is reasoned that the particular aims of the analyst determine the suitability of the method (Rhodes, 1998), although this means that very few studies of fire history are comparable (Whitlock, 2001), diminishing both their academic effectiveness and practical application.

Methods include (1)**Absolute Particle Counts** such as employed by Iversen (1941) (Rhodes, 1998), a method counting all charcoal fragments present on the slide regardless of size variations, a matter investigated more carefully by (2) **Size Class Methods,** which are based on the understanding that larger particles fall out closer to the source of the fire, while smaller particles may be carried further and thus making it possible to distinguish local from regional fires by assigning particles to predetermined size categories (Asselin and Payette, 2005; Rhodes, 1998), (3) **Subjective Estimates** based on a percentage area approximations (Rhodes, 1998) and the (4) **Point-Count Method** (Clark, 1982). This last method has been selected for use in this project in that it balances the necessity for objective quantification (the benefit of the Absolute Counts and the Size Class methods) with rapid processing time (the benefit of the Subjective Method). Clark's (1982) Point Count Method, estimates the area of charcoal present per unit of sediment, through traversing a statistically significant number of Fields of View (FOV) across the pollen slide and counting the number of charcoal particles (regardless of size) in each FOV, that touch a point on the eye-piece reticle. The completed counts are then converted into the estimated area according to an equation (Clark, 1982).

The clear advantage of fossil charcoal analysis is the picture it provides of the long term nature of fire in the environment, a record stretching further back than is available from tree-ring data (Whitlock, 2001). Furthermore, it is possible for charcoal particles to be counted alongside pollen during slide analysis, reducing the time spent on both separate preparation and counting. In this way, when coupled with pollen records, the vegetative response to fire can be better understood (Whitlock, 2001). The drawback of this combined analysis, however, is that the chemical and mechanical methods used to extract the pollen from the sediment matrix, may dissolve, damage or alter the charcoal fragments (Rhodes, 1998), seldom made up of pure carbon (Goldberg, 1985 as cited by Rhodes, 1998), and therefore potentially biasing the count procedure towards the microscopic size fraction (Whitlock, 2001). However, as Clark's (1982) Point-Count Method does not take fraction size into consideration, this does not pose as severe a disadvantage as it would for the Size Class method. Furthermore, charcoal records are weakened by both the discontinuous sampling strategy employed for pollen analysis and the difficulty in obtaining fine-resolution chronological control through the sediment core, owing to dependency on a few radiometric dates and the variability of sedimentation rate within the core (Whitlock, 2001). This means that it is generally impossible to isolate specific fire events (Whitlock, 2001), as certain samples may integrate a number of discrete charcoal fluctuations into a single peak. For these reasons, charcoal curves do not necessarily provide data robust enough for a stand-alone investigation, however, when combined with other proxy measures, particularly with pollen data, they may provide an important element for the reconstruction for past environments.

4.7.3 Clark's (1982) Point-Count Method

Clark's (1982) point-count method proceeds by counting the number of charcoal particles that "touch" a line of the eyepiece reticle, in a single field of view (FOV). The magnification the slide is viewed under, and number of lines (from here on called points) applied, is determined by analyst discretion and the general size of the particles, so that only one point will touch a particle (Clark, 1982). Clark (1982) recommends that in the case of a dispersed sample, a greater number of points may be applied, but in a very dense matrix, it is preferable to apply fewer points. In the pollen slides prepared for this project, the charcoal particles present were small and scattered, for this reason counts were made under a magnification of 100x, applying 100 points in each FOV.

To determine a representative and statistically valid number of counts, an initial 1-4 transects were counted. The estimated probability of a point falling on charcoal (eP) was then determined according to the following calculation:

eP = No. of points falling on charcoal (C)/ No. of pts applied (N)

(Clark, 1982)

A relative error (S_p/eP) was then selected (in this case a 10% relative error) and the necessary number of counts for that chosen error could then be worked out according to:

$$N = (1-eP)/\ eP\ (S_p/eP)^2$$

(Clark, 1982)

This then provides the number of points that should be applied, which would be divided by 100 to get the number of FOVs required for an analysis at 90% confidence. Counts proceed quickly, noting the number of charcoal particles in contact with a reticle point, then moving to the next FOV. To provide a representative cover of the slide, the zig-zag sampling procedure used for pollen analysis was applied here.

Once counts are complete, P is recalculated, followed by estimating the area of charcoal present on the sample slide (A). This is obtained by multiplying the new probability (P) of a point being in contact with charcoal, by the area of the slide (11.5 cm^2). The standard deviation is then calculated. As exotic marker grains were used for absolute pollen counts, these were employed to determine the estimated area of charcoal per unit volume of sediment (A_c), according to the following equation:

$$A_c = A.M / M_p . V$$

Where
A = Estimated area of charcoal on slide
M = Original No. of marker grains
M_p = No. of Counted marker grains
V = volume of sediment sample

(Clark, 1982)

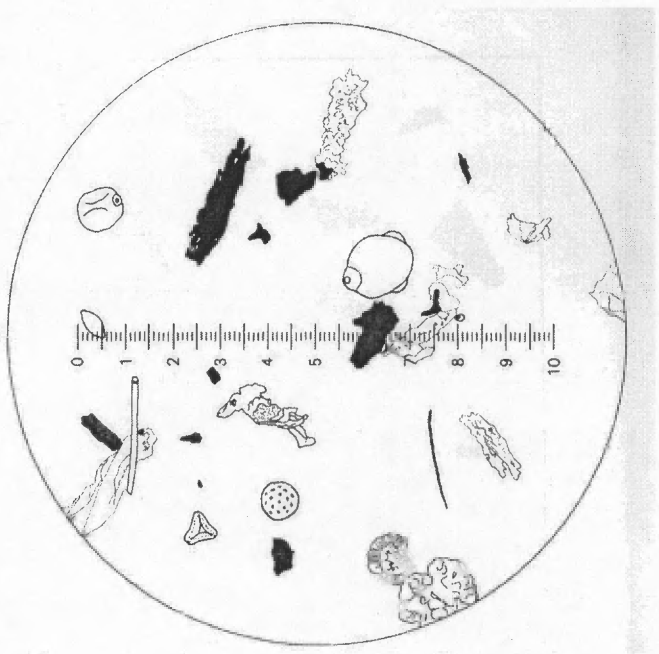


Figure 4.5: A sketch illustrating a single FOV, with 11 points applied, but charcoal "touching" only one point on the eyepiece reticle (Clark, 1982)

4.8 Conclusions

The appropriate organic content of extracted sediments focused the study on Groenvlei, an endhoreic coastal lake, close to the Knysna forests. The overarching project aim is to provide an understanding of vegetation community dynamics over the time period defined by the sediments extracted (dated by both radiocarbon and luminescence dating means) and two forms of analysis have been described to provide proxy evidence to this end. Pollen analysis, is applied in an attempt to resolve the fluctuations of the vegetation communities, and by understanding their ecological significance, account for their likely environmental stimuli. The charcoal analysis is proposed to provide a measure of regional fire prominence through time, and by relating these fluctuations to those occurring in pollen data, provide further insight into the importance of fire as a long-term ecological tool in the forest environment. The pollen analysis method has been widely applied with good results and is seen to be the more potentially rigorous of the methods used. It is, however, subject to a number of limitations, not least of which is the inherent bias of analyst subjectivity. While not necessarily stand-alone, the charcoal counts should be viewed as a secondary proxy, providing support and reference through a system of checks and balances, vital in palaeoecological investigations.

Chapter 5:
RESULTS

5.1 Introduction

The effectiveness of a palaeoecological project in achieving its aims is evidently reliant on the proxy methods applied and the chronological resolution available. Both of these are, however, ultimately dependent on the reliability of the evidence preserved in sediments, both the literal and historical matrix from which these methods of assessing the past are abstracted. In recognition of the significant role that the sediments play, after presenting the results of the dating methods employed, incorporating comment on the validity of the determined ages, the sediments are described and presented in diagrammatic form, and related visually to the chronology in the form of an age-depth graph, an important method of estimating sedimentation rates and providing a means of interpolation of ages, for depths not dated by radiometric means. As the short core GKS2 was also sampled to provide a greater resolution to pollen analysis of the upper (more recent) zones, the cores are correlated by lithology to estimate their degree of conformity.

The second part of this chapter then relates the results of the multi-proxy analyses performed, reporting the results of the pollen analysis of GK1 and GKS2, in an amalgamated form, in various diagrammatic structures (both absolute and relative frequency) related to stratigraphy. Diagrams based on grouped habitat zones are presented first, followed by diagrams presenting the fluctuations of individual pollen spectra, a method which thereby promotes schematic clarity while still providing the basis of necessary detail for interpretation purposes. The results of the charcoal analysis are presented alongside the pollen analysis, as both are proxies for ecological processes. For clarity of interpretation of the pollen sequences, the diagrams have been divided into pollen assemblage zones, based on cluster analysis, allowing for contrast and comparison between diagrams and between zones. These zones are provided with interpolated ages based on the age-depth graph. The changes occurring within these zones are thereafter detailed, while their interpretation follows in Chapter 6.

5.2 Chronology and Sediment Analysis

Sediments were sampled from GK1 for both radiocarbon dating of bulk organic samples and luminescence dating of sand fractions. Three organic samples were retrieved from the GK1 core at particular depths (see Table 5.1). The radiocarbon ages, determined by the Quaternary Dating Research Unit (QUADRU) at the CSIR in Pretoria, are presented in Table 5.1 together with their equivalent calendar ages calibrated using the online calibration system CALPAL (Weninger *et al.*, 2006). These dates set the temporal frame of the project to within the Holocene, although the fact that ages from samples 2 and 3 are so similar (despite the difference in depth), indicates a very rapid sedimentation rate in that section of the core.

Table 5.1: Radiocarbon dates based on organic bulk samples extracted from GK1

No.	Core Depth (cm)	Lab No.	Radiocarbon Age (BP)	Calibrated Age (BP)	Calibrated Age (AD/BC)
1	31-36	Pta- 9491	580 ± 40	594 ± 41	1356 ± 41 AD
2	158-163	Pta – 9481	7410 ± 70	8245 ± 75	6295 ± 75 BC
3	400- 405	Pta- 9497	7630 ± 130	8441 ± 125	6491 ± 125 BC

Table 5.2 below presents the preliminary results of the luminescence dating procedure, undertaken at the Centre for the Environment, Oxford University. Gaps in the data set at levels 4, 6 and 7 and age reversals evident at levels 8, 9 and 10, are the result of the (as yet) incomplete nature of the analysis. These estimates are based on dosimetry readings from other studies in the area (e.g. Bateman *et al.*, 2004) and calibrated to radiocarbon ages retrieved for GK1 (Pers. Comm., Chase, 2006). It is still necessary to obtain dose rates for the core in particular, a process that was incomplete at time of writing. Although the combination of luminescence results with the radiocarbon ages would provide a more confident chronology, time constraints and incomplete analysis necessitate the exclusion of luminescence dates from subsequent analyses.

Table 5. 2: Luminescence ages based on bulk sand samples extracted from GK1

Level No.	Core Depth (cm)	Lab. No.	Age Estimates (BP)	Error
1	73	GK05- 1-1	3260	560
2	84	GK05-1-2	6360	1170
3	100	GK05-1-3	7420	1420
4	123	GK05-1-4	-	-
5	156	GK05-1-5	8170	1570
6	168	GK05-1-6	-	-
7	220	GK05-1-7	-	-
8	274	GK05-1-8	6310	1270
9	303	GK05-1-9	6710	1220
10	335	GK05-1-10	6500	1210
11	381	GK05-1-11	60.000	-
12	428	GK05-1-12	-	-

Table 5.2, below, describes the sediments extracted from the GK1 coring site, according to sediment type, texture and Munsell colour. It is evident that the core is predominantly sandy with organic sections confined to the surface (level 1 and 2) and basal layers (level 16 and 17). Much of the core is dominated by grey medium-grained sand, most likely the result of dune mobility. The yellow striations evident in level 10, may be evidence of aeolian sand deposition. The variation in sediment texture, and various features such as CaCl nodules (3) may also provide information on the nature of the regional and depositional environment, (Cornish-Bowden, 2005). Shell lenses, consisting of complete (9) to fragmented molluscan testae (5, 7, 11) occur through the core, have formed the basis for the palaeoecological study by (Kirsten, 2005), and together with a systematic sediment analysis (Cornish-Bowden, 2005) provide palaeo-environmental information for periods between organic deposition.

Table 5. 3: Description of GK1 lithology, including Munsell Notation

Level No.	Core Depth (cm)	Description of the Lithology	Munsell Notation
1	0- 35	Fibrous and peaty, dark-brown organic matter	5YR 1.7/1
2	35-45	Sandy sediments but with fine clay and silty organic inclusions	5YR3/1
3	45-62	Light brownish grey sediment containing Calcium Chloride nodules	10YR6/2
4	62-83.5	Yellowish-brown medium-grained sand	2.5YR6/1
5	83.5-88.5	Partially fragmented shell layer	2.5Y8/3
6	88.5-101.5	Medium-grain sand layer	2.5Y4/1
7	101.5- 105	Partially fragmented shell layer	2.5Y8/3
8	105-168	Sandy layer coarsening downwards	2.5Y5/1
9	168-173	Coarser grained sand matrix bearing intact testae	2.5Y8/3
10	173-217	Grey medium-grained sediments bearing clear yellowish-grey stratifications towards the bottom of the section	5Y5/1 2.5Y7/3
11	217-240.5	Greyish-brown sand, fining with depth, bearing fine shell fragments	2.5Y5/2
12	240.5-274.5	Grey fine-grained sand, with brown striations	5Y5/1
13	274.5-281.5	Fine dark-greyish brown clay	2.5Y3/2
14	281.5-289	Greyish brown fine-grained sand	2.5Y5/2
15	289-310	Dark olive-grey, coarse-grained sand sediments, bearing intact testae	5Y3/2
16	310-337	Very dark-grey sand interspersed with organic sections	5Y3/1
17	337- 412.5	Very dark medium-grained sand layer, interspersed with fine black organic silt	5Y4/1 7.5YR2/1

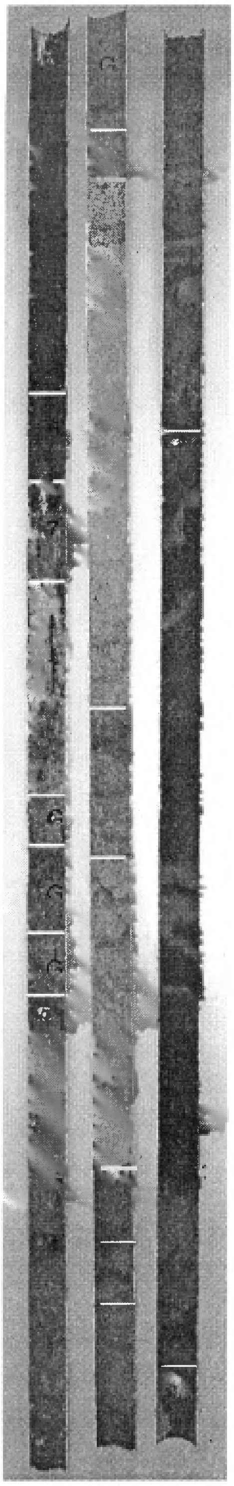


Figure 5. 1: A photograph of the core, with divisions corresponding to the lithological description in Table 5.3

