CLIMATIC RECONSTRUCTION USING WOOD CHARCOAL FROM ARCHAEOLOGICAL SITES

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ABSTRACT

This thesis assesses the feasibility of using wood charcoal from archaeological sites as a palaeoclimatic indicator. Three techniques are described: (i) charcoal identification from Xylem Anatomy. (ii) Ecologically Diagnostic Xylem Analysis and (iii) stable carbon isotope analysis on wood charcoal. The first is a well established method of environmental reconstruction. This is the first systematic application of Ecologically Diagnostic Analysis and the first application of stable carbon isotope analysis on wood charcoal.

Charcoal identification shows that the most common woody species at Elands Bay today are also evident in the archaeological record over the last 4000 years, indicating a relatively stable plant community composition. Previous studies of wood anatomy have shown that there are links between vessel size, vessel number and climate. This study demonstrates that the wood anatomy of *Rhus* is not simply related to climatic factors, necessitating the employment of a wide range of statistical analytical techniques to identify climatic signals. In contrast, the anatomy of *Diospyros* shows strong correlations with temperature. Factor analysis of anatomical parameters of charcoal from Elands Bay archaeological sites indicates that there have been temperature changes over the last 4000 years. Stable carbon isotope ratios ($^{13}C/^{12}C$) of plants have been found to be a useful indicator of water use efficiency; plants in drier habitats exhibit more positive values than their more mesic relatives. The results of an isotopic analysis on modern wood charcoal show that $^{13}C/^{12}C$ ratios can be related to temperature and rainfall. The climatic component of the range in variation of $^{13}C/^{12}C$ in the archaeological record is not as easy to identify due to increased use of fossil fuels since the beginning of the Industrial Revolution.

Indications are that wood charcoal does carry a climatic signal. A larger sample from more areas may give more dependable results.

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PREFACE AND ACKNOWLEDGMENTS

This study arose out of the question of what actually determined the settlement pattern of prehistoric hunter gatherer societies. Is climate and environment the overriding control or as some scientists have suggested, is climate only incidental? How much does climate control the settlement patterns of prehistoric people? The thesis explores and considers three techniques for using wood charcoal from archaeological sites as a palaeoclimatic indicator. The project is conducted within the framework of the Later Stone Age of the south-western Cape Province, South Africa. The research reported here is my own, and I am responsible for the opinions and conclusions.

I am indebted to a great many people who have assisted me in this project. They are too many to mention individually, but I am grateful to them all. Inspiration for the project came from a seminar by Anton Scholtz given at the Botany Department of the University of Cape Town (UCT) in 1986. Professor John Parkington has suggested that the prehistoric settlement patterns of people at Elands Bay have been influenced by climate, and Anton Scholtz's Environmentally Diagnostic Xylem Analysis (EDXA) provided an ideal tool to test for climatic change.

The Palaeobotany Section at the South African Museum has an excellent laboratory specifically designed for analysing the relationship between wood anatomy and climate. Without the use of this laboratory the project would not have been possible. I would like to thank Anton Scholtz of the South African Museum for not only supervising the wood anatomical section of this project, but also for the use of his laboratory and his unflagging enthusiasm and support for this project. I developed the photographs for the project in the darkrooms of the Department of Archaeology of the University of Cape Town and the Departments of Archaeology and Permo-Triassic Palaeoentology of the South African Museum. In this regard I would like to thank Mike Herbert, Graham Avery and Clive Booth for the use of their darkrooms.

This thesis depended quite considerably upon radiocarbon dates and charcoal samples from the archaeological sites at Elands Bay which were provided by Professor John Parkington. Throughout the project I had the close cooperation of Professor John Parkington and Roydon Yates of the Spatial Archaeology Research Unit at UCT, and would like to thank them for sharing their ideas with me, and supplying me with both published and unpublished data. I would also like to thank John Parkington for co-supervising the thesis, and providing stimulating encouragement.

Dirk Versveld of the Forestry Research Institute at Jonkershoek kindly showed me around the area, and helped me collect samples of wood at Jonkershoek. Sue Dean helped me collect the sample from the Karoo Biome Project site at Tierberg near Prince Albert. The wood sample from Saasveld was organised by Jeremy Midgely and collected by Carlo Jacobs of the Saasveld Forestry Research Centre. Charlie Boucher supplied me with invaluable information on the physiology of *Zygophyllum*.

As an independent test on the results of EDXA, stable carbon isotope analysis of some of the charcoal samples was carried out. I relied heavily upon fellow members of the Archaeometry Research Unit at the University of Cape Town for assistance in the practicalities of stable carbon isotope research. In this regard, I am grateful to Judith Sealy, Julia Lee Thorpe, John Lanham, Anne Cohen and Dawn Sholto-Douglas.

Francis Thackeray of the Archaeometry Research Unit, spent many hours teaching me the basics of statistics and advising me as to which tests were appropriate for this study. John Lanham provided the technical and computer support for the project. I am especially grateful to Professor Nik van der Merwe, leader of the Archaeometry Research Unit for supervising this thesis, providing the support for it and for his constant encouragement throughout the project.

Anton Scholtz (Palaeobotany SAM), John Parkington (Archaeology UCT), Judith Sealy (Archaeology UCT), and Willy Stock (Botany UCT) read and commented on all or parts of this manuscript, I thank them all. Finally, I would like to thank my colleagues who

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This thesis is dedicated to two people. Firstly to my father, Ronald February. He was responsible for initiating my interest in archaeology and was always interested in what I was doing. My greatest regret is that he did not live to see me finish. Secondly it is dedicated to the memory of Z.K. Matthews, the first black South African to graduate from a South African university.

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CHAPTER ONE

INTRODUCTION

Introduction

This project sets out to assess the feasibility of using wood charcoal from archaeological sites as a palaeoenvironmental climatic indicator. The project also attempts to assess the relationship between climate and the settlement patterns of Holocene Later Stone Age people. The research concentrates on the archaeological sites in the area surrounding the west coast village of Elands Bay (Fig 1). Three techniques for palaeoclimatic reconstruction using wood charcoal from archaeological sites are discussed.

Major components of most archaeological sites are stone, bone and charcoal; charcoal often being the most abundant plant material. Locked into charcoal are the specific wood variables determined by climate at the time the wood was being formed. Using modern specimens as a key, the palaeoclimate for the area surrounding the Verlorenvlei at Elands Bay can be reconstructed, from archaeological charcoal

Charcoal identification and relative abundance.

Much work has been done using wood charcoal from archaeological sites in the reconstruction of a woody environment. The pioneering work in this field is that of Salisbury and Jane (1940) and Godwin and Tansley (1941). Subsequently other workers have made contributions to the research field such as; Hadac and Hasek (1949), Slavikova-Vesela (1950), Vernet (1973, 1976); Kraus Marguet (1980), Deacon (1979), Prior (1983) and Tusenius (1986). A recent full literature survey on charcoal studies in archaeology was produced by Tusenius (1986). In all the studies, mentioned above, the emphasis lay in a detailed study of environmental change through wood identification from xylem anatomy.

The identification of wood charcoal to genus/species level is possible because the different genera have distinctive combinations of anatomical features visible under the microscope. During the process of transpiration trees conduct water and dissolved minerals from the roots to the leaves via vessels and tracheids (the tracheary system). Minerals and water can be stored in another group of less specialised cells called parenchyma cells. These parenchyma cells are also depositories for waste material such as dissolved silicates. Trees and shrubs require mechanical support and this is attained via another group of cells, the fibre cells. It is the characteristic arrangement of these groups of cells, in the horizontal and vertical sections, that make it possible for wood anatomists to identify wood to genus or species level. Wood, when burned, maintains its anatomical structure, so that wood charcoal can also be identified to genus or species level by the characteristic arrangement of different cell types.

The ability to identify wood charcoal enables wood anatomists to compile lists of the species composition of the wood charcoal from archaeological sites. With environmental/climatic change, the types of wood brought into these archaeological sites should also change because of changes in abundance of species in the area around the study site. The composition of the charcoal assemblage of any site should reflect the woody vegetation of the area surrounding the site including any major changes in shrub /tree cover which may have occurred.

EDXA: a new approach to climatic reconstruction.

Scholtz (1986) first realised the potential significance of certain wood anatomical variables for explaining palaeoclimatic change. He developed new methods by which charcoal from archaeological fires can be used to reconstruct a history of vegetation and climate. Scholtz's (1986) Ecologically Diagnostic Xylem Analyses (EDXA) is directly based on the relationships between plant anatomy, physiology and ecology (Carlquist 1966, 1977a&b, 1982, Baas 1982 and Baas, *et al.* 1983). It is not designed to describe the anatomy of wood, but rather to measure a wide range of potentially ecoclimatically

significant wood variables observable in a cross section. The most important of these variables are vessel diameter, ray area, vessel area, number of vessels and relative volume flow (Carlquist 1966, Baas 1982, Dickison & Phend 1985). Measurements on the wood anatomy of charcoal from archaeological sites may be related to climate when compared to measurements on a modern sample from areas of known temperature and rainfall.

Stable Carbon Isotopes

As an independent test of the results obtained from EDXA, stable carbon isotope analyses of some of the charcoal samples were carried out. The mix of C_3/C_4 plants changes along a moisture/temperature gradient Tieszen *et al.* (1979), moreover, recent studies suggest that the ratio between the stable isotopes ^{13}C and ^{12}C can be a good estimate of water use efficiency (Farquhar & Richards 1984, Hubick *et al.* 1986). Water stress induces some stomatal closure (Cowan 1982) which results in more positive $^{13}C/^{12}C$ values (Hubick *et al.* 1986). The result is that $^{13}C/^{12}C$ become more positive with increasing drought. By analysing the $^{13}C/^{12}C$ of the archaeological sample and a modern correlate, similar trends in climatic gradient between EDXA and isotopic ratios can be sought.

Rationale for this project

Radio-carbon dates from the various sites around the Verlorenvlei indicate that people changed their subsistence strategies through time (Parkington *et al.* 1986). Changes in subsistence strategy are not necessarily the result of environmental stimuli (Mazel 1987). Nevertheless, a thorough understanding of environmental aspects is required before further archaeological research can be undertaken.

It has been suggested (Parkington *et al.* 1988) that at least some of these changes in settlement patterns have been largely influenced by shifts in climate. In order to test this suggestion, an independent measure of environmental change is required. Changes

increasingly emphasized the extent to which vessel size and number varies with temperature and rainfall (Carlquist 1966, 1975, 1977a, Baas 1982, Zhang *et al.* 1988, Wilkins & Papassotiriou 1989). In 1988 Zhang *et al.* were the first to publish the results of a study undertaken specifically to establish change in the anatomy of a single species along an ecological gradient. No such study has been undertaken in South Africa and only one study (van der Walt *et al.* 1988) has been undertaken using different species of the same genus from areas with different rainfall.

van der Walt *et al.* (1988) working in South Africa compared the relationship between annual rainfall and wood anatomy of the genus *Pelagonia*. Only 24 specimens from a range of localities were analysed. The high range in variation of wood anatomical variables within a tree and between different trees (Akachuku & Burley 1979 & van den Oever, et al. 1981), clearly indicate the necessity for more rigorous statistics than one sample from a particular geographic location. Using a much larger sample an attempt is made here to assess whether there is a relationship between temperature, rainfall and the wood anatomy of shrubs of the winter rainfall area of the Western Cape. It is hoped that the present study will also serve to emphasise the need for rigorous statistical methods in wood anatomical studies.

In his pioneering study, Scholtz (1986) using wood charcoal from Boomplaas Cave established differences in wood anatomy which he attributed to climatic change. Scholtz (1986) was recording climatic change over thousands of years. This thesis is an application of Scholtz' (1986) methods in an attempt to ascertain the level of precision available in EDXA.

Scholtz's (1986) work was of a pioneering nature. His research at Boomplaas Cave was no more than a very preliminary test for this methodology. Few of the electron micrographs he used were taken specifically for his project. He recorded climatic

change over thousands rather than hundreds of years. He also did not make use of a modern database.

This thesis is a systematic application of Scholtz' (1986) methodology to a problem area, the Verlorenvlei (Fig 2), in order to test its precision and practicability. There are many levels at which the EDXA approach should be tested, the most important of which are range in variation in wood anatomical structure:- from one rainfall regime to the next, between genera, between species, within a specific species, within a specimen, between wood and charcoal and between the different components of the same plant. The main questions addressed in this thesis are; (i) What exactly is the relationship between xylem morphology and climate? (ii) What level of precision can be obtained with this method, hundreds or thousands of years?

The first step in answering these questions was the identification of the most important wood types available to prehistoric people. This information was obtained in two stages; (i) by an initial survey of the Verlorenvlei area, to ascertain what indigenous wood is available in the area today, and (ii) by the microscopic examination and identification of charcoal recovered from archaeological excavations at Spring Cave, Mike Taylors Midden and Tortoise Cave (Fig 2), to ascertain whether there has been any significant change in species used for firewood within the last 4000 years.

Archaeological and modern wood samples were compared anatomically. Two families, *Ebenaceae* and *Anacardiaceae*, were chosen for EDXA analyses, because samples were available throughout the archaeological sequence as well as in the modern environment. Samples from different climatic zones were collected for comparison and potentially significant wood variables measured, using the computer program edxa2. This information was compared to measurements done on archaeological samples to seek changes through time.

Another aspect to this thesis is the identification of archaeological charcoal specimens. Identification of charcoal is possible because wood when charcoaled does not lose any of its distinctive anatomical features. Previous research has indicated that it is possible to reconstruct the vegetation mosaic or climate of an area on the basis of an analysis of the relative abundance of wood preserved as charcoal in archaeological sites. This section of the thesis is an application and criticism of the theory behind this type of analysis.

In order to obtain an independent test on the results of both EDXA and morphological type analysis, some of the charcoal was subjected to stable carbon isotope analysis. The rationale behind this approach is that the ratio between the stable isotopes ^{12}C and ^{13}C can be a good estimate of water use efficiency (Hubick *et al.* 1986). This is the first study that attempts to correlate $^{13}C/^{12}C$ measurements on wood charcoal to temperature and rainfall.

In summary, this thesis serves to evaluate three methods of environmental reconstruction. It also addresses some of the archaeological problems at Elands Bay. Wood charcoal forms a major component of most archaeological sites. It is possible that analysis of this charcoal can provide further evidence for the factors that underpin changing patterns in prehistoric subsistence patterns and land use by Later Holocene Stone Age People.

Thesis layout

The rest of this thesis is divided into six chapters. Chapter Two is a discussion of the archaeology, geology, geography, and vegetation of the research area. Charcoal identification and relative abundance of wood morphological types is dealt with in Chapter Three. In Chapter four the EDXA approach to wood anatomy is discussed. In the next chapter observations made and formulae developed in Chapter four are applied to the archaeological sample. Moving away from wood anatomy, Chapter Six is

an examination of the stable carbon isotope values of wood charcoal. Chapter Seven, the conclusion, summarises the results and discusses the implications of the analyses for archaeology and wood anatomical studies.

CHAPTER TWO

THE ARCHAEOLOGY OF THE AREA SURROUNDING ELANDS BAY

Introduction

The research area from which archaeological samples were obtained for this study is focussed at Elands Bay, on the west coast of South Africa at latitude 32°19' south and longitude 18°20' east (Fig 1). Feeding into this bay is a coastal lake called the Verlorenvlei (Fig2), which is in turn fed by a river of the same name flowing in a north westerly direction across the coastal plain of the south-western Cape. This river is substantial but seasonal, to the extent that it is only after good rains that the sandbar blocking the mouth of the vlei is broached (Grindley & Grindley 1987). Elands Bay is, archaeologically, one of the most intensively researched areas in South Africa today. Over the past twenty years, a group of researchers led by John Parkington have systematically surveyed, recorded and excavated the archaeological sites in great detail. This chapter consists of a short description of the geography, archaeology and ecology of the area, concentrating on those aspects of the ecology pertinent to an understanding of palaeoclimatic reconstruction using wood charcoal.

Geology and Geography

The surface geology of the area follows a north west/south east plane, which is the direction of the geological fault running through the area. The most prominent feature other than the Verlorenvlei itself is the Bobbejaansberg or Elandsberg running parallel to the coast, rising to 114 metres above sea level and dropping at Cape Deseada to a narrow, rocky and exposed point called Baboon Point. South of Babboon Point the cliffs decrease in height to merge with the coastal platform about six kilometres further south (Miller 1987). The hills to the north east rise for about two or three hundred metres above sea level and are covered in reddish brown to white sands, frequently displaying hummocks (heuveltjies) (Butzer 1979). The soils of the area have not been

comprehensively analysed but are probably sandy, acid and nutrient poor (Sinclair *et al* 1986)

Rocky outcrops such as that at Baboon Point and the much less prominent Mussel Point about 2kms south of Baboon Point are extremely important to archaeological research in the area, as these are host to a high biomass of filter feeding mussels (*Choromytilus meridionalis*) or, if wave action is reduced, to grazing limpet colonies of the genus *Patella*.

The Environment at Elands Bay

Ecologically, Elands Bay, because of its oligotrophic soils, evergreen sclerophyllous shrublands and winter rainfall, is classified as a Mediterranean shrubland as defined by and Moll Bossi (1984) and Moll and Jaarman (1984). Within this Mediterranean shrubland Grindley *et al.* (1982) recognises five vegetation types namely strandveld, fynbos, rocky outcrop, marsh and karoid communities. The two most common vegetation groupings are arid forms of fynbos and strandveld. Fynbos occurs inland of the dune cordon, on deep leached acid sands, whilst strandveld grows adjacent to the coast (Grindley *et al.* 1982). It is probable that strandveld and fynbos vegetation are delineated by soil type, with strandveld growing in the alkaline soils, and fynbos on acid soils (Grindley & Grindley 1987).

The major woody species on the Bobbejaansberg today are *Diospyros glabra* ((L.) de Winter), *Rhus scytophylla* (Ecklon & Zeyher), *Euclea racemosa* (Murray), *Pterocelastrus tricuspidatus* ((Lam.) Sonder), *Zygophyllum morgsana* (L.) and *Lycium* spp. Cliff vegetation occurs in shaded rocky areas protected from fire. It is possible that this latter vegetation formed a major source of firewood for prehistoric communities. Prominent vegetation includes *Heeria argentea* ((Thunb.) Meissner), *Maytenus oleoides* ((Lam.) Loes.), *Rhus scytophylla, Salvia sp., Cliffortia ruscifolia* (L.) and *Ruschia maxima* ((Haw.) L.Bolus).

The coastal foreland and that area of dune sand abutting the Bobbejaansberg has a different species composition. In this area, major woody species are, *Euclea racemosa, Zygophyllum morgsana, Ruschia frutescens* , *Ruschia maxima, Lycium* sp. and *Rhus* sp.

In the field, selection of species most amenable to study was made on the basis of prevalence.

Rainfall

There is no weather station at Elands Bay, the closest one being that at Redelinghuys about 20kms inland. There are problems in extrapolating from rainfall records at Redelinghuys to Elands Bay, because of potential orographic rain, caused by the Bobbejaansberg, increase in fog close to the coast, and the general climatic amelioration caused by the Benguela current. Rainfall at Elands Bay probably fluctuates around a mean of 200mm per year. This rainfall is almost entirely caused by cyclonic lows which move north-eastward, bringing cold fronts out of the South Atlantic. The fronts are normally accompanied by moderate to strong westerly to north westerly winds, and are restricted to the winter months of May to October. In summer the belt of westerlies moves further south, and few of the cold fronts actually make contact with the coast. The winds during this period are strong to moderately strong south easterly, giving rise to dry windy summers (Parkington 1986). Sinclair *et al* (1986) point out that there is a high incidence of fog at Elands Bay. This fog can provide as much as 130mm of rainfall in 120 fog days, thereby making more moisture available to plants than is indicated by the rainfall data (Sinclair *et al* 1986).

Archaeology

Human occupation at Elands Bay dates back to the Early Stone Age, as there are handaxes on top of the Bobbejaansberg. The emphasis in research, however, has been directed on the last 12 000 years. This archaeological research has recently been reviewed by Parkington *et al.* (1988) and the following summary makes extensive use of

reviewed by Parkington *et al.* (1988) and the following summary makes extensive use of this review article. Archaeological remains are recorded in approximately 100 sites discovered in the bay area, as a result of which the spatial patterning through time is becoming better understood.

The melting of the ice sheets at the end of the Pleistocene resulted in a rise in sea level which gradually flooded the coastal plain, home to large herds of bovids and equids (Klein 1980). Concomitant with and the probable reason for this melting is a global increase in temperature of between five and ten degrees centigrade (Butzer 1973, Deacon 1982). These environmental changes would have affected the subsistence patterns of people at the time.

In the period between 11 000 B.P. and 8000 B.P. archaeological remains are rare, restricted to two or three of the larger cave sites. It is probable that in the terminal Pleistocene, population levels were low, and people were concentrated in small mobile bands following the large herds of grazing animals. In support of this hypothesis, the bones of large bovids and equids are more prominent in terminal Pleistocene levels than later in the same sequence. After 9000 B.P. the bones of large grazers become extremely rare, and at least three become extinct (Klein 1980). At this time, human occupation was limited to several caves on the Bobbejaansberg (Parkington 1986).

Between 7700 and 4300 B.P. there is a hiatus in occupation at all the sites around the Verlorenvlei. It has been suggested that the complete absence of human occupation for 3400 years can be directly related to a rising sea level (Flemming 1977, Miller 1987), as well as lower rainfall and higher temperatures (Parkington 1986). Progressive rise of sea levels would have resulted in the flooding of the Verlorenvlei with sea water, so that the salt/freshwater boundary retreated many miles upstream. This, along with lower precipitation, reduced the amount of fresh water available to prehistoric people at the coast. Parkington (1986) suggests a rise in sea level of about 2cms per year. Flemming

(1977), working in the Langebaan lagoon, approximately 100kms to the south, records a mid-Holocene rise in sea level of 3 metres above present levels. The most convincing evidence for a mid Holocene rise in sea level has been a reported raised beach dated to 3800 B.P. (Yates *et al.* 1986). The rising sea level would have submerged the rocky platforms which house the shellfish colonies.

A reduction in the size of the mussel colonies, an increase in the area of sandy beaches, along with a decrease in available fresh water would be no incentive for people to exploit the coast. In short, the area surrounding the mouth of the Verlorenvlei would have been less attractive to people than it had previously been (Parkington 1986, Parkington *et al.* 1988). Excavations in the Cape fold belt have produced several dates between 8000 and 5000 years ago, suggesting that there was mid Holocene occupation at those areas more favorable to human occupation at the time (Parkington 1986).

Regular occupation at the coast was resumed 4000 years ago, at a time when the Verlorenvlei was still fully estuarine (Yates *et al.* 1986, Parkington *et al.* 1988). Perhaps because the coast would still have been a relatively unpleasant place to live, there is no evidence for people living in open sites. Visits are only recorded in three rock shelters. It is probable that at this period, people were moving from the open sites of the sandveld through to the coast, collecting mussels at the coast, then moving back into the sandveld (Manhire 1987). This hypothesis is based on the similarity in stone tool assemblages in the undated sandveld and dated cave deposits between 4400 and 3000 B.P. (Manhire 1987, Parkington *et al.* 1988).

As the sea level dropped from a mid Holocene high, with a probable isostatic rise in the land surface (Miller 1987) the extensive rock platforms at places like Baboon Point and Mussel Point became exposed intertidally (Parkington 1986). Settlement at 3000 B.P. was still organised around cave sites. Shortly after this settlement patterns changed abruptly, as people began to exploit the rich mussel beds exposed by the lowered sea

level (Parkington 1986). For more than a millennium, between 1800 and 3000 B.P. there was a substantial accumulation of coastal debris, concentrated around open sites such as Mike Taylor's Midden (also known as Elands Bay South) and Kreefbaai. This accumulation of *Choromytilus* was considerably more intense than in the preceding millennium. Between 4400 and 3000 years ago shell deposits dominated by *Choromytilus* are estimated to be between 100 and 300 cubic metres per site. The deposit at Mike Taylors Midden (MTM), however, represents approximately 10 000 cubic metres of shell accumulated in a single millennium (Parkington *et al.* 1988, Buchanan 1988). This deposit consists almost entirely of black mussel (*Choromytilus meridionalis*). The archaeological deposit at Spring Cave represents a transition period, when people were still living in cave sites but were also exploiting the black mussel.

There is another major change in site distribution patterns at Elands Bay circa 1800 B.P. with the introduction of pottery and domestic stock into the area. Whereas sites of the previous millennium can be measured in thousands of cubic metres of deposit, these later sites are much smaller, measurable in tens or hundreds of cubic metres (Parkington *et al.* 1986). Site distribution patterns change substantially from a few large open sites to a scatter of apparently more ephemeral sites which may be caves, rock shelters or open middens (Parkington *et al.* 1986). Spring Cave and Tortoise Cave were occupied during this period, but MTM shows no indication of occupation.

Prior to 1800 B.P. occupational debris consisted almost entirely of *Choromytilus meridionalis*. After 1800 years ago the contents of these middens are no longer uniform, indicating that people were exploiting the full range of marine foods available to them (Buchanan 1988). Parkington *et al.* (1986) and Parkington *et al.* (1988) argue that these changes in pattern, coincidental with the introduction of domestic stock into the area, indicate a response by hunter gatherers to pastoralists, resulting in competition for resources and the relocation of hunter gatherers to those areas not occupied by pastoralists. In inland sites of the same age there is a heavier emphasis on plant foods,

represented by plant food debris such as corm cases, wooden digging sticks and stone tools used in the manufacture of digging sticks.

Summary of the archaeological record

The Holocene archaeological record is one of change, as people adapted either to a changing environment, or to changes in social relations. These changes are well documented archaeologically, and are represented in changes in site distribution and subsistence patterns at Elands Bay. Indications are that there are three major changes in settlement patterns during the Holocene. Terminal Pleistocene/Early Holocene sites are few and widely dispersed, probably relating to highly mobile bands of hunter gathers following the herds of grazing animals. Between 7700 and 4300 B.P. there are no occupational horizons in any of the sites excavated at Elands Bay. Sites from the Cape Fold Belt have been dated to this period, suggesting that the Cape Fold Belt was more favorable to human occupation at the time. From 4300 to 3000 B.P. people at Elands Bay tended to live in two or three of the larger rock shelters. It has been suggested that environmental conditions at this time were still not suitable for human occupation of open sites (Parkington *et al.* 1988). Between 3000 B.P. and 1800 B.P. archaeological sites are restricted to large open sites situated on the coast. These sites contain vast accumulations of black mussel, almost to the exclusion of anything else. After 1800 years ago and coincidental with the appearance of pastoralists, site distribution patterns indicate a tendency for people to move back into the rock shelters, including many very small ones (Parkington *et al.* 1988).

Conclusion

In this chapter the archaeological, geological, geographical and ecological context in which this thesis is presented was discussed. Within this discussion is the necessary background to enable an understanding of the archaeological and environmental aspects of the rest of this thesis. The following chapters describe an application of three

approaches to palaeoenvironmental climatic reconstruction using wood charcoal from archaeological sites. The next chapter is a discussion of the first of these techniques.

CHAPTER THREE

CHARCOAL IDENTIFICATION AND RELATIVE ABUNDANCE

Introduction

This chapter details the results of analysis of charcoal from MTM, Spring Cave and Tortoise Cave (Fig 2) in terms of species composition and relative abundance of wood morphological types. The emphasis of this section of the study is an analysis of environmental change through wood identification from xylem anatomy. This identification is made possible because charcoaled wood does not lose any of its distinctive anatomical features.

Analysis of charcoal from the archaeological sites of Tortoise Cave, Spring Cave and MTM (Fig 2) should show changes in species composition concomitant with climatic change through time. This charcoal represents the remains of firewood collected by people, who made specific choices on the types of fuelwood they required. The archaeological record will, therefore, always be skewed in the direction of the favoured fuelwood available to people at the time of collection. People when collecting firewood concentrate on a selection of favoured species (Gandar 1982, Milton & Bond 1986). As such, the charcoal composition of an archaeological site is not a reflection of the woody species growing in the area. With environmental change the species composition of these favoured fuelwoods would of necessity also change. It is on the basis of this assumption that environmental change can be inferred from wood anatomy.

Firewood selection strategies

The collection of fuelwood, and the consequent fossil charcoal sample, is not primarily representative of the environment at the time the wood was collected. It represents, rather, the relative abundance of dry fuel wood species. The dynamics of the transition from potential firewood to charcoal are socioeconomic and not environmental. The

results of morphological analysis on charcoal from Elands Bay will therefore reflect the selection of certain woody species by people. Differences in species composition will reflect environmental change.

Methods

The identification of wood to genus/species level is possible because the different genera have distinctive combinations of anatomical features visible microscopically. When charcoaled wood retains these distinctive anatomical features (Salisbury and Jane, 1940, Deacon *et al.* 1983, Tusenius 1986). Positive identification of fossil charcoal is achieved by comparison with photomicrographs of identified modern specimens. This identification is hampered by wood anatomical variability (Rendle and Clarke 1934, Barefoot and Hankins 1982, Zimmerman 1983). The variation in wood anatomy is due to a number of ecological as well as physiological causes. The set of factors involved are discussed more fully in Chapter 4. It is sufficient to state here that a number of researchers have indicated the need for exhaustive research to identify a single piece of wood positively (Carlquist 1980, Baas 1982, Scholtz 1986).

It is not only the natural diversity between different samples of wood from the same tree that makes positive identification of charcoal samples difficult. Further factors affecting the positive identification of fossil charcoal are the state of preservation of some of the charcoal, the fact that only transverse sections of wood were used for identification, and the use of only one photomicrograph per section of fossil charcoal. Inherent in the use of a larger sample, are the very reasons that make positive identification unreliable.

In ecological wood anatomy contradictory demands such as these have to be resolved at an early phase in the research. In this study it was decided to forego painstaking taxonomic identification in favour of a large body of data. As a result, in excess of 100 pieces of charcoal were analysed from each well dated stratigraphic unit of three

archaeological sites from the last 4000 years at Elands Bay (Fig 2). The difficulty of precise identification of fossil charcoal meant that charcoal pieces were grouped into morphological types. Where possible these morphological types were associated with a specific genus.

The association of morphological types with specific genera are most likely correct in the case of *Ruschia*, *Diospyros/Euclea* and *Zygophyllum*, because of the very distinct nature of the wood anatomy of these genera. The morphological types for *Ruschia*, however, may include other *Mesembryanthemaceae*. A total of nine morphological types were identified in the various assemblages. A tenth category was used for all wood not identifiable because of breakage or bad preservation. Of the 1200 pieces of charcoal examined single photomicrographs were only taken of the morphological types *Rhus*, *Zygophyllum* and *Diospyros/Euclea*.

To enable computerised identification of fossil charcoal a checklist of the most common wood anatomical variables was compiled. The relevant qualitative features visible through a microscope could then be checklisted and loaded onto computer. A data base programme was formatted and used to group all charcoal pieces with the same features. Anatomical features chosen relate to growth rings, vessels, parenchyma, rays and fibres. These features were chosen from Kromhout (1975) and Tusenius (1986) and adapted to suit the Elands Bay assemblages.

Results

The results of the analysis are presented in Table 1 and Figures 3 and 4.

The most significant trend concerns the morphological type likely to equate with the genus *Ruschia*. *Ruschia* is most common at 3000 B.P. (55% of total sample) 2500 B.P. (51%) and 840 B.P. (47%, Fig 3). These results, however, are only true for MTM and

Spring Cave, as there is no *Ruschia* recorded in the archaeological sample from Tortoise Cave.

From Figure 3 and Table 1 it can be seen that: The morphological Type A is more common at Tortoise Cave 1600 years ago than at Spring Cave and MTM. Spring Cave has a maximum of 12% of Type A at 1150 B.P., and MTM 11% at 2000 B.P.. The percentages of Type A in the archaeological record decrease when the percentages of *Ruschia* increases. This suggests an inverse relationship between the two. The morphological type *Zygophyllum* also shows some opposite trends to *Ruschia*, but these are not as clear as those exhibited by the morphological Type A. The percentages of *Lycium* increase at 1600 B.P. but otherwise do not vary much. *Pterocelastrus, Rhus* and *Diospyros/Euclea* show no remarkable trends (Table 1).

The total percentage of charcoal identified into one of ten categories, is different at Tortoise Cave, Spring Cave and MTM (Fig 4). These ten categories consist of the most common identifiable morphological types in the archaeological record. Spring Cave and MTM have high proportions of identifiable charcoal. Tortoise Cave, on the other hand, has much lower percentages of identifiable charcoal (Fig.4). Identifiable charcoal from Tortoise Cave is also not of the same morphological types as the charcoal from MTM and Spring Cave (Fig 3).

It is likely that the charcoal that does not fall into one of the ten categories, represents a wide diversity of species. Thus the 30 - 40% of wood charcoal not identified at Tortoise Cave (Fig 4) is probably composed of a number of species, rather than just one or two.

Discussion

Relative distribution of woody species at Elands Bay today

It is apparent that the most common woody species at Elands Bay today, are also evident in the archaeological record over the last 4000 years (Fig 3). The proportions in

which certain species are represented do not reflect the composition of these species in the environment today. This suggests that human selection has altered the relative percentages of these species in the archaeological record.

A subjective impression of the relative percentages of woody species on the coastal backdunes showed that near MTM today, *Euclea racemosa* is the most important species. The second most important species is the succulent arborescent mesembryanthemum *Ruschia frutescens*. *Zygophyllum morgsana* also represents a relatively high canopy cover but not as high as the first two. In a similar location at Rocher Pan just south of Elands Bay, Tinley (1985) found that *Euclea racemosa* had a relative percentage canopy cover of 32%, *Ruschia frutescens* 18%, *Rhus glauca* 9%, and *Zygophyllum morgsana* 8%. Using a synthesis of Tinley's results and personal observation at Elands Bay it was deduced that *Euclea racemosa* is by far the most common woody plant on the coastal back-dunes, followed by *Ruschia frutescens*, *Zygophyllum morgsana* and *Rhus glauca*.

Relative distribution of archaeological charcoal.

Mesembryanthemaceae make up a very small proportion of the modern population of woody species on the back-dunes at Elands Bay. This is not the case in the archaeological record. The morphological types for *Ruschia* show consistently high percentages in the archaeological record (Fig 3).

The morphological type *Diospyros/Euclea* is probably represented entirely by *Euclea* in the archaeological record at MTM, because there is no *Diospyros* growing on these dunes today. This type is less common in the archaeological record compared to the modern sample (20% as opposed to 32%). *Zygophyllum*, on the other hand constitutes 15-20% of the archaeological sample, more than double the 8% mentioned by Tinley (1985). Thus the relative abundance of those species in the archaeological record does not reflect the relative abundance of species in the area today.

The major woody species at Elands Bay today are present in the archaeological record over the last 4000 years. This representation is not directly proportional to the relative abundances of these species at Elands Bay today. It would seem that this disproportional representation cannot be attributed to environmental change. To have some environmental/climatic basis the archaeological record and the modern sample should correlate at some point in time. These two cannot be consistently out of phase with each other. It is suggested that the relative abundances of woody taxa represented in the archaeological record at Elands Bay (Fig 3) are an indication of human selection in firewood procurement strategies. People were very specific about the types of woody species they selected for firewood. This observation is in keeping with studies done on the firewood procurement strategies of contemporary subsistence farmers (Gandar 1982, Milton & Bond 1986).

Environmental differences between sites

Environmental conditions between coastal and inland sites are very different. It is possible that but for overgrazing and too frequent fires, the area around Tortoise Cave would have a higher frequency of fynbos species than any of the other sites under investigation. The relative percentages of wood morphological types from the different sites shows the distinction between Tortoise Cave and the other sites (Table 1, Fig 3). This distinction is also clearly visible in the percentages of identifiable charcoal from the archaeological sites at Elands Bay (Fig 4). The evidence supports the hypothesis that the charcoal sample from Tortoise Cave represents both a different environment as well as a different subsistence strategy.

Tortoise Cave is situated approximately 4500 metres away from the coast, facing in an easterly direction. The vegetation in the vicinity of this site is not subjected to the same climatic conditions as that of the coastal sites. Wind and the salt spray carried by winds, are the overriding reasons behind the coastal dune vegetation, with its comparatively

poor species diversity compared with the inland sites. *Ruschia* and *Zygophyllum* are the most suitable forms of firewood available on the dunes and it is these species that are collected preferentially by prehistoric people. At Tortoise Cave, on the other hand, preferred species are Type A and *Zygophyllum* (Fig 3).

Archaeological interpretations

Reflected in the archaeological record at Elands Bay, is the environmental difference between the sites. There is however no environmental/climatic change reflected in the charcoal composition of these sites through time. The charcoal samples do show changes in relative abundance of certain species between 3000 and 2000 B.P. (Fig 3). These changes cannot be ignored, and may be representative of the changing socio-economic status of people.

Spring Cave and MTM are situated relatively close to the coast (500 metres and 50 metres respectively). These two sites have similar local environments. Hunter-gatherers living at Spring Cave would have been forced to collect firewood down slope of the cave in a similar environment to MTM because of the line of cliffs in which the cave is situated.

At about 3000 B.P. people living at Elands Bay first begin to exploit the rich mussel beds at Baboon Point and other similar rocky intertidal zones (Parkington *et al.* 1988). They were still living in cave sites such as Spring Cave when this change in subsistence strategy is registered in the archaeological record. It is at this time that the percentages of the *Ruschia* morphological type from Spring Cave is high (50%, Fig 3). Over time the percentages of *Ruschia* at these sites declines to almost 10% of the total.

The suggestion is that when people first begin to exploit the mussel colonies in the rocky intertidal zone at places like MTM, they prefer to use *Ruschia*. With time the dry

wood supply of *Ruschia* becomes impacted to the extent that people are forced to diversify their firewood collecting strategies.

After 1800 B.P., with the introduction of sheep and pottery into the area, the socio-economic status of these people may have changed abruptly to a society under stress, exploiting a wide range of natural resources. This situation is reflected in peoples firewood procurement strategy as a more diverse selection of wood is recorded in the archaeological record. Even during this phase, *Ruschia* is still the preferred fuelwood (Fig 3).

Summary & Conclusions

This chapter discussed the results of analysis of charcoal from three archaeological sites at Elands Bay in terms of the relative abundance of wood morphological types. From this analysis it can be shown that; The relative abundance of charcoal morphological types in the archaeological record at Elands Bay over the last 4000 years is not determined by climate. Rather the dynamics of the transition from potential firewood to charcoal are socio-economic. The only morphological type to reflect the impact of people is Ruschia between 3000 and 2000 B.P. (Fig 3). An independent sample of wood charcoal taken from one of these sites and dating to this period should be analysed, to see whether this hypothesis will hold. Climatic change at Elands Bay has not been sufficient to markedly influence the species composition of wood brought into the sites by people (Fig 3). Species composition, however, does reflect the difference in environment between Tortoise Cave, Spring Cave and MTM (Fig 4).

The relative abundance analysis shows that there has been no major changes in climate at Elands Bay during the last 4000 years. An alternative method for determining palaeoclimatic change may indicate subtle changes in climate during this period. Inherent in relative abundance analysis is the identification of charcoal morphological types from xylem anatomy. In the next chapter, these identifications are used in a

different approach to palaeoclimatic reconstruction called Ecologically Diagnostic Xylem Analysis.

CHAPTER FOUR

ECOLOGICALLY DIAGNOSTIC XYLEM ANALYSIS OR EDXA: METHODOLOGY AND APPLICATION TO MODERN SAMPLES.

Introduction

During the process of transpiration, woody plants transport water and dissolved mineral salts from the roots to the leaves via the xylem vessels. A number of researchers have demonstrated that the diameter of these vessels decreases whilst the vessel frequency increases with increasing drought (Carlquist 1977a, Baas 1982, Zhang *et al.* 1988, van der Walt 1988). This chapter reports the results on analysis of vessel morphology of plants from the western Cape. Also included in this chapter is the rationale behind and methods used in the EDXA approach to wood anatomy.

Ecologically Diagnostic Xylem Analysis (EDXA), refers to an efficient economical way of measuring all the features visible in a cross section of wood. It is a computer based approach to quantitative wood anatomical studies, in which measurements made on a digitising tablet are automatically fed into a database. The primary intent of EDXA is not wood identification, "but rather to measure a wide range of the functionally significant wood anatomical variables which are observable in transverse section (Scholtz, 1986)."

Potential uses for EDXA

The EDXA approach to wood anatomy can be used to relate any number of wood anatomical variables observable in cross section, to climate. These variables include vessel size and number, porosity, rays, growth rings and fibres. Over the past two decades, there has been some research relating all of these wood anatomical variables to various aspects of climate. EDXA is designed to test and reinforce these correlations.

