A HISTORICAL PERSPECTIVE ON RECENT LANDSCAPE TRANSFORMATION: INTEGRATING PALAEOECOLOGICAL, DOCUMENTARY AND CONTEMPORARY EVIDENCE FOR FORMER VEGETATION PATTERNS AND DYNAMICS IN THE FLEURIEU PENINSULA, SOUTH AUSTRALIA.

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> The past is not dead. It is not even past.
>
> William Faulkner

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ABSTRACT

Palaeoecological records, documented historical records and remnant vegetation were investigated in order to construct a multi-scaled history of vegetation pattern and change in the Fleurieu Peninsula, South Australia over the last c. 8000 years. The inquiry aimed to better understand post-European landscape transformation; thus addressing the inherently historical components of the problems of regional biodiversity loss, land sustainability and the cumulative contribution to global climate change.

The relationships between environmental variables, either directly or indirectly representing the environmental regimes, affecting vegetation distribution and (1) remnant vegetation and (2) historical records of nineteenth century vegetation pattern, were investigated. The potential of relationships, when extrapolated in geographic space, to represent pre-European vegetation pattern was considered. It was shown that nineteenth century records, made during the first systematic land surveys, were suitable for quantitative landscape investigations. In some cases these records provided the only means of assessing ecological patterns prior to widespread vegetation removal. Remnant vegetation provided a vital adjunct to the interpretation and use of historical records. However, their utility for landscape-scale reconstruction of potential historical vegetation was limited by their poor environmental distribution. Remnant vegetation and environmental relationships more markedly represented patterns of European land selection than historical environmental relations.

Modern pollen production, distribution and the pollen morphology of members of the Myrtaceae family were investigated to provide a basis for the interpretation of fossil pollen records. Fossil pollen, charcoal and sediments from the European period were investigated at three sites. Substantial changes to terrestrial and wetland vegetation occurred in the initial phase of European settlement. No obvious response in floristic composition of the overstorey of sclerophyll vegetation types was detected. However, intensified burning regimes, selective harvesting and grazing affected understorey composition. Wetland vegetation underwent further dramatic changes later in the European period, probably in response to broad scale vegetation clearance carried out in the mid- twentieth century causing regional shifts in hydrological and nutrient regimes. Lower sedimentation rates since land clearance suggests relative catchment stability since that time.

A Holocene palaeoecological record was investigated to place European impacts in a long-term context. It revealed a transition from an early Holocene-*Eucalyptus* dominated woodland to an *Allocasuarina* dominated wet heath in the humid mid-Holocene and a return to *Eucalyptus* dominated woodland in the drier Late Holocene. Charcoal and pollen records suggested that Aborigines occupied the highland forested regions of the Fleurieu Peninsula throughout the mid-late Holocene and that the upland wetlands may have constituted an important resource base. Substantial vegetation changes occurred through the period of Aboriginal occupation but these changes seem to be in response to changing climate regimes rather than being anthropogenic in nature.

The degree to which the different sources were comparable, and could be integrated, was discussed by considering their relative classificatory, spatial and temporal resolution and their accuracy. It was contended that a multiple-line history is required to reveal historical ecological relations and human impacts. Integrated sources showed that recent European changes occurred at a much greater rate than those in the Holocene and differed in nature in fundamentally important ways. Pre-historical disturbances were local while post-European were broad scale and thus regional. Pre-historical vegetation changes resulted in reduction or migration of community types while post-European resulted in their elimination. Regional vegetation changes of the post European period invoked permanent changes to other integrated components of the biotic and abiotic environment and these changes are without precedent in the Holocene.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and, to the best knowledge and belief, contains no material previously published or written by another person, except when due reference is made in the text.

Sophia Bickford

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LIST OF ABBREVIATIONS

SAPP	South Australian Parliamentary Papers
SRPSA	Statistical Register of the Province of South Australia
RBCMB	Rapid Bay Council Minute Book
SAGG	South Australian Government Gazette
YCMB	Yankalilla Council Minute Book
DB	diagram book
FB	field book
DCDB	District council data base
GIS	geographical information system
PVM	potential vegetation modelling
DEM	digital elevation model
EDA	exploratory data analysis
TWI	topographic wetness index
E%	elevation percentile index
ANR	annual net radiation
TEDA	Topographic Environmental Domain Analysis
DENR	Department of Environment and Natural Resources (South Australia)
NPWS	National Parks and Wildlife Service
m	metres
cm	centimetres
mm	milimetres
Ma	Million years
ha	hectares
BP	years before present

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CHAPTER 1

1. INTRODUCTION

1.1 Research context and aims

Vast and rapid transformations of the environment occurred around the world in the nineteenth century with population increases, imperial colonisation of the New World and technological advances (Worster, 1988, Kates *et al.,* 1990). The first significant documented concern which portrayed the effects and potential consequences of human environmental impact was in the written in the nineteenth century in the work of George Perkins Marsh (1865). In his book, *Man and Nature; or Physical Geography as Modified by Human Action,* Marsh aimed to:

> 'indicate the character and, approximately, the extent of the changes produced by human action in the physical conditions of the globe we inhabit; to point out the dangers of imprudence, and the necessity of caution in all operations which, on a large scale, interfere with the spontaneous arrangements of the organic and inorganic world; to suggest the possibility and the importance of the restoration of disturbed harmonies and the material improvement of waste and exhausted regions....' (Marsh 1865, p.3).

Since Marsh's seminal work there have been many influential writings on the nature and complexities of recent human ecosystem transformation (Thomas, 1956; Carson, 1963; Turner *et al.*, 1990). Interest in understanding the nature of societal-environmental relations has only developed with increased awareness about the principle role human agency has in global change. Human affected global change to (1) biodiversity, (2) agricultural sustainability and (3) global climate change (Oldfield, 1998) have been identified as the three components of most concern to continued human existence. Global change has been considered to be both (1) systemic, that is involving changes to whole earth systems and (2) cumulative, that is involve many local changes that in aggregate have a global effect (Wasson, 1998). Cumulative human impacts differ with bioregions and their settlement and land use histories, thus their understanding requires individual local to regional scale investigations.

The recognition that many of the significant human impacts on environments occurred in the past, has resulted in studies of human interactions in past environmental changes being accepted as one of the necessary lines of investigation in understanding and managing environmental issues of global significance (Oldfield, 1998). A historical perspective allows for the elucidation of the inherently historical components of present day environmental relations and problems. In recognition that changes at any one point in time can only be understood in the context of longer term dynamics in systems where change is ever-implicit, historical studies provide a means to understand recent dynamics against the range of natural and anthropogenic changes that have been historically operative in a landscape (Foster *et al.,* 1997; Clark 1990). Such a perspective contributes to understanding societal-environmental relations (Simmons, 1990; Redman, 1999), explaining present day ecological relations (Greig Smith, 1983; Foster, 1992, ; Motzkin *et al.*, 1999) and in setting baselines for environmental restoration or rehabilitation (Clark, 1990; Roberts and Sainty, 2000).

This thesis investigates the environmental history of an agricultural region in South Australia, the Fleurieu Peninsula. This region is facing considerable biodiversity and land use sustainability issues, key components of cumulative global change, due to the extensive transformation of pre-European environments since European settlement. This study aims to (1) qualify the nature, timing and cause of changes to the vegetation through the European period of settlement (2) investigate vegetation dynamics driven by climate, natural disturbances and Aboriginal land use, through the Holocene but prior to European settlement (3) compare the rate, kind and magnitude of pre-European and post-European environmental changes. The Holocene is selected as an appropriate temporal period within which to compare vegetation-environment dynamics for it is an epoch in which contemporary vegetation communities were established in Australia. Environmental changes through earlier time periods, may not be as directly comparable for they were characterised by vegetation types that are largely without analogue in the modern Australian vegetation (Hope and Kirkpatrick, 1988). Due to the pivotal position vegetation plays in ecosystem function, and its vital role in human existence, vegetation history coalesces with environmental-societal issues. Consequently historical vegetation dynamics are focused upon in this environmental history. The thesis brings together three different lines of evidence for historical vegetation pattern: (1) documented historical data, (2) environmental data and (3) contemporary evidence. Documented evidence (surveyors records, explorers accounts, historical pictorial records) provide evidence for the historical period only, environmental data (sedimentary stratigraphic, palynological and charcoal records) provide otherwise unobtainable information on the prehistoric period and contemporary evidence (remnant native vegetation distribution) is a necessary starting point to allow interpretation of historical data as well as potentially providing evidence itself.

The Fleurieu Peninsula was selected as a study area for it is a botanically important region which has undergone extensive transformation since European settlement. The vegetation of the Fleurieu Peninsula region is of high conservation significance. The region is part of the environmentally heterogeneous Mount Lofty Ranges Botanical Region. It shows more diversity than any other in the botanical region in South Australia, yet the area has more extinct, rare and endangered plant species than anywhere else in the state (Lang and Kraheunbeuhl, 1987). Ninety percent of its once continuous savannah woodland, sclerophyll forest and scrub cover has been removed and replaced with an agrarian landscape of improved pastures, cultivated fields and plantation timber. It was believed that historical investigation in this region would contribute to (1) increased understanding of the impacts of European settlement on temperate woodland and forest environments in Australia and (2) provide a vital perspective the for present day environmental issues of the region.

1.2 Environmental history and retrospective studies

Environmental history has recently emerged as a discipline, its origins beginning in the 1970s in response to increasing concern of human impacts on natural environments (Worster, 1988). It has been defined as an interdisciplinary arena involving:

> 'the investigation and description of previous states of the biophysical environment, and the study of the history of human impacts on and relationships with the non-human setting. Environmental history seeks to explain landscapes and issues of today and their evolving and dynamic nature, and from this to elucidate the problems and opportunities of tomorrow.' (Dovers, 1994)

Worster (1988) considers environmental history to proceed on three levels, although not always at once in a single project. The first level deals with understanding nature itself, as organising and functioning in times past. The second, seeks to understand how human social and economic structures interact with the environment. The third is more philosophical, involving how cultural constructs become part of the dialogue with nature, at particular time and place. It has been argued that in a sense now all histories are environmental histories, for all social and economic choices have had direct or indirect repercussions for processes and patterns in, and the quality of, all biophysical environments (Batterbury and Bebbington, 1999).

Environmental history is considered worthwhile in explaining the essential 'how, who and why' to the 'what and when' by explaining the contexts of environmental changes (Dovers, 2000). However, further to this, environmental history is distinctly characterised by notions of relevance. The issues on which environmental history can inform are required to comprehend biophysical dynamics such as disturbance, succession, ecosystem development and soil erosion. These processes operate at temporal and spatial scales greater than can be investigated by conventional experimentation but can be elucidated in historical records (Wasson and Clark, 1985; Davis, 1989; Foster, 1992). The nature and periodicity of historical disturbance regimes, and the responses of ecosystems to those regimes, can provide information on 'natural' levels of variation. Such information is required for formulation of management directives aimed at conserving natural ecosystems that are dependent on continual disturbance and flux. Such information can also contribute to the defining of the limits of reversible variation and thresholds for irreversible change. Because ecosystems are inherently dynamic they may be at any particular stage of successional and ecosystem development at any one point in time. It is of utmost importance to modern ecological studies to know the current developmental stage of an ecosystem or vegetation type before comparative or quantitative ecological studies can be undertaken (Likens, 1989; Foster *et al.*, 1998). The description of the nature of former environments provides baselines in which to ground debate, or direct conservation strategies, on what we might aim to return to in highly modified environments in need of restoration.

Environmental history of necessity involves multiple disciplines and the adoption of a variety of methods of inquiry. The reconstruction of the elements and functioning of past landscapes before human modification is an essential starting point for the construction of an environmental history. Ecology, in examining the interaction between abiotic and biotic (communities or ecosystems) entities, provides the most help in this regard. Plant ecology is of particular use because vegetation plays a pivotal role in whole ecosystem function, and therefore by proxy integrated histories of environmental change can be deduced from the history of vegetation. Throughout human history societies have had a strong dependency on vegetation resources and so vegetation can provide a backdrop for the confluence of human and natural histories. This notion was encapsulated by Worster (1988) when he wrote 'Where people and plants come together more issues in environmental history cluster than anywhere else. Take away plant ecology and environmental history loses its first step'.

Multi-discipline or multi-source approaches to environmental history are also required to encompass the full temporal and spatial range of scales that significant human impacts can occur over (Batterbury and Bebbington, 1999), and the antecedent histories that contextualise them. Delcourt and Delcourt (1988) defined a hierarchy of four operational time-space domains which focus on biotic responses to environmental changes as they are expressed in resolvable vegetation patterns; the micro-, meso-, macro- and mega-scaled domains. Each level in the hierarchy is bounded by the next higher level, but each encompasses ecological patterns and processes occurring at all lower levels. The environmental disturbance regimes, biotic responses and vegetation patterns operational within those domains are shown in Figure 1. 1. The *micro-scale* domain occupies time spans from 1-500 years and spatial areas of 1 metre to 100 hectares. The disturbance regimes driving change at this scale include natural disturbance events such as fires and wind damage and human activities. The *meso-scale* domain covers a temporal span from 500-10000 years, and spatial areas form 1km^2 - 10^4 km^2 which encompasses events during the span of an interglacial interval and areas ranging from watersheds of most second order streams to mountain ranges up to 1^0 latitude x 1^0 longitude. At the lower end of the scale prevailing disturbance regimes, climatic fluctuation and human land uses affect change to vegetation formations. The *macro-scale* domain covers a temporal span from 10000-1 million yrs and areas from 10^4-10^6 km^2, which spans one to many glacial-interglacial cycles and encompasses an area of a physiographic province to a subcontinent. The *mega-scale* domain encompasses regional and global scale changes to climate regimes affect vegetation changes at this scale. The mega-scale domain is operational from a million years before present to the late

Proterozoic era and over areas greater than 10^{12} m^2. At this scale plate tectonics drive global climate change and evolution of the biota.

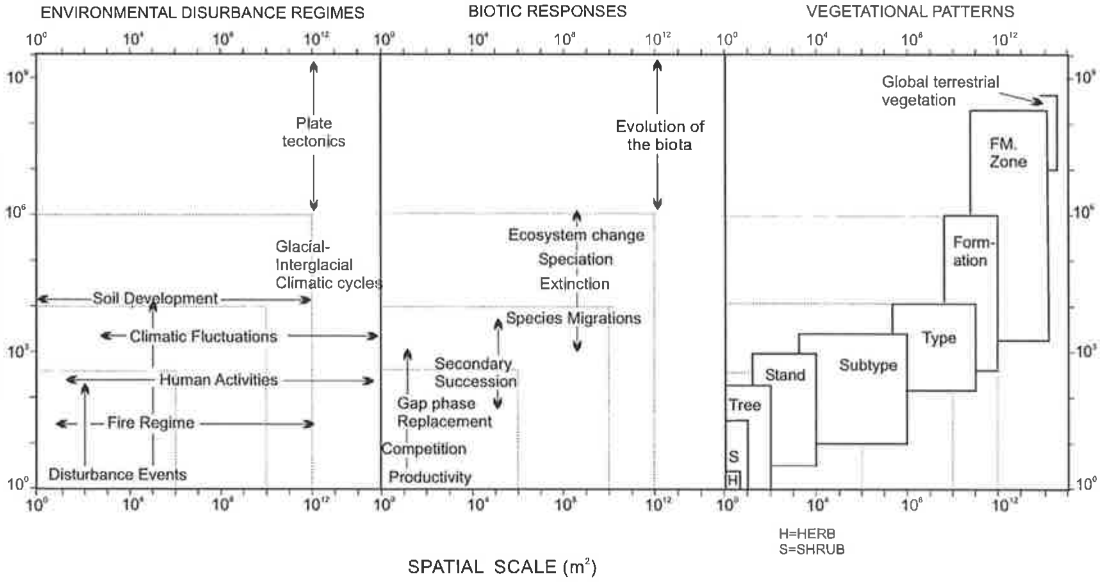

Figure 1. 1 The temporal and spatial domains in which environmental disturbance regimes, biotic responses and vegetation patterns operate. Figure adapted from Decourt and Delcourt (1988).

Various disciplines consider vegetation dynamics and they resolve patterns of environmental change at different temporal and spatial scales. The disciplines are (1) ecology, in the form of 'long term' monitoring, observation and experiment (Likens, 1989); (2) historical ecology, using fine resolution palaeoecological techniques and other forms of historical data (Davis *et al.,* 1993); and (3) traditional palaeoecology which uses long-term environmental records. The temporal scales over which they span are indicated in Figure 1. 2.

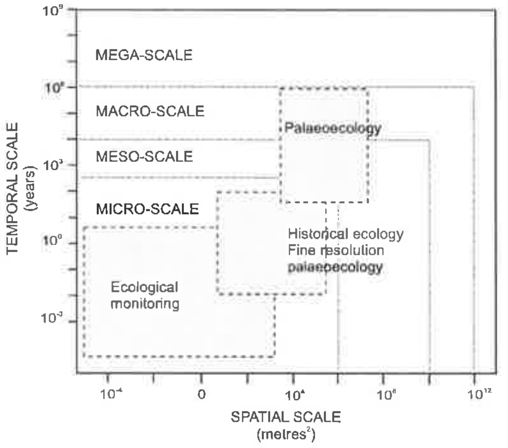

Figure 1. 2 The temporal and spatial scales over which methods of study of vegetation dynamics usually operate. The space-time domains are those defined by Delcourt and Delcourt (1988) and described in this chapter.

Studies in traditional ecology are largely restricted to the micro-scale domain, historical ecology the meso-scale domain and traditional palaeoecology the macro-scale domain. The time span covered by greatest human environmental impact is on a time scale of years to centuries, which is the time domain most encompassed by studies in historical ecology. However if the aim is to contextualise recent human disturbances with longer term human and climate driven changes then the meso-scale time domain is of interest and palaeoecological methods of study need to be adopted. There is little overlap between the methods of study and the space- time domains they occupy. Historical ecology is poised to possibly complete the continuum from ecological experiment, observation and monitoring to long term palaeoecology. The adoption of methodologies which provide this continuum is required through the undertaking of multidisciplinary investigations, which combine information from different data sources at different temporal scales.

1.2.1 Sources of evidence of historical vegetation and change

1.2.1.1 Environmental evidence

Wetland sedimentary basins or lakes can provide uninterrupted records of geologically recent sediments, which can provide microfossil and microcharcoal remains from the surrounding catchment or region (Birks and Birks, 1980). Preserved pollen can be used to recreate past vegetation patterns and be used as a proxy for reconstruction of past climates (Kershaw, 1988) and charcoal can be used to reconstruct fire histories (Patterson *et al.,* 1987). The nature of sediments themselves is also useful for environmental reconstruction.

The main requirements for palaeoecological studies of environmental history are (1) environmental contexts where evidence survives, (2) dating techniques, (3) extraction and analytical techniques and theoretical frameworks for the interpretation, explanation and reconstruction of the past (Birks and Birks, 1980; Oldfield and Clark, 1990). Environmental records potentially provide temporally continuous and long term records of vegetation patterns at a particular site. They provide a quantitative or semi-quantitative reconstruction of vegetation patterns which is generally interpretable in scientific terms (Oldfield and Clark, 1990). Their application in the reconstruction of recent vegetation dynamics is dependant on the presence of undisturbed regional deposition sites and the ability to date and interpret evidence in relation to the vegetation pattern that produced it. Where prehistoric human technology has incorporated deliberate and systematic environmental manipulation, then palaeoenvironmental records become an integral part of the record of human occupation. They have assisted the artefactual record in archeological studies in answering question of human distribution, environmental resource utilisation and impacts of utilisation (Head, 1988).

Most palaeoecological studies have considered macro-scale plant biogeographic reconstructions but there has been recent concentration on the deciphering of recent vegetation histories and community dynamics, operating over shorter spatial time frames and at finer scales of ecological classification and spatial resolution (Ritchie, 1995; Davis *et al.*, 1993; Foster and Zebryk, 1993; Bradshaw and Miller, 1988). These finer scale studies encompass the time-space domain of historical ecology. In order to achieve this palaeoecological methods have had to be refined in their analysis of temporal resolution, taxonomic resolution of pollen types (Birks, 1996), spatial scale of analysis (Prentice, 1995; Calcote, 1995; Sugita, 1994), improving chronologies, and the development of appropriate statistical techniques to interpret fine resolution studies (Green and Dolman, 1988). Most fine resolution palaeoecological studies have been carried out in North American and Europe. The diversity of the Australian native flora, combined with the fact that many of the dominant taxa have indistinguishable pollen morphologies, possibly explain the relative paucity of the use of these methods in the Australian environment.

1.2.1.2 Documentary evidence

Documentary evidence, of various types, can be used to inform of historical vegetation patterns through the historical period (Butlin and Roberts, 1996;) (which is the time since European exploration and settlement in Australia). Documentary records are generally specific for time and location. The information they provide is usually temporally discontinuous. They are generally qualitative or descriptive and so can be poorly related to scientific constructs (Oldfield and Clark, 1990). In cases, they may directly record human effects and consequences. Early land survey records and other historical maps have provided useful evidence for pre-European vegetation pattern in regions of Australia (Jeans, 1978; Smith, 1988; Fensham, 1989; Lunt 1997a; Fensham and Fairfax, 1997). Accounts by early explorers and settlers, local histories, regional natural history journals, land use reports, early photographs and paintings have also provided information on vegetation pattern in Australia (Fensham, 1989; Lunt, 1997a, 1998; Croft, *et al.,* 1997). Challenges to their use, in reconstruction of former environments and assessment of change, include the interpretation of qualitative historical descriptions and the spatial extension of site-based records.

1.2.1.3 Contemporary evidence

The current distribution and composition of remnant vegetation can provide evidence for recent historic vegetation pattern if vegetation has not comprehensively changed since the historical time of interest. Its successful use is dependant upon the extent and distribution of remnant vegetation in a region and its degree of modification since the time under investigation. It has been used to reconstruct pre-European vegetation pattern in highly altered regions in Australia, usually in combination with other historical sources (Croft *et al.*, 1997; Fensham, 1989). In some instances in Australia contemporary evidence has provided the most detailed and easily interpreted information on both structure and floristics of historical patterns (Fensham and Fairfax 1997). The use of remnant vegetation patterns to reconstruct historical patterns has relied on the subjective extrapolation of vegetation and environment relationships at the site of remnant vegetation to sites without vegetation.

1.2.1.4 Combining methodologies

The use of multiple data sources offers a perspective on the past which is potentially richer than reliance on any single one. The omissions or distortions in one source may be counterbalanced by the information from another. Combinatorial approaches also allow historical investigations to span different time-space domains. Different lines of evidence have different properties, strengths and weaknesses. For example environmental records usually form a continuous time series but not always at a high temporal resolution. Data from historical records have a high temporal resolution but are often discontinuous or semi-continuous in nature. A basic requirement for multidisciplinary work is the need comparability between different data sources, in space as well as through time. Whether information from different sources are commensurable is a key issue to their integration. Histories from multiple source provide the means to construct the most accurate history possible, with different lines potentially acting as checks on others.

Problems with combining multidisciplinary sources include matching continuous with discontinuous time series, the dating of proxy data, uneven taxonomic resolution, biased representation, and the frequent lack of locational correspondence between different data sets (Butlin and Roberts, 1996).

1.3 Environmental change in Australia

The following is a general discussion of the changes that have occurred to Australian forests and woodlands from the late Quaternary, through the Holocene and to European settlement. It focuses on the history of temperate southern Australia. It is presented as a regional and temporal backdrop of environmental changes and dynamics to those investigated in this study.

Current biogeographic boundaries of the Australian flora were in place by the mid-Pleistocene but their boundaries have fluctuated in response to cycles in temperature and aridity of the glacial and interglacial cycles (Hope and Kirkpatrick, 1988). In general, vegetation patterns in eastern-Australia varied during the Pleistocene from *Poaceae-Asteraceae* steppes of the glacial maxima, with *Eucalyptus* and *Allocasuarineaceae* existing in refugia only, to *Eucalyptus* and *Allocasuarina* woodlands and forests of the warm interglacial periods (Singh and Geissler, 1985; Kershaw *et al.,* 1991; D'Costa *et al.,* 1989; Kershaw, 1995). It is thought that during cold phases dominant tree species were restricted to refugia and when climate ameliorated they re-expanded their ranges from these refugia (Hope and Kirkpatrick, 1988; Kershaw, 1995), which is in contrast to the migrational responses to glaciation shown by Northern Hemisphere flora. It has been suggested that the lack of extensive glaciation in Australia has produced, or allowed the survival of, a greater range of floristic elements in the Australian vegetation. Within the wide range of inter-specific variation of the Australian flora much intra-specific variation is present. This variation has been viewed as increasing the adaptability of particular species to different environments and environmental change. This is particularly true of species in southern parts of Australia where species have wide ecological ranges or are buffered against environmental change by having large genetic pools (Hope, 1994; Kershaw, 1981).

There is reliable evidence that Aboriginal people have been present in Australian for at least 40000 years BP (Mulvaney and Kamminga, 1999). While it has been well established that Aborigines purposefully burned the landscape (Jones, 1969; Hallam, 1975) the effects on Australian landscape remain a matter of contention (Bowman, 1998). It has been speculated that a rise in sclerophyllous over rainforest vegetation resulted from the first impact of Aborigines (Kershaw, 1986), their impact on the vegetation being largely to accelerate existing trends rather than causing wholesale landscape change (Kershaw *et al.,* in press). More certain is that Aboriginal firing did act as a local disturbance agent and its impacts varied depending on vegetation type and occupancy history. Aboriginal-effected changes include the shift from low densities to high densities of trees in Eucalypt forests (Ellis, 1985) the shift of vegetation boundaries of fire sensitive species (Ash, 1988) and the demography of certain trees (Bowman and Kirkpatrick, 1984). Long term palaeoecological studies have shown that Australian woodlands and forests have been dynamic ecosystems over the Pleistocene, but overall, have been remarkably resilient to significant climate changes and Aboriginal land use.

The Holocene was a time of relative climatic and vegetation stability in comparison to the Pleistocene (Bowler *et al.*, 1976). However southeastern Australian vegetation has been shown to be dynamic throughout this period in response to smaller scale climatic variations and possibly widespread increases in Aboriginal populations in the mid to late Holocene (Lourandos, 1997). At about 10000 years BP temperature and precipitation levels are believed to be similar to present day values and vegetation had its greatest change in the last 18000 years with *Eucalyptus* woodland expanding to forest in the highlands of southeastern Australia and *Allocasuarina* forest replacing grasslands. Between 8000 and 4000 years BP precipitation and temperature were at present day values or higher and vegetation increased in density with an increase in *Eucalyptus* and *Allocasuarinaceae*. The period around 4000 years BP was the driest of the Holocene with temperatures lower than today and experienced greater climatic variability. *Eucalyptus* woodlands expanded at this time, possibly in response to increased climate fluctuation and Aboriginal burning practices (Kershaw, 1986).

Over the 150-200 years since European settlement in Australia the rate of ecosystem change has accelerated and the landscape of much of Australia has been transformed (Adamson and Fox, 1982;

Rolls, 1985; Dovers, 1994; Heathcoate, 1994). The impact on vegetation has not been homogenous across the continent, but patterns of landuse, and resultant impact, are closely related to the climatic and topographic zones in Australia. The temperate regions of south eastern Australia and the Mediterranean-climate regions of South Australia and southern-Western Australia have been heavily modified for agriculture (Hobbs and Hopkins, 1990). These regions have experienced extensive clearance of native vegetation cover, soil loss, soil salinity and acidification problems. Clearance of native vegetation reduces the continuous natural range of ecosystems as well as the diversity of habitats and ecological processes occurring within them. Species diversity is negatively affected by vegetation clearance and floral and faunal extinctions have occurrred and the potential for further extinctions in agricultural regions is high (Leigh *et al.*, 1984). Remaining vegetation usually exists as isolated patches surrounded by agricultural matrices creating fragmented landscapes (Williams and Goodwins, 1987). Native vegetation has also been impacted since European settlement by timber collection in native forests, grazing by ungulates, mining, the invasion of non native plant and animal species and the alteration of fire regimes (Hobbs and Hopkins, 1990). With the loss of floral species, and the faunal components of these ecosystems, changes to nutrient and energy cycling have resulted (Saunders *et al.,* 1991). Pollination and seed dispersal has also been altered with bird and mammal decline (Saunders *et al.,* 1991). Seedling establishment and nutrient cycling is affected with loss of burrowing or mound building animals. While many species have been lost, others have invaded (Kloot, 1983). The degree of invasion depends on vegetation; shrub communities have been relatively resistant to invasion while woodland communities have generally been more susceptible (Cale and Hobbs 1991). Natural and Aboriginal disturbance regimes have been radically changed since settlement and have impacted vegetation (Hobbs and Huenneke, 1995).

1.4 Research strategy

In order to construct an environmental history of the Fleurieu Peninsula through the Holocene, with respect to analysing recent European landscape transformation, palaeoecological, historical documentary and contemporary evidence revealing historical vegetation are used. Multiple sources are adopted to attain the most complete and accurate history possible, and one which spans the entire temporal period of interest. Lines of evidence are, where possible, analysed independently so that comparable data may be used as a valid checks on the accuracy of another, before being integrated along a temporal course. Where possible, techniques that expand the opportunity of comparison of different sources are investigated. The temporal period classified by each evidence type and the spatial domains they occupy are indicated in Figure 1. 3.