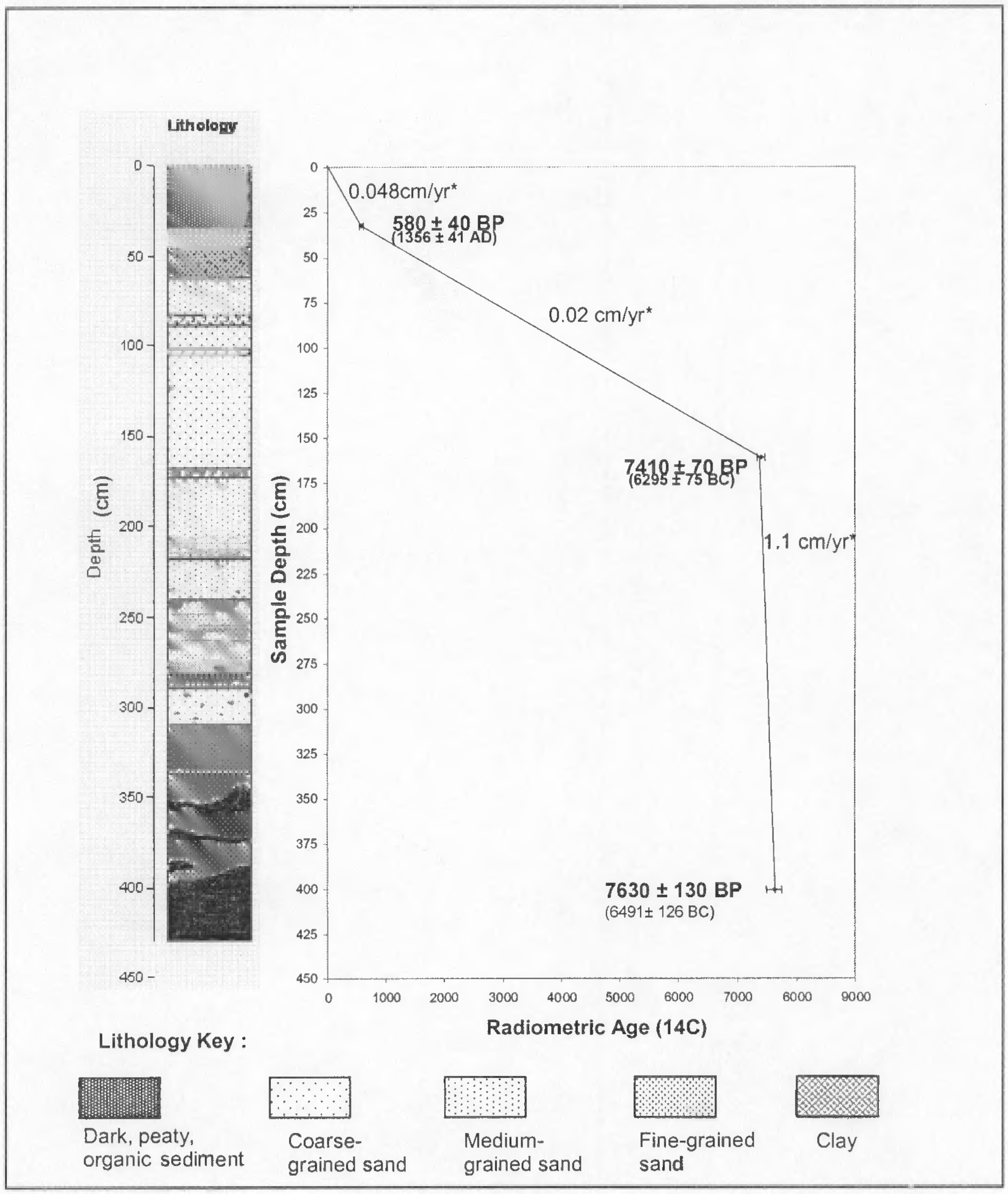


Figure 5.2: A diagrammatic representation of the GK1 core lithology and an age-depth curve based on Radiocarbon ages. Calibrated ages appear in brackets below the Radiocarbon age. Approximate sedimentation rate is indicated by (*)

To provide greater clarity on the relationship between the radiocarbon ages (presented in Table 5.1) and the extracted sediments from which the dates were obtained (photographed in Fig. 5.1 and described in Table 5.3), an age-depth graph has been placed parallel to a diagrammatic representation of GK1 sediment core (see Fig. 5.2 above). This illustrates the estimated sedimentation rate based on an assumed linear relationship between available ages (radiocarbon dates) and stratigraphic depth. For organic upper sections, it is estimated that sediments were laid down at a rate of 0.06 cm/yr. Thereafter, in the transition to coarse-grained sandy sediments, sediment accumulation appears to have assumed a slower rate of 0.02cm/yr. From 160 cm to the end of the core, a section encompassing a range of sediments (from coarse-grained sands (9) fining to medium-grained sands to clay (13), and then back to fine sands and silts), there is an ostensibly rapid increase in sedimentation rate to 1.1cm/yr.

It is apparent that this sand layer (42 -295cm) imposes an effective hiatus on the pollen sequences extracted from these sediments. Fig. 5.2 indicates that the sand layer (from 160cm to depth) accumulated very rapidly, and that this section of the presumed discontinuity may be overrepresented owing to the practice of presenting pollen sequences by depth. The potentially more significant discontinuity is presented by the section 36 cm- 158cm where there is an appearance of very slow accumulation of material of a highly sandy nature and very little in the way of organics, over a substantial period. Given the coastal position of the vlei, and the rapidity of accumulation of sandy sediments, similar to those in the section 160 cm to depth, it may be more likely that deflation or erosion of sections of these sediments may have occurred at this point, giving the impression of a more gradual accumulation rate. It is probable that the sedimentation rate is more complicated than the available range of ages may allow, and further dating (particularly in the section from 42-158cm) may clarify the nature of the sedimentation during this period. It may have been that this sand layer was laid down in a single deposition episode, and erosional forces may have removed sediments leading to the appearance of more gradual accumulation in upper sandy sections, a potentially significant environmental indicator, but impossible to resolve without further analysis.

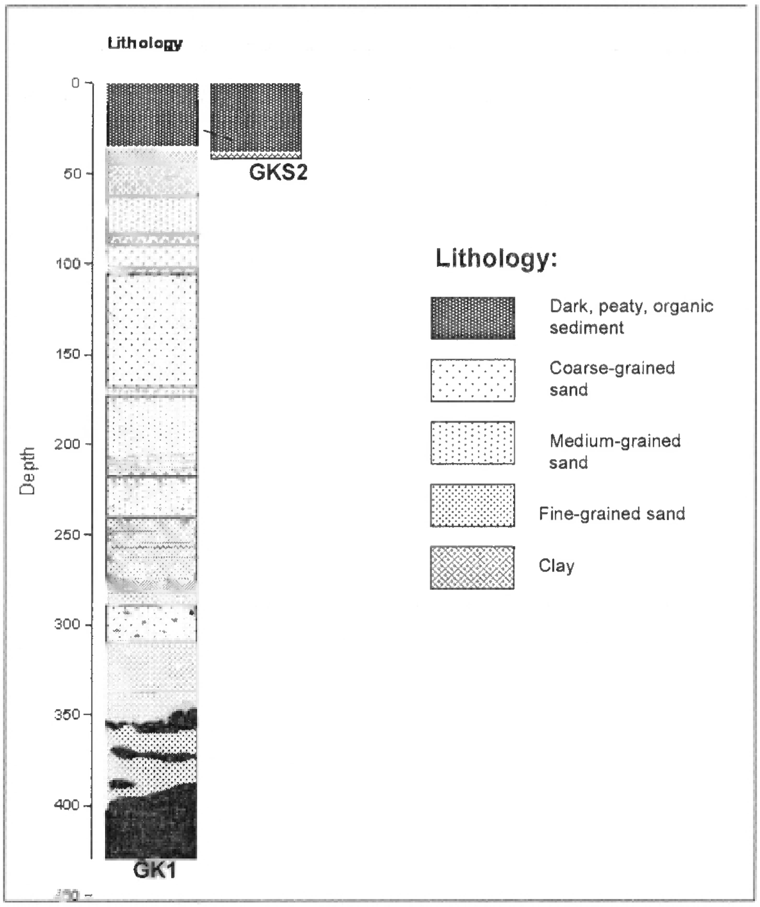


Figure 5.3: A Comparative diagram based on stratigraphical association of lithologies of GK1 and GKS 2

Figure 5.3 above, presents a diagrammatic comparison of the short core GKS 2 with GK1. As indicated in Fig. 5.3, the short core consists of an upper section (0-39cm) of peaty organic material, followed by a 3 cm section of the fine sandy sediments with clay and organic inclusions found in GK1(see Table 5.3, level 2). This diagram indicates that the stratigraphy of GK1 and GKS 2 are marginally out of alignment, and that 5cm difference is not regarded as significant displacement considering that the range of each sampling point is 3cm at 5 cm intervals. The spatial proximity of the two cores, their similarity in sediment type and the very near alignment of strata between GKS2 and GK1, therefore allows for the integration of the two pollen and charcoal sequences.

5.3 Pollen and Charcoal Analysis

5.3.1 Pollen Assemblage Zones

The established method of presenting pollen analysis data is in stratigraphical diagrams. As it is often necessary to present data for all taxa, as their presence or the fluctuations of individual taxa may have a particular environmental significance, these pollen diagrams may be frequently complex or conceptually bewildering (Birks and Gordon, 1985). For this reason, pollen zones are defined, splitting the sequences into smaller units, facilitating description of variation within and between zones, and observing the differences that may occur between diagram forms (i.e. between relative and absolute frequency graphs) owing to the type of representation used.

Figure 5.4 below presents the result of a numerical zonation. A single linkage cluster analysis algorithm was applied by the Constrained Incremental Sum of Squares (CONISS) programme in TGView 2.02 (Grimm, 2004). This programme assigns data to clusters, with data cases within a cluster bearing a greater similarity to each other than to other clusters, but constraining these groups to stratigraphically adjacent levels. These clusters are then plotted in the form of a dendrogram, or hierarchical tree, which is based on the fact that as you move up the hierarchy, data is less and less similar. In order to produce this dendogram, data from both absolute and relative frequency counts were used, producing identical results (see Fig. 5.4). In the relative frequency case, however, 'Wetland/Local' data was excluded, as it is suggested that the potentially greater representation of local taxa in relation to regional taxa, may affect the cluster process (Birks and Gordon, 1985; Grimm 1987). Although the numerical methods preserve the objectivity of the clustering process, the actual designation of zones is left to analyst discretion.

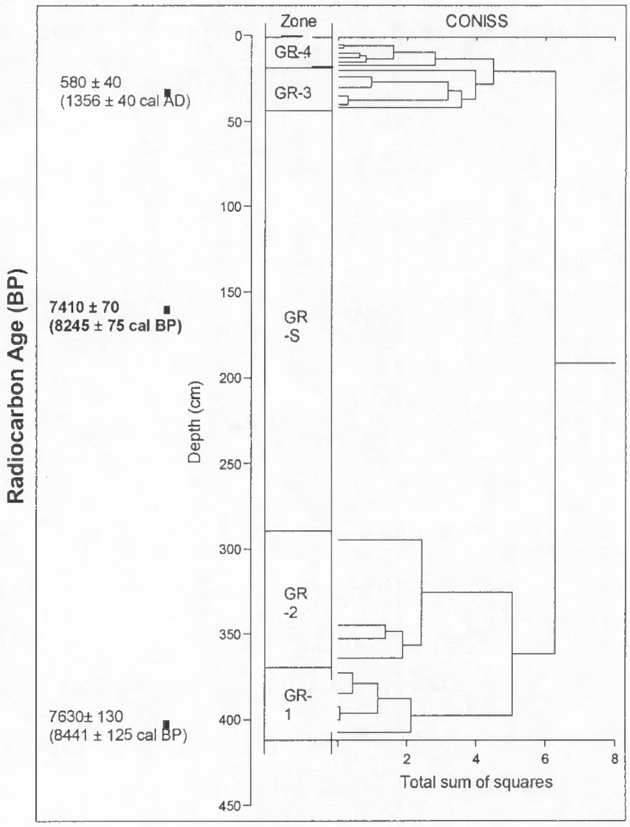


Figure 5.4: A CONISS dendrogram used for delineating pollen zones, calibrated age shown in brackets

As is evident in the distance of the second order splits, the dendrogram is divided into two main clusters, separated by the sand section from 42-295cm (designated as GR-S). Major zones boundaries were drawn according to 3rd order splits. These zone boundaries were provided with calibrated ages, interpolated from the age-depth graph in Fig. 5.2. It is important to recognise that these ages are therefore estimates, provided as an aid to description.

5.3.2 Pollen Diagrams

62 pollen taxa were identified during analysis, with obscured or damaged pollen excluded from the count. Full slide counts were undertaken (with a minimum count number of 120 exotic *Lycopodium* markers) with the lowest pollen count (70 grains) reached at 42cm, a possible consequence of increasing sandiness of the sediment medium at that depth (see Figure 5.5 below)

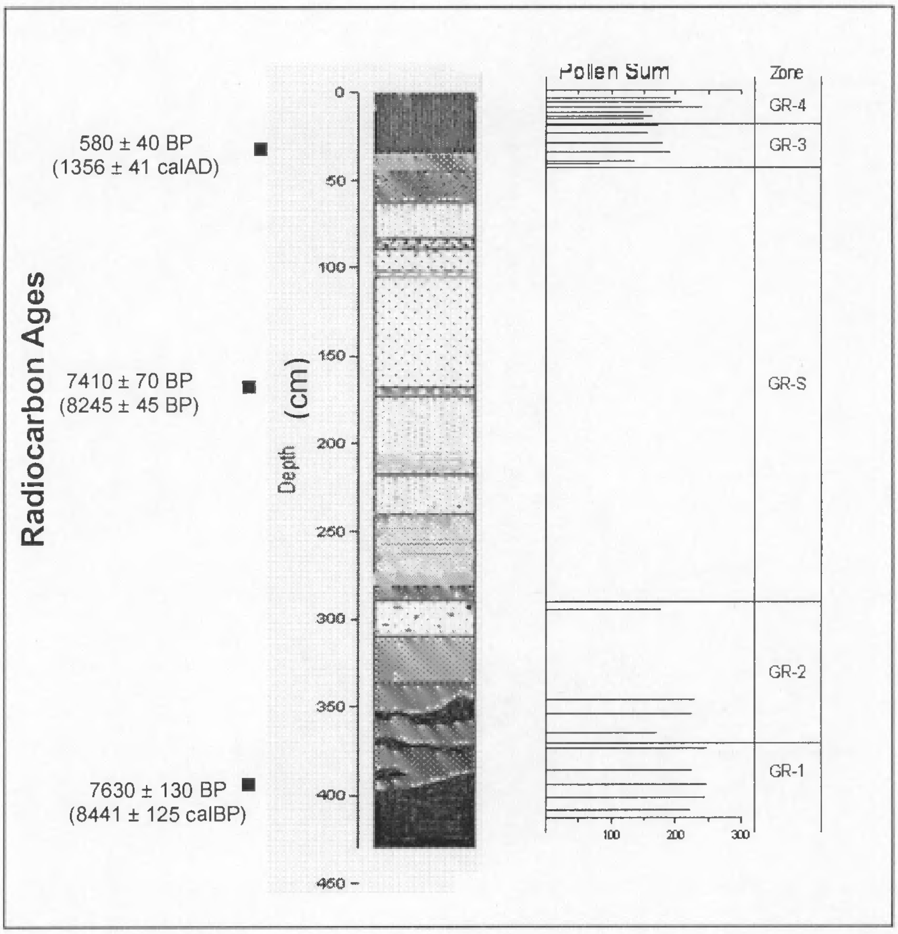


Figure 5.5: The Pollen Sum in relation to depth and lithology

Pollen diagrams were produced using the programme TGView 2.02 (Grimm, 2004). Two forms are depicted here, namely absolute frequency and relative frequency representations. Both methods have a number of benefits and draw-backs (described in Chapter 4) and it is reasoned that by producing the data in both formats, a clearer course of trends may be established.