Baas (1982) points out that as early as 1889 Vesque was of the opinion that taxonomic identification using wood anatomy was not possible because of the intraspecific diversity brought about by ecological factors. In their study of the *Styracaceae* Dickison and Phend (1985) found correlations between latitude and multiseriate ray frequency, ray height, fibre tracheid diameter, vessel frequency and both vessel and tracheid wall thickness. Fidel and Roig (1986) in their observations on *Adesmia horrida* found that trees growing on well watered slopes were diffuse porous, while those growing under water restriction were ring porous. These findings are in agreement with Lipschitz and Waisel (1970) who showed high variability in porosity due to environmental variation.

Den Outer and van Venendaal (1976) found a significant correlation between increased ray tissue and environmental conditions between savannah and rain forest trees of the same species. A number of researchers have shown the correlation between ray height and higher latitudes and altitudes (Carlquist 1966, van den Oever *et al.* 1981 and Wilkins & Papassotiriou 1989). Zhang *et al.* (1988) found strong correlations between average annual ring width and rainfall in *Syringa oblata* on Mount Taibei in China.

Relationship between xylem vessels and climate

There are thus a number of aspects to the potential use of EDXA. This study, however, focuses on only one of these aspects: the relationship between vessel morphology, frequency and climate. Based on his observations of the *Asteraceae* Carlquist (1966) may have been the first to point out this pattern. His observations have been upheld by further studies such as those of Carlquist (1975) Baas (1982) and Zhang *et al.* (1988).

Carlquist (1975) suggested that wood anatomical diversity is controlled not only by environmental pressures but also by growth habit. Plant physiology is directly related to wood anatomy and it is this relationship of structure and function that is important to wood ecological studies (Baas 1982). Plant physiological studies such as that of Zohary (1962) related rates of transpiration to vessel size and number. He noted that most

species with low transpiration rates have smaller and more numerous vessels than those species with higher transpiration rates.

Further research (Fahn 1962, 1964 and Baas *et al.* 1983) has lent credence to Zohary's (1962) work. Fahn (1962) demonstrated that the cycle of cambial activity of plants in the Negev desert corresponds to the rainy season. Fahn and Sarnat (1963) showed that the period of cambial activity was essentially similar in four different genera from the Negev. Activity began at the beginning of the rainy season, and cell division stopped at the end of or shortly after the season. Rates of transpiration, vessel size and number, and rainfall are therefore closely related.

Waisel *et al.* (1970) took these observations one step further in their investigation into the cambial activity in *Zygophyllum dumosum* (Boiss). Their experiments showed that in the younger plants cambial activity is stopped temporarily by water stress, as watering after a period of drought resulted in immediate reactivation of the cambial cells. In older plants growing in the wild, the period of cambial activity was extended by watering. Once dormant, however, the older plants would only resume growth at the correct season. If transpiration rates, vessel size and rainfall are closely related and older plants only grow at a specific season, then the age of a plant is important for studies attempting to identify the ecological component of wood anatomy. Such studies cannot be carried out on immature plants, or on that section of the xylem that relates to the plant when it was young.

In order to establish the predictive value of certain vessel element features, Carlquist (1977a) analysed a cross section of the woody vegetation of Australia to determine the correlation between wood anatomy and environment. Carlquist's (1977a) results confirm his (1975) hypothesis showing a strong relationship between wood anatomy and environment, especially with regard to his indices of Vulnerability.

Carlquist (1977a) constructed an index termed vulnerability, based on the hypothesis that the more numerous the vessels the less likelihood there is of serious impairment of conduction due to accidental embolism. Vulnerability is calculated by dividing mean vessel diameter by the number of vessels in a transverse section of wood. The lower this ratio, the more capable a plant is of withstanding water stress (Carlquist 1977a).

Baas *et al.* (1983) related cambial activity, maximum vessel diameter and transpiration rates. They noted that their sample of Middle East flora showed high values for maximum vessel diameter. They related this pattern to high transpiration rates in the hot summers and ample water supply to the root system. More specifically, vessel diameter increases with increase in transpiration rates due to high temperatures and ample water supply (Baas *et al.* 1983). This logical adaptation had been stressed by Carlquist (1980). Water transpiration rates of broad-leafed trees in sunny lowland localities is great. The occurrence of wide vessels in these trees represents an adaptation to the environmental conditions under which they live (Carlquist 1980).

This trend is confirmed by Zhang *et al.* (1988) from research into the ecological anatomy of *Syringa oblata* on Mount Taibei in northwestern China. On Mount Taibei rainfall increases with altitude, from 675mm (1000m) to 900mm (1800m). Zhang *et al.* (1988) found a strong positive correlation between rainfall and vessel size and frequency. They also noted a steady increase in plant size and stem diameter with increasing rainfall. Other studies such as that of Wikins and Papassotiriou (1989) on *Acacia Melanoxylon* in Australia, confirm these results.

Efficiency versus Safety

Zimmerman (1978, 1982, 1983) has emphasised that, within a tree, vessel size and number of vessels per mm^2 can be seen as a compromise between efficiency and safety. Efficiency refers to a plant's ability to pump water, as wide vessels are more efficient conductors than narrow vessels. The principle is exactly the same as drinking a

milkshake out of a wide or narrow straw, the wide straw is much more efficient than the narrow one. Zimmerman (1983) demonstrates the relationship between tube width and conduction using the Hagen-Poiseuille equation. The Hagen-Poiseuille equation states that:

$$Lp = \frac{r^4}{8n}$$

Parabolic flow causes the flow rate to be proportional to the fourth power of the vessel radius (r). Lp refers to hydraulic conductivity and n refers to the viscosity of the liquid, the other terms are constant. The r^4 relationship means that a slight increase in vessel radius is equivalent to an enormous increase in ability to transport sap. The relationship is so enormous that three vessels with relative diameters of 1, 2 and 4 and having surfaces areas of 1, 4 and 16 will have relative conductivities of 1, 16 and 256. The proportional percentage of sap transported by three such vessels will be 0.4, 5.9 and 93.7 (Zimmerman 1978, 1982, 1983).

Increased vessel diameter may increase conductivity, but concomitant with this increase in conductivity is a decrease in safety. Two trees, with similar transpiration rates and root systems, but with different vessel size classes, will react differently to accidental vessel embolism. Although both trees are able to conduct the same amount of water, the one tree has numerous small vessels, and the other has a few large vessels. In the event of any vessel injury causing the permanent blockage of a vessel, and because of the R^4 relationship, the damage done to the tree with wide vessels will be very much greater than in the tree with narrow vessels. The more numerous the vessels the smaller the chance that the disabling of a given number of vessels will seriously affect conduction (Zimmerman 1982, 1983).

Problems and Considerations

As illustrated above, research over the last two decades supports the basic hypothesis that vessel diameter decreases whilst vessel frequency increases with increasing

drought. Although this hypothesis is superficially sound, the theory is too simplistic, as wood anatomical variability is affected by more than just temperature or rainfall (Baas 1976). Carlquist (1977a) and Carlquist and Hoekman (1985) found that a considerable deviation from a linear relationship between vessel diameter and vessel frequency can and does occur.

This variability in quantitative wood anatomical features is observable in a number of instances including variation within a species/genus, within the same microenvironmental area, within a tree, within the same branch, from the pith to the cambium, and across a single growth ring (Rendle and Clarke 1934, Akachuku and Burley 1979, van den Oever *et al.* 1981, Barefoot and Hankins 1982.) This variation accounts for a very high 'noise level' when attempting to relate wood anatomical variables to climate. In order to unearth the climatic component of the wood anatomical variation, suitable statistical methods need to be applied to the results of analysis (Carlquist 1980, Baas 1982).

Methods

Modern sample

It is only possible to identify and evaluate fossil charcoal in the context of a modern reference collection. This reference collection is important for an understanding of the extent to which xylem structure changes with rainfall and temperature. Results of EDXA (and latter isotopic analysis) on modern wood specimens can then be compared with fossil specimens in order to develop hypotheses about palaeoclimatic change.

The within-tree variability between roots, twigs and branches makes it extremely hazardous to infer relationships between wood anatomy and climate, when one has a random sample of wood. The wood anatomy of any given tree varies so much throughout the plant that ecological trends in wood anatomy only make sense when samples are collected from similar heights on a tree (Zimmerman 1983). There is a

strong positive correlation between wood element size and frequency, and plant size (Baas *et al.* 1984, Zhang *et al.* 1988) In an attempt to control for this variation, wood was cut from branches of similar size, age and position on the tree.

Within any given area, there is a range in wood anatomical variation due to microclimate. The results obtained from the analyses of fresh wood are to be compared with wood charcoal from archaeological sites. Wood from archaeological sites reflects the firewood gathering strategies of prehistoric people. Firewood was probably gathered from a range of local environments, although not necessarily unselectively. Therefore, no selection was made when collecting contemporary wood specimens within a sample area. The only exception to this was a control for microclimate, where wood was collected from as small an area as possible.

In his analysis of the fossil charcoal from Boomplaas cave on the South coast, Scholtz (1986) reports a strong correlation between temperature, rainfall and the wood anatomical structure of *Rhus*. The results of Scholtz' (1986) work led to the decision that *Rhus* would be a suitable genus to use for the present study. In order to ascertain the reliability of trends in climatic variation established from fossil samples of *Rhus*, fossil samples of both *Diospyros* and *Zygophyllum* were also chosen for analysis. Comparisons of the results of EDXA for all three genera should show similar trends in climatic change through time.

In order to relate the wood anatomy of *Rhus* and *Diospyros* to climate, it was important that samples were collected close to weather stations that recorded both temperature and rainfall. Sample areas along the west coast were severely limited by the paucity of such weather stations. In an attempt to include a diverse ecological/climatic gradient, samples were collected from a number of areas in the winter rainfall regime (Fig 1). As a result, the modern sample comes from areas as diverse as the semi-desert of the Richtersveld and the afro-montane forests of Saasveld (Figure 1). One of the most

common woody species at Elands Bay, both in archaeological deposits and the modern environment, is *Zygophyllum morgsana*. This species does not, however, occur away from the coast. For this reason, only three modern specimens of *Zygophyllum morgsana* were collected, although an archaeological sample was analysed. All modern specimens were collected from undisturbed sites as close to the nearest weather station as possible.

The stations where samples were collected can be divided into three groups, West coast, South coast and Karoo. Samples were collected from ten stations including Elands Bay (Fig 1). There are, however, no rainfall or temperature records for Elands Bay itself, the nearest weather station Redelinghuys, being 20kms inland. Six *Rhus glauca* (Thunb.), twenty-eight *Rhus scytophylla* and eleven samples of *Diospyros glabra* were collected at Elands Bay.

Samples were collected from four areas along the West coast and cover a range of environmental conditions along that coast (Fig 1). The most Northerly site is in the Richtersveld, where four samples of *Rhus incisa* (L.f.) were collected from the base of the granite slabs below Mount Tattersberg on the western edge of the Springbok flats. Closer to Elands Bay, and with a climate and ecology very similar to Elands Bay, is the Vredenburg Peninsula (Fig 1). A sample of ten *Rhus glauca* and twelve *Diospyros glabra* was collected from an undisturbed area above a quarry ±500 metres south of the West Point fish factory. Approximately ten kilometres inland from the Vredenburg Peninsula and therefore, with a climate slightly different from Vredenburg is a phosphate mine. Four samples of *Rhus laevigata* (L.) were collected on the property of this mine, about two kilometres north east of the Langebaanweg military airfield. About fifty kilometres south east of Langebaanweg, near Atlantis, is Pella: a research station funded by the Foundation for Research and Development. The final west coast sample was collected from this botanical research station. Six samples of *Rhus laevigata* and eleven samples of *Diospyros glabra* were collected here.

The second major sampling area can be broadly defined as south coast. Collections were taken from a rather diverse climatic range starting with the winter rainfall site at Jonkershoek (Fig 1) and extending east to the all year rainfall site at Saasveld. Jonkershoek is a Forestry Department research station near Stellenbosch. Four samples of *Rhus angustifolia* (L.) and two of *Rhus glauca* were collected from immediately around the weather station behind the administration offices. The *Diospyros* sample was taken from higher up the mountain above the dam, near a rain gauge marked 20A. There is probably a difference of about 100-200mm of rain per year between these two stations (Dirk Versveld pers comm.). The samples were taken well clear of the forest/plantation because a forest canopy decreases the amount of precipitation available to understory plants. From this area eleven samples of *Diospyros glabra* were collected. Three samples of *Rhus* and thirteen samples of *Diospyros* were collected in a Kloof on the Langeberg, about five kilometres from Montagu. A sample area closer to the coast and therefore more deserving of the term south coast, is Riversdale (Fig 1). A mixed sample of twenty specimens of *Rhus* was collected here. This sample included *Rhus lucida* (L.), *Rhus glauca, Rhus undulata* (Jacq.) and *Rhus longispina* (Ecklon & Zeyher). The sample area itself was not restricted to Riversdale, but consisted of a transect from Riversdale through to the coast. The different samples were collected from a number of different microclimates and microenvironments. These microenvironments were extremely diverse and included afro-montane forest, valley bushveld, mountain fynbos and coastal fynbos. In contrast to the Riversdale sample, the Saasveld sample (Fig 1) was extremely homogeneous. This sample is the only one that I did not collect personally, as the twenty samples of *Rhus chirindensis* (Baker) were collected by Carlo Jacobs of the Saasveld Forestry Research Centre. All the specimens were collected from the area of indigenous forest directly in front of the Administration building at Saasveld.

The final sample came from the FRD funded Karoo Biome Project site 'Tierberg' 27kms from Prince Albert, the only Karoo site included (Fig 1). The area is very flat and dry, and the only available samples came from the banks of rivers. The thirty seven specimens collected here included eight *Rhus lucida* (L.) nine *Rhus undulata* (Jacq.), eleven *Diospyros lycioides* (Desf.) and nine *Diospyros austro-africana* (de Winter).

Sample preparation

Within a tree vessel diameters tend to be greater in roots than in stems, and greater in the stem than in branches. Vessel diameters also tend to increase with increases in branch diameter (Zimmerman 1978, 1983). As a control for this variation samples collected in the field all have diameters of approximately 2cm. As soon as possible after these samples were brought into the laboratory, and before they could dry out, a 1cm thick disk was cut off the end. The dimensions, pith and any non-conformities on the surface of the disc were traced onto a transparency so that the exact measurements of the transverse section of the wood are preserved. It is then possible to pinpoint precisely which section of the disc was used for further analyses. Using a hammer and chisel, this disc was then cut into squares about 5mm wide, incorporating both the pith and the cambium. These squares were stored in vials containing a 50% glycerol/alcohol solution. All samples were allocated a museum number and relevant details pertaining to the sample were stored in a computerised data base. The exact location of collection including details such as soil type and slope, were also recorded.

Microtoming and staining

Because of the hardness of the sample, it was essential that a base sledge microtome be used for thin sectioning, and a number of these microtomes were tested. Base sledge microtomes are available in a variety of shapes and sizes, but the one that gave the best results is made by Reichert Jung (Model OmE). Good results were obtained with a horizontal blade angle of about thirty degrees, and vertical angle between 10 and 15 degrees.

Microtome knives were also tested. These knives are graded on the profile of the cutting edge whereby 'A' is the shallowest and 'D' the steepest. The best results came from a 'C'(60°) profile knife, although a 'D' (45°) profile did give some good results. Disposable blades look exactly like disposable razor blades and are clamped in a rigid holder. These blades cut the softer specimens, but are not rigid enough for the harder ones, tending either to warp, dig into the sample or chip. *Rhus* and *Zygophyllum* have extremely hard wood, and proved to be very difficult to microtome. Wood can either be softened by steam blasting, or boiling. Steam blasting gave the best results. A jet of steam is directed onto the transverse section to be microtomed, softening the wood sufficiently to be cut when the knife is drawn through the sample. Only the surface of the wood is immediately affected by this softening process. There is no observable affect on the wood anatomy. Boiling, on the other hand, was found to soften the entire piece of wood, which may change its structure

Samples were cut in transverse section at thicknesses of between 25 and 30 microns. These sections were stained by putting them into vials containing a mixture of alcohol, glycerol and safrinin red, and left overnight. The stained sections were mounted in Kaisers gelatin-glycerin on glass microscope slides (den Outer & van Veenendal 1976). Photographs were taken under a photomicroscope at a magnification of 40X. A graticule was also photographed at the same magnification so that exact magnifications could be calculated when the photographs were developed and printed. The photographs were printed on 203 X 254mm paper and measurements of a number of wood anatomical features were then made using a digitiser.

Climatic variables

Sixteen macroclimatic variables have been chosen to represent the major climatic factors influencing plant energy and water potential (Table 2). In general the most important ecoclimatic variables affecting plant growth are ambient temperature and

water availability. These are reflected by measurements of air temperature and precipitation. The most basic aspects of temperature and precipitation are represented by six variables. These represent, for each factor, the average, maximum and minimum values during the year. These records were retrieved from the Weather Bureau publication WB40 (1986) and are presented in Table 3.

The other important factor affecting plant growth, is the relationship between water supply and demand. This relationship, termed evapotranspiration, must be estimated because very few measurements of actual evapotranspiration are available. Thus, this potential rate of water loss is referred to as Potential Evapotranspiration (Thornthwaite 1948, Thornthwaite & Matter 1957). It is the expected loss of water into the atmosphere through both surface evaporation, and the biological processes of respiration and transpiration. Potential evapotranspiration is strongly dependent on temperature; the greater the temperature the greater the potential evapotranspiration.

This study makes use of the Thornthwaite method for measuring potential evapotranspiration, not because it is the best method in use today, but because it is the most widespread. Thornthwaites model of evapotranspiration is not accurate all over the world, as it generally underestimates PE in tropical areas and in windy areas (Box 1981a, 1981b). These problems should not affect the use of the Thornthwaite model here because accurate measures of evapotranspiration are not used. The measures of potential evapotranspiration are used only as a comparative index.

The independent variables used in this study to register solar energy are: average annual temperature (TAN), maximum monthly temperature (TMAX), minimum monthly temperature (TMIN), the difference between the two (DIFT), The minimum monthly evapotranspiration (PEmin), maximum monthly evapotranspiration (PEmax), average annual evapotranspiration (PE) as well as the range between the maximum and minimum values for potential evapotranspiration (Table 2).

The moisture category used in this study is represented primarily by annual precipitation (PAN), minimum monthly precipitation (PMIN) and maximum monthly precipitation (PMAX). Also represented here are precipitation for the warmest month (PWARM) and precipitation of the coldest month (PCOLD), the difference between the maximum and minimum values (DIFP) as well as Thornthwaites moisture index (MI) (Table 2). This moisture index is defined by Thornthwaite and Mather (1962), and is an estimate of the relative xeric or mesic conditions of a climate. It is calculated from the expression 100[(P/PE)-1] where P is equal to precipitation and PE is potential evapotranspiration (Thornthwaite and Matter 1957 & 1962). The potential moisture index is negative in arid areas, positive in moist areas and 0 where evaporation is equal to evapotranspiration. PMI is closely linked to actual evapotranspiration, which is a function of soil type, soil moisture content, land management practices and vegetation cover. It is a measurement of real water loss rather than climatic water demand as is the case in potential evapotranspiration (O'Brien 1988).

EDXA procedure

The aim of this study was to quantify relationships between modern climate and wood anatomy, and to extrapolate the results into the archaeological record. The methods used have been discussed by Scholtz (1986), but are also discussed here. A complete list of the wood anatomical variables measured is given in Table 4.

The EDXA programme is in fact a synthesis of two computer programmes. The first one is called the points programme, drives the digitising tablet, and is thus the programme that makes it possible to measure wood anatomical features on a digitiser. It is in the setup procedure of the Points programme that all observations relevant to a specific specimen are entered. These observations include location, genus, species and magnification. The magnification can be entered in or digitised from a scale bar. The Points programme also measures vessel area, ray area, excluded area and the

percentage of area covered by vessels. Another aspect of the Points programme is the measurement of vessel diameter. The programme allows for the measuring of radial and tangential diameter of seventy vessels in two size class ranges. The results of this measurement are expressed in microns (μm).

Using one primary ray and up to seven secondary rays the final aspect of the Points programme is the measurement of Minimum Branch Diameter. A full description of this method of analysis will be given in Chapter 5.

Measurements made in the Points programme are stored in a database. The EDXA programme then computes the various EDXA variables (eg. NUMV, MEANV, AREAV) and writes the results to a second database. The following is a discussion of the variables and computations used in this analysis.

Total vessel area

This variable is measured by means of a point count, the rationale and methodology of which is well documented (e.g. Clarke, 1982). A plastic sheet, marked out in a 10mm square grid is placed over the photograph to be measured on the digitiser tablet. The size of the grid can vary; the smaller the size, the more accurate the result. The Points programme allows choice of grid size, and after experimentation, a 10mm grid size was found to be suitable for the size of photograph used. Photographs were placed at a slight angle to the lines of the grid, (15°/20°) so that any radial or tangential arrangement of vessels would not lie along any of the axes of the grid. The standard 203X254mm photograph has 515 point intersects using a 10mm grid size. Total vessel area is then calculated using the number of point intersects (515). The number of points is counted, and the answer is expressed as a percentage of the total area measured. For example, if there are 500 points on the grid, and 250 of these fall on vessels, then .50mm^2 or 50% of the total area is covered by vessels. If the area covered is 2mm^2

then, we have a total vessel area of .1mm² as 50% or half of 2mm² is covered by vessels.

Pieces of fossil charcoal are often too small to fill the whole photograph, are badly preserved, or are deformed in the charcoaling process. The programme allows for a point count of these areas, which are then subtracted from the number of points on the grid, to give a new figure for the calculation of total vessel area.

Tangential vessel diameter (TANGV measured in μm)

Radial vessel diameter (RADV measured in μm)

Number of vessels per mm² (NUMV)

Radial vessel diameter refers to the diameter of a vessel in the same plane as the direction of the rays. The diameter of a vessel at right angles to the direction of the rays is the Tangential Vessel Diameter. Radial and Tangential Vessel Diameters are measured on the digitiser. The average RADV or TANGV is then calculated by taking the radial or tangential mean of the five largest vessels measured. Measurements of Radial and Tangential Vessel Diameter are dictated by the need for these measurements to be used in the calculation of maximum, minimum, mean and range of vessel diameters, relative conductivity and vulnerability.

A maximum of fifty vessels per section of wood was measured, as the Points programme has the capacity for the measurement of only fifty vessels. Using the measurements for RADV and TANGV, the EDXA programme applies the area formula for an ellipse to calculate vessel area for each vessel. The area of an ellipse equals πab where π (3.14) is equal to the circumference divided by the diameter, a is equal to the semimajor axis (half the radial diameter) and b is equal to the semiminor axis (half the tangential diameter). Mean vessel area is then calculated by dividing the sum of the areas of the measured vessels by the number of vessels measured. This value (ie mean vessel area)

is then divided into the total vessel area to obtain a figure for Number of vessels (NUMV).

Maximum vessel diameter (MAXV)

Minimum vessel diameter (MINV)

Mean vessel diameter (MEANV).

Range in vessel diameter (RANGV)

Maximum vessel diameter (MAXV) is the mean of the five largest vessels measured and Minimum Vessel Diameter is the mean of the five smallest vessels measured.

Mean Vessel Diameter (MEANV) is obtained by dividing the sum of the vessel diameters by the number of vessels measured (NUMV).

Range in vessel diameter (RANGV) is the difference between the values for MAXV and MINV.

Area covered by rays (percentage of area) (AREAR)

Area covered by rays is measured by point count in exactly the same way as area covered by vessels.

Relative conductivity per mm (RELV)

Relative conductivity is proportional to the fourth power of the vessel radius multiplied by the number of vessels (R^4 X NUMV). The result is then divided by 2 X 10^6 to allow for vessel inefficiency, and to obtain a figure small enough to work with. Zimmerman (1983) calculated xylem vessels to be perhaps only half as efficient as ideal capillaries. Van den Oever *et al.* (1981) divide their figures for relative conductivity by 10^6 in order to obtain numbers small enough to work with.

The relative conductivity figure (MEANV^4 X NUMV) first formulated by Zimmerman and Brown (1971) and used by van den Oever *et al.* (1981) is slightly modified and termed relative volume flow by Zimmerman (1983) and Scholtz (1986). This modification, calculates RELV for each measured vessel and multiplies it by the average of the five largest vessels because of the much greater conductivity of the larger vessels. Relative volume flow is the best calculation of how much water an area of xylem can transport. It is thus a good indicator of plant adaptation to water availability (Scholtz 1986).

Vulnerability (VULN)

This term, defined by Carlquist (1977a&b) is simply the MEANV divided by the NUMV. VULN is based on the hypothesis that the more numerous the vessels the less likelihood of serious impairment due to accidental embolism. The lower this ratio, the more capable the plant is of withstanding water stress (Carlquist 1975, 1977a&b, 1980, Rundel & Stecker 1977, Zimmerman 1982, 1983).

As already stated, the aim of this project has been to quantify relationships between climate and wood anatomy and to extrapolate the results into the archaeological record. The EDXA programme is ideally suited for this purpose, as it measures a wide range of wood variables which may have some correlation with climate. It also allows for the analyses of both modern (fresh) and archaeological (charcoal) samples of wood.

Results From Contemporary Wood Samples

Table 5 is a list of the areas from which samples of *Rhus* were obtained. The original observations derived from EDXA for shrubs and trees of the genus *Rhus* collected from different climatic zones are summarised in Table 6. Average values, maximum and minimum values and standard deviations per site and per species are presented in Tables 7 and 8. A correlation coefficient matrix is presented in Tables 9 and 10. The correlation coefficient matrix presented in Table 9 does not include the observations for

Saasveld. The poor results for correlation coefficients represented in Table 9 and 10, prompted a multilinear regression analysis, the results of which are shown in Table 11. The correlation coefficient matrix is given in R values, but the results of the multiple regression analysis is in R^2 values. As with the correlation matrix, the results for analyses of wood anatomical variables from Saasveld are presented separately.

Table 12 is a list of the areas from which specimens of *Diospyros* were collected. Included in Table 13 is the exact location as well as Latitude and Longitude. The specimen number as well as the general location from which each collection was made is provided in Table 13. The original observations from EDXA of *Diospyros* collected from different climatic zones are also summarised in Table 13. Average values, maximum and minimum values and standard deviations are presented in Tables 14 and 15. The correlation coefficient matrix presented in Table 16 does not include the observations for Tierberg which are presented in Table 17.

Statistics

Using Tables 6 (*Rhus*) and 13 (*Diospyros*), it is apparent that there is a wide range in variation of vessel quantitative features within an ecological area. This has been well documented in the literature (Akuchuka & Burley 1979, van den Oever *et al.* 1981, Baas 1982, Carlquist 1982). Variations of structure within a species and also within an individual plant make wood identifications difficult (Zimmerman 1983). Such variations make it hard to correlate xylem features such as vessel diameter with climate or environment.

Carlquist (1977a) in his analysis of wood across an ecological transect of Western Australia, acknowledged that statistical separation of wood anatomical variables between different floras is not achieved. Ranges are often so wide that no particular significance can be drawn from them. What is significant to Carlquist (1977a), however, is that overall patterns in wood quantitative features do follow ecological categories.

Carlquist (1980) and Baas (1982) recommend that because of the wide range in variation of most quantitative and qualitative wood characteristics, means are probably the most useful measure of the ecological component of wood anatomical variation. Baas concludes that "statistical methods are needed to unearth the ecological component of the range in variation of xylem (1982:45)".

On the basis of the conclusions of both Carlquist (1980) and Baas (1982) statistical methods were used in this study. These statistical methods were performed using the computer programmes 'Lotus' and 'Statgraphics'. Means, averages and standard deviations were obtained using Lotus. Lotus was also used for simple linear as well as multiple regression analysis. Statgraphics was used for the correlation coefficient matrices and for factor analysis.

Relationships were obtained between climatic variables and wood anatomical variables by means of linear regression analysis: $Y=(MX+C)$, where Y is a climatic variable, M is the X coefficient (slope), X is a wood anatomical variable and C is a constant. Where relationships were not immediately visible with simple linear regression analysis, multiple regression analysis was undertaken. This made it possible to obtain relationships between several wood anatomical variables and climate (Table 11). This approach involves the use of more than one wood anatomical variables as X coefficients (X1,X2,...,Xn). These are MAXV, MINV, RADV, TANGV and MEANV.

Correlation coefficient matrices were compiled in order to establish the strength of the relationships between various wood anatomical features and climatic variables. These matrices were obtained by correlating the averages for the various wood anatomical variables with mean values for climatic variables (Tables 9,10,16 & 17).

Discussion on results for Rhus

The impression is often created that the wood anatomy of species from desert environments differ markedly from related species from wetter areas (Webber 1936, Carlquist 1980, Baas *et al.* 1983). In their analysis of wood from Israel, Java and North Western Europe, Baas *et al.* (1983) found that certain genera, including *Rhus*, do not show changes in wood anatomy concomitant with ecological change. The desert species showed the same wood anatomy as the Mediterranean species. The results of the correlation coefficient matrix for *Rhus* in this study do not show a marked difference between desert species and their more mesic relatives, yet it is possible to identify wood anatomical change within the genus *Rhus*. Correlation coefficients, linking climatic data with wood anatomical variables show weak to very weak correlations between wood anatomy and climate. The highest correlations are those linking precipitation of the warmest month to various wood anatomical features (Table 10). When the wood anatomical observations for Saasveld are excluded from the correlation coefficient matrix, the same results are not obtained (Table 9).

Of all the areas sampled, Saasveld is the only one that falls outside of the winter rainfall regime. It also has the highest incidence of summer rainfall. Baas *et al.* (1983) show positive correlations between high values for vessel diameter, high transpiration rates and ample water supply. It comes as no surprise, therefore, that when correlations are made between climatic variables and wood anatomy, including samples from Saasveld, there is a strong correlation between certain wood anatomical features and precipitation of the warmest month (Table 10).

In their study of the wood anatomy of *Syringa oblata var giraldii* Zhang *et al.* (1988) found not only strong positive correlations between rainfall and wood element size, but also similar correlations between plant size and vessel size. With an increase in rainfall and altitude on Mount Taibei, in China, they found not only that vessel size increased

whilst vessel number decreased, but also that plant size increased. Their samples from the lower rainfall area are from shrubs 2-3 metres tall, whereas the samples from higher up the mountain are from trees up to 4 metres tall. Their results show a clear increase in vessel size as stem diameter increases. These findings are in complete agreement with Baas *et al.* (1984) who reported a decrease in vessel diameter in dwarf trees and Waisel *et al.* (1970) who demonstrate that the cambial activity of plants stops with water stress, although the period of this activity can be extended by availability of water.

Samples from Saasveld were taken from the branches of small trees up to 6 metres in height. Samples of *Rhus* taken from other areas were from small shrubs usually up to a maximum of 2 metres in height. The correlation coefficient matrix for *Rhus*, including results obtained for small trees from the Saasveld forest, may indicate a bias due to plant size.

When the results for Saasveld are excluded from the analysis, the only correlations between climatic variables and wood anatomy is number of vessels and temperature (Table 9). The relationship is very weak, and no reliable estimates of temperature can be made from it. At this level of analysis Baas *et al.* (1983) are certainly correct in their findings, as it would seem that there is no guaranteed relationship between the wood anatomy of *Rhus* and climate. It is possible that this lack of association between wood anatomy of *Rhus* and climate can be related to species change over. *Rhus* does not adapt to a specific environment by changing its wood anatomy but it does change its leaves. Depending on the environment, it is the species rather than the wood anatomical variables, that change. This is clearly illustrated at Elands Bay today, where *Rhus glauca* grows on the immediate coastal foreland in the vicinity of Mike Taylor's Midden, whereas *Rhus scytophylla* grows in the less extreme environment of the Bobbejaansberg. At Tierberg, there are two species of *Rhus*, each occupying a different ecological niche, with no difference in wood anatomy.

The *Rhus* fossil sample from Boomplaas Cave analysed by Scholtz (1986) shows a high degree of variation in xylem anatomy, which he relates to climatic change. It is possible that the lack of association between the wood anatomy of *Rhus* and climate exhibited in the present study, may be due to different branch sizes and different species. Scholtz (1986) identifies a single species (*Rhus undulata*) from the fossil charcoal at Boomplaas cave. This species does show changes in wood anatomy, which Scholtz (1986) relates to climatic change.

Going beyond a simple one to one correlation, and taking Baas' (1982) advice, the *Rhus* sample was subjected to further statistical analysis. Using a multilinear regression analysis (Table 11, Fig 5-6) high correlations between the wood anatomy of *Rhus* and climate were obtained. The results are interesting in that the difference between Saasveld and the rest of the sample area is clearly highlighted (Table 11 & Fig 5). Excluding Saasveld from the analysis, it is possible to obtain strong correlations between the five wood anatomical variables and rainfall (Fig 6). Correlations with temperature are also possible but not as strong.

Conclusions: Rhus

In order to unearth the ecological component of the variation in the wood anatomy of *Rhus*, a number of statistical methods are required. These include not only correlation analysis but also simple linear regression analysis as well as multilinear regression analysis. The results show correlations between wood anatomy of the winter rainfall area and the all year rainfall area, specifically with regard to precipitation of the warmest month. The ecological variation in wood anatomy within the winter rainfall area is more complex. Baas *et al.* (1983) are certainly correct in stating that at this level of analysis, there is no variation in the wood anatomy of *Rhus* due to ecological factors. Both the present study and that of Baas *et al.* (1983) used several species of *Rhus* as it was not possible to obtain a single species from a wide range of climatic zones.

Scholtz (1986), using fossil charcoal from Boomplaas cave, arrived at a conclusion based on a single species. There are however no modern correlates for Scholtz' (1986) results. It would appear that simple regressions are not sufficient to develop formulae to predict climatic data from fossil charcoal. The results of the multilinear regression analysis are promising (Fig 5 & 6), and the application of this method to charcoal will be discussed in the next section of this thesis.

Discussion of the results for Diospyros

Average values for *Diospyros lycioides* and *Diospyros austro-africana* from Tierberg indicate that species occupying different niches in the same environment have completely different wood anatomy (Table 15). The reasons for the vastly different values for different species from the same environment probably relate to differences in plant physiology. To enable definition of this variance, experiments in transpiration and photosynthetic rates, leaf size and root depth are necessary. Such experiments are beyond the focus of this study but would prove interesting for further research. It is enough to note that with regard to *Diospyros*, studies relating wood anatomy to climatic conditions have to focus on a single species from different environments. It proved difficult to obtain samples of a single species from areas with well recorded weather data. As a result samples from only four areas were used in this study. To verify the results, future research will have to concentrate on a larger sample of all species of *Diospyros*.

The only species of *Diospyros* growing at Elands Bay today is *Diospyros glabra*. It was decided that samples of this species would be collected from as many areas as possible. The results of EDXA were subjected to correlation analysis as well as simple linear regression.

The correlation coefficient matrix for *Diospyros* shows strong relationships between wood anatomy and climate (Fig 7 & 8, Tables 16 & 17) Including average values for a combination of the species from Tierberg there are strong correlations between wood

anatomical variables and temperature (Fig 7 & 8, Table 17). Without the Tierberg sample these correlations are stronger (Table 16). Tangential vessel diameter is the only wood anatomical variable that correlates with rainfall. Almost all other wood anatomical variables show some relationship with temperature. Those variables showing strong correlations with temperature are MINV, RANGV, RADV, AREAR, NUMV, AND VULN. It is this strong correlation between temperature and most wood anatomical variables that suggests that in the south-western Cape, temperature during the growing season is the single most important variable affecting plant growth. Observations on *Diospyros* have shown that cambial activity starts at the end of August and stops at the end of November. If water supply is adequate the period of cambial activity could be extended well into the summer, when temperatures are at an optimum. During the coldest periods of the year *Diospyros* remains dormant. It is also during the coldest period of the year that rainfall is highest. This too would suggest that it is temperature rather than rainfall during the growing season that is the most important variable for plant growth.

The correlation coefficient matrix for *Diospyros* (Table 16 & 17) shows an increase in vessel size corresponding to a decrease in vessel number with increasing temperature. This also suggests that *Diospyros* reacts to temperature during the growing season. High temperatures mean high transpiration rates. With an adequate supply of water *Diospyros* responds to these high transpiration rates by increasing vessel size.

Carlquist (1980) feels that the challenge to future research lies in integrating ecology, wood anatomy and physiology. This is certainly brought into focus here, where the wood anatomy of *Diospyros* suggests high transpiration rates during the growing season. If high transpiration rates during the growing season results in a small number of wide vessels, then contrary to expectations, it is not water that is the limiting factor to plant growth, but temperature. The summer months in the western Cape are hot and dry. Unfortunately, the lack of research into the physiological characteristics of *Diospyros*

makes it impossible to comment on the interaction between wide vessels and high transpiration rates in summer when water is limited, and temperatures are high.

Conclusions: *Diospyros*

The results of both simple linear regression analysis, and correlation analysis (Fig 7 & 8, Tables 16 & 17) suggest that there are strong relationships between the wood anatomy of *Diospyros* and temperature. Unfortunately these strong correlations do not extend to rainfall. It is possible that using multiple regression analysis, rainfall can also be related to wood anatomy. However, the sample of *Diospyros* used in this study was too small for statistically meaningful results from multiple regression analysis. The results from the correlation analysis are strong enough to suggest that it is possible to develop formulae to predict temperature from the wood anatomy of *Diospyros*. These formulae are composed of the results for simple regression analysis.

Application of formulae to Elands Bay sample

The formula derived from analysis of a contemporary wood sample from different rainfall and temperature regimes was also applied to a modern sample from Elands Bay. An analysis of the contemporary wood sample from Elands Bay serves two purposes. Firstly, as explained earlier, there are no climatic records for Elands Bay as there is no weather station. It is, extremely important to gain some knowledge of the modern climate at Elands Bay before hypotheses about past climate can be formulated. It also serves as a check to see if the method is working before being applied to the fossil specimens.

Summary: Rhus

An analysis of the modern *Rhus* sample from Elands Bay shows that there is no correlation between wood anatomy and either temperature or rainfall despite the correlations obtained in Figures 4 & 5. In attempting to gain some perspective on the exact nature of the problem the relationship between vessel diameter and number of vessels was examined (Fig 9). The graph (Fig 9) shows a strong relationship between

vessel diameter and vessel number. The problem is that observations of modern samples from Elands Bay do not correlate with observations from other localities. The observations show that the number of vessels per unit area, in the modern samples from Elands Bay, is much greater than from other sample areas. Analysis of modern samples suggest that the temperature (16.5°C) and rainfall (250mm) regime at Elands Bay should be roughly comparable to results from the Vredenburg peninsula some seventy kilometres to the south. Wood anatomical variables should therefore also be roughly comparable. This is not the case with *Rhus*.

The reasons for the discrepancy between Elands Bay and other sample areas, with regard to *Rhus*, is not clear and may be attributed to a high incidence of mist at Elands Bay during summer. Future research will have to concentrate on this problem, in an attempt to identify the exact nature of the differences. Mist and fog make more moisture available to plants than is indicated by the rainfall data (Sinclair 1986). Increased incidence of fog in the archaeological record may be registered in the wood anatomy of *Rhus* from Elands Bay

Summary: Diospyros

As discussed earlier, both correlation analysis and simple regression analysis on the fresh wood sample of *Diospyros* suggests that certain wood anatomical variables are closely correlated to temperature. Those variables that show strong correlations with temperature are MINV, RANGV, RADV, AREAR, NUMV and VULN. RANGV (ie MAXV - MINV) has the highest correlations with temperature. As temperature increases the range of vessel diameters decreases (Fig 7).

The formula for a straight line graph, developed out of simple linear regression analysis of contemporary wood samples was applied to the modern data from Elands Bay. The results (0 on the X axis in Figs 10 & 11) provide a reasonable estimate of the

contemporary temperature for Elands Bay. This is similar to the average temperature at Cape Columbine, the nearest west coast weather station some 70kms to the south.

The application of this formula to the fossil charcoal from Elands Bay will be discussed in the next section.

CHAPTER FIVE

EDXA: RESULTS FROM ARCHAEOLOGICAL CHARCOAL SAMPLES

Introduction

EDXA observations on modern wood samples from a variety of different environments in the western Cape (see Chap 4) are now used to interpret the climatic record preserved in samples of archaeological charcoal from sites around Elands Bay.

Shrinkage

Inferences about climatic change cannot be developed from wood charcoal before the differences between fresh and carbonised wood have been investigated. This chapter includes a discussion on the amount of shrinkage which *Rhus* and *Diospyros* undergo when charcoaled.

Factor Analysis

The climatic component of the variation in the *Rhus* fossil sample is not immediately obvious. It was suggested that a factor analysis may help to distinguish the underlying forcing factors where wood variability is determined by multiple factors. This chapter also contains a factor analysis on the archaeological *Rhus* and *Diospyros* sample.