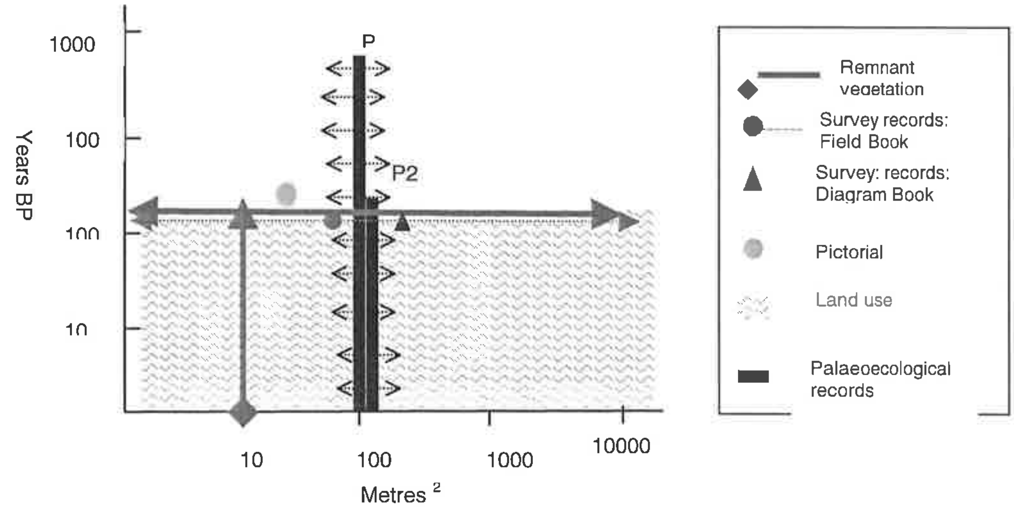

Figure 1. 3 The temporal and spatial scales over which historical data used in this study occupy and or will be extended to.

The temporal reconstruction of environments at, or near to European arrival, is analysed to provide a baseline from which to assess the type and magnitude of post-European changes. To do this relationships between environmental gradients and (1) documented historical records of vegetation pattern and (2) remnant vegetation are investigated. The potential of these relationships, when extended into geographic space, to represent historical vegetation distribution is analysed. The potential of pollen analyses to represent present day vegetation heterogeneity is analysed through pollen distribution and morphology studies. Fossil pollen and charcoal is analysed through the European period. Investigation of vegetation dynamics prior to European settlement is then considered by the analysis of a palaeoecological record extending through the Holocene. Historical data is then combined to reconstruct vegetation pattern at the time of European settlement in the region, assess changes to that pattern since settlement, and compare these patterns of change to pre-European vegetation changes. The analytical framework adopted in this study is graphically represented in Figure 1. 4. The objectives of the thesis are:

1. To investigate the spatial, temporal and classificatory resolution with which documentary records of early European vegetation pattern, made by surveyors, explorers and early settlers, resolve historical vegetation. To do this records are collated, interpreted and cartographically represented.
2. To characterise the environmental variables of the Fleurieu Peninsula possibly effecting, or acting as surrogates for variables that effect, vegetation pattern in a digital and spatially continuous form using digital terrain and climate modelling techniques.
3. To investigate the relationships between historical vegetation records and environment using quantitative modelling techniques and spatially extend relationships to areas unclassified by historical observation to generate potential historical vegetation maps.

4. To investigate the relationships between remnant vegetation and environment using quantitative modelling techniques and spatially extend relationships to areas unclassified by historical observation to generate potential historical vegetation maps.
5. To examine the relationship between modern pollen deposition and present day vegetation of the Fleurieu Peninsula to assist in the interpretation of pollen diagrams. Investigate the morphology of pollen of the dominant Myrtaceae species, the dominant members of all extant vegetation communities in the Fleurieu Peninsula in order to resolve possible changes in Myrtaceae composition in pollen diagrams.
6. To investigate the dynamics of vegetation through the European period by the examination of pollen and charcoal records from three sedimentary sites.
7. To investigate the dynamics of sclerophyll vegetation in the region through the Holocene from a single sedimentary site.
8. To examine where in space and time individual data sources concur. At points of contact compare the lines of evidence. Assess the accuracy, strengths and limitation of each line of evidence in its ability to represent historical vegetation pattern and change and resolve the causes of change.
9. To integrate evidence sources to interpret the nature, causes and effects of post-European changes to vegetation in the region and compare those changes with longer term Holocene vegetation dynamics.

The study is presented in this thesis as follows. Chapter two describes the biotic and abiotic environment of the Fleurieu Peninsula and discusses its Aboriginal and European settlement and land use histories. Documentary records are analysed and mapped in chapter three. The modelling of environmental surfaces is undertaken and used to build potential historical vegetation models with documentary records in chapter four. Potential historical vegetation models are built with remnant vegetation records in chapter five. Chapter six presents a survey of modern pollen rain from the remnant vegetation communities in the Fleurieu Peninsula. Palaeoecological records from the European period are examined in chapter seven. Holocene palaeoecological records are examined in chapter eight. Chapter nine and ten evaluate and integrate historical data sources. The nature of European impact in the Fleurieu Peninsula is discussed.

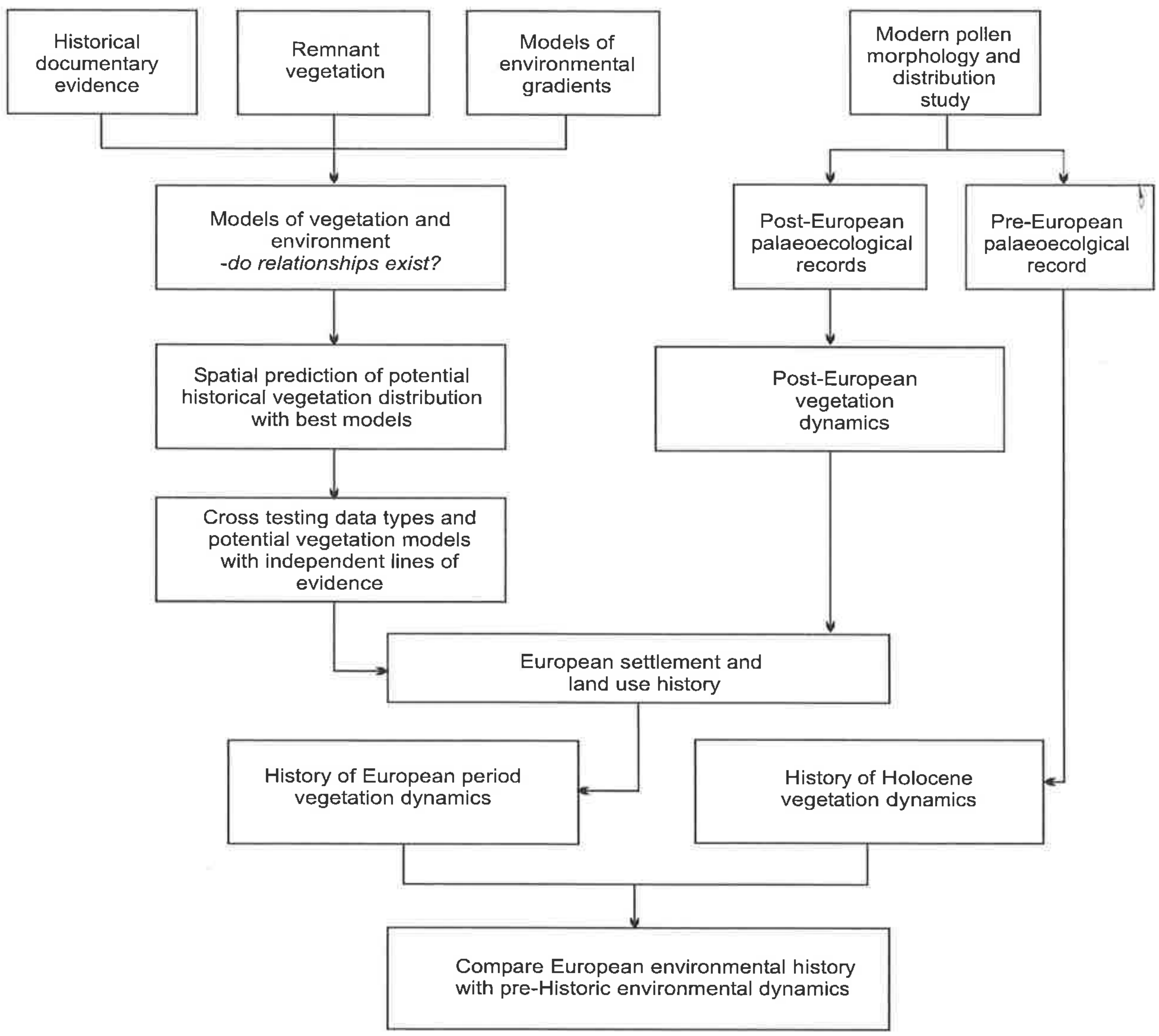

Figure 1. 4 Analytical framework for constructing vegetation history of the Fleurieu Peninsula

CHAPTER 2

2. The Fleurieu Peninsula

The Fleurieu Peninsula is the portion of South Australia ($35^{0}15'$-$35^{0}45$ S, 137^{0}-139^{0}E), lying to the south of the city of Adelaide (Figure 2. 1). The Peninsula extends from Cape Jervis in the west, to Lake Alexandrina in the east. The Great Australian Bight defines its southern boundary and the Gulf of St. Vincent the western part of its northern boundary. The eastern part of the Fleurieu Peninsula's northern limits is diffuse and thus have been variously defined using cadastral boundaries and geographic features. Definitions using geographic features define the boundary with the topography of the southern portion of the Mount Lofty Ranges (Lamprey and Mitchell, 1979) and those using cadastre with the northern boundaries of the Hundreds of Myponga, Nangkita and eastern portion of the Hundred of Goolwa (Williams and Goodwins, 1987). The region encompasses an area of approximately 155000 ha, being about 40 km in length and 20 km wide and lies with in the Mount Lofty Block Environmental Province (Laut, 1977). This chapter presents a review of studies of the physical and biotic environments in the Fleurieu Peninsula. It also provides a review of human pre-history and of European settlement and agricultural history in the region.

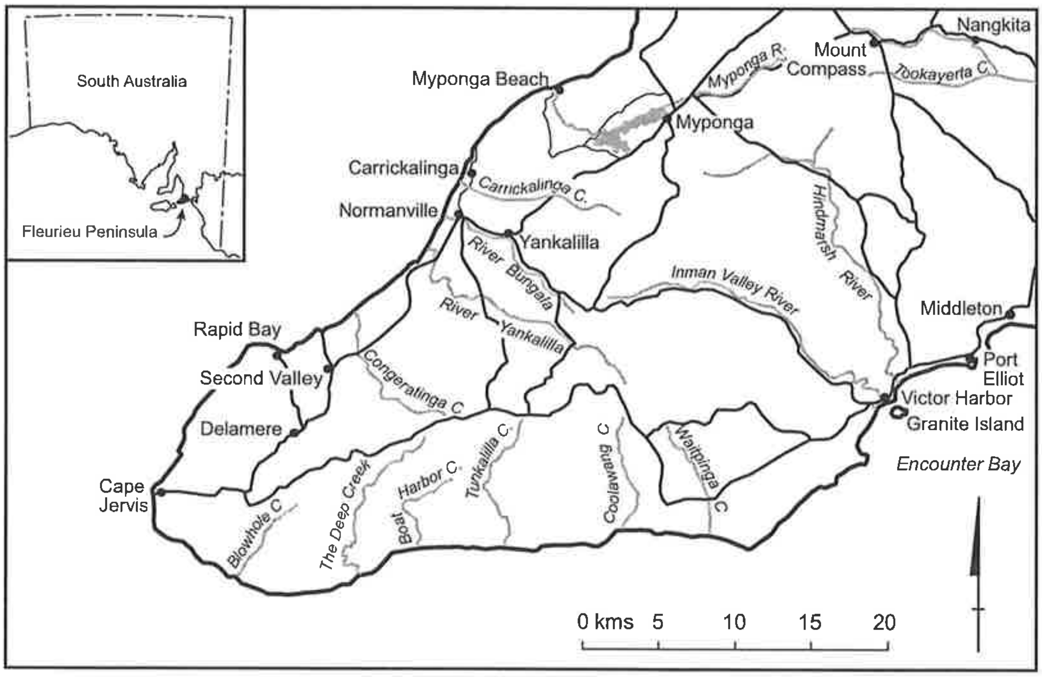

Figure 2. 1 Location of the Fleurieu Peninsula in South Australia, Australia

2.1 Topography

The broad physiographic feature of the Fleurieu Peninsula is a dissected ridge and vale topography imparted by the north-south stretching Mount Lofty Ranges. The uplands have a near level lateritecapped summit surface which ranges in elevation from 200 to 412 m. They are drained by several major streams; the Hindmarsh, Inman and Yankalilla Rivers and numerous intermittent creeks and tributaries (Figure 2. 2).

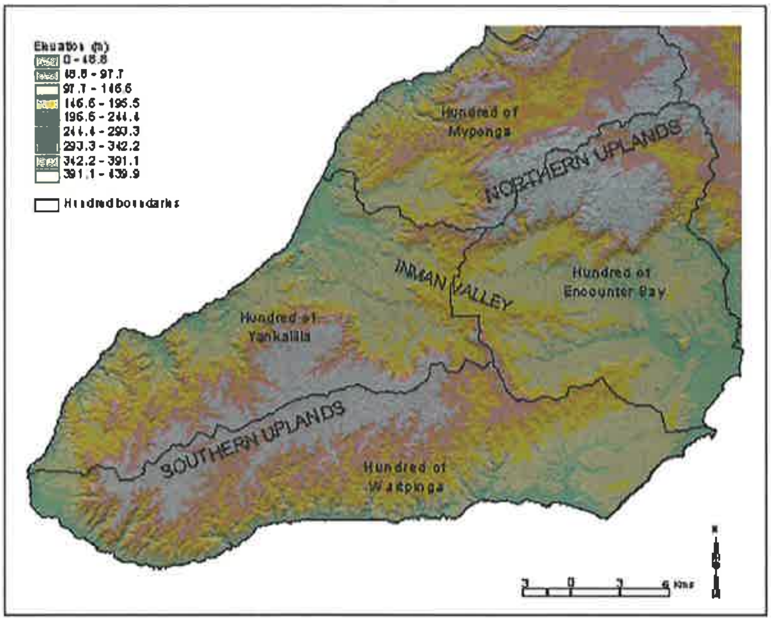

Figure 2. 2 Study region showing elevation and major physiographic features.

The Inman River has produced a broad valley that runs east west through the Peninsula and divides the region into two upland areas. The western and southern escarpments of the uplands are steep sloped with most of the settlement along the river flats. The eastern slopes are less steep than the western and gradually merge in to the eastern flat country of the Murray River region. The upland regions are surrounded by bedrock benches, which have resulted from the removal of weathered material from the summit surface (Bourman, 1973). Much of the coastline is characterised by steep cliffs developed on the resistant Pre-Cambrian and Cambrian bedrock. The cliffs are interspersed by coves and short beaches, backed by ancient dunes (Lamprey and Mitchell, 1979).

2.2 Geology

The geological history of the Fleurieu Peninsula is very long and varied. This is reflected in the relatively complex surface geology in the region (Lamprey and Mitchell, 1979). The Peninsula is underlain by a series of folded sediments and meta-sediments, termed the Barossa Complex, of Archaean to early Cambrian origin (1800 Ma). These rocks are predominantly schists, gneisses and pegmatites. They occur as outcrops at Yankalilla, Houghton and south of Normanville. Late Pre-Cambrian (800 Ma) conglomerates, limestones, shales and sandstones, which in places have been metamorphosed to form marble, schist and quartzite were overlain on the Barossa Complex. These rocks, which were deposited within shallow seas of the Adelaide geosyncline, form the Adelaide System rocks of upper Proterozoic age. This sequence is well exposed especially on the western side of the Ranges (Daily *et al.*, 1976). The eastern side of the ranges differs from the western because of an underlying sequence of metamorphosed mid-Cambrian sedimentary rocks termed the Kanmantoo Group. These rocks constitute the basement rock for much of the Peninsula. The metasediments of this group have undergone several stages of folding forming anticlinal and synclinal structures. Unlike the limestones and shales of the older Normanville group these sediments were mainly impure, felspar rich sandstones and silt stones. The resistance of these peaks to weathering is demonstrated by the existence of Wilson Hill (232 m), Mount Desert (294 m), Crozier Hill (158 m), Kerby Hill (281 m), Tower of Babel (315 m), Strangeways Hill (315 m) and Inman Hill (271 m). Igneous intrusions are seen in restricted areas of the Fleurieu Peninsula. During the Delamarian-Orogenty (490 Ma) granite intruded the Kanmantoo group (Milnes *et al.*, 1977) and is seen in the Encounter Bay region. Younger igneous dykes have been recognised in several other locations (Lamprey and Mitchell, 1979). Late Paleozoic (Permian) glaciene sediments were deposited extensively over Fleurieu Peninsula (Campana, Wilson and Whittle, 1953; Bourman, 1973; Daily *et al.*, 1976). Sands, clays and boulder beds known as Cape Jervis beds were deposited over the southern peninsula in irregular thickness as the surface glaciers receded. Fluvioglacial deposits are also present, resulting from the modification and redistribution of the glacial sediments by rivers and streams. Glacial pavements are exposed in the Inman Valley at Glacier Rock and as a 'roche moutonnee' called Stone Hill near Inman Valley and are the oldest landforms of the peninsula. After the Permian glaciation there is no known sedimentary record in the Adelaide region for some 200 million years, but it is believed that there was a period of extensive erosion which produced a flat peneplained landscape. Remnants of this landscape are evident as a Mesozoic lateritic mantle covering the summit surface of the central high plain from Mount Compass to Spring Mount. The mantle is characterised by great depths of weathering and secondary iron accumulations. Various other post Permian sediments are seen in the Peninsula - Cainozoic fossiliferous limestone resting on the Kanmantoo Group metasediments of the Waitpinga Creek and bryozoal limestones in the upper Hindmarsh and Myponga Valleys (Daily *et al.*, 1976). The numerous climate changes and sea level fluctuations which characterised the Quaternary resulted in raised beaches near Cape Jervis and coastal dunes which occur in intervals from Normanville to Middleton, and back shore deposits, some capped with calcrete, river alluvia, high level alluvial material and calcareous aeolianite found at Cape Jervis.

2.3 Soils

Early consideration of the soils of the Fleurieu Peninsula and Adelaide region identified the presence of two soil zones, the lateritic podsols of the hills and the red brown earths of the plains (Stephens, 1961). However subsequent finer scale soil mapping reveals that the region is characterised by a complex

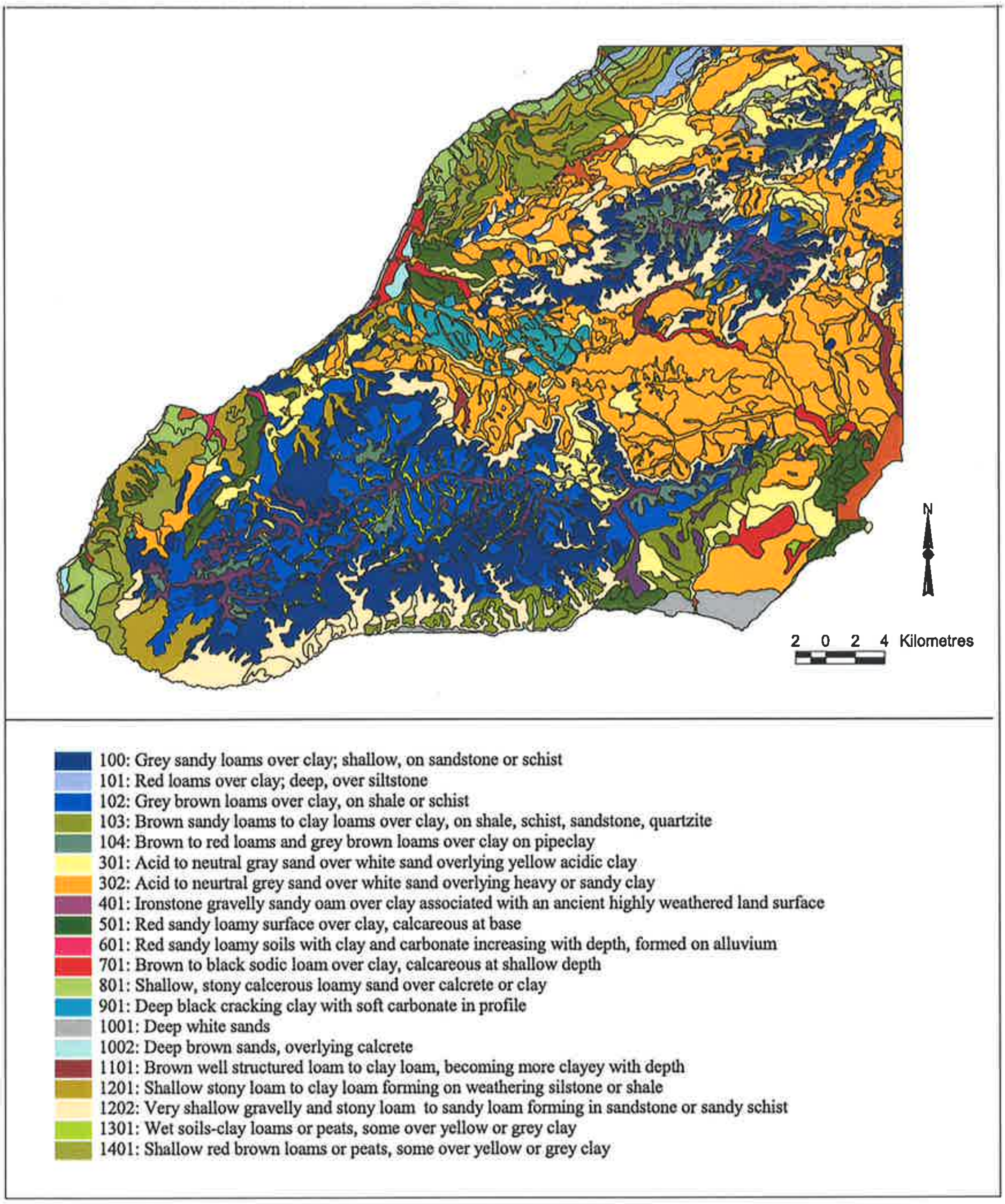

Figure 2. 3 Soils of the study region. (PIRSA Land and Information, 1999)

mosaic of diverse soil types (Northcote 1977, Maschmedt, 1999). Important or dominant soil units are the extensive areas of laterites (Ironstone gravelly sands to loams with thick clayey subsoils), which occur on the dissected tablelands south west of Mount Compass and on the Range Road highlands. Widespread on the slopes surrounding the remnant lateritic mantle are quartz rich soils. These soils are derived from Cambrian metasediments and are shallow to moderately deep acid-neutral loamy sands to clay loams with red, brown or black clayey subsoils. Other important soil units are developed on the glacial sands and clay of the Inman Valley system. These soils are acid-neutral sands over clayey subsoils. They are also found in the Mt Compass region and between Cape Jervis and Second Valley.

The coastal hills are characterised by felspar rich finer grained soils. The clays of the coastal plains near Cape Jervis have high clay contents. They are red to dark red soils which clay content increases with depth. The alluvial flats of watercourses and low-lying waterlogged areas in the Mount Compass region contain peat soils. Shallow stony soils occur on the steep slopes in the Deep Creek region, and cliffs between both Cape Jervis and Second Valley and Myponga and Yankalilla.

Primary Industries and Resources South Australia, Land and Information (1999) produced a generalised soil map of the region. The map showed 14 principle soil profile forms. Some of the principle profile forms exhibit a range of textural soil types (Figure 2. 3).

2.4 Climate

The Fleurieu Peninsula has a well-defined Mediterranean climate, with cool wet winters and hot dry summers. The regional topography is largely responsible for what is an anomalous climate when compared to those of otherwise similar locations in South Australia. As well as regional topography influencing climate of the region, latitude and exposure to easterly moving atmospheric pressure systems of highs in summer and lows in winter explain regional and seasonal climate patterns (Schwerdtfeger, 1976).

Mean annual rainfall in the Fleurieu Peninsula ranges from 425 mm on the coast at Cape Jervis to 950 mm west of Parawa. The region experiences strongly polarised seasonal rainfall with most falling in the winter months as a result of the passage of low pressure systems which generally move in an easterly direction south of the region (Robertson, 1975). Spatial patterns of precipitation are influenced by regional topography. Most significantly, the ranges induce orographic rainfall during the winter months (Schwerdtfeger, 1976), thus higher precipitation values are found in the ranges than the plains. Westerly winds associated with the low pressure systems in the south also contribute to the highlands receiving greater rainfall than the plains and coastal areas (Robertson, 1975). Precipitation values on the eastern side of the ranges are lower than the western plains and highlands, the region experiencing a rain shadow effect. During summer prolonged dry periods of up to two months can occur in the region. Rare thunderstorms are responsible for any precipitation during January and February and they are more frequent over the eastern plains than the ranges (Schwerdtfeger, 1976). Evaporation is highest during this period and the spasmodic rain, though occasionally heavy, is usually rapidly returned to the atmosphere.

Mean daily maximum temperatures in the Fleurieu Peninsula vary from around 12ºC to 14ºC in July to 24ºC to 27ºC in the summer months (Robertson, 1975). Mean daily minimum temperatures vary from around 4ºC to 6ºC in winter to a maximum of 12ºC to 14ºC. In the summer months the region falls into two distinct sections with regard to temperature. The portion of the Peninsula south of Inman Valley, Yankalilla and Port Elliot is significantly cooler than northern and eastern regions, due to its proximity to the coast. The same spatial pattern of temperature distribution is not so clearly defined in winter months. On average, coastal regions experience temperatures several degrees higher than those experienced on the flats and hill regions, because night radiation cooling is much more marked inland. Frosts are more commonly experienced in the winter months in the inland regions than the coastal areas (Robertson, 1975).

Average relative humidity varies from 45-55% in the summer months to 66-84% in the winter months. There is little variation in the spatial distribution of humidity or cloudiness across the region (Robertson, 1975). Wind strength is variable in summer with coastal and exposed areas experiencing sea breezes. Coastal and eastern hills face slopes and crests are subject to strong winds during the winter and spring; these are associated with low pressure systems of Southern Ocean origin.

2.5 Vegetation

The Fleurieu Peninsula is part of the Southern Lofty Botanical Region in the Flora of South Australia (Jessop and Toelken, 1986). It is a floristically diverse region, containing some 2000 native and naturalized alien species (Dashorst and Jessop, 1990). The steep habitat gradient imposed by the Mount Lofty Ranges is responsible for the region being the most floristically diverse in South Australia (Lang and Kraehenbeul, 1987; Sparrow, 1991).

Specht (1972) defined two landsystems in the humid regions of South Australia; the 'savannah' and the 'sclerophyll'. Both are present in the Fleurieu Peninsula. The savannah systems support open grassy woodlands carrying predominantly *Eucalyptus camaldulensis, E. leucoxylon E. viminalis* and *Allocasuarina verticillata* over herbaceous understoreys commonly composed of species in the families of Poaceae and Cyperaceae, and occasional scattered low shrubs. The sclerophyll systems support *E. obliqua* open forests and *E. obliqua, E. baxteri, E. fasciculosa,* and *E. cosmophylla*, low to very low woodlands. They are united by their understoreys of sclerophyllous under-shrubs, dominated by genera in the families of Epacridaceae, Myrtaceae, Fabaceae and Xanthorrhoeaceae. Boomsma (1948) conducted the only major ecological survey in the region prior to widespread native vegetation removal, which occurred from the 1950s. He mapped the vegetation at a scale of 2 miles to an inch (Figure 2. 4) but commented that vegetation pattern in the region varied at a considerably smaller scale. The study described the distribution of 10 vegetation associations[1], and more than 20 'forest types' within these associations (Table 2. 1).

Later surveys of the vegetation of the region concur with Boomsma's observation that at small scales there is much heterogeneity of vegetation types in the region (Lamprey and Mitchell, 1979; Mitchell, 1983; Williams and Goodwins, 1987). Habitat factors controlling vegetation pattern in the Fleurieu

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[1] Boomsma used the classification scheme as proposed by Wood (1937). An 'association' is defined as any natural group occurring in similar habitats and a modification of only the tree stratum of an association by a small change in environment is termed a 'type' of the association.

Peninsula were considered by Boomsma (1948) and the distribution of *Eucalyptus* species in the Mount Lofty Ranges by Specht and Perry (1948).