Figure 5.6 and Figure 5.7 illustrate the results of grouping the taxa according to modern botanical and ecological knowledge (see Appendix A), with Figure 5.6 presenting this in absolute frequency form and Figure 5.7 in relative frequency form. Owing to the space constraints of including the data for all taxa in absolute frequency count form, the individual behaviour of each identified pollen type is presented in Figure 5.8 (in relative frequency form), while Fig. 5.9 presents (in absolute frequency form) a number of individual taxa identified in Chapter 4 (Table 4.1) as likely ecological indicators. This means that important individual fluctuations can be assessed in both absolute and relative form as well. Full count lists are available in Appendix D. The fluctuation of pollen sequences depicted in these graphs will be described zone by zone in section 5.3.3.

Table 5.4: Results of the Charcoal Analysis (Clark's Point-Count Method [1982])

Depth (cm)	Estimated Area on Slide (95% Confidence)	Estimated Area of Charcoal (cm2/cm3
5	0.75 ± 0.1	139.37
7	1.83 ± 0.28	295.7
10	1.69 ± 0.26	247.29
12.5	1.63 ± 0.3	270.4
15	1.18 ± 0.2	174.03
17	2.39 ± 0.3	212.5
20	0.37 ± 0.07	30
24	0.35 ± 0.06	64.396
30	0.06 ± 0.014	8.85
35	0.95 ± 0.11	87
40	0.3816 ± 0.07	24.2
42	0.023 ± 0.008	4.03
295	0.109± 0.024	9.8
345	0.25± 0.06	35.2
353	0.46 ± 0.07	43.61
364	0.46 ± 0.05	80.64
373	0.69 ± 0.1	74.98
385	0.35 ± 0.06	67.75
393	0.52 ± 0.06	38.65
400.5	0.58 ± 0.08	50.84
408	0.44 ± 0.06	59.25

Table 5.4 above presents the results of the charcoal counts, the most prominent feature being the substantial increase in charcoal towards the surface. These results are depicted in the pollen diagrams alongside the pollen sequences in an effort to facilitate description of changes. These fluctuations will also be considered zone by zone in section 5.3.3.

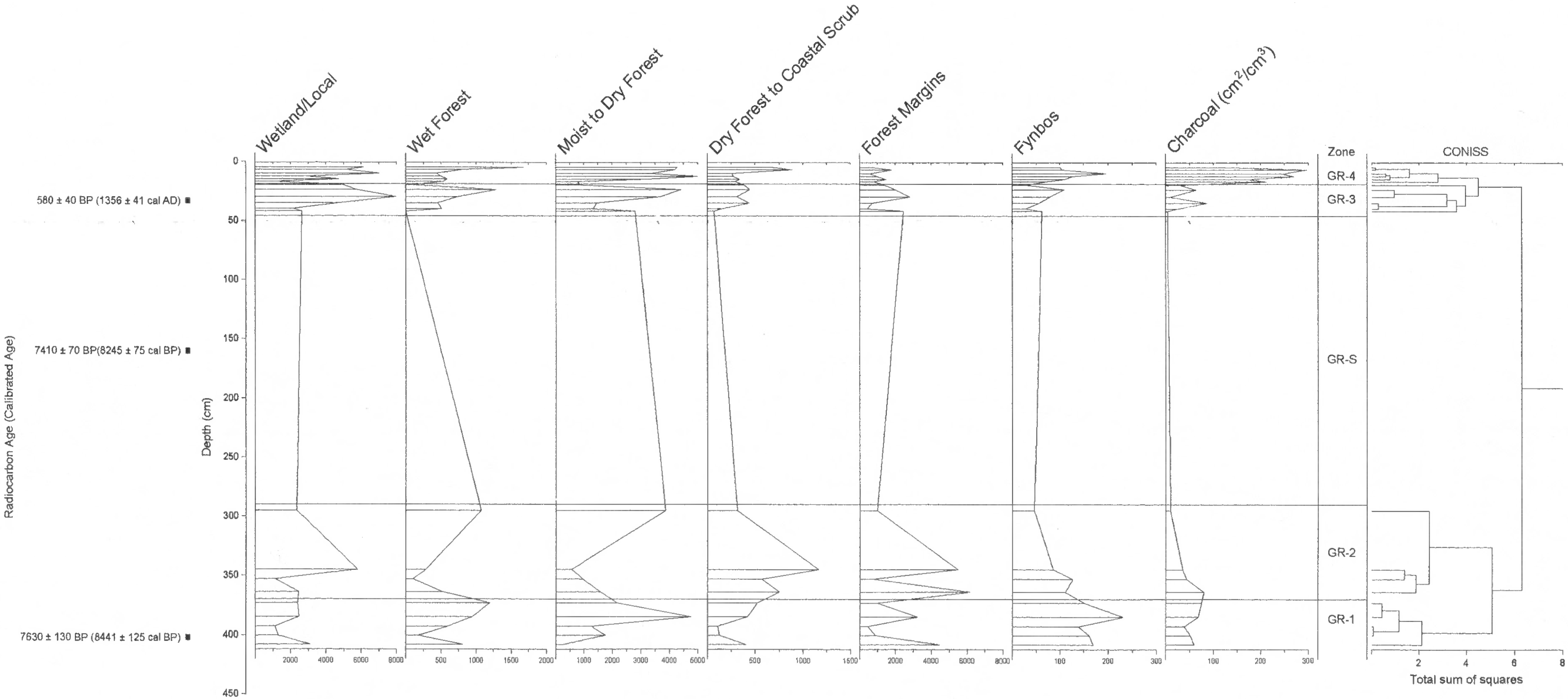


Figure 5.6 An absolute frequency diagram illustrating the results for ecological groups and the charcoal record.

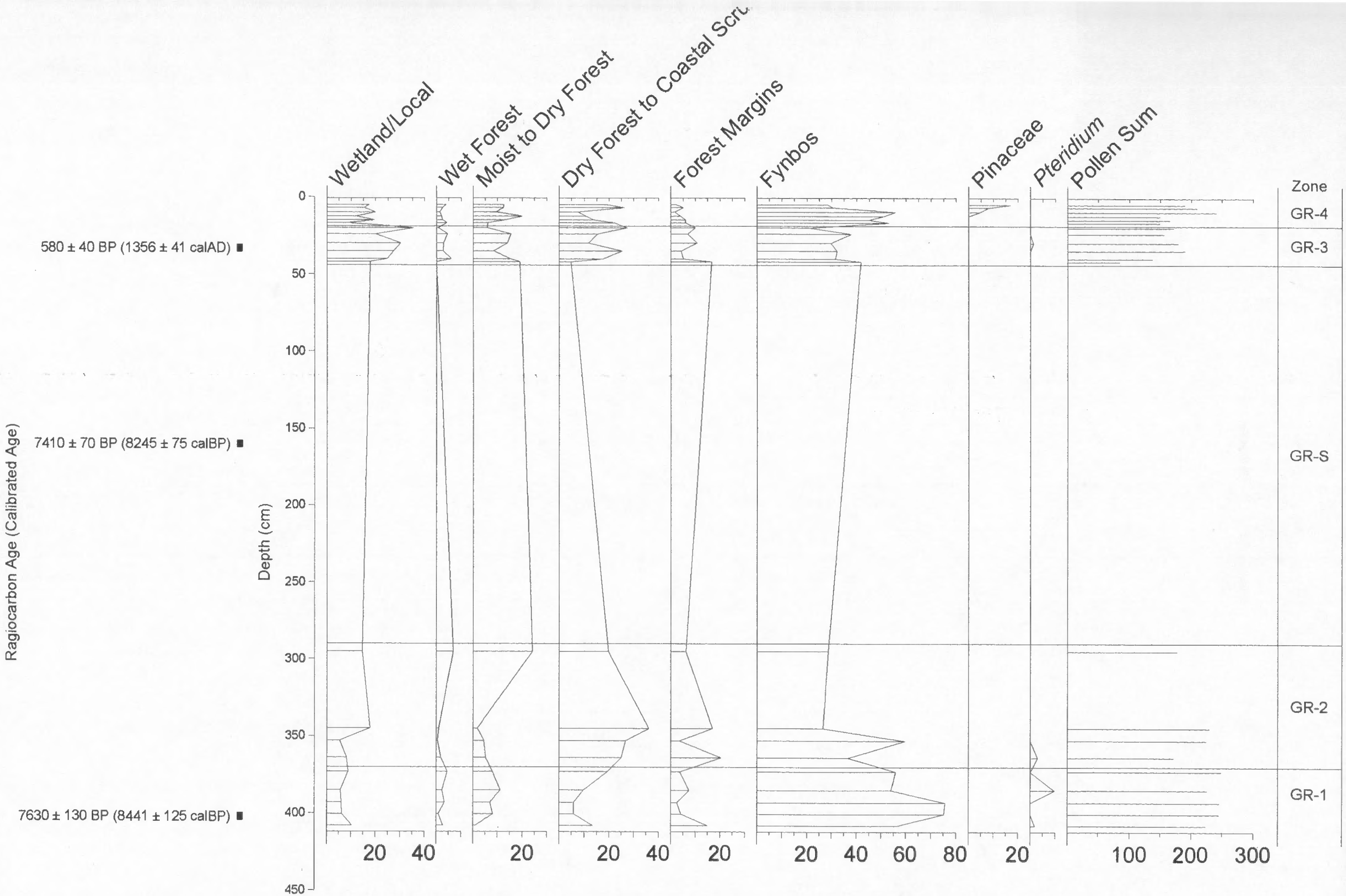


Figure 5.7 A relative frequency diagram, indicating the percentage contributions of ecological groups to the pollen sum, as well as the charcoal record.

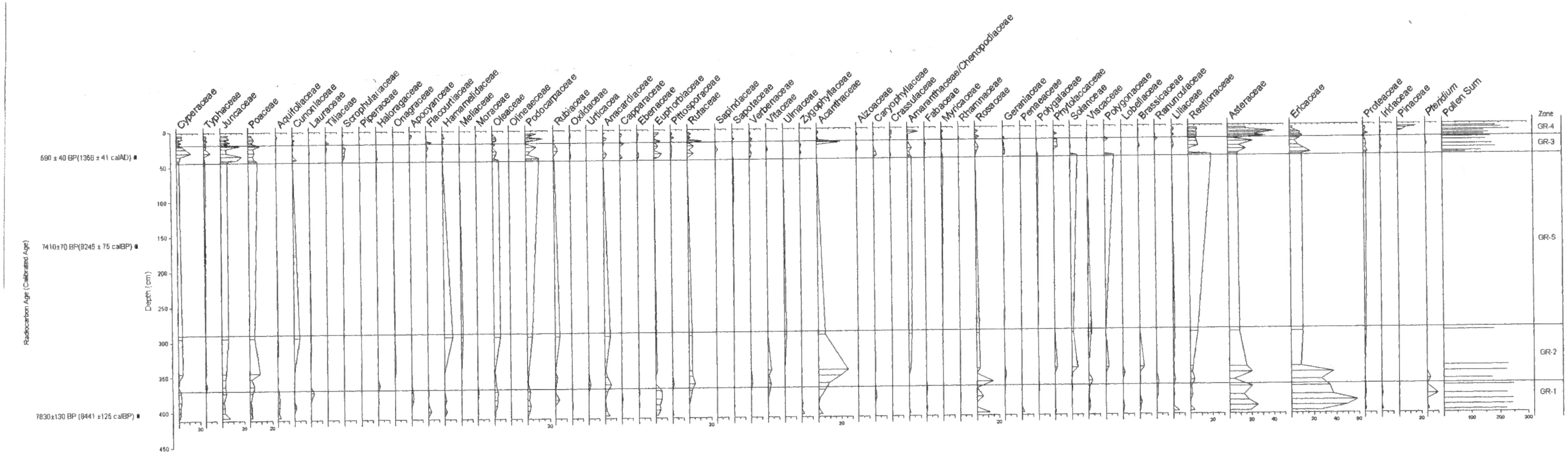


Figure 5.8 A relative frequency diagram indicating the individual contribution of identified pollen taxa to the pollen sum.

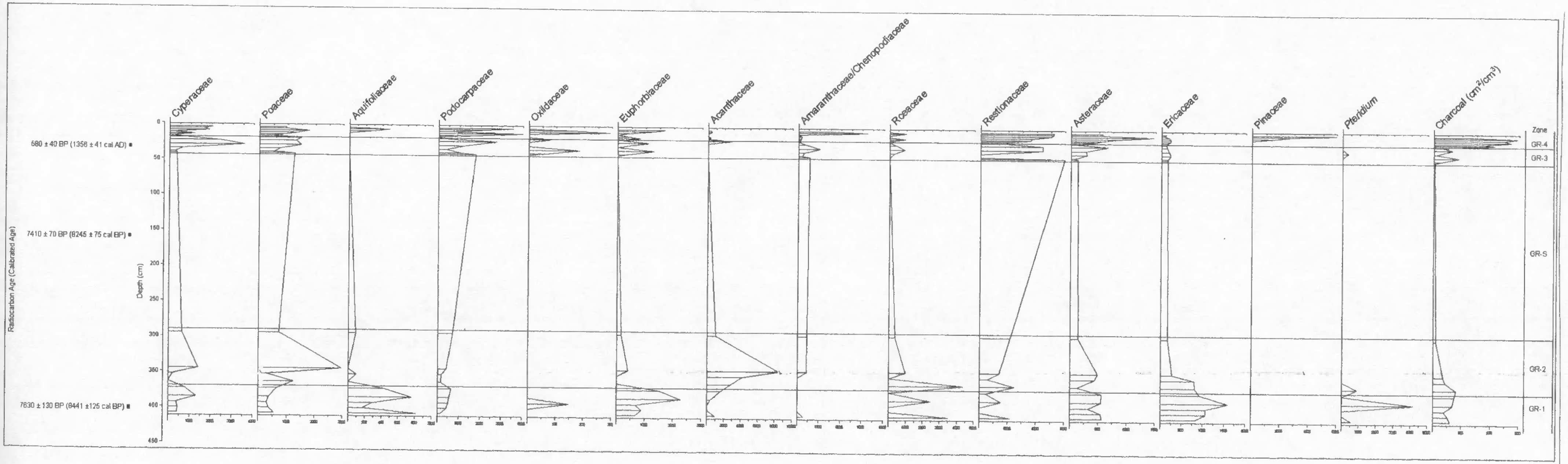


Figure 5.9 An absolute frequency pollen diagram of identified ecological indicators (see Table 4.1), including the charcoal record.

5.3.3 Description of Pollen Zones

a. Zone GR-1 (ca. 8500- 8400cal. BP)

Both the absolute and relative frequency graphs (Fig 5.6 and 5.7) of ecological groupings indicate the clear dominance of fynbos in this zone, largely backed by high Ericaceae pollen (peaking at 80%) and to a lesser degree Asteraceae (around 20%) evident in Fig. 5.8, frequencies that are not reached again in the sequence.