Minimum Piece Diameter

A number of researchers have suggested that wood anatomical variation can be related to branch diameter (Zimmerman 1983, van Den Oever, *et al.* 1981). This has meant that all samples analysed using EDXA have also been analysed for minimum branch diameter. The final aspect to this chapter is a discussion of the possibilities of relating estimates of minimum branch size to human firewood procurement strategies.

Methods

Archaeological sample

The recovery of charcoal from archaeological sites for purposes other than that of radiocarbon dating has been a relatively recent phenomenon at the University of Cape Town, although others have been doing so for a number of years (Deacon 1979, Deacon *et al.* 1983). As a result the charcoal obtained for this study was originally selectively sampled from the exposed surfaces of excavations specifically for radiocarbon dating, rather than ecological studies. This, however, is not true of the sample from MTM excavated by Buchanan (1988) where all charcoal was kept from an excavation $3m^3$ in extent.

Genera collected for analysis

In his analysis of the fossil charcoal from Boomplaas Cave in the southern Cape, Scholtz (1986) reports a strong correlation between temperature, rainfall and the wood anatomical structure of *Rhus*. The results of Scholtz's (1986) work led to the decision that *Rhus* would be a suitable genus to use for the present study. In order to ascertain the reliability of trends in climatic variation established from fossil samples of *Rhus*, fossil samples of *Diospyros* and *Zygophyllum* were also analysed. Three genera were selected on the assumption that all three would register similar trends in climatic change.

Ten assemblages were selected from Tortoise Cave, MTM and Spring Cave (Fig.2). At least 100 pieces of charcoal were chosen from each assemblage. Two methods of sampling were adopted. In the upper levels of the excavations where charcoal is abundant, a random sample of approximately 100 pieces was taken using 1cm square graph paper and computer generated random numbers. The smaller assemblages were sampled either as above, or all pieces were taken, up to a maximum of 105 pieces (Table 1).

Sample preparation

It is not possible to cut through charcoal with a sharp object as the cell walls are extremely brittle and tend to crumble, forming a fine dust which clogs up the cells, so that the piece is useless for taxonomic work. There are, however, two ways of preparing samples of charcoal for microscopy. Tusenius (1986) ran a feasibility study on these and concluded that, "Embedding charcoal specimens is a rather laborious and time-consuming process and, in most cases does not seem worth all the extra effort" (1986:21). It was this conclusion and discussions with both Madelon Tusenius and Anton Scholtz that persuaded me to use the fracture/snap method of obtaining transverse sections of charcoaled wood.

In the fracture/snap method a paring knife which has a very fine serrated edge was used to make an incision perpendicular to the grain and through 360 degrees around the circumference of the piece of charcoal. The section is then snapped by placing the incision on a straightened paper clip and applying pressure on either side, or by placing the incision on a thumbnail and applying pressure with the left and right index fingers.

The smoothest half of each section was then mounted in 'Prestik' on a glass slide, whilst the other half was placed in a tiny plastic zip-lock bag, labelled and sealed for future use. These bags were stapled together in batches of ten or twenty before being boxed. Three samples were mounted on each glass slide, and the slides stored in specifically designed cardboard boxes, which hold ten glass slides. Once mounted in 'Prestik' on a glass slide the charcoal is ready for examination under a microscope.

The fracture/snap method of preparing samples for microscopy has one inherent problem: the prepared surface is very rarely, if ever, absolutely flat. For this reason an incident light microscope cannot be used for either identification or photography, as it does not have the depth of field necessary to work with an uneven surface. Dissecting microscopes on the other hand, may have the necessary depth of field, but they very

rarely have the magnification. All the physical examination of charcoal for this study was done using a darkfield reflected light microscope, which has both depth of field, and a magnification of at least 100X.

Scanning Electron Microscope procedure

After the initial identification, a Scanning Electron Microscope (SEM) was used for the photography. The main reason for using a SEM for the photography is because it has far superior resolution and depth of field compared to any photomicroscope. All photography on the scanning electron microscope was carried out at a magnification of 100X and at a working distance of 18mm. When the resulting photographs were printed, the total magnification is 164X. Tusenius (1986:22) describes the preparation procedure necessary for working with charcoal on the SEM. This procedure is the same for most electron microscope work. The only deviation from the normal procedure was the adaption of a normal electron microscope stub to take a large galvanised iron washer. The charcoal pieces were mounted on the washer using an alkaline glue mixed with graphite powder, and the whole was screwed onto the stub with a 4mm diameter screw. The washers could be unscrewed from the stub and stored separately whilst the stub was then reused. If for any reason repeat photographs had to be taken of these specimens the washers could very easily be screwed back onto the stub. In an attempt to obtain an approximately level photographic surface, the mounting surface was sandpapered flat. This also helped to keep all the samples at the same height

Results of EDXA on charcoal

Table 18 consists of a list of the sites from which archaeological samples were collected. The stratigraphic level from which each sample was taken, and radiocarbon dates for these levels are also included in Table 18. Figure 2 shows the spatial relationship between the archaeological sites. The EDXA observations for charcoal samples of *Rhus, Diospyros* and *Zygophyllum* are summarised in Tables 19, 20 and 21 respectively. Average values, minimum and maximum values and standard deviations are presented

in Tables 22-24. Average values for temperature and rainfall are plotted through time in Figures 10-11. The results of a factor analysis on fossil charcoal are plotted in Figures 12 and 13. The results of the MPD analysis including results for *Rhus* are expressed graphically in Figures 14-17.

Discussion

Shrinkages accompanying carbonisation

Wood shrinks when charcoaled, with, according to Beall *et al.* (1974), an amount of shrinkage between 24 and 30% in both radial and tangential directions. Other authors (Cousins 1975, Schweingruber 1978) quote similar figures. On account of this shrinkage formulae developed from fresh wood morphology cannot be applied directly to charcoal.

The shrinkages accompanying carbonisation are considered to be uniform, as the ratio between cell diameter and cell wall thickness does not change in the charcoaling process (Cousins 1975). What does change is the number of vessels in a given area. From the shrinkage factors produced by Beall *et al.* (1974), Cousins (1975) calculated this increase to be as much as a doubling of cells in a given cross section of the original wood.

Scholtz (1986) has expressed misgivings about the actual shrinkage factors quoted, especially as Eberhard & Poynton (1987) record shrinkage factors by volume rather than area ranging from 7% to 30%. Scholtz (1986) pointed out that the shrinkages accompanying carbonisation can be affected by the quality of the wood. Hard woods may have different shrinkage factors to softwoods, or the presence of resins may produce hotter fires which may also affect shrinkage.

From the point of view of using fossil charcoal to develop hypotheses about climate, the exact nature of this shrinkage clearly requires investigation, before formulae developed

from fresh wood samples can be applied to fossil charcoal. To gain some idea of the amount of shrinkage to which *Rhus*, *Diospyros* and *Zygophyllum* are subjected when burned, some of the fresh wood sample was charcoaled. Ecologically diagnostic xylem analysis was then used to obtain data on the wood anatomical variables visible in transverse section. Averages for the charcoaled sample were then compared with averages for the fresh sample.

Methods

Six samples of *Rhus*, six samples of *Diospyros* and three samples of *Zygophyllum* were chosen for analysis. Discs approximately three centimetres in length were cut and wrapped in tinfoil. These parcels were placed in a muffle furnace, the temperature of which was gradually taken up to a maximum of 500°C after 1.5 hours. The furnace was then switched off and allowed to cool down slowly. The charcoal samples were prepared for electron microscopy as described in Chapter 3.

Results on shrinkage

Average results for charcoal are substantially different from those for fresh wood (Table 25). Shrinkage compares well with that quoted in Beall *et al.* (1974) and is approximately 30% in the radial and tangential directions for *Diospyros*. The values differ slightly for *Rhus* where shrinkage is 20% in the tangential direction and 30% in the radial (Table 25). The number of cells in a given area is, of course, considerably increased. The results for *Diospyros* show that the number of vessels increases by 2.34 times. *Rhus* on the other hand, does not shrink to the same extent as *Diospyros*, showing an increase in number of vessels of only 1.29 times.

These results give credence to Scholtz' (1986) misgivings, showing that it is not practicable to apply a general shrinkage factor to all types of wood and all wood anatomical variables. Shrinkage differs markedly depending on the type of wood and the anatomical variable considered.

Future research on shrinkage

Future research should concentrate on defining the exact nature of the shrinkage, in which there are a number of unanswered questions. All wood types used for developing hypotheses with regard to wood anatomy and climate should be subjected to these experiments. A range of experiments on different charcoaling methods, using different temperatures, should be undertaken as the temperature of the charcoaling process or the method of charcoaling may have an effect on shrinkage.

Conclusions on Shrinkage

These experiments on wood shrinkage during carbonisation show the necessity for more research on wood shrinkage factors. Until more is known about wood type and shrinkage, the shrinkage factors represented in Table 25 will be used in converting values for charcoaled wood to fresh wood. All pieces of charcoal analysed in this study have been corrected for shrinkage by being multiplied by the values from Table 25. For example, to convert the values for number of vessels obtained from a piece of *Rhus* fossil charcoal, to fresh wood values, the charcoal values are multiplied by $^{1}/_{1.29}=.77$. After correcting for shrinkage, formulae developed out of the analysis of contemporary wood samples are applied to the fossil sample.

Discussion on EDXA results for Rhus fossil charcoal

Once corrected for shrinkage, the formula for a straight line graph developed out of the results for multiple regression analysis (Table 11) was applied to the fossil charcoal. It became apparent that results obtained from archaeological samples of *Rhus* mirrored those of the modern sample from Elands Bay. The formula derived from an analysis of contemporary wood samples from different resource zones could not be extrapolated into the archaeological record.

As with the modern sample, the relationship between vessel diameter and number of vessels was examined (Fig 9). The graph (Fig 9) shows a strong negative or inverse relationship between vessel diameter and vessel number for both modern and archaeological samples. The problem is that observations from both modern and archaeological samples from Elands Bay differ from observations from other localities. The observations show that the number of vessels per unit area, in both modern and archaeological samples from Elands Bay, is much greater than from other sample areas. There is also a difference in maximum vessel diameter, whereby the archaeological sample from Elands Bay shows a higher incidence of large vessels compared with other sample areas.

The reasons for the discrepancy between Elands Bay and other sample areas, with regard to *Rhus*, is not clear and may be attributed to a high incidence of mist at Elands Bay during summer. Future research will have to concentrate on this problem, in an attempt to identify the exact nature of the differences. Parkington (1980, 1984) has suggested that the hiatus in occupation at Elands Bay between 8000 and 4000 years ago, was caused by an increase in aridity marked by frequent sea mists. If it can be proved that the wood anatomy of *Rhus* at Elands Bay does react to mist, then Parkington's (1980, 1984) hypothesis with regard to the hiatus can be tested.

The wide range of variation seen in modern *Rhus* from Elands Bay seems to be mirrored in the archaeological sample. This suggests that the wood anatomy of *Rhus* from Elands Bay is reacting to a different environmental signal compared with *Rhus* from other locations. Further research and further statistical techniques need to be applied to the sample of *Rhus* from both modern and archaeological sites in order to unveil the ecological meaning of the variation through time.

Discussion on EDXA results for Diospyros fossil charcoal

Both correlation analysis and simple regression analysis on the fresh wood sample of *Diospyros* suggests that certain wood anatomical variables are closely correlated to temperature (Fig 7-8). As discussed in Chapter 3, those variables that show strong correlations with temperature are MINV, RANGV, RADV, AREAR, NUMV and VULN. RANGV (ie MAXV - MINV) has the highest probable correlations with average annual temperature (Fig 7). As temperature increases the range of vessel diameters decreases.

The formula developed out of an analysis of modern *Diospyros* samples was applied to the fossil charcoal (Figs 10-11). The results are unbelievable, as it is impossible to consider a 20°C difference in average annual temperature over 1000 years (Fig 11 between 2000 and 1000 B.P.), especially as estimates for the coldest interval of the last 130 000 years is only 5°C-10°C lower than the present (Deacon & Lancaster 1988). Although precise temperatures are not obtainable using this method, it is possible that the results for *Diospyros* depict a trend of increasing temperature from 4000 B.P. to the present.

Factor Analysis

It has been suggested (Francis Thackeray pers. comm.) that a factor analysis may reveal the ecological component of the variation in wood anatomy, where variability is determined by multiple factors. Summary statistics developed out of factor analysis incorporate a series of wood anatomical variables rather than resorting to the use of single variables. Factor analysis using the whole range of wood anatomical variables may help to distinguish the underlying forcing factors determined by climate (Thackeray pers comm).

A factor analysis was performed on three genera of fossil charcoal found in the archaeological deposit of three sites at Elands Bay. This in effect amounted to three

separate factor analyses, one each, for *Rhus*, *Diospyros* and *Zygophyllum*. Having no modern comparative collection for *Zygophyllum*, it was not possible to perform simple regression or multiple regression analysis on fossil charcoal of this genus. Table 26 lists the factor scores for each wood anatomical variable in a three factor solution, where the principle component factor (Factor 1) accounted for in excess of 50% of the variance. The percentage variance accounted for by Factor 1 is 59% for *Rhus*, 62% for *Diospyros* and 56% for *Zygophyllum*.

Maximum vessel diameter and radial vessel diameter have the highest factor loadings in Factor 1 for both *Rhus* and *Diospyros*. It has been argued earlier that vessel diameter is strongly related to temperature. High values indicate high temperatures during the growing season. It is probable that Factor 1 is strongly related to temperature and high values for a summary statistic based on Factor 1 will indicate high temperatures.

High factor loadings for specific wood anatomical variables were compared with results of correlation analysis (Table 9 & 16) for the same wood variables, in order to pinpoint the climatic variable registered. MAXV for *Rhus*, has a high positive score on Factor 1. In the correlation analysis, MAXV has a high correlation with minimum potential evapotranspiration (PEMin). RADV and TANGV, which have the second and third highest scores in Factor 1, also correlate well with PEMin in the correlation matrix. Factor 1 can therefore be related to PEMin, which, in turn, is closely correlated to the monthly mean for the daily minimum temperature (TMIN).

The results of a factor analysis for *Diospyros* also show high factor loadings on Factor 1 for MAXV and RADV. From the correlation matrix, it is suggested that Factor 1 in *Diospyros*, is also correlated to TMIN.

In a factor analysis on *Zygophyllum*, the highest factor loadings in Factor 1 are for RELV (Relative Volume Flow) and MAXV. As explained in Chapter Four, no modern

analogues for *Zygophyllum* were analysed for this study, therefore, the highest factor loadings cannot be compared with a correlation matrix. Graphs of *Zygophyllum*, *Rhus* and *Diospyros* may be used to correlate the fossil sequence. Plotted on the same graph, the three genera may show similar trends, thereby indicating marked changes in climate through time.

In order to observe changes in time, on the strength of Factor 1, a summary statistic was calculated for each genus and for each assemblage. This statistic was calculated by multiplying the factor scores for each wood anatomical variable by the EDXA results for the same wood variable, and then summing the products. In this way, a single value reflecting the strength of Factor 1 for each assemblage is obtained. These values have been plotted for the archaeological sequence at Elands Bay and are presented in Figures 12-13.

A second summary statistic was calculated for each genus in order to plot all three genera on the same graph. This statistic calculated all the values obtained in the first summary statistic, and assigned each a value by weight between 0 and 100 (Fig 13).

Conclusions on factor analysis

Using summary statistics based on factor analysis, it is possible to indicate climatic change through time. The scale of this change is relative, as it is not possible to record absolutes such as millimeters of rainfall or degrees centigrade. A comparison of the three genera plotted in Figure 13, indicate that marked changes in climate probably did occur. The results of the EDXA suggests that prior to 3000 B.P., temperatures were high, declining to a low at 3000 B.P.. After 3000 B.P. temperatures increase till about 1700 B.P. when there is again a decrease in temperature until 1200 B.P.. After 1200 B.P. temperatures remain stable to the present (Fig 12-13).

It is possible that what is being recorded is a combination of temperature and rainfall. When temperatures were high 4000 years ago rainfall was lower, and as temperatures fluctuate through time, so does rainfall.

Minimum Piece Diameter (MPD)

The range in variation in vessel diameter exhibited by *Rhus* and *Diospyros*, may be related to branch diameters of different sizes. Zimmerman (1983) argued that the range in variation of wood anatomical variables, "*from roots to twigs in an individual tree make it extremely dangerous to set up correlations of certain xylem features (such as vessel diameter) with habitat and draw conclusions about functional adaptations when one has only a random sample of wood from each species* (Zimmerman 1983:86)". Zimmerman's warning should not be taken lightly. The problem, however, can be minimised by the analysis of large numbers of charcoal fragments.

An alternative method to analysing large numbers of charcoal, is the measurement of branch diameter. The EDXA programme does allow for the measurement of minimum branch diameter, thereby allowing for a reasonable estimate of the minimum size of the branch from which various pieces of charcoal originated. Results, however, do not differ markedly when the sample of charcoal from Elands Bay is controlled for branch diameter. The problem is that when the sample is sorted into pieces from different size classes, sample sizes are far too small for statistically reliable results. What is needed is a larger sample controlled for branch diameter where all pieces of similar size are grouped together. This sample may show a more reliable correlation with climate. In excess of 1000 pieces of charcoal from the archaeological sites at Elands Bay were used in the present study. To control for branch diameter the sample size will have to be increased by at least three times.

Minimum Piece Diameter analysis was developed by Anton Scholtz (1986) in an attempt to control for branch diameter as described above. Once he had done this, he

realised that MPDA may also be useful for an understanding of how human behavior contributes towards creating the charcoal assemblages found in archaeological sites. MPDA is built into the Points programme and is thus a part of EDXA (see Chapter 4).

As the name implies, MPDA estimates the minimum diameter of the piece of wood from which identified fragments of charcoal were derived. Using MPDA it is possible to establish the distribution of branch sizes for identified species within a particular archaeological charcoal assemblage. Assemblages can be compared to establish whether the same size classes have been utilised at a specific archaeological site through time. From this analysis hypotheses can be developed with regard to the proximity of certain trees to archaeological sites at various periods in time.

Methods

An estimate of the minimum diameter of the branch from which a piece of charcoal was derived can be obtained by the extension and measurement of the rays visible in a transverse section of that piece of charcoal. This is done in the Points programme using SEM photomicrographs and a digitising tablet (see Chapter 4). A total of 8 rays are utilised in the analysis. Using one ray as the primary axis, seven other rays are measured and extended to meet the primary ray at a hypothetical pith. On the digitiser a number of points are randomly selected along a ray. Using the formula for a straight line graph, the points programme then calculates the length of the straight line from the edge of the photograph, to where it intersects the primary ray. After seven such measurements, the radius of the branch is calculated by the formula R = L X S/Magn, where L = ray length, S = shrinkage factor of 25% and Magn = magnification factor. Diameters are then obtained by multiplying the result by two.

Prior to sectioning and microtoming the radii of 58 modern specimens of *Diospyros* were measured with a ruler. The same sample was then dissected and analysed for Minimum Piece Diameter. As the pith is never in the centre of the wood, these radii

were measured at the greatest distance between the pith and the cambium. Before sectioning and microtoming the actual radii of all 58 specimens were known. These results could then be compared with the results from MPDA.

Sample sizes are far too small to develop hypotheses with regard to patterns of human selection and use of firewood, however, certain trends in the minimum piece size of fossil charcoal from Elands Bay cannot be ignored.

Results

Average MPD for *Rhus, Diospyros* and *Zygophyllum* are plotted through time in Fig 14 and Fig 15. Figs 16 & 17 compare actual and estimated branch diameters for the modern sample of *Diospyros*. The results of the analysis are incorporated into Tables 19 to 24.

Discussion and conclusion on MPDA

Figure 16 shows that there is no direct correlation between actual piece radius and estimated piece radius. These results are to be expected, as photomicroscopy did not always include the area furthest from the pith. A movement of one or two millimetres could easily cause the great range in variation seen in Figure 16. A more rigorous and methodical analytical approach might result in a tighter grouping of the results. Scholtz (1986) used the term minimum in order to qualify the piece diameter measurements *"since estimation of the diameter of the mother branch through extension of the radii observed in an isolated area of xylem tissue can only indicate that the branch was at least that diameter"* (Scholtz 1986:247).

Scholtz (1986) suggested that, with a large enough sample, the results of analysis should be consistently lower for the estimated radius than the actual radius. Figure 17 clearly shows this distinction between actual radius and estimated radius. With regard to the 58 modern specimens of Diospyros tested, the actual radius of 80% of the pieces were

between 9mm and 12mm. Using MPDA, the estimated diameters of 80% are between 6mm and 10mm (Fig 17). The relative size distribution (Fig 17) for the modern sample of *Diospyros* suggests that even though there is a wide range of estimated size classes, it is possible that with a large enough sample, estimates of minimum piece diameter can be calculated.

These results should, however, be treated with the utmost caution, as a section with an estimated radius of 7mm could have come from any piece of wood right across the spectrum with a radius between 8mm and 17mm (Fig 16). By the same token a series of pieces of wood with a diameter of 12mm gave results stretching from 6mm to 13mm. Scholtz (1986) is certainly correct in his statement that results of analysis show consistently lower results for estimated radius than the actual radius (Figs 16 & 17).

The archaeological sample has some interesting trends with regard to MPDA. The largest estimated radius for the fossil sample are between 6.5 and 7.5mm. The modern sample on the other hand has an actual diameter of between 8 and 17mm and an estimated diameter of between 4 and 16mm. This clearly deserves some explanation. Great care was taken with the *Diospyros* reference sample, to take the photographs and hence the measurements from an area close to but not including the phloem. Measurements were, therefore, taken as far from the centre of the wood as possible, so that the maximum possible radius could be recorded. This was also done on the archaeological samples of wood, yet results for the archaeological samples show that minimum radii are substantially smaller than for the experimental samples. The suggestion is that the wood charcoal from archaeological sites is not representative of the sizes of the individual pieces of wood that originally went into making the charcoal. The outer portion of any piece of wood does burn away, the remains, as charcoal would have been scuffed around and trampled upon. Measurements carried out on this charcoal were probably taken closer to the centre of the wood than the measurements on the experimental charcoal. The results of MPDA on archaeological charcoal samples

REFERENCES

Akachuku, A.E. & Burley, J. 1979. Variation of wood anatomy of *Gmelina arbora* Roxb. in Nigerian plants. *International Association of Wood Anatomists Bulletin* n.s.,**4**:94-99.

Baas, P. 1973. The wood anatomy of *Ilex* (*Aquifoliaceae*) and its ecological and phylogenetic significance. *Blumeae* **21**:193-258.

Baas, P. 1976. Some functional and adaptive aspects of vessel member morphology. In Baas, P., Bolton, A.J. & Catling, D.M. eds., *Wood Structure in Biological and Technological Research* pp.157-181. Leiden Botanical series N°.3 Leiden University Press, The Hague.

Baas, P. 1982. Systematic, phylogenetic and ecological wood anatomy - History and perspectives. In Baas, P. ed., *New perspectives in wood anatomy*: 23-58. The Hague: Martinus Nijhoff.

Baas, P., Werker, E. & Fahn, A. 1983. Some ecological trends in vessel characters. *International Association Of Wood Anatomists Bulletin (IAWA Bulletin)* n.s.,**4**:141-159.

Baas, P., Lee Chenglee, Zhang Xinying, Cui Keming & Deng Yuefen. 1984. Some effects of dwarf growth on wood structure. *International Association of Wood Anatomists Bulletin* n.s.,**5**:45-63.

Baas, P., Esser, P.M., van der Westen, M.E.T. & Zandee, M. 1988. Wood anatomy of the *Oleaceae*. *International Association of Wood Anatomists Bulletin* n.s., **9(2)**:103-182.

Barefoot, A.C. & Hankins F.W. 1982. *Identification of Modern and Tertiary Woods.* Claredon Press Oxford.

Beall, F.C., Blankenhorn, P.R. & Moore, G.R. 1974. Carbonised wood - physical properties and use as an SEM preparation. *Wood Science*. **6**:212.

Box, E.O. 1981(a) Predicting physiognomic vegetation types with climate variables. *Vegetatio* **45**:127-139.

Box, E.O. 1981(b) *Macroclimate and Plant forms: An introduction to predictive modeling in phytogeography*. Dr W. Junk Publishers The Hague, Boston & London.

Buchanan, W.F. 1988. *Shellfish in prehistoric diet*. British Archaeological Reports International Series 455. Oxford: British Archaeological Reports.

Butzer, K.W. 1973. Geology of Nelson Bay Cave, Robberg, South Africa. *South African Archaeological Bulletin* **28**:97-110.

Butzer, K.W. 1979. Geomorphology and geo-archaeology at Elandsbaai, Western Cape, South Africa. *Catena* **6**:157-166.

Carlquist, S. 1966. Wood Anatomy of Compositae: a summary, with comments on factors controlling wood evolution. *ALISO* **6**:25-44.

Carlquist, S. 1975. *Ecological strategies of xylem evolution.* Berkeley: University of California Press.

Carlquist, S. 1977(a). Ecological factors in wood evolution: a floristic approach. *American Journal of Botany*. **64**:887-896.

Carlquist, S. 1977(b). Wood anatomy of *Peneaceae* (Myrtales): comparative, phylogenetic and ecological implications. *Botanical Journal of the Linnaean Society* **75**:211-227.

Carlquist, S. 1980. Further concepts in ecological wood anatomy with comments on recent work in wood anatomy and evolution. *ALISO* **9**:499-553.

Carlquist, S. 1982. Wood anatomy of *Illicium* (*Illiciaceae*). Phylogenetic, ecological, and functional interpretations. *American Journal of Botany* **69**:1587-1598.

Carlquist, S. & Hoekman, D.A. 1985. Ecological wood anatomy of the woody Southern Californian Flora. *International Association of Wood Anatomists Bulletin.* n.s., 6(4):319-347.

Clark, R.L. 1982. Point count estimation of charcoal in pollen preparations and thin sections of sediments. *Pollen et spores* **24**(3-4):523-530.

Cousins. W.J. 1975. Optical microscopy of charcoal. *Journal of Microscopy* **105**:15-18.

Cowan, I.R. 1982. Regulation of water use in relation to carbon gain in higher plants. In Lange, O.L., Nobel, P.S., Osmond, C.B. & Ziegler, H. eds., Physiological Plant Ecology II. Water Relations and Carbon Assimilation. *Encyclopedia of Plant Physiology New Series* **12B**:589-613. Springer-Verlag, Berlin.

Craig, H. 1953. The geochemistry of the stable carbon isotopes. *Geochimica et Cosmochimicha Acta* **3**:53-92.

Craig, H. 1957. Isotopic standards for carbon and oxygen and correction factors for mass- spectrometric analysis of carbon dioxide *Geochimicha et Cosmochimica Acta* **12**:133-149.

Deacon, H.J. 1979. Excavations at Boomplaas Cave - a sequence through the Upper Pleistocene and Holocene in South Africa. *World Archaeology* **10**:241-257.

Deacon, H.J., Scholtz, A. & Daitz, L.D. 1983. Fossil charcoals as a source of palaeoecological information in the fynbos region. In Deacon, H.J., Hendey, Q.B. & Lambrechts, J.J.N. eds., *Fynbos palaeoecology a preliminary synthesis. South African National Scientific Programmes Report* **75**:174-182.

Deacon, J.C.G. 1982. *The Late Stone Age in the Southern Cape, South Africa.* Unpublished Ph.D thesis, University of Cape Town.

Deacon, Janette & Lancaster, N. 1988. *Late Quaternary Palaeoenvironments of Southern Africa.* Claredon press, Oxford.

den Outer, R.W. & van Veenendaal, W.L.H. 1976. Variation in wood anatomy of species with a distribution covering both rain forests and savanna areas of the Ivory Coast. West Africa. *Leiden Botanical Series* **3**:182-195, Leiden University Press, The Hague.

Dickison, W.C. & Phend, K.D. 1985. Wood anatomy of the *Styracaceae*: evolutionary and ecological considerations. *International Association of Wood Anatomists Bulletin* n.s.,**1**:36.

Eberhard. A.A. & Poynton, R.J. 1987. Fuelwood calorific values and preferences as criteria for the choice of tree species for planting in South Africa. Conference proceedings, *Renewable energy potential in Southern Africa*. Held at the University of Cape Town in 1986.

Ehleringer, J.R. & Cooper, T.A. 1988. Correlations between carbon isotope ratio and microhabitat in desert plants. *Oecologia*. **76**:562-566.

Fahn, A. 1962. Xylem structure and annual rhythm of cambial activity in woody species of the East Mediterranean regions. *International Association of Wood Anatomists Bulletin* n.s., **1**:2-6.

Fahn, A. 1964. Some anatomical adaptations of desert plants. *Phytomorphology* **14**:93-102.

Fahn, A. & Sarnat, C. 1963. Xylem structure and the annual rhythm of development of trees and shrubs of the desert. IV. *Shrubs*. *The Bulletin of the Research Council of Israel.* Section D. Botany. **IID**,**4**:198-209.

Farquhar, G.D. & Richards, R.A. 1984. Isotopic Composition of Plant Carbon Correlates with Water-use Efficiency of Wheat Genotypes. *Australian Journal of Plant Physiology* n.s.,**11**:539-552.

Fidel, A & Roig, J. 1986. The wood of *Adesmia Horrida* and its modifications by climatic conditions. *International Association of Wood Anatomists Bulletin* n.s.,**7(2)**:129-135.

Flemming, B.W. 1977. Distribution of recent sediments in Saldanha Bay and Langebaan Lagoon. *Transactions of the Royal Society of South Africa.* **42**:317-340.

Freyer, H.D. 1979a. On the ^{13}C record in tree rings. I. ^{13}C variations in Northern Hemisphere trees during the last 150 years. *Tellus* **31**:124-138.

Freyer, H.D. 1979b. On the ^{13}C record in tree rings. II. Registration of microenvironmental CO_2 and anomalous pollution effect. *Tellus* **31**:308-312.

Freyer, H.D. 1980. Record of environmental variables by ^{13}C measurements in tree rings. In Jacoby, G.C. ed., *Proceedings of the International Meeting on Stable Isotopes in Tree-Ring Research* pp13-21. New Paltz, New York. U.S. Department of Energy Publication N°.12.

Freyer, H.D. 1981. ^{13}C record in tree rings during the past half millennium- climatic fluctuations and anthropogenic impact -. Paper presented at *IAMAP Third scientific assembly*, Hamburg FRG.

Gandar, M. 1982. Some social and environmental aspects of the use of fuelwood in Kwazulu. In Bromberger, N. & Lea, J.D. eds., *Rural studies in Kwazulu* pp147-152. University of Natal (Pietermaritzburg).

Godwin, H. & Tansley, A.G. 1941. Prehistoric charcoals as evidence of former vegetation, soil and climate. *Journal of Ecology* **29**:117-126.

Grindley, J.R., Lane, S.B. and Robertson, H.N. 1982. The environment and ecology of Verlorenvlei. In Grindley, J.R., Lane, S.B. & Robertson, H.N. *Verlorenvlei a challenge to conservation.* Papers presented at a symposium on 'conservation at Verlorenvlei' held in September 1980, organised by the School of Environmental Studies and the Department of Archaeology, University of Cape Town. University of Cape Town. Cape Town.

Grindley, J.R. & Grindley S.A. 1987. The ecological and biological history of Verlorenvlei. In Parkington, J. & Hall, M. eds., *Papers in the Prehistory of the Western Cape, South Africa* pp.97-119. British Archaeological Reports International series **332**. Oxford: British Archaeological Reports.

Hadac, E. & Hasek, M. 1949. Remnants of woods from the prehistoric fire-places in Bohemia. *Studia Botanica Cechoslovaca* **10**:136-148.

Hubick, K.T., Farquhar, G.D. & Shorter, R. 1986. Correlation between water-use efficiency and carbon isotope discrimination in diverse peanut (*Arachis*) Germplasm. *Australian Journal of Plant Physiology* **13**:803-816.

Keeling, C.D., Mook, W.G. & Tans, P.P. 1979. Recent trends in the $^{13}C/^{12}C$ ratio of atmospheric carbon dioxide. *Nature* **277**:121-123.

Klein, R. G. 1980. Environmental and ecological implications of large mammals from Upper Pleistocene and Holocene sites in southern Africa. Annals of the South African Museum **81**:223-283.

Krauss-Marguet, I. 1980. Contribution a l'histoire de la vegetation postglaciaire des Grands Causses d'apres l'analyse anthracologique du gisement prehistorique de la Poujade (Commune de Millau- Aveyron). Academie de Montpellier, Universite des Sciences et Techniques de Lanquedoc.

Kromhout, C.P. 1975. 'n Sleutel vir die mikroskopiese uitkenning van die vernaamste houtsoorte van Suid-Afrika. *Departement van Bosbou Bulletin* **50**:547-557.

Libby, W.F. 1955. *Radiocarbon Dating.* Chicago: University of Chicago Press.

Lipschitz, N. & Waisel, Y. 1970. Effects of environment on relations between extension and cambial growth of *Populus euphratica* Oliv. *New Phytologist* **69**:1059-1064.

Long, A. 1982. Stable carbon isotopes in tree rings. In Hughes, M.K., Kelly, P.M., Pilcher, J.R. & LaMarche, V.C. Jr. eds., *Climate from tree rings* pp13-18. Cambridge University Press, Cambridge.

Manhire, A.H. 1987. *Later Stone Age settlement patterns in the sandveld of the South Western Cape Province, South Africa.* Cambridge Monographs in African Archaeology 21, British Archaeological Reports International Series 351 Oxford: British Archaeological Reports.

Mazel, A.D. 1987. The archaeological past from the changing present: towards a critical assessment of South African Later Stone Age studies from the Early 1960's to the early 1980's. In Parkington, J. & Hall, M. eds., *Papers in the Prehistory of the Western Cape, South Africa* pp. 504-529. British Archaeological Reports International series **332**. Oxford: British Archaeological Reports.

Miller, Duncan. 1987. Geoarchaeology at Verlorenvlei. In Parkington, J. & Hall, M. eds., P*apers in the Prehistory of the Western Cape, South Africa* pp.46-77. British Archaeological Reports International series 332. Oxford: British Archaeological Reports.

Milton, S.J. & Bond, C. 1986. Thorn trees and the quality of life in Msinga. *Social Dynamics* **12(2)**:64-76.

Moll, E.J. & Bossi, L. 1984. Assessment of the extent of the natural vegetation of the Fynbos Biome of South Africa. *South African Journal Of Science* **80:**351-352.

Moll, E.J. & Jaarman, M.L. 1984. A clarification of the term fynbos. *South African Journal of Science.* **80**:351-352.

Mooney, H.A., Troughton, J.H. & Berry, J.A. 1977. Carbon Isotope ratio measurements of succulent plants in southern Africa, *Oecologia* **30**:295-305.

O'Brien, E.M. 1988 Climatic correlates of species richness for woody "edible" plants across southern Africa. *Monograph Systems in Botany of the Missouri Botanical Garden.* **25**:385-401.

Parkington, J.E. 1980. Time and place: some observations on spatial and temporal patterning in the Later Stone Age sequence in Southern Africa. *South African Archaeological Bulletin* **35**:73-83.

Parkington, J.E. 1984. Changing views of the Later Stone Age of South Africa. In Wendorf, F. & Close, A. eds., *Advances in World Archaeology* 3:90-142. Orlando: Academic press.

Parkington, J.E. 1986. Landscape and subsistence changes since the last glacial maximum along the western Cape coast. Straus, L.G. ed., *The end of the Palaeolithic in the Old World.* British Archaeological Reports International series **284**. Oxford: British Archaeological Reports.

Parkington, J.E., Yates, R., Manhire, A. and Halkett, D. 1986. The social impact of pastoralism in the south-western Cape. *Journal of Anthropological Archaeology* **5**:313-329.

Parkington, J., Poggenpoel, C., Buchanan, B., Robey, T., Manhire, T. and Sealy, J. 1988. Holocene coastal settlement patterns in the western Cape. In Bailey, G. & Parkington, J. eds., *The Archaeology of Prehistoric Coastlines* pp 22-41. Cambridge: Cambridge University Press.

Prior, J. 1983. Investigations on archaeological charcoals from Swaziland, using SEM techniques. In Vogel, J.C. ed., *Proceedings of the International Symposium on Late Cainozoic Palaeoclimates of the Southern Hemisphere, Swaziland* pp 353-360. Rotterdam:Balkema.

Rendle, B.J. & Clarke, S.H. 1934. The diagnostic value of measurements in wood anatomy. *Tropical woods.* **40**:27-37.

Rundel. P.W. & Stecker. R.E. 1977. Morphological adaptations of tracheid structure to water stress gradients in the crown of *Sequoiadendron giganteum. Oecologia* **27**:135-139.

Salisbury, E.J. & Jane, F.W. 1940 Charcoals from Maiden Castle and their significance in relation to the vegetation and climatic conditions in prehistoric times. *Journal of Ecology* **28**:310-325.

Scholtz, A. 1986. *Palynological & Palaeobotanical studies in the Southern Cape.* Unpublished M.A. thesis, Department of Archaeology, University of Stellenbosch.

Schweingruber, F.H. 1978. *Microscopic wood anatomy: structural variability of stems and twigs in recent and subfossil woods from Central Europe.* Swiss Federal Institute of Forestry Research, Birmensdorff.

Sealy, J.C. 1986. *Stable carbon isotopes and prehistoric diets in the south-western Cape Province, South Africa.* Cambridge Monographs in African Archaeology **15**, BAR International Series **293**, Oxford.

Sinclair, S.A., Lane, S.B., and Grindley, J.R. 1986. Estuaries of the Cape. In Heydorn, AEF and Morant, PD eds. *CSIR Research Report* 431, Part II: Synopses of available information on individual systems. Report number 32 Verlorenvlei (CW13). Stellenbosch.

Slavikova-Vesela, J. 1950. Reconstruction of the succession of forest trees in Czechoslovakia on the basis of an analysis of charcoals from prehistoric settlements. *Studia Botanica Cechoslovaca* **11**:198-224.

Smith, B.N. & Epstein, S. 1971. Two categories of $^{13}C/^{12}C$ ratios for higher plants. *Plant Physiology* **47**:380-384.

Sofer, Z. 1980. Preparation of carbon dioxide for stable carbon isotope analysis of petroleum fractions. *Annals of Chemistry.* **52(8)**:1389-1391.

Stuiver, M. & Brazuinas, T.F. 1987. Tree cellulose $^{13}C/^{12}C$ ratios and climatic change. *Nature* **328**:58-60.

Thornthwaite, C.W. 1948. An approach towards a rational classification of climate. *Geographical review* **38**:55-94.

Thornthwaite, C.W. & Mather, J.R. 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. *Climatology* **10(3)**:185-311. Elmer (New Jersey).

Thornthwaite, C.W. & Mather, J.R. 1962. Average Climatic Water Balance Data of the Continents, Part 1. Africa. *Publications in Climatology*, Volume **15**, N°.2. Laboratory of Climatology, Centerton, New Jersey.

Tieszen, L.L., Senyimba, M.M., Imbamba, S.K., & Troughton, J.H. 1979. The distribution of C_3 and C_4 grasses and carbon isotope discrimination along an altitudinal and moisture gradient in Kenya. *Oecologia* **37**:337-350.

Tinley, K.L. 1985. *Coastal Dunes of South Africa*. South African National Scientific Programmes report number **109**. Issued by The Foundation for Research and Development. Council for Scientific and Industrial Research. Pretoria.

Tusenius, M. 1986. *Charcoal analytical studies in the north-eastern Cape.* Unpublished M.A. thesis, Department of Archaeology, University of Stellenbosch.

Underhill, L.G. 1979. *Introstat.* Department of mathematical statistics University of Cape Town.

van den Oever, L., Baas, P. & Zandee, M. 1981. Comparative wood anatomy of *Symplocos* and latitude and altitude of provenance. *International Association of Wood Anatomists Bulletin* n.s.,**2**:3-24

van der Merwe, N.J. 1982. Carbon isotopes, photosynthesis and archaeology. *American Scientist* **70**:596-606.

van der Merwe, N.J. & Vogel, J.C. 1983. Recent carbon isotope research and its implications for African archaeology. *The African Archaeological Review* **1**:33-56.

should therefore be treated with the utmost caution even though the results do show some very distinct patterns which can be directly related to the archaeological record.

Conclusion

The similarity in the results of the analysis on the archaeological sample for *Rhus* and *Diospyros* leads to the conclusion that similar factors are involved. There is very little literature on firewood procurement strategies of hunter gatherers. It can, however, be safely assumed that apart from serious over-exploitation of the resource, wood collected for firewood is dry wood. Therefore the composition of any such collection will reflect, to some extent, the composition of the dry wood supply of an area (Gandar 1982). When, as is the case at Elands Bay, hunter gatherers follow specific settlement patterns for hundreds of years, it is possible that the dry wood supply in the immediate vicinity of camping sites becomes impacted to the extent that people are forced to use smaller and smaller pieces of wood through time. With a change in subsistence strategy, a new supply of dry wood becomes available, and the larger size classes are exploited first. What we may be seeing in the *Diospyros* and *Rhus* sample from Elands Bay, is the impact on the dry wood supply by hunter gatherers over time. The general tendency is for the minimum piece diameter of the firewood to decrease through time, from 4000 B.P. to the present. The decrease is interrupted briefly when people reschedule their settlement and begin to choose new locations in which to camp.