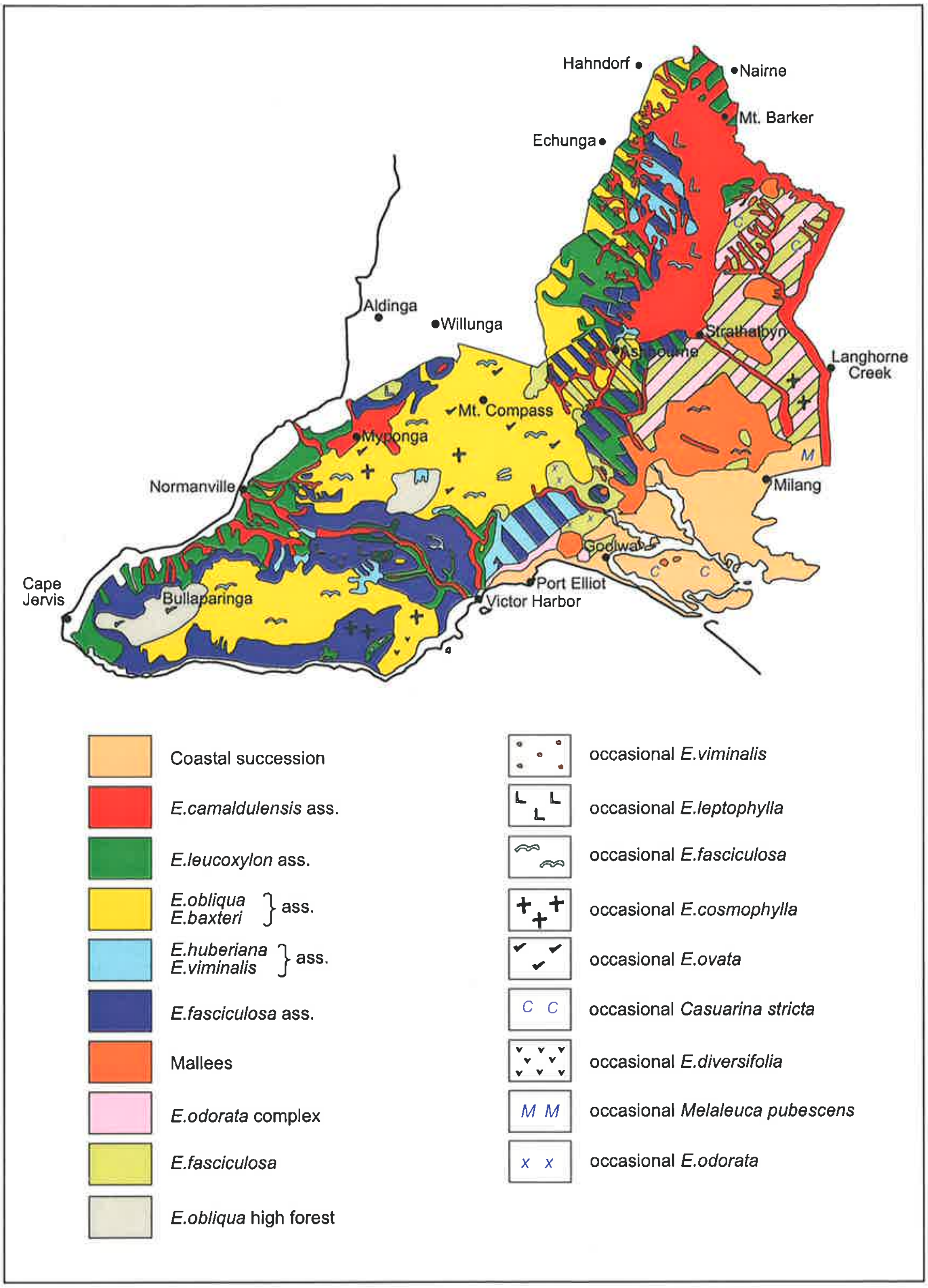

Figure 2. 4 Distribution of plant communities on the Fleurieu Peninsula as mapped by Boomsma (1953). *Casuarina stricta=Allocasuarina verticillata, Melaleuca pubescens=M.lanceolata.*

Table 2. 1 Associations and forest types occurring within them described by Boomsma, 1948.

Association	Forest type	Formation/understorey
E. obliqua	*E. obliqua*	savannah woodland/ medium sclerophyll forest/ high sclerophyll forest/ sclerophyll scrub
	E. obliqua / E. baxteri	sclerophyll scrub
	E. obliqua /E. fasciculosa	sclerophyll scrub
	E. obliqua /E. cosmophylla	sclerophyll scrub
	E. obliqua / E. baxteri- E. anceps	sclerophyll scrub
	E. obliqua / E. ovata	sclerophyll understorey
	E. obliqua / E. viminalis	savannah woodland – open understorey
	E. obliqua / E. rubida	savannah woodland -- open understorey
E. baxteri	*E. baxteri*	sclerophyll scrub
	E. baxteri/ /E. diversifolia / E. fasciculosa	sclerophyll scrub
	E. baxteri/ E. cosmophylla	sclerophyll scrub
E. camaldulensis	*E. camaldulensis*	savannah woodland
	E. camaldulensis /E. ovata	waterlogging tolerant species
	E. camaldulensis /E. ovata / E. viminalis	savannah woodland
	E. camaldulensis /E. viminalis	savannah woodland
	E. camaldulensis /E. leucoxylon	savannah woodland but grades to sclerophyll understorey on poor soils
	E. camaldulensis/ Allocasuarina muelleriana	savannah woodland
E. fasciculosa	*E. fasciculosa*	both savannah woodland and sclerophyll scrub
	E. fasciculosa /E. baxteri /E. cosmophylla	sclerophyll scrub
	E. fasciculosa /mallee eucalypts	sclerophyll scrub
	E. fasciculosa /E.viminalis	savannah woodland
	E. fasciculosa /E. odorata	savannah woodland
	E. fasciculosa /A. verticillata	savannah woodland
E. viminalis	*E. viminalis/ E. leucoxylon*	savannah woodland
	E. viminalis /E. fasciculosa/E.ovata	savannah woodland/sclerophyll woodland-modified
	E. viminalis /E.ovata	not classified
E. leucoxylon	*E. leucoxylon*	savannah woodland
	E. leucoxylon /E. fasciculosa	sclerophyll scrub
E. ovata	*E. ovata*	waterlogging tolerant species
	E. ovata /E. leucoxylon	not classified
Banksia marginata	*Banksia marginata*	sclerophyll scrub-sclerophyll woodland transition
Allocasuarina verticillata	*Allocasuarina verticillata*	savannah woodland
Melaleuca pubescens lanceolata	*Melaleuca pubescens*	not classified

Both suggested the sensitivity of *Eucalyptus* distribution to changes in water-balance induced by variation in rainfall, solar radiation and evaporation potential. Physiological studies, considering stomatal conductance, support the conclusions of the importance of water availability in these early ecological studies (Sinclair, 1980). *Eucalyptus obliqua* had a higher water potential maxima and much lower stomatal conductance than *E. fasciculosa* resulting *in E. obliqua* suffering water stress in summer, where as *E. fasciculosa* does not. Soil texture in relation to its bearing on water relations and soil fertility were identified as important factors affecting topo- and meso-scaled distribution patterns (Boomsma, 1948; Specht and Perry, 1948). The importance of soil type on *Eucalyptus* distribution was also demonstrated by Green (1995) in a study of the ecology of the structural dominants of the Central Mount Lofty Ranges. Mitchell (1983) considered the distribution of vegetation types of the sclerophyll woodlands and forests of the Fleurieu Peninsula in relation to rainfall, aspect, geology and landform. He concluded that while certain communities were correlated to these variables, in others clear trends were difficult to elicit. He thought that this was possibly due to the low reliability of the geological information and the complexity of interaction between variables.

The influence of fire on the distribution of the vegetation in the region has received considerably less attention than physical habitat factors. Studies of pyric succession in sclerophyllous communities (Noble, 1986; Specht, 1972) have concluded that pyric succession is usually only seen in the understorey plants. Most dominant overstorey species survive burning and so original structure and composition is retained. Cochrane (1963) describes a post-fire succession in the understorey of *Eucalyptus obliqua* forests in the Mount Lofty Ranges. In the first year after a fire, the ash and burned logs are colonised by lower plant forms such as liverworts, other small herbaceous species and seedlings of many shrub species. In the second year a number of small shrubs species, including *Ixodia achillaeoides*, commonly known as fire weed, become dominant. It can dominate for 3-5 years. After four to six years, slower growing shrubs of *Leptospermum myrsinoides* overtop the *Ixodia*, often accompanied by *Pultenaea daphnoides* and *Hakea rostrata*. Eventually this group is replaced by *Acacia myrtifolia* and *Pultenaea daphnoides* which form an understorey after about 10 years. These individuals can live for at least 20 to 30 years and then if an area remains unburnt for 30 or more years, the understorey starts to thin out.

Only nine percent of the original extent of native vegetation cover remains in the Fleurieu Peninsula (Williams and Goodwins, 1987). The remaining native vegetation exists as small isolated fragments surrounded by a predominantly agricultural matrix; over 65% of the vegetation is located in patches less than 10 ha in size and only three patches exceed 500 ha. Due to the extensive European transformation of landscapes in this region the area has more extinct, rare and endangered plant species than anywhere else in South Australia (Lang and Kraheunbeuhl, 1987). It was surveyed by the S.A. Department of Environment and Natural Resources (DENR) in 1986. Survey data was classified into structural and floristic groupings and mapped using aerial photographs. The communities identified in the study region are listed in Table 2. 2 and their distribution is shown in Figure 2. 5. The vegetation cover of the region is dominated by introduced shrubs, herbs and grasses. Many of these are weed species which became naturalised early in European settlement (Kloot, 1983) and cultivated pasture herbs and grasses.

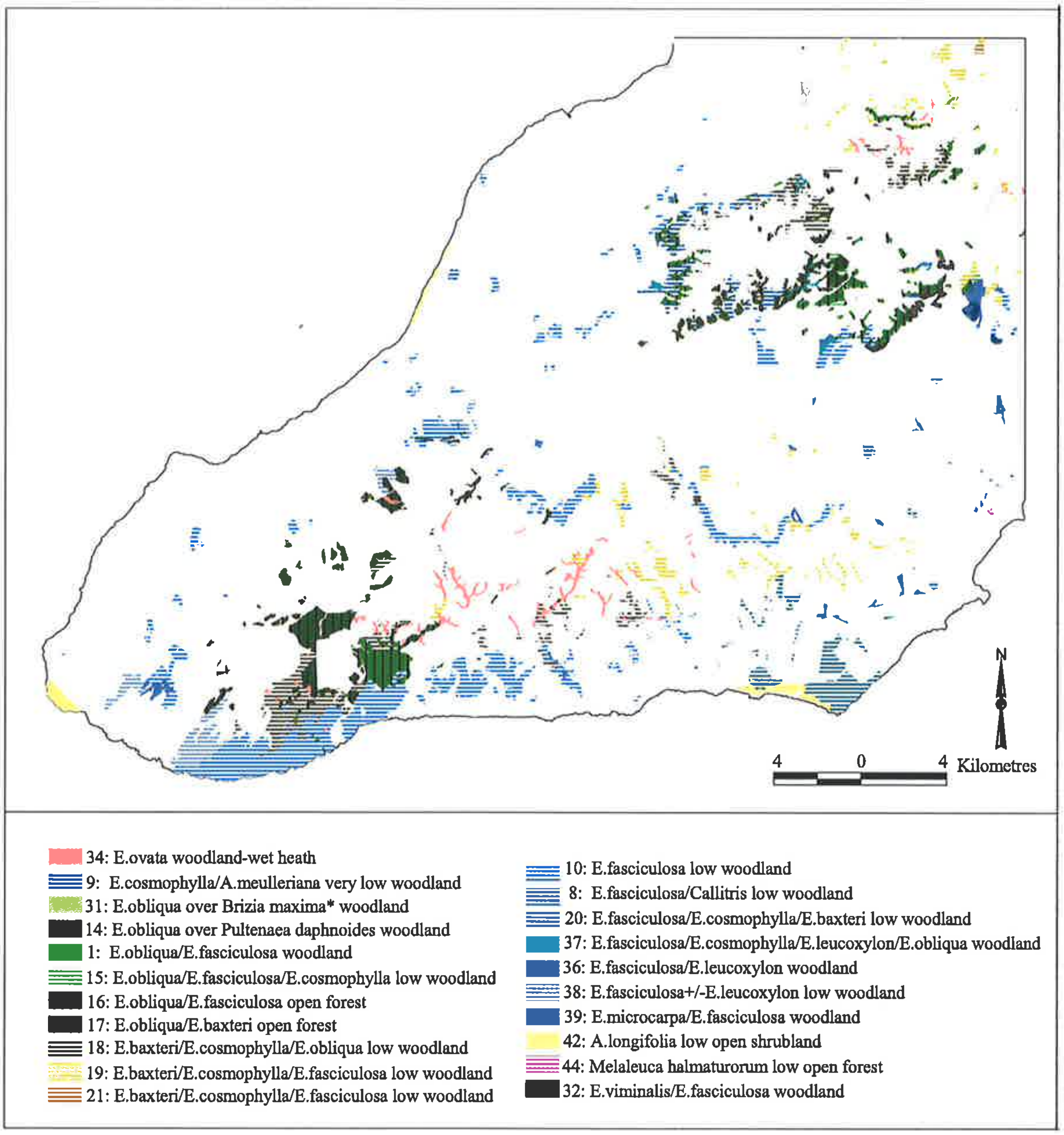

Figure 2. 5 Distribution of the remnant vegetation plant communities of the Fleurieu Peninsula as classified and mapped by DENR (1988).

Table 2. 2 Communities in the Fleurieu Peninsula as classified and mapped by DENR (1988) and their area of occupation in Fleurieu Peninsula. Source: Southern Mount Lofty Ranges Floristic Vegetation Mapping (GIS), Environmental Database of SA (IDA Branch, Planning SA).

Regional Floristic Description	Area	Community
Eucalyptus obliqua, E. fasciculosa over *Acrotriche serrulata, Gonocarpus tetragynus, Hibbertia exutiacies, Lepidosperma semiteres* Woodland	3.9	1
Eucalyptus fasciculosa, Callitris preissii over *Amyema miquelii, Calytrix tetragona, Astroloma conostephioides* Woodland	23.9	8
Eucalyptus cosmophylla over *Calytrix tetragona, Hibbertia riparia, Astroloma humifusum, Arthropodium strictum, Allocasuarina muelleriana, Schoenus breviculmis, Goodenia primulacea* (NC), *Hakea carinata* Very low woodland	394.3	9
Eucalyptus fasciculosa over *Astroloma humifusum, Chamaescilla corymbosa, Olearia ramulosa, Drosera whittakeri* Low woodland	3899.7	10
Eucalyptus obliqua over *Pultenaea daphnoides* Woodland	199.2	14
Eucalyptus obliqua, E. fasciculosa, E. cosmophylla over *Hakea rostrata, Lepidosperma semiteres, Leptospermum myrsinoides* Low woodland	91.6	15
Eucalyptus obliqua, E. fasciculosa over *Gonocarpus tetragynus, Xanthorrhoea semiplana, Lepidosperma semiteres* Open forest	1298.5	16
Eucalyptus obliqua, E. baxteri over *Acrotriche serrulata, Pultenaea daphnoides, Hakea rostrata, Lepidosperma semiteres, Goodenia ovata, Pteridium esculentum* Open forest	1513.6	17
Eucalyptus baxteri, E. cosmophylla, E. obliqua over *Lepidosperma semiteres, Banksia marginata, Pultenaea involucrata* Low woodland	1732	18
Eucalyptus baxteri, E. cosmophylla over *Gonocarpus tetragynus, Hypolaena fastigiata, Leptospermum myrsinoides, Platylobium obtusangulum* Low woodland	800	19
Eucalyptus fasciculosa, E. cosmophylla, E. baxteri over *Hibbertia riparia, Brachyloma ericoides* Low woodland	816.5	20
Eucalyptus baxteri, E. cosmophylla, E. fasciculosa over *Gonocarpus tetragynus, Correa reflexa, Lepidobolus drapetocoleus* Low woodland	15.9	21
Eucalyptus viminalis ssp., *E. fasciculosa* over *Pteridium esculentum, Dichondra repens, *Briza maxima* Woodland	143.4	32
Eucalyptus ovata over *Goodenia ovata* Wet forest-heath	485.9	34
Eucalyptus fasciculosa, E. leucoxylon ssp. over *Acacia pycnantha, Astroloma humifusum* Woodland	422.2	36
Eucalyptus fasciculosa, E. cosmophylla, E. obliqua, E. leucoxylon ssp. over *Gonocarpus tetragynus, Hibbertia exutiacies, Lomandra dura, Arthropodium strictum, Dianella revoluta, Gonocarpus mezianus, Acrotriche serrulata, Hakea rostrata, Pimelea linifolia* Woodland	83.6	37
Eucalyptus fasciculosa, +/- E. leucoxylon ssp. over *Acacia pycnantha, Cheilanthes austrotenuifolia, Olearia ramulosa, Hibbertia riparia, Xanthorrhoea semiplana* ssp. *tateana, Gonocarpus mezianus* Low woodland	633.3	38
Eucalyptus microcarpa, E. fasciculosa over *Acacia pycnantha, Astroloma humifusum, Olearia ramulosa* Woodland	59.7	39
Acacia longifolia, Spinifex sericeus Low open shrubland	310.7	42
Melaleuca halmaturorum Low open forest	3.9	44

2.6 Fauna

Twenty eight species of mammals were represented at the time of European settlement of which nine are no longer present (Table 2. 3). *Macropus fuliginosus* (Western Grey Kangaroo) is the most common and conspicuous native mammal and has benefited from the introduction of exotic pasture grasses (Lamprey and Mitchell, 1979). *Cercatetus concinnus* (Southern Pigmy Possum) has adapted well to introduced plant communities, while *Isodon obesulus* (Southern Brown Bandicoot) and *Rattus lutreolus* are greatly reduced in numbers (NPWS, 1985). A number of introduced species of mammals are present on the peninsula and some have become serious pests and threats to native mammal populations (NPWS, 1985).

Over 200 species of birds have been recorded in the Fleurieu Peninsula (Lamprey and Mitchell, 1979), four of which are extinct in the region and four endangered (NPWS, 1985). At least eight species of frogs occur on the peninsula as well as a variety of lizards, snakes and tortoises. Those occurring in conservation parks have been documented by the NPWS (1985). The peninsula supports relatively few native freshwater fish due to the absence of any major streams (Scott, Glover and Southcott, 1974).

Table 2. 3 List of extinct native mammals and those with present day occurrence on the Fleurieu Peninsula. Table compiled from data from NPWS (1985).

Species	Common name	Regional status
Dasyurus viverrinus	Eastern Quoll	extinct
Phascogale calura	Red-tailed Phascogale	extinct
Phascogale tapoatafa	Brush-tailed Phascogale	extinct
Myrmecobius fasciatus	Numbat	extinct
Bettongia lesueur	Burrowing Bettong	extinct
Macrotis lagotis	Greater Bilby	extinct
Bettongia penicillata	Bettong	extinct
Macropus rufus	Red Kangaroo	extinct
Macropus eugenii	Tammar Wallaby	extinct
Isodon obesulus	Southern Brown Bandicoot	rare
Rattus lutreolus	Swamp rat	rare
Macropus fuliginosus	Western Grey Kangaroo	common
Trichosurus vulpecula	Common Brush-tail Possum	common
Antechinus	Yellow-footed Antechinus	common
Rattus fuscipes	Bush rat	common
Hydromys chrysogaster	Water rat	common
Tachyglossus aculeatus	Short-beaked Echidna	common
Cercatetus concinnus	Southern Pigmy Possum	
Tadarida spp.	Mastiff Bats	common
Chalinolobus spp.	Wattled Bats	common
Miniopterus schreibersii	Common Bent-winged Bat	common
Microchiroptera sp.	Insectivorous Bats	common
Sminthopsis murina	Common Dunnart	
Eptesicus pumilus	Little Cave Eptesicus	

2.7 Pre-history

There is archaeological evidence that by 25000-30000 years BP people had colonised most habitats in what was to become Australia (Mulvaney and Kaminga, 1999). The original antiquity and temporal pattern of Aboriginal occupation of the Fleurieu Peninsula can only be inferred from nearest dated archaeological sites which have environmental affinity with the region by making the assumptions that occupation trends were pan-regional. An excavation in Seton Cave in Kangaroo Island revealed human occupation from about 16000 years BP (Lampert, 1981). At that time, near the last glacial maximum when sea levels were 130 metres below present, the site of Seton Cave lay in an upland, being the southern most extension of the Mount Lofty Ranges uplift. This region was then drier, and probably vegetated with a very open *Eucalyptus* woodland (Clark, 1983). Apart from occasional visits the site was unoccupied until about 11000 years BP.

At the time of European arrival the Fleurieu Peninsula was occupied by two Aboriginal groups, the Kaurna and the Ngarrindjeri (Tindale, 1974). The Kaurna occupied the lands on the western side of the ranges, their territory extending from Cape Jervis in the south to Port Wakefield in the north. The Ngarrindjeri occupied the eastern side of the ranges, their territory extending from Tunkalilla Beach, which is just east of Cape Jervis, west to Swanport on the River Murray in the north and to Kingston in the south east (Tindale 1974). The Jultiwia, or Stringy Bark Ranges marked the eastern boundary of the Kaurna's range. Tunkalilla beach was given as the actual boundary with the Ngarrindjeri. The Inman Valley was occupied by the Ngarrindjeri. The Kaurna were arranged as a number of separate small groups, who spent most of their time in particular areas; the south, or the north or the Adelaide plains. The southern horde, based at Rapid Bay, spoke a slight dialect of the Kaurna language (Tindale, 1974). Five hordes, occupying particular regions, also composed the Ngarrindjeri (Tindale, 1974).

It has been proposed that the Fleurieu Peninsula had been largely depopulated of Kaurna and Ngarrindjeri by the early nineteenth century, before official colonisation of South Australia. Depopulation was due to two epidemics of smallpox, the first in 1789 and second in 1829-30, and the significant interaction between local tribes and sealing settlements on Kangaroo Island (Amery, 1998; Jenkin, 1979). G. French Angas wrote that the smallpox epidemics in the 1820s to 1830 '...severely depopulated the district...' (French Angas, 1847). In 1841 the population density in the Adelaide region, running from the southern Fleurieu to North of Adelaide, was estimated to be only 'one in every 4 ½ square miles' (Tiechelmann, 1841). Ellis (1976) suggested there were no more than 500 Kaurna over their entire territory in 1836 and another source suggests there were 650 in 1842 (South Australian Register of 30 Jan.1842). It is not known how many Ngarrindjeri there were at the time of European settlement but their numbers probably declined rapidly (Jenkin, 1979). By 1881 a census suggests numbers were as low as only 24 individuals (Census, 1881). G.B. Wilkinson, a settler who lived at Bullaparinga, near Delamere, wrote of the population demise of southern Fleurieu Peninsula Aborigines around the 1840s:

> 'During the short time I was in the country, I could perceive a great diminution in the number of natives and should say they were less by one third than when I saw them about seven years before. In one part a tribe of thirty or forty was reduced to twelve or fifteen and these had joined neighbouring tribes, so than as a distinct tribe they were lost. This was at a part of the coast between Rapid and Encounter Bays, called Tunkalilla and Waitpinga district. ... The blacks told me themselves that this was their country but their friends were 'crack-aback' meaning dead. In other parts the decrease has been great, though not to the same extent.' (Wilkinson, 1848).

Due to population devastation, the historical record of Aboriginal society and their use of landscape are quite likely to be different to those of preceding centuries (Mulvaney and Kamminga, 1999), ethnographic records do provide some evidence of Aboriginal use of environment. Aboriginal use of fire had been observed in the region as early as 1802 by Flinders who recorded that recorded fires scattered along the coastline of the St Vincent's Gulf. There is evidence that in 1837 some of the Aboriginal fires were large in extent:

> '....the watchers on the deck beheld a fire on one of the hills, which seemed to spread from hill to hill with amazing speed....at the end of summer as this was, the natives had set fire to the long grass to enable them to more easily to obtain the animals and vermin on which a great part of their living depends' (Finlayson, 1903).

As in many other parts of Australia, Aboriginal firing was common and apparent. This is indicated by action taken shortly after settlement legislating against the practice (South Australian Government Gazette, 1839, in Ellis, 1976). Both the coastal plains and the ranges were both utilised for procurement of food resources and raw materials by the Kaurna (Ellis, 1976). Ellis suggests that the coastal areas were preferred in the summer months and for the timbered ranges in the winter but the close proximity of the two regions would have allowed for movement in between. The following account describes occupation of the Yankalilla area:

> ...when the natives occupied this part of the country they were usually encamped close to the mouth of the Gorge River and also in the vicinity of Davey's River, some distance further up the coast....In the recollection of the first white settlers the natives were never numerous on the Normanville coast, although there were considerable numbers at Rapid Bay. Mainly the blacks came over from Encounter Bay on infrequent hunting and fishing excursions (*Observer* 3 Oct. 1914).

Vegetable foods formed the greater part of the Kaurna diet (Ellis, 1976; Clarke, 1985, 1986, 1988) because of the reliability and diversity of available sources. Roots and tubers from species in the genera Compositae, Liliaceae and Cyperaceae were utilised. The yam daisy, *Microseris lanceolata* was an important all year round staple (Clarke, 1988). Seeds and fruits were sourced from species in numerous genera; however most important were *Acacia* seeds (from a variety of species) and *Enchylaena tomentosa* from the Coorong area (Clarke, 1985). The environmental impact of Aboriginal food sourcing practices and technologies are difficult to disentangle from other potential causes of change in environmental records, such as climate (Kershaw *et al.*, 2001, 1995; Redman, 1999). However that they helped to create and maintain much of Australia's grasslands is widely supported by ethnological and ecological records (Bowman, 1998). Their practices may also affect tree demography, within some regions regular burning practices favouring 'fire weeds' like *Eucalyptus* over other genera (Hope and Kirkpatrick, 1988).

Accounts in local history books and newspapers from the Willunga, McLaren Vale and Noarlunga areas confirm that Aboriginal people continued to camp and pass through southern districts, presumably accessing traditional resources, to the early twentieth century (Gara *et al.*, 1999).

2.8 European settlement and land use history

English and French government sponsored voyages led by Captain Matthew Flinders, in the *Investigator,* and Captain Nicolas Baudin, in *Le Géographe,* in late March and early April of 1802, were the first to chart the coast of the Fleurieu Peninsula (Horner, 1987; Cooper, 1952). The British settled the region at the end of 1836. Between this time Kangaroo Island was inhabited by British and American sealers, deserters and escaped convicts, who made brief forays to the mainland and rapidly reduced the island's seal and kangaroo populations (Gara *et al.*, 1999). The first settlement in the Fleurieu Peninsula was the temporary camp of the Colonel William Light's survey party at Rapid Bay in September 1836. Light was surveying the eastern coast of Gulf St Vincent aboard the *Rapid* in order to select a site for the capital of the new settlement, and official settlement occurred a few years later around Yankalilla, Rapid Bay and Encounter Bay. Towns at these sites were declared in 1837 (Pridham, 1955), and surrounding lands were surveyed in late 1839 and early 1840. Land was taken up from that time but populations remained below 270 people to the early 1850s, due to the region's geographical isolation from Adelaide. At this time most inhabitants were farmers, agricultural labourers and shepherds (Census, 1846, 1851) and practiced subsistence farming and grazing (Bourman, 1970). Roads connecting the region to the capital city and jetties allowing transport of produce, were built in the early 1850s (Bourman, 1970; Williams, 1985). In conjunction with strong markets for wheat that developed with the gold rushes in Victoria and elsewhere in Australia and overseas (Stow, 1883), grain growing and commercial flour production expanded and formed the backbone of the agricultural industry in the region until around 1868. Populations rapidly expanded from 270 to 3317 people in the Council areas of Rapid Bay, Yankalilla and Myponga in a matter of twenty years (Census, 1871). However the release of land in the mid North, adjoining peninsulas and Mallee regions and the advent of new technologies that enabled broad acre farming, combining with a fall in demand for wheat in Victoria, saw a sudden demise of the wheat industry in the region (Williams, 1974). Problems of economic viability of producing wheat in the region were compounded by that fact that holdings in the Fleurieu Peninsula were small and intensive cropping without fertilisers had depleted soils and reduced productivity (Pridham, 1955; Williams, 1985). Cultivated lands were abandoned or converted to grazing and dairy farming and wattle bark collection and cultivation assumed greater importance. The region's population almost halved and remained low to the early to mid twentieth century when the native vegetation of the uplands was cleared, nutrient correction and the use of fertilisers prompted an expansion of grazing and plantation forestry in these areas. They, along with dairy farming remain the major land uses in the region. About 67% of land is used for grazing, 14% dairying, 4% national parks, 4% plantation forests, 7% native vegetation and 1% is cropped (Southern Hills Soil Conservation Board, 1995). A more detailed history of the dominant land uses in the region follows and are the major phases of land use are summarised in Figure 2. 6.