The absolute frequency habitat grouping (Figure 5.6) illustrates a coincident reduction in pollen frequency for all habitat groups (around 390cm), as well as charcoal, lead by an initial decline in Wet Forest indicators. This decline is not as marked in the relative frequency graph (Fig. 5.7). While fynbos spectra decrease in Fig. 5.6, they appear to increase towards a sequence maximum in Fig. 5.7. This is most likely an artefact of its representation as percentage data, as although this shows an increase, it is merely an increase relative to the other groups, illustrating the importance of both types of data interpretation.

Forest Margin representation shows high amplitude of fluctuation that appears to be in a reciprocal relationship with Fynbos in the relative frequency graph Fig. 5.7. After a number of peaks and troughs, evident in both Fig. 5.6 and Fig. 5.7, forest margin indicators begin to peak towards the end of the zone, as Fynbos pollen begins its decline. This signal is due predominantly to the fluctuation of Rosaceae (Fig. 5.8).

In the beginning of the zone, Dry Forest to Coastal Scrub pollen matches Forest Margins spectra in accounting for 15% of the total pollen (Fig. 5.7). After the concurrent decline, the Dry Forest to Coastal Scrub component begins a steady increase through the zone to 25% at its end (Fig. 5.7). Fig. 5.8 indicates that while Acanthaceae peaks are registered towards the end of the zone, for the most part the Dry Forest to Coastal Scrub signal is dominated by a steady Euphorbiaceae contribution, with Anacardiaceae reappearing and Rutaceae entering the assemblage towards the end of the zone.

The relative frequency digram (Fig 5.7) indicates that Moist to Dry Forest does not increase above 15% in this zone. After the decline around 390cm, the absolute frequency digram (Figure 5.6) registers a substantial peak in Moist to Dry Forest groups, a peak that is suppressed in the relative frequency curve of Fig. 5.7. Subsequently, this habitat component begins its decline towards the end of the zone. Fig. 5.8 registers a steady contribution of Oleaceae that begins its decline at the end of the zone. Flacourtiaceae, evident at the beginning of the zone, does not reappear. Rubiaceae and Apocynaceae appear near the end of the zone (post-decline), while Podocarpus pollen appears to mimic the group's signal.

As with the Moist to Dry Forest signal in Fig. 5.7, the apparent peak of Wet Forest pollen registered in 5.6 (second highest frequency reached in the entire sequence) is suppressed in Fig. 5.7, indicating that group accounts for no more that 5% of the pollen in this zone. As shown previously, the Wet Forest group declines ahead of the rest of the groups, potentially indicating an environmental fluctuation in relation to moisture. Wet Forest, like Moist to Dry forest, declines towards the end of the zone. Fig. 5.8 indicates that Aquifoliaceae is the dominant contributor in this zone, declining at 390cm but resuming its signal thereafter. Cunoniaceae appears post decline, while Lauraceae, rare in the rest of the sequence, is found at the end of the zone.

Wetland pollen frequencies are low in comparison with the rest of the sequence, and also register the decline concurrently with the Wet Forest group. The majority of the signal is composed of Cyperaceae, with low contribution of Poaceae and Typhaceae (see Fig. 5.8) Thereafter, there is an increase that remains stable towards the end of the period.

The charcoal signal, shows a similar decline at the point where the other curves indicate low frequencies. Thereafter, the signal increases towards the end of the zone

b. Zone GR-2 (ca. 8400 to 8300 cal. BP)

The ecological groups in both relative (Fig. 5.6) and absolute (Fig. 5.7) representation indicate that the zone begins with Wet forest and Moist to Dry Forest declining, after their peaks towards the end of GR-1. Fig. 5.8, indicates the very low counts for both Wet Forest, and Moist to Dry Forest pollen in this zone. A reduction in the pollen abundance is registered in Wetland Local, Wet Forest and Forest Margin pollen spectra, with a lesser decline evident in the Dry Forest to Coastal Scrub group at around 350cm. At this point, however, Fynbos registers a minor peak. While Fynbos, Forest Margins, Dry-forest to

Coastal Scrub and Wetland/local all decline towards the end of the zone, Wet Forest and Moist-Dry Forest increase.

The relative frequency group diagram (Fig 5.7) again indicates that Fynbos pollen is the major contributor, although reduced relative to Zone GR-1. Figure 5.8 shows that this is related to lower Ericaceae pollen counts in particular. Asteraceae pollen registers a trough corresponding with the charcoal peak. Restionaceae pollen peaks at the beginning of the zone, although it is reduced around 350cm, thereafter regaining it signal towards the end of the zone.

After Fynbos, the second highest percentages are registered by Dry Forest to Coastal Scrub components, a signal largely accounted for by the significant peak in Acanthaceae pollen (Fig. 5.8, 5.9). The backbone of this group's signal is provided by Anacardiaceae, Rutaceae, and to a lesser degree Vitaceae, beginning towards end of last zone, but tapers off towards end of Zone GR-2 (Fig. 5.8). Euphorbiaceae pollen, high in Zone GR-1, is diminished. There is also a minor presence of Pittorporaceae and Verbenaceae before the decline, which is not regained, with a presence of Ulmaceae towards the end.

The Moist to Dry Forest signal shows that although present, Oleaceae, Podocarpaceae and Rubiaceae are reduced relative to GR-1, although they do increase towards the end of the zone (see Figs 5.8, 5.9).

The steady presence of Aquifoliaceace, from GR-1 in the Wet Forest group is reduced in GR-2. Haloragaceae appears at the cusp of GR-2, with a very minor presence of Onagraceae, and Cunoniaceae towards the end.

Wetland/Local signal shows a shift in dominance from Cyperaceae to Poaceae as indicated by Fig. 5.8, 5.9.

The charcoal signal declines after a minor peak at the beginning of the zone (a peak concurrent with a decline in fynbos). Thereafter, the signal decreases to its lowest levels registered in the sequence.

c. Zone GR-3 (ca. 790 to ca 1620 cal AD)

The pollen record resumes, after the interruption created by deposition of sand, registering relatively low pollen concentrations across the board. Early low frequencies are registered in Fynbos, Forest Margins, Moist to Dry Forest, and to a lesser extent in Wet Forest and Wetland/Local, with a minimum in Dry Forest to Coastal Scrub components at the commencement of the zone. Following this decline, Fig. 5.6 registers peaks in Moist to Dry Forest and Wetland/Local components, with a concurrent peak in Wet Forest, all of which fall off rapidly towards the end of the zone. This decline towards the end of the zone, is also registered in Fynbos and Forest Margins (in Fig. 5.6 and 5.7), with Dry Forest to Coastal Scrub showing only a relatively minor decrease at this point, but a decline later on.

The Fynbos group's signal is composed of a stable Restionaceae count, with presence of Asteraceae low at the beginning of the zone, but increasing inconsistently toward the end of the zone, where there is a rapid fall off that corresponds with the declines in other groups. Ericaceae pollen declines prior to this. Proteaceae, for the first time in the pollen sequence, shows a fairly steady presence (Fig 5.8).

The Forest Margin signal in this zone is largely dominated by Rosaceae as well as the presence of Geraniaceae, Phytolaccaceae. Low levels of Myricaceae and Fabaceae are apparent in this zone, while elements such as Polygonaceae and Ranunculaceae appear towards the close of the zone (Fig 5.8).

The signal in Dry Forest to Coastal Scrub is dominated by Euphorbiaceae and Rutatceae (see Fig. 5.8). Anacardiaceae, Capparaceae and Ebenaceae are present at the beginning of the zone, with the first two reappearing in the peak just before the close of the zone. Acanthaceae peaks substantially before the close of the period and appears to be the major source of the signal peak at this point (Fig. 5.9, 5.8). Zygophyllaceae and Sapindaceae, both absent throughout the rest of the sequence, are present here.

Oleaceceae, Podocarpaceae and Rubiaceae are the most substantial contributors to the Moist-Dry Forest group (see Fig. 5.8). Fig. 5.8 indicates that the decline seen just after the start of the period is a response to declines in Podocarpaceae and Oleaceae (Fig 5.8, 5.9). At the point of this decline, Oxalidaceae indicates a presence (Fig 5.9). Podocapaceae maxima are registered in this zone, just after the start of the period (Fig. 5.9). These frequencies are almost regained after the early trough, when the rapid decline occurs near the end of the zone (Fig. 5.9). This decline is echoed in the signal for Olea, Rubiaceae and Flacourtiaceae (Fig 5.8).

For the Wet Forest component, Fig. 5.8 indicates the presence of Cunoniaceae at the beginning of the zone, with a relatively high presence of Scrophulariaceae. The end of the zone indicates an introduction of Tiliaceae pollen.

In this zone, charcoal regains its counts after the low in GR-2. The zone illustrates best the potential inverse relationship between Fynbos and Forest Margins, and charcoal. The low levels of Fynbos and Forest Margin vegetation near the beginning of the zone, correspond with a peak in charcoal, with the opposite occurring further up the zone.

d. **Zone GR-4 (ca. 1620 cal AD to present)**

The uppermost zone begins with the low pollen frequencies of the decline around the cusp of GR-2 and GR-3, especially registered in Wetland/Local, Wet Forest and Moist to Dry Forest, with Dry Forest to Coastal Scrub registering only a minor decrease.

Fynbos recovers higher frequencies, lost in zone GR-3, however Fig. 5.8 and 5.9 indicates a shift to dominance from Ericaceae to Asteraceae. Restionacaee remain stable while the Proteaceae signal registers the decline, visible in the group's signal. This increase in dominance again of fynbos occurs concurrently with a significant increase in charcoal, reaching levels unprecedented in the rest of the sequence.

The reciprocal relationship between Forest Margins and Fynbos is maintained in this zone (evident in Fig. 5.7), although pushed in favour of fynbos, with Forest Margin frequencies reaching their lowest for the entire sequence. Fig. 5.8 indicates that the signal is dominated again by Rosaceae, with Myricaceae showing larger representation here. Rhamnaceae and Polgonaceae are present at the beginning of the zone, but do not reappear following the decline.

Dry Forest to Coastal Scrub, while not registering the decline at the beginning of the zone, appears to follow a jagged stepwise decline (in Fig. 5.6) to a zonal low at around 10cm, thereafter registering an increase towards the surface. This zone is again dominated by Euphorbiaceae, Rutaceae and Anacardiaceae. The potentially anomalous peak in Acanthaceae occurring at the end of GR-3, flattens out, although still maintaining a presence throughout GR-4. Sapotaceae, absent in the rest of the sequence, appears at the beginning of this zone. Amaranthaceae/Chenopodiaceae levels, spike towards the surface.

After the early trough in Moist to Dry forest, the group recovers its pre-trough levels, reaching a sequence maximum at this point. Subsequent to this (around 10cm) another decline is evident in the pollen sequence, particularly so in the Podocarpaceae pollen sequence (see Fig. 5.8, 5.9). Rubiaceae plays a less prominent role in this zone, while Podocarpaceae and Oleaceae maintain a presence, with Olea falling off towards the surface. Hamamelidaceae shows a greater presence, while Flacourticeae, present at the beginning of the zone, does not reappear. Apocynaceae, absent since zone GR-1, reappears towards the surface.

Wet Forest, does not appear to regain its pre-trough values evident in GR-2. A further decline (around 10cm) is also evident, although not to the same degree as at the cusp of GR-2/GR-3. This pattern is most likely created by an absence in both Tilia and Cunonia at this level (Fig. 5.8). Aquifoliaceae, absent since GR-1/2 reappears. This group, thereafter, increases to its sequence maxima at the surface.

The exotic tree *Pinus* is registered (from 10cm) in this zone, increasing towards surface, its significance registered (by the relative graph form) in that as a single genus, it accounts for 20% of the surface pollen (Fig 5.7). Furthermore, as the date of its introduction is known from historical records, this group provides a chronological label, aiding interpretation.

5.3.4 General

Despite the interruption created by sand, the pollen sequence provides a number of interesting fluctuations. Most prominent is the greater dominance of Fynbos in pollen assemblages of the lower core sections, relative to upper sections representative of more recent periods, while charcoal levels reach unprecedented levels in this recent zone. Four significant declines are registered in almost all groups, in zone GR-1 (390cm) a decline is evident in Fig 5.6, although not as clear in Fig 5.7; in zone GR-2 (350cm), the beginning of zone GR-3 (40cm) and at the beginning of zone GR-4 (10cm). These zones are provided with interpolated ages that have been calibrated according to CalPal (Weniger *et al.*, 2006) to provide a guide for interpreting the likely environmental influences and correlating them to documented events.

The basic standardization process that occurs when changing raw data into percentage or relative form means that the sequence curves are smoothed. This is clear when comparing the absolute form in Fig. 5.6 with the relative form in Fig. 5.7. While the same signal may be registered in both graphs, the effect appears exaggerated in 5.6 in relation to 5.7.

The effects of presenting the data in relative form can be further noted in zone GR-1, in the discrepancy between the representation of Fynbos between Fig. 5.6 and 5.7. While Fig. 5.6 registers a correspondent depression in the charcoal and fynbos graphs at around 390cm, Fig. 5.7 indicates that at this point fynbos is increasing towards its predominance. This apparent shifting of peaks occurs again where Fig. 5.7 registers an apparent decrease around 385cm, which does not register in 5.6, instead there is a steady decline towards the end of the zone. The absolute frequency graphs, however, can also be misleading. As each taxon or group is presented individually, there is no standard scale, limiting comparison between groups to the concurrence of their peaks or troughs. It is only by analysis of both graphing types that the actual signal may be accounted for, showing the potentially misleading nature of the visual representation.

5.4 Conclusions

The sediments extracted from the study site at Groenvlei are dated (by radiocarbon methods) and described. The spatial proximity, lithological and stratigraphical closeness of GK1 and GKS2 allow for the integration of sequences extracted from these cores. After zonation of pollen diagrams by cluster analysis, the fluctuations occurring within and between groups are detailed. It is evident that a number of environmental fluctuations have occurred during the time periods analysed, and that through comparison of different graphical representations, the signal of change is enhanced.

Chapter 6:
DISCUSSION

6.1 Introduction

So as to account for the project results, detailed in the previous chapter, and to address these in terms of the research objectives, the initial focus of this discussion is in interpreting and advancing explanations for the patterns visible in the pollen record, thus attending to the broad, primary objective of understanding the long-term nature of change of the vegetation communities of the Kynsna region. However, in order to produce a comprehensive and holistic interpretation of the region's environmental history, the secondary objectives, highlighted at the outset of the project, namely: (1) the scale of human influence on the environment in terms of long-term change and (2) the role and prominence of fire in the region's environmental history, would evidently lend varyingly significant supportive roles to the principal aim, and will therefore be discussed generally within the body of the interpretation, but will be addressed individually towards the end of the discussion.

While the accuracy of a palaeo-record is based on a meticulous collection, treatment and presentation of data, the accuracy of interpretation requires a substantial dependence on contextual support, justifying the importance of a comprehensive, but thorough, literature review. Part of this contextual support is provided in Chapter 2, which details the modern environmental and ecological processes that operate to produce the distribution and heterogeneity of vegetation communities across the landscape. This modern environment stands as an analogue community, using biological and ecological knowledge to inform studies of the past, through Uniformitarian principles. The second form of contextual evidence that allows for interpretation to be resolved, is insight gained from previous studies of fluctuations in climates both locally and regionally (presented in Chapter 3), and their likely influence on terrestrial communities.