The *Zygophyllum* sample does not exhibit the same trends as does *Diospyros* and *Rhus*. Although Zygophyllum does occur on the Bobbejaansberg, it is more common along the coast. *Zygophyllum* is capable of growing in an area where there is a high percentage of salt spray and is common on dunes close to the coast.

During the process of transpiration, *Zygophyllum* takes up water containing salt. The salt is then deposited in the leaves which eventually drop off. The salinity of the soil steadily increases as more of these leaves drop off and decompose. The plant is not

capable of assimilating the increased inputs of salt and eventually dies. Because of this cycle, in coastal areas with a high percentage of wind borne salt spray, *Zygophyllum* morgsana will not grow to any substantial size (C Boucher pers comm). It is not surprising therefore that the *Zygophyllum* sample falls into a narrow MPD size class.

Summary

In the previous chapter, the relationship between wood anatomy, temperature, and rainfall was discussed. Formulae were also developed which could be used to relate specific wood anatomical variables to rainfall and temperature. In this chapter the formulae were applied to charcoal from archaeological sites to interpret the climatic record preserved in wood charcoal from archaeological sites. Some trends are visible in the results of EDXA. Indications are that prior to 3000 B.P. temperatures at Elands Bay were high declining to a low at 3000 B.P. The temperature then increases to about 1700 B.P. after which there is again a decline in temperature to 1200 B.P.. After 1200 B.P. temperatures remain relatively stable to the present (Fig 12-13). The results of EDXA are not definitive, as both the archaeological and modern sample sizes are too small to draw conclusions on climate and environment during the late Holocene. The results for *Diospyros* in particular are promising. It is possible that, with a large enough sample, estimates of climate can be made using this genus.

Information with regard to MPDA and human selection criteria show that at 4000 B.P. minimum piece size is larger than at any other time in the late Holocene (Fig 15). The results correlate well with the archaeological record, specifically with regard to site distribution patterns and human subsistence patterns. There are, however, problems inherent in the MPDA technique. The emphasis of this project was not directed toward MPDA. A more rigorous and analytical approach may produce more positive results.

The next chapter is an isotopic investigation of wood charcoal to determine whether $\delta^{13}C$ values correlate with temperature and rainfall.

CHAPTER SIX

STABLE CARBON ISOTOPE ANALYSIS OF FOSSIL CHARCOAL

Introduction

This chapter considers the potential for using as a palaeoenvironmental climatic indicator $^{13}C/^{12}C$ measurements on wood charcoal from archaeological sites. The results of $^{13}C/^{12}C$ measurements on both modern and archaeological charcoal are presented. Comparisons are made between $^{13}C/^{12}C$ measurements of wood charcoal, temperature and rainfall. Comparisons are also made between $^{13}C/^{12}C$ measurements of archaeological wood charcoal and contemporary wood charcoal. This analysis stems from the observation that the ratio between the stable isotopes ^{12}C and ^{13}C can be a good estimate of water use efficiency in plants (Farquhar & Richards 1984).

The carbon cycle

Carbon occurs naturally in three isotopic forms. Before nuclear weapons testing in the 1950's and 1960's added large amounts of ^{14}C to the atmosphere the ratio of $^{12}C:^{13}C:^{14}C$ was about $100:1,1:10^{-10}$ averaged out over the whole globe (Sealy 1986). The constant disintegration through time of the radioactive nuclide ^{14}C enabled Libby (1955) to develop a radiocarbon dating method for organic material. Dated samples, however, sometimes yielded spurious results. Attempts to calibrate the system led to the discovery that, since tree cellulose is formed from carbon acquired during photosynthesis, the $\delta^{13}C$ values of plants are directly related to photosynthetic pathway (see e.g. Smith & Epstein 1971, van der Merwe 1982, Stuiver & Braziunas 1987).

The standard used in ^{14}C dating is European oak (*Quercus robur* (L.)). In order to calibrate the results to this standard, the $^{13}C/^{12}C$ ratio is measured, and expressed as $\delta^{13}C$. The calculation of $\delta^{13}C$ involves a comparison between the $^{13}C/^{12}C$ ratio of the sample relative to a standard. The universally accepted standard in carbon and oxygen

isotope analysis is Peedee belemnite (PDB) (Craig 1953, 1957). The PDB standard has a ^{13}C content higher than most other organic materials, and has been assigned a value of $0‰$. $\delta^{13}C$ values are calculated relative to this limestone from the equation:

$$\delta^{13}C = \left(\frac{^{13}C/^{12}C_{\text{sample}}}{^{13}C/^{12}C_{\text{standard}}} - 1 \right) X\ 1000‰$$

Depletion or enrichment of ^{13}C is expressed in parts per mille ($‰$). Most organic materials are depleted in ^{13}C relative to the limestone standard and therefore have negative values (Sealy 1986).

The proportion of ^{12}C to ^{13}C can change in chemical reactions because ^{12}C is slightly smaller and lighter than ^{13}C, and thus reacts faster. The $^{13}C/^{12}C$ ratio in the atmosphere is practically constant, but as CO_2 is taken up by plants during photosynthesis, fractionation of the isotopes occurs due to the diffusion effect of the cell wall and the kinetic effect in the chemical reactions. Thus $\delta^{13}C$ values of plant tissues is different from that of the atmosphere. The result of this fractionation is a bimodal distribution of $\delta^{13}C$ values which group around $-26.5‰$ for C_3 plants and $-12.5‰$ for C_4 plants (van der Merwe 1982).

Relationship between plant water use and $\delta^{13}C$ values

Recent studies suggest that the ratio between the stable isotopes ^{12}C and ^{13}C can be a good estimate of water use efficiency (Farquhar & Richards 1984; Hubick *et al.* 1986). With water stress there is some stomatal closure (Cowan 1982) which in turn results in less negative $\delta^{13}C$ values (Hubick *et al.* 1986). Ehleringer & Cooper (1988) sampled all species along a moisture gradient, clearly identifying a change in $\delta^{13}C$ values from $-24.2‰$ in the driest habitats to $-26.6‰$ for wetter habitats. It is this relationship between $\delta^{13}C$ and the amount of water available to the plant that we hope to test in a modern context and apply archaeologically.

Sampling strategy

Samples of fresh wood were collected from four areas in the southern and south-western Cape, with known rainfall/temperature records. Three of the locations were from the highest and lowest rainfall areas of the winter rainfall region of the south-western Cape, whilst the fourth sample is from an all year rainfall area. Two of the sample areas (Montagu & The Richtersveld) were from very dry locations and the other two (Saasveld & Jonkershoek) from the wetter extreme.

The range in environmental conditions dictated that different genera be used. Samples of *Rhus* from Montagu, Richtersveld and Saasveld were analysed, whilst samples of *Diospyros* came from Montagu, Elands Bay and Jonkershoek. One sample area, Montagu, had both *Rhus* and *Diospyros* so that it was possible to collect samples of both these genera from this location. Using the Montagu sample it was possible to compare $\delta^{13}C$ values between *Rhus* and *Diospyros*, from the same location.

The archaeological sample was wood charcoal from three closely related archaeological sites dating back to 4000 years B.P.. This charcoal was identified (see Chapter 3), and only specimens from the family *Ebenaceae*, genus *Diospyros/Euclea* were chosen for analysis. As in the rest of this study the three sites used were Tortoise Cave, Spring Cave, and Mike Taylor's Midden.

Sample preparation and methods

All stable carbon analysis was done in the archaeometry laboratory at the University of Cape Town. Modern wood samples were wrapped in tinfoil and charcoaled in a muffle furnace at 500°C so that all analysis would be on charcoal rather than on fresh wood. Samples were then soaked in a one molar solution of warm sodium hydroxide (NaOH) to remove humic acids, and rinsed until the rinse water became neutral. The sample was then soaked in a one molar solution of warm hydrochloric acid (HCl) to remove

carbonates, and again rinsed with distilled water until neutral. Finally the samples were dried in a freeze drier overnight.

Sections of charcoal weighing approximately 0.02 grams, from close to the outer margin of the wood, but not including the phloem, were analysed. Sample combustion was in sealed quartz tubes as described by Sofer (1980). The sample, copper oxide, and a piece of silver foil were loaded into quartz tubes, the tubes evacuated to less than 10^{-2} Torr, sealed off with an oxy-butane torch and heated for a minimum of four hours at 800°C. The CO_2 produced was separated from any nitrogen and water vapor on a gas separation line (see Sealy 1986 for a full description of this methodology). $\delta^{13}C$ measurements were carried out on a Micromass 602E spectrometer. This is a 90° sector double-collector instrument with a dual inlet system. The references were done against a laboratory reference gas related to the Chicago PDB marine carbonate standard by calibration against six NBS reference standards. (see van der Merwe 1982 and Sealy 1986).

Results

The results of the analysis on contemporary wood samples are given in Table 27. Table 28 enables the average $\delta^{13}C$ values of contemporary wood samples to be compared to each of the resource zones from which they are derived. Figure 18 is one such comparison showing the relationship between $\delta^{13}C$ values and rainfall in the warmest month. In Figures 19 a comparison is made between average annual temperature and $\delta^{13}C$ values. Figure 20 compares $\delta^{13}C$ values of wood charcoal from Elands Bay today to that of charcoal through time. Averages and standard deviations for the archaeological samples are given in Table 29.

Discussion of Results

Rainfall

The results for the modern sample is entirely consistent with the results of Ehleringer and Cooper (1988). The drier sites of Montagu and the Richtersveld average out at -24.3‰ and -24.4‰ respectively, and the wetter sites of Jonkershoek and Saasveld average out at -25.4‰ and -26.8‰. Grouping the totals of the two wettest sites together, and the totals of the two driest sites together two distinct groups are formed. The distributions of $\delta^{13}C$ values for wet and dry sites were compared by means of the Mann-Whitney U-test (tables obtained from Underhill 1979). The two distributions show themselves to be significantly different (Mann-Whitney approximate Z-value = 2.517, $p < 0.01174$).

Thornthwaite indices of evapotranspiration

Not only can $\delta^{13}C$ values be related to rainfall, but these values can also be related to potential evapotranspiration as calculated using the Thornthwaite (1948) indices. Potential evapotranspiration is measured in millimeters. Empirically derived it is the unit of measurement for the combined evaporation from the soil surface and transpiration from the plant (Thornthwaite 1948). It is the direct antithesis of rainfall, i.e. it represents the movement of water back into the atmosphere. Indices of potential evapotranspiration are particularly useful as it is by these measures that one can calculate the exact water needs of a particular environment. By measuring potential evapotranspiration, the actual amount of water available to the plant can be calculated. There is less water available to the plant in areas of high potential evapotranspiration (PE), because of a combination of high ambient temperature and low precipitation. The relationship between $\delta^{13}C$ values and evapotranspiration may be important for establishing the relationship between the plant, temperature and rainfall.

Temperature

There is a strong relationship between $\delta^{13}C$ values and temperature (Fig 19). As average annual temperature decreases so $\delta^{13}C$ values become more negative. This relationship is however more complex than is at first apparent. Rainfall of the warmest month also has a strong relationship $\delta^{13}C$ values (Fig 18). As rainfall increases so $\delta^{13}C$ values become more negative. The results from this study do not only record single climatic variables such as rainfall and temperature but a complex integration of the two which is probably linked to the growing season of the plant.

Another determinant effecting $\delta^{13}C$ values

The fossil fuel effect

$\delta^{13}C$ values of wood are not determined primarily by climatic effects. If ambient atmospheric $\delta^{13}C$ values change then the isotopic values of plants will also change as plant cellulose is largely composed of carbon (Long 1982, van der Merwe 1982). The increasing use of fossil fuels since the beginning of the industrial revolution has added to atmospheric CO_2 levels. Ambient atmospheric $\delta^{13}C$ values are around -7‰ and fossil fuels have $\delta^{13}C$ values of around -25‰ (Wigley 1982, van der Merwe 1982). Increasing use of fossil fuels should therefore shift the $\delta^{13}C$ values of plants towards more negative values.

Keeling *et al.* (1979) measured a reduction in atmospheric $\delta^{13}C$ values from -6.69‰ to -7.34‰ between 1956 and 1974. Not all authors have obtained similar results. Freyer's results from both North America (1979a & 1979b, 1980) and Northern Sweden (1981) consistently show a decrease in $\delta^{13}C$ values of 2‰ between 1845 and 1970 which he attributes to the fossil fuel effect and global deforestation.

Results of *Diospyros* from Elands Bay, analysed for this study, concur with Freyer's (1979a & 1979b 1980) results. Contemporary wood charcoal $\delta^{13}C$ values are consistently more positive than the fossil sample by at least 2‰. Using the Mann-

Whitney U-test, it can be shown that these two samples are significantly different (Mann-Whitney approximate Z-value = 2.88, $p<0.004$). These results lead to the conclusion that $\delta^{13}C$ values of tree cellulose after 1950 should be corrected for fossil carbon production by at least $2^{o}/_{oo}$. This is in accordance with Freyer (1979a & 1979b 1980) and Wigley (1982). All average $\delta^{13}C$ values for archaeological wood charcoal in this study have therefore been corrected for the fossil fuel effect by $-2^{o}/_{oo}$.

Archaeological significance

From the graph (Fig 20) the two samples that are the most different, are Melanie (4200 B.P.) and All Black (3000 B.P.) The two distributions do not yet on the available data show themselves to be significantly different (Mann-Whitney approximate Z-value = 1.470, $p<0.141$). In fact, no two groups of archaeological samples show a distribution that is significantly different using the Mann-Whitney U-test. There is no significant difference in the range in variation of $\delta^{13}C$ values within the archaeological sample. This is so, even though it can be shown that $\delta^{13}C$ values from two modern samples from different environments are significantly different. The graph (Fig 20) shows some similarities to those graphs obtained using EDXA. No similarities or differences between the isotope results and EDXA results can be discussed, however, because the results of a Mann-Whitney U-test shows no significant differences within the isotope results.

$\delta^{13}C$ values and environmental change

The results of a relative abundance analysis (Chapter 3) show a very clear distinction in the relative percentages of identifiable wood between Tortoise Cave and other sites at Elands Bay. The conclusions drawn in Chapter 3 are that there are two microclimatic zones at Elands Bay. The results of a relative abundance analysis (Chap 3) show a very clear distinction in the relative percentages of identifiable wood between Tortoise Cave and other sites at Elands Bay. The conclusions drawn in Chapter 3 are that there are two microclimatic zones at Elands Bay. These areas have different rainfall, temperature

regimes and therefore have different vegetation types growing on them. The results from the isotopic analysis for the present study show a strong relationship between $\delta^{13}C$ values, rainfall and temperature. On the basis of these results, it was felt that the $\delta^{13}C$ values from radiocarbon dates may show some significant trends in the difference between these sites.

For a number of years John Parkington has been receiving radio-carbon dates from the CSRI laboratory in Pretoria. In order to calibrate these dates $\delta^{13}C$ values are measured. These $\delta^{13}C$ measurements accompanying radio-carbon dates have different values for the different archaeological sites (Fig 21). These patterns reflect those evident in the analysis of wood morphological types (Chap 3). The differences can only be interpreted in the context of environmental/climatic change because the selection of firewood does not influence $\delta^{13}C$ measurements. These results confirm the hypothesis developed in Chapter 3, that rainfall/temperature regimes and therefore environment is different between the inland and the coastal sites at Elands Bay.

The $\delta^{13}C$ measurements of the fossil charcoal from Spring Cave between 400 and 1100 B.P. are different from the other sites. These samples are markedly more enriched than most C_3 plants, whereas those values from 3000 B.P. have more typical C_3 values (Fig 21). The relative abundance analysis used charcoal samples from the same levels and squares as were sent off for radio-carbon dating. From the relative abundance analysis we know that the samples from Spring Cave have a high percentage of *Ruschia* at 800 and 3000 B.P. (Fig 4).

Ruschia, a *mesembryanthemaceae* utilises the CAM (crassulacean acid metabolism) photosynthetic pathway. These plants may follow both the C_3 or the C_4 photosynthetic pathways. They have the ability to fix carbon by day, when they use the C_3 pathway, as well as by night, when they use the C_4 pathway. The extent to which they switch between

photosynthetic pathways is determined by the environment (van der Merwe and Vogel 1983).

Under different environmental conditions, the $\delta^{13}C$ values of C_3 plants vary from about -20‰ to -35‰. C_4 plants on the other hand may vary from -9‰ to -16‰ (van der Merwe 1982). C_4 plants grow in arid climates with a high degree of solar radiation during the growing season (van der Merwe 1982). C_3 plants on the other hand grow in more moderate climates. There are few naturally occurring C_4 plants in Europe and America, whereas in the hot dry deserts of Africa, most grasses are C_4. In the western Cape winter rainfall area, the majority of trees, grasses and shrubs follow the C_3 photosynthetic pathway.

The $\delta^{13}C$ values of the fossil charcoal from Spring Cave between 400 and 1100 B. P. are markedly more enriched than most C_3 plants, whereas those values from 3000 B.P. have more typical C_3 values (Fig 18). The range in $\delta^{13}C$ values in the wood charcoal of CAM plants from different environments is not known. Mooney *et al.* (1977) have shown that average values for CAM plants are around -16.5‰. These plants show peaks near the C_3 and C_4 averages. The extent to which these peaks correlate with environment is crucial, as very different $\delta^{13}C$ values suggest a link between the photosynthetic pathway of mesems and the prehistoric environment.

These preliminary results are interesting, and should be developed further. What is needed is an intensive research programme to analyse the difference in $\delta^{13}C$ values of *Ruschia* from different ecoclimatic zones. This research should show changes in $\delta^{13}C$ values of Ruschia as rainfall/temperature regimes change. It may then be possible to link $\delta^{13}C$ values, photosynthetic pathway of Ruschia, temperature and rainfall. At present, there is only a hint that it may have been hotter and drier in the last 1000 years.

Conclusions

The results of analysis on wood charcoal presented in this study have shown differences in $\delta^{13}C$ values through time as well as from different macroclimatic zones. It is suggested that part of this variation is due to increased use of fossil fuels since the beginning of the Industrial Revolution. On the basis of this conclusion it is further suggested that all $\delta^{13}C$ values of fossil wood should be corrected by -2‰ if results are to be compared to a modern sample. Previous figures such as that of less than -1‰ as suggested by Keeling *et al.* (1979) are too low.

Climatic influence on $\delta^{13}C$ values is not as easy to identify as the fossil fuel effect although results so far have shown that stable isotopes in wood charcoal do reflect climatic influences. The problem is that the climatic signal generated by either temperature or rainfall is not immediately identifiable.

The separation of the two climatic variables is important for future research. This may be possible with careful site selection, sample replication and network sampling. Only four sampling areas were used in this study in order to correlate $\delta^{13}C$ values of wood charcoal with temperature and rainfall. Sample sizes were very small, a total of only 35 modern samples were used in this study. A larger sample from more areas may show more reliable results. The field is still in the early stages of development as such, interpretations based purely on $\delta^{13}C$ values of wood charcoal should not be extrapolated into the archaeological record. Only when the results from the isotopic analysis of wood charcoal from archaeological sites show statistically significant results, or exhibit similar patterns to those of other independent studies, such as EDXA, can archaeological interpretations be made.

Using $\delta^{13}C$ values accompanying radiocarbon dates it is possible to show differences between microenvironments at Elands Bay. The patterns reflect those evident in the

analysis of wood morphological types (Chapter 3). These values also hint that it may have been hotter and drier in the last 1000 years.

The analysis in this chapter confirms the consideration that stable carbon isotope analysis is a useful tool for palaeoenvironmental reconstruction. Wood charcoal does indeed bear a climatic signal, this signal however is extremely complex. As yet, it is not possible to extrapolate results obtained from a modern sample into the archaeological record.

CHAPTER SEVEN

CONCLUSIONS

The basis of this thesis is a discussion of three methods of climatic reconstruction using wood charcoal from the archaeological sites at Elands Bay. One of these techniques (wood identification from xylem anatomy) is well established and has been widely applied in archaeology. This is the first systematic application of the second technique (Ecologically Diagnostic Xylem Analysis), and the first application of the third technique ($^{13}C/^{12}C$ measurements on charcoal).

Relative abundance of wood morphological types

Relative abundance analysis refers to an analysis of environmental change through wood identification from xylem anatomy. This identification is made possible because wood when charcoaled does not lose any of its distinctive anatomical features (Salisbury and Jane 1940). Positive identification of fossil charcoal is achieved by comparison with photomicrographs of identified modern specimens.

The results of an analysis of 1200 pieces of charcoal from Tortoise Cave, Spring Cave and Mike Taylors Midden show that the most common woody species at Elands Bay are also evident in the archaeological record over the last 4000 years. This means that climatic change over the last 4000 years has not been sufficient to influence the species composition of wood brought into the sites by people. There are however differences in species composition of the charcoal from Tortoise Cave on the one hand and MTM and Spring Cave on the other. These differences reflect the fundamental differences in environment between the sites. But for overgrazing, the vegetation around Tortoise Cave should be largely comprised of coastal fynbos, whereas around MTM and Spring Cave strandveld vegetation predominates.

The relative abundance of charcoal morphological types in the archaeological record at Elands Bay cannot be taken to relate to climate. Rather the dynamics of the change from potential fuelwood to charcoal are socio-economic. People made specific choices about the types of wood they collected. The relative abundance of the charcoal morphological types reflect this selection criteria. There are, however, differences in species composition between Tortoise Cave and the other sites which are reflected in the archaeological record. These differences indicate the merits of the technique.

Ecologically Diagnostic Xylem Analysis

Previous studies have indicated a causal link between vessel diameter, vessel frequency and climate (Carlquist 1977a&b, Baas 1982, Baas *et al.* 1988, Zhang, *et al.* 1988). These same researchers have pointed out that the diameter of xylem vessels decrease whilst the vessel frequency increases with increasing drought. Scholtz (1986) was the first to realise the potential for using the variation in anatomy of wood charcoal from archaeological sites to infer palaeoclimatic change. Scholtz (1986) developed a computer based technique for measuring a wide range of potentially ecoclimatically significant variables observable in a cross section of wood. This thesis is a systematic application of Scholtz's EDXA approach to wood anatomy in order to test its precision and applicability. The two questions which are important here are; (i) What exactly is the relationship between vessel size, vessel number and rainfall? (ii) If there is a good relationship between these variables in the winter rainfall area of the western Cape, then what level of precision are we looking at in the archaeological record, hundreds or thousands of years?

Reliable reconstructions of climate from wood anatomy require that the natural range in variation of vessel size and number of specific genera in the south-western Cape has to be known. Carlquist (1977a) and Carlquist & Hoekman (1985) found that a considerable deviation from a linear relationship between vessel diameter and vessel frequency can and does occur. This range in wood anatomical variables accounts for a

very high 'noise level' when attempting to associate wood anatomical variables with climate. These problems can be solved by using suitable statistical methods as well as a large sample size. A second requirement for reliable climatic construction from wood anatomy, is the determination of the percentage of shrinkage accompanying carbonisation. This study incorporated both a wide range of statistical methods as well as an independent study to determine the amount of shrinkage accompanying carbonisation.

The results of this analysis show that *Rhus* does not show a marked difference in wood anatomy between desert species and their more mesic relatives. Correlation coefficients linking climatic data with wood anatomy show weak to very weak correlations. *Diospyros* on the other hand, exhibits strong relationships between wood anatomical variables and climate. The correlation coefficient matrix shows very strong correlations between wood anatomy and temperature.

Comparing the results of a correlation coefficient matrix and multiple regression analysis it is possible to unearth the ecological component of the variation in the wood anatomy of *Rhus*. The results show correlations between the anatomy of *Rhus* from the winter rainfall area, and the all year rainfall area, specifically with regard to PWARM. Within the winter rainfall area, however, and using multiple regression analysis, there are still weak to very weak correlations between climate and the anatomy of *Rhus*.

Formulae developed from the analysis of modern samples were applied to samples of archaeological charcoal from sites around Elands Bay. From the results obtained for *Diospyros*, there is a 20°C difference in average annual temperature over 1000 years (Fig 10-11). Average annual temperature at Elands Bay today should be about 16°C. Considering that estimates of the change in temperature since the last glacial maximum 17 000 years ago are of the order of 5-10°C (Deacon and Lancaster 1988), a

temperature difference of 20° in a thousand years is impossible to consider. Formulae developed out of an analysis of contemporary *Rhus* samples are equally unsatisfactory.

It was suggested (F. Thackeray pers. comm.) that a factor analysis may reveal the ecological component of the variation where variability is determined by multiple factors. A factor analysis was performed on three genera of fossil charcoal found in the archaeological record at Elands Bay. High factor loadings for specific wood anatomical variables were compared with results of correlation analysis to determine the climatic variable registered. Using summary statistics based on factor one all three genera are plotted on the same graph (Fig 13). This graph shows a high correlation between the results for *Rhus*, *Diospyros* and *Zygophyllum*. A comparison of the three genera indicates that changes in climate probably did occur and can be related to wood anatomy.

The relationship between xylem morphology and climate is more complex than was envisaged at the start of this project. Different genera relate differently to the environment. As such, not all genera are suitable for studies relating wood anatomy to climate. From this study it would appear that unless a range of statistical methods are applied, the wood anatomy of *Rhus* cannot be related to climate. The wood anatomy of *Diospyros* on the other hand does have strong correlations with temperature. Extrapolating these correlations into the archaeological record does not give meaningful results. The analysis of both *Rhus* and *Diospyros* only exhibit similar results when a factor analysis is applied to the data.

The results of a factor analysis suggest that around 4000 B.P. temperatures at Elands Bay were high declining to a low at 3000 B.P.. After 3000 B.P. temperatures increase till about 1700 B.P. when there is again a decrease in temperature until 1200 B.P. After 1200 B.P. temperatures remain stable to the present. These results are not entirely satisfactory and much research needs to be done before the climatic component of

wood variation observable on a contemporary wood sample can be extrapolated into the archaeological record.

Stable carbon isotopes

Moving away from wood anatomy, this section of the thesis considers the potential for using as a palaeoenvironmental climatic indicator $^{13}C/^{12}C$ measurements on wood charcoal from archaeological sites. Comparisons are made between $\delta^{13}C$ measurements of archaeological wood charcoal and contemporary wood charcoal. This analysis stems from the observation that the ratio between the stable isotopes ^{13}C and ^{12}C can be a good indicator of water use efficiency with plants in drier environments exhibiting more positive $\delta^{13}C$ values (Farquhar & Richards 1984). The results of the analysis presented in this study pinpoints differences in $\delta^{13}C$ values through time, as well as from different microclimatic zones.

The results of an isotopic analysis on a modern sample of wood from four different areas shows that $\delta^{13}C$ values can be related to rainfall and temperature. Analysis of two cool-wet areas and two warm-dry areas do show statistically significant differences in $\delta^{13}C$ values (Mann-Whitney approximate Z-value = 2.52, $p<0.01$). The climatic component of the range in variation in the archaeological record is not as easy to identify. There is no significant difference in the range in variation of $\delta^{13}C$ values within the archaeological sample (Mann-Whitney approximate Z-value = 1.32, $p<0.2$). It is suggested that the differences between the archaeological and the modern sample is the result of an increased use of fossil fuels since the beginning of the Industrial Revolution (Mann-Whitney approximate Z-value 2.88, $p<0.004$). This 'fossil fuel effect' has lowered the $^{13}C/^{12}C$ ratio of trees and other plants by as much as $2‰$. On the basis of these results it is concluded that all $\delta^{13}C$ values of archaeological charcoal should be corrected by $-2‰$, if results are to be compared to a modern sample. The major objective of future research should be to identify and separate the climatic component within the range in variation of wood charcoal from archaeological sites.

Results of analysis were obtained from a very small modern sample (35 specimens). Only four sampling areas were used to correlate $\delta^{13}C$ values of charcoal to temperature and rainfall. It may be possible to obtain more reliable results from the archaeological record by revising the sampling strategy. A larger sample from more areas may give more dependable results. This may also be possible by careful site selection, sample replication and network sampling. Only when the results from the isotopic analysis of wood charcoal from the archaeological sites show statistically significant results can archaeological interpretations be made from these results.

Wood charcoal does indeed bear a climatic signal. Using $\delta^{13}C$ values accompanying radiocarbon dates it is possible to show differences between environments at Elands Bay. $\delta^{13}C$ values for Tortoise Cave are significantly different from MTM and Spring Cave. These values reflect the results of the analysis of wood morphological types. This confirms the use of $\delta^{13}C$ measurements on wood charcoal from archaeological sites as a palaeoenvironmental climatic indicator. As yet, there are still problems in extending the results of analysis of contemporary charcoal into the archaeological record.

Conclusion

In this project I originally set out to determine the feasibility of using wood anatomy as a palaeoenvironmental climatic indicator. As an independent test on the results of this analysis, I decided to use stable carbon isotope ratios of wood charcoal. The correlations between isotopes ($\delta^{13}C$ values), wood anatomy (EDXA) and climate suggests that both of these techniques have merit. There are, however, problems inherent in extrapolating the results obtained from an analysis of a contemporary wood sample into the archaeological record. As the discipline is still in its infancy, there are a number of teething problems. With time, and further research, these should be sorted out. A considerable amount of work still needs to be done, on a very basic level, before these techniques can be applied in an archaeological context. Future research should

concentrate on the range in variation of both wood anatomical variables and $\delta^{13}C$ values within a plant, between individuals and between different species growing in the same macroclimatic conditions.

van der Walt, J.J.A., Werker, E. & Fahn, A. 1988. Wood Anatomy of *Pelargonium* (*Geraniaceae*) *International Association of Wood Anatomists Bulletin.* n.s.,**8(2)**:95-108.

Vernet, J.L. 1973. Etudes sur l'histoire de la vegetation du sud-est de la France au Quaternaire, d'apres les charbons de bois principalement. *Paleobiologie continentale* **IV**:1-90.

Vernet, J.L. 1976. La vegetation pendant le Post-Glaciaire apport des charbons de bois. *La Prehistoire francaise, CNRS edit.* **II**:95-103.

Waisel, Y., Lipschitz, Nili & Fahn, A. 1970. Cambial Activity in *Zygophyllum dumosum* (Boiss.) *Annals of Botany* **34**:409-414.

Weather Bureau. 1986. *Climate of South Africa.* Climate Statistics up to 1984. WB **40**. Weather Bureau, Department of Environment Affairs, Government Printer, Pretoria.

Webber, I.E. 1936. The woods of sclerophellous and desert shrubs and desert plants of California. *American Journal of Botany* **23**:181-188.

Wigley, T.M.L. 1982. Oxygen-18, Carbon-13, and Carbon-14 in tree rings. In Hughes, M.K., Kelly, P.M., Pilcher, J.R. & LaMarche, V.C. Jr. eds., *Climate from tree rings* pp18-21. Cambridge University Press, Cambridge.

Wilkins, A.P. & Papassotiriou, S. 1989. Wood anatomical variation of *Acacia Melanoxylon* in relation to latitude. *International Association of Wood Anatomists Bulletin* n.s.,**10 (2)**201-207.

Yates, R.J., Miller, D.E., Halkett, D.J., Manhire, A.H., Parkington, J.E. & Vogel, J.C. 1986. A late mid-Holocene high sea level: a preliminary report on geoarchaeology at Elands Bay, western Cape Province, South Africa. *South African Journal of Science.* **82**:164-165.

Zhang Xinying, Deng Liang & Pieter Baas. 1988. The ecological wood anatomy of the Lilacs (*Syringa Oblata var. giraldii*) on Mount Taibei in Northwestern China. International Association of Wood Anatomists Bulletin n.s.,**9**(1):24-30.

Zimmerman, M.H. 1971. Transport in Xylem. In Zimmerman, M.H. & Brown, C.L. eds., *Trees: Structure and Function*. pp.169-220. Springer Verlag, New York.

Zimmerman, M.H. 1978. Structural requirements for optimal conduction in tree stems. In Tomlinson, P.B. & Zimmerman, M.H. eds., *Tropical trees as living systems* pp.517-532. Cambridge University Press, London, New York & Melbourne.

Zimmerman, M.H. 1982. Functional Xylem Anatomy of angiosperm trees. In Baas P. ed., *New Perspectives in Wood Anatomy*. Nijhoff/Junk, The Hague.

Zimmerman, M.H. 1983. *Xylem structure and the ascent of sap.* Springer-Verlag, Berlin.

Zimmerman, M.H. & Brown, C.L. 1971. *Trees: Structure and Function.* Springer, New York, Heidelberg, Berlin.

Zohary, M. 1962. Plant life of Palestine - Israel and Jordan *Chronica Botanica* n.s.,**33**. Ronald Press New York.

TABLE 1

PERCENTAGES OF IDENTIFIABLE CHARCOAL FROM ELANDS BAY ARCHAEOLOGICAL SITES.

Site	SC	SC	SC	TC	MTM	MTM	MTM	SC	TC	TC
Layer	AshIV	DBM	Bravo	ABDII	E4/5	E5/9	E5/10	Allbl	SM2	Mela
N^{o} of Samples	105	105	105	105	219	104	105	105	104	101
^{14}C Date	460	840	1150	1600	2000	2300	2500	3000	3500	4200
Dios/Euclea	24	13	4	14	19	19	20	9	1	5
Rhus	5	5	1	8	0	0	0	4	0	3
Zygophyllum	14	9	14	17	21	18	7	17	21	16
Ruschia	20	47	27	0	12	34	51	55	1	0
Lycium	9	5	18	1	1	4	0	1	0	0
Pterocelastras	0	1	0	1	18	0	0	0	0	0
Type A	3	1	12	24	11	2	1	1	19	23
Type B	0	0	0	3	0	0	0	0	17	11
Type C	0	0	0	3	0	0	0	0	10	5
Total %	75	81	76	71	81	73	79	87	69	63
Unidentifiable	11	12	21	6	7	9	10	11	4	13
Unidentified	24	7	3	23	12	18	11	2	27	24

SC = Spring Cave
TC = Tortoise Cave
MTM = Mike Taylors Midden.

TABLE 2

CLIMATIC VARIABLES: SYMBOLS AND UNITS OF MEASUREMENT.

VARIABLE	SYMBOL	UNIT OF MEASUREMENT
POTENTIAL EVAPOTRANSPIRATION	PE	MM
ACTUAL EVAPOTRANSPIRATION	AE	MM
ANNUAL PE	PEAN	MM/YR
MAXIMUM MONTHLY PE	PEMAX	MM/MO
MINIMUM MONTHLY PE	PEMIN	MM/MO
RANGE IN MONTHLY PE	DIFPE	MM/YR
RAINFALL	P	MM
ANNUAL P	PAN	MM/YR
AVERAGE MONTHLY P	PAVM	MM/MO
ACTUAL AVERAGE MONTHLY P	ACTP	MM/MO
MAXIMUM MONTHLY P	PMAX	MM/MO
MINIMUM MONTHLY P	PMIN	MM/MO
RANGE IN MONTHLY P	DIFP	MM/YR
PRECIPITATION WARMEST MONTH	PWARM	MM/MO
PRECIPITATION COLDEST MONTH	PCOLD	MM/MO
MOISTURE INDEX	PMI	(RATIO)
TEMPERATURE	T	CENT
ANNUAL T	TAN	CENT
MAXIMUM MONTHLY T	TMAX	CENT
MINIMUM MONTHLY T	TMIN	CENT

MM = MILLIMETRES

CENT = DEGREES CENTIGRADE

MO = MONTH

YR = YEAR

TABLE 3

CLIMATE STATISTICS USED IN THIS STUDY.

	SAAS	JONK	LANG	MONT	PELLA	RICHT	RIVER	VREDE	TIER
PAN	920	1096	265	318	438	162	459	244	172
AE	8.2	10	9.7	13.6	9.8	11.7	11.4	6.7	13.5
PEMAX	12.4	19.3	19	28.5	16.2	24.7	21.2	10.4	26.3
PEMIN	5.2	3.7	5.9	3.8	4	3.2	4.7	4.5	4.2
DIFPE	7.2	15.6	13.2	24.7	12.2	21.5	16.5	5.9	22.1
PMI	895	1564	388	278	488	144	341	508	39
PMIN	50	31	4	12	10	4	26	4	10
PMAX	96	167	46	40	63	27	46	46	26
DIFP	46	136	42	28	53	23	20	42	17
PWARM	74	34	6	12	10	4	27	4	14.5
PCOLD	70	155	38	36	60	27	39	38	10
PAVM	77	91	20	27	37	24	38	19	14
TAN	21	22	23	25	22	24	24	19	23
TMAX	24	28	28	31	27	30	29	21	30
TMIN	18	17	18	19	18	17	20	16	16
DIFT	6	11	10	12	9	13	9	5	14

SAAS = Saasveld

JONK = Jonkershoek

LANG = Langebaanweg

MONT = Montagu

PELLA = Pella

RIVER = Riversdale

VREDE = Vredenburg Peninsula

TIER = Tierberg

TABLE 4.