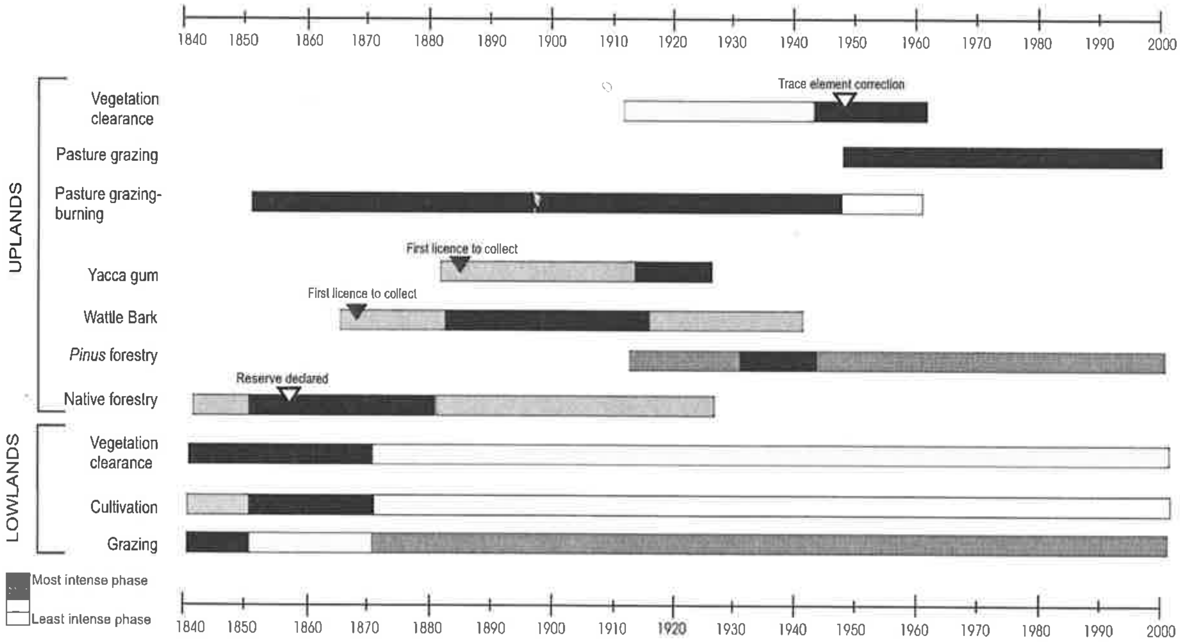

Figure 2. 6 The major land uses in the Fleurieu Peninsula from 1840 to present.

2.8.1 *Cultivation*

From the beginning of European settlement in South Australia there was a strong emphasis on cereal production. The first ten years of settlement in the Fleurieu Peninsula would have been on a relatively small, subsistence scale, producing enough to sustain early settlers (Pridham, 1955; Bourman, 1970). However around 1850 cropping greatly expanded in the region (Figure 2. 7).

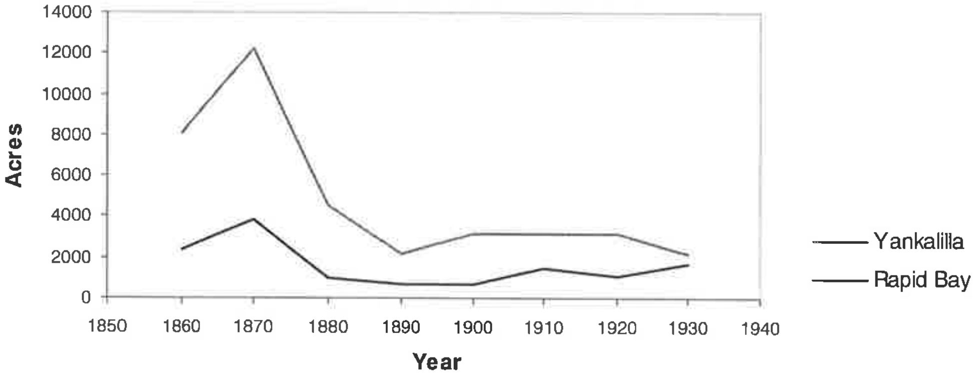

Figure 2. 7 Area of land cultivated in the District Councils of Yankalilla and Rapid Bay from 1860-1930. Data from SRPSA.

Four flour mills were established in the region at Second Valley, Yankalilla and Normanville between 1850 and 1854 (Williams, 1985). The 'lands' system was the predominant cultivation method used by early colonists in the Mount Lofty Ranges regions (Twidale, 1971). The practice involved ploughing obliquely to contours in furrows 5-6 metres wide and around 12 cm deep. A ridge separated each furrow. Flats and slopes to 15^0 were ploughed in such a way. It was likely that these practices were responsible for considerable soil loss through sheet and gully erosion. Most of the cultivation was on the unstable Permian sands and clays in the region, supporting open woodlands carrying *E. leucoxylon* and *E. camaldulensis*, trees used as marker of soil fertility by early colonists (Moon, 1969; Williams, 1973). There is imprint in the landscape today of lands cultivation. In places lands patterns are evident (Twidale, 1971) or the gullies and gutters they were the precursors of (Bourman, 1970; Twidale, 1971). Cropping was a relative intense but short phase of the agricultural history of the Fleurieu Peninsula. The industry abruptly ended around 1870 and many farms were abandoned or returned to pasture. G. Sutherland travelled through the Fleurieu Peninsula after it's agricultural heyday and decline and wrote the following description of Second Valley

> 'Fine undulating country meets the view, upon which it is evident that a considerable amount of authority has been carried on... Yet a large amount of land in this locality has reverted from farming to grazing... the lower part of Second Valley is now one large grass paddock, in various parts of which maybe seen the evidence of ploughing in bygone days' (Sutherland, 1889, p.13).

Sutherland alludes to the deterioration of the land that followed abandonment with the invasion of introduced weeds

> 'Large tracts of land are presently held by private owners to little or no purpose. It is certainly melancholy to note to what a large extent of good land has been practically abandoned and is now over run by stinkwort and other noxious weeds' (Sutherland, 1889, p.1)

2.8.2 Grazing

Considerable numbers of sheep and cattle were brought into the area from the time of first settlement of the Fleurieu Peninsula. One of the largest pastoral ventures in the Colony in 1841, running 5000 head of sheep, was that of the Jones brothers at Delamere and Second Valley. The grasses of the savannah woodlands would have been primary targets of first graziers and there is evidence that they were rapidly exploited. Carmichael (1973) records that by 1842 in the Inman Valley 'all the palatable grasses had been removed' and some first settlers were already moving on to new frontiers in the colony. Interest would have turned to the unsurveyed lands referred to as the 'Waste Lands'. Holders of 80 acre sections were entitled to 2 square miles of commonage on Waste Lands at a rental of 10 shillings per square mile and additional commonage at 20 shillings per square mile. Depasturing licenses to graze on commonage were obtained from the Colonial Government until 1852 when control of their issue was transferred to District Councils (SAGG, 1855). Crown land rangers were appointed to monitor grazing activities in these regions. Williams (1985) records that at this time sheep were taken, in flocks of about 600, by shepherds to the highlands to graze (Williams, 1985). A listing of stockholders in the Rapid Bay and Yankalilla region shows that by 1844 there were at least 11300 head of sheep in the region (Williams, 1985). A list of persons who had taken depasturing licenses to grazing on Common Land in the year 1851 in the Hundred of Yankalilla showed 3890 head of cattle[2] were licensed at that time (SAGG, 1850). Despite the grazing license system installed early in settlement it is

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[2] Cattle was used to describe all types of livestock. Sheep and goats were referred to as 'small cattle' and horned cattle, horses, mules and asses were known as 'great cattle' (SA Govt. Gazette, 1855)

likely that much uncontrolled pastoral activity occurred so the actual stock numbers and the areas they first infiltrated remains speculative.

From the time that the Yankalilla and Rapid Bay District Councils were established in 1854 and 1856 respectively, councils issued grazing licenses locally. Individual councils were responsible for making estimates of the number of cattle the land was capable of carrying and to issue licenses accordingly. The District Council of Rapid Bay designated stocking rates to be five large cattle per 80 acres. The later 1850's saw population in the region expand greatly, reaching 2551 by 1860. License records from the District Council of Rapid Bay indicate that the number of cattle grazing on Common Lands fluctuated between about 1900 and 4000 head during the years 1864-1870 (RBCMB, 1864-1878). The actual numbers grazed were probably higher as much unlicensed grazing probably took place; an example of this occurring is given in the RBCMB 1864-78 where there is a record of a Mr Bull being fined for the grazing of 900 lambs without license. State statistical records show that from 1860-1870 there were between 6-9000 head of sheep and cattle in the Rapid Bay region. About one quarter of stock held in the district were grazed in the highlands. Numerous accounts of nuisance wild cattle running in the highlands in the 1850s were made (Williams, 1985), suggesting much uncontrolled grazing also occurred inadvertently. Both cattle and sheep were grazed from the time of initial settlement. Cattle grazing steadily diminished in importance from 1860 onwards in the region, while sheep numbers increased. Figure 2. 8 shows sheep and cattle numbers recorded for the District Councils of Yankalilla and Rapid Bay from 1860-1930 in the state Statistical Register (SAPP, 1860-1930).

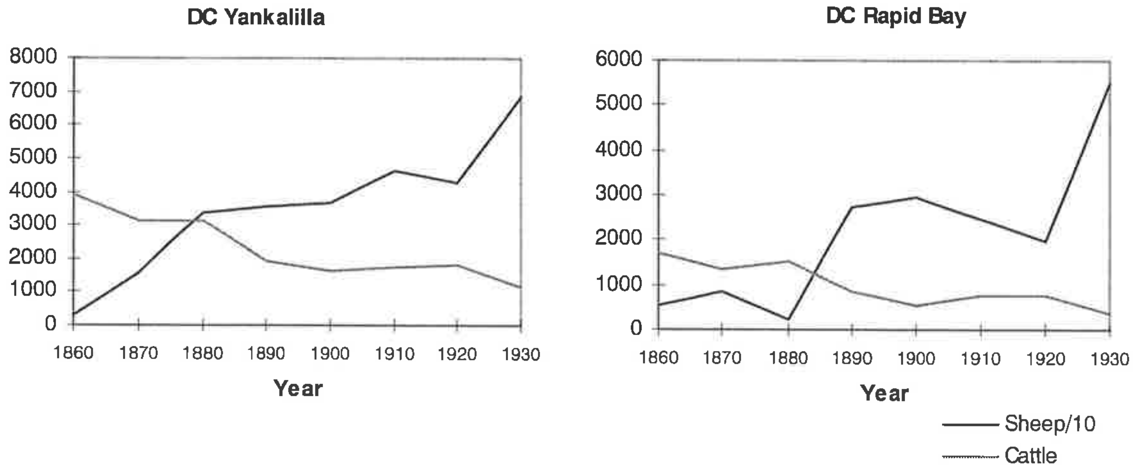

Figure 2. 8 Number of head of sheep and cattle in the District Councils of Yankalilla and Rapid Bay from 1860-1930. Data from the SRPSA (SAPP, 1860-1930).

W.B. Sells, an affluent pastoralist and sheep breeder, is attributed as being the first grazier to run stock in the central scrubbier part of the plateau.. He established his run in 1880 and it extended from Tunkalilla to Cape Jervis (Williams, 1985).

By 1890 the highland regions had been surveyed and released for sale or lease. Between 1880 and 1890 the area of land taken by lease increased from about 10,000 acres (2500 ha) to over 50,000 acres (12,000 ha) in the District Council of Rapid Bay and 20,000 to 40,000 acres in the District Council of Yankalilla (Figure 2. 9). Over the same time sheep numbers increased ten fold in the Hundred of Waitpinga but only rose slightly in the Hundred of Yankalilla from 33540 to 36820. Burning to stimulate palatable fodder was essential to grazing operations for without it, especially on the more scrubby areas, the land did not contain enough pasture grass to support even light sheep grazing (Robertson, pers. comm.). Graziers burned parts of their holdings every two to five years (Williams, pers comm). The generally acknowledged carrying capacity of the land at that time was one sheep to every ten acres. Running sheep on regularly burned native sclerophyllous vegetation was referred to as 'rough grazing' and was practiced to 1930 (Williams, 1985). Through this time the area of land occupied and utilised in the region steadily increased.

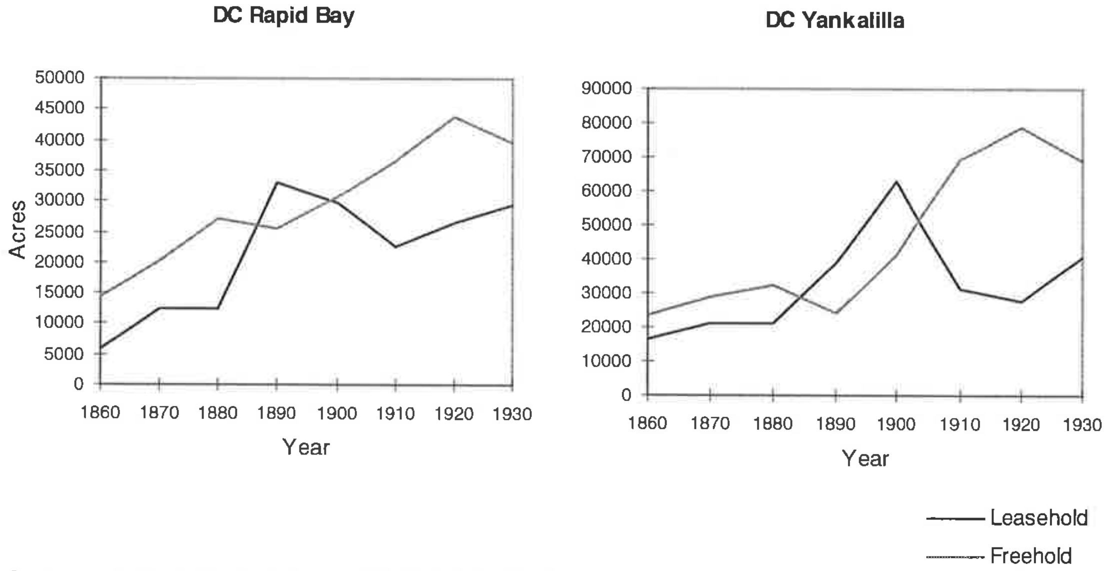

Figure 2. 9 The area under lease and freehold in the District Councils of Yankalilla and Rapid Bay from 1860-1930. Data from the SRPSA (SAPP, 1860-1930).

Williams (1985) suggests that before 1880 most of the graziers ran stock on the fringes of the plateau and on the Stringy Bark forests south of Second Valley and Delamere. This seems plausible as the fringes of the Plateau would have been accessible and more grassed than the highlands which were characterised by their sclerophyllous understoreys. The forests were possibly more open and heavily grassed than the lower sclerophyllous scrubs so were also preferentially selected. However grazing licenses were issued around the Deep Creek as early as 1865 (RBCMB, 1864-78).

2.8.3 *Native timber collection and forestry*

Official records of timber collection in South Australia are scarce (Williams, 1974) and the Fleurieu Peninsula is no exception to this. However it seems that considerable timber collection occurred from the time of settlement on both alienated and unalienated land. From early in European settlement the large *Eucalyptus leucoxylon* and *E. camaldulensis* trees of grassy woodlands were cut for building materials and fuel (Lewis, 1975) and were ring-barking to clear land for cultivation (Adamson and Osborn, 1924). *Allocasuarina verticillata*, distributed on the grassy woodlands, were cut providing a valuable fodder crop for cattle, firewood and construction timber (Williams, 1974).

A letter by Rev. R.W. Newland, to the Government indicates that there was interest in the collection of timber from the Stringy Bark forests of the upland regions around Waitpinga as early as 1840:

> 'I and one of my men have discovered a fine range of Stringy Bark timber on the hills about ten miles west of this place [Encounter Bay], and we have formed a road and made an entrance to the forest and brought to my residence broad palings and shingles to my house. Having been at very considerable expense and trouble in the search for the forest and then in opening it, may I beg that any orders the Government may give for split timber of any kind may be given to me, as I have already engaged splitters and intend to draw as much as I can to sell at Encounter Bay.' (State Records SA, Research Note 160).

Illegal, and later licensed but largely uncontrolled, logging activities in the Stringy Bark forests began from at least as early as 1842 (Blum, 1985). Blum records that timber collection was the main industry in the Hindmarsh Tiers region in the eastern side of the Fleurieu Peninsula in 1842. The timber collected was predominantly Stringy Bark (Williams, 1985). Itinerant sawyers and splitters set up temporary camps and digging saw pits in convenient places (Blum, 1985; Williams, 1988) and moved on when all the easily accessible timber had been gathered. The 1846 Colonial Census records that 5 of the 190 inhabitants in the Yankalilla and Cape Jervis region were sawyers and splitters. This may have been an underestimate of actual numbers since the itinerant nature of the work would cause some to miss the census count. Williams (1988) recorded that sawyers and splitters lived in 'gypsy like encampments' and 'moved on when easily accessible timber had been collected'.

Merchantable timber was a premium and scarce resource in the new colony (Williams, 1974; Lewis, 1975) and from the early 1850s when road and jetty building made the Fleurieu Peninsula more accessible to Adelaide collection intensified. From 1853 local councils issued Timber Collection licenses for supposedly a fixed term and amount of timber. Crown Land rangers were appointed by colonial and local governments to control collection. However it is likely that control was difficult and thus of little effect. Records in 1860s minute books of prosecution for illegal cutting from Crown Lands provide evidence for unlicensed timber collection (YCMB, 1856-78). Early in the Colony's development it was realised that timber resources were being exploited too rapidly. In 1855 there were moves to repeal the 1852 Timber License Bill and give control of timber licenses back to the colonial government as 'land was being depreciated by collection of timber from it' (SAGG, 1855). Surveyor General George Goyder visited the Rapid Bay Councillor William Randall in 1859 to discuss timber resources in the area. The outcome of the visit was the demarcation of the Second Valley Forest in the Hundred of Waitpinga in 1864. This acted to reserve timber on the Crown land bounded by '... the Dog Trap, following the Sawpit Gully in a south westerly direction, to its head near the Blowhole; and from thence in a westerly direction to join the Table Land Road, following the same to the head of Bedlam Flat; and thence down the main gully to the Dog Trap aforesaid'(SAGG, 1864). An order put before Government to establish government forests in South Australia in 1870 suggests that early timber collection severely depleted the colony's original reserves (Lewis, 1975).

Timber licenses were the largest revenue source for the Rapid Bay Council through the 1860s, with more people licensed to cut timber than graze cattle in the yet unsurveyed highlands (RBCMB, 1864-78). The 1860s were a decade of establishment of short lived mining ventures in the southern Fleurieu Peninsula and some of these operations used considerable timber resources for operating steam engines (Blum, 1985; Dutton, 1849; Williams, 1985). The largest of these was the Talisker Galena mine which operated between 1862 and 1872 on sections 1552-1558, C and 1610-1614 in the Hundred of Waitpinga. Williams (1985, p.49) writes 'Much timber was cut to fuel the mining operations, brick kiln and accommodation for the miners. It was cut from nearby areas. The area adjacent to the mine was rapidly stripped of trees.' To provide extra timber a saw pit was established in Saw Pit Gully between the present Range Road and Three Bridges Road (sections 40 and 56, Hundred of Waitpinga). Exporting timber was possible by the 1860s with the building of jetties in Rapid Bay, Normanville and Second Valley (Williams, 1985) and timber was cut for the purpose. In 1866 a Mr Redman was contracted to supply 16,000 sleepers for the Port Adelaide Railway and he collected timber from the 'Tiers' near Finnis Vale (Blum, 1985). Albert Jones (pers. comm.) recalled that his grandfather cut smaller Stringy Bark timber between the 1870s and 1880s for export to places, including the Yorke Peninsula, for telegraph poles. The 1884 survey field books record a track marked 'old wood track' on the easterly ridge above the Springs Road swamp catchment suggesting the area around this site was almost certainly logged during the early phase of European occupancy.

After survey in the mid 1870s to 1880s the land in the highland was offered for lease or sale. Once land had been surveyed, timber collection was prohibited. However native timber collection continued from this time with several companies extracting timber from the Second Valley Forest. To 1910 the Glenbrook timber company, sourced native timber, supplying mines in Broken Hill. Thomas Backhouse established a saw mill in 1913, which was purchased by Junction North Mine Company in 1916 to supply timber for their Broken Hill mining operations. This operation sourced timber from the Second Valley forest until 1923.

While the unregulated nature of the license system precludes assessment of estimates of areas logged or volume of timber removed, it appears as though the most intensive phase of native timber collection in the region was probably from the mid 1850s to the 1880s. By the 1880s all the large timber in the forests is likely to have been removed with timber logging shifting to the removal of smaller trees. The logging companies collecting native timber remained operative in the Fleurieu Peninsula until the early twentieth century and presumably were harvesting regrowth timber from the early intensive harvest phases.

From 1912 native vegetation on the highlands began to be cleared for forestry plantings of *Pinus radiata*. Mainly areas carrying taller Stringy Bark forest were selected for forest establishment (Jones, pers comm.). The first forest plantation of *Pinus radiata* on the Fleurieu Peninsula was established in 1912 on historical section number 221 in the Hundred of Waitpinga. Subsequent forestry plantings were made yearly from that time with the biggest expansion occurring in 1934 and 1945.

2.8.4 Wattle bark industry

Wattlebark, particularly that from *Acacia pycnantha,* had been recognised as a valuable tanning agent from an early time in European settlement, with wattle being sent to England as early as 1841 (Blum, 1985). Collection and milling for Adelaide and export markets formed a sizable industry in the Yankalilla and Rapid Bay regions from the 1880s to the 1920s (Sutherland, 1889; Blum, 1985; Williams, 1985), but it is unclear when wattle collection began in the region. It was likely to be have been at least in progress by 1867 with licenses for its collection from Crown Lands being issued by the colonial government from that time and by the District Council of Rapid Bay in 1869. Blum (1985) reports that in 1870 over 1000 tons were shipped directly from Second Valley alone. At this time harvest was mainly from native forests and woodlands and regrowth on previously cultivated fields which had been abandoned in the agricultural decline in the early 1870s in the region. Collection was destructive, entailing the stripping of bark from larger trees. Uncontrolled collection lead to a decline in supply by the 1880s. In 1884 Department of Forestry report included recommendations for their conservation and methods for their cultivation (Blum, 1985).

From the late 1800s to the 1920s the forests and scrubs of the highlands were also employed for wattle collection and cultivation. In 1890 on the Sell's property east of Second Valley, 900 acres of wattle were conserved and 60 cultivated. The Stringybark forest areas east of Delamere were favoured for production. The Glenbrook Wattle Company leased about 7000 acres north of Black Bullock Creek on the upper reaches of Deep Creek (around sections 48-66) and sections 210 and 211 in the Hundred of Waitpinga from 1902 to 1924. Albert Bennett held an area of approximately 2700 acres near the Range Road and Three Bridges Road during the 1920s. Production in these areas involved burning and/or ringbarking the taller trees to clear the land, spreading of wattle seed in the winter months and the running of another low intensity fire to encourage germination. The scrubs of the highlands were also utilised for collection. Stands of wattles were encouraged by '...thinning out the yaccas and other bushes. The dry residual was set alight....cracking open the hard shell of the wattle seed permitting easy germination when the next rain fell' (Blum, 1985 p. 29).

Between 1891 and 1919 inclusive production records for District Councils were recorded in the state Statistical Register (SAPP). They show that a total of 21714 tons of wattle bark was produced in the Rapid Bay and Yankalilla regions (Figure 2. 10). The industry declined from the late 1920s with the introduction of improved pastures and falling world tannin prices (Williams, 1985).

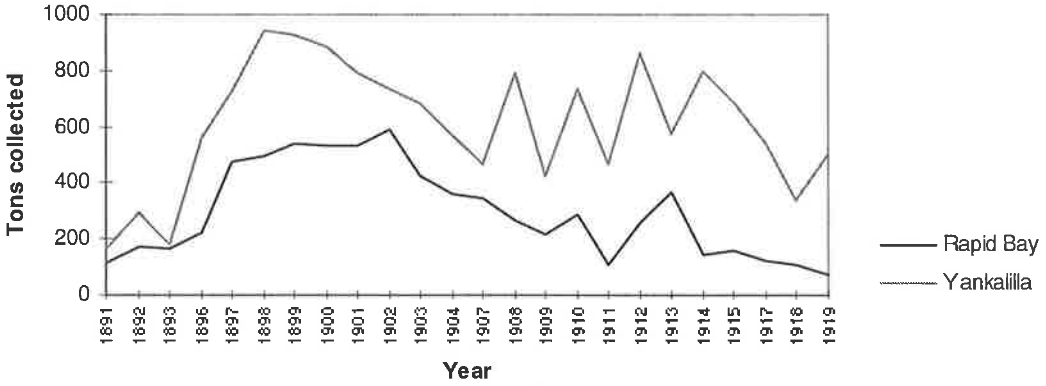

Figure 2. 10 Annual volumes of wattle bark produced in the District Councils of Yankalilla and Rapid Bay from 1891-1919. Data from the SRPSA (SAPP, 1890-1920).

2.8.5 *Yacca collection*

The resin from yaccas (*Xanthorrhoea* spp.) was harvested and used extensively by both Aborigines and Europeans (Neagle, 1997); *Xanthorrhoea semiplana* spp. *tateana* was the species most exploited. Kangaroo Island had been the main source of supply, but from about 1916 to 1930 considerable collection occurred in the scrubs and forests of the southern Fleurieu Peninsula (Neagle, 1997; Williams, 1985. Neagle reports that from this time most collection occurred in the Deep Creek and Second Valley areas. It is likely that gum collecting occurred in the district at lower levels of intensity early in European settlement. The first license to collect yacca gum issued by the District Council of Rapid Bay was in 1880 (RBCMB, 1878-1914). Harvest entailed firstly removing the crown leaves. The lower leaves, which contained the resin at their base, were then hacked off with an axe. In most cases the harvesting process resulted in the death of the plant. In some cases the vegetation was burned in advance of harvesting, most likely to clear other vegetation from the site. In the Fleurieu Peninsula the smaller, slower growing yaccas that occurred on the poorer country carried the larger flakes of resin and were favoured for collection (Williams, 1985). No records of the actual locations where yacca gum was collected or the quantities taken were found to exist. South Australian Statistical Register data shows that considerable quantities were collected in the State from 1910 to 1968 (Figure 2. 11). The industry in the Fleurieu Peninsula may have finished earlier than elsewhere in the state because local sources were depleted. Given that *Xanthorrhoea* regeneration is slow, it is likely this indicates that the industry had a significant effect on reducing *Xanthorrhoea* numbers in the Fleurieu Peninsula.

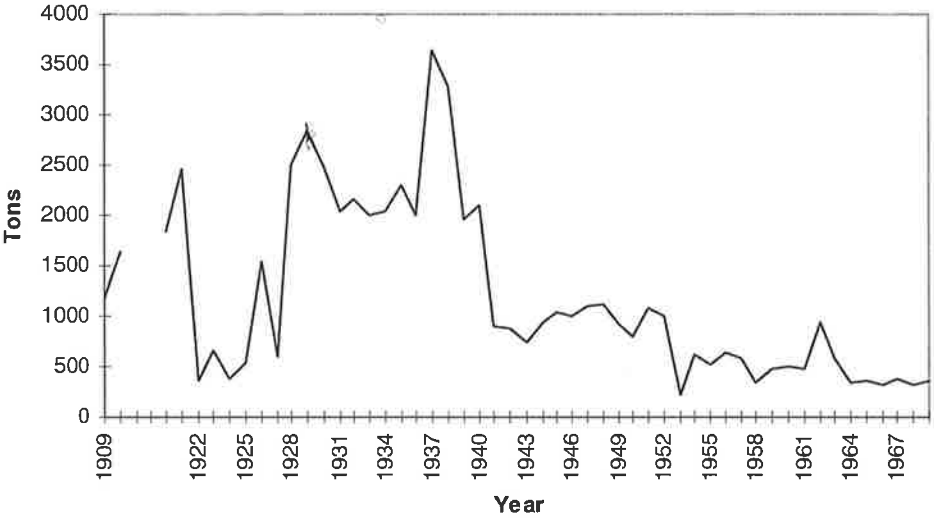

Figure 2. 11 Annual volumes of Yacca gum collected in South Australia from 1909 to 1968. Data from the SRPSA (SAPP, 1900-1968).

2.8.6 Land clearance for improved pastures

Only small experimental patches of land were cleared for agriculture in the upland regions prior to the 1930s. Most ventures met with little success due to the depauperate nature of the soils. Land clearance data recorded in the State Statistical Records shows that between the years 1908 and 1932, 5184 acres (~2356 hectares) were cleared in the district councils of Rapid Bay and Yankalilla. Between the years 1936-1942 a further 8728 acres (~3967 hectares) were cleared in the combined Hundreds of Yankalilla and Waitpinga. The impetus to clear was partly brought on by mechanical advances providing able tractors with scrub rollers. Williams and Moore established a land clearing business in the Parawa region in 1937 (Williams, 1985). The clearance process involved rolling the vegetation with the scrub roller, or a log dragged behind a tractor, burning and then ploughing with a majestic plough. Superphosphate was available at this time and some attempts were made to grow agricultural and horticultural crops. Success was limited until in 1948 when CSIRO work lead to the discovery of trace element deficiencies in the highland soils (Williams, 1974). Molybdenum and copper were added and cropping and pasture responded favourably. This, in combination with soldier settlement programs, provided the impetus for more extensive native vegetation clearance. The total area of previously cleared vegetation in the Fleurieu Peninsula was removed from the late 1940s to around 1965 (Figure 2. 12). Subterranean clover, white clover and rye grass were sown on cleared land and lands were then predominantly employed to graze sheep.