The interpretation below, therefore, drawing on both modern understanding and the general palaeo-settings assumed from other records, is based on both absolute and relative frequency pollen diagrams produced in Chapter 5. In comparing the two types of data presentation, it is apparent that some peaks and troughs in the pollen sequence appear not to coincide or are out of phase with one another. This is likely to be an artefact of their representation- the effect of signal exaggeration in absolute form (as the data is not standardized) and compensating fluctuations owing the interdependence of data, in relative forms. For this reason only the concurrent peaks and troughs in both diagrams (relative and absolute) are described and interpreted below.

6.2 Chronology

Reliability of dating is one of the most significant aspects of palaeoecological interpretation, in that it allows for the record to be placed in a temporal context that is essential for interpretative processes. However, it is an aspect of the methodology that is generally out of the researcher's control. In order to provide a system of checks and balances, the sediments were sent for both radiocarbon and luminescence dating. Unfortunately, the final results of the luminescence dating were not yet available at the time of writing, requiring interpretation to be based entirely around the radiocarbon dates. A number of limitations surrounding these dates may cause an initial wariness as to their reliability. Most significantly an age-model reliant on only three dates, may not produce as accurate a temporal framework as would be hoped for. Furthermore, these dates were calibrated according to terrestrial ^{14}C curves, however, the coastal nature of Groenvlei and the possibility of oceanic incursions in the past, may have meant that there was some deviation from a true terrestrial ^{14}C record (Pers. Comm S. Woodborne, 2006). However, both of the older dates [7410 ± 70 BP and 7630 ± 130 BP] have low standard deviations, suggesting that the number of excursions from the mean during the highly accurate counting procedures were relatively few, therefore upping statistical confidence in these ages. In terms of the reliability of the upper date (580 ± 40 BP), it is effectively supported by its the stratigraphical relationship (evident in the age model in Fig 5.2), to the presence of a historical marker in the form of *Pinus* pollen (that can be accurately dated to its introduction at the beginning of the 20th century). Therefore, while it is important to interrogate the reliability of the radiocarbon dates, it is likely that these dates reflect the true age of the sediments.

6.3 Interpretation of the Pollen Record

6.3.1 Introduction:

Despite the palaeoecological record being incomplete, in that that a substantial sand lens partitions the pollen sequence into two discrete units, the dating of the record reveals that these units provide important community 'snapshots' of ambiguous time periods during the region's Holocene record.

The early section of the pollen sequence has been dated to around 8500 cal BP (7500 radiocarbon BP), fitting into the period designated as the Altithermal (8-6 ka BP) While temperature increases for the period appear to be spatially similar across southern Africa, rainfall patterns as well as definite timings of the event appear to be more complicated, (Partridge *et al.*, 1999; Cohen and Tyson, 1995). In the Knysna region in particular, prior to 7ka BP Martin (1968) considered conditions to be drier than today, however at 7 ka BP, he emphasized the complexity of the record, indicating that conditions may either have been affected by the local impacts of mobilized sand dunes, or that conditions were more mesic. As he notes: "*The formulation of the pollen diagrams...based on one site, and without antecedents in the same geographical area, is, of necessity, tentative and subject to later revision.*" (Martin, 1968, p. 113). This thereby advocates the importance of further study, with this section of the pollen sequence, at the very least, providing an interesting form of comparison with previous studies, but potentially obtaining a clearer understanding of an uncertain period.

The upper part of the pollen sequence covering the last 800 years, is another period of debate in Holocene earth history, spanning the Medieval Warm Period and the Little Ice Age, periods of contention among palaeo-researchers. While early designation of these events, was met with doubt (Tyson *et al.*, 2000), their occurrence and coincidence, particularly for the LIA has been increasingly reported in southern Africa by high resolution means (e.g. Holmgren *et al.*, 1999), thereby shifting the event away from the controversial towards a more general acceptance of both the regional significance and the global teleconnection of such events (Tyson *et al.*, 2000). Whether expression of this event is visible on the south coast boosts further interest in this section of the pollen sequence.

The latter part of the sequence is of further value in that it spans the period of increasing culturalization of the landscape. The lack of a clear understanding of the scale of impact created by human influence has resulted in a number of differing conclusions among the forest 'literati' as to the nature of anthropogenic-related environmental change. While historical records are instructive *because* of their subjectivity, by providing insight into the social conditions and the perception of the environment at the time they were written, an objective and well dated record would therefore be of great importance in resolving the magnitude of impacts (if at all visible) and viewing them against the background of longer term climatic fluctuations.

Interpretation is made from basal sequences forward in time. The observed patterns are accounted for by means of reference to acknowledged environmental processes, as well as peer-reviewed articles.

6.3.2 ca. 8500- 8300 cal. BP

The general pattern visible in early sections of the pollen sequence is an overall decline of Fynbos (from sequence maxima at the start) and an increase in Dry-forest to Coastal Scrub over the period while both Wet and Moist-Dry forest indicate relatively high frequencies (in GR-1) followed by a decline in GR-2 towards 350cm, just as Dry forest to Coastal Scrub is reaching its zenith. The presence of elements such as the Wet forest tree taxa, Aquifoliaceae, Cunoniaceae and Lauraceae, as well as the fern Pteridophyta, all reaching frequencies not seen again in the sequence, indicate that conditions during this early period (GR-1) must have been sufficiently moist to support such hygrophytic elements. The peaks for Moist to Dry forest, and the steady presence of Cyperaceae (taken to be indicative of locally moist conditions) during GR- 1 and its decline in GR- 2 also support this idea, while the lower levels of Dry forest and Coastal Scrub may be due to wetter conditions. The steady increase of Dry-Coastal Scrub through to GR- 2, consisting of hardy taxa capable of growing in more adverse conditions (Acanthaceae), with the decline in Fynbos, and Cyperaceae, and substantial decline in Moist and Wet forest types suggest a fairly significant environmental agent, potentially associated with the climatic warming of the Altithermal (8-6ka) and the various local environmental changes that would be contingent upon this.

The sea surface temperature (SST) record by Cohen and Tyson (1995) inferred from $\delta^{18}O$ isotope record from marine mollusc shells at Nelson's Bay Cave, very near to the Groenvlei site, indicate low SSTs for 8600BP and 6300BP (see Fig. 6.1 below). Low SSTs result from enhanced upwelling of cold South Indian Central Water along the eastern edge of the Agulhas bank, today a generally short-lived summer phenomenon (Schumann *et al.*, 1982; Beckley, 1983 as cited by Cohen and Tyson, 1995). This upwelling, although not on the same scale as the Benguela upwelling system, is powered by increased influence of alongshore winds of ridging easterly waves (Cohen and Tyson, 1995), the atmospheric circulation pattern such as associated with the Altithermal (see Chapter 3). Cooler SSTs along the coast, generally correlated with wetter conditions in the interior, however, would produce drier coastal conditions with reduced SSTs, resulting in reduced evaporation and relative humidity, and consequently reduced cloud formation and precipitation. According to this evidence, Cohen and Tyson (1995) report that conditions [during the early period of the pollen sequence] would be expected to show drier conditions from 9 ka BP, and not the early wetter period as suggested by the pollen sequence in GR- 1.

Martin's (1968) pollen record from Groenvlei accords well with the current sequence in that similar trends and groups are found in both sequences. Although Martin's (1968) record also indicates the presence of hygrophytic elements (in GR- 1), he dismisses their importance by attributing their appearance to relative fluctuations in comparison to lower representation of herbaceous pollen. However, the fact that these elements appear at all (as the trees groups are mostly insect pollinated), and do not reach these levels again in the rest of the sequence, promote recognition of their significance. Furthermore, the availability of the absolute frequency diagram (Fig 5.6) in this project, which provides data fluctuations independent of one another, show that the Wet and Moist forest really do increase and is not merely a function of relative representation.

This, therefore, places the early part of the sequence in a perplexing light. While other records (i.e Martin, 1968; Cohen and Tyson, 1995) suggest that this period should be drier, GR- 1 clearly indicates a wetter phase.

On closer analysis of the $\delta^{18}O$ record (Cohen and Tyson, 1995: see Fig 6.1 below), however, a gap in the record is evident from 8.6 to 6.3 ka BP (9.8 to 7.1 ka cal. BP[CALPAL: Wenginer *et al.,* 2006]) and it is inferred by the authors that conditions in the intervening period were stable. This may not necessarily have been the case. Cohen and Tyson (1995) themselves report a disparity in the model as drier conditions are evident during this period in pollen records from the interior (e.g. at Wonderkrater, Rietvlei, Badsfontein and Blydefontein) (Cohen and Tyson, 1995), a condition more generally associated with warm SSTs owing to the influence of westerly waves (see Chapter 3). This would diminish upwelling, with warm plumes of Agulhas current surface water being pushed by prevailing south-westerlies, towards the coast (Lutjeharms and van Balgooyen, 1988; Goschen and Schumann, 1990, as cited by Cohen and Tyson, 1995) increasing SSTs and resulting in wetter coastal conditions (as a function of increased evaporation and relative humidity off of the warm ocean water).

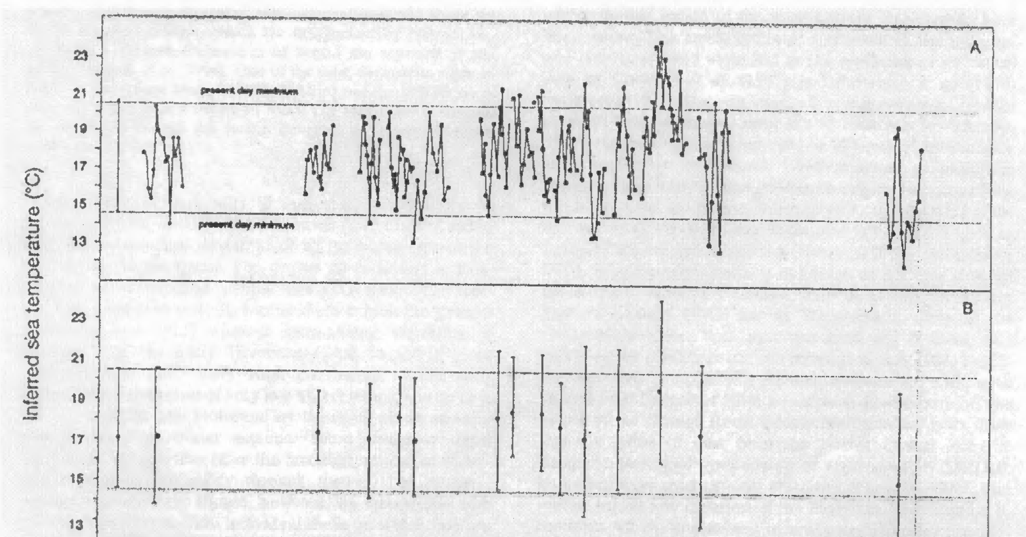


Figure 6.1: The $\delta^{18}O$ record from marine molluscs at Nelson's Bay Cave (Cohen and Tyson, 1995)

It is proposed that the period just before 8.4 ka cal. BP (7630 ± 130 BP radiocarbon age), local conditions were influenced by warmer SSTs and consequently wetter maritime air associated with westerly circulation. The influence of the westerlies during this period, may account for the drier conditions registered at some sites in the interior of the country (Cohen and Tyson, 1995). The presence of the hygrophytic elements and the sequence maxima for Fynbos (Ericaceae) and the presence of Oxalidaceae, both more generally associated with winter rainfall regimes, provide evidence in support of this premise.

The record from Vankervelsvlei, inland of Groenvlei, indicates a switch from a drier and cooler period to a warmer, moist period around 7.1 ka BP (radiocarbon) that appears in this record to continue for around 2000 years (Irving, 1998). The Groenvlei record, however, does not show this persistence of mesic conditions as GR- 2 indicates a fall off of Wet forest, lagged by Moist to Dry forest while frequencies of Dry forest to Coastal Scrub, steadily increase. Wetland components show a shift in dominance from Cyperaceae (an indicator of moist conditions) to Poaceae (generally an indicator of summer rainfall). This may be indicative of (1) steadily drying conditions associated with warmer terrestrial temperatures and cold adjacent SSTs associated with the Altithermal, and/or (2) increasing prominence of sandy conditions, and the community expression of the physiological effects of sand, associated with the remobilization of sand dunes associated with sea level fluctuations of +2m of the Altithermal (Marker, 1997).

The fact that the sequence decline is registered earlier in Wetland and Wet forest, two habitat types not generally adjacent and, therefore, unlikely to be affected by the same local event, but both highly dependent on moist conditions for their survival and expression in the pollen sequence, suggest that the primary environmental stimulus at this time was a reduction in moisture. This pattern accords better with other records for the time period, and is most likely the beginning of Altithermal expression.

Conditions would be drier owing to the influence of increased upwelling and reduced SSTs, resulting in reduced atmospheric moisture at the coast, probably sufficient moisture to support hardy groups, but not the more delicate. Further accounting for the decline in forest, is that a warming and a shift to more summer rainfall, and the increase in storminess associated with convection rain of the easterlies, may have had adverse effects on Wet forest through tree fall, and increased evaporation rates owing to higher terrestrial temperatures, unprecedented since the last interglacial (Tyson, 1999).

Marker (1997) shows that Altithermal warming (8-6 ka BP) resulted in a +2m increase in sea levels along the south coast, with a likely consequence being the mobilization of sand dunes. The gradual colonisation of these sand dunes by hardy Coastal Scrub members may account for their increasing prominence through GR- 1 and its peak in GR- 2. The decrease in Fynbos during this period may also be accounted for by the combination of increasingly sandy nature of the local environment, (as Ericaceae and Asteraceae are not known for colonising dunes [Martin, 1968]), and the shift to more summer-dominated rainfall patterns.

It is suggested that the period, over GR- 1 and 2, may represent the change over of prevailing atmospheric circulation, a shift in dominance from westerly-dominated systems to the easterly-dominated systems of the Altithermal. Local environmental stimuli, particularly owing to the proximity of the coast and the effects of adjacent sea surface temperatures and the mobility of sand dunes, were the most significant influences on terrestrial vegetation of the Knysna forests, at this time.

6.2.3 Period of Hiatus in the Pollen Record

This sand section spans a substantial period of the record imposing a significant hiatus in the record. Although this project can make no environmental inferences from this section, apart from the evidently significant role of sand dunes, other forms of proxy evidence may provide some indication of the general environmental trend.

6.2.4 ca. 790 to ca 1620 cal AD

In GR- 3, after substantial disruption created by the sand section, the palaeoecological sequence resumes. However, the lowest pollen count is registered here, possibly the result of greater influence of sand in the sample matrix. In general, Fynbos appears further diminished in comparison to its frequencies at the start of the pollen sequence, while Wetland/Local shows an increase relative to previous frequencies (with an increase in presence of Typhaceae and Juncaceae). Just after the beginning of the zone, a decline is registered first in Wetland/local, and followed by Wet Forest and Moist to Dry forest, forest margins, Fynbos and lagged later by Dry forest and Coastal Scrub. The decline is recovered with high percentages of Moist-Dry forest, Wet forest and Wetland/local showing signs of a mesic environment, in accordance with Scholtz's (1986) record. These frequencies are, however, lost abruptly towards the end of the zone.