LIST OF WOOD ANATOMICAL VARIABLES MEASURED

MPD	MINIMUM PIECE DIAMETER
MAXV	MAXIMIMUM VESSEL DIAMETER
MINV	MINIMUM VESSEL DIAMETER
RANGV	RANGE IN VESSEL DIAMETER
RADV	RADIAL VESSEL DIAMETER
TANGV	TANGENTIAL VESSEL DIAMETER
MEANV	MEAN VESSEL DIAMETER
RELV	RELATIVE VOLUME FLOW
AREAV	AREA COVERED BY VESSELS
NUMV	NUMBER OF VESSELS
VULN	VULNERABILITY

TABLE 5

LOCATIONS FROM WHICH MODERN SAMPLES WERE COLLECTED

Major loc.	Minor location	Location	Latitude	Longitude
Elands Bay	Elandsberg	small kloof, 500m SE trig 631	32° 19'	18° 20'
Elands Bay	Elandsberg	6 m outcrop 400m S trg 631	32° 19'	18° 20'
Elands Bay	Elandsberg	N/S gulley 350m SE trg 631	32° 19'	18° 20'
Elands Bay	hill SE Verlorenvlei	NW of outcrop 300m below TC	32° 19'	18° 20'
Elands Bay	Elandsberg	HSM,500m SE factory slope	32° 19'	18° 20'
Elands Bay	Elandsberg	area below EBC,S radar station	32° 19'	18° 20'
Elands Bay	coast w. Elandsberg	area on and around MTM	32° 19'	18° 20'
Elands Bay	Elandsberg	300mSE oftrig 631 top of hill	32° 19'	18° 20'
Elands Bay	Elandsberg	SE slope of Mnt 300-400m trig	32° 19'	18° 20'
Riversdale	road verge	10kms along gravel road east	34°	21°
Riversdale	kaffrarian thicket	5kms S Riversdale left fork	34°	21°
Riversdale	fynbos	Swartheuvel 15kms S Riversdal	34°	21°
Riversdale	fynbos	30kms S Riversdale to Stilbay	34°	21°
Riversdale	forest	35kms S Riversdale to Stilbay	34°	21°
Riversdale	coastal fynbos	2kms from coast	34°	21°
Riversdale	dune forest	approx 5kms from Riversdale	34°	21°
Atlantis	Pella	FRD botanical research station	33° 31'	18° 32'
Vredenburg	W.Point fish factory	granite quarry SW of factory	32° 50'	17° 51'
Montagu	kloof on Langeberg	in kloof 5kms SW of Police station	33° 47'	20° 07'
Langebaanweg	phosphate mine	2kms NE of military airfield	32° 58'	18° 10'
Richtersveld	Springbok flats	granite slabs below Mnt Tattasberg	28° 02'	17° 01'
George	Saasveld	forest in front of offices	33° 58'	22° 32'
Prince Alfred	Tierberg	drain channels on study site	33° 20'	22° 02'
Stellenbosch	Jonkershoek	weather station behind offices	33° 58'	18° 56'

TABLE 6

RESULTS OF EDXA FOR MODERN SPECIMENS OF RHUS

Rec	Spec	Loc	Genus	Species	*Mpd	Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
29	102	Eland	Rhus	glauca	0.50	21	66	36	30	75	66	54	47	17	71	13	0
30	114	Eland	Rhus	glauca	0.60	23	84	40	43	89	84	64	88	22	65	12	0
27	108	Eland	Rhus	glauca	0.70	27	80	42	38	88	83	60	90	25	85	14	0
31	114	Eland	Rhus	glauca	0.70	14	76	38	37	76	80	57	64	20	74	15	0
28	108	Eland	Rhus	glauca	0.70	24	73	50	23	82	73	61	78	23	75	10	0
32	114	Eland	Rhus	glauca	0.70	18	79	50	28	92	83	66	105	27	78	12	0
25	103	Eland	Rhus	glauca	0.60	15	65	39	26	70	67	52	56	22	102	13	0
26	108	Eland	Rhus	glauca	0.60	15	69	34	35	75	67	52	27	10	44	17	1
5	19	Eland	Rhus	scytophylla	0.70	2	73	37	35	70	82	56	43	14	55	8	1
35	50	Eland	Rhus	scytophylla	0.70	18	70	38	31	77	72	55	62	21	88	13	0
22	94	Eland	Rhus	scytophylla	0.50	12	82	36	46	90	81	62	79	19	61	11	1
11	34	Eland	Rhus	scytophylla	0.60	16	64	34	30	69	62	46	37	17	94	11	0
14	61	Eland	Rhus	scytophylla	0.80	10	73	38	34	74	84	57	50	15	58	21	0
17	67	Eland	Rhus	scytophylla	0.90	14	83	41	41	90	82	63	54	13	42	12	1
18	62	Eland	Rhus	scytophylla	0.90	13	84	45	39	97	84	68	58	13	36	17	1
3	11	Eland	Rhus	scytophylla	0.80	20	76	44	32	86	75	60	69	20	68	15	0
23	83	Eland	Rhus	scytophylla	0.60	15	87	50	37	90	95	71	95	20	51	9	1
33	50	Eland	Rhus	scytophylla	0.90	8	76	42	34	82	77	61	49	14	47	9	1
24	83	Eland	Rhus	scytophylla	0.60	15	82	50	31	88	85	65	93	24	69	17	0
16	67	Eland	Rhus	scytophylla	1.20	5	79	39	39	83	77	61	63	17	54	17	1
20	65	Eland	Rhus	scytophylla	0.60	4	91	44	47	94	96	67	86	17	44	12	1
21	89	Eland	Rhus	scytophylla	0.90	9	76	46	29	89	68	62	61	17	56	11	1
36	45	Eland	Rhus	scytophylla	0.90	13	66	33	33	70	68	51	39	15	73	15	0
13	54	Eland	Rhus	scytophylla	0.90	30	79	42	37	91	78	64	64	16	49	12	1
34	45	Eland	Rhus	scytophylla	0.50	11	69	40	29	75	67	56	41	14	54	11	1
9	35	Eland	Rhus	scytophylla	0.80	8	77	29	48	85	78	59	45	12	42	13	1
4	22	Eland	Rhus	scytophylla	0.80	20	87	25	62	95	81	62	59	13	39	11	1
12	54	Eland	Rhus	scytophylla	0.90	16	74	36	37	79	74	57	43	13	51	14	1
10	34	Eland	Rhus	scytophylla	0.70	10	72	37	35	78	75	54	44	15	61	9	0
15	61	Eland	Rhus	scytophylla	1.00	8	82	38	44	89	80	61	44	11	37	0	1
19	66	Eland	Rhus	scytophylla	0.60	10	93	51	41	93	94	72	82	15	36	11	1
8	32	Eland	Rhus	scytophylla	0.60	16	70	40	30	74	72	58	45	14	54	0	1
7	32	Eland	Rhus	scytophylla	1.00	1	73	40	32	82	71	58	42	13	47	5	1
95	60	Eland	Rhus	scytophyll	4.00	6	74	44	29	78	74	59	20	6	22	0	2
96	49	Eland	Rhus	scytophyll	0.60	10	90	60	30	105	92	76	51	10	21	0	3
80	236	Jonke	Rhus	angustifolia	0.50	2	80	45	34	88	81	63	22	5	18	0	3
82	235	Jonke	Rhus	angustifolia	0.80	15	79	44	34	89	75	62	21	6	19	0	3
79	238	Jonke	Rhus	angustifolia	0.50	8	90	44	45	99	86	67	33	7	19	5	3
78	237	Jonke	Rhus	glauca	0.40	10	79	42	37	91	77	61	21	6	20	0	3
77	240	Jonke	Rhus	glauca	0.60	14	66	38	28	71	69	54	15	5	24	0	2
81	239	Jonke	Rhus	glauca	0.50	16	70	41	28	73	67	55	22	8	32	0	1
65	177	Lange	Rhus	laevigata	0.70	19	85	42	42	85	96	60	21	5	18	14	3
63	179	Lange	Rhus	laevigata	0.70	17	77	42	34	89	72	59	20	6	21	12	2
64	178	Lange	Rhus	laevigata	0.50	9	92	54	37	98	94	73	25	5	11	11	6
66	180	Lange	Rhus	laevigata	0.80	17	97	41	56	102	100	69	35	6	16	7	4
93	170	Monta	Rhus	lucida	0.60	9	74	45	29	83	66	60	18	5	19	0	3
91	171	Monta	Rhus	lucida	0.90	11	80	46	34	85	86	65	34	8	25	0	2
68	172	Monta	Rhus	lucida	1.00	15	67	39	28	71	68	53	8	3	14	9	3
46	147	Pella	Rhus	laevigata	0.40	22	78	18	59	82	80	44	19	5	30	6	1

Rec	Spec	Loc	Genus	Species	Mpd	Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
42	332	Pella	Rhus	laevigata	0.68	0	84	43	41	99	78	62	34	9	28	2	2
41	331	Pella	Rhus	laevigata	0.73	3	89	55	34	106	78	71	38	8	20	3	3
48	146	Pella	Rhus	laevigata	0.40	22	86	28	58	94	84	58	64	14	49	9	1
43	328	Pella	Rhus	laevigata	0.70	5	85	48	36	89	86	67	34	8	22	3	3
47	145	Pella	Rhus	laevigata	0.40	24	73	22	50	90	59	47	17	5	26	15	1
69	182b	Richt	Rhus	incisa	0.50	15	73	37	36	78	69	56	11	3	13	0	4
67	181	Richt	Rhus	incisa	0.40	15	64	36	27	70	70	53	15	5	25	7	2
97	183	Richt	Rhus	incisa	0.50	9	64	36	27	70	62	52	9	3	16	0	3
72	182a	Richt	Rhus	incisa	0.50	0	69	32	36	75	65	51	14	5	24	12	2
60	137	River	Rhus	glauca	4.00	19	68	26	42	73	75	51	32	11	51	11	1
43	139	River	Rhus	glauca	0.70	14	67	21	46	73	72	45	43	17	95	8	0
37	140	River	Rhus	glauca	0.40	9	48	33	15	52	50	41	11	7	58	10	0
40	142	River	Rhus	glauca	0.70	19	65	32	33	75	67	52	40	14	61	14	0
45	136	River	Rhus	glauca	0.60	6	58	18	40	60	59	39	14	7	50	17	0
39	144	River	Rhus	longispina	0.60	1	53	26	27	58	55	41	17	10	74	16	0
38	143	River	Rhus	longispina	0.30	12	59	30	29	68	55	46	31	15	85	18	0
108	125	River	Rhus	lucida	0.50	3	70	43	26	73	71	58	17	5	21	0	2
106	124	River	Rhus	lucida	0.50	4	74	39	35	81	76	58	19	6	22	0	2
42	138	River	Rhus	lucida	0.40	19	77	21	56	90	75	57	46	11	40	9	1
44	135	River	Rhus	lucida	0.60	35	76	29	46	78	79	55	32	9	36	13	1
105	129	River	Rhus	lucida	0.80	8	67	46	20	74	71	56	20	7	29	0	1
104	128	River	Rhus	lucida	0.70	6	82	43	39	93	78	57	35	10	36	0	1
41	134	River	Rhus	lucida	0.30	22	74	25	49	81	79	51	47	14	62	16	0
107	126	River	Rhus	lucida	0.50	3	73	36	36	72	77	55	16	5	21	0	2
103	127	River	Rhus	lucida	0.60	5	67	43	23	70	70	55	19	7	30	0	1
92	130	River	Rhus	sp	0.50	2	61	36	25	70	57	47	6	3	17	0	2
101	131	River	Rhus	sp	0.80	1	67	43	23	70	70	55	14	5	22	0	2
84	132	River	Rhus	sp	0.60	2	61	31	30	66	59	47	6	3	16	0	2
114	217	Saas	Rhus	chirindensis	0.60	8	80	52	27	88	77	67	40	10	28	0	2
112	205	Saas	Rhus	chirindensis	0.60	11	88	49	39	94	86	67	28	6	17	0	3
85	209	Saas	Rhus	chirindensis	0.50	11	85	60	24	89	95	74	28	6	14	0	5
113	216	Saas	Rhus	chirindensis	0.40	11	95	57	38	111	86	74	32	6	14	0	5
75	221	Saas	Rhus	chirindensis	0.60	8	84	37	46	90	82	63	14	3	11	8	5
74	220	Saas	Rhus	chirindensis	0.70	16	78	42	36	83	76	59	14	4	14	8	4
86	212	Saas	Rhus	chirindensis	0.80	3	88	57	31	106	77	74	15	3	7	0	10
87	210	Saas	Rhus	chirindensis	0.50	7	94	65	28	113	87	79	34	6	12	0	6
83	219	Saas	Rhus	chirindensis	0.50	12	98	53	45	115	86	77	21	3	8	0	9
115	204	Saas	Rhus	chirindensis	0.70	13	84	50	34	92	85	67	23	5	15	0	4
100	213	Saas	Rhus	chirindensis	0.70	10	103	74	28	115	109	89	32	4	7	0	11
90	218	Saas	Rhus	chirindensis	0.50	3	81	52	28	87	89	68	20	4	13	0	5
88	203	Saas	Rhus	chirindensis	0.70	3	98	65	32	115	90	80	31	5	10	0	7
111	206	Saas	Rhus	chirindensis	0.60	7	87	52	34	99	80	68	24	5	15	0	4
89	211	Saas	Rhus	chirindensis	.60	7	87	67	19	98	83	78	25	4	10	0	7
102	214	Saas	Rhus	chirindensis	0.70	11	87	44	43	84	94	65	39	9	25	0	2
109	207	Saas	Rhus	chirindensis	0.80	4	88	41	46	100	86	67	25	5	15	0	4
99	208	Saas	Rhus	chirindensis	0.60	7	89	60	29	96	90	76	24	4	10	0	7
76	222	Saas	Rhus	chirindensis	0.50	8	88	62	25	106	77	76	26	5	11	7	6
110	215	Saas	Rhus	chirindensis	0.50	7	90	60	29	99	88	76	26	5	11	0	6
67	370	Tier	Rhus	lucida	0.88	0	72	35	36	84	66	58	21	6	24	4	2
70	376	Tier	Rhus	lucida	1.00	4	84	51	33	87	87	67	57	14	37	5	1
86	368	Tier	Rhus	lucida	0.77	5	56	34	22	62	56	45	17	9	58	3	0
79	373	Tier	Rhus	lucida	0.60	2	77	44	32	89	69	59	36	11	39	4	1
66	357	Tier	Rhus	lucida	0.85	0	70	37	33	75	72	55	31	11	44	4	1
68	356	Tier	Rhus	lucida	1.06	4	73	50	23	81	69	60	23	7	25	5	2
69	377	Tier	Rhus	lucida	0.92	3	75	52	23	84	74	63	40	11	37	3	1

Rec	Spec	Loc	Genus	Species	Mpd	Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
90	366	Tier	Rhus	undulata	0.76	1	59	34	25	62	64	48	24	11	61	4	0
89	359	Tier	Rhus	undulata	0.57	1	64	37	27	74	62	51	24	10	50	5	1
88	360	Tier	Rhus	undulata	0.64	3	61	33	28	68	58	45	13	7	43	5	1
93	361	Tier	Rhus	undulata	0.72	3	69	31	38	72	71	51	27	10	48	5	1
72	364	Tier	Rhus	undulata	0.66	3	75	45	30	75	93	63	60	17	54	3	1
71	372	Tier	Rhus	undulata	0.52	1	64	35	29	65	68	50	13	6	30	3	1
73	378	Tier	Rhus	undulata	0.64	2	67	47	20	76	75	57	41	14	55	3	1
57	164	Vrede	Rhus	glauca	0.80	14	66	25	41	83	59	45	43	18	101	17	0
26	405	Vrede	Rhus	glauca	0.64	2	73	37	36	83	73	58	63	20	73	0	0
27	404	Vrede	Rhus	glauca	0.63	0	65	41	23	76	58	54	26	10	45	4	1
28	408	Vrede	Rhus	glauca	0.52	0	62	36	26	70	59	47	22	10	57	4	0
98	162	Vrede	Rhus	glauca	1.20	6	65	38	27	71	62	52	18	7	32	0	1
29	409	Vrede	Rhus	glauca	0.50	1	66	36	29	75	61	49	17	7	38	4	1
52	163	Vrede	Rhus	glauca	1.10	23	58	17	41	67	51	38	20	9	70	13	0
30	406	Vrede	Rhus	glauca	0.78	1	61	35	25	71	57	49	22	10	52	4	0

REC = South African Museum accession number

MPD is in centimetres

MCO = minimum coefficient of variation for MPD.

TABLE 7

AVERAGE VALUES FOR ENTIRE MODERN ASSEMBLAGES OF RHUS FROM EACH SITE

		*Mpd	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
Saasveld	Mean	0.60	88.93	55.41	33.53	99.42	86.55	72.61	26.51	5.60	13.72	1.20	6.06
n = 20	Std Dev	0.10	6.20	9.36	7.43	10.46	7.55	6.88	7.07	1.65	5.28	2.85	2.37
	Max	0.8	103.1	74.2	46.5	115.5	109.8	89	40.48	10.3	28.7	8.6	11.64
	Min	0.4	78.6	37.9	19.4	83.4	76.3	59.2	14.41	3.2	7.3	0	2.34
Tierberg	Mean	0.76	69.57	40.75	28.82	75.84	70.83	55.56	30.93	10.68	43.59	4.49	1.40
n = 14	Std Dev	0.16	7.37	7.13	5.25	8.56	9.60	6.86	14.14	3.13	11.48	0.68	0.51
	Max	1.06	84.8	52.3	38.1	89.8	93.3	67.8	60.1	17.3	61.3	5.4	2.4
	Min	0.52	56.6	31.4	20.2	62.6	56.7	45	13.74	6	24.4	3.5	0.78
Elands Bay	Mean	0.73	77.44	41.29	36.16	83.91	78.37	60.54	59.73	16.82	57.68	11.59	1.21
n = 35	Std Dev	0.17	7.40	6.72	7.42	8.81	8.49	6.10	20.24	4.63	18.74	5.10	0.59
	Max	1.2	93	60.2	62.1	105.1	96.8	76.1	105.72	27.6	102	21.7	3.47
	Min	0.4	64.5	25.8	23.1	69.8	62.6	46.8	20.15	6.2	21.9	0	0.49
Jonkershoek	Mean	0.55	77.75	42.87	34.92	85.92	76.22	60.68	22.96	6.53	22.38	0.88	2.86
n = 6	Std Dev	0.13	7.61	2.65	5.68	9.97	6.45	4.68	5.20	0.86	5.04	1.98	0.67
	Max	0.8	90.1	45.8	45.3	99.9	86.3	67.9	33.24	8.1	32.8	5.3	3.52
	Min	0.4	66.7	38	28.5	71.8	67.5	54.2	15.63	5.8	18.5	0	1.69
Langebaan	Mean	0.67	87.98	45.30	42.68	93.98	91.03	65.83	25.87	5.88	16.98	11.43	4.16
n = 4	Std Dev	0.10	7.73	5.33	8.23	6.87	10.71	6.14	5.87	0.62	3.61	2.56	1.34
	Max	0.8	97.7	54.5	56.1	102.3	100.5	73.7	35.55	6.7	21.7	14.3	6.27
	Min	0.5	77	41.6	34.7	85	72.9	59.3	20.73	5.1	11.7	7.3	2.73
Montagu	Mean	0.83	74.07	43.60	30.43	80.23	74.10	60.00	20.66	5.90	19.67	3.03	3.14
n = 3	Std Dev	0.17	5.24	3.19	2.55	6.43	8.87	5.14	10.46	2.21	4.29	4.29	0.42
	Max	1.00	80.2	46.2	34	85.6	86.6	65.8	34.23	8.7	25.1	9.1	3.65
	Min	0.60	67.4	39.1	28.2	71.2	66.9	53.3	8.79	3.3	14.6	0	2.62
Pella	Mean	0.55	82.92	36.03	46.88	93.80	78.07	58.60	34.82	8.62	29.63	6.82	2.18
n = 6	Std Dev	0.15	5.51	13.79	10.11	7.59	8.66	9.89	15.53	3.11	9.32	4.45	0.81
	Max	0.68	89.5	55.3	59.7	106.8	86.4	71.4	64.71	14.9	49.1	15.3	3.45
	Min	0.4	73.1	18.6	34.3	82.9	59.9	44.3	17.76	5.5	20.7	2.9	1.19
Richtersveld	Mean	0.47	67.83	35.75	32.08	73.90	66.95	53.60	12.54	4.55	19.83	5.10	2.91
n = 4	Std Dev	0.43	3.79	1.85	4.38	3.55	3.29	1.99	2.42	0.98	4.96	5.42	0.86
	Max	0.5	73.30	37.20	36.80	78.90	70.30	56.70	15.42	5.80	25.30	12.80	4.19
	Min	0.4	64.00	32.60	27.70	70.40	62.20	51.20	9.44	3.50	13.50	0.00	2.12
Riversdale	Mean	0.55	67.22	33.10	34.12	72.97	68.59	51.35	25.05	9.15	43.97	7.20	1.58
n = 19	Std Dev	0.14	8.36	8.36	10.64	9.58	9.20	6.02	12.91	4.04	23.20	7.29	0.85
	Max	0.80	82.90	46.70	56.70	93.00	79.50	58.60	47.86	17.20	95.40	18.70	2.90
	Min	0.30	48.40	18.20	15.10	52.60	50.00	39.70	6.63	3.00	16.40	0.00	0.47
Vredenburg	Mean	0.77	64.98	33.56	31.43	74.79	60.44	49.44	29.36	11.78	59.03	5.99	0.95
n = 8	Std Dev	0.24	4.26	7.56	6.61	5.55	5.79	5.56	15.15	4.50	20.99	5.84	0.36
	Max	1.2	73.8	41.3	41.1	83.6	73.3	58.3	63.7	20.3	101.6	17.7	1.6
	Min	0.5	58.3	17.3	23.8	67.3	51.5	38.5	17.8	7.2	32.6	0.0	0.5.

* MPD is in centimetres.

TABLE 8

AVERAGE VALUES FOR INDIVIDUAL SPECIES OF RHUS FROM EACH SITE

		*Mpd	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
Saasveld	*R.chirindensis*												
	AVG	0.60	88.93	55.41	33.53	99.42	86.55	72.61	26.51	5.60	13.72	1.20	6.06
n=20	STD	0.16	19.88	14.92	10.18	23.50	19.85	16.86	8.91	2.00	5.92	2.80	2.65
	MAX	.80	103.1	74.2	46.5	115.5	109.8	89	40.48	10.3	28.7	8.6	11.64
	MIN	.40	78.6	37.9	19.4	83.4	76.3	59.2	14.41	3.2	7.3	0	2.34
Tierberg	*R.lucida*												
	AVG	0.87	72.96	43.67	29.27	80.80	71.01	58.79	32.57	10.29	38.14	4.53	1.69
n=7	STD	0.14	7.91	7.29	5.43	8.46	8.50	6.47	12.69	2.36	10.70	0.62	0.54
	MAX	1.06	84.8	52.3	36.3	89.8	87.2	67.8	57.15	14	58.4	5.3	2.4
	MIN	0.60	56.6	34	22.6	62.8	56.7	45.5	17.66	6.8	24.4	3.6	0.78
Tierberg	*R.undulata*												
	AVG	0.64	66.19	37.83	28.37	70.87	70.64	52.34	29.28	11.07	49.04	4.44	1.11
n=7	STD	0.08	4.82	5.60	5.02	5.08	10.58	5.62	15.27	3.70	9.47	0.74	0.25
	MAX	0.76	75.5	47.2	38.1	76.8	93.3	63	60.1	17.3	61.3	5.4	1.66
	MIN	0.52	59.9	31.4	20.2	62.6	58.8	45	13.74	6	30.1	3.5	0.79
Elands Bay	*R.glauca*												
	AVG	0.68	74.55	41.65	32.90	81.30	75.81	58.56	69.97	21.00	74.79	13.70	0.82
n=8	STD	0.70	6.31	5.67	6.34	7.66	7.59	5.02	23.95	5.07	15.34	2.10	0.18
	MAX	0.7	84	50.7	43.1	92.4	84.9	66.2	105.72	27.6	102	17.7	1.18
	MIN	0.5	65.7	34.4	23.1	70.4	66.3	52.1	27.86	10.1	44.6	10.1	0.51
Elands Bay	*R.scytophylla*												
	AVG	0.76	78.30	41.18	37.12	84.69	79.13	61.13	56.69	15.58	52.61	10.96	1.33
n=26	STD	0.18	7.49	6.99	7.44	8.97	8.60	6.27	17.91	3.67	16.53	5.55	0.61
	MAX	1.2	93	60.2	62.1	105.1	96.8	76.1	95.35	24.2	94.4	21.7	3.47
	MIN	0.40	64.5	25.8	29	69.8	62.6	46.8	20.15	6.2	21.9	0	0.49
Jonkeshoek	*R.glauca*												
	AVG	0.50	72.13	40.57	31.63	79.13	71.63	56.87	20.08	6.63	25.73	0.00	2.32
n=3	STD	0.08	5.46	1.82	4.22	8.99	4.44	2.96	3.19	1.04	5.31	0.00	0.56
	MAX	0.6	79.6	42	37.6	91.8	77.8	61	22.93	8.1	32.8	0	3.05
	MIN	0.4	66.7	38	28.5	71.8	67.5	54.2	15.63	5.8	20	0	1.69
Jonkeshoek	*R.angustifolia*												
	AVG	0.60	83.37	45.17	38.20	92.70	80.80	64.50	25.85	6.43	19.03	1.77	3.39
n=3	STD	0.14	4.79	0.45	5.02	5.10	4.62	2.41	5.23	0.62	0.38	2.50	0.12
	MAX	0.8	90.1	45.8	45.3	99.9	86.3	67.9	33.24	7.3	19.3	5.3	3.52
	MIN	0.5	79.4	44.8	34.5	88.7	75	62.6	21.98	5.9	18.5	0	3.24

		*Mpd	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
Langebaan		*R.laevigata*											
	AVG	0.67	87.98	45.30	42.68	93.98	91.03	65.83	25.87	5.88	16.98	11.43	4.16
n=4	STD	0.10	7.73	5.33	8.23	6.87	10.71	6.14	5.87	0.62	3.61	2.56	1.34
	MAX	0.80	97.7	54.5	56.1	102.3	100.5	73.7	35.55	6.7	21.7	14.3	6.27
	MIN	0.5	77	41.6	34.7	85	72.9	59.3	20.73	5.1	11.7	7.3	2.73
Montagu		*R.lucida*											
	AVG	0.8	74.07	43.60	30.43	80.23	74.10	60.00	20.66	5.90	19.67	3.03	3.14
n=3	STD	0.17	5.24	3.19	2.55	6.43	8.87	5.14	10.46	2.21	4.29	4.29	0.42
	MAX	1.0	80.2	46.2	34.0	85.6	86.6	65.8	34.2	8.7	25.1	9.1	3.7
	MIN	0.6	67.4	39.1	28.2	71.2	66.9	53.3	8.8	3.3	14.6	0.0	2.6
Pella		*R.laevigata*											
	AVG	0.23	82.92	36.03	46.88	93.80	78.07	58.60	34.82	8.62	29.63	6.82	2.18
n=6	STD	0.16	5.51	13.79	10.11	7.59	8.66	9.89	15.53	3.11	9.32	4.45	0.81
	MAX	0.68	89.5	55.3	59.7	106.8	86.4	71.4	64.7	14.9	49.1	15.3	3.5
	MIN	0.40	73.1	18.6	34.3	82.9	59.9	44.3	17.8	5.5	20.7	2.9	1.2
Richtersveld		*R.incisa*											
	AVG	0.47	67.83	35.75	32.08	73.90	66.95	53.60	12.54	4.55	19.83	5.10	2.91
n=4	STD	0.04	3.79	1.85	4.38	3.55	3.29	1.99	2.42	0.98	4.96	5.42	0.86
	MAX	0.5	73.3	37.2	36.8	78.9	70.3	56.7	15.42	5.8	25.3	12.8	4.19
	MIN	0.4	64	32.6	27.7	70.4	62.2	51.2	9.44	3.5	13.5	0	2.12
Riversdale		*R.glauca*											
	AVG	0.56	61.78	26.38	35.40	67.06	65.06	46.10	28.64	11.64	63.58	12.42	0.76
n=5	STD	0.13	7.47	5.99	10.96	8.92	9.29	5.35	13.18	3.82	16.46	3.36	0.18
	MAX	0.7	68.5	33.3	46	75.5	75.9	52.9	43.87	17.2	95.4	17.6	1
	MIN	0.4	48.4	18.2	15.1	52.6	50	39.7	11.78	7.1	50.6	8.4	0.47
Riversdale		*R.lucida*											
	AVG	0.54	73.84	36.62	37.22	79.59	75.60	56.22	28.36	8.68	33.50	4.38	1.89
n=9	STD	0.14	4.78	8.48	11.48	7.47	3.36	2.17	11.80	2.90	12.31	6.40	0.62
	MAX	0.80	82.9	46.7	56.7	93	79.5	58.6	47.86	14.5	62.6	16.6	2.74
	MIN	0.30	67	21.3	20.6	70.5	70.3	51	16.46	5.5	21.3	0	0.81
Riversdale		*R.sp*											
	AVG	0.63	63.30	36.80	26.50	69.23	62.30	50.17	9.31	3.87	18.70	0.00	2.72
n=3	STD	0.12	2.62	4.96	2.82	1.86	5.73	3.49	3.75	1.16	2.77	0.00	0.20
	MAX	0.80	67	43.2	30.4	70.6	70.3	55.1	14.61	5.5	22.6	0	2.9
	MIN	0.50	61.4	31.1	23.8	66.6	57.2	47.5	6.63	3	16.4	0	2.44
Vredenburg		*R.glauca*											
	AVG	0.43	64.98	33.56	31.43	74.79	60.44	49.44	29.36	11.78	59.03	5.99	0.95
n=8	STD	0.48	4.26	7.56	6.61	5.55	5.79	5.56	15.15	4.50	20.99	5.84	0.36
	MAX	1.2	73.8	41.3	41.1	83.6	73.3	58.3	63.65	20.3	101.6	17.7	1.61
	MIN	0.50	58.3	17.3	23.8	67.3	51.5	38.5	17.78	7.2	32.6	0	0.45

* MPD is in centimetres.

TABLE 9

Correlation matrix obtained from analysis of wood anatomy of *Rhus* and climatic variables at eight stations (Montagu, Pella, Vredenburg, Jonkershoek, Tierberg, Riversdale, Langebaanweg and Richtersveld) only *r* values >0.50 are listed.

	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Vuln	Pan	AE	PEmax	PEmin	Pmi	Pmin	Pmax	DifP	Pwarm	Pcold	Pavm	Tan	Tmax	Tmin	DifT
MaxV	1.00																								
MinV	0.63	1.00																							
RangV	0.81		1.00																						
RadV	0.97	0.51	0.87	1.00]																					
TangV	0.95	0.73	0.68	0.86	1.00																				
MeanV	0.91	0.88	0.52	0.82	0.94	1.00																			
RelV							1.00																		
AreaV		-0.50				-0.60	0.76	1.00																	
NumV	-0.65	-0.66		-0.53	-0.68	-0.79	0.54	0.95	1.00																
Vuln	0.72	0.73		0.59	0.79	0.85		-0.89	-0.93	1.00															
Pan											1.00														
AE												1.00													
PEmax												0.98	1.00												
PEmin					0.53									1.00											
PMI											0.95				1.00										
Pmin											0.85				0.67	1.00									
Pmax											0.98				0.99	0.73	1.00								
DifP											0.92				0.98		0.98	1.00							
Pwarm											0.83				0.66	0.99	0.72	0.58	1.00						
Pcold											0.97				0.99	0.71	0.99	0.98	0.69	1.00					
Pavm											0.99				0.93	0.84	0.96	0.91	0.82	0.90	1.00				
Tan								-0.65	-0.67			0.86	0.89									1.00			
Tmax								-0.60	-0.64			0.93	0.95									0.96	1.00		
Tmin																							0.54	1.00	
DifT									-0.52			0.89	0.91									0.79	0.93		1.00

TABLE 10

Correlation matrix obtained from analysis of wood anatomy of *Rhus* and climatic variables at nine stations (Montagu, Pella, Vredenburg, Jonkershoek, Tierberg, Riversdale, Langebaanweg, Richtersveld and Saasveld) only *r* values >0.50 are listed.

	MaxV	MinV	RangV	RadV	TangV	AvgV	RelV	AreaV	NumV	Vuln	Pan	AE	PEmax	PEmin	Pmi	Pmin	Pmax	DifP	Pwarm	Pcold	Pavm	Tan	Tmax	Tmin	DifT
MaxV	1.00																								
MinV	0.76	1.00																							
RangV	0.63		1.00																						
RadV	0.98	0.72	0.64	1.00																					
TangV	0.96	0.77	0.55	0.89	1.00																				
MeanV	0.92	0.94		0.89	0.91	1.00																			
RelV							1.00																		
AreaV	-0.51	-0.54				-0.61	0.70	1.00																	
NumV	-0.71	-0.69		-0.63	-0.74	-0.78		0.95	1.00																
Vuln	0.80	0.89		0.76	0.80	0.93		-0.77	-0.85	1.00															
Pan		0.53		0.52		0.54					1.00														
AE												1.00													
Pemax												0.98	1.00												
Pemin	0.53			0.50	0.61									1.00											
Pmi											0.93				1.00										
Pmin		0.63				0.59				0.58	0.86				0.63	1.00									
Pmax											0.95				0.99	0.65	1.00								
Difp											0.79				0.94		0.94	1.00							
Pwarm		0.73		0.52		0.67				0.66	0.79				0.56	0.98	0.57		1.00						
Pcold											0.90				0.97		0.99	0.97		1.00					
Pavm		0.51				0.52					0.99				0.92	0.85	0.94	0.78	0.79	0.90	1.00				
Tan												0.88	0.90									1.00			
Tmax												0.94	0.96									0.96	1.00		
Tmin																						0.54		1.00	
DifT												0.90	0.93									0.79	0.93		1.00

TABLE 11

RHUS:

R^2 VALUES FOR MULTILINEAR REGRESSION ANALYSIS USING MAXV, MINV, RADV, TANGV AND MEANV

	WITH SAASVELD	WITHOUT SAASVELD
PAN	0.51	0.87
AE	0.58	0.55
PEMAX	0.76	0.73
PEMIN	0.77	0.82
PMI	0.32	0.72
PMIN	0.86	0.98
PMAX	0.29	0.78
DIFP	0.21	0.73
PWARM	0.95	0.96
PCOLD	0.23	0.78
PAVM	0.52	0.82
TAN	0.81	0.81
TMAX	0.72	0.71
TMIN	0.68	0.70
DIFT	0.64	0.55

TABLE 12

AREAS FROM WHICH SAMPLES OF DIOSPYROS WERE COLLECTED

Major Loc	Minor Loc	Location	Latitude	Longitude
Elandsbay	hill SE Verlorenvlei	NW of outcrop 300m below TC	32° 19'	18° 20'
Atlantis	Pella	FRD botanical research station	33° 31'	18° 32'
Vredenberg	W.point fish factory	granite quarry SW of factory	32° 50'	17° 51'
Montagu	on farm	In kloof 5kms SW of Police station	33° 47'	20° 07'
Prince Alfred	Tierberg	drain channels on study site	33° 20'	22° 02'
Stellenbosch	Jonkershoek	weather station behind offices	33° 58'	18° 56'

TABLE 13

ALL RESULTS OF EDXA FOR MODERN SPECIMENS OF *DIOSPYROS*.

Rec	Spec	Location	Species	*Mpd	Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
8	417	Elands Bay	*glabra*	0.9	4	84	38	46	95	82	60	29	7	26	0	2
7	418	Elands Bay	*glabra*	0.9	2	74	30	44	75	77	53	22	7	33	0	1
1	12a	Elands Bay	*glabra*	0.9	12	62	35	26	78	57	49	8	3	19	5	2
14	419	Elands Bay	*glabra*	1.3	2	76	27	49	94	66	50	21	7	33	0	1
9	416	Elands Bay	*glabra*	0.6	2	57	28	29	65	64	41	7	4	31	0	1
11	413	Elands Bay	*glabra*	0.7	1	70	30	39	77	72	50	16	6	29	0	1
13	411	Elands Bay	*glabra*	0.7	0	89	35	54	101	88	60	23	5	19	4	3
10	415	Elands Bay	*glabra*	0.8	1	73	33	40	86	69	55	19	6	26	5	2
15	419	Elands Bay	*glabra*	0.8	2	81	33	47	97	76	56	25	7	28	4	1
85	414	Elands Bay	*glabra*	0.7	0	69	36	33	79	65	53	18	6	29	5	1
2	12b	Elands Bay	*glabra*	1.0	20	75	40	35	88	67	58	17	5	19	23	2
12	412	Elands Bay	*glabra*	1.2	0	60	29	31	67	59	43	5	2	17	4	2
57	439b	Jonkershoek	*glabra*	1.0	3	73	37	35	88	63	54	21	7	32	4	1
18	435	Jonkershoek	*glabra*	0.8	1	62	30	32	71	57	46	11	5	32	4	1
20	436	Jonkershoek	*glabra*	1.2	3	72	34	37	81	71	50	21	8	38	5	1
19	431	Jonkershoek	*glabra*	0.8	0	64	33	30	70	66	47	13	6	34	6	1
21	439a	Jonkershoek	*glabra*	0.7	0	60	26	34	72	57	43	10	5	33	5	1
44	438	Jonkershoek	*glabra*	0.7	2	54	29	25	66	53	42	4	2	17	6	2
22	437	Jonkershoek	*glabra*	0.9	0	74	27	47	88	66	50	20	7	32	6	1
17	433	Jonkershoek	*glabra*	0.9	2	80	36	44	94	72	53	15	4	21	5	2
25	429	Jonkershoek	*glabra*	1.2	1	80	38	42	95	70	61	19	5	18	5	3
24	434	Jonkershoek	*glabra*	0.6	1	83	37	46	100	73	55	27	8	31	5	1
23	432	Jonkershoek	*glabra*	0.7	1	71	34	36	83	70	52	16	6	27	5	1
16	430	Jonkershoek	*glabra*	0.8	1	75	41	33	87	69	56	12	4	16	0	3
52	337	Montagu	*glabra*	1.6	5	77	40	37	89	75	57	13	4	15	4	3
70	175	Montagu	*glabra*	0.7	15	84	44	40	97	75	60	10	2	9	0	6
71	173	Montagu	*glabra*	0.4	10	80	49	31	86	83	62	18	5	16	0	3
54	340b	Montagu	*glabra*	0.8	1	63	36	27	81	55	49	9	4	21	4	2
53	335	Montagu	*glabra*	0.9	0	67	37	29	87	65	52	12	4	21	4	2
94	174	Montagu	*glabra*	0.4	10	85	51	35	108	79	69	11	2	7	0	9
50	333	Montagu	*glabra*	0.7	1	66	33	33	72	64	50	12	5	24	3	2
55	340a	Montagu	*glabra*	0.7	5	67	32	35	93	57	49	12	5	26	3	1
73	339	Montagu	*glabra*	0.6	16	80	37	43	104	65	56	12	3	13	12	4
49	334	Montagu	*glabra*	0.7	1	80	36	44	93	74	56	16	5	19	4	2
51	338	Montagu	*glabra*	0.6	1	65	34	30	78	64	49	13	6	31	3	1
62	176	Montagu	*glabra*	1.2	16	87	44	43	106	83	64	18	4	13	15	4
56	336	Montagu	*glabra*	0.8	1	77	38	39	83	73	58	27	8	28	4	2
36	325	Pella	*glabra*	1.0	0	87	42	44	107	74	63	29	7	22	4	2
33	322	Pella	*glabra*	1.3	4	71	40	30	92	64	57	21	6	25	4	2
32	323	Pella	*glabra*	1.0	2	75	47	28	86	82	61	24	7	23	4	2
31	324	Pella	*glabra*	0.8	1	69	41	28	85	62	57	16	5	21	6	2
92	326	Pella	*glabra*	0.8	0	83	45	38	116	70	65	31	7	22	4	2
39	320	Pella	*glabra*	0.9	2	79	32	46	100	77	59	29	8	30	3	1
40	329	Pella	*glabra*	1.1	1	72	41	31	89	64	58	15	5	18	3	3
37	327	Pella	*glabra*	0.8	1	85	47	37	103	79	67	27	6	17	3	3
38	321	Pella	*glabra*	0.9	1	71	36	34	86	70	56	9	3	11	3	4
34	330	Pella	*glabra*	0.8	1	96	45	50	116	84	69	37	7	20	6	3
35	319	Pella	*glabra*	0.7	1	75	33	42	84	73	52	16	5	24	3	2
61	392	Tierberg	*austro-afr*	0.7	2	59	36	23	66	60	48	25	12	64	4	0
59	391	Tierberg	*austro-afr*	1.0	4	52	30	21	60	53	41	12	7	56	4	0
63	387	Tierberg	*austro-afr*	0.9	2	71	40	30	77	68	53	23	8	38	3	1
65	369	Tierberg	*austro-afr*	0.7	2	67	33	34	73	68	50	18	7	38	3	1
62	388	Tierberg	*austro-afr*	0.9	5	89	38	51	96	91	59	40	10	34	2	1
58	389	Tierberg	*austro-afr*	0.7	2	60	34	26	70	57	46	17	8	50	4	0
64	375	Tierberg	*austro-afr*	1.1	4	62	33	28	71	63	47	16	7	41	4	1
91	365	Tierberg	*austro-afr*	0.6	0	59	34	25	66	59	46	18	9	53	4	0
60	390	Tierberg	*austro-afr*	0.9	5	63	28	35	70	64	45	15	7	41	4	1
77	383	Tierberg	*lycioides*	0.7	2	77	45	32	83	75	61	25	7	25	4	2
80	386	Tierberg	*lycioides*	0.6	2	87	49	38	99	86	67	33	8	22	4	3
74	371	Tierberg	*lycioides*	0.7	3	85	33	52	93	80	65	39	9	26	4	2

Rec	Spec	Location	Species	*Mpd	Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
76	385	Tierberg	*lycioides*	0.8	1	87	53	34	103	81	70	27	6	15	4	4
82	381	Tierberg	*lycioides*	0.9	10	69	32	36	76	74	52	13	5	23	4	2
84	379	Tierberg	*lycioides*	1.0	4	82	36	46	87	86	62	27	7	22	3	2
75	384	Tierberg	*lycioides*	1.0	1	85	44	40	92	83	63	37	10	31	4	2
78	374	Tierberg	*lycioides*	0.9	1	97	41	55	115	92	70	30	6	14	5	4
83	382	Tierberg	*lycioides*	0.6	0	79	46	33	90	80	63	25	7	22	5	2
87	363	Tierberg	*lycioides*	0.7	1	82	42	40	91	77	61	24	6	21	4	2
81	380	Tierberg	*lycioides*	0.7	5	79	33	45	84	79	58	24	7	25	4	2
1	401	Vredenburg	*glabra*	0.9	2	69	36	32	74	75	54	17	6	26	3	2
58	165	Vredenburg	*glabra*	0.7	24	75	22	53	95	61	47	28	9	47	23	0
47	398	Vredenburg	*glabra*	0.7	2	71	21	49	77	67	44	15	6	35	3	1
4	400	Vredenburg	*glabra*	0.7	2	58	30	27	62	55	45	12	6	38	4	1
3	399	Vredenburg	*glabra*	0.7	2	70	32	38	78	66	50	14	5	27	3	1
6	397	Vredenburg	*glabra*	0.6	2	64	31	32	65	76	50	26	11	53	5	0
59	167	Vredenburg	*glabra*	0.3	27	77	19	58	88	70	47	44	13	62	10	0
46	403	Vredenburg	*glabra*	0.7	3	80	44	36	95	78	60	18	5	17	4	3
45	395	Vredenburg	*glabra*	0.7	1	62	28	33	64	64	45	10	5	30	6	1
2	402	Vredenburg	*glabra*	0.6	9	71	40	31	82	68	56	30	10	39	2	1
51	166	Vredenburg	*glabra*	0.4	15	66	22	44	67	68	41	12	4	26	8	1
5	396	Vredenburg	*glabra*	0.5	4	88	38	50	90	92	60	28	7	22	0	2

REC = South African Museum Record Number

SPEC = South African Museum specimen number

* MPD is in centimetres

Mco = minimum coefficient of variation of the mpd average.