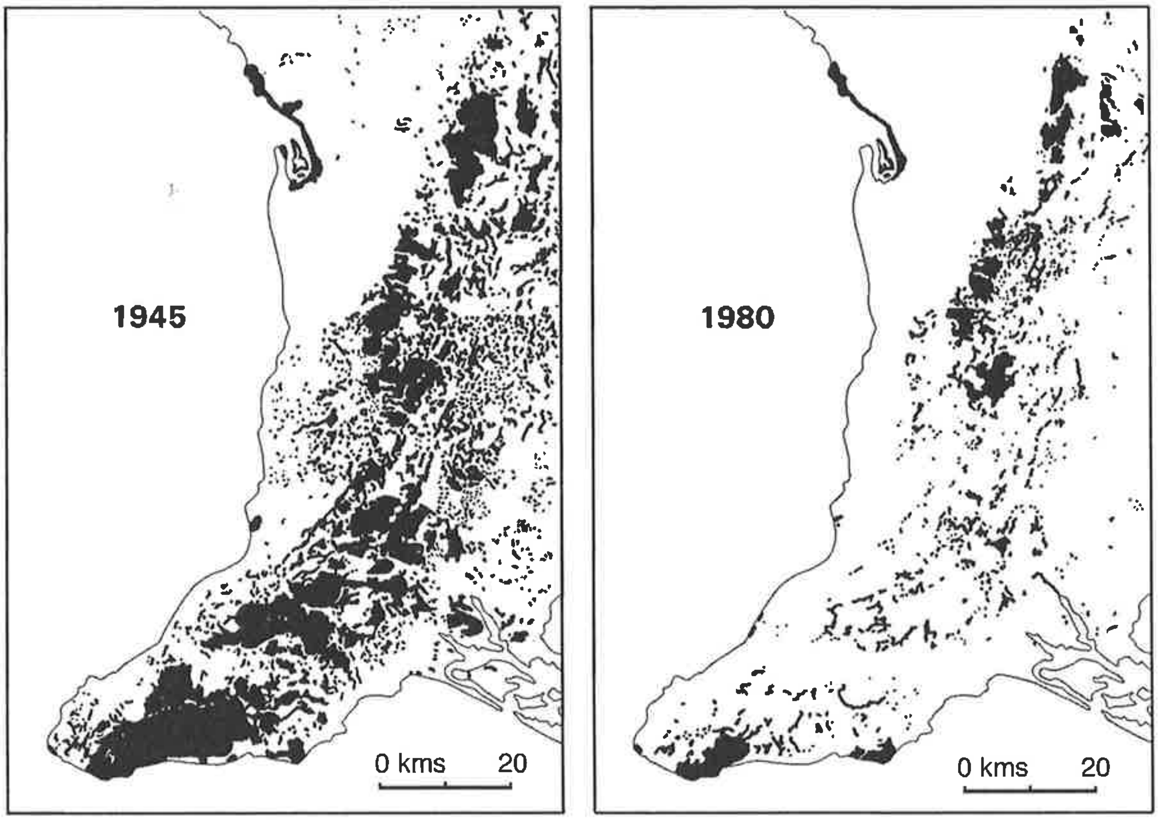

Figure 2. 12 Native vegetation in the Southern Mount Lofty Ranges 1945-1980. (Environment Protection Council of South Australia, 1988).

2.9 Conclusion

Two broad physiographic regions characterise the Fleurieu Peninsula, the uplands of the Mount Lofty Ranges and the lowlands of the western embayments and Inman Valley. These two regions are characterised by different climates, geologies, soil types, terrain units and vegetation types. As a consequence their history of settlement and exploitation by Europeans differs also. Both physiographic regions have been heavily modified since European settlement.

CHAPTER 3

3. DOCUMENTED RECORDS OF HISTORICAL VEGETATION

3.1 Introduction

Documented historical records, in the form of descriptions, maps and pictorial representations of landscapes, made around the time of European settlement, have been the primary sources for the reconstruction of pre-settlement vegetation patterns in heavily modified landscapes in Australia (Smith, 1988; Fensham and Fairfax, 1997; Lunt, 1997a; Fensham, 1998). Descriptions by explorers usually provide accounts of vegetation as it changed along the routes they took. Where the route taken is identifiable, and where their observations are effectively descriptive, they have proved useful in the reconstruction of prior vegetation patterns (Fensham, 1988; Croft *et al.*, 1997). Landscape paintings have been useful supplementary sources to documentary records in vegetation reconstruction (Fensham, 1988). Both sources usually provide spatially exiguous records of historical vegetation pattern.

The only significant official source of systematically collected data recording historical vegetation in Australia are surveyors records and plans (Jeans, 1978). Most of the early land survey information on environments is in the form of sketches of dominant landforms and a description of the vegetation types associated with land forms or unit area being surveyed (Jeans, 1978). Vegetation is usually described in terms of the dominant overstorey species and/or structural configuration. Early survey records have provided the basis for the reconstruction of the historical vegetation of the Darling Downs, Queensland (Fensham and Fairfax, 1997), the northern Adelaide plains, South Australia (Smith, 1988) and the grasslands of East Gippsland region, Victoria (Lunt, 1997a; Lunt 1997b).

Where interpretation of historical terminology (Fensham and Fairfax, 1997) and accurate location of documentary records has been achieved, pre-impact reconstructions allowed quantitative analyses of vegetation change (Delcourt and Delcourt, 1996; Lunt, 1997b). Interpretation of colloquial species names in historical vegetation records is not difficult when the names have not changed, or are traceable in other historic records. Where colloquial names have changed, remnant vegetation has been useful in their interpretation (Fensham and Fairfax, 1997). The spatial location of areas described by individual historical records may be achieved with the use of base maps showing historical survey boundaries, extant toponyms and landscape referents (usually topographic features).

This chapter investigates documented and pictorial records which contain information on the early European vegetation of the Fleurieu Peninsula. The investigation considers the type of information contained in records as it relates to modern vegetation classifications. It considers the scale and accuracy with which it records can be spatially located. Records are mapped using a geographic information system[1] (GIS). Historical vegetation patterns are discussed in relation to their accuracy, spatial distribution and classificatory resolution.

3.2 Methods

3.2.1 *Sources*

Historical data was collected from various sources. Journals and letters written by European explorers and early settlers of the Fleurieu Peninsula were studied for observations of landscape and vegetation. Most of this material was held in published or archival form in the Mortlock Library of South Australiana within the State Library of South Australia and in the collections of the South Australian State Records. Landscape images were also sought from the collections of the State Gallery of South Australia. In most cases searches were limited to material pre-dating 1900. The Mortlock Libraries collection of pictorial images was also searched for landscape images.

The Survey Records Department, Department of Environment and Natural Resources, Adelaide (formerly the Department of Lands) holds survey records, dating from the settlement of the Colony of South Australia to the present day. Diagram books, field books, first survey plans and hundred maps constructed during the initial survey of lands in the Fleurieu Peninsula were examined for reference to vegetation cover. Descriptions of vegetation and agricultural suitability were transcribed from diagram books for the hundreds in the study area.

3.2.1.1 Survey history

Crown land was apportioned into parcels, known as sections, before it was made available for purchase and settlement. Section boundaries were first drafted, whilst surveying, in field books. Information from field books was later compiled in the South Australian Land Survey Office into larger map form or transcribed into diagram books. In South Australia, the second unit in the survey hierarchy of apportioned land, after the section, was the hundred. Four hundreds were declared in 1846, in the Fleurieu Peninsula; Waitpinga, Yankalilla, Encounter Bay and Myponga. Diagram books were organised by hundred units. The hundred maps depicting the surveyed section boundaries were drawn at a scale of two inches to one mile.

There were four phases of survey in the Fleurieu Peninsula. The first was a topographic survey undertaken on foot by the Surveyor General, Colonel William Light, and his assistant surveyor Boyle Travers Finnis in 1836 when selecting for a site for the capital city of the new Colony. Finnis resided at a camp at Rapid Bay set up by Light's party under a direction to 'examine the country inland from

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[1] The term GIS is variously used and defined, in this thesis it is used to indicate a set of hardware and software tools used for storing, retrieving and analysing and displaying spatial data (Burrough and McDonnell, 1998) rather than including the suite of personnel and databases used in some definitions.

the direction of Encounter Bay and Yankallyilla' (Finnis, 1836, p.12). Finnis kept a diary at the time, but he did not make any reference to the local vegetation. Sections were not laid during these surveys, due to the uncertainty of where the capital was to be and the desire for first sections to be as near as possible to that site. Presumably Finnis made topographic sketches while surveying, as plans by Light and Finnis of areas around Adelaide exist (held by the Public Records Office in London) but none from the Yankalilla-Rapid Bay district were found. It is possible plans were burnt by a fire in Light's cottage that reportedly destroyed much of the survey material compiled by Light and his team (Dutton and Elder, 1991).

The second phase of survey took place at the inception of settlement of the Colony, between the years 1839 and 1840, during which five separate surveys were conducted. The surveys were at Rapid Bay, Yankalilla, Myponga, Inman Valley and Waitpinga. These surveys were the first to be undertaken in the new Colony after survey of areas directly around Adelaide. They were necessarily undertaken with haste, due to the pressing requirements of immediate settlement and food production to take place in the Colony. Private individuals who had no or little experience in surveying conducted the surveys (Poynter, 1965). Eighty and 134 acre sections were delineated. That surveyors of this time were unpractised and unfamiliar with the landscape is apparent in the plans and the field book notes they constructed. Their accompanying notes of topography and vegetation were scant or non-existent and sections were often poorly surveyed, requiring later re-survey.

The third phase of survey in the region took place between 1841 and 1875. This period saw the expansion of areas surveyed around the land of the first surveys and also some resurvey of sections poorly surveyed previously. Eighty and 134 acre sections were delineated during this period, even though there was a movement in South Australian at the time toward larger section sizes as the 80 acre section had proven to be too small to be profitable (Williams, 1974). This trend is evident in the appearance of larger sections during this period. By this time direction to surveyors had been clearly formulated. In 1840 Edward Charles Frome, Surveyor-General, had written '*Instructions for the interior survey of South Australia*' and amongst these instructions stated 'the primary objectives in view... are – the division of all land available for the purposes of agriculture into sections containing eighty acres and the determining and marking out the best main lines of communication through the Province, upon which the direction of the boundaries of sections will in great measure depend.' and that 'Each surveyor should make notes in his Field Book (to be afterwards entered into a journal) of the nature of the soil, description of the timber, facilities for forming and repairing roads, peculiar geological formations &c., &c. in the different districts'. Despite this instruction field books from this survey period were largely devoid of vegetation records, however general and sporadic reference to vegetation cover was made in the diagram book plans. A more common observation recorded in diagram books during this phase was an assessment of potential agricultural suitability of each section.

The final phase of survey took place during the 1880s which completed the survey of the Fleurieu Peninsula into section parcels. In this phase, surveys covered most of the land of higher elevation in the ranges of the Fleurieu Peninsula. The surveyor, S.W. Herbert carried most of the survey in the region. Frome's 1840 survey instructions were more strictly adhered to; sketches of the topography and watercourses were made in field books. Accompanying these drawings were written observations of vegetation and soil-type.

Vegetation descriptions in field books exist as text written within or over several sections. Structural and floristic qualities of the vegetation were described. By way of the placement and size of vegetation descriptions in field book drawings, it appeared that these descriptions may contain information of the distribution and possibly extent of that vegetation-type. This was suggested to be the case by the fact that often more than one vegetation observation was made per section and these observations occupied unique domains within that section. Additionally some observations appeared to be aligned to particular topographic features represented in the drawings.

The diagram book section descriptions from this time are generally brief and suggest environmental homogeneity for that section, even when more than one vegetation type was recorded in the field book drawings. Keys accompanying diagram book plans provide summaries for each section of the environmental observations recorded in field books and also provide the surveyor's assessment of the suitability of the sections for agriculture.

3.2.2 Paleographic transcription: GIS development

Base maps of the historical section boundaries to which both section and field book text observations of vegetation related to were required to allow the construction of GIS coverages of vegetation descriptions. Historical hundred maps represent the original section boundaries and numbers. Sequent hundred maps were drafted for each hundred in the Fleurieu Peninsula as survey progressed during the nineteenth and early twentieth centuries. The most recent and complete hundred map, containing section boundaries and numbers as were designated in original surveys, was drafted in 1935. A digital version of this map was not known to be in existence, however, contemporary land parcel maps for the region, District Council Data Base (DCDB) maps, were available. Despite some boundary changes and subdivision of sections in townships, in most areas the historical section boundaries were apparent in DCDB maps. A digital copy of the DCDB for the region was edited to resemble the historical hundred maps with original section boundaries and numbers. Map editing was done by visually comparing hard copy of hundred maps and manually editing section boundaries in *ArcInfo* Edit (ESRI, 1997). The process involved, first clipping the DCDB coverage to the study area, removing roads and subdivision boundaries, redrawing of changed boundaries, rebuilding as a polygon coverage and finally assigning the original section numbers to section polygons. The procedures used in this process are described in detail in Appendix 1.

Descriptions of sections recorded in diagram books, were transcribed into the digital base map of historical section units by the following process. Section information, including (1) the year of survey, (2) the surveyor's name, (3) agricultural descriptions, (4) structural vegetation references and (5) floristic vegetation references was compiled into a spreadsheet. Not all classes of information were present for each section.

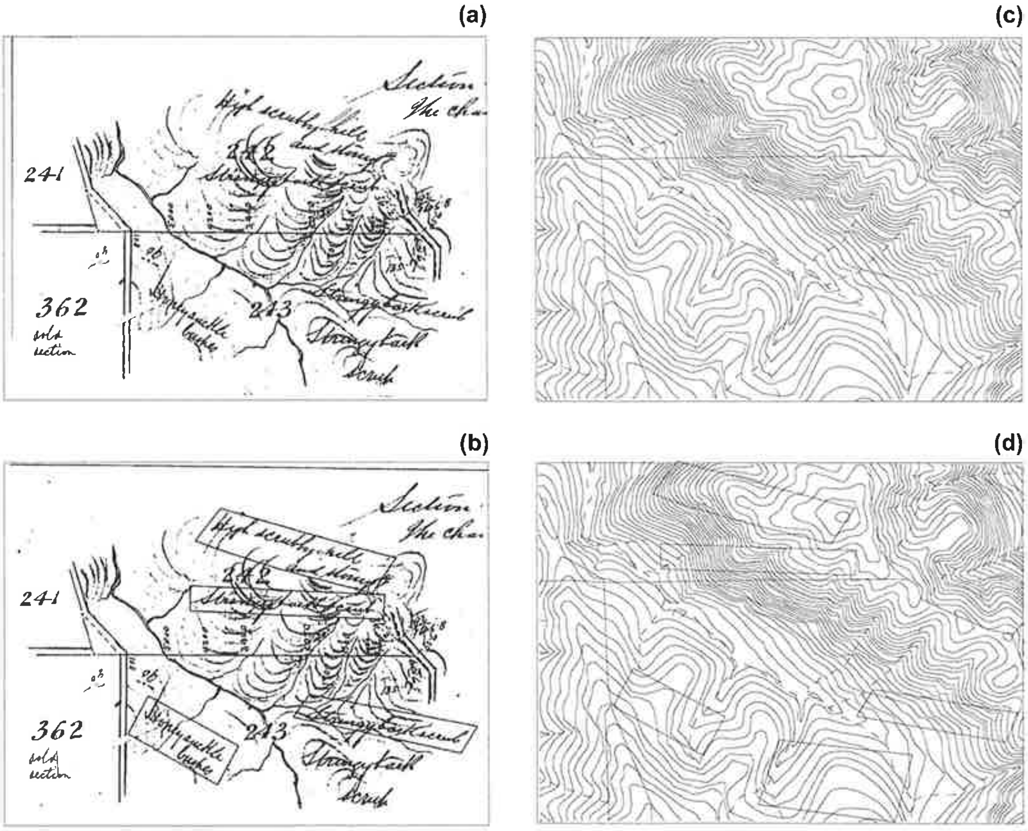

Figure 3. 1 A schematic representation of the stages involved in geolocating field book text descriptions of vegetation types within survey sections. (a) A typical field note book drawing showing section boundaries and numbers, topography, drainage lines and vegetation 'text' descriptions. (b) Areas assumed to be most likely correctly classified by each text observation. (c) Contemporary drainage, contour and historical section boundaries from the digitised historical hundred plans that were used as background coverages to assist the placement of areas classified by text positions. (d) The placement of the manually digitised polygons of areas that are assumed to be most likely correctly classified by each text observation. Polygons from each vegetation type were built as a new monotypic coverage.

Data was imported into the *ArcInfo* INFO program as a table. Data was related by section numbers to the respective historical hundred maps containing those sections. Table records were added as attributes to the polygon attribute tables of section coverages. Where re-surveys generated multiple entries for a single section due to re-survey of that section the most descriptive entry was entered to the GIS database.

Text descriptions of vegetation contained in field books from the survey of the Hundreds of Waitpinga, Yankalilla, Encounter Bay and Myponga were retrieved by manual digitising into a GIS. The digitising procedure was carried out using the sub program *Arctools/edit* in *Arc/Info.* The location of the position of text within sections was determined by displaying historical section boundaries and contemporary contour and stream coverages as background covers. The topography and stream lines marked by surveyors were similar to the modern coverages and thus allowed comparison and placement of text relative to those features. The position of field book text was located on the digital coverage and then a rectangular polygon over the text covered was digitised. The retrieval procedure is exemplified in Figure 3. 1.

Text descriptions were only digitised if it was possible to determine their location with some certainty. In the few cases where surveyors drew boundaries showing the extent of a particular vegetation observation the boundary was digitised as accurately as possible. Text observations of each descriptive type were digitised into separate coverages. Survey drawings of some sections extended to several field book entries on different pages and sometimes several descriptions of the vegetation for a single section were made. Each text entry was digitised and it was found that repeat descriptions matched in both nomenclature and location. This provided a check of the consistency of the nomenclature used by surveyors and further indication that the field book text descriptions contained spatial information indicating distribution of the vegetation type they referred to.

Early explorers and settlers written records describing qualities of vegetation, and pictorial representations of landscape and vegetation, were examined for their ability to be spatially located. In the case of written records reference to locatable townships and other landscape referents were used to designate the probable region pertaining to the description. Coordinates defining the geolocation of the 'probable areas' were taken from topographic maps of the region and used to build a GIS coverage of observations. The titles of pictorial records, often relating to extant toponyms, in association with the matching of any distinguishing topographic features with topographic maps, were used to define their probable locations. Records were mapped as point locations.

3.2.3 Terminological interpretation

Early Australian surveyors referred to vegetation composition with colloquial plant names and vegetation structure with terms which often had regionally specific meanings. For example, 'scrub' is commonly used in early surveys across Australia. In Queensland and New South Wales it referred to rainforest vegetation, yet in South Australia, being without rainforest, it obviously had a different meaning. Many early surveyors in Australia used adjectives describing the density and height of the vegetation. Without the presence of temporally concurrent photographs of vegetation stands being described, calibration or interpretation of these terms must be done indirectly using remnant vegetation or cross reference with other historical vegetation descriptions. Both indirect approaches are adopted here in an attempt to interpret the floristic, structural and finally 'community' descriptions of vegetation contained in the records of surveyors. The most useful historical source used to interpret 1880s vegetation classes was the study of the ecology of the Fleurieu Peninsula undertaken by Boomsma (1948). The comparison of historical vegetation with modern was done by intersection of respective vegetation layers in a GIS. Both approaches of interpretation rely on the assumption that no gross vegetation change has occurred between the present (remnant vegetation as mapped by DENR (1988)), 1948 (Boomsma's study) and vegetation observations of the 1880s.

3.3 Results

3.3.1 Explorers and travellers descriptions and pictorial records

The voyages of discovery of Southern Australia undertaken by Captain Matthew Flinders, in the *Investigator,* and Captain Nicolas Baudin, in *Le Géographe,* charted the Fleurieu Peninsula coast in late March and early April of 1802 and provide the first written descriptions, and much of the geographical nomenclature, of the region. Both voyages spent several days in St Vincent's Gulf (Horner, 1987; Cooper, 1952), however despite a brief attempt by Flinders and his naturalist, Robert Brown, and to reach Mount Lofty, no land exploration was undertaken by either voyage. Consequently descriptions of the region were made from the sea while tracking the coast. Accounts from these voyages provide only generalized descriptions of the appearance of the landscape of the eastern side of the St. Vincent's Gulf. The actual location of the features described from the coast is difficult to ascertain and descriptions seem to provide some conflicting information on the vegetation of the region.

Matthew Flinders named Mount Lofty and described the Mount Lofty Ranges as a 'range of moderately high, well wooded hills rising in height to Mount Lofty'. Peter Good, gardener on the same voyage, provides a slightly more detailed description of the Mount Lofty Ranges:

> 'a high range of hills which in ascent appeared broken rock with little vegetation but towards the bottom of the hills appeared well wooded and the greatest part of the summit were covered with vegetation, much smoak [sic] rising between the foot of the hills and the shore' (Flinders, 1814).

Flinders drew a chart of the Fleurieu Peninsula on which he described the southern coast of the Fleurieu Peninsula, from Cape Jervis to Victor Harbour, as being 'high and barren land much interspersed by gullies'(Flinders, 1814). No further descriptions of the Fleurieu Peninsula were found from the Flinders voyage. More detailed description of the environment and several pictorial representations were made on neighbouring Kangaroo Island where the Investigator moored for several days (Perry and Simpson, 1962; Flinders, 1814).

Nicolas Baudin followed the eastern coast of the Gulf of St Vincent, or Gulf de Josephine as he named it, 'close in' and described the shore and mainland:

> 'The shore sometimes presents perpendicular cliffs....little coves, terminating in sandy beaches where it should be easy to land. The interior of the coast, up to a certain distance is a range of mountains, piled atop of each other on most of which is exposed bare rock; the scene is often picturesque and even agreeable, despite the aridity of the soil....The chain of

> mountains, which is not very extensive, is replaced by a low level land, covered with trees and forms the inlet advancing northwards.'(In Cooper, 1952, p.76).

In two later journal entries Baudin again mentions his impression of the lack of vegetation of the land on the eastern side of the Gulf:

> '...most of the ranges were devoid of trees or clothed with others that have lost their leaves and for the most part only reveals an arid land covered with dry straw herbage.' (In Cooper, 1952 p.87).

And:

> 'This part of the land was nearly devoid of trees but offered nevertheless, several picturesque points of view.' (In Cooper, 1952, p.88).

Baudin's mention of 'dry straw herbage' suggests that in this description of 'ranges' he was also referring to the western plains flanking the Mount Lofty Ranges. The observations were made in early April, before the opening winter when little green grass would have been present.

Descriptions of the treelessness of the Mount Lofty Ranges contradict those made by Flinders and Good further suggesting Baudin was including the grassy woodland plains in his impression.

Freycinet, aboard the *Casuarina,* the second brig accompanying *Le Géographe,* described the coast of the Fleurieu Peninsula. But unlike Baudin, he did not give the impression that the land was so lacking in tree cover:

> 'Just north of Cape D'Alembert (Cape Jervis) the coast turns sharply to the east and forms Hortense Bay [Normanville-Yankalilla] with Cape Laetitia as its northern extremity. Although not mountainous, the coast here is fairly high; everywhere one sees arid soil covered with dry grass and drooping trees'(In Cooper, 1952, p.50).

Freycinet is likely to be describing the vegetation of the coastal hills and plains running at least between between Cape Jervis and Yankalilla. *Allocasuarina verticillata* most obviously fit the description of 'drooping trees' although the habit of *Eucalyptus* may also have appeared as drooping to Freycinet.

Peron, the naturalist on the Baudin expedition, only made a brief description of the Fleurieu Peninsula and Mount Lofty Ranges region and in the exploration journal provided no clue as to the vegetation he saw, only writing '...very high land with several rows of mountains, apparently of granite' (Cooper, 1952 p87). As with the Flinders voyage, more time was spent around Kangaroo Island and so considerably more natural collection and description was undertaken than on the neighbouring mainland (Horner, 1987).

European presence in South Australia was scant between the time of the Baudin and Flinders expeditions in 1802 and the establishment of the colony in 1836. In 1831 the boat *Isabella,* captained by Captain Collet Barker, was dispatched by Governor Darling of New South Wales to investigate Lake Alexandrina. The expedition travelled along the eastern side of St Vincent's Gulf. Barker anchored in what was to be called Rapid Bay and from here he and several of his companions crossed overland to the mouth of the River Murray (Elder, 1984). Barker lost his life trying to swim across the Murray. No account of Barker's voyage or of the first overland travel by a European of the Fleurieu Peninsula is known to exist (State Records SA, Research Note 309).

From early in the 1800s bands of whalers and sealers from Tasmania occupied Kangaroo Island and made journeys to the mainland to both hunt and procure Aboriginal wives (Amery, 1998). A single brief account pertaining to the Fleurieu Peninsula from this time was made by Jones, a whaler travelling on the schooner *Henry* in June 1834 landed at Cape Jervis. He noted:

> 'the land was very fine, the soil rich and covered with fine grass to the very top: the timber was gum, sheoak, and wattle, but no scrub... ...' (Napier, 1835, p.35).

Jones moored in the Victor Harbour region and travelled inland on foot and also described the vegetation as being open:

> '...the country was very fine, the soil rich and black, the grass very high and thick, and the country abounding with Kangaroo and emues [sic]; the hindquarters of one kangaroo here killed weighed 105lbs. The country is not very thickly wooded; open spots of 400 to 500 acres occur frequently. And there is no scrub on any part...' (Napier, 1835, p.36).

In 1836 Colonel William Light was dispatched from England in the *Rapid* to find a suitable site for the capital city of the newly-planned colony of South Australia. His first point of landing on the mainland of South Australia was in September on the Fleurieu Peninsula at Rapid Bay. Enthusiasm and excitement are evident in Light's first impressions of the landscape recorded in his *Brief Journal*:

> 'I went on ashore and was enchanted with the appearance of the whole. A fine stream of fresh water ran through the middle of the valley into the sea, and the soil was rich beyond my expectations;...I walked up one of the hills and there was an appearance of fertility and a total an absence of those wastes and barren spots, which the accounts in England had led me to believe.' (In Elder, 1984, p.67).

This visit provided the first pictorial depictions of the landscape of the Fleurieu Peninsula. Colonel Light painted a watercolor of Rapid Bay (Figure 3. 2), depicting part of the bay and surrounding northern hills. The work is faint and sketch-like, however the impression of the hills is that they are very lightly, if at all, tree covered. John Michael Skipper, a lawyer and amateur artist, arrived in the *Africaine* in 1836 and painted a small watercolour of the Rapid Bay and surrounding hills from the boat (Figure 3. 3). This painting illustrates a greater areal extent, than does Light's watercolour. The land closest to the shore is depicted as having a very light cover of trees and the more distant hills are dotted with trees, giving an impression of an open woodland.

A useful observer, Dr John Woodforde, surgeon aboard the *Rapid*, kept a regular diary of the voyage and he too wrote of the landscape around Rapid Bay in positive terms. He attempted to describe the new vegetation as best as its unfamiliar nature allowed:

> 'the cape, as far as we have seen, consists of beautiful valleys and corresponding hills. This soil is very good and the grass growing in its natural state is abundant… ….The trees and plants are very numerous. Of the former the Gum tree grows to an immense size rivalling in splendour our English Oak. The Gum, the Oak and the wattle tree abound here also—the later affords a very astringent bark which is much used in the colonies for tanning. I also found the common bramble and a beautiful scarlet vetch, several kinds of lupin and heart's ease. One of our party likewise found a primrose similar to that found in England. The land here not being thickly wooded may be cultivated with very little trouble and there are many spots that appear to me to be particularly eligible for settling farmer in its present state would fatten stock of any description.' (Woodforde, September 28, 1836, pp.13-14).

This description provides some information of the floristic composition of the trees painted in Light's and Skipper's watercolours. However interpretation of the some of the plant names Woodforde uses is difficult. The common bramble could be the spiny *Acacia paradoxa*; 'Oak' is possibly sheoak, wattle trees description could have included *Acacia pycnantha* and 'scarlet vetch' a red flowering species in the Leguminosae family or *Epacris impressa*.

Descriptions made by Mary Thomas on November 6th 1836 of the Rapid Bay region concur with Skipper and Light's paintings and the descriptions made by Light and Woodforde. Thomas, a passenger on the *Africaine* wrote:

> 'The country as far as we could see was certainly beautiful, and resembled an English park, with long grass in abundance and fine trees scattered about, but not so many as to make it unpleasant, and no brushwood. We were about a hundred yards from the nearest lagoon, where at the time there was plenty of water and very clear. Nor was it bad tasted though not from a running stream' (In Thomas, 1925, p.58).

Figure 3. 2 *Rapid Bay* 1836 by Colonel William Light.

Figure 3. 3 *Rapid Bay* 1836, by John Michael Skipper.

Another description made by Mary Thomas in her diary from the same location reads:

> A party from the vessel went on shore and gave on their return a most enchanting account of the country which everywhere resembled a gentleman's park, grass growing in the greatest luxuriance and the most beautiful flowers in abundance, with birds of splendid plummage ... ' (In Thomas, 1925 p.26)

John Woodforde remained camped at Rapid Bay from Sept 8th 1836 to January 27, 1837 with a survey party, while Light carried out reconnaissance survey of other parts of South Australia. Woodforde occupied himself with shooting expeditions inland from the Rapid Bay and occasionally accompanying the surveying party on their walks, from which he made several descriptions of the regional vegetation. On one occasion he walked inland '3 miles from Rapid Bay' and wrote:

> 'the soils in the valleys is excellent but that on the hills is shallow and mixed with rocks and stones of many kinds ... we found some fine Cypress and Cedar tree, likewise daisies similar to those in English meadows' (Woodforde, 1836: p.17).

The 'Cypress' and 'Cedar' tree descriptions are probably *Callitris preissii*, Southern Cypress pine, and, or, *Exocarpus cupressiformis*, Native Cherry, both similar in habit to a cypress and members of cedar description. Members of the *Juniperus* family (Cupressaceae) are colloquially referred to as Cedar.