The trough registered early in GR- 3 accords well with Cohen and Tyson's (1995) recognition of low summer and winter SSTs from Nelson's Bay cave around 650 BP. This trough around 1 ka BP, is also evident in Martin's (1968) record, which he uses as evidence that forest was declining prior to European influence. This decrease in SST (and therefore consequent decrease in coastal moisture) may be the result of extreme upwelling conditions associated with ridging easterlies, related to warmer conditions, and may possibly be an expression of early Medieval Warm Period. However, this decline occurs coincidently with low pollen counts (see Fig 5.5), and therefore, may be the result of preservation issues associated with the sandy matrix of the samples.

The reduced Fynbos frequencies may suggest persistence of summer-dominated rainfall. Analysis of the components of this signal reveal the appearance of Proteaceae for the first time in the sequence. This potentially indicates community progression from an herbaceous-dominated group to woodland taxa, an indication that the local community may be responding to the decreased influence of mobile sand (Martin, 1968).

The generally moister conditions allowing for increasing spread of woodland was brought to an abrupt termination at the end of the zone, a sudden decline registered across the board around the late 1600s. Fig. 5.5 indicates that the pollen sum was not excessively low, and therefore unlikely that this decline is a result of poor pollen preservation. It is very possible that this is, in fact, an expression of the Little Ice Age, an event associated with Maunder minimum in sunspot activity (Tyson *et al.*, 2000).

This event produced the most globally recognised period of cold and aridity since the Younger Dryas (Tyson *et al.*, 2000), with the extreme of this period in the interior of the country dated to 1700 AD from the high resolution study of colour banding of a stalagmite from Makapansgat (Holmgren *et al.*, 1999). Cohen and Tyson (1995) suggest that, during this period, the circumpolar vortex expanded, increasing the dominance of the westerlies, possibly trailing very cold air from the Antarctic in deep fronts across South Africa. This would correspond with reduced upwelling, and the south westerly winds would introduce plumes of warm Agulhas current surface water towards the coast, resulting in generally wetter coastal conditions, and generally drier conditions for the interior. This abrupt decline in vegetation during a period that appears to be increasingly moist, indicates that at the close of GR- 3 (around 1700 AD), that vegetation decline may have been determined by temperature; that cold and potentially windy conditions placed vegetation under physiological stress. The only group not appearing to respond to the decline is that of Dry forest to Coastal Scrub. However, investigation of the components of this signal indicate that the group signal is almost entirely composed (of what appears at first to be an anomalous spike), of Acanthaceae (*Justicia)* (see Fig 5.8, 5.9). This genus, an under-storey inhabitant of dry forest margins and coastal scrub, can thrive in a wide range of temperatures and environments and is known for its recovery from frost by resprouting shoots in spring (see Table 4.1).

Although not explicit in his record, Martin (1968) also indicates a decline in pollen spectra prior to colonial arrival. Just as abruptly as the LIA expressed itself, it came to an end (Tyson *et al.*, 2000), with conditions allowing for the expansion of forests and woodland towards the surface through GR- 4.

6.2.4 ca. 1620 to Present

Post 'LIA' decline (around the end of GR- 3) forest communities appear briefly to recover their former frequencies, with Moist to Dry forest registering its sequence maximum at the beginning of GR- 4. Wet forest, although lower than before the LIA decline, does reflect a certain degree of recovery. Fynbos increases over this zone, registering its second highest frequencies since GR- 1, with a shift in dominance of

Ericaceae to Asteraceae. Forest margins, again, show a reciprocal decline. The most obvious component of the results, however, is the unprecedented rise in charcoal.

GR- 4 spans the period of colonial entrance into the region, and the opening and closing of the forests for timber exploitation (Phillips, 1931; van Daalen, 1980). Although, in general, this activity could be expected to complicate the record, a product of their influence in the area provides the record with a significant benefit, through the introduction of the alien *Pinus*. The appearance of Pine in the record (at 10 cm) can be fairly accurately dated by historical records (van Daalen, 1980) to the beginning of the 20th century, when plantations were established to provide income to woodcutters (Mackay, 1997; van Daalen, 1980), when the severity of forest exploitation was finally acknowledged. This is, therefore, an exceptional chronological marker, pinpointing the stage of significant human disturbance in the record.

Evident at 10cm is a decline in most vegetation groups. The expression of this minimum corresponds with the Pine marker, indicating that this event occurred late in the 19th century. As the pollen sum does not register any particularly low counts, and is therefore not related to pollen preservation, it is proposed that this is may be the result of (1) increasingly dry environmental conditions, (2) an increase in fire frequency, or a significant fire event or (3) impact of human disturbance through timber harvesting,

Historical accounts suggest that, towards the end of the 19th century, a number of drought years occurred and these may go some way to account for the decline evident in forest communities. Phillips (1931) reports drought years at 1869, 1881, 1891, 1895, 1899 (Phillips, 1931, as cited by Geldenhuys, 1989), while Bond (1997) reports extended periods of berg winds in 1869, a further climatic feature that may result in the desiccation and potential decline of vegetation. However, if climatic events alone accounted for the reduction in forest, other hardier habitat groups (such as Coastal Scrub) may not be affected simultaneously, instead showing a lag time. This suggests that while the climatic drying may have set adverse conditions precipitating the decline, other variables may own a degree of responsibility.

Geldenhuys (1994) has shown that a combination of berg wind fires and topography, more than any other environmental determinant (for example topography alone, edaphic conditions, vegetation dynamics) accounts for the patchy nature of forests evident across the landscape today. These berg winds dry out vegetation in their course, making even generally moist forest more susceptible to a burn. Such conditions are said to have prevailed at around the time of this decline in forest communities, with Bond (1997) reporting consecutive days of berg winds blowing before the ignition of the great fire of 1869 (Watson and Cameron, 2002). This fire was started for land management purposes at Portland Estate near Knysna, and fanned by strong winds, devastated thousands of hectares of forest between George and Humansdorp (Mackay, 1997). A maximum peak in charcoal corresponds with the decline in vegetation, indicating that fire, and potentially the 1869 fire, may have been responsible for the reduced expression in the pollen sequence. However, comparison of high fire frequencies with fire-sensitive species such as *Podocarpus*, a group generally unable to coppice, and therefore more sensitive to fire (Watson and Cameron, 2002) does not show an obvious relationship (see Fig 5.9). Although *Podocarpus* is reduced at the time of the maximum charcoal spike, the levels for this pollen type are relatively substantial for the rest of the zone, where charcoal counts are still significantly high. This may be an indication of stratigraphic contamination of the charcoal record, the great dispersal distance of *Podocarpus* preventing any relationship from developing, or it might be that the substantial decrease in *Podocarpus* pollen at this particular point may be owing to the unsustainable timber harvesting that historical records imply (van Daalen, 1980).

This decline of the forest communities, therefore, also corresponds with the period of their maximum human exploitation. Extraction of timber trees, with particular demand for the felling of the largest and finest trees, would result in not only their individual removal, but also a reduction of gene and resource value (Phillips, 1931). Section clearance, a forestry method introduced near the end of the 19^{th} century, cleared entire portions of the forest at a time, creating irreparable damage to the forest canopy, and thereby introducing large quantities of sunlight to the usually shaded seedling and sapling stages of growth (Phillips, 1931). Records imply that once the canopy was ruptured these areas were then sold off for agricultural purposes (van Daalen, 1980). Reduction in forest patch size would have likely increased edge effects, making the forest core more susceptible to wind or fire damage, while disturbance of the delicate nutrient cycle would also be likely, in turn affecting forest growth and biasing the vegetation towards hardier Fynbos dominance. A relative increase is evident for Fynbos groups at the time when a decline is apparent in the record for Wet forest, but more significantly for Moist-Dry forest. The latter was almost certainly the more impacted of the two, the Wet forest mostly out of range by being high up on mountain slopes or inaccessible in deep kloofs. Historical records indicate that most of logging operations centred on the more readily accessible platform and foothill forests (Phillips, 1931), that are mostly composed of Moist-Dry forest trees (Geldenhuys, 1993). *Podocarpus,* in particular, was one of the most sought after timber trees that is present in the record, and this shows a substantial decrease around this time.

Towards the surface, there appears to be a considerable increase in the representation of Chenopodiaceae, indicators of drying/salt marsh conditions. This may be further evidence of human disturbance, but more recent than colonial impacts. It is possible that this is a reflection of increasing salinity of the vlei owing to a lowering of the water table by increasing population of the nearby town.

6.4 Synthesis

A pollen sequence extracted from sediments from Groenvlei, a site previously studied by Martin (1968), is presented here. Apart from the absence in this record for the period between 7-1 ka, created by the massive deposition of sand, the pollen sequence accords well with Martin's (1968), although higher resolution for upper sections, and advances in palaeoecological research have served to provide slightly different interpretations for coincident periods. Martin (1968) emphasized the complexity of the record around 7ka, providing two alternative interpretations for the expression of pollen in the sequence; that conditions were either affected by sand or that they were more mesic. Evidence from this record corroborates the latter, suggesting that the region was wetter and potentially influenced by warm SSTs of the adjacent ocean, under dominance of westerly circulation. After this, it is suggested that conditions steadily aridified under the influence of the low SSTs created by increased upwelling, under more easterly-dominated circulation, associated with the Altithermal. This record thereby suggests that GR- 1 and 2 illustrate a period of transition between prevailing circulation patterns, and that the vegetation patterns illustrate, more importantly, the knock-on effects of these on local scale coastal environments (through the proximity to the ocean and reinvigoration of dunes).

After the interruption, the sequence resumes, indicating a decline almost immediately that agrees well with the recording of cools SSTs at Nelsons Bay Cave (Cohen and Tyson, 1995) that may be evidence of the Medieval Warm Period. This period's expression is, however, spatially and temporally irregular (Tyson *et al.*, 2001; Tyson *et al.*, 2000) therefore difficult to define by correlating it to other records. Furthermore, the low pollen sum at this point indicates that this decline may be the result of poor pollen preservation. Thereafter, conditions improved with forest and woodland communities expanding. This came to an abrupt end in the late 1600s, with a sweeping deterioration of nearly all vegetation types. The temporal proximity of this decline to the extreme of the Little Ice Age, registered at Makapansgat, (which accords well with global records [Tyson *et al.*, 2000]) suggests this decline may be an expression of a global period of cold.

Vegetation showed recovery, with most groups reaching pre-LIA levels in GR- 4. This zone is associated most significantly with the influence of humans on the landscape. The substantial rise in charcoal from near the onset of the zone, which chronologically agrees with commencement of European colonial exploitation of the forest, suggests that fire was applied by colonists most likely with intention to modify the landscape. The decline in forest communities can be dated by the appearance of Pine in the record, to the late 19^{th} century, a period that accords with a series of drought years, the most significant exploitation of the forest by woodcutters and merchants, and one of the greatest fires on record- that of 1869. It is difficult to resolve the individual, relative contributions of these processes, although what is likely is that drier climates set the conditions for change and that it was human disturbance, through both burning and logging that produced the decline, the effect of which is comparable in the pollen sequence to that of the Little Ice Age.

6.4.2 The Scale of Human Influence in the Knysna Forest

Although fire is a significant environmental disturbance, and a tool that has been available to humans for a substantial period, it is not possible to resolve the pre-colonial inhabitant's impacts on the environment without coincident archaeological and palaeoecological sites. For this reason, early human impacts are effectively subsumed into climatic fluctuations. As soon as historical documentation is available, however, human disturbance can begin to be assessed. The entrance of European colonists in the 1700s, means that a written historical record is available from this period. These records, however, have variously implied that colonial impacts were significant (Phillips, 1931; van Daalen, 1980), that forests were declining prior to colonial entrance (Phillips, 1931, Martin, 1968) and that logging may not have been so significant after all (Geldenhuys, 1989, 1994).

The current pollen sequence, the interpretation of which is indebted to the increased understanding of the mechanisms that drive climatic change, has put forward a sequence that illustrates the significance of human involvement in an environment (both directly through logging and indirectly through the lighting of fires). While it is likely that climatic conditions may have contributed to the decline, it is suggested that intensive and extensive human impact in the region resulted in the expression of decline, and by comparing these with previous fluctuations in the record, indicates that anthropogenic environmental change is not only evident in a long-term record, but the scale of change at the end of the 19th century is almost comparable with the Little Ice Age, a global climatic phenomenon.

6.4.3 The Role and Prominence of Fire in the Knysna Forest Environment

Both means of ignition and fire spread may be accounted for by natural phenomena operating for millennia. This does not, however, discount the significance of human-related ignition. Lightning-initiated fires are more prominent here than elsewhere (Horne, 1981) and under berg wind conditions, fires may burn extensive areas including forest stands, fuelled by hot, dry winds from the interior. Geldenhuys (1994) suggests that berg wind fires, account for the location and fragmentation of forest in the region. It is possible that under extreme conditions of high fire intensity, forested stands may burn as flank, crown or ground fires (van Wilgen *et al.*, 1990).

Such conditions would truncate the forest nutrient cycles and hardier Fynbos species would pioneer the disturbed site and in so doing erode the forest margin. In this way, Fynbos holds a competitive advantage over forest, with frequent fires favouring Fynbos recruitment (Manders *et al.*, 1992). Therefore, it would be anticipated, that high Fynbos levels would coincide with lower levels of forest margins and vice versa. The recurring nature of this reciprocal relationship is clearly reflected in the pollen sequence in Fig 5.6, evident in GR- 1, 2 and 3. It is assumed that at periods of high Fynbos frequencies, forest margins are outcompeted, however, if disturbance in the form of fire is excluded vegetation will begin to build up allowing the increase in forest, leading to a less frequent, but potentially higher intensity fire (see Chapter 2, Fig 2.8 Manders *et al.*, 1992).

The relationship between fire and Fynbos is less obvious: It appears in GR- 1 and 2 that minima in Fynbos frequencies occur concurrently with increases in charcoal, illustrating a potential lag in charcoal settling. In GR- 3, however, minor declines in Fynbos and charcoal occur concurrently, while in GR- 4, the massive and unprecedented rise in charcoal obscures any relationships in the data.

The coincidence, in GR- 4, of a massive rise in charcoal with the entrance of colonials into the region, is alluring. Although it has been suggested that the climate may have been drier, or affected by extended berg winds, dry periods in the sequence are recorded before without such significant changes in charcoal deposition (e.g. GR- 2). While the conditions may have resulted in vegetation being prone to fires, their actual lighting, a rare natural occurrence, is more likely as a result of anthropogenic incendiaries.

Charcoal counts presented here are not clearly able to illustrate the results of individual fire events (as discussed in Chapter 4) as the sampling interval may have integrated several discrete peaks in a single sample. Furthermore, firm relationships with either groups of vegetations (e.g. Fynbos) or individual taxa (e.g. fire sensitive *Podocarpus*) are not explicit. This means that this type of proxy evidence is unable to provide any hard information on the average return interval of fire in the forest environment, nor any information about the ecological role of fire, although it is almost certain that the relationship between Fynbos and forest margins *is* fire maintained. What the record does present, however, is the prominence of fire in upper zones relative to lower strata of the pollen sequence, in tantalizing chronological correspondence with the prominence of humans in the environment.

6.5 Implications for the Future of the Knysna Forest

It is apparent that climate is constantly changing and this has subsequent effects on the nature of landscapes. While there are clear distinctions between the changing climates of the future, and those of the past, "palaeo-anologues" may be useful in anticipating (and thus compensating for) ecosystem changes (Huntley, 1990; Meadows *et al.*, 1993). The fact that humans, before the industrial revolution, managed to create impacts on the environment at a magnitude similar to that of a global climatic event, should provide ample warning that ecosystems may not necessarily cope with both climatic and human stress. What is reassuring, however, is that the pollen record appears to reflect a degree of regeneration towards the surface, a potential response to imposed conservationist measures.