TABLE 14

AVERAGE VALUES FOR DIOSPYROS GLABRA

		Mpd	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
Elandsbay	Mean	0.9	73.0	33.2	39.8	83.9	70.6	52.7	18.0	6.0	26.1	4.5	2.1
n = 12	Std	0.2	9.2	3.9	8.3	11.4	8.9	5.9	7.2	1.6	5.6	6.1	0.6
	Max	1.3	89.5	40.0	54.0	101.1	88.3	60.7	29.4	7.8	33.3	23.1	3.1
	Min	0.6	57.8	27.7	26.4	65.1	57.0	41.0	5.1	2.6	17.2	0.0	1.3
Jonkershoek	Mean	0.9	71.2	34.0	37.2	83.4	66.0	51.2	16.2	5.9	28.0	5.1	2.0
n = 12	Std	0.2	8.5	4.5	6.4	10.5	6.2	5.3	5.9	1.6	7.3	1.7	0.7
	Max	1.2	83.9	41.4	47.3	100.1	73.1	61.0	27.0	8.2	38.6	6.9	3.4
	Min	0.6	54.6	26.5	25.5	66.9	53.8	42.2	4.2	2.5	16.4	0.0	1.3
Montagu	Mean	0.8	75.7	39.6	36.1	91.0	70.6	56.6	14.6	4.7	19.1	4.8	3.7
n = 13	Std	0.3	8.2	5.6	5.6	10.7	8.8	6.1	4.5	1.3	7.1	4.4	2.2
	Max	1.6	87.9	51.0	44.6	108.7	83.8	69.0	27.1	8.0	31.0	15.8	9.7
	Min	0.4	63.8	32.2	27.1	72.7	55.7	49.1	9.3	2.7	7.1	0.0	1.6
Pella	Mean	0.9	78.9	41.2	37.6	97.2	73.1	60.9	23.6	6.5	21.7	4.4	3.0
n = 11	Std	0.2	8.1	5.1	7.4	11.7	7.2	4.8	8.0	1.5	4.5	0.9	0.8
	Max	1.3	96.4	47.6	50.5	116.4	84.9	69.1	37.9	8.6	30.0	6.0	4.8
	Min	0.7	69.8	32.9	28.0	84.6	62.0	52.9	9.7	3.1	11.9	3.3	2.0
Vredenberg	Mean	0.6	70.3	30.5	39.9	77.4	68.9	49.8	20.6	7.3	35.5	6.1	1.6
n = 12	Std	0.2	8.7	7.5	9.9	11.5	9.9	6.3	9.8	2.6	12.4	5.5	0.7
	Max	0.9	88.8	44.0	58.6	95.5	92.4	60.8	44.3	13.0	62.8	23.0	3.5
	Min	0.3	56.6	19.1	27.5	62.3	52.3	41.6	8.2	4.2	17.4	0.0	0.8
Tierberg	Mean	0.8	75.1	38.9	36.2	83.6	74.2	56.9	25.5	8.2	33.9	4.3	2.1
n = 21	Std	0.1	11.9	6.6	9.4	13.6	11.2	8.5	8.4	1.8	13.6	0.6	1.1
	Max	1.1	97.4	53.1	55.7	115.2	92.6	70.6	40.7	12.3	64.4	5.5	4.8
	Min	0.6	52.8	28.2	21.9	60.9	53.1	41.7	12.4	5.1	14.7	2.3	0.7

TABLE 15

AVERAGE VALUES FOR DIOSPYROS AUSTRO-AFRICANA AND DIOSPYROS LYCIOIDES.

		Mpd	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
austro-africana	Mean	0.8	65.3	34.5	30.8	72.6	65.1	48.9	21.0	8.9	46.6	4.0	1.1
n = 9	Std	0.2	10.2	2.9	8.9	9.9	11.0	4.9	8.3	1.6	9.5	0.7	0.3
	Max	1.1	89.5	38.4	51.1	96.2	91.3	59.9	40.7	12.3	64.4	4.6	1.7
	Min	0.2	10.2	2.9	8.9	9.9	11.0	4.9	8.3	1.6	9.5	0.7	0.3
lycioides	Mean	0.8	82.4	42.2	40.3	91.8	81.0	62.9	28.9	7.7	24.4	4.5	2.8
n = 12	Std	0.1	7.0	6.4	8.0	9.8	5.2	5.0	7.1	1.8	6.7	0.5	0.9
	Max	1.0	97.4	53.1	55.7	115.2	92.6	70.6	39.9	11.9	41.3	5.5	4.8
	Min	0.1	7.0	6.4	8.0	9.8	5.2	5.0	7.1	1.8	6.7	0.5	0.9

TABLE 16

Correlation coefficient matrix obtained from analysis of wood anatomy of *Diospyros* and climatic variables at four stations (Montagu, Pella, Vredenburg and Jonkershoek) only *r* values >0.50 are listed.

	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	vuln	Pan	AE	PEmax	PEmin	DifPE	PMI	Pmin	Pmax	DifP	Pwarm	Pcold	Pavm	Tan	Tmax	Tmin	DifT
MaxV	1.00																										
MinV	0.96	1.00																									
RangV	-0.52	-0.73	1.00																								
RadV	0.98	0.99	-0.64	1.00																							
TangV	0.87	0.73		0.76	1.00																						
MeanV	1.00	0.96	-0.52	0.98	0.86	1.00																					
RelV			0.58		0.57		1.00																				
AreaV		-0.56	0.94				0.78	1.00																			
NumV	-0.83	-0.95	0.90	-0.89	-0.54	-0.83		0.79	1.00																		
AreaR	-0.87	-0.95	0.80	-0.95	-0.52	-0.88		0.56	0.92	1.00																	
Vuln	0.79	0.89	-0.81	0.81	0.61	0.78		-0.80	-0.95	-0.77	1.00																
Pan					-0.68							1.00															
AE	0.50	0.71	-0.96	0.59			-0.64	-0.98	-0.89	-0.70	0.89		1.00														
PEmax		0.59	-0.94				-0.75	-1.00	-0.81	-0.59	0.83		0.99	1.00													
PEmin		-0.52	0.88				0.52	0.73		0.72		-0.71	-0.73	-0.71	1.00												
DifpE		0.60	-0.95				-0.75	-1.00	-0.82	-0.60	0.82		0.99	1.00	-0.74	1.00											
PMI	-0.50				-0.80						-0.53	0.96			-0.51		1.00										
Pmin					-0.68		-0.51					0.97			-0.82		0.90	1.00									
Pmax					-0.73							0.99			-0.62		0.99	0.95	1.00								
DifP					-0.73							0.98			-0.56		0.99	0.92	1.00	1.00							
Pwarm					-0.70		-0.50					0.98			-0.80		0.92	1.00	0.95	0.93	1.00						
Pcold					-0.70							1.00			-0.64		0.98	0.95	1.00	0.99	0.96	1.00					
Pavm					-0.67							1.00			-0.72		0.96	0.98	0.99	0.98	0.98	0.99	1.00				
Tan	0.58	0.78	-0.99	0.69		0.58	-0.55	-0.95	-0.93	-0.80	0.88		0.98	0.95	-0.81	0.96								1.00			
Tmax	0.50	0.72	-1.00	0.63		0.50	-0.60	-0.94	-0.89	-0.78	0.81		0.97	0.95	-0.88	0.95								0.99	1.00		
Tmin	0.76	0.89	-0.90	0.81		0.75		-0.86	-0.98	-0.83	0.98		0.94	0.89	-0.62	0.88								0.95	0.90	1.00	
DifT		0.61	-0.98	0.52			-0.67	-0.92	-0.80	-0.72	0.70		0.93	0.92	-0.93	0.93								0.95	0.98	0.81	1.00

TABLE 17

Correlation coefficient matrix obtained from analysis of wood anatomy of *Diospyros* and climatic variables at five stations (Montagu, Pella, Vredenburg, Jonkershoek, Tierberg) only *r* values >0.50 are listed.

	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln	Pan	AE	PEmax	PEmin	DifPE	PMI	Pmin	Pmax	DifP	Pwarm	Pcold	Pavm	Tan	Tmax	Tmin	DifT
MaxV	1.00																										
MinV	0.96	1.00																									
RangV	-0.52	-0.75	1.00																								
RadV	0.92	0.88		1.00																							
TangV	0.77	0.72			1.00																						
MeanV	0.99	0.96	-0.55	0.89	0.80	1.00																					
RelV					0.74		1.00																				
AreaV							0.88	1.00																			
NumV	-0.66	0.68		-0.87		-0.60		0.83	1.00																		
AreaR	-0.82	-0.92	0.84	-0.70	-0.66	-0.86				1.00																	
Vuln	0.72	0.76	-0.59	0.82		0.67		-0.73	-0.93	-0.52	1.00																
Pan					-0.75		-0.50					1.00															
AE		0.71	-0.97			0.53				-0.78	0.58		1.00														
PEmax		0.63	-0.95							-0.68	0.59		0.99	1.00													
PEmin			0.62	-0.51			0.58	0.71	0.70		-0.51	-0.74			1.00												
DifpE			-0.96							-0.69	0.60		0.99	1.00		1.00											
PMI					-0.86	-0.51	-0.50					0.97			-0.57		1.00										
Pmin					-0.65		-0.51					0.95			-0.83		0.86	1.00									
Pmax					-0.78							0.99			-0.66		0.99	0.93	1.00								
DifP					-0.79							0.98			-0.61		0.99	0.89	1.00	1.00							
Pwarm					-0.56							0.89			-0.77		0.80	0.98	0.87	0.83	1.00						
Pcold					-0.79		-0.50					0.99			-0.68	1.00	0.99	0.91	1.00	0.99	0.84	1.00					
Pavm					-0.73							1.00			-0.75	0.99	0.96	0.95	0.99	0.98	0.90	0.99	1.00				
Tan	0.59	0.79	-0.96	0.61		0.60		-0.51	-0.70	-0.78	0.78		0.92	0.92	-0.69									1.00			
Tmax	0.51	0.74	-1.00			0.54			-0.53	-0.82	0.62		0.96	0.95	-0.65									0.97	1.00		
Tmin	0.58	0.62		0.79		0.52	-0.56	-0.88	-0.99		0.95				-0.67									0.70	0.53	1.00	
DifT		0.62	-0.96							-0.80			0.94	0.93	-0.50									0.86	0.95		1.00

TABLE 18

LIST OF ARCHAEOLOGICAL SITES AT ELANDS BAY FROM WHICH CHARCOAL SAMPLES WERE ANALYSED

SITE	LAYER	SAMPLES STUDIED	^{14}C DATES IN YEARS BP	^{14}C PTA N°
SPRING CAVE	ASH IV D9/II	105	460 ± 40	Pta-4062
SPRING CAVE	DARK BROWN MIDDEN	105	840 ± 50	Pta-4042
SPRING CAVE	BRAVO	105	1150 ± 50	Pta-4035
TORTOISE CAVE	ABD II/K2	105	1620 ± 50	Pta-3310
MIKE TAYLORS MIDDEN	E4/5	219	± 2000	
MIKE TAYLORS MIDDEN	E5/9	104	± 2300	
MIKE TAYLORS MIDDEN	E5/10	105	2460 ± 50	Pta-3207
SPRING CAVE	ALL BLACK	105	2970 ± 60	Pta-4033
TORTOISE CAVE	SM2/AA2	104	3520 ± 60	Pta-3604
TORTOISE CAVE	MELANIE/S1	101	4190 ± 60	Pta-3608

TABLE 19

Results of Environmentally Diagnostic Xylem Analysis of *Rhus* charcoal recovered from the archaeological sites at Elands Bay.

*Rec	*Spec	Location	*Mpd	*Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
78	101	SC DBM	3	27	50	27	23	56	53	40	28	18	142	15	0.28
75	61	SC DBM	5	39	49	25	23	54	54	38	16	11	93	8	0.41
82	103	SC DBM	2	10	59	31	27	59	64	47	34	16	87	14	0.55
77	105	SC DBM	4	37	36	21	15	46	33	28	17	22	334	3	0.09
76	84	SC DBM	2	14	53	27	26	53	59	41	30	18	130	16	0.31
21	1.1	TC ABD2	3	45	66	26	39	65	69	45	30	13	76	10	0.59
137	105	TC ABD2	5	27	86	41	44	93	87	63	38	8	26	23	2.37
138	20	TC ABD2	3	13	52	24	28	60	48	38	14	9	75	36	0.51
141	26	TC ABD2	2	35	55	30	25	67	57	44	22	12	77	9	0.57
142	76	TC ABD2	4	7	64	36	28	78	56	51	23	9	44	24	1.15
143	64	TC ABD2	8	33	50	29	20	62	44	38	9	6	53	31	0.72
144	104	TC ABD2	9	14	56	33	23	65	53	44	20	11	70	23	0.63
139	16	TC ABD2	7	20	59	34	25	70	57	47	20	9	52	34	0.92
140	37	TC ABD2	1	26	62	37	25	69	61	46	35	17	96	14	0.49
112	1.23	TC DAVE	4	25	76	30	45	91	72	52	49	16	70	1	0.74
111	2.27	TC DAVE	2	36	70	28	41	83	66	48	37	14	75	12	0.64
108	2.20	TC MELA	5	39	68	34	33	71	69	50	26	10	49	18	1.01
152	12	TC MELA	4	18	75	32	42	82	69	50	22	7	36	5	1.39
18	2.2	TC MELA	3	7	64	21	42	62	66	41	20	9	66	7	0.62
145	22	TC MELA	9	41	61	43	18	83	48	53	17	7	31	20	1.69
19	2.8	TC MELA	2	29	76	32	44	79	77	55	54	16	62	12	0.89
146	95	TC MELA	3	59	79	36	43	92	72	59	86	23	78	10	0.76
109	2.28	TC MELA	5	17	54	30	23	56	55	41	24	14	105	14	0.39
148	45	TC MELA	7	13	63	38	24	70	59	50	39	16	81	14	0.62
150	30	TC MELA	2	28	55	31	24	61	55	42	21	12	83	11	0.51
147	48	TC MELA	3	20	52	30	21	60	45	40	14	9	71	14	0.56
17	2.6	TC MELA	5	22	58	29	29	62	61	47	30	14	77	18	0.61
149	44	TC MELA	4	32	58	25	33	63	57	43	20	10	67	17	0.64
151	83	TC MELA	6	78	63	36	26	73	58	51	37	15	74	12	0.69
110	2.27	TC MELA	4	38	66	30	35	63	72	48	38	15	82	8	0.59
20	2.8	TC MELA	2	5	68	31	37	77	71	52	45	16	73	12	0.71
69	102	SC ASHIV	2	27	50	24	26	55	54	39	14	9	73	4	0.54
80	96	SC ASHIV	2	27	40	24	15	39	45	33	8	8	95	0	0.35
68	102	SC ASHIV	4	38	39	21	18	39	44	31	6	7	85	3	0.37
79	52	SC ASHIV	2	39	38	25	13	39	39	31	11	12	165	11	0.19
81	40	SC ASHIV	4	55	43	19	23	44	47	32	11	10	113	9	0.29
74	103	SC BRAVO3		12	41	22	19	45	39	32	6	6	68	10	0.48
73	98	SC ALLBL	3	55	44	25	19	47	50	35	13	11	110	8	0.32
72	77	SC ALLBL	2	29	50	30	20	52	55	41	20	13	96	0	0.43
71	39	SC ALLBL	3	11	54	34	19	59	56	43	19	11	73	8	0.59
70	38	SC ALLBL	4	34	57	27	29	64	62	43	22	11	74	13	0.58

* Rec = South African Museum record number
* Spec = South African Museum specimen number
* Results for MPD are in Millimetres
* Mco = Minimum coefficient of variation for MPD.

TABLE 20

Results of Environmentally Diagnostic Xylem Analysis of *Diospyros* charcoal recovered from the archaeological sites at Elands Bay.

*Spec	Location	*Mpd	*Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
37	TC SM2	6	60	65.2	40.4	24.8	80.6	58.6	52.5	41.52	6	76.3	13	0.69
3	TC SM2	4	5	63.4	27.2	36.2	84.3	52.1	47.1	34.66	5	81.2	13	0.58
18	SC DBM	7	45	42.5	24.4	18.1	45.8	44.8	33.4	7.53	7	79	26	0.42
73	SC DBM	4	13	51.9	21.4	30.5	57.4	51.4	38.1	12.08	7	65.3	29	0.58
15	SC DBM	3	27	46.6	20.3	26.3	50.4	49.1	32.2	6.22	5	60.2	32	0.53
99	SC DBM	4	33	50.9	20.4	30.5	65.9	42	31.9	7.63	5	62.9	27	0.51
46	SC DBM	2	20	47.3	18.1	29.2	51.8	44.1	31.7	10.21	8	97.9	16	0.32
14	SC DBM	6	29	43.8	22.2	21.7	53.8	39.6	31.9	4.19	4	48	22	0.66
52	SC DBM	1	45	43.9	26	17.9	43.7	48.6	35	8.64	7	76.9	9	0.45
7	TC ABD2	5	14	53.6	19	34.6	75.7	40.7	34.3	10.24	6	64.8	24	0.53
39	TC ABD2	4	17	60.6	27.7	33	70.5	58.7	45.5	22.9	10	63.1	23	0.72
67	TC ABD2	5	17	57.2	27.5	29.7	61.6	59.5	41.3	8.25	4	32.6	24	1.27
8	TC ABD2	3	19	52.9	25.4	27.5	51.9	55.4	37.3	7.48	4	41.9	23	0.89
72	TC ABD2	4	25	53.9	29.5	24.4	47.2	62.2	41.1	9.24	5	42.1	15	0.98
21	TC ABD2	4	22	52.4	27	25.4	65.2	45.8	38.9	15.38	9	79.4	17	0.49
29	TC ABD2	5	8	46.4	27.4	19	63	40.9	37.5	8.02	6	54	16	0.69
18	TC ABD2	7	18	49.6	29.4	20.2	59.8	44.2	37.8	0.26	6	52.8	22	0.71
77	TC ABD2	8	18	49.6	26.1	23.5	62.6	47.4	37.4	8.43	6	52.9	20	0.71
84	TC ABD2	4	6	59.7	30	29.7	52.2	71.3	42.1	11.83	6	43.4	18	0.97
19	TC ABD2	3	30	60.2	31.7	28.5	66.3	57.3	46.4	36.07	7	98.6	30	0.47
83	MTM E4/5	2	31	56.6	20.2	36.4	62.1	52.4	35.9	12.65	7	66.1	16	0.54
22	MTM E4/5	3	24	60.3	27.3	32.9	62.1	60.9	43.6	14.95	7	47	9	0.93
2	MTM E4/5	8	49	69.9	34.7	35.2	82	61.5	46	27.62	1	63.1	31	0.73
16	MTM E4/5	2	24	48.9	21.3	27.7	52.5	49.3	35.8	11.91	9	84.2	12	0.42
47	MTM E4/5	5	32	58.5	25.9	32.6	65.1	53.8	40.2	12.71	7	51.5	30	0.78
30	MTM E4/5	4	13	65.3	28.6	36.7	77.7	59.7	48.1	30.09	2	66	17	0.73
19	MTM E4/5	6	30	67.1	27.1	40	54.6	83.9	46.7	23.79	9	53.4	15	0.88
37	MTM E4/5	4	21	54.7	26.6	28.1	60	53.2	42.8	18.45	0	69.3	21	0.62
77	MTM E4/5	2	30	43.8	22.1	21.6	50.3	47.5	33.4	13.16	2	132.9	22	0.25
16	MTM E4/5	1	36	48.9	22.1	26.8	57.2	43.7	34.2	15.04	1	121.6	8	0.28
3	MTM E4/5	2	21	60.8	24.9	35.9	61.2	67.6	43	16.26	8	51.9	18	0.83
7	MTM E4/5	2	23	54	19.1	34.9	56.7	53.9	39.2	20	1	91	15	0.43
20	MTM E4/5	4	20	53.8	19.4	34.4	55.5	53.8	37.9	21.45	3	105.5	13	0.36
13	MTM E4/5	2	8	42	22.5	19.5	46	42.4	32.3	8.95	8	104.9	21	0.31
4	MTM E4/5	2	15	50.4	20.8	29.5	60.3	46.6	37.4	14.73	0	87.3	25	0.43
94	MTM E4/5	3	12	60.5	31.3	29.2	63.5	59.3	48.6	25.67	1	60.6	19	0.80
67	MTM E5/10	4	12	55.3	25.8	29.5	55.9	59	40.2	4.8	2	21.3	32	1.89
34	MTM E5/10	4	9	67.1	34	33.2	80.1	57.4	51.4	23.98	9	43.2	28	1.19
48	MTM E5/10	5	13	62.7	30.4	32.4	73.5	59.4	47.7	18.12	8	43	24	1.11
67	MTM E5/10	3	37	57.2	26.3	30.9	57.6	58.4	41.2	5.84	3	23.5	36	1.75
29	MTM E5/10	5	22	54.9	30.2	24.8	55.6	55.9	41.1	7.97	4	35.5	35	1.16
17	MTM E5/10	8	41	58.4	33.2	25.2	60.2	59.6	44.7	13.07	6	42.2	23	1.06
31	MTM E5/10	1	38	56.2	32.4	23.7	60.8	52.5	42.5	12.64	7	50.6	18	0.84
93	MTM E5/10	3	23	57.4	35.1	22.3	68.7	54.9	45.7	10.76	5	33.8	21	1.35
37	MTM E5/10	2	12	61.7	29.1	32.6	67.2	61.5	45.2	18.62	8	49.8	24	0.91
26	MTM E5/10	6	32	56.6	24.5	32.1	59.7	60.7	41	12.49	7	49.7	30	0.82
1	MTM E5/10	6	14	51.1	22.6	28.4	49.8	58.1	37.8	7.39	5	42.8	10	0.88
72	MTM E5/10	8	30	58.7	29.2	29.5	64.4	58.3	42.8	9.5	5	33.5	32	1.28
62	MTM E5/10	5	31	61.4	30.2	31.2	71.7	55.4	44.8	14.81	7	43.1	26	1.04

Spec	Location	Mpd	Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
80	MTM E5/10	5	27	48.7	26.8	21.8	60.3	42.1	37.5	6.43	4	41.8	26	0.90
50	TC MELA	7	21	64.5	25.5	39	88.2	51.6	46.7	20.38	8	46.9	16	1.00
82	TC MELA	5	64	52	21.5	30.5	67.5	42.3	35.5	5.9	4	37.4	25	0.95
51	TC MELA	8	25	60.2	27.3	32.9	81.1	50.8	46.2	21.62	9	54.9	17	0.84
98	TC MELA	5	17	53.9	28.1	25.7	76.4	40.8	38.1	8.23	5	42.4	26	0.90
68	TC MELA	7	41	62.3	30.1	32.2	80.5	50.6	45.5	16.97	7	45.8	34	0.99
22	TC MELA	3	33	60.5	26.8	33.7	61.6	68.1	43.6	26.78	3	82.7	36	0.53
65	SC ASHIV	4	32	53.2	22.4	30.7	58.6	51.4	37.9	9.34	6	49.7	29	0.76
16	SC ASHIV	4	51	68.8	27.6	41.2	74.4	67.8	51	21.5	8	36.8	13	1.38
1	SC ASHIV	3	18	41.9	25.1	16.8	51.9	36.1	33.6	7.38	6	73.8	25	0.46
	SC ASHIV	7	22	45.1	26.7	18.5	67.4	33.6	35.6	4.64	3	39.1	12	0.91
2	SC ASHIV	2	24	56	24.3	31.7	70.7	55.5	39	11.05	7	56.9	17	0.69
43	SC ASHIV	3	14	62.8	30.3	32.5	70.3	60.5	44.7	17.62	8	48.5	8	0.92
17	SC ASHIV	4	5	53.9	24	29.8	63.9	52.9	40.1	10.03	6	48.5	25	0.83
3	SC ASHIV	4	52	54	23.8	30.2	61.5	50.2	35.2	5.98	4	43	33	0.82
31	SC ASHIV	3	4	57.1	26.2	30.9	64.4	51.9	40.1	10.49	6	45.4	0	0.88
19	SC ASHIV	0	54	61.7	33.4	28.3	63	61.7	47.6	18.14	8	45.5	17	1.04
9	SC BRAVO	2	5	56.1	34.5	21.7	58.7	59.7	44.3	11.49	6	40.1	24	1.10
29	SC BRAVO	4	8	38.7	16.4	22.3	50.3	37.5	30	4.68	5	67.2	19	0.45
30	SC BRAVO	6	37	46.9	25.6	21.3	59	43.8	38.1	11.14	8	71.4	18	0.53
55	SC BRAVO	2	13	42.7	18.8	23.8	48.7	37.4	27.7	5.95	6	99.6	26	0.28
63	SC ALLBL	3	20	53.8	26.2	27.6	58.1	53.9	40.2	13.05	8	61.8	29	0.65
60	SC ALLBL	2	9	57.3	24.3	32.9	63.1	58.8	39	8.89	5	40.2	23	0.97
25	SC ALLBL	6	48	66.2	25.5	40.7	68	66	43.7	17.08	7	47.4	11	0.92
55	SC ALLBL	6	25	57.3	26.1	31.1	60.6	57.1	40.1	9.13	5	41.1	17	0.98
15	SC ALLBL	2	17	54.6	24.8	29.8	59.5	53.9	38.1	11.35	7	63.4	17	0.60

* Spec = South African Museum specimen Number
* Results for MPD are in millimetres
* Mco = Minimum coefficient of variation for MPD

TABLE 21

Results of Environmentally Diagnostic Xylem Analysis of *Zygophyllum* charcoal samples recovered from the archaeological sites at Elands Bay.

*Rec	*Spec	Location	*Mpd	*Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
43	38	SC DBM	4	11.5	42.5	24.1	18.3	48.6	38	32.4	10.05	10	117.3	8	0.28
46	58	SC DBM	6	8.9	48.7	29.1	19.6	50	48.4	37.7	16.6	12	108.2	10	0.35
44	41	SC DBM	1	35.8	53.4	26	27.4	58.8	48.9	37.9	13.73	9	76.5	8	0.49
47	58	SC DBM	5	10.5	44.8	28.9	15.9	47.3	45	36.6	18.12	14	138.3	10	0.26
49	93	SC DBM	2	8.1	40.1	16.2	23.9	45.9	36	26.4	8.14	8	135.6	13	0.19
40	19	SC DBM	5	17.6	56.2	32.7	23.5	72.5	47.3	43.8	20.41	11	73.7	3	0.59
41	19	SC DBM	4	39.5	57.1	27.7	29.4	68.9	49.9	40.2	22.85	13	98.8	3	0.41
48	93	SC DBM	4	39.9	35.2	17.3	17.9	45.1	29.9	24.9	2.92	4	85.2	13	0.29
45	41	SC DBM	3	21.8	53.2	24.2	29	56.3	53.8	37.5	16.04	10	93.3	8	0.4
42	28	SC DBM	4	35.3	58.3	26.6	31.7	66.3	57	42.1	22.49	11	80.8	14	0.52
30	64	SC ALLB	3	9.8	45.6	19.6	26	43.6	52.3	33.7	13.82	11	121.2	15	0.28
26	45	SC ALLB	6	7.1	57.7	25.1	32.6	63.8	53.6	40	14.82	8	62.5	9	0.64
29	69	SC ALLB	3	9.5	40.4	22.4	18.1	47.5	37.2	31.4	6.51	6	84	15	0.37
31	64	SC ALLB	3	25.1	38.1	22.1	16	43.9	34.1	28.9	6.28	7	115.6	18	0.25
51	79	SC ALLB	5	25.5	53.5	37.2	16.3	55.6	54.6	44.8	25.45	14	92	10	0.49
22	9	SC ALLB	5	1.2	42.5	18.2	24.4	42.5	43.6	30.4	13.07	13	166.9	6	0.18
25	13	SC ALLB	4	2.2	48.2	24.7	23.5	48.3	50.7	36.4	13.41	10	92.1	9	0.4
24	12	SC ALLB	4	1.4	40.5	18.5	22	48.8	35	28.3	4.21	4	70.9	4	0.4
50	79	SC ALLB	4	29.9	53.3	36.1	17.2	55.1	54.6	45.1	21.74	12	76.4	7	0.59
27	48	SC ALLB	6	9.8	43.1	28.9	14.2	54.8	38	36.4	4.59	3	37.4	6	0.97
28	51	SC ALLB	2	5.3	47.9	26.6	21.3	54.1	44.1	37.9	9.89	7	63	12	0.6
63	46	SC ASHIV	2	13.8	47.4	25	22.4	55.1	41.7	35	12.69	10	102.3	7	0.34
56	85	SC ASHIV	4	24.4	45.9	24.2	21.7	43.1	49.8	32.3	9.43	8	100.3	9	0.32
57	38	SC ASHIV	4	4	44.6	25.5	19.1	57.7	36.1	35.8	5.75	4	47	7	0.76
54	79	SC ASHIV	6	43.2	51.1	23.1	28	60.1	44.3	37.4	11.64	8	70.3	9	0.53
68	56	SC ASHIV	6	32.5	37.5	19.3	18.2	46	32.7	26.9	11.58	15	261.3	3	0.1
55	81	SC ASHIV	8	23	57.5	31.8	25.8	64.3	54.6	44.8	29.25	15	95.3	10	0.47
58	38	SC ASHIV	8	39	43.2	23.4	19.8	58.9	33.1	34	8.66	7	84.3	12	0.4
67	56	SC ASHIV	3	12.4	48.9	24	24.8	53.7	47.7	36.3	14.57	11	102.3	5	0.35
64	46	SC ASHIV	3	33.1	46.8	26.3	20.5	63.7	36.3	34.6	13.83	11	119.6	6	0.29
52	97	SC ASHIV	3	29.9	42.9	19.2	23.8	51.8	36.6	29	7.89	8	117.8	8	0.25
59	9	SC ASHIV	5	33	41.5	23.1	18.4	54.5	36.3	32.7	5.27	5	60.8	8	0.54
65	49	SC ASHIV	3	4	61.3	30.9	30.5	77.3	53	46.2	26.73	12	73.7	8	0.63
62	47	SC ASHIV	3	13.6	53.2	24.3	28.9	56.4	54.3	38.8	20.43	12	102.3	9	0.38
66	49	SC ASHIV	3	29.9	59.4	33.9	25.5	78.1	49	45.1	18.34	9	56.9	9	0.79
53	97	SC ASHIV	2	11.8	41	18.6	22.4	56.5	31.8	30.6	8.05	8	103.7	8	0.3
60	9	SC ASHIV	5	30.9	45.2	22.3	22.9	60.7	37.7	33	6.93	6	70.5	10	0.47
61	47	SC ASHIV	5	39.2	48.4	23.1	25.4	50.5	50.3	35.3	13.53	10	103	4	0.34
38	20	SC BRAVO	2	21.1	36.2	13.3	22.9	33.4	44.4	24.5	3.59	4	95.3	7	0.26
33	1	SC BRAVO	3	14.1	38	23.5	14.6	42.7	36.9	31.2	10.56	12	154.6	8	0.2
39	23	SC BRAVO	1	48.1	55.3	22	33.3	63.5	49.4	37.7	12.35	7	59.6	16	0.63
35	15	SC BRAVO	9	42.6	50.5	19.2	31.4	58.2	52.6	36.1	10.57	7	68	18	0.53
32	1	SC BRAVO	4	22.6	40	22.5	17.6	38.4	43.5	31.2	10.22	10	137.4	9	0.23
36	77	SC BRAVO	2	13	36	18.3	17.7	38.1	34.7	27.1	9.24	12	210	8	0.13
34	15	SC BRAVO	3	32.9	41.6	19.3	22.3	56.3	37.4	31	7.69	7	97.8	11	0.32
37	77	SC BRAVO	0	0	37.2	18.6	18.6	40.8	36.5	26.7	7.69	10	174.8	8	0.15
153	99	TC ABD2	5	32.4	44	29.5	14.4	64.7	31.7	36.4	11.45	9	93.3	16	0.39
154	2	TC ABD2	7	3.5	66.1	38.6	27.5	72.3	63.8	51.4	47.84	19	91.1	7	0.56
155	10	TC ABD2	3	38.7	48.3	24.7	23.6	63.1	38.3	35.1	14.17	11	111	10	0.32
156	6	TC ABD2	8	31.9	54.5	28.3	26.2	71.6	46.9	40	18.33	11	85.9	12	0.46

Rec	Spec	Location	Mpd	Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
157	13	TC ABD2	3	37.5	45.9	21.2	24.7	47	45.8	30.9	16.64	15	193.5	12	0.16
158	25	TC ABD2	8	30	39.6	19.7	19.9	44.3	36.7	28.2	5.85	6	102	13	0.28
159	48	TC ABD2	3	24.7	47.4	26.5	20.9	54.7	43.8	36.5	11.13	8	81.4	9	0.45
160	57	TC ABD2	1	50.9	43.8	23.5	20.3	45.8	45.9	33.5	6.85	6	67.6	12	0.49
161	61	TC ABD2	7	51.9	53.6	34	19.6	55.1	55.3	43.2	17.1	10	68.8	7	0.63
162	73	TC ABD2	3	33.3	45.1	23.6	21.6	48.1	44.9	35.1	10.45	8	86.6	18	0.4
163	90	TC ABD2	6	21.3	50.4	23.6	26.8	56	47.1	40.3	15.27	10	78.7	17	0.51
164	67	MTM E4/5	5	25.9	42.6	24.7	17.9	42.9	47.3	34.9	11.74	10	107.7	13	0.32
165	54	MTM E4/5	4	35.5	40.2	26.5	13.7	37.8	45.6	32.7	9.28	9	113.7	15	0.29
166	21	MTM E4/5	2	10.2	42.6	24.4	18.2	53.6	42.3	34	11.58	10	116.6	16	0.29
167	23	MTM E4/5	5	6.1	54.9	34.8	20.1	70.3	45.9	45.4	27.1	14	89.6	15	0.51
168	27	MTM E4/5	3	12.6	46	29.2	16.8	44.5	47.6	37.1	18.3	15	137.6	14	0.27
169	31	MTM E4/5	2	21	53.3	26.5	26.7	48.3	62.5	40	20.98	13	102.5	18	0.39
170	34	MTM E4/5	4	39.2	41	20.8	20.2	43.4	40.4	29.3	7.56	8	120	17	0.24
171	35	MTM E4/5	3	3.6	46.3	27.7	18.6	52.3	44.6	35.9	15.79	13	127.7	13	0.28
172	43	MTM E4/5	7	23.2	49.8	30.5	19.3	45.5	55.5	38.5	17.33	12	106.1	24	0.36
173	46	MTM E4/5	3	22.3	44.1	28	16.2	48	48.8	36.1	14.83	12	121.9	13	0.3
174	49	MTM E4/5	7	46.9	55.3	27.9	27.5	57.7	54.4	40.4	24.51	14	108.8	17	0.37
175	21	MTM E5/10	3	8.5	50.5	25.7	24.8	65.2	41.9	37.3	16.8	12	108.2	14	0.34
176	6	MTM E5/10	8	36.4	51.8	28.6	23.2	52.3	57.1	39.7	17.29	11	90.1	10	0.44
187	10	TC SM2	3	8.3	52.9	23.3	29.6	60.7	47.9	38.4	14.55	9	75.9	16	0.5
188	9	TC SM2	5	9.6	38.8	21.6	17.3	41.4	38.9	29.6	5.64	6	90.5	21	0.33
189	18	TC SM2	2	8.7	56.3	32.7	23.6	62.8	54.1	45	21.32	11	69.9	10	0.64
190	23	TC SM2	2	8.1	47.7	22.7	25	52.6	46.1	35	6.7	5	52.2	11	0.67
191	45	TC SM2	7	18.2	55.5	32.5	23.1	57.9	61.6	43.1	23.86	13	92.9	8	0.46
192	78	TC SM2	7	6.1	45.3	25.1	20.2	45.5	48.8	34.2	10.4	9	98.1	14	0.35
193	96	TC SM2	3	2.4	56.3	30.2	26.1	56.8	60.9	42.2	19.56	11	75.9	17	0.55
194	98	TC SM2	6	7.8	42.3	24	18.3	52.3	38.1	34.9	12.54	11	115	16	0.3
195	102	TC SM2	4	0.6	47.8	26	21.9	51.3	47.2	36.1	14.02	11	103.6	15	0.35
196	105	TC SM2	4	16.3	52.4	22.9	29.5	53.2	56.3	38.1	12.57	8	67.2	20	0.57
197	4	TC MELA	2	14	38.9	21.9	17	47.1	33.6	29.9	5.19	6	84.2	15	0.35
198	16	TC MELA	5	16.7	39.1	18.4	20.8	50.4	33.6	28.8	8.14	9	136.4	12	0.21
199	10	TC MELA	4	16.7	40.2	24.9	15.3	50	35.8	32.4	7.02	7	88.1	9	0.37
200	27	TC MELA	4	2.6	43.4	20.7	22.7	50.8	39.3	31.4	2.95	2	34.3	9	0.92
201	37	TC MELA	4	10.7	53.3	24	29.3	65.1	44.7	36.2	18.2	12	114.2	12	0.32
202	49	TC MELA	4	20.9	43.5	23.2	20.3	51.6	39.6	33	12.8	11	134.2	10	0.25
203	55	TC MELA	3	5.6	46.4	22.8	23.5	47.6	47.8	35.8	9.34	7	71	10	0.5
204	81	TC MELA	4	13.4	43.3	25	18.3	59.1	33.3	35.4	10.83	9	94.2	10	0.38
205	101	TC MELA	2	16.7	46.4	22.3	24.1	55.5	41.5	35.4	9.86	8	78.1	9	0.45
147	48	TC MELA	3	20	52	30.7	21.3	60	45.5	40	14.77	9	71	14	0.56
150	30	TC MELA	2	28.7	55.9	31.3	24.6	61.5	55.7	42.7	21.4	12	83.8	11	0.51
151	83	TC MELA	6	78.6	63.4	36.5	26.9	73.6	58.9	51	37.03	15	74.1	12	0.69
149	44	TC MELA	4	32.3	58.6	25.1	33.5	63.8	57.8	43.1	20.11	10	67.5	17	0.64
148	45	TC MELA	7	13.9	63.3	38.7	24.6	70	59.3	50.8	39.33	16	81.6	14	0.62
152	12	TC MELA	4	18.7	75	32.9	42.1	82.1	69.6	50.1	22.43	7	36	5	1.39

* Rec = South African Museum record number
* Spec = South African Museum specimen number
* Results for MPD are in Millimetres.
* MCO = Minimum coefficient of variation for MPD.

TABLE 22

Average values of EDXA variables for *Rhus* charcoal from the archaeological sites at Elands Bay

		*Mpd	*Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
SC DBM	AVG	3	25	49	26	23	54	52	39	25	17	157	11	0
N = 5	MAX	5	39	59	31	27	59	64	47	34	22	334	16	0
	MIN	2	10	36	21	15	46	33	28	16	11	87	3	0
	STD	1	11	7	3	4	4	10	6	7	3	90	5	0
TC ABD2	AVG	4	26	63	32	31	73	61	47	27	11	65	20	0
N = 11	MAX	9	45	86	41	45	93	87	63	49	17	96	36	2
	MIN	1	7	50	24	20	60	44	38	9	6	26	1	0
	STD	2	10	10	4	8	11	11	6	11	3	18	10	0
TC MELA	AVG	4	30	64	32	32	70	62	48	33	13	69	13	0
N = 15	MAX	9	78	79	43	44	92	77	59	86	23	105	20	1
	MIN	2	5	52	21	18	56	45	40	14	7	31	5	0
	STD	1	18	7	5	8	10	9	5	17	4	18	4	0
SC ASHIV	AVG	2	37	42	22	19	43	46	33	10	9	106	5	0
N = 5	MAX	4	55	50	25	26	55	54	39	14	12	165	11	0
	MIN	2	27	38	19	13	39	39	31	6	7	73	0	0
	STD	0	10	4	2	4	6	4	2	2	1	32	4	0
SC BRAVO		3	12	41	22	19	45	39	32	6	6	68	10	0
SC ALLBL	AVG	3	32	51	29	22	55	56	41	18	11	88	7	0
N = 4	MAX	4	55	57	34	29	64	62	43	22	13	110	13	0
	MIN	2	11	44	25	19	47	50	35	13	11	73	0	0
	STD	0	15	4	3	4	6	4	3	3	0	15	4	0

* MPD is in millimetres

* MCO = minimum coefficient of variation for MPD.

TABLE 23

Average values of EDXA variables for *Diospyros* charcoal from the archaeological sites at Elands Bay.