Light provided further descriptions in his *Brief Journal* of areas in the Fleurieu Peninsula. He anchored at Second Valley and from here walked to Yankalilla (Williams, 1919; Elder, 1984) writing of the Second Valley:

> '... we beheld a valley three times as large as the last [Rapid Bay] and equally rich in soil; there is an abundance of wood all the way, yet not so thick that Agriculture might not be persued without the trouble of clearing. From this we walked to Yankalilla over undulating ground of good quality and wooded in the same way mentioned.'(In Elder, 1984, p.66).

Light was much taken by the landscape at Yankalilla: 'I was enchanted with this spot, it put me in mind of some of the orchards in Devonshire, and I found it plentifully supplied with fresh water' (In: Dutton and Elder, 1991, p.164). Light painted 'View at Yankalilla' (Figure 3. 4), a watercolour of the survey party in Yankalilla. The painting depicts tents on a reasonably flat plain by a river, which is probably the river Bungala, and distant hills. The valley floor and surrounding hills are covered by scattered trees and a few trees of larger stature line the river's edge. While the scale of the painting is difficult to ascertain, and can not be assumed to be correct, the painting does provide a means of generally interpreting the highly qualitative description of tree density made at the time. Trees cover clearly looks to be less than 10% and thus conforms to the modern definition of open woodland.

Figure 3. 1 *View at Yankalilla*, 1836, by Colonel William Light

The openness of the tree cover of the Yankalilla region was recorded by other early visitors. John Morphett, a land agent and employee of the South Australia company, accompanied Light on his survey of Yankalilla in 1836 and his descriptions are similar to those made by Light:

> 'The portion of this which I have explored consists of a fine rich soil with abundant herbage, and some very fine trees. These are principally blue gum, which is a most elegant tree of great magnitude growing only on rich land. When I visited it with Mr. Kingston we measured one of these lords of the Australian forest and found it to be twenty one feet in girth. Fourteen and fifteen foot is a very common size, with a straight trunk in many instances sixty feet high. Although I have stated this plain [Yankalilla], and several other places, to be well-wooded, it must not be assumed that a great outlay would be required for clearing. Generally it would not be advisable to fell a single tree for sheep feeding, and, in numerous instances, it would not be necessary for agricultural purposes. (Morphett, 1836, p.7).

Morphett notes that some of the coastal hills are less timbered, indicating that some plains were possibly very open. This description probably pertains to the Myponga Beach region:

> 'Above Yanky Lilly the hills come in a very bold manner to the sea, but soon recede again, leaving an undulating country for a few miles of a singular description. The different elevations have perfectly flat tops, are covered with a nice herbage, and are more bare of trees than we have hithero seen' (Morphett, 1836, p.8).

In a letter discussing reasons for favouring the site chosen for the capital, Morphett writes in February of 1837 of the Fleurieu Peninsula to Adelaide, further emphasising the openness of the plains:

> 'The country from Cape Jervis upwards is very picturesque,...a range of hills with valleys opening through to the back...and all would furnish good feed during the winter. The country between there and the sea is very diversified, in some places undulating and in others level with plains both open and elegantly wooded. There are many streams running

> into the sea, with very deep channels, These in summer are low and a few of them dry ... Any person landing on the coast for the first time at the present season might entertain an unfavourable impression for the soil because the land looks bare and sterile.' (Morphett, 1936, p.31).

Early travellers frequently mentioned the abundance of grass in certain parts of the Fleurieu Peninsula. Y.B. Hutchinson made an overland journey to Encounter Bay and Lake Alexandria in 1837. He passed through Willunga, ascended the hills to the south of it and then followed a 'beaten track', which was presumably Aboriginal (Clarke, 1996) to Encounter Bay. He made mention of both the stringy bark or 'scrubby' country and open grassy lands. Just after he had ascended the Willunga Hills he wrote:

> 'The whole forest had been burnt and the fallen trunks lay concealed by the shoots which had sprung from the stumps and were 3-5 feet high ... dined on a pretty level and open plain, covered with long thick grass and having a stream through the middle of it' (State Records SA, Research Note 831).

An abundance of grass is again recorded by Hutchinson. He describes the Mootiparinga Valley [Hindmarsh Valley];

> 'We proceeded through a flat valley about 8 miles long and 2 miles wide with a stream running across it, and covered with the most luxuriant grass I have ever seen in the colony.' (State Records SA, Research Note 831).

Four years after the first formal surveys and land uptake in the Yankalilla and Rapid Bay regions, George French Angas painted a series of watercolours, from which lithographs were made by J.W. Giles, and published in the *South Australian Illustrated* (French Angas, 1847). French Angas was commissioned by the South Australia Company, who sought to promote the new colony, and used views of South Australian scenery to do so. Eight of these works are of scenes located in the Fleurieu Peninsula. While it can reasonably expected the works have had a propagandist role (Bonyhady, 1985), and depict ideal pastoral scenes, they provide further putative evidence of the structure, particularly of dominant overstorey tree density in grassy woodland formations, around the time of European settlement.

The work 'Currakalinga looking over St Vincent's Gulf' shows the hills above Carrikalinga and the course of the Carrikalinga Creek to the Gulf (Figure 3. 5). The vegetation on the hills is grassy open woodland, with little evidence of shrub understorey being present. The type of trees comprising the woodland are not easily discerned. But, in notes accompanying the lithograph, French Angas (1847) wrote 'the trees in this scene are predominantly Casuarinae or she-oak with Eucalyptus near the water...'. That Casuarina, most probably *Allocasuarina verticillata*, was a conspicuous component of the grassy woodlands in the region is further suggested by an excerpt from a letter written by an 1850s inhabitant of Yankalilla 'there are not many kinds of tree here, the gum tree and the sheoak are perhaps the commonest.... .the cattle are very fond of it and if you fell one of the trees you will soon have cattle fighting to get at it' (Wornum, 1850,in Williams, 1991, p.52).

Figure 3. 2 *Currakalinga* (overlooking St Vincents Gulf), 1844, JW Giles after George French Angas.

Yattagolinga' (Figure 3. 3) is described by Angas as a scene 'representing the high and bold hill between Rapid Bay and Cape Jervis...the spot is about 3 miles inland from Rapid Bay, on the property of Messers Phillips... the trees on the right are two species of *Xanthorrhoea*, and those on the left are young silver wattles'.

Figure 3. 3 *Yattagolinga*, 1844, JW Giles after George French Angas

The painting provides further evidence of the openness of the tree cover in the Rapid Bay region, particularly on the steeper slopes of the hills. From the large stature and particularly emphasised crowns of the mid ground trees it appears as though *Eucalyptus* dominate the overstorey tree cover. A pair of foxes are represented in the foreground and it is probable that they were additions made by the lithographer, to liken the landscape to notions of an ideal English countryside. Comparison of the original watercolour of 'Encounter Bay' (French Angas, AGSA) and the derived lithograph in the *South Australia Illustrated*, shows that Giles did take the liberty of changing French Angas's works. French Angas has carefully painted a tree with droopy, cylindrical and slender foliage, very likely to be *Allocasuarina verticillata*, in the foreground of 'Encounter Bay'. Giles has depicted the same tree but changed the foliage to a brighter green and fuller more ovoid shape, making it more in character with the foliage of European trees in order to make the foreign landscape more familiar and appealing to prospective immigrants.

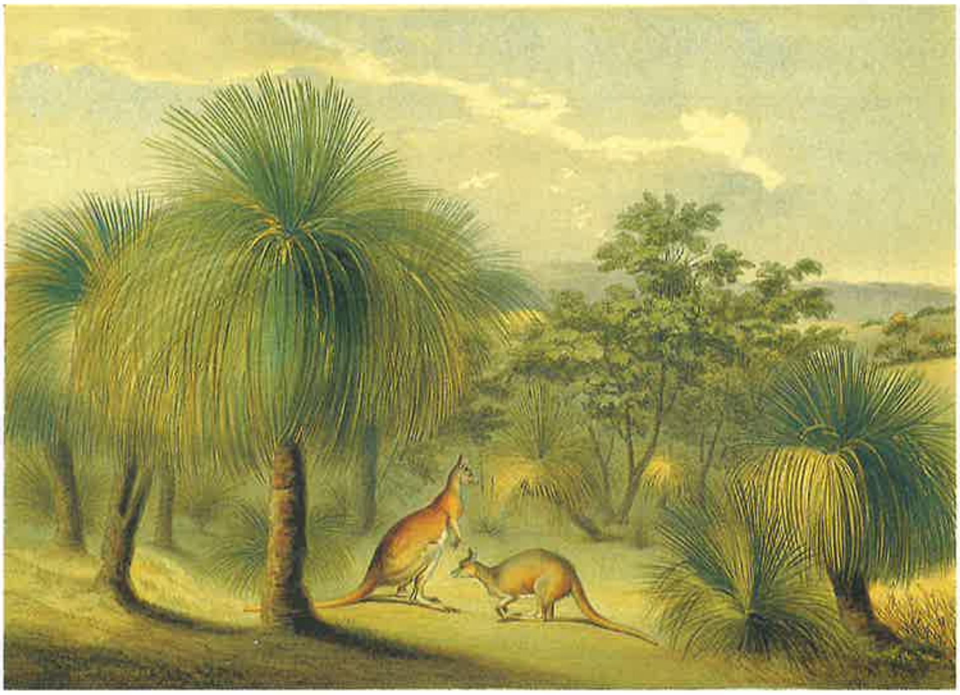

Figure 3. 4 *Grass trees at Yankalilla with the red Kangaroo*, 1844, JW Giles after George French Angas

'Yattolgolinga' shows *Xanthorrhoea* to have been an understorey component of the grassy woodlands. Another French Angas work 'Grass trees at Yankalilla with the red Kangaroo' portrays two kangaroos surrounded by stand of grass trees which clearly stand taller than them (Figure 3. 4). The picture is accompanied by the following description of *Xanthorrhoea*:

> 'this scene depicts the largest variety of the Xanthorrhoea which is to be met in South Australia....this magnificent species occurs most frequently in the glens and gullies of the mountains about Rapid Bay and Cape Jervis, not far from the picturesque residence of Mr Kemmis [Yankalilla], and vary from 10-15 feet in height'.

'Entrance to the Gorge at Yankalilla' by French Angas portrays the plain at the fore of The Gorge about two kilometres to the south of Normanville, and the hills that form The Gorge (Figure 3. 8). Casuarina, low *Xanthorrhoeas*, herbs and long grass are painted in the foreground. *Eucalyptus* shaped trees form a very open cover on the plain and hills. The trees are not uniformly patterned; large patches are without them on the hill faces.

Figure 3. 8 *Entrance to the Gorge at Yankalilla*, 1844, JW Giles after George French Angas

Only very few early descriptions and a single picture of the sclerophyll woodlands vegetation were found from the early exploration and settlement period. Woodforde in 1836 walked to the more elevated inland range regions behind Rapid Bay and his diary provides the first known description of the sclerophyll woodland formations in the region:

> 'We travelled further inland than I have yet been and the country, especially the hills is much more wooded than our immediate neighbourhood. Thus Gum trees are of an immense size and would make an abundance of fine timber, the common diametre of a fully grown tree is from three to four feet. The soils on the hills is very bad, being dry and filled with stones, most of which are strongly impregnated with iron.'(Woodforde, 1836, p.48).

Edward Snell travelled from Tunkalilla Beach to Second Valley in 1850 and made the following description of the highland vegetation, which provide the only information on the density of the *E. obliqua* and *E. baxteri* forests at a time close to settlement.

> 'ascend up a hill covered with a dense forest of thin oak, Gum and grass trees - on reaching the top all we could see was a mass of forest spreading over the ranges and gullies for hundreds of square miles...we proceeded through a stringy bark forest, the trees were very large and straight and so close in many places that scarcely a ray of sunshine could find its way through them.' (Snell, 1856 in Griffiths, 1988).

Snell made a sketch of the stringy bark forest during his travels and it shows overstorey trees to be closely spaced, with crowns touching and gives the impression of *Xanthorrhoea* being a major component of the understorey (Figure 3. 9).

Figure 3. 9 Stringy bark forest east of Rapid Bay, 1850, by Edward Snell.

Figure 3. 10 shows locations of early paintings and observations made by explorers and settlers. Table 3. 1 and Table 3. 2 present a summary of the vegetation information interpreted from descriptive and pictorial records.

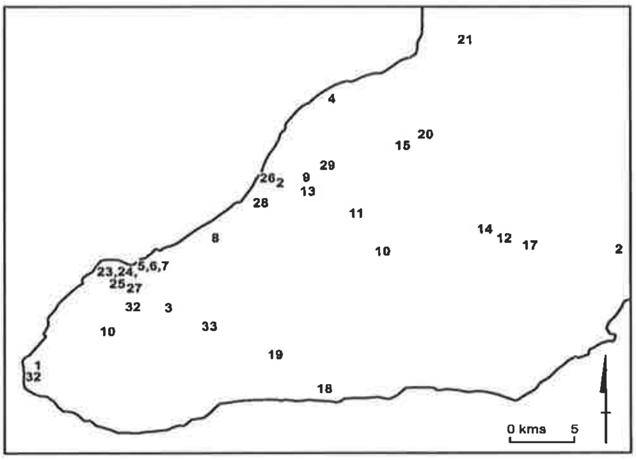

Figure 3. 10 Locations of pictorial and descriptive records of vegetation from 1802-1889 summarised in Tables 3.2 and 3.3. Numbers 1-21 are descriptive records (Table 3.2) and numbers 22-34 are pictorial records (Table 3.3).

Table 3. 1 Descriptive accounts of pre-1880 vegetation. Map location refers to location of observation depicted on Figure 3. 10. Vegetation structure is described using the following abbreviations: T=trees, TT=dense trees, TO=trees but open, S= scrub or shrubs, G=grass, GG=much grass.

Site no. Fig 3.10	Author of description	Source	Authors description of location of observation	Vegetation description	Floristic references
1	Jones, 1834	Napier, 1835	Cape Jervis	Hills: G, T, no S	gum, sheoak and wattle
2	Jones, 1834	Napier, 1835	Hindmarsh Valley	Valley: GG, TO	
3	Morphett, 1836	Morphett, 1836	Ranges behind Rapid Bay?	Hills: T	
4	Morphett, 1836	Morphett, 1836	Myponga region	Hills: TO	
5	Woodforde, 1836	Elder, 1984	Rapid Bay	-	immense gum trees, common bramble, scarlet vetch, heart's ease, primrose
6	Morphett, 1836	Morphett, 1836	Hills around Rapid Bay	Hills: T	
7	Thomas, 1836	Thomas, 1925	Rapid Bay	GG, TO, no S	
8	Light , 1836	Elder, 1984	Second Valley to Yankalilla	TO	
9	Morphett, 1836	Morphett, 1836	Yankalilla	GG, TO	
10	Woodforde, 1837	Woodforde, 1837	Rapid Bay to Cape Jervis	T	
11	Herbertt, 1842	Morphett, 1941	Yankalilla (north side of Bungala)	T	manna (*Eucalyptus viminalis*)
12	Brock, 1843	Brock, 1843	Inman Valley	Valley: TO?	
13	Brock, 1843	Brock, 1843	Yankalilla	G	
14	Wilkinson, 1849	Wilkinson, 1849	Inman Valley (road to Yankalilla)	Hills near valley: GG, no T, no S Distant hills: TT	
15	Snell, 1850	Griffiths, 1988	Yankalilla to Myponga	Hills: S	grass tree, scrub
16	Wornum, 1850	Williams, 1991	Bald Hills	TO	gum tree and the sheoak
17	Wilkinson, 1849	Wilkinson, 1849	Inman Valley	Valley: no G (but 'grass originally here')	
18	Snell, 1850	Griffiths, 1988	Slopes from Tunkalilla	Hill slopes: TT, S	thin oak, gum and grass trees
19	Snell, 1850	Griffiths, 1988	Plateau above Tunkalilla	Plateau: TT	
20	Sutherland, 1889	Sutherland, 1889	Myponga region	Ridges: S Valleys: TO	
21	Sutherland, 1889	Sutherland, 1889	South from Sellicks Hill	TO, G S	

Table 3. 2 Pictorial works representing pre-1850 landscapes and vegetation in the Fleurieu Peninsula. Map location refers to location of observation depicted on Figure 3. 10. Vegetation structure is described using the following abbreviations: T = trees, TT = dense trees, TO = trees but open, S= scrub or shrubs, G = grass, GG = much grass.

Site no. Fig 3.10	Artist, title and year undertaken	Description of location	Depicted vegetation structure	Possible floristic composition of vegetation
22	William Light, *View of Yankalilla*, 1836	Probably mouth of Bungala River	Hills: TO River: T, S Plain: Open - shrubs	*Eucalyptus*
23	William Light, *Rapid Bay*, 1836	Rapid Bay	Bay: 0T, 0S Cliff and hills: 0T	-
24	JM Skipper, *Rapid Bay*, 1836	Rapid Bay and surrounding hills	Shore: OT Hills: TO	-
25	G French Angas, *Rapid Bay, with encampment of Yankallilah blacks*, 1844	Rapid Bay	Shoreline: OT, OS Coastal hills: OT and TO, few shrubs	-
26	A. Butler after William Light, *Second Valley*, 1836	Probably Rapid Bay or Normanville	River plain: 0T Surrounding hills: T	-
27	G. French Angas, *Mount Lofty from Rapid Bay*, 1844	Cliffs above Rapid Bay	Hill tops: (foreground): TO, SO, H, G Hills (background): TO	*Allocasuarina*, herbs, small *Eucalyptus* or wattle and *Banksia*
28	JW Giles after GF Angas, *Entrance to the Gorge, Yankalilla*, 1844	Yankalilla.	Plain: TO Hills: TO, OT	*Allocasuarina*, *Eucalyptus*, *Xanthorrhoea*
29	JW Giles after GF Angas, *Currakalinga – looking over St Vincents Gulf*, 1844	Top of Carrickalinga Creek.	Hills: TO Plain: TO Creekline: TT	*Eucalyptus*, *Allocasuarina*
30	JW Giles after GF Angas, *Cape Jervis*, 1844	Cape Jervis.	Bay: TO Hills: TO and OT	
31	JW Giles after GF Angas, *Grass Trees at Yankallillah with the Red Kangaroo*	Yankalilla	Plain: TO, S, H, G	Tall *Xanthorrhoea*, *Acacia* trees, *Eucalyptus* with big crowns in the distance.
32	JW Giles after GF Angas, *Yattagolinga*, 1844	Rapid Bay	Plains: TO Hills: TO	*Xanthorrhoea*, white barked Eucalyptus, wattles
33	Edward Snell, *Stringy bark forest East of Rapid Bay*, 1850	Stringy bark forest east of Rapid Bay	Plateau of ranges: TT, S, G	*E. obliqua* and/or *E. baxteri*, *Xanthorrhoea* and grass
34	Edward Snell, *Water hole on the road to Rapid Bay*, 1850	Water hole on the road to Rapid Bay	Plateau of ranges: TT	*E. obliqua* and/or *E. baxteri*

3.3.2 *Survey records*

3.3.2.1 Species information: terminological interpretation and distribution of observations

The following terms were found in the Fleurieu Peninsula survey records describing floristic qualities of vegetation; stringy bark, yacca, grass tree, small gums, gum, mallee, sheoak, tea tree, prickly acacia, wattle, grass, honey suckle and bushes. Each common name is discussed in relation to the species or group of species to which it is most likely referring to, the number and areal extent of observations. Maps of the distribution of observations are presented as Figures 3.11 to 3.21.

3.3.2.1.1 Stringy Bark

Observations of stringy bark were widely made in the 1880s phase of survey in field book notes and diagram books (Figure 3. 11). They were occasionally made in the 1840-75 survey period. Stringy Bark is the presently-used colloquial name for three species of *Eucalyptus* occurring in the Mount Lofty Ranges; *E. obliqua, E. baxteri* and *E. goniocalyx.* Of these species, only *E. obliqua* (Messmates Gum) and *E. baxteri* (brown stringy bark) have present day distributions in the Fleurieu Peninsula, occurring as dominant overstorey species in the sclerophyll communities in the more elevated parts of the region. The term stringy bark is accompanied with forest, scrub, stunted, trees or bushes. Such qualifications provide some insight into whether *E. obliqua* or *E. baxteri,* or a combination of both, is the subject of the reference. Stringy Bark presence was recorded on total of 243 sections, which encompass an area of 25 966 ha. A total of 203 field book text records of stringy bark occurrence were digitised and classified an area of 1470 ha.

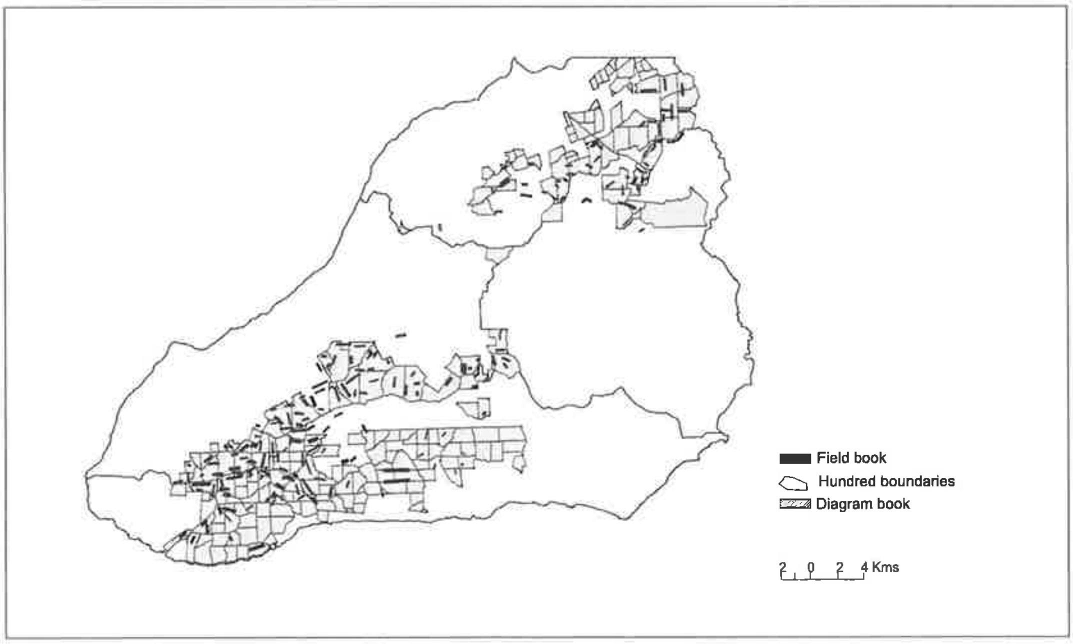

Figure 3. 11 Survey sections recorded as having stringy bark present and the field text observations of stringy bark locations within sections.

3.3.2.1.2 Grass trees and yacca

Records of grass tree and yacca presence were widely made in the 1880s diagram and field books (Figure 3. 12). Grass tree and yacca have present day usage as colloquial names for *Xanthorrhoea* spp. and it is likely that the meaning of the term has not changed since it was used in the original *Xanthorrhoea semiplana* subsp. *tateana* is the only member of the genus extant in the Fleurieu Peninsula today. The species was once considered to be two, *X. semiplana,* a stemless, or with very short stem, type and *X. tateana,* a longer stemmed type with a stem 1-4m high (Black, 1978). The section data classify an area of 35 422 ha and field book text an area of 912 ha.

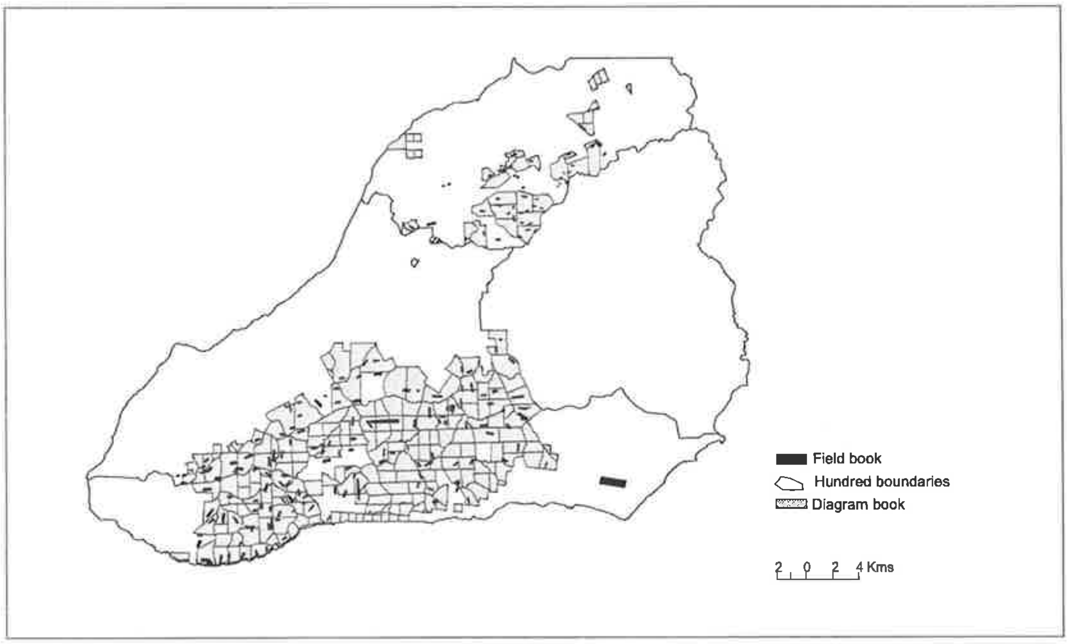

Figure 3. 12 Sections which were recorded as having grass tree or yacca present and the field text observations of grass tree or yacca locations within sections.

3.3.2.1.3 Small (low) gums

Observations of small gums, stunted gums, and low gums were widely made in the 1880s section and field book text survey records (Figure 3. 13). Low, stunted and small gum records are treated as equivalent terms. In numerous instances small gums were recorded in the field book notes and transcribed into the diagram book as 'gum scrub' and so small gums were assigned to sections with the gum scrub description. Gum has present day use as a colloquial name for white-barked *Eucalyptus* species. White-barked *Eucalyptus* types were distinguished by surveyors from other types, as indicated by the rough and dark-barked species, *E. obliqua* and *E. baxteri,* being referred to as stringy bark. It is likely that more than one species is encompassed by the description of small gums. *Eucalyptus leucoxylon* subsp. *leucoxylon, E. viminalis* subsp. *cygnatensis, E. fasciculosa, E. camaldulensis, E.ovata* and *E. cosmophylla* are the commonly occurring smooth-barked *Eucalyptus* species with distributions in the Fleurieu Peninsula today. *Eucalyptus cosmophylla* and *E. fasciculosa* have stunted or small tree forms. *Eucalyptus cosmophylla,* cup gum, occurs as a bush to a small tree from 2 to 5 metres high and *E. fasciculosa,* pink gum, as a tree from 5 metres to on infertile soil and to 15 metres on fertile soils. *Eucalyptus leucoxylon* occurs as a tall open woodland species but also in a stunted form in association with *E. fasciculosa.* It is unlikely that *E. camaldulensis* or *E. viminalis* were described as small gums as both species are more prominently distributed in the regions of lower elevation, not included in the 1880s survey, and rarely occur in dwarf form. A total of 83 sections amounting to 6534 ha are classified as small gums and 302.2 ha were classified by field book text observations.

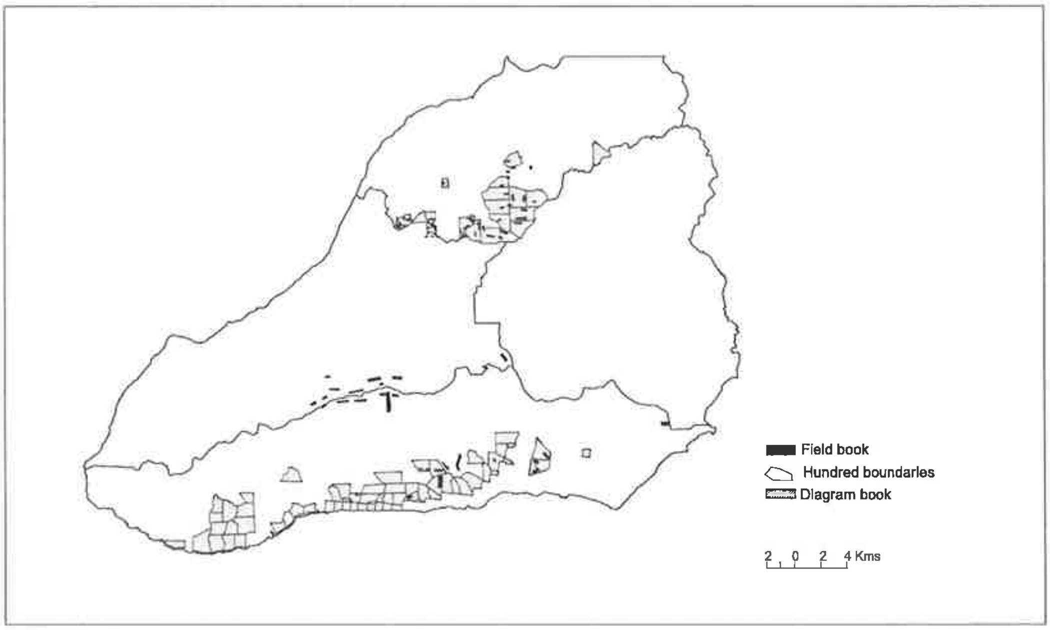

Figure 3. 13 Sections recorded as having small gums present and the field text observations of small gums locations within sections.