The most cited prediction used in global climate models is that of a presumed increase of carbon dioxide content of the atmosphere in the coming century. This effect would result in plants that use C3 pathways (such as forests) benefiting from enhanced photosynthetic efficiency in a warmer world, (Bazzaz, 1990). This prediction is not so simple, however, as this will not be a stand alone event, and as is evident in the record, local-scale (coastal) climate processes have an important control on terrestrial vegetation, and therefore, these need to be taken into consideration, along with numerous other factors, in estimating future response.

Although the sequence provided here is not as extensive and continuous as some, forest appears to maintain a more or less steady presence. The reductions in forest that do occur, however, appear to be correlated to extreme or significant climatic events. It is proposed that the environmental diversity created by the topography that has ensured forest persistence and ability to regenerate in the past, may provide a similar function in the future. However, while landscape diversity may explain the presence and type of forest communities occurring in the region, their distribution in the landscape is said to be accounted for almost exclusively by their relation to berg wind channels (Geldenhuys, 1994), emphasizing the significance of fire in vegetation dynamics. Researchers suggest that fire frequency will increase in a warmer world (Peters, 1991), and that fragmentation of forests may increase, raising their vulnerability to change (Peters, 1991). The record suggests that since the entrance of colonials, the microscopic charcoal deposition, said to be indicative of regional fire dynamics, has increased substantially. Given the increasing population density since then, and consequent rise in the likelihood of fire ignition, with vegetation perhaps more prone to burn, the most significant threat to forest is considered to be increased fire frequency.

6.6 Conclusions

Disruption and change are, however, natural processes in the environment. Indeed it is disruption that results in the sequential dominance of various species in an ecosystem, which in turn mould the particular interactions that both ensure a degree of stability and produce the distinctive dynamics that allows biodiversity to flourish. Although natural succession is essentially triggered by disturbance or change, the degree of disturbance and its rate of occurrence will determine the recovery period of the ecosystem (Meffe and Carol, 1994). Since most environments are not in a state of equilibrium (Meffe and Carol, 1994) extensive human modification or restructuring of an environment, as is evident in the record, has the ability to alter the direction natural succession will take.

Chapter 7:

CONCLUSION

The broad objective of this project was to establish an understanding of the community dynamics of the Knysna forest region, over the period defined by the sediments extracted from Groenvlei, an endorheic vlei in the Wilderness Lake system. These sediments were analysed, described and dated and it was evident that upper and lower sections of organics were separated by the substantial deposition of sand, that would result in a hiatus in any derived pollen record. Chronological control of the sequence is provided by radiocarbon dates, as luminescence dating required further analysis to provide reliable results. The extraction, analysis and counting procedures of pollen analysis were performed and the results were presented in two forms, namely relative and absolute diagrams, in an effort to compensate for the deficiencies of each. Microscopic charcoal fragments present on the slides were counted alongside pollen grains, using Clark's (1982) Point-Count Method. Cluster analysis defined the pollen sequence into zones for descriptive purposes, while the provision of interpolated and calibrated ages, defined general time periods for these zones.

The resultant diagrams showed very similar results to previous studies by Martin (1968), however, the interpretation of fluctuations occurring in coincident periods (identified by radiocarbon dating) differed slightly owing to a higher resolution record for upper sections, as well as advances in palaeo-research subsequent to his investigation. It is suggested that at 8.5 ka calBP conditions at Groenvlei were inferred to be wetter, possibly owing to the maritime influence of warm sea surface temperatures associated with westerly-circulation. Hereafter, it is suggested that there was a transition to more easterly-dominated circulation, associated with the Altithermal. Furthermore, recent high resolution studies (such as Holmgren *et al.*, 1999) have identified the regional significance of the Little Ice Age in southern Africa. The chronological coincidence of a significant decline in vegetation groups at Groenvlei with the maximum expression of cold i.e. 1700 AD (Tyson *et al.,* 2000), suggests that these events may be related.

Although not distinct in Martin's (1968) record, he indicates that a decline appears "... *to have set in several hundred years ago, well before obvious European influence can be detected.*" (Martin, 1968, p.133), noting the event but not accounting for it.

The sediments from Groenvlei, presented 62 pollen taxa belonging to various habitat groups that occur in the region. To fulfil the objective of understanding community dynamics of the period defined by the sediments extracted, these taxa were divided into habitat groups of wet forest, moist-dry forest, dry forest to coastal scrub, fynbos (heath elements) and wetland/local, according to Geldenhuys (1993). Community dynamics evident in the pollen record indicate the reciprocal relationship between fynbos and forest margins, a relationship typifying the "afromontane debate", as it is likely managed by fire. The pollen record indicates successive phases of dominance and subordinance between these two groups, since the early Holocene, reinforcing the fact that fire and fynbos have long been part of the environment, and that this particular pattern is not determined by recent human disturbance.

While the pollen record presents this relationship fairly clearly, the charcoal record appears more complex. Comparison of charcoal frequencies with groups (e.g. fynbos) or with individual taxa (e.g. *Podocarpus*) does not show a consistent relationship. The charcoal record is therefore unable to provide an indication of the return frequency of fire (as the sampling interval and chronological resolution is too coarse) nor the relationship with fire prone groups or fire sensitive taxa. If the charcoal counts are then merely viewed as an expression of continuum, then the records shows that fire has long been part of the environment, and that either fire frequency or intensity has increased substantially since the 1700s.

It appears that landscape diversity ensures niche availability for these various groups and allows a degree of flexibility for vegetation migration over the long term. This means that there is a degree of ecosystem stability, with only significant environmental events likely to cause great alterations of communities. A number of events in the record illustrate such alterations, potentially including the expression of Altithermal conditions, the Little Ice

Age and human disturbance of 'felling and firing' during colonial period. For the most part, however, there is a more or less stable representation of communities.

Given that "*The synergy between climate change and habitat destruction would threaten many more species than either factor alone.*" (Peters, 1991, p.113), this record of adverse climate conditions, overlaid by direct and indirect human disturbance, provides an important case-study for the future of climate change. While disturbance and change are natural processes in the environment, it is the magnitude of the disturbance and the rapidity of change that determine the ability of communities to rehabilitate. The fragmented nature of the forests, is suggested to increase their vulnerability. The pollen record, however, indicates that declines are successively followed by regeneration, even in the case of the most recent decline likely to be human-induced, an encouraging observation for conservation.

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Appendix A:

SPECIES LIST FOR IDENTIFIED TAXA

Table A: Species list for identified pollen families, including a generalised ecological affinity (based on Geldenhuys, 1993). For full species list, see Geldenhuys (1993) Floristic composition of southern Cape forests with annotated checklist. *S.Afr.J.Bot*, **59**(1):26-44

Ecological Group	Family	Genus	Species
Wetland/Local	Cyperaceae	*Cyperus*	*papyrus*
		Carex	*aethiopica*
		Asterochaete	*glomerata*
		Scirpus	*littoris*
	Typhaceae	*Typha*	*capensis*
	Juncaceae	*Juncus*	*capensis*
			isolepis ludwigii
			lomatophyllus
	Poaceae	*Phragmites*	*australis*
		many other	
Wet Forest	Aquifoliaceae	*Ilex*	*mitis*
	Cunoniaceae	*Platylophus*	*trifoliatus*
		Cunonia	*capensis*
	Lauraceae	*Octea*	*bullata*
		Cassytha	*ciliolata*
	Tiliaceae	*Sparrmania*	*africana*
		Grewia	*occidentalis*
	Scophulariaceae	*Nemesia*	*meilissifolia*
		Diclis	*reptans*
		Halieria	*lucida*
		Teedia	*lucida*
		Sutera	*aethiopica*
			cordata
		Harveya	*capensis*
			stenosiphon
	Piperaceae	*Piper*	*capenses*
		Peperoma	*refusa*
			tetraphylla
	Haloragaceae	*Laurembergia*	*repens*
	Onagraceae	*Epilobium*	*hirsutum*
Moist-Dry Forest	Apocynaceae	*Acokanthera*	*oblongifolia*
			oppositifolia
		Carissa	*bispinosa*
		Gonioma	*kamassi*
	Flacoutiaceae	*Kiggelaria*	*africana*
		Scolopia	*mundii*
			zyheri
		Trimeria	*grandifolia*
		Dovyalis	*lucida*
			rhamnoides

			rotundifolia
	Hamamelidaceae	*Trichocladus*	*crinitus*
			ellipticus
	Meliaceae	*Ekebergia*	*capensis*
	Moraceae	*Ficus*	*burt-davii*
			sur
	Oleaceae	*Chionanthus*	*foveolata*
			peglerae
		Olea	*europa*
			capensis
			exasperata
		Jasminium	*angulare*
	Oliniaceae	*Olinia*	*ventosa*
	Podocarpaceae	*Podocarpus*	*falcatus*
			latifolius
	Rubiaceae	*Burchellia*	*bubalina*
		Gardenia	*thunbergia*
		Rothmannia	*capensis*
			globosa
		Canthium	*ciliatum*
			inerme
			mundianum
			pauciflorum
			spinosum
		Psydrax	*obovata*
		Psychotria	*capensis*
		Galopina	*circaeoides*
	Oxildaceae	*Oxalis*	*incarnata*
			stellate
	Urticaceae	*Laportea*	*grossa*
			peduncularis
		Droqutia	*iners*
		Didymodoxa	*capensis*
Dry Forest-Coastal Scrub	Anacardiaceae	*Loxostylis*	*alata*
		Laurophyllus	*capensis*
		Rhus	*chirindensis*
			crenata
			glauca
			longispina
			lucida
			refracta
			rehmanniana
			undulata
	Capparaceae	*Capparis*	*sepiaria*
		Maerua	*racemulosa*
	Ebenaceae	*Euclea*	*crispa*
			natalensis
			polyandra
			racemosa
			schimperi
			undulata

		Diospyros	*dichrophylla*
			glabra
			pallens
			whyteana
	Euphorbiaceae	*Andrachne*	*ovalis*
		Lachnostylis	*hirta*
		Adenocline	*acuta*
		Leidesia	*procumbens*
		Acalypha	*capensis*
			ecklonii
		Tragia	*sp*
		Ctenomeria	*capensis*
		Clutia	*affinis*
			alaternoides
			laxa
			pulchella
		Excoecaria	*simii*
		Euphorbia	*kraussiana*
	Pittosporaceae	*Pittosporum*	*viridiflorum*
	Rutaceae	*Zanthophyllum*	*capense*
			davyi
		Calondendrum	*capense*
		Agathosma	*ovata*
		Empleurum	*unicapsulate*
		Vepris	*lanceolata*
		Clausena	*anisata*
	Sapindaceae	*Allophylus*	*decipiens*
		Dodonaea	*angustifolia*
		Hippobromus	*pauciflorus*
	Sapotaceae	*Sideroxylon*	*inerme*
	Verbenaceae	*Clerodendron*	*glabrum*
	Vitaceae	*Rhoicissus*	*digitata*
			tormentosa
			tridentata
		Cyphostemma	
	Ulmaceae	*Celtis*	*africana*
	Zygophyllaceae	*Zygophyllum*	*morgsana*
	Acanthceae	*Thunbergia*	*gregeana*
		Dicliptera	*zeylanica*
		Hypoestes	*aristata*
			forskaolei
		Siphonoglossa	*leptantha*
		Isoglossa	*ciliata*
			eckloniana
			grantii
			hypoestiflora
			prolixa
			sylvatica
		Justicia	*aneselliana*
	Azioaceae	*Pharnaceum*	*thunbergii*
		Tetragonia	*glauca*
	Caryophyllaceae	*Drymaria*	*cordata*

		Silene	*bellidiodes*
			crassifolia
			primulifolia
			undulata
	Crassulaceae	*Cotyledon*	*orbiculata*
		Crassula	*cordata*
			ericoides
			lactea
			orbicularis
			pellucida
			perforata
			rubricaulis
			sarmento
			spathulata
			subulata
	Amaranthaceae	*Amaranthus*	*thunbergii*
		Nelsia	*quandrangula*
		Pupalia	*atropururea*
Forest Margins	Fabaceae	*Schotia*	*afra*
			latifolia
		Calpurnia	*aurea*
		Virgilia	*divaricata*
			oroboides
		Crotalaria	*capensis*
		Argrolobium	*tormentosum*
		Psoralea	*affinis*
			cordata
			pinnata
		Otholobium	*fruticans*
		Desmodium	*repandum*
		Dumasia	*villosa*
		Erythrina	*caffra*
		Rhynchosia	*caribaea*
		Dipogon	*lignosus*
	Myricaceae	*Myrica*	*cordifolia*
			humilis
			quercifolia
			serrata
	Rhamnaceae	*Scutia*	*myrtina*
		Rhamnus	*prinoides*
		Phylica	*axillaris*
			pinea
			purpurea
	Rosaceae	*Rubus*	*pinnatus*
		Alchemilla	*capensis*
		Prunus	*africana*
	Geraniaceae	*Pelargonium*	*cordifolium*
			papilionaceum
			zonata
	Penaeceae	*Penaea*	*cneorum*
	Polygalaceae	*Polygala*	*fruticosa*
			myrtifolia

	Phytolaccaceae	*Phytolacca*	*americana*
			octnadra
	Solanaceae	*Solanum*	*aculeastrum*
			aculeatissimum
			geniculatum
			giganteum
			hermanii
	Viscaceae	*Viscum*	*obscurum*
			roturgifolium
	Polygonaceae	*Rumex*	*sagittatus*
		polygonum	*saligofolium*
	Lobeliaceae	*Cyphia*	*digitata*
			neterophylla
		Lobelia	*anceps*
			coronopifolia
			cuneifolia
			neglecta
			pubescens
	Brassicaceae	*Lepidium*	*ecklonii*
		Cardamine	*africana*
	Ranunculaceae	*Knowltonia*	*cordata*
			filia
			vesicatoria
		Clematis	*brachiata*
		Ranunculus	*multifidus*
Fynbos(heath)	Liliaceae	*Bulbine*	*latifolia*
		Trachyandra	*ciliata*
		Chlorophytum	*comosum*
		Aloe	*arborescens*
			ferox
		Gasteria	*acinacifolia*
		Agapanthus	*praecox*
		Tulbaghia	*violacea*
		Ornithogalum	*dubium*
			longbracteatum
		Protasparagus	*aethiopicus*
			macowanii
			setaceous
		Myrsiphyllum	*asparagoides*
			scandens
			volubile
	Restionaceae		
	Asteraceae	*Veronia*	*anisochaetoides*
			mespilifolia
		Mikania	*natalensis*
		Felicia	*aculeata*
			westae
		Brachlaena	*glabra*
			neriifolia
		Tarchonanthus	*camphoratus*
		Heiphrysum	*cymosum*
			petiolare

		Osmitopsis	*osmitoides*
		Hippia	*frutescens*
		Peyrousea	*umbellata*
		Cineraria	*tobata*
		Senecio	*amabilis*
			angulatus
			crenatus
			deltoideus
			illicifolius
			mikanioides
			quinquelobus
		Euryops	*virgneus*
		Chrysanthemoides	*monilifera*
		Gerbera	*cordata*
	Ericaceae	*Erica*	*canaliculata*
			copiosa
			curviflora
			densifolia
			gibbosa
			seripholia
			sparsa
		Simchelius	*multiflorus*
	Proteacea	*Faure*	*macnaughtonii*
		Protea	*mundii*
		Leucadendron	*conicurr*
			eucaltyptifolium
	Iridaceae	*Dietes*	*iriroides*
		Aritea	*ensifolia*
		Ixia	*polystachya*
		Melasphaerula	*ramosa*
		Chasmanthe	*aethiopica*
		Gladiolus	*sempervirens*
		Anapalina	*caffra*

Appendix B:

LABORATORY PROCEDURES FOR THE EXTRACTION OF FOSSIL POLLEN FROM MINERAL RICH SEDIMENT

Source: Revised from Faegri *et al.*, (1989), Moore *et al.*, (1991), Horowitz (1992), Baxter (1996) and Irving (1998)

Note:

- Maintain the laboratory as a sterile and contained environment in order to prevent contamination between samples or through airborne pollen fallout.
- Strictly adhere to laboratory safety procedures, wearing appropriate protective clothing/equipment
- Discard chemical waste into appropriate containers, and ensure regular waste collection.
- Centrifuge samples in sealable 100ml polypropylene tubes at 3000 rpm for 5 minutes. Ensure opposite tubes are balanced.
- Set water bath to 95 °C.