			*Mpd	*Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Vuln
TC	SM2	AVG	5	32	64	33	30	82	55	49	38	5	78	0.64
N = 2		MAX	6	60	65	40	36	84	58	52	41	6	81	0.69
		MIN	4	5	63	27	24	80	52	47	34	5	76	0.58
		STD	1	27	0	6	5	1	3	2	3	0	2	0.05
SC	DBM	AVG	3	30	46	21	24	52	45	33	8	6	70	0.50
N = 7		MAX	7	45	51	26	30	65	51	38	12	8	97	0.66
		MIN	1	13	42	18	17	43	39	31	4	4	48	0.32
		STD	1	10	3	2	5	6	3	2	2	1	14	0.10
TC	ABD2	AVG	4	18	54	27	26	61	53	39	8	6	56	0.77
N = 11		MAX	8	30	60	31	34	75	71	46	36	10	98	1.27
		MIN	3	6	46	19	19	47	40	34	0	4	32	0.47
		STD	1	6	4	3	4	8	9	3	11	1	18	0.23
MTM	E4/5	AVG	8	49	69	34	40	82	83	48	30	9	132	0.93
N = 16		MAX	1	8	42	19	19	46	42	32	8	0	47	0.25
		MIN	1	9	7	4	5	8	9	5	6	3	25	0.22
		STD	1	9	7	4	5	8	9	5	6	3	25	0.22
MTM	E5/10	AVG	4	24	57	29	28	63	56	43	11	5	39	1.16
N = 14		MAX	8	41	67	35	33	80	61	51	23	9	50	1.89
		MIN	1	9	48	22	21	49	42	37	4	2	21	0.82
		STD	2	10	4	3	4	7	4	3	5	1	7	0.25
TC	MELA	AVG	5	33	58	26	32	75	50	42	16	6	51	0.87
N = 6		MAX	8	64	64	30	39	88	68	46	26	9	82	1.00
		MIN	3	17	52	21	25	61	40	35	5	3	37	0.53
		STD	1	15	4	2	3	8	8	4	7	2	14	0.16
SC	ASHIV	AVG	3	28	55	26	29	64	52	40	11	6	48	0.87
N = 10		MAX	7	54	68	33	41	74	67	51	21	8	73	1.38
		MIN	0	4	41	22	16	51	33	33	4	3	36	0.46
		STD	1	18	7	3	6	6	10	5	5	1	9	0.23
SC	BRAVO	AVG	3	16	46	23	22	54	44	35	8	6	69	0.59
N = 4		MAX	6	37	56	34	23	59	59	44	11	8	99	1.10
		MIN	2	5	38	16	21	48	37	27	4	5	40	0.28
		STD	1	12	6	7	0	4	9	6	3	1	21	0.31
SC	ALLBLACK	AVG	3	24	57	25	32	61	57	40	11	6	50	0.82
N = 5		MAX	6	48	66	26	40	68	66	43	17	8	63	0.98
		MIN	2	9	53	24	27	58	53	38	8	5	40	0.60
		STD	1	13	4	0	4	3	4	1	3	1	9	0.16

* MPD is in millimetres

* MCO = Minimum coefficient of variation for MPD.

TABLE 24

Average values of EDXA variables for *Zygophyllum* from the archaeological sites at Elands Bay

			*Mpd	*Mco	Maxv	Minv	Rangv	Radv	Tangv	Meanv	Relv	Areav	Numv	Arear	Vuln
SC	DBM	AVG	3	21	48	25	23	55	45	35	14	10	49	9	0.38
N = 10		MAX	6	39	58	32	31	72	57	43	22	14	138	14	0.59
		MIN	1	0	35	16	15	45	29	24	0	4	0	3	0.19
		STD	1	14	7	4	5	9	7	5	7	2	61	3	0.12
SC	ALLB	AVG	4	9	46	25	21	50	45	35	9	8	36	10	0.47
N = 11		MAX	6	29	57	37	32	63	54	45	25	14	166	18	0.97
		MIN	2	0	38	18	14	42	34	28	0	3	0	4	0.18
		STD	1	11	6	6	5	6	7	5	9	3	61	4	0.21
SC	ASHIV	AVG	4	24	47	24	23	58	42	35	10	9	65	7	0.43
N = 17		MAX	8	43	61	33	30	78	54	46	29	15	261	12	0.79
		MIN	2	0	37	18	18	43	31	26	0	4	0	3	0.10
		STD	1	12	6	4	3	8	7	5	9	3	71	2	0.17
SC	BRAVO	AVG	3	24	41	19	22	46	41	30	5	8	84	10	0.31
N = 8		MAX	9	48	55	23	33	63	52	37	12	12	210	18	0.63
		MIN	0	0	36	13	14	33	34	24	0	4	0	7	0.13
		STD	2	15	6	3	6	10	6	4	5	2	86	3	0.17
TC	ABD2	AVG	4	32	48	26	22	56	45	37	14	10	96	12	0.42
N = 11		MAX	8	51	66	38	27	72	63	51	47	19	193	18	0.63
		MIN	1	3	39	19	14	44	31	28	0	6	67	7	0.16
		STD	2	12	6	5	3	9	8	6	12	3	33	3	0.13
MTM	E4/5	AVG	4	22	46	27	19	49	48	36	14	11	113	15	0.33
N = 11		MAX	7	46	55	34	27	70	62	45	27	15	137	24	0.51
		MIN	2	3	40	20	13	37	40	29	0	8	89	13	0.24
		STD	1	13	5	3	3	8	6	4	8	2	12	3	0.07
MTM	E5/10	AVG	5	22	51	27	24	58	49	38	17	11	99	12	0.39
N = 2		MAX	8	36	51	28	24	65	57	39	17	12	108	14	0.44
		MIN	3	8	50	25	23	52	41	37	16	11	90	10	0.34
		STD	2	13	0	1	0	6	7	1	0	0	9	2	0.05
TC	SM2	AVG	4	8	49	26	23	53	49	37	14	9	84	14	0.47
N = 10		MAX	7	18	56	32	29	62	61	45	23	13	115	21	0.67
		MIN	2	0	38	21	17	41	38	29	5	5	52	8	0.30
		STD	1	5	5	3	4	6	7	4	5	2	18	3	0.13
TC	MELA	AVG	3	20	50	26	24	59	46	38	15	9	55	11	0.54
N = 15		MAX	7	78	75	38	42	82	69	51	39	16	136	17	1.39
		MIN	2	2	38	18	15	47	33	28	2	2	0	5	0.21
		STD	1	17	10	5	6	9	11	7	10	3	51	2	0.29

* MPD is in millimetres
* MCO = minimum coefficient of variation.

TABLE 25

DIOSPYROS AND *RHUS*: SHRINKAGE FACTORS FOR CERTAIN WOOD ANATOMICAL VARIABLES.

Diospyros	Maxv	Minv	Radv	Tangv	Meanv	Areav	Numv
charcoal	51.71	25.87	59.09	49.71	37.99	7.13	61.17
fresh	73.03	33.24	83.85	70.59	52.73	6.00	26.13
% shrinkage	29.19	22.19	29.53	29.58	27.96	118.89	234.13
difference	1.41	1.29	1.42	1.42	1.39	0.84	0.43

Rhus	Maxv	Minv	Radv	Tangv	Meanv	Areav	Numv
charcoal	58.83	30.36	60.88	63.91	45.30	12.60	74.50
fresh	77.44	41.28	83.91	78.37	60.54	16.81	57.68
% shrinkage	24.03	26.45	27.45	18.45	25.17	25.04	129.16
difference	1.32	1.36	1.38	1.23	1.34	1.33	0.77

TABLE 26

LIST OF FACTOR SCORES, FACTOR ONE, FOR *RHUS, DIOSPYROS* AND *ZYGOPHYLLUM*

RHUS		*DIOSPYROS*		*ZYGOPHYLLUM*	
MAXV	0.9959	MAXV	0.9934	MAXV	0.9407
MINV	0.8990	MINV	0.8738	MINV	0.9352
RANGV	0.8047	RANGV	0.9109	RADV	0.7121
RADV	0.9847	RADV	0.8978	TANGV	0.7944
TANGV	0.9765	TANGV	0.9231	RELV	0.9781
RELV	0.9326	RELV	0.5359	AREAV	0.6646
AREAV	0.6171	AREAV	-0.0876	NUMV	0.2478
NUMV	-0.2820	NUMV	-0.6091	VULN	0.4254
VULN	0.8261	VULN	0.8423		

TABLE 27

$\delta^{13}C$ values of charcoal from samples of wood in the Cape Province

UCT SAMPLE NUMBER	GENUS	SPECIES	LOCALITY	$\delta^{13}C$ °/∞
2832	*Rhus*	*lucida*	Montagu	-24.6
2833	*Rhus*	*lucida*	Montagu	-23.8
2934	*Rhus*	*lucida*	Montagu	-24.2
2835	*Rhus*	*chirindensis*	Saasveld	-28.2
2836	*Rhus*	*chirindensis*	Saasveld	-26.0
2837	*Rhus*	*chirindensis*	Saasveld	-25.4
2838	*Rhus*	*chirindensis*	Saasveld	-27.2
2839	*Rhus*	*chirindensis*	Saasveld	-27.1
2840	*Rhus*	*incisa*	Richtersveld	-25.0
2841	*Rhus*	*incisa*	Richtersveld	-24.0
2842	*Rhus*	*incisa*	Richtersveld	-24.2
2843	*Diospyros*	*glabra*	Montagu	-23.6
2844	*Diospyros*	*glabra*	Montagu	-24.2
2845	*Diospyros*	*glabra*	Montagu	-24.9
2846	*Diospyros*	*glabra*	Montagu	-24.6
2847	*Diospyros*	*glabra*	Elands Bay	-24.4
2848	*Diospyros*	*glabra*	Elands Bay	-23.3
2849	*Diospyros*	*glabra*	Elands Bay	-24.8
2850	*Diospyros*	*glabra*	Elands Bay	-24.2
2851	*Diospyros*	*glabra*	Elands Bay	-26.4
2852	*Diospyros*	*glabra*	Elands Bay	-24.2
2853	*Diospyros*	*glabra*	Elands Bay	-25.7
2854	*Diospyros*	*glabra*	Jonkershoek	-26.8
2855	*Diospyros*	*glabra*	Jonkershoek	-27.1
2856	*Diospyros*	*glabra*	Jonkershoek	-25.2
2857	*Diospyros*	*glabra*	Jonkershoek	-24.2
2858	*Diospyros*	*glabra*	Jonkershoek	-25.5
2859	*Diospyros*	*glabra*	Jonkershoek	-24.0
2860	*Diospyros*	*glabra*	Jonkershoek	-24.4
2861	*Diospyros*	*glabra*	Jonkershoek	-25.9
2862	*Diospyros*	*glabra*	Jonkershoek	-22.6

TABLE 28

Average $\delta^{13}C$ values for charcoaled wood from the Cape Province

AREA	No. OF SAMPLES	$\delta^{13}C$ MEAN	$\delta^{13}C$ STD DEV
MONTAGU	7	-24.27	0.46
SAASVELD	5	-26.78	0.83
RICHTERSVELD	3	-24.37	0.45
ELANDSBAY	7	-24.71	0.98
JONKERSHOEK	9	-25.06	1.35

TABLE 29

$\delta^{13}C$ Values For Charcoal From Archaeological Sites At Elandsbay

UCT LAB Nº	GENUS	LAYER	DATE	$\delta^{13}C$ VALUES
2885	*Diospyros/Euclea*	ASHIV	460	-23.1
2886	*Diospyros/Euclea*	ASHIV	460	-23.7
2887	*Diospyros/Euclea*	ASHIV	460	-21.3
2890	*Diospyros/Euclea*	ASHIV	460	-23.4
2892	*Diospyros/Euclea*	ASHIV	460	-20.8
2893	*Diospyros/Euclea*	ASHIV	460	-21.8
2904	*Diospyros/Euclea*	ASHIV	460	-22.4
2899	*Diospyros/Euclea*	ABDII	1600	-20.4
2900	*Diospyros/Euclea*	ABDII	1600	-22.4
2901	*Diospyros/Euclea*	ABDII	1600	-21.7
2902	*Diospyros/Euclea*	ABDII	1600	-22.8
2903	*Diospyros/Euclea*	ABDII	1600	-21.5
2870	*Diospyros/Euclea*	E4/5	2000	-20.9
2871	*Diospyros/Euclea*	E4/5	2000	-23.2
2872	*Diospyros/Euclea*	E4/5	2000	-23.5
2874	*Diospyros/Euclea*	E4/5	2000	-21.6
2875	*Diospyros/Euclea*	E5/10	2500	-25.4
2876	*Diospyros/Euclea*	E5/10	2500	-22.2
2877	*Diospyros/Euclea*	E5/10	2500	-23.0
2878	*Diospyros/Euclea*	E5/10	2500	-21.7
2879	*Diospyros/Euclea*	E5/10	2500	-23.7
2895	*Diospyros/Euclea*	ALL BLACK	3000	-21.3
2896	*Diospyros/Euclea*	ALL BLACK	3000	-22.9
2897	*Diospyros/Euclea*	ALL BLACK	3000	-20.6
2898	*Diospyros/Euclea*	ALL BLACK	3000	-19.7
2865	*Diospyros/Euclea*	SM2	3500	-22.8
2866	*Diospyros/Euclea*	SM2	3500	-22.7
2867	*Diospyros/Euclea*	SM2	3500	-23.2
2868	*Diospyros/Euclea*	SM2	3500	-22.4
2869	*Diospyros/Euclea*	SM2	3500	-23.5
2880	*Diospyros/Euclea*	MELANIE	4200	-22.5
2881	*Diospyros/Euclea*	MELANIE	4200	-27.5
2883	*Diospyros/Euclea*	MELANIE	4200	-21.0
2884	*Diospyros/Euclea*	MELANIE	4200	-22.2
2905	*Diospyros/Euclea*	MELANIE	4200	-24.9

TABLE 30

Averages for $\delta^{13}C$ Values Of Charcoal From Elandsbay Archaeological Sites

SITE	Nº OF SPECIMENS	LAYER	DATE	$\delta^{13}C$	STD DEV.
SPRING CAVE	7	ASHIV	460	-22.37	1.00
TORTOISE CAVE	5	ABD11	1620	-21.78	0.82
MTM	4	E4/5	2000	-22.30	1.09
MTM	5	E5/10	2500	-23.18	1.28
SPRING CAVE	4	ALL BLACK	3000	-21.12	1.18
TORTOISE CAVE	5	SM2	3500	-22.90	0.38
TORTOISE CAVE	5	MELA	4200	-23.63	2.33

FIGURE 1. MAP OF RESEARCH AREA IN THE SOUTH-WESTERN CAPE SHOWING LOCALITIES MENTIONED IN THE TEXT

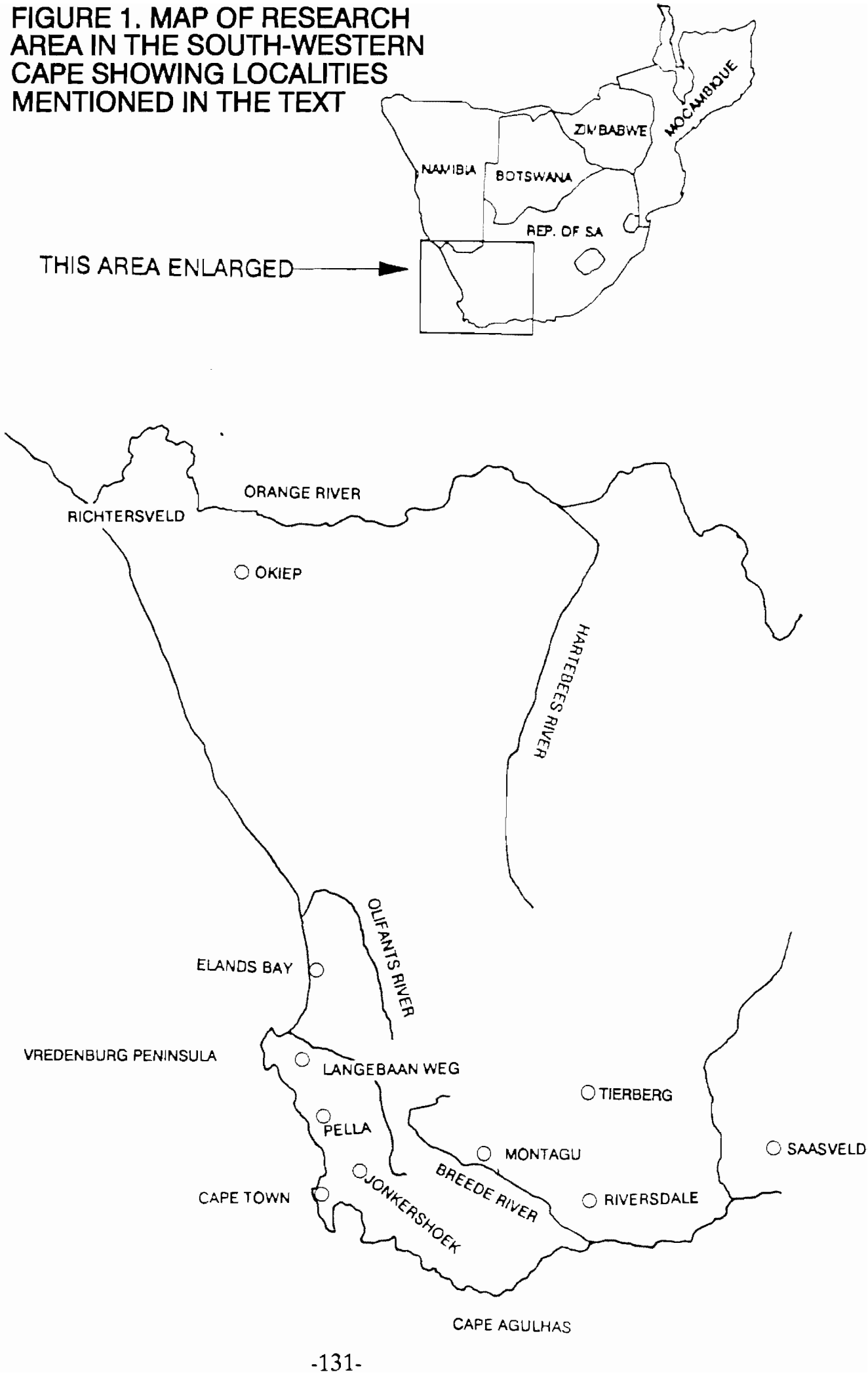


FIGURE 2. MAP OF ELANDS BAY SHOWING THE LOCATION OF THE ARCHAEOLOGICAL SITES FROM WHICH SAMPLES OF CHARCOAL WERE ANALYSED

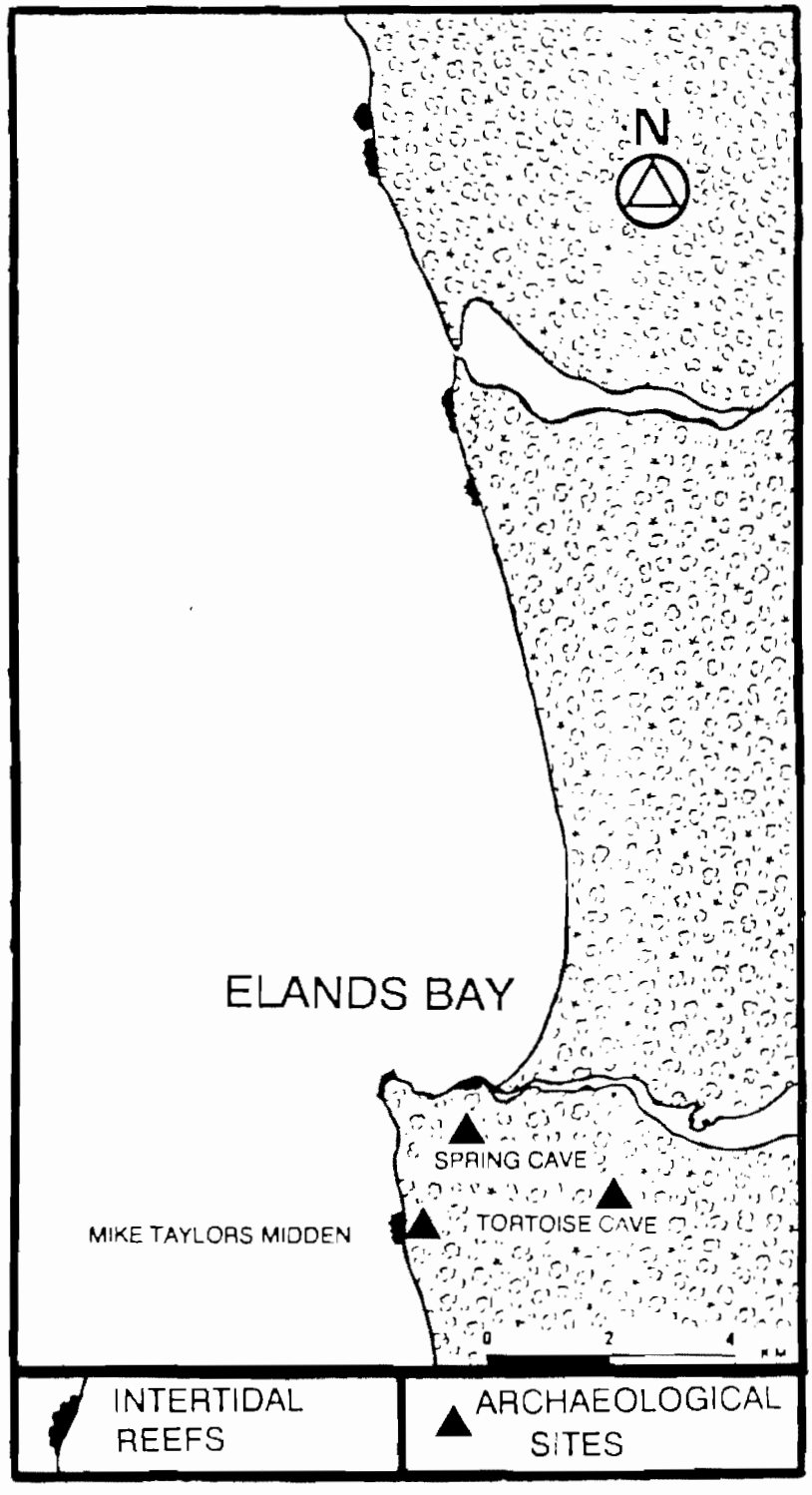


Figure 3. Percentages of identifiable charcoal from the archaeological sites at Elands Bay

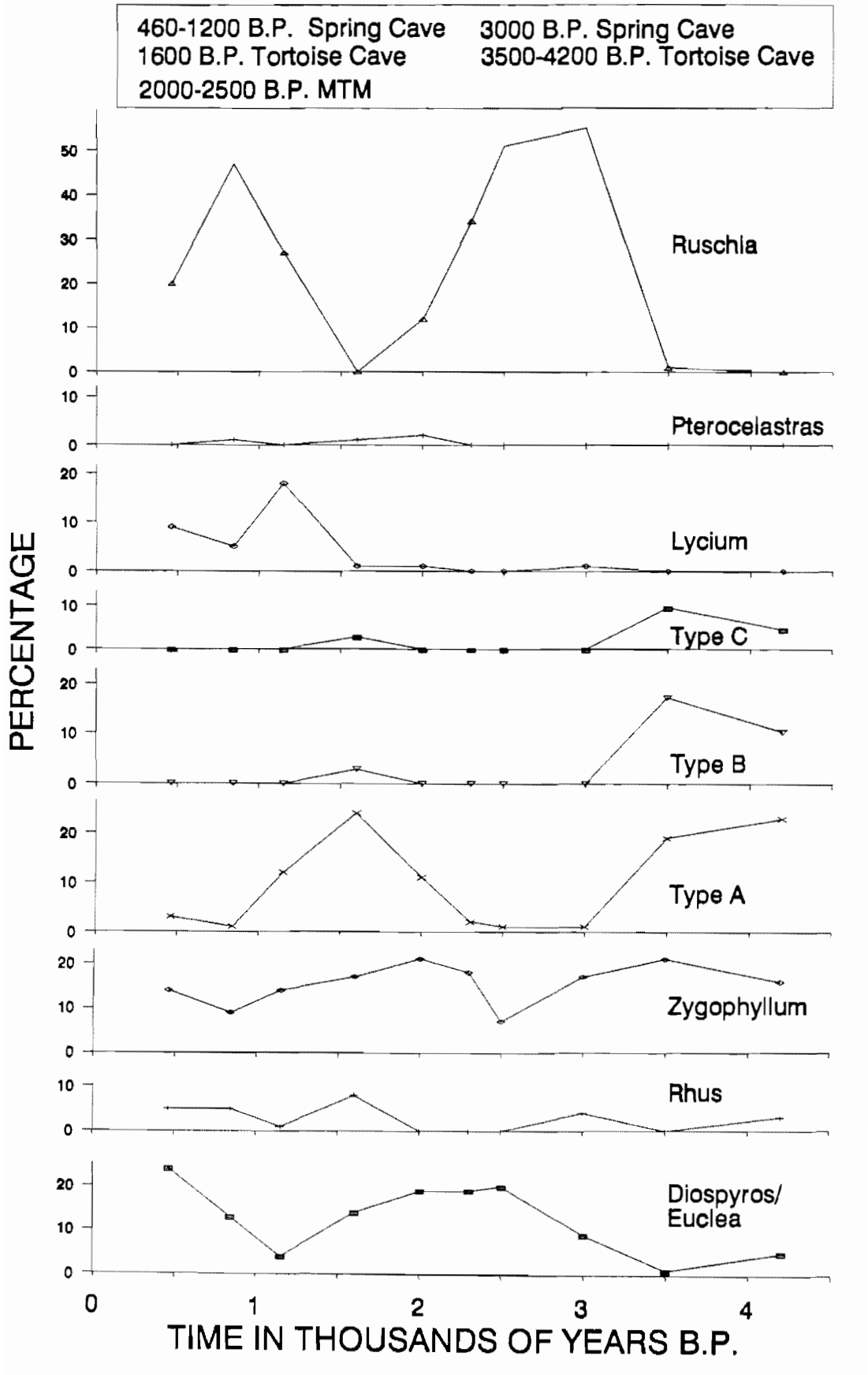


Figure 4. Percentages of identifiable charcoal from the archaeological sites at Elands Bay

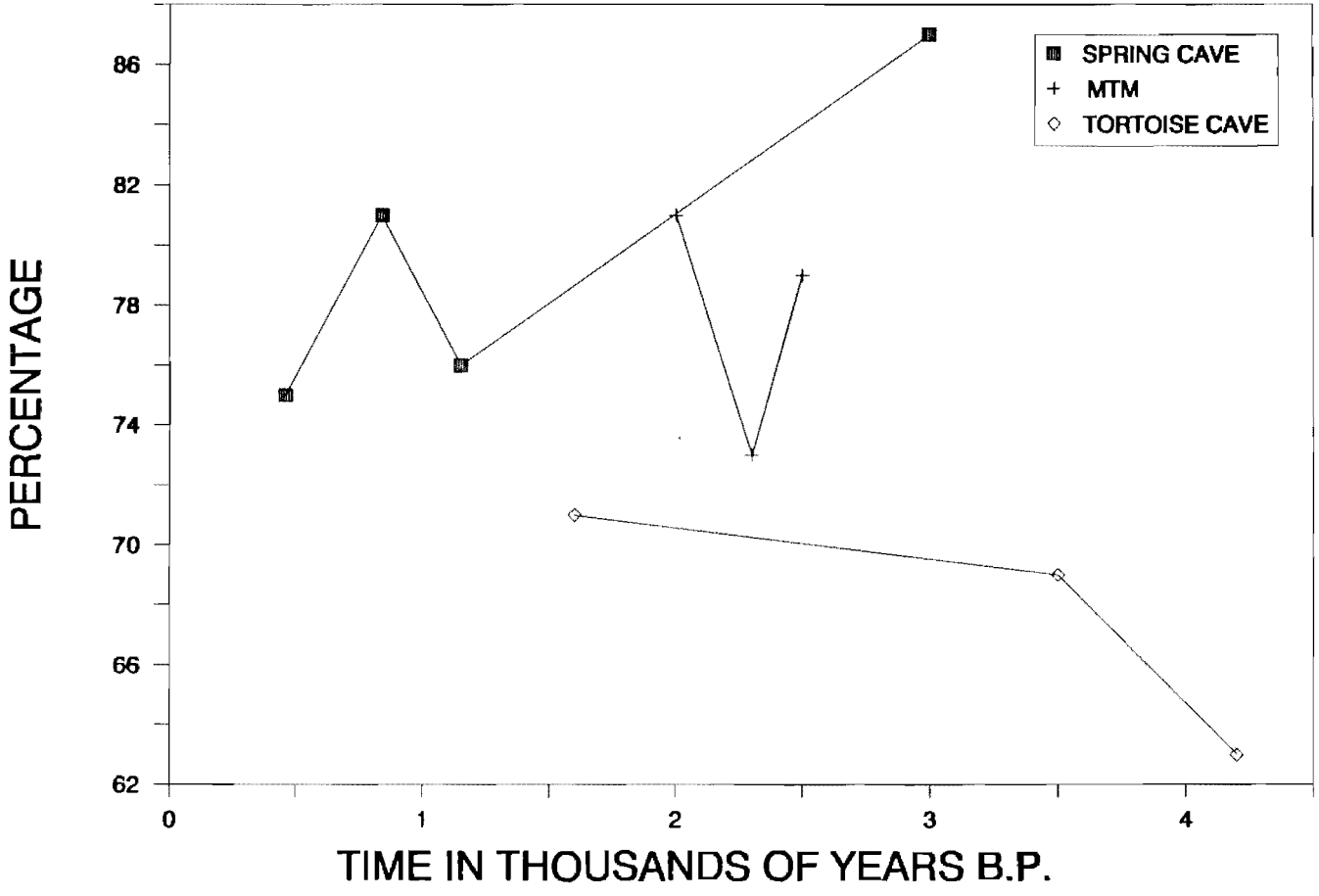


Figure 5. Predicted values for precipitation of the warmest month for all sites except Elands Bay from Rhus using multiple regression analysis

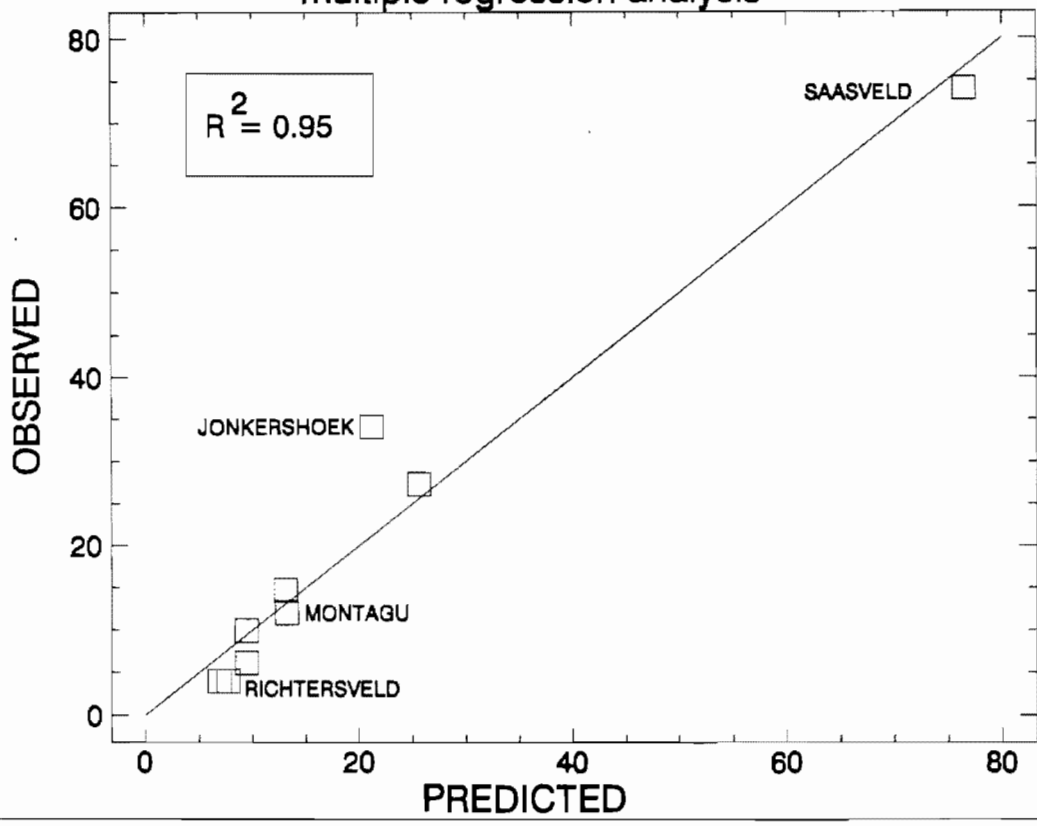


Figure 6. Predicted values for average annual rainfall for all sites except Saasveld and Elands Bay from Rhus using multiple regression analysis

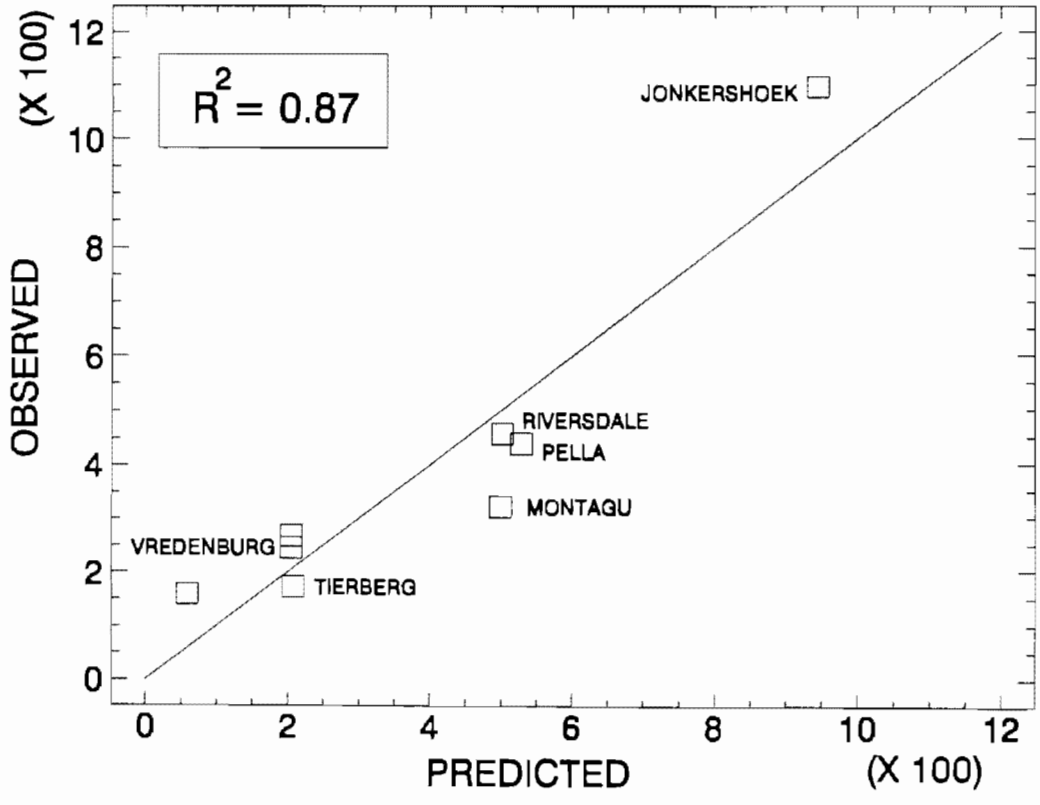


Figure 7. Estimated average annual temperature for all sites except Elands Bay from Diospyros Rangv using simple linear regression analysis

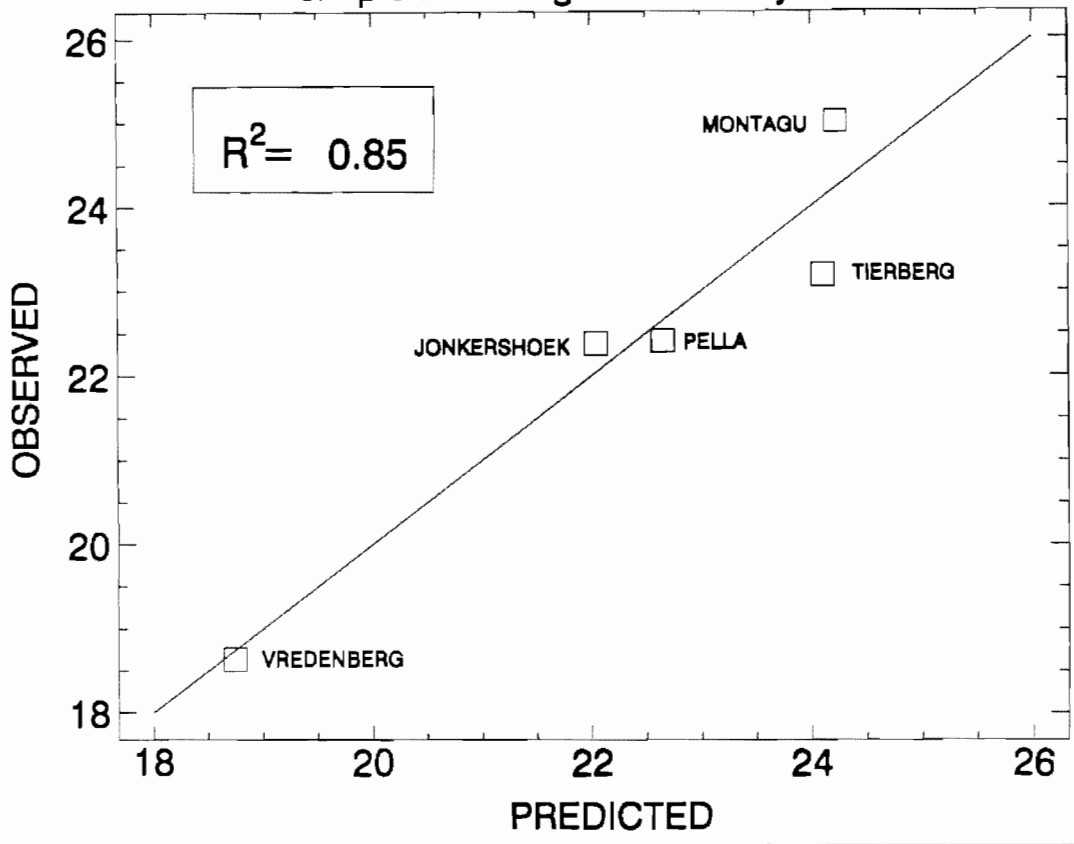


Figure 8. Estimated minimum monthly temperature for all sites except Elands Bay from Diospyros NUMV using simple linear regression analysis

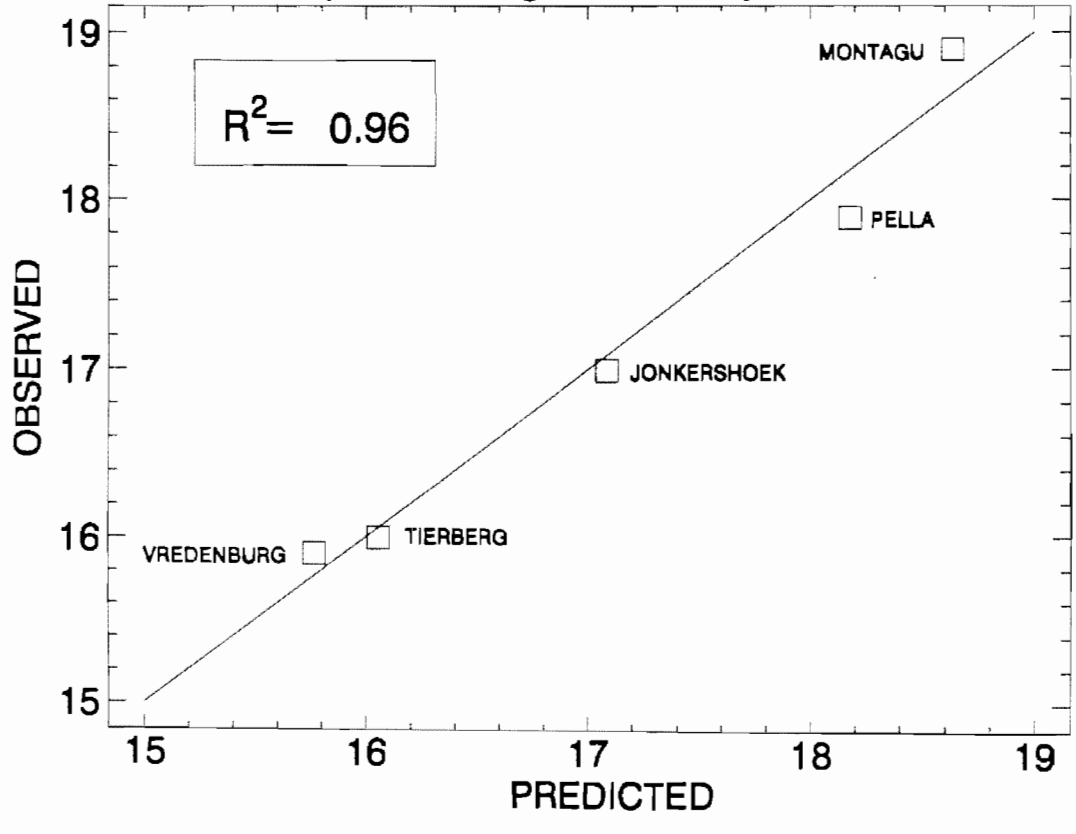


Figure 9. Relationship between MEANV and NUMV for both the contemporary wood sample as well as the archaeological sample for Rhus. The archaeological sample has been corrected for shrinkage