3.3.2.1.4 Gums

Gums were occasionally recorded on sections in diagram books occasionally in the 1841-1875 survey but were more commonly recorded in section descriptions and in field books in the 1880s surveys (Figure 3. 14). It is possible that the description of gum was loose usage of the description of small gum. However it is also possible that the term was being used more specifically and is referring to the taller white-barked species; *E. viminalis, E. leucoxylon, E. ovata* and *E. camaldulensis. Eucalyptus fasciculosa* could be included in both *gum* and *small gum* classes as it occurs as a tree of medium height as well as in a stunted form. Further information on the taxa or taxon possibly being referred to can be gleaned from consideration of the spatial distributions of field book and section descriptions of *gum* observations. The distribution and mean area of observations are different, suggesting that the observation types maybe referring to different *Eucalyptus* species. Field book text records of gum were more localised than records of other species, occupying a mean area of approximately 1 ha per observation compared with a mean area ranging from 4 to 12 ha for other text observations.

A number of sections with localised text records of gum presence in field books were not recorded as having a cover of gum in the transcribed diagram book. *Eucalyptus camaldulensis* and *E. ovata* both have specific ecological niches, and thus localised patchy distributions, in the uplands of the Fleurieu Peninsula; E *camaldulensis* along creek lines and *E. ovata* along swamp courses. Tall and localised stands of *E. leucoxylon* woodland were also occasionally found on patches of more fertile soil in the ranges (Boomsma, 1948; Jones, pers comm). It is possible that the text observations are more likely to be recording the presence of either, or all, of these species. A total of 41 text observations of gums were recorded, amounting to a classified area of 41.8 ha. A total of 66 sections had gums recorded and they cover an area of 4660 ha.

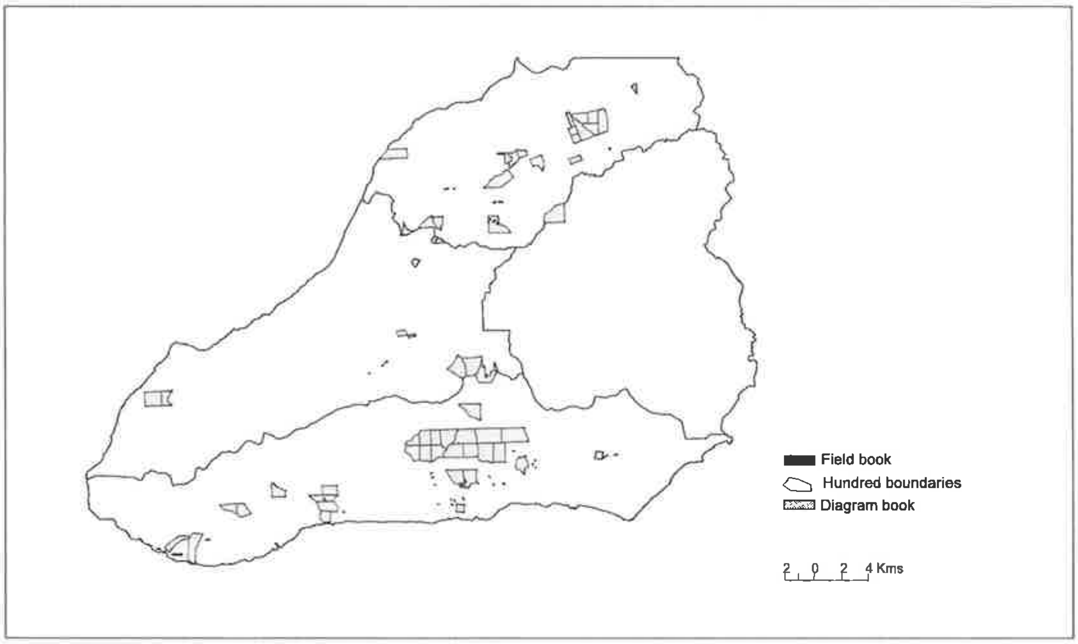

Figure 3. 14 Sections recorded as having gums present and the field text observations of gums locations within sections.

3.3.2.1.5 Mallee

Various modern usages of the word mallee exist. It can be a description of the growth habit of stunted and multi-stemmed *Eucalyptus* species, a name for the region where mallee species dominate and a noun describing species which exhibit a stunted and multi-stemmed growth habit. Mallee species with present day distributions on the Fleurieu Peninsula are *E. diversifolia, E. cnerifolia, E. rugosa, E. oleosa and E. anceps* and they all could be the subject of reference of the mallee description. It is not possible to discern the historical mallee observations to species level or if other stunted *Eucalyptus* species are being encompassed by the term. *Eucalyptus diversifolia* is the most abundant extant mallee species in the region, however Boomsma (1948) describes communities in the Waitpinga region, the area where historical observations were made, as being composed of mixes of all mallee species and with *E. fasciculosa.* Mallee was not a widely used term by surveyors, with only 8 sections covering an area of 2273 ha being classified (Figure 3. 23).

3.3.2.1.6 Sheoak

The colloquial name, sheoak, for species in the genus *Allocasuarina,* was used to describe the vegetation of sections surveyed in the 1841-75 and 1880's survey periods (Figure 3. 15). There are five extant *Allocasuarina* species in the Fleurieu Peninsula and they are *A. verticillata, A. meulleriana, A. pusilla, A. striata* and *A. robusta.* It is likely that the use of sheoak in the 1850s survey of the lower elevation and drier parts of the Fleurieu Peninsula refers to the grassy woodland tree species *A. verticillata.* These sections were described as being 'mostly timbered with sheoak'. Some of these sections were adjoined by sections described as having a cover of sheoak '... with a few gums and wattles' suggesting that a formation dominated by *A.verticilllata* was being described. Records in the sclerophyll landsystem areas are likely to be referring to *A. muelleriana, A. pusilla, A. striata* and/or *A. verticillata.* These species assume shrub habitats in the understorey of highland sclerophyll systems. *A. robusta* has only rare occurrence in swampy regions near Mount Compass so is probably not identified by these descriptions. Section description classify an area of 3850 ha.

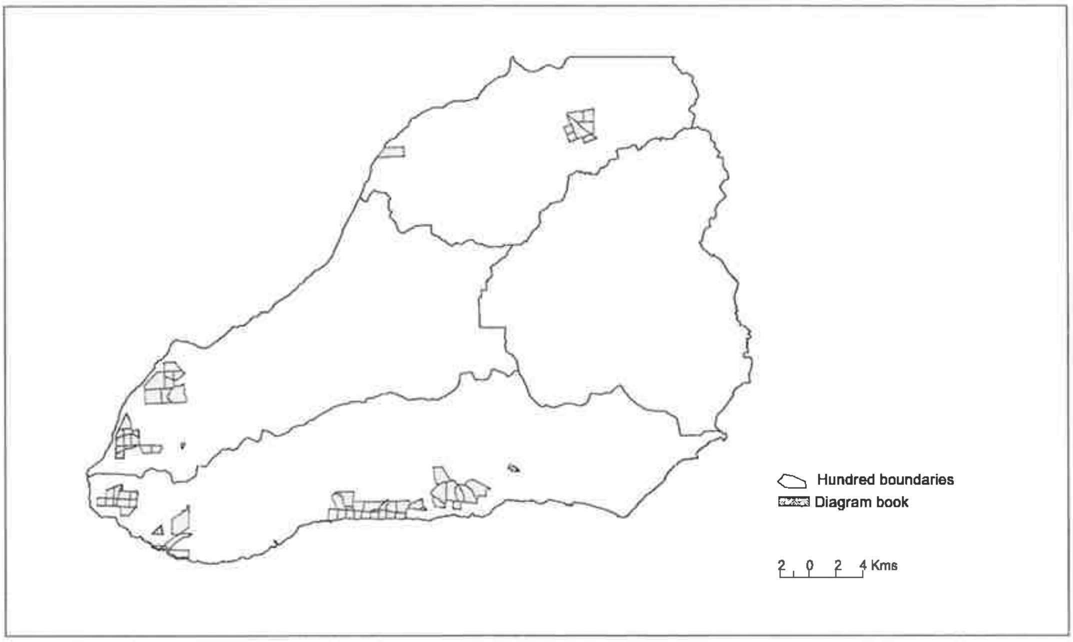

Figure 3. 15 Sections recorded as having sheoak present and the field text observations of sheoak locations within sections.

3.3.2.1.7 Tea tree

Tea tree is the still-used colloquial name for *Leptospermum* spp. Its presence was noted infrequently in the Fleurieu Peninsula surveys (Figure 3. 16) mostly in swamp areas. There are two swamp species in the region, *L. continentale* and *L. lanigerum.* Either of these could be the subject of the references.

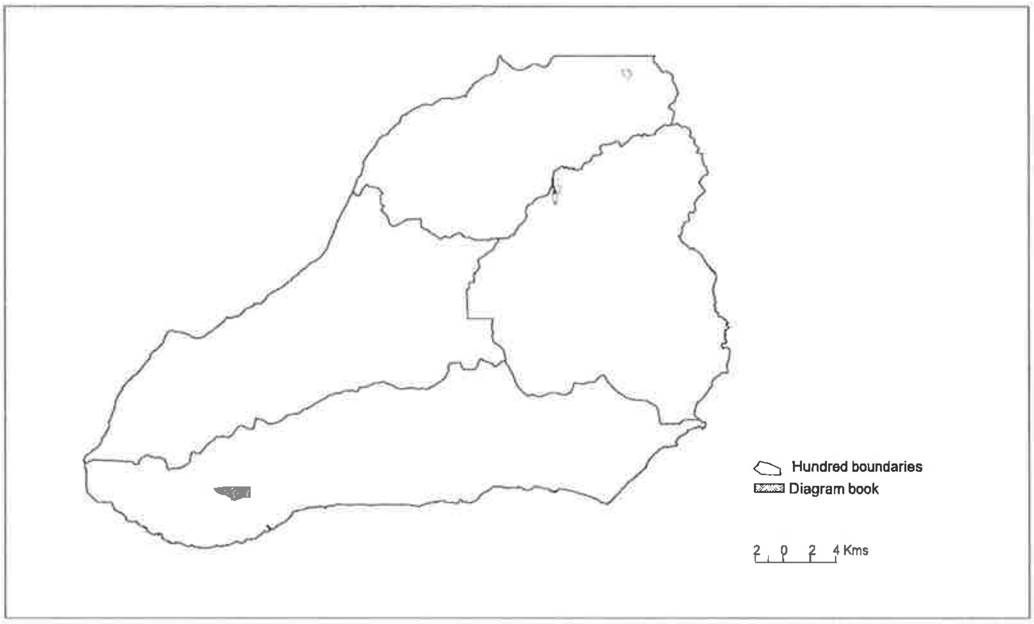

Figure 3. 16 Sections recorded as having tea tree present.

3.3.2.1.8 Honeysuckle

In South Australia, honeysuckle was the nineteenth century common name for *Banksia marginata* (Stow 1883), although it is likely that in the 1880s surveyors were using the term loosely to describe *Banksia* spp. *Banksia marginata* and *B. ornata* occur on the Fleurieu Peninsula. The sections in the Waitpinga region classified as having *Banksia* present, currently contain both species. *Banksia marginata* is more common on the ridge of the ranges, than is *B. ornata,* and so it is possible that observations in these regions are referring to *B. marginata.* The sections on which honeysuckle was described as being present are shown in Figure 3. 17 and classify an area of 2528 ha.

3.3.2.1.9 Prickly acacia and hedge bush

Observations of prickly acacia were made by S.W. Herbert in the 1880s surveys but were not found in earlier surveys of the region (Figure 3. 18). Prickly hedge bush and hedge bush, were recorded in field books and on occasions transcribed as prickly acacia, or just acacia, in the diagram book record for the same section. This indicates that acacia, prickly hedge bush and prickly acacia were used at times as equivalent terms of description. There are at least 11 indigenous species of *Acacia* on the Fleurieu Peninsula, but only *A. verticillata* (Prickly moses) and *A. paradoxa* (Kangaroo thorn) have spiny stipules and could be described as prickly. Both species have broad distributions across the Fleurieu

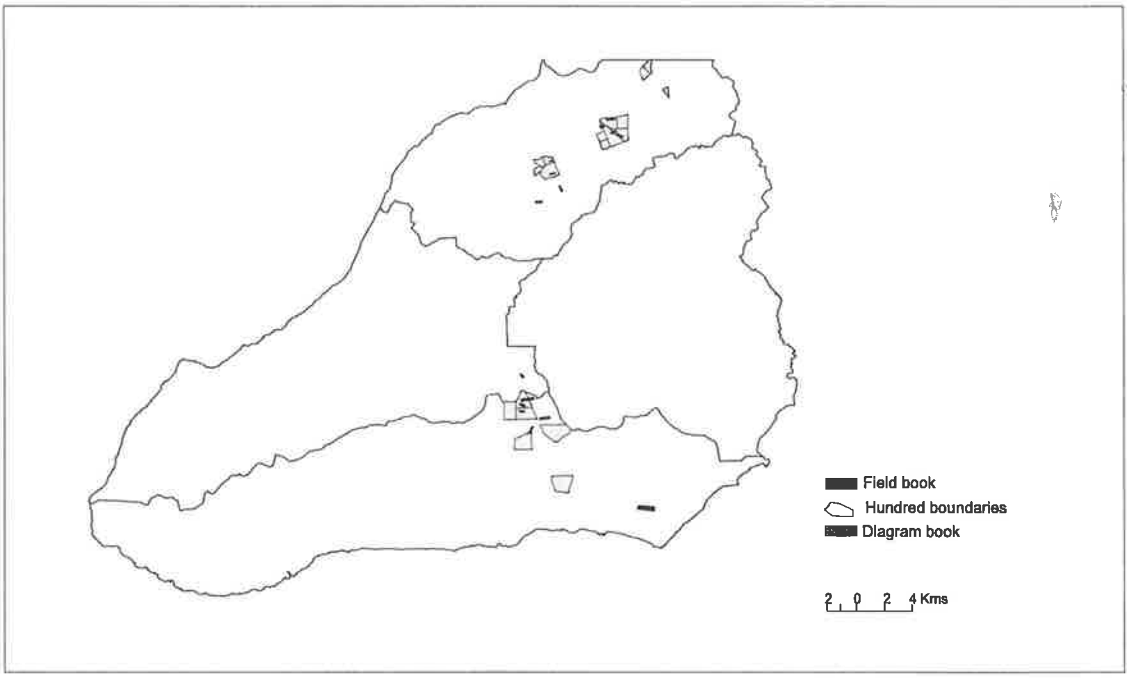

Figure 3. 17 Sections recorded as having honey suckle present and the field text observations of honeysuckle locations within sections.

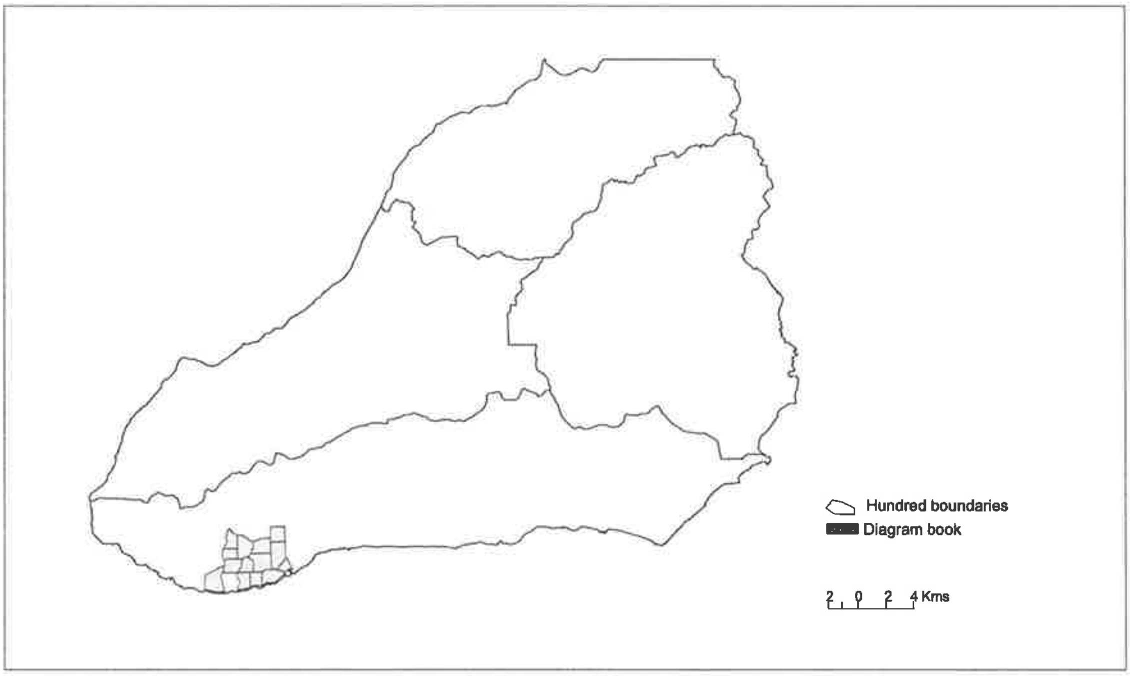

Figure 3. 18 Sections recorded as having prickly acacia present.

Peninsula and commonly co-occur. *Acacia verticillata* is a shrub 1-4m tall is usually found in damp places (Dashorst and Jessop, 1990) and *A. paradoxa,* a shrub 2-4m high, often occurs as a hedge (Black, 1978). *Acacia paradoxa* may be the species being described where surveyors record hedge bush or prickly hedge bush. In other cases where prickly acacia is recorded either *A. paradoxa* or *A. verticillata* could be present. The sections on which they are recorded cover an area of 15555 ha.

3.3.2.1.10 Wattles

Wattles, the common name for *Acacia* spp., were recorded as being components of the understorey in 1880 survey section records. *Acacia myrtifolia* and *A. pycnantha* are the most common species in the region today. *Acacia myrtifolia* is more commonly distributed on the highland regions as an understorey component of numerous sclerophyll associations while *A. pycnantha* is a common member of woodland understoreys. S.W. Herbert also used the term acacia so it is possible that wattle was referring to particular species of *Acacia.* At the time of survey the wattle bark industry was well established in the colony and possibly *A. pycnantha*, the species employed in the industry, were selectively called wattle. It is unlikely that the term is referring to *A.verticillata* or *A.paradoxa* as they are distinguished by the *prickly acacia* description. Sections denoted as having wattle are shown in Figure 3. 19 and cover an area of 1627 ha.

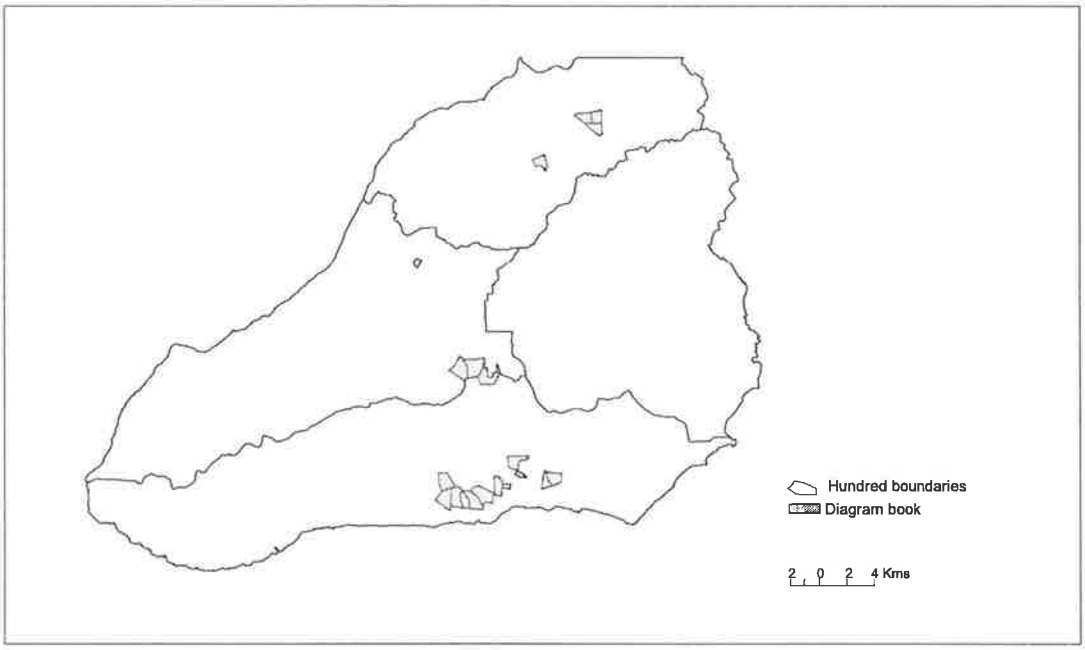

Figure 3. 19 Sections recorded as having wattles present.

3.3.2.1.11 Grass and grassland

Grass and grassland were recorded only in the 1880s surveys and, as such, observations are primarily restricted to areas of the sclerophyll landsystem. Grass would have been noted for the pastoral value it added. In some cases the observation was attributed to localised regions within a section and, in others, seemed to refer to the presence of grass in the understorey of possibly the whole section. For example a section was described as 'good grassland' and also as having a cover of small gums, sheoak and wattle while another was described as scrubby but with 'grass in watercourses'. Attributing precise species to the description is not possible, however *Neurachne alopecuridea* is presently a common understorey member of the *E. fasciculosa* very low woodlands in the region. At times the absence of grass was mentioned, particularly on scrub sections. A typical section description providing example of this is 'Stringy Bark scrub with a thick undergrowth of grass trees and bushes, no grass'. Sections having grass or grassland records are shown in Figure 3. 20. The area classified by these section observations is 3721 ha, most of the sections are situated along coastal regions.

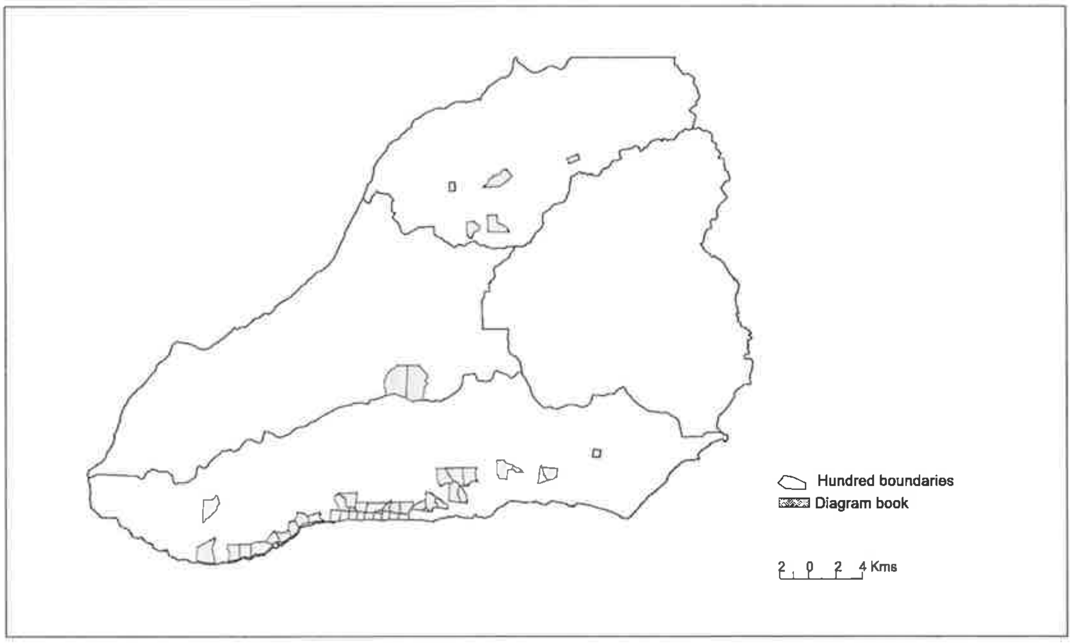

Figure 3. 20 Sections recorded as having grass and grassland present.

3.3.2.1.12 Bushes

The description dense bushes or dense undergrowth of bushes was widely used by 1880s surveyors, usually in conjunction with an overstorey species. An example is 'Stringy Bark scrub with an undergrowth of dense bushes'. Observations are mainly restricted to the highlands and are probably referring to sclerophyllous shrubs in the Proteaceae, Epacridaceae, Myrtaceae, Fabaceae and other families that dominate the understorey of these systems. Stringy bark scrub was sometimes described as being composed of 'Stringy Bark bushes', indicating that stunted forms of usually overstorey dominant Myrtaceae could have been included in this description in instances. The description, although floristically ambiguous, is useful in giving an indication of the density of the understorey at the time. Figure 3. 21 illustrates the sections to which this description was given and they classify an area of 2028 ha.

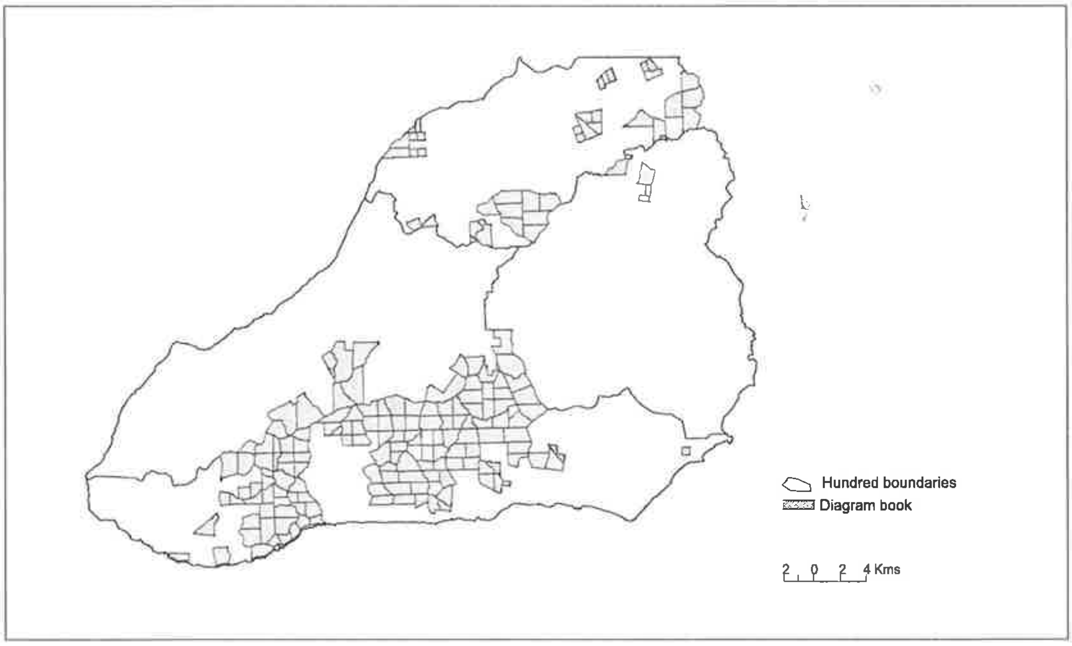

Figure 3. 21 Sections recorded as having bushes present.

Floristic observations and the species they are likely to represent are summarised in Table 3. 3.

Table 3. 3 Floristic names used by early surveys in Fleurieu Peninsula and species they may represent.

Historical description	Possible species	Sections		Text	
		No.	Area	No.	Area
grass tree	*Xanthorrhoea semiplana* subsp. *tateana*	243	35422	202	912
stringy bark	*Eucalyptus obliqua, E. baxteri*	243	25966	203	1470
small gums	*E. cosmophylla, E. fasciculosa, E. leucoxylon*	83	6534	74	302
gums- section	*E. fasiculosa, E. leucoxylon, E. viminalis, E. cosmophylla*	66	4660		
gums-text	*E. camaldulensis, E.ovata*			41	41.8
sheoak	*Allocasuarina verticillata, A. striata, A.robusta, A.muelleriana*	75	3850	8	40.7
honeysuckle	*B. marginata, B. ornata*	2528	22	17	97.7
Tea tree	*L. lanigerum, L. continentale, L.myrsinoides*	3	182	-	-
Wattles	*Acacia myrtifolia, A. pycnantha*	26	1627	-	-
Prickly acacia	*A. paradoxa, A. verticillata*	14	1555	-	-
Mallee	*E. cnerifolia, E. socialis, E. dumosa, E.diversifolia*	8	2273	-	-
Grass	Numerous species—possibly including *Danthonia* spp., *Stipa* spp. *Poa* spp. *Neurachne* sp.	51	3721	-	-
Bushes	Sclerophyllous shrubs and possibly small trees. Including members of the families Proteaeceae, Epacridaceae, Fabaceae and Asteraceae	186	20281	-	-

3.3.2.2 Vegetation information

Information on vegetation structure, as well as floristic composition, was provided by surveyors in the 1850s and 1880s survey periods. The structural distinctions made were grassland, heath, scrub and forest. Structural classes appear to have been used precisely and exclusively of each other, as illustrated by certain section descriptions of vegetation. Section 201 in the Hundred of Waitpinga was described as 'scrubby in part and forest in part', section 227 as 'scrub and grassland' and section 61, 'same as section 62 with the exception Stringy Bark scrub not forest'. These examples suggest that surveyors distinguished between forest, scrub and grassland. Historical photographs of the vegetation would allow calibration of the structural descriptions. However no photos were found from the survey periods. interpretation of structural terms and their use in combination with floristic descriptions, thus relies on reference to contemporary vegetation and to historical texts. The following is an interpretation of the vegetation types, referred to in the 1880s surveys, using both comparisons with contemporary vegetation and historical texts.