A. Addition of Exotic Marker Grains

1. Add one *Lycopodium clavatum* tablet to each sample.
2. Add 1.5ml of distilled water to each sample
3. Seal tube and mix sample thoroughly on a vortex mixer.
4. Leave for 24 hours
5. Resuspend sample using the vortex mixer. Centrifuge and decant supernatant.

B. Removal of Humic Acids

1. Add 10 ml of 10% Sodium Hydroxide (NaOH) and place in a water bath for 10 minutes.
2. Remove samples and wet sieve through 106μm sieve using distilled water.
3. Place resultant wash into labelled polypropylene tubes, centrifuge, decant and recombine into a single sample.
4. Wash in distilled water, centrifuge and decant. Repeat.

5. If the supernatant is still darkly coloured, rewash in 10% NaOH and repeat step 4, until supernatant is clear.

C. Removal of Clastic Material (Cold Hydrofluoric Acid treatment)

1. Add 20 ml 10% Hydrochloric acid (HCl)
2. Place in water bath for 20 minutes, stir, centrifuge and decant.
3. Working in the fume cupboard, add 15ml of 40% Hydrofluoric acid (HF) to each sample, transferring the HF from a container to the sample using a polypropylene syringe to reduce incidence of splashing/spilling.
4. Leave samples for 24-48 hours. The length of the treatment depending on the grittiness of the sample. Stir samples at regular intervals.
5. Seal tubes tightly, centrifuge and decant the supernatant into an appropriate waste container using a polypropylene syringe.
6. Add 10 ml of 10% HCl, stir, centrifuge and decant.
7. Wash in distilled water, centrifuge and decant supernatant.
8. Neutralize any spills and ensure that any equipment/surfaces that may have come into contact with HF are thoroughly rinsed, to prevent any accidental contact.

D. Removal of Cellulose and Organic Matter (Acetolysis Digestion)

1. Working in the fume cupboard, make up the acetolysis mixture (9 parts Acetic Anhydride to 1 part Sulphuric acid)
2. Dehydrate sample by adding 10ml of glacial acetic acid, mix, centrifuge and decant.
3. Add 10ml acetolysis mixture and place in the water bath for 3 minutes.
4. Stop reaction by adding 5ml of glacial acetic acid. Centrifuge and decant.
5. Add 10 ml glacial acetic acid, centrifuge and decant
6. Wash in mixture of 9ml distilled water and 1ml 10% NaOH to neutralize sample, centrifuge and decant.
7. Wash twice in distilled water, adding 1 drop aqueous safranin stain to the second wash. Centrifuge and decant.

8. Add 5ml Tert- butanol alcohol (TBA), stir, centrifuge and decant to just above the pellet.
9. Transfer the sample into a labelled storage vial using a micropipette, washing the pipette tip and vial with TBA to ensure thorough transferral of sample material.
10. Add equal amount of glycerol to TBA-sample suspension, mix thoroughly to suspend pollen material in glycerol.

E. **Mounting**

1. Place a drop of glycerol onto a warm, labelled sterile glass microscope slide.
2. Using the micropipette, extract an appropriate quantity of suspended glycerol-TBA-pollen mixture (e.g. 0.02 ml) and release onto the warmed glycerol on the slide.
3. Allow TBA content to evaporate.
4. Lower the coverslip carefully onto the glycerol-pollen suspension to avoid air bubbles forming, and allow for glycerol to spread evenly to the edges of the slide.
5. Using a larger pipette, seal the slide by applying a thin boarder of molten glycerine jelly (impregnated with phenol) in a steady stream around the edges of the slide.

Appendix C:

STATISTICS FOR *LYCOPODIUM* SPORE TABLETS

INFORMATION ON SPORE TABLETS

Lycopodium spore tablets (batch 483216) (September 2004)

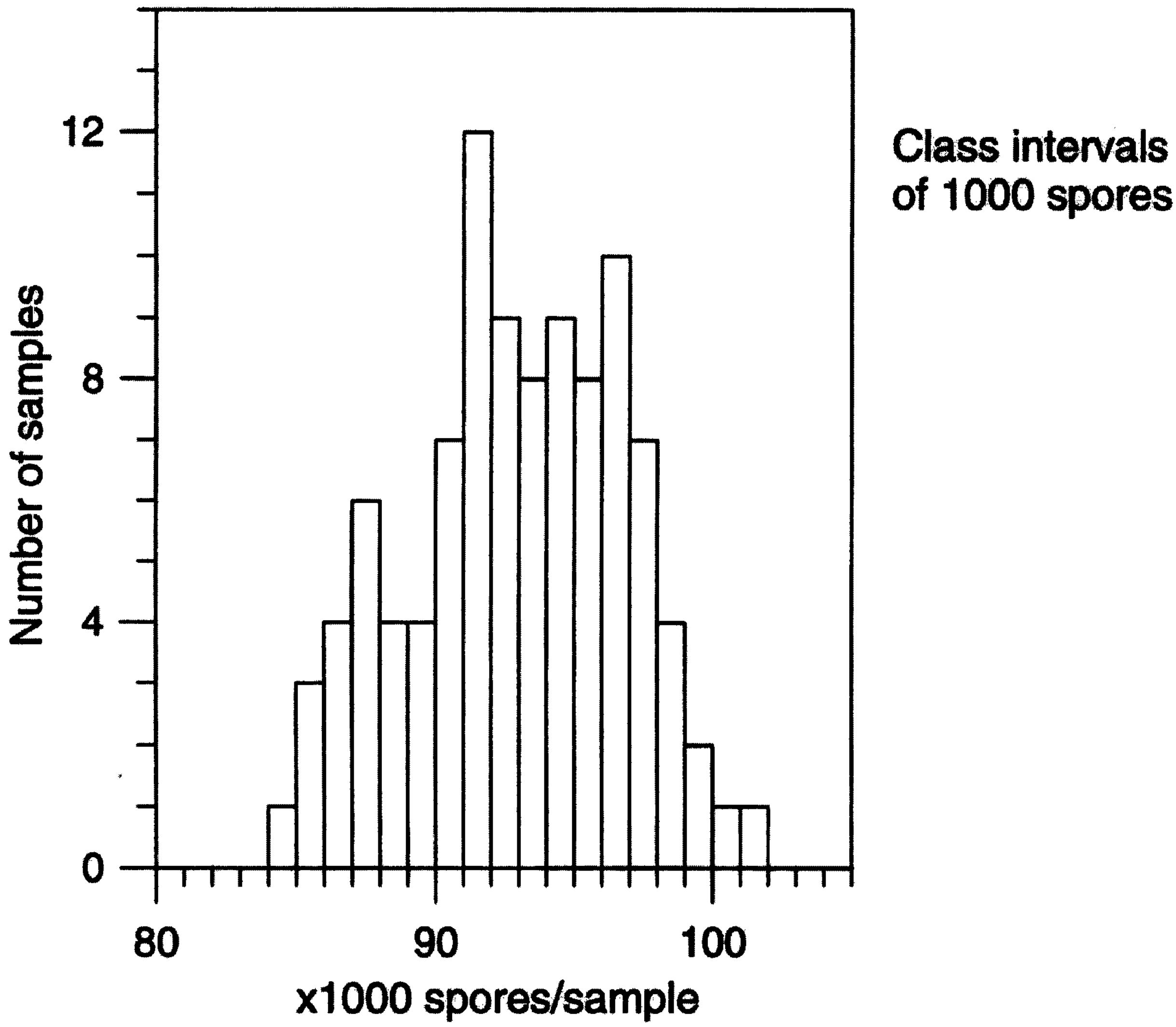
Lycopodium spore tablets can be dissolved in water or in HCl, but not in NaOH. They have been prepared in a slightly different way compared to that described by Stockmarr (1971, 1973). The tablets are thus based mainly on sodium bicarbonate together with polyvinylpyrilidon and polyethyleneglycol, which must be carefully washed away with water and finally with diluted HCl before further treatment. The spores are acetolysed.

The spore concentration has been determined with an electronic particle counter, Coulter Counter ZB (cf. Stockmarr 1973), tube size 140 µm. 100 samples of five tablets each taken from different places in the batch were prepared by dissolving the tablets in Isoton II NaCl solution in 100 ml flasks. 20 counts each of 0.5 ml were made on each sample.

Result of the calibration (5 tablets): X = 92914 s = ± 3820 V = ± 4.1 %

For one tablet: X = 18583

The distribution of the samples is shown in the figure below.



Appendix D:

RAW POLLEN COUNT DATA

		Wetland/Local					
Depth (cm)	Sample No	Lycopodium	Cyperaceae	Typhaceae	Juncaceae	Poaceae	Total
5	GK 1.1	11	100	4	13	5	33
7	GK 2.1	10	115	5	11	6	32
10	GK 1.2	13	127	4	19	12	48
12.5	GKS 2.2	1	112	5	4	8	18
15	GK1.3	8	126	3	15	6	32
17	GKS 2.3	2	209	3	3	5	13
20	Gk 1.4	9	228	4	30	18	61
24	GKS 2.4	13	101	3	8	7	31
30	GK 1.6	24	126	11	9	10	54
35	GKS 2.6	7	203	1	36	8	52
40	GKS 2.7	4	293	1	21	8	34
42	GK 1.7	2	106	1	5	7	15
295	GK 1.8	7	207	1	10	8	26
345	GK 1.9	10	132	1	9	21	41
353	GK 1.10	2	196		7	3	12
364	GK 1.11		106	2	5	7	14
373	GK 1.12	7	171		9	6	22
385	GK 1.13	7	98		4	2	13
393	GK 1.14	5	250		6	4	15
400.5	GK 1.15	5	212		6	4	15
408	GK 1.16	3	138		16	4	23

Wet Forest								
Trees						Forbs		
Aquifoliaceae	Cunoniaceae	Lauraceae	Tiliaceae	Scrophulariaceae	Piperaceae	Hallorhagaceae	Onagraceae	TOTAL
	3		4	1			1	9
3			1				1	5
2					1			3
	3							3
			2			1	1	4
	2		4					6
							1	1
	1		2	4				7
		1		3		1		5
	1			3		1		5
	5			1		2		8
								0
1	9	1					1	12
							2	2
1								1
						3		3
4		7						11
4						1		5
4	4							8
2								2
6								6

Moist to Dry Forest											
Trees									Forbs		
Apocyanceae	Flacourtiaceae	Hamamelidaceae	Meliaceae	Moraceae	Oleaceae	Olineaeceae	Podocarpaceae	Rubiaceae	Oxildaceae	Urticacea	TOTAL
1		2			1		19				23
5		1		2	3		14		1		26
3		5			8		3	2	2		23
	1				5		24				30
		2			6		12	2			22
	8	1					0				9
					4		3	2	1		10
	3	1	1				15	4			24
		1		1	7	1	8	7			25
	1				6		4	3	2		16
		1			2		17		1		21
					5		10	1			16
		14	3		10		8	8			43
					1		3				4
					3		2	4		1	10
					3		1	2		3	9
3	1			2	8		6				20
4		3			7		3	8			25
	2				6		7		2		17
	7	5		1	2		5				20
					1		1				2

Dry-Forest to Coastal Scrub Trees and Shrubs											
Anacardiacea ce	**Capparacea e**	**Ebenacea e**	**Euphorbiace ae**	**Pittosporace ae**	**Rutacea e**	**Sapindacea e**	**Sapotacea e**	**Verbenacea e**	**Vitacea e**	**Ulmacea e**	**Zygophyllace ae**
3		1	9	2	2		3	2			
	4	4	8	4	7			3			
	3	2	3		1			1			
5		1		5	4						
4	1	2	3	1			3	4			
			9	1	19			3			
1	6		2		2		1				
			6	2	9			3			2
				2	3	4			2		
6		3	14	2	10			4			2
2	3	2	5	1	1			2			
							1				
9			2		5					3	
2			3		7				7		
5					7			2	2		
10				2	9			2	4		
6		2	14		6				4		
	2		12		3						
2		1	9								2
3			10								
9			5	2					1		4

Dry Forest to Coastal Scrub Forbs					
Acanthaceace	Aizoaceae	Caryophyllaceae	Crassulaceae	Amaranthaceace/Chenopodiaceae	TOTAL
2			2	10	36
3			2	20	55
	3	2	3		18
				1	16
2			2	1	23
				1	33
35					47
				2	24
	2	1		7	21
		4		3	48
		4	1	3	24
				3	4
11				5	35
60		1		3	83
44					60
16					43
15		1			48
2		3			22
					14
1					14
7				2	30

Forest margins Trees and Shrubs									
Fabaceae	**Myricaceae**	**Rhamnaceae**	**Rosaceae**	**Geraniaceae**	**Penaeaceae**	**Polygalaceae**	**Phytolaccaceae**	**Solanceae**	**Viscaceae**
	1	1						1	
	4		6						
							2	1	
	1						5		
	1	1	6					1	
1	2	1	3	2					
						1	6		
2	1		2	1			5		
1	1		6	1			7	1	
1			3	3				1	
1	1		1	2		2			
	1					1		5	
			4					3	4
			7				5	12	
				3				1	
			25						6
2						1		1	2
		1	13						
								1	2
2									3
			26		5		1		

Forest Margins :Vines		Forbs		
Polygonaceae	Lobeliaceae	Brassicaceae	Ranunculaceae	TOTAL
1				4
		1		11
		1		4
				6
			1	10
				9
6			4	17
				11
		2		19
				8
				7
7				14
				11
6		9		39
	4			8
		1	3	35
			3	9
			3	17
		3		6
	3	2		10
			1	33

Fynbos										Pollen Sum
geophyte							Exotics			
Liliaceae	Restionaceae	Asteraceae	Ericaceae	Proteaceae	Iridaceae	TOTAL	Pinaceae	Pteridium		
2	14	30	6	2		54	32			196
4	16	35	4	4	1	64	17			219
	17	100	13	4		134	11			249
	11	50	14		1	76				153
3	12	37	14	7	1	74				172
	11	50	17	1		79				149
	11	9	15	1		36				172
1	12	35	7	3	1	59				156
3	15	18	13	4		53		2		197
		31	24	4	2	61				190
		13	25	5		43				137
	17	7	9	2		35				85
2	12	16	19	2		51				218
1	5	35	20			61				232
1	3	46	84			134				235
3	7	7	46			63		5		174
	2	51	85	1		139				252
2	4	29	84	2	1	122		22		230
		43	143			186				246
		62	121	1		184				246
11	8	42	61	2	2	126		4		229