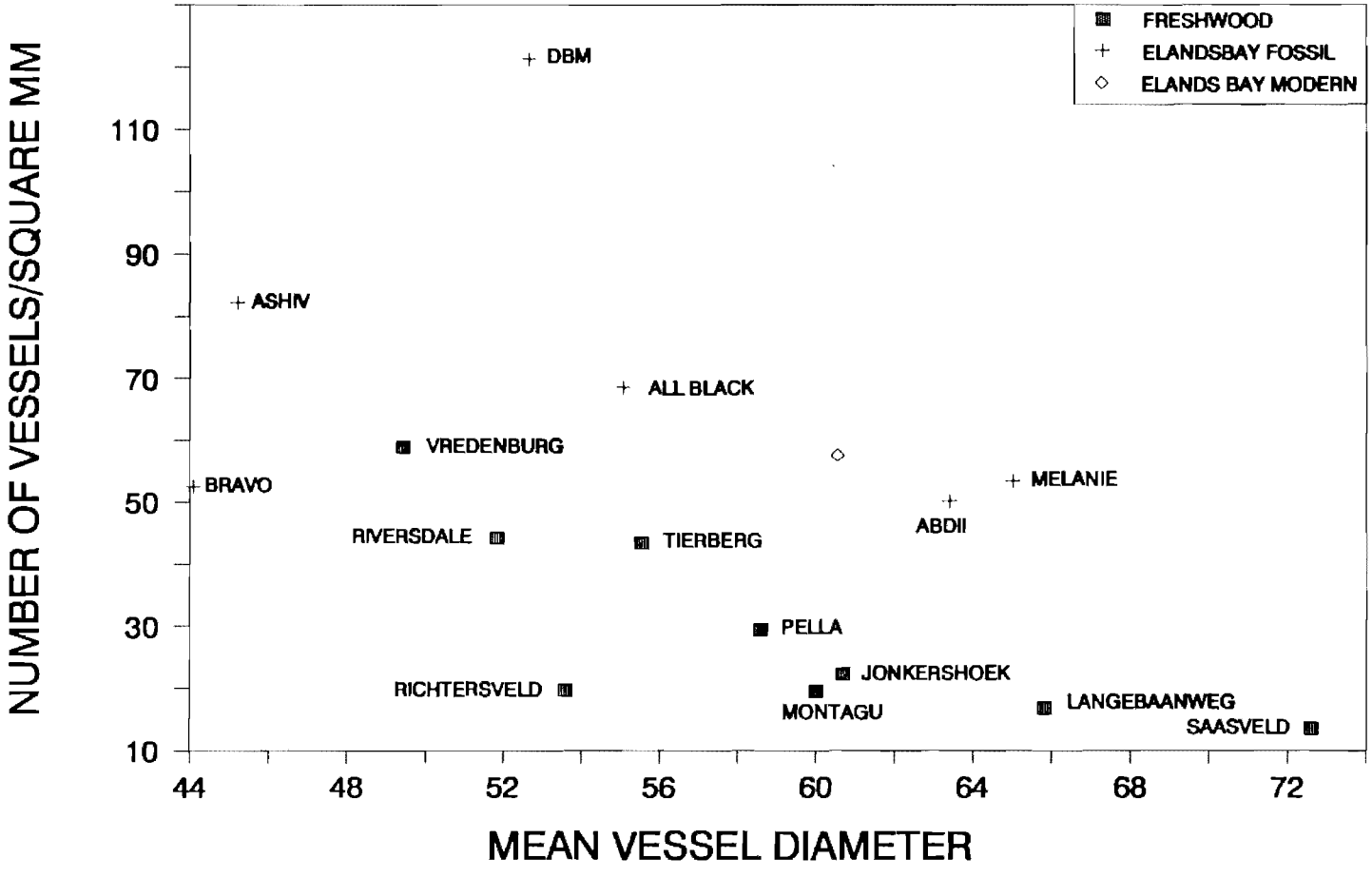


Figure 10. Estimated minimum temperature for Elands Bay derived from Diospyros NUMV

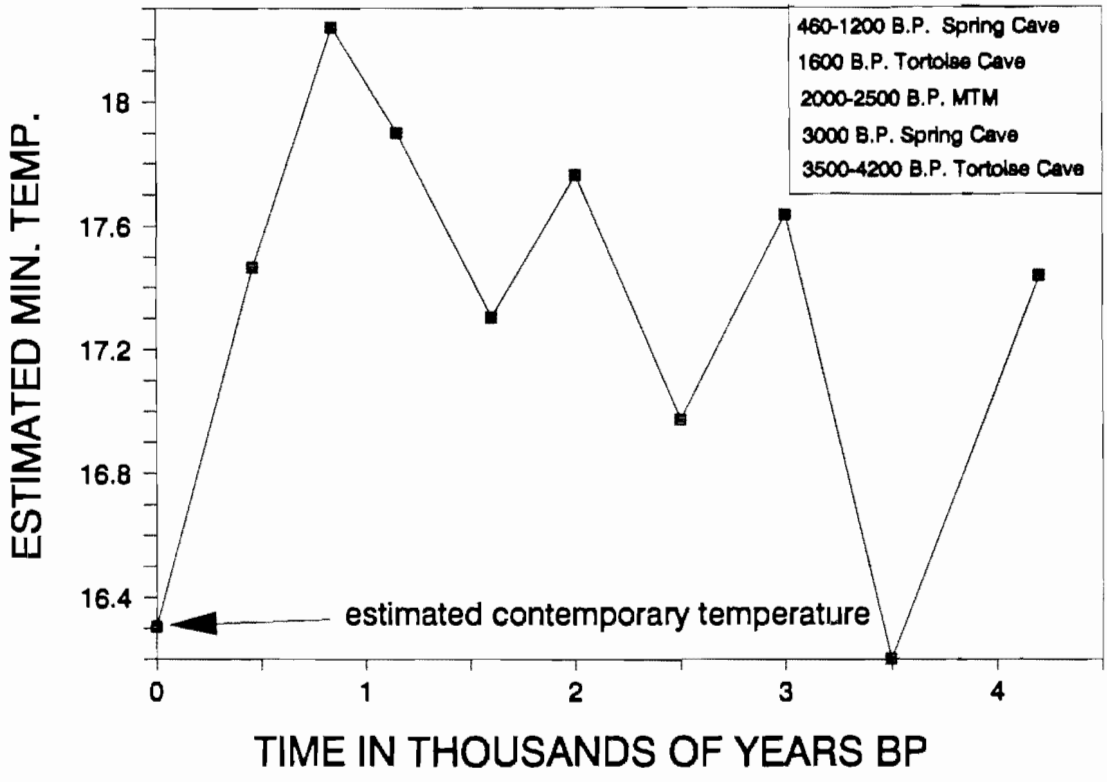


Figure 11. Estimated annual temperature for Elands Bay derived from Diospyros RANGV

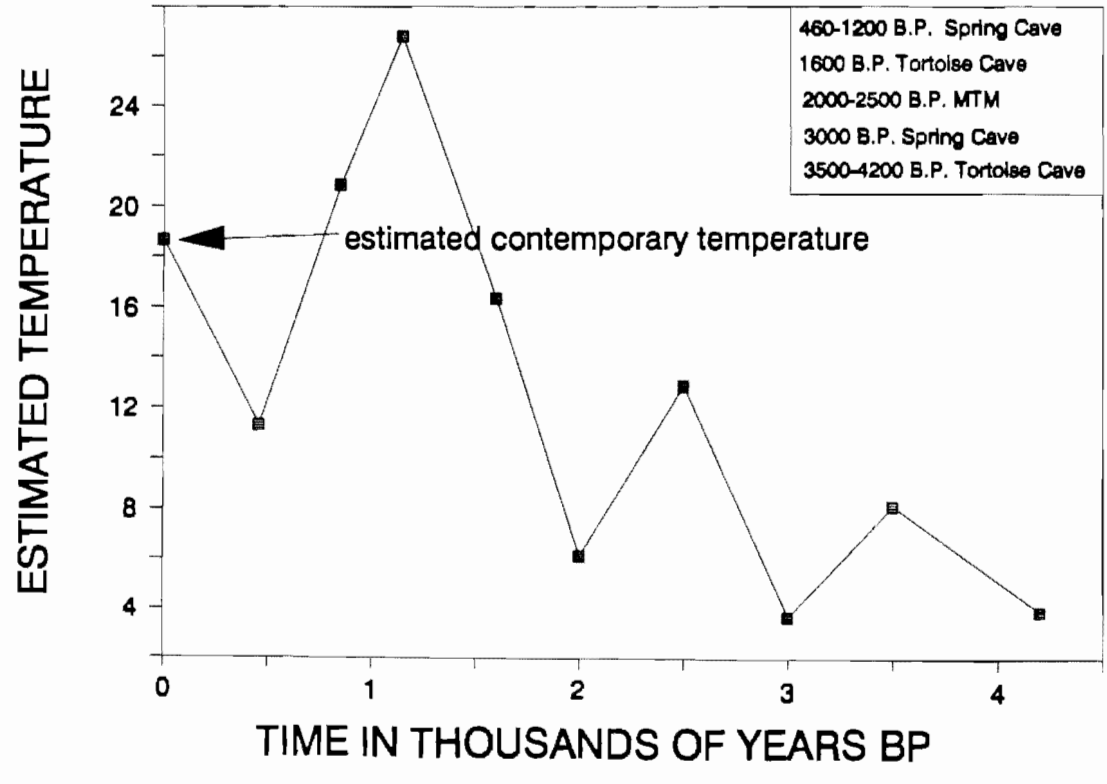


Figure 12. Results of a summary statistic based on Factor one of a factor analysis on Diospyros and Zygophyllum charcoal from the archaeological sites at Elands Bay

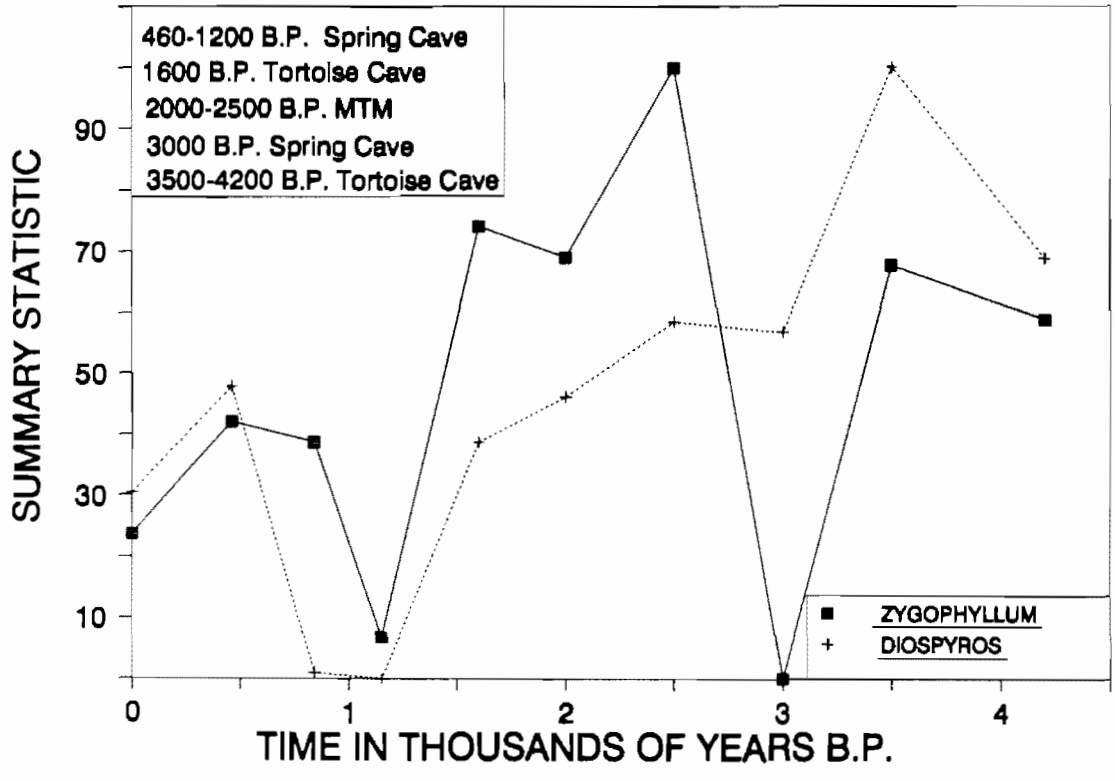


Figure 13. Results of summary statistic based on factor one of a factor analysis using Rhus, Diospyros and Zygophyllum charcoal from the archaeological sites at Elands Bay. Values are included only for times at which data for all three genera are available

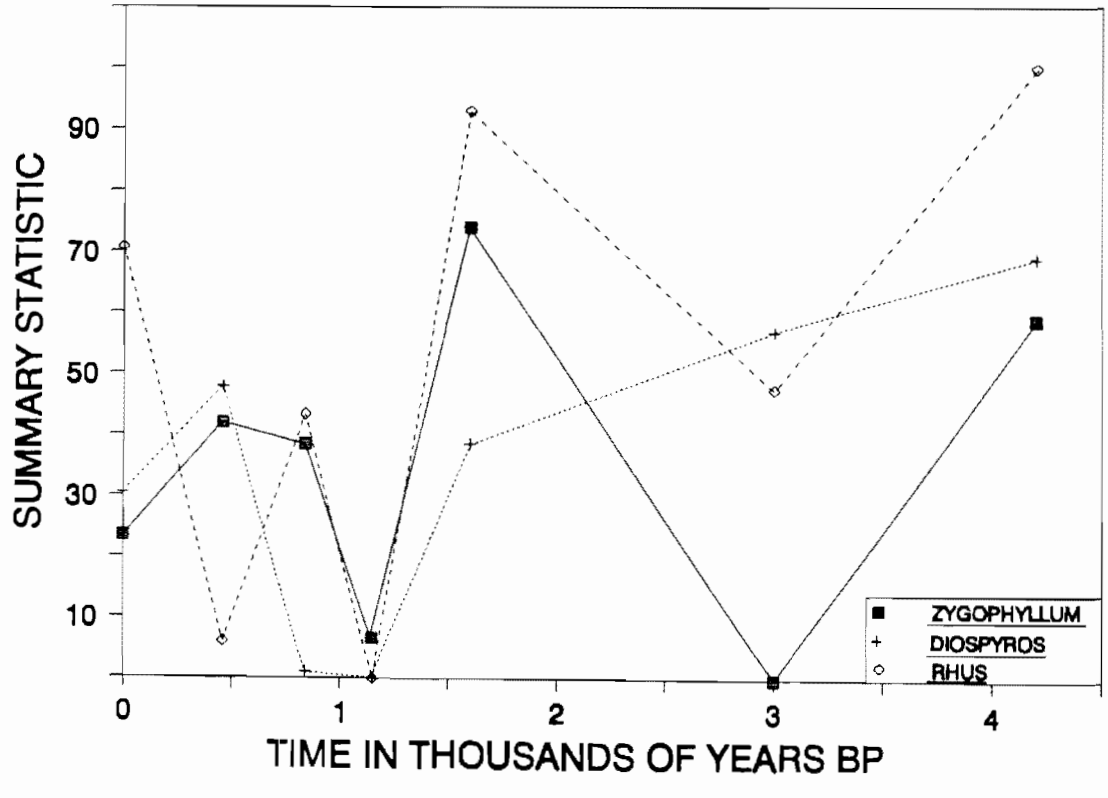


Figure 14. Average MPD for Zygophyllum charcoal samples from Elands Bay archaeological sites

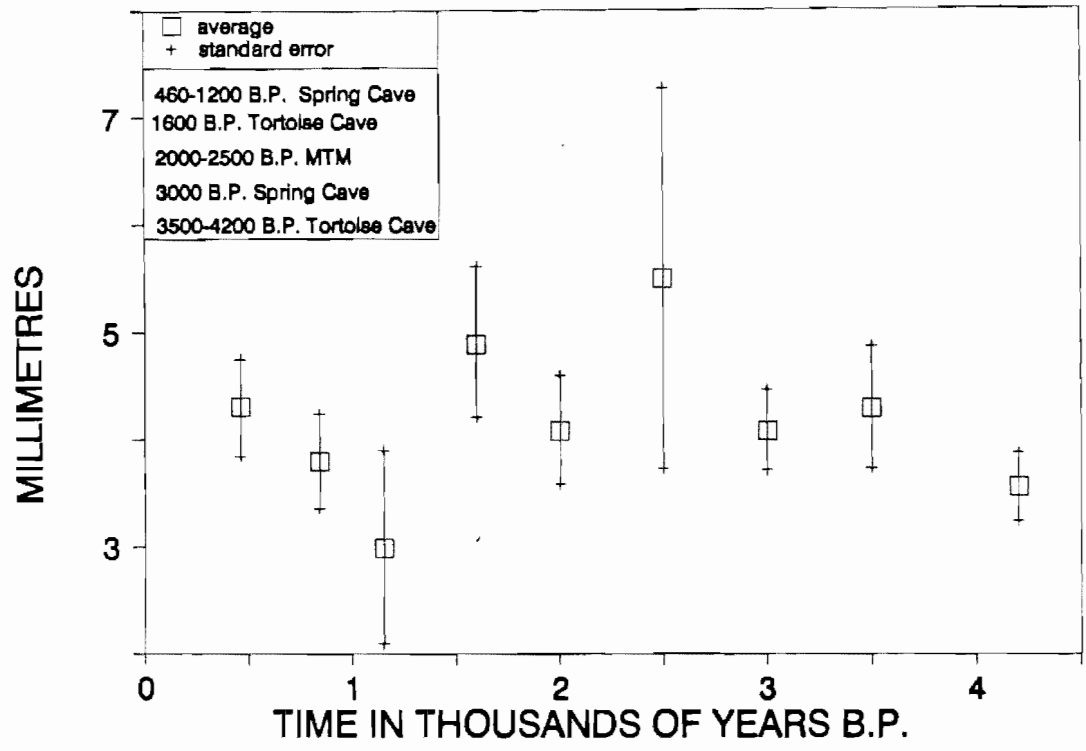


Figure 15. Average MPD for Diospyros and Rhus charcoal samples from the archaeological sites at Elands Bay

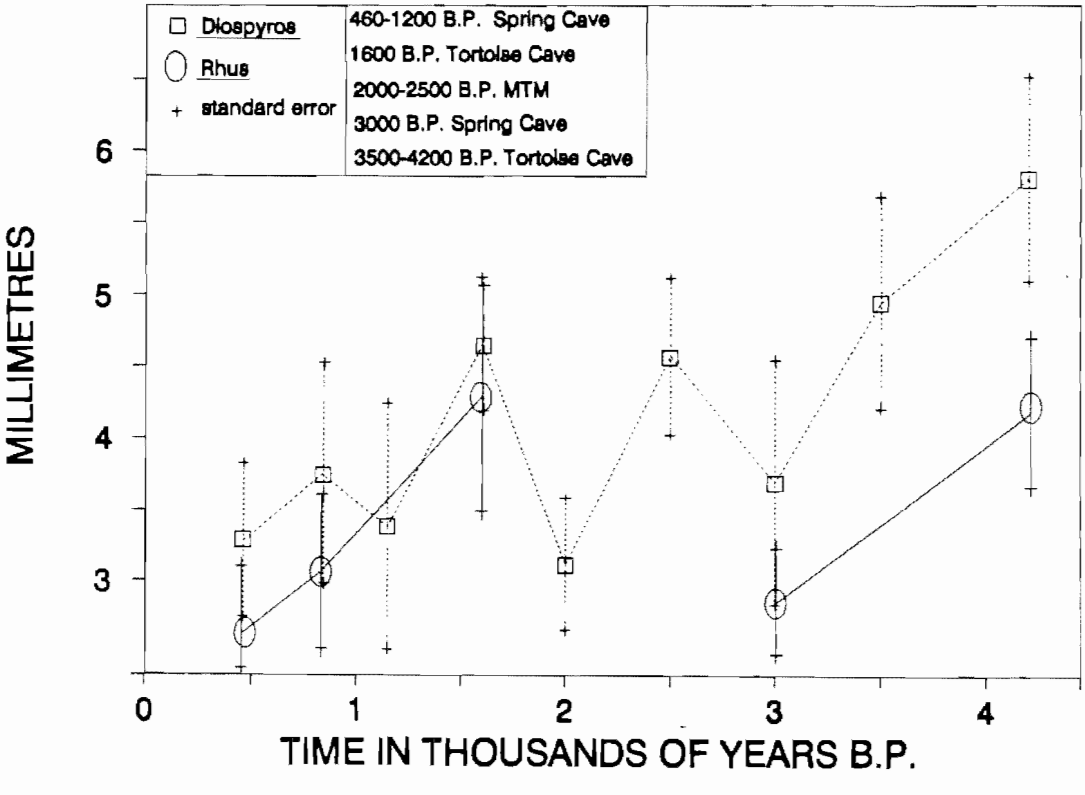


Figure 16. Comparison between actual and estimated piece diameter for contemporary samples of Diospyros

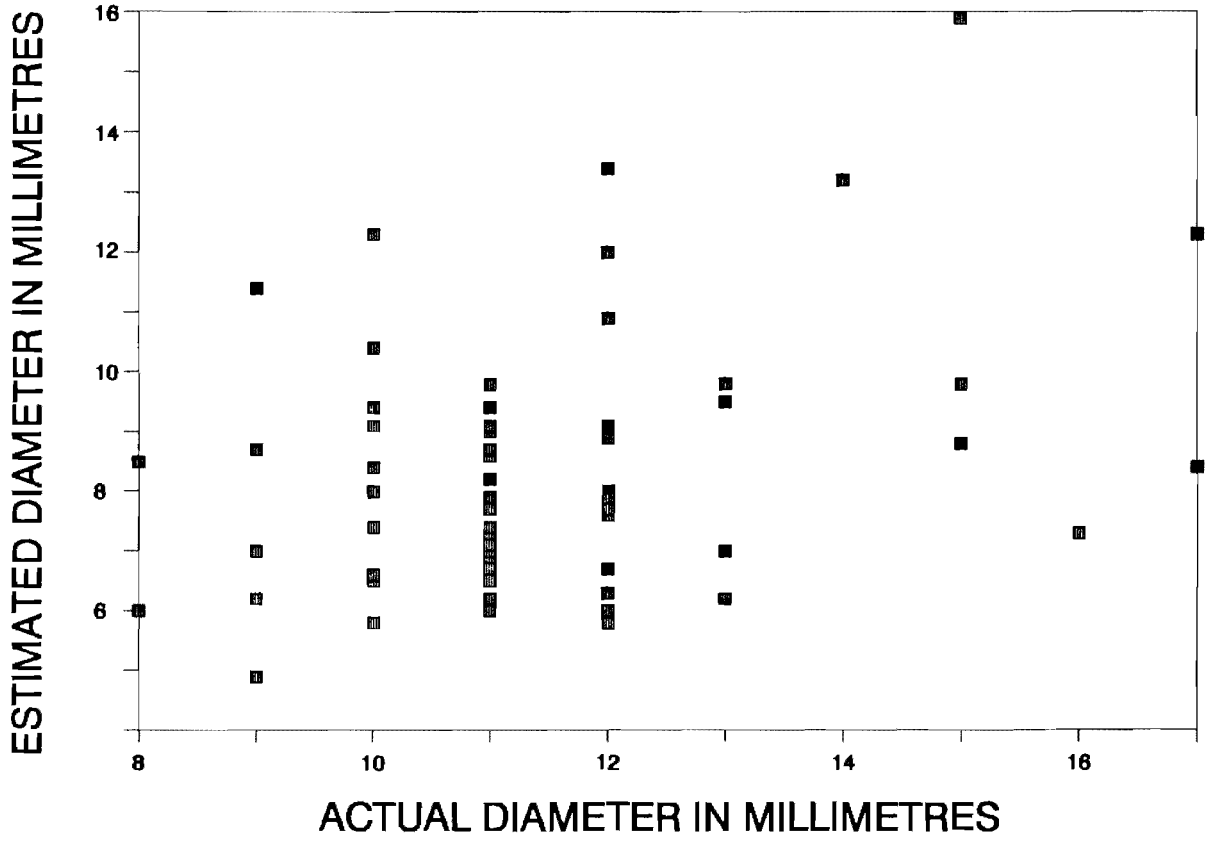
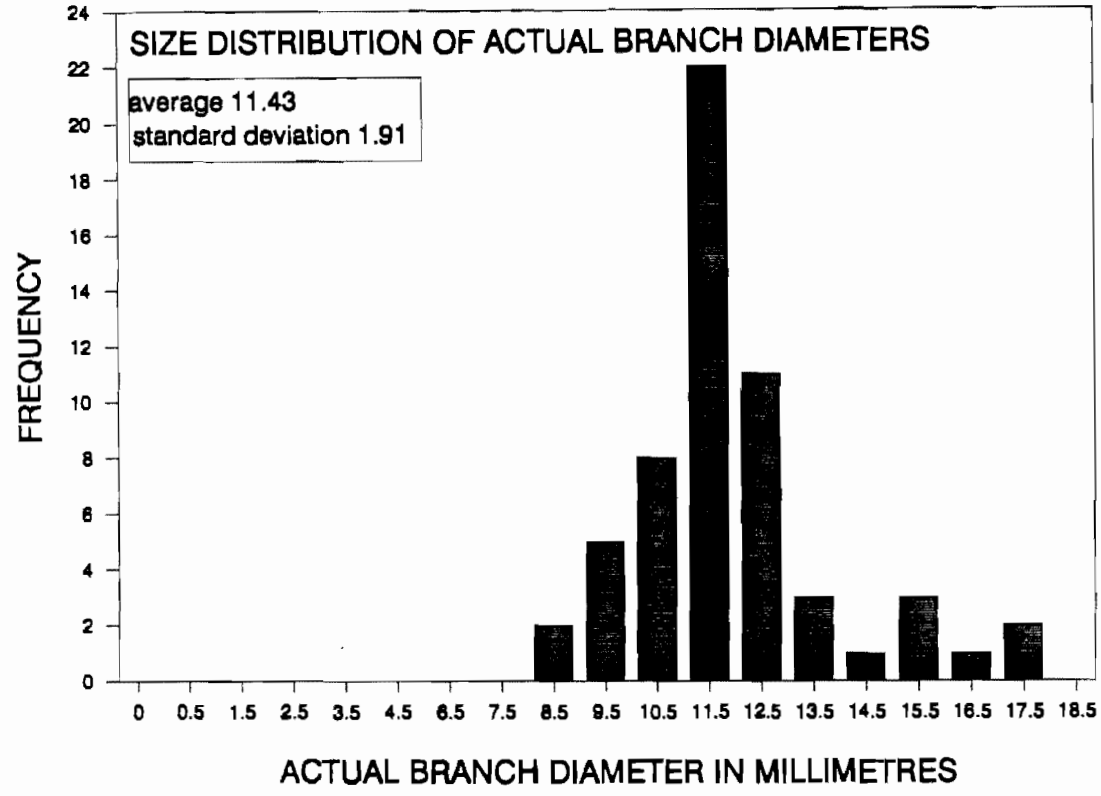


Figure 17. Relative size distribution for modern samples of Diospyros



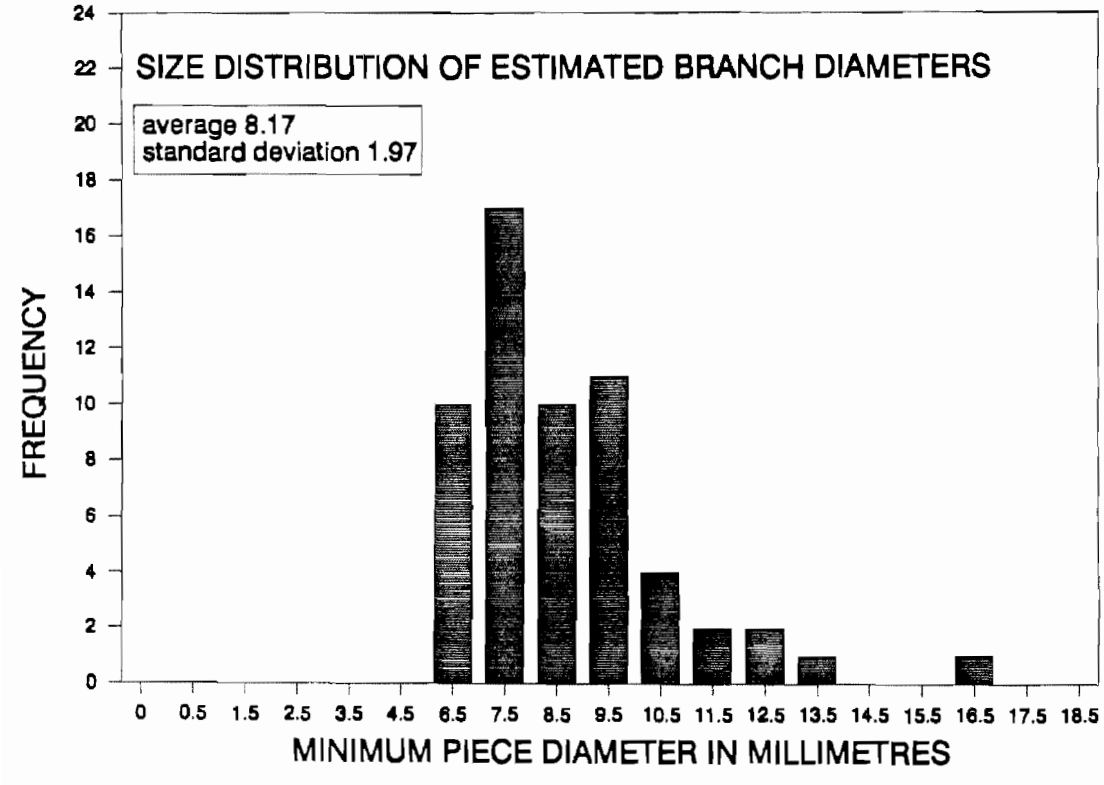


Figure 18. Relationship between mean $\delta^{13}C$ values and rainfall in the warmest month

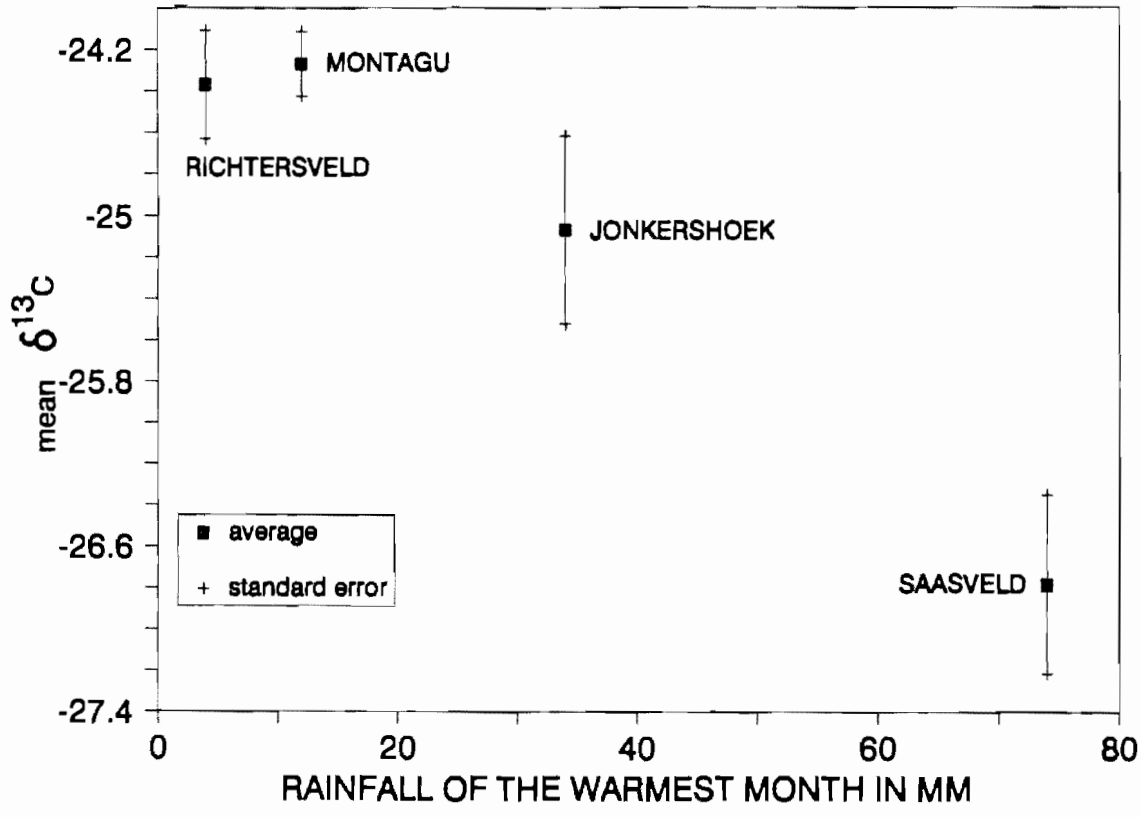


Figure 19. Relationship between mean $\delta^{13}C$ values and average annual temperature

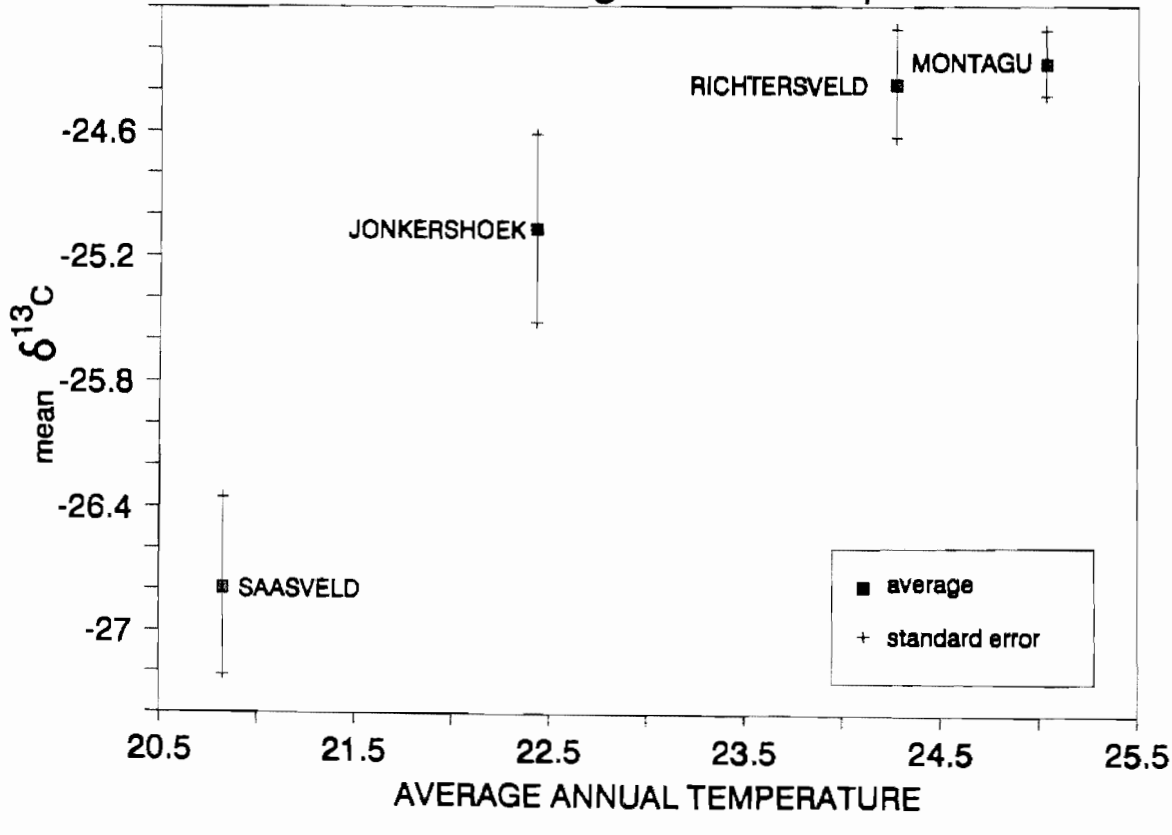


Figure 20. Stable carbon isotope ratios of Diospyros charcoal from both the modern and the archaeological sites at Elands Bay. The archaeological sample has been corrected for shrinkage.

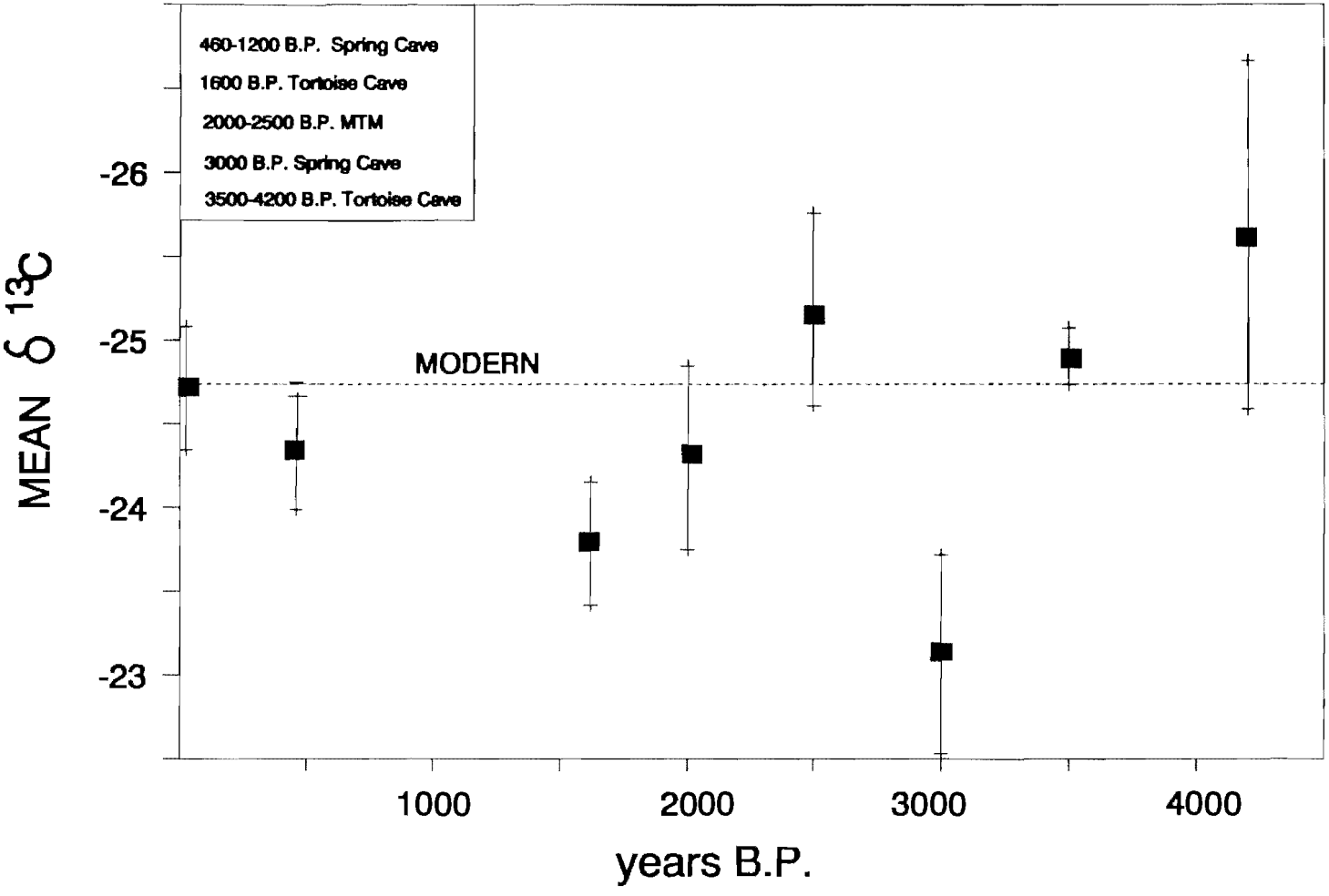


Figure 21. Mean $\delta^{13}c$ values from radiocarbon dates for the archaeological sites of MTM, Elands Bay Cave, Hailstorm Midden, Spring Cave and Tortoise Cave