3.3.2.2.1 Stringy bark forest

Stringy bark forest was the only forest type recorded in historical surveyor's records of the Fleurieu Peninsula. The term forest is a collective noun referring to trees that comprise an area of forested land, but also a description of a plant formation composed of trees having a crown density of greater than 30% and heights from 5 to 30 metres (Specht, 1972). Given that forest was distinguished from other treed areas, the scrubs, it can be deduced that surveyors were not using forest as a collective noun, but rather describing structural attributes of the vegetation. In question then, is what were the structural qualities being identifying as forest. Little information qualifying the use of the term at that time is available. A single description of forests of the 'mountainous districts' of South Australia, made at the time of the 1880s survey, was made by Stow (1883). He wrote 'the forests have not the fullness and lofty growth of those of other countries. The underwood is of a medium size and, more open and less difficult to penetrate; the forests are of less extent and are intercepted by tracts of grassland. The trees do not seem crowded and seldom do the branches of a tree reach a neighbouring one'. However the lack of spatial and ecological information in the description do not make it particularly useful in relation to the interpretation of surveyors' use of the stringy bark forest description. It cannot be ascertained whether Stow's description pertains to *E. obliqua*-dominated open forests or other formation types in the more highly elevated regions of the Adelaide district.

Surveyors used the description of stringy bark forest with the adjectives and qualifications of dense, thick, thickly timbered and well timbered. Thickly timbered and dense were used interchangeably between field book and diagram book descriptions of the same section and so can be considered to be referring to the same quality of the vegetation. An example of this is found in sections 39-41, Hundred of Waitpinga. These sections are recorded in the diagram book as being 'thickly timbered with Stringy Bark forest and dense undergrowth of grass trees and other bushes' while the field book notes record 'dense Stringy Bark forest' on the same section. Thick and dense were also used interchangeably and thus are likely to be referring to the same quality in the vegetation. The description 'well timbered' may have been used variously, in reference to tree density or tree height. In some cases, it was apparent that well timbered was referring to 'forest' sized trees; sections 51-54, Hundred of Waitpinga, are described in the diagram books as 'Well timbered with gums and Stringy Bark...no arable, good pasture land' and in the field book the area is described as being covered with 'Stringy Bark forest and grass tree bushes'. Section-resolution forest observations were classed into two groups (1) Stringy bark forest and (2) Dense stringy bark forest. Field book text observations of forest, on the other hand, were mostly made as 'Stringy Bark Forest'.

Most dense stringy bark forest section records were accompanied with the description 'dense understorey', suggesting that 'dense' in relation to forest was relating to the density of canopy trees. Measures of tree density cannot be ascertained from records.

Understorey observations associated with stringy bark forest and recorded in diagram books, were grass tree, bushes and herbs. Grass trees were recorded on almost all section records with stringy bark forest or stringy bark dense forest.

A survey of the vegetation in 1948 by Boomsma contains the description of two stringy bark forest types occurring on the Fleurieu Peninsula; *E. obliqua* high sclerophyll forest and *E. obliqua* medium sclerophyll forest, a transitional community between high forest and sclerophyll scrub. The understoreys of both the medium and high forest were described as being dense and composed of *Acacia pycnantha, A. myrtifolia, Xanthorrhoea, Acrotriche serrulata, Hibbertia stricta, Pteridium esculentum, Lepidosperma semiteres, Platylobium obtusangulum, Hakea ulicina,* and *H. rostrata.* These descriptions and maps were made 70 years after the 1880s survey and so little in the way of structural composition of the survey description can be gleaned from them- the structural attributes of the vegetation may have changed substantially between these points in time.

The area of stringy bark forest observations intersecting remnant vegetation shows that the majority of both section and field book text observations occur on present day open forest with *E. obliqua* as one of the dominant components of the overstorey. Figure 3. 22 shows the relative areas of intersection of mapped historical section level and field book text resolution stringy bark forest observations and remnant vegetation communities.

Approximately 75% of historical text, and 55% of section observations, which spatially intersect remnant vegetation are on present day *E. obliqua* and *E. baxteri* open forest over *Acrotiche serrulata, Pultenaea daphnoides, Hakea rostrata, Lepidosperma semiteres, Goodenia ovata* and *Pteridium esculentum.* A further 18% of section observations are found on *E. obliqua* and *E. fasciculosa* open forest over *Gonocarpus tetragynus, Xanthorrhoea semiplana* subsp. *tateana* and *Lepidosperma semiteres.* The remaining ~25% of section and text observations are found on low woodland communities (Communities 10, 18 and 19[2]). These results are evidence that the historical and modern usage of the term forest are commensurable. The areas of mismatch are not large and could be the result of surveyors mapping inaccuracies or error in the process of geo-location of

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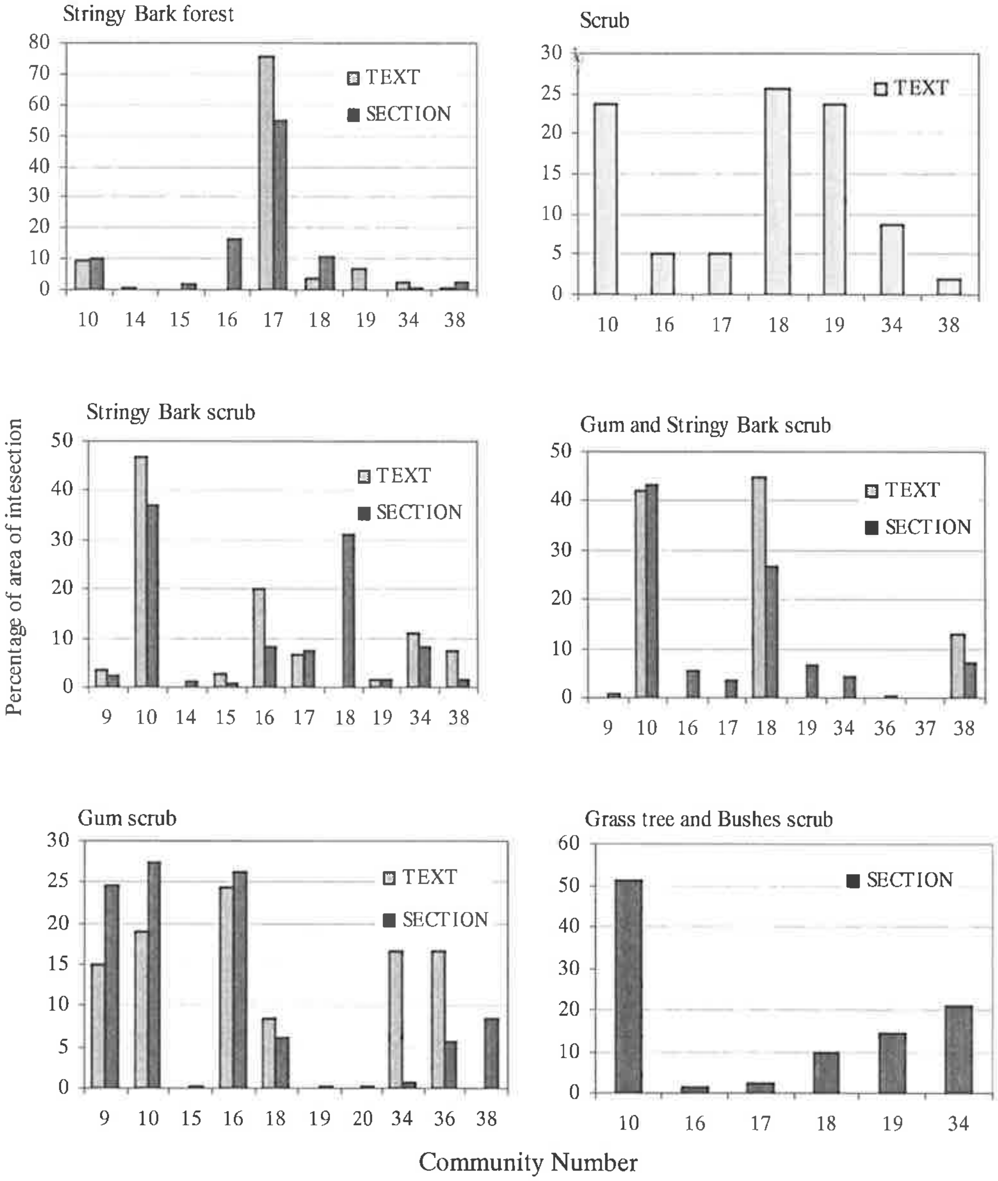
[2] The communities are described in the previous chapter in Table 2.3.

historical descriptions and modern mapped boundaries, rather than evidence for vegetation change at these sites.



	Description	Comm.	Description
14	*E. obliqua* woodland	20	*E. fasciculosa / E. cosmophylla/E.baxteri* low woodland
17	*E. obliqua / E. baxteri* open forest	38	*E. fasciculosa* +/- *E.leucoxylon* low woodland
34	*E. ovata* wet forest-heath	15	*E. obliqua / E.fasciculosa/ E. cosmophylla* low woodland
36	*E. fasciculosa /E. leucoxylon* woodland	10	*E. fasciculosa* low woodland–heath
19	*E. baxteri/ E. cosmophylla* low woodland	9	*E. cosmophylla* very low woodland
16	*E. obliqua / E. fasciculosa* open forest	18	*E. baxteri/ E. cosmophylla/E.obliqua* very low woodland

Figure 3. 22 The relative areas of intersection of the section and text level resolution historical vegetation classes (a) stringy bark forest, (b) Scrub, (c) stringy bark scrub, (d) gum and stringy bark scrub, (e) gum scrub and (f) Grass tree and bush scrub on remnant vegetation communities. The remnant vegetation classes are described in more detail in Table 2.2

The distributions of section and text String Bark forest records are shown in Figure 3. 23 and Figure 3. 24. A total of 57 sections were designated as stringy bark forest comprising 6382 ha. An area of 724 ha was classified by 113 field book text observations.

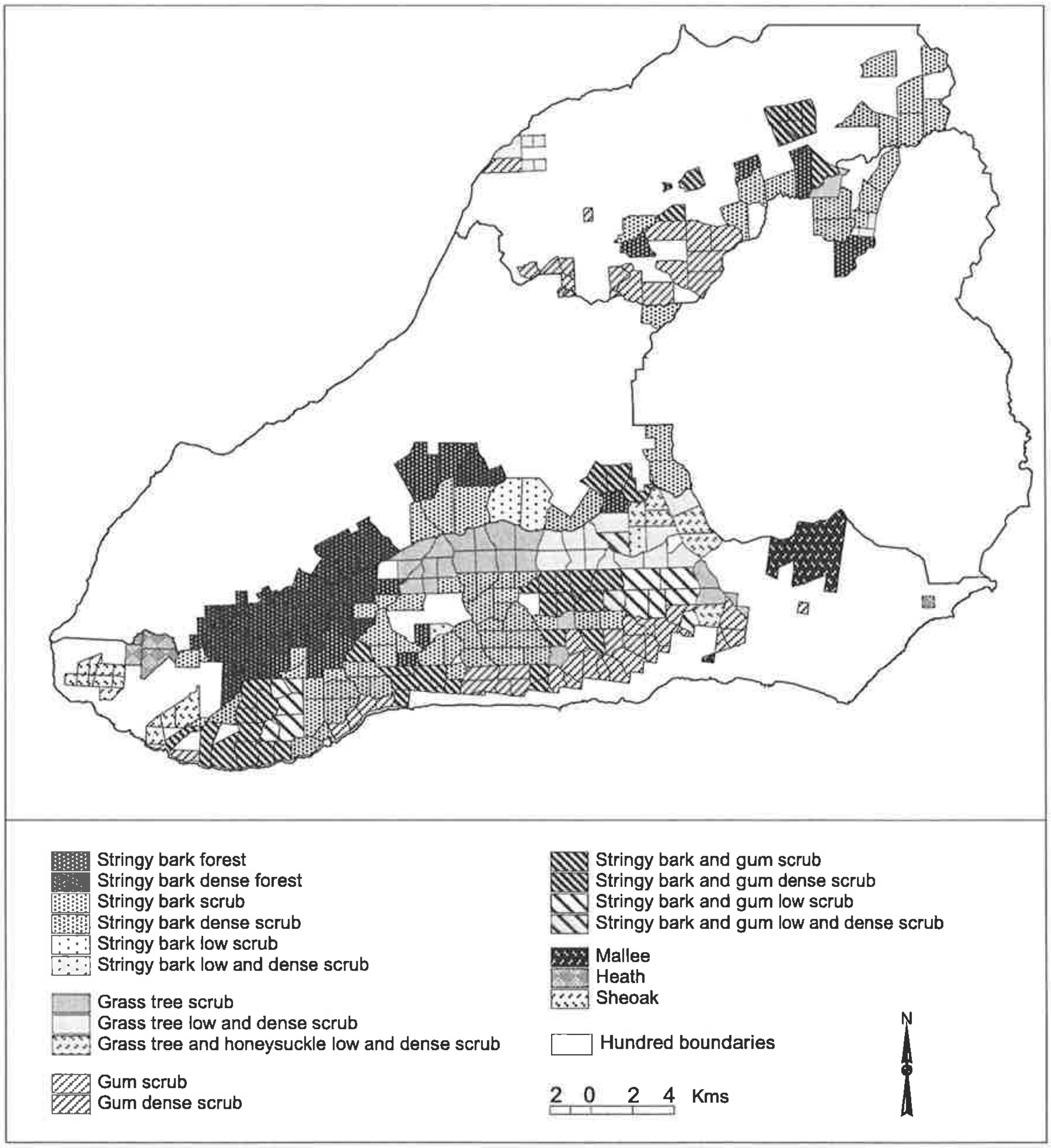


Figure 3. 23 The distribution of historical vegetation communities or classes derived from section resolution floristic and structural observations

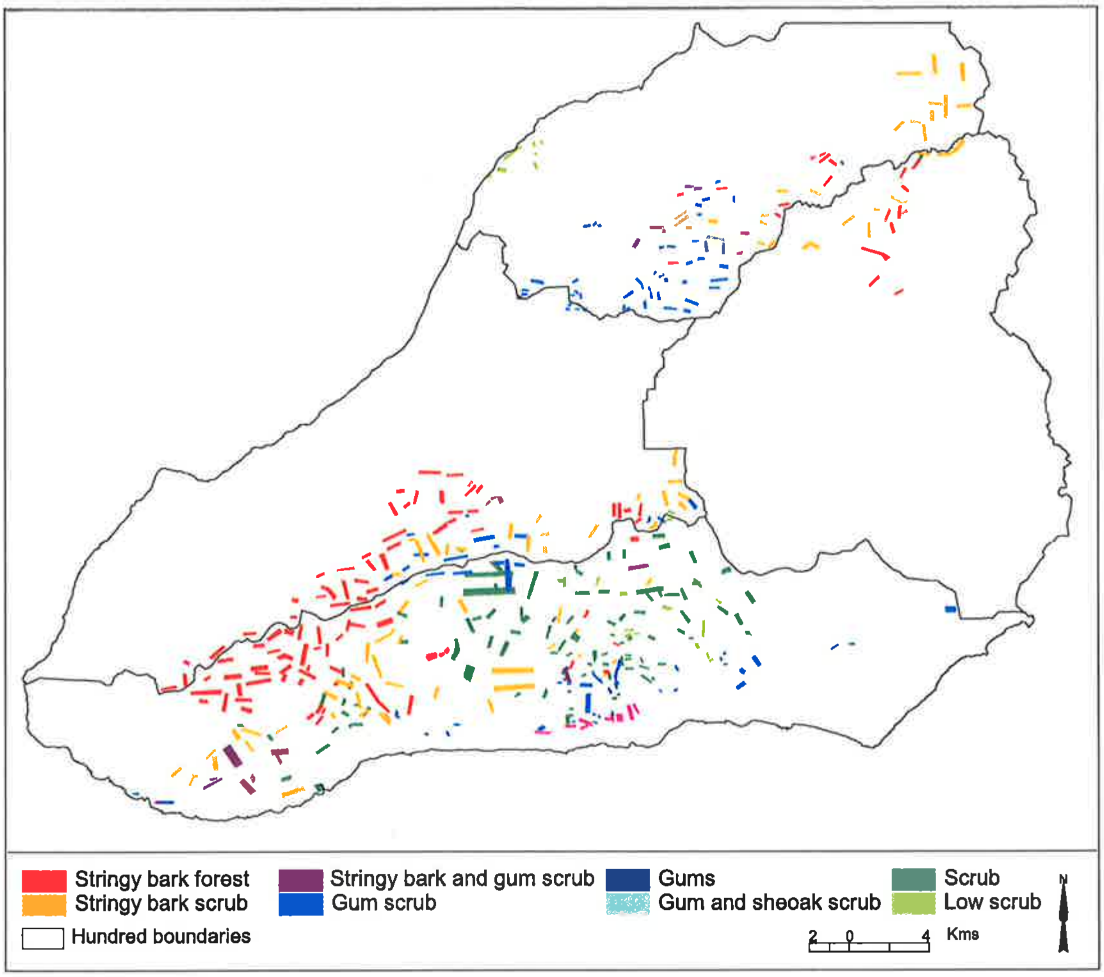


Figure 3. 24 The distribution of historical vegetation communities transcribed from text in surveyors field books.

3.3.2.2.2 Scrub

Scrub was used as a term to describe vegetation, both on its own and with qualification of its floristic composition, in field books in the 1880s surveys. In the corresponding diagram books it was generally used with floristic qualification.

Scrub was a broadly used term to describe vegetation in the nineteenth century in Australia, with various regional meanings (Jeans, 1978; Mills, 1988). The Oxford English Dictionary denotes that in Australia and New Zealand scrub is used to describe 'any tract of heavily wooded country, whether bearing small or large trees'. However in South Australia it is likely that scrub was used to describe vegetation of lower height than that termed forest. This is demonstrated in two nineteenth century descriptions of South Australian 'scrub'. Behr (1851) wrote *On the Character of the South Australian Flora in General* in which he distinguishes scrub from grassland: 'The scrub differs.....for an utter want of a turf. Its almost entire want of herbaceous plants is compensated by a profusion of bushes and small trees'. Stow (1883) describes extent of the 'Scrub Lands' of the Colony 'they appeared all over the area of South Australia, extending more or less in the different districts'. He described their vegetation as being:

> '... of stunted character, and the scrub is nearly destitute of grasses and other herbage...the general impression given by the scrub is dismal although the great variety of shrubby plants associated there make it highly interesting to the botanist. These shrubs generally reach the height of four to six feet, interspersed with stunted and ramified trees of the genera *Casuarina, Eucalyptus, Santalum*...forming sometimes impenetrable thickets. Everyone avoids the scrub as much as possible. All the scrubs in the different districts produce the same common impression, but the plants comprising them are not of the same genera and species' (Stow, 1883).

Survey records provide further evidence that scrub was the term used for vegetation cover that was without tall dominant trees. 'Thick bushes' were denoted to occur on section 277, Hundred of Waitpinga, and then the record was transcribed into diagram book being 'scrub'.

Scrub is used in survey descriptions, singularly and with the following adjectives and qualifications; dense, thick, low, low and thick, low and dense, very, thickly timbered and very thickly timbered. Examination of records, for the same section in both field books and diagram books, showed that dense and thick were used interchangeably and thus can be considered to be describing the same or similar qualities of scrub type. For example the field book record for section 267, Hundred of Waitpinga, reads 'dense scrubby hills' and the diagram book records as 'low thick scrub with dense undergrowth of grass trees and other bushes'; and section 242, Hundred of Waitpinga, records 'very thick scrub' and in the diagram book 'dense scrubby hills'. 'Very scrubby' could be describing dense scrub as the descriptions are used interchangeably between field book and diagram book denoting of the vegetation of section 255, Hundred of Waitpinga.

Scrub, dense scrub, low scrub and low and dense scrub were likely to have been used to describe structural qualities of the vegetation akin to those encompassed by its present day definition. That is, as a descriptor of vegetation characterised by shrubs 2-8 metres height, and of varying densities, with foliage coverage from 30 to 100% (Specht, 1972).

The use of the description 'scrub' without any floristic description on some areas, while in other areas it being qualified with a floristic description, could be a result of loose usage of the term. In some places scrub may have been used because the community was without an obvious or recognisable canopy dominant. A widely distributed community present in 1948 (Boomsma, 1948) was *E. baxteri-E. cosmophylla* scrub. Boomsma recorded that this type had an understorey of *Allocasuarina stricta, Xanthorrhoea, Hakea rostrata, H. ulicina and Lepidosperma semiteres,* that was often equal in height as the dominants. Figure 3. 22 shows the relative areas of intersection of historical scrub records with remnant vegetation. Most scrub records occur on *E. fasciculosa* low woodland, *E. baxteri-E. cosmophylla-E. obliqua* low woodland and *E. baxteri- E cosmophylla* low woodland. The later community is uniquely high to unqualified scrub records adding weight to the above supposition that Boomsma's *E. baxteri-E. cosmophylla* type was being described as scrub by historical surveyors and this was possibly due to the difficulty in discerning a clear overstorey tree-type.

The distribution of scrub records transcribed from field books is shown in Figure 3. 23 and section records in Figure 3. 24. There is a small overlap between areas of digitised text observations of scrub with gum scrub and stringy bark scrub (10.25 and 6.25ha respectively), showing that 'scrub' could have been used to refer to both these community types and that either the eucalypts were not obvious or the land considered too unremarkable to warrant mention of those present. Text observations of scrub occurred on sections denoted as small gum scrub (81 ha), grass tree scrub (81 ha), stringy bark scrub (81 ha) and stringy bark dense scrub (161ha).

3.3.2.2.3 Low scrub

Observations of low scrub, without indication of the species comprising the formation, were made in field books as text descriptions in the 1880s surveys. 'Low scrub' was used in combination with floristic descriptions in diagram book section records. Historical sections descriptions in which the low scrub field book text observations occurred on characterised the vegetation as being grass tree scrub, gum and stringy bark low and dense scrub and small gum scrub. Low scrub observations were not numerous in field books, amounting to 89ha of classified land. Their distribution is shown in Figure 3. 24. Only 3.5ha of this intersected with remnant vegetation with 70 of them occurring on *E. baxteri-E. cosmophylla* low woodland. The remaining 30% was on *E. fasciculosa* low woodland.

3.3.2.2.4 Stringy bark scrub

Vegetation was described as stringy bark scrub in the 1880s survey period in field books and corresponding diagram book records. Section descriptions of stringy bark scrub were mostly denoted as being dense or without further structural qualification. In a few cases they were classed as being low or low and dense. As with stringy bark forest, stringy bark scrub section descriptions were nearly always associated with the presence of grass trees and bushes and less frequently with herbs, bushes and prickly acacias. The distribution of stringy bark scrub section and field book text records is shown Figure 3. 23 and Figure 3. 24. Ninety text records were digitised and they classify an area of 646 ha and 44 section records classifying an area of 9694 ha.

Boomsma (1948) described two Fleurieu Peninsula vegetation types as scrubs dominated by stringy bark species. One type is dominated by *E. baxteri* alone and is included in his *E. baxteri* association. The other is a mix of *E. obliqua* with *E. baxteri* and is described as part of his *E. obliqua* association. The types share similar understoreys of *Allocasuarina striata, Banksia marginata, Spyridium thymifolium, Olearia floribunda, Xanthorrhoea* and *Acacia myrtifolia* which vary in density from 'moderately dense' to 'dense'. He proposed that the degree of density is related to firing regimes and that the moderately dense scrub is probably more representative of the pre-European condition. Boomsma notes that most of the pure *E. baxteri* type had been cleared.

The relative areas of historical field book text and section observations classed as stringy bark scrub on classes of remnant native vegetation are shown in Figure 3. 22. Of field book text observations spatially intersecting remnant vegetation, 45% occur on present day *E. fasciculosa* low woodland and ~20% with *E. obliqua-E. fasciculosa* open forest. The relative areas of intersection of sections observations is slightly different, with about 38% occurring on *E. fasciculosa* low woodland and about 32% on *E. baxteri* and *E. cosmophylla* low woodland. Areas amounting to less than 12% of both text and section observations were found to occur on present day communities 9, 14, 17, 19, 34 and 38.

While 80% of stringy bark scrub field book text records and 92% of section records occur on communities that are presently low woodland, and thus are analogous to scrub, there is considerable variation in the floristic composition of these communities. Unlike the floristic match between historical and modern stringy bark forest records, stringy bark scrub records are most numerous on a low woodland community dominated by *E. fasciculosa*. Although it cannot be discounted that this community is that which was being described by surveyors under the stringy bark scrub classification, other factors could explain this proportional distribution pattern. *Eucalyptus fasciculosa* low woodland is relatively highly represented in the Fleurieu Peninsula (Table 2.3) while Boomsma (1948) noted that most of the *E. baxteri* dominated scrubs (low woodlands) had been cleared. By the fact that *E. fasciculosa* low woodlands are proportionately highly represented in the present landscape and *E. baxteri* possibly present in areas that are disproportionately low in comparison to their pre- European extent, historical records have more chance of occurring on *E. fasciculosa* low woodlands. The distribution of records of stringy bark scrub over numerous remnant communities (Communities 15, 19 and 14) could also be indicating that the stringy bark scrub description encompassed a wide range of community types.

3.3.2.2.5 Gum and stringy bark scrub

Gum and stringy bark scrub was a vegetation description recorded in the 1880s survey phase in field and diagram book records. It was often recorded as being 'dense' and at times 'low' or 'low and dense'. Section records classified an area of 5518 ha (Figure 3. 23) and field book text as 111.2 ha (Figure 3. 24) as being gum and stringy bark scrub. Because of their localised nature, text book observation of gum and stringy bark scrub were most likely referring to communities dominated by a mix of stringy bark species and white barked gum species. Section records may have been likewise referring to a mixed overstorey, although they could possibly have been referring to small gum scrubs and stringy bark scrubs both present, but distinct, within a section.

Boomsma (1948) described a number of communities with occurrence in the Fleurieu Peninsula with mixed small gum and stringy bark canopy dominants. They were; (1) *E. obliqua* - *E. fasciculosa* often open with *A. paradoxa* in drier areas; (2) *E. obliqua-E. viminalis* with an understorey that is usually open with bracken, grasses and the occasional clump of *Leptospermum myrsinoides, Allocasuarina verticillata, Xanthorrhoea* and *Acacia pycnantha;* (3) *E. baxteri-E. cosmophylla* with an understorey of *Allocasuarina stricta, Xanthorrhoea, Hakea rostrata, H. ulicina and Lepidosperma semiteres;* (4) *E. fasciculosa-E. obliqua* with a similar understorey to *E. obliqua-E. fasciculosa* and (5) *E. fasciculosa- E. baxteri - E. cosmophylla* with an understorey including *Leptospermum myrsinoides, Melaleuca gibbosa, Allocasuarina verticillata, Banksia marginata* and *B. ornata.*

Various combinations of species of white barked gums and stringy bark occur as overstorey dominants in the remnant vegetation in the Fleurieu Peninsula. Figure 3. 22 shows the relative distribution of historical records, that occur on remnant vegetation, on remnant vegetation classes. About 40% of the field book text and section observations of gum and stringy bark are located on present day *E. fasciculosa* low woodland. Approximately the same area of field book text records occur on *E. baxteri - E. cosmophylla - E. obliqua* low woodland. Between 8 and 12% of observations of text and section observations occur on *E. fasciculosa* ± *E. leucoxylon* woodland. Despite a small area under text observation (39 ha compared to 110 ha for stringy bark scrub and stringy bark forest) these results suggest that gum and stringy bark scrub was referring to communities dominated by *E. baxteri* and or *E. obliqua* with *E. cosmophylla.* Again high percentages of intersection are found on the remnant community with the greatest areal extent in the region, *E. fasciculosa* low woodland, and this could be for the same reasons as those discussed for stringy bark scrub observations. Little intersection was found with other communities co-dominated by *E. fasciculosa* (Communities 15, 20 21), however they presently occupy very little area and it can not be concluded that, if present at the time of survey, they would not have been classified as gum and stringy bark scrub. Additionally little coincidence was found between historical records and *E. baxteri - E. cosmophylla* low woodland. However this could be because this community is not greatly represented in the vegetation, rather than a lack of equivalence between it and historical classes.

3.3.2.2.6 Small gum scrub

Gum scrub was a vegetation description recorded in field books and corresponding diagram books in the 1880s survey phase. It was mostly denoted without further qualification, although in places, it was described as 'low' or 'dense'. Figure 3. 23 shows the distribution of sections classified as 'small gum scrub' and Figure 3. 24 the location of text records. An area of 302 ha was classified as small gum scrub by text observations and 4178 ha by section records.

Boomsma (1948) describes three Fleurieu Peninsula vegetation types with small gum dominance; (1) *E. fasciculosa* with an understorey of *Allocasuarina verticillata, Hakea rugosa, H. ulucina, Acacia pycnantha, Scaevola microcarpa, Lomandra filiformis, Pimelia spathulata, Xanthorrhoea semiplana* and grasses; (2) *E.cosmophylla,* occurring as isolated patches in *E. obliqua*scrub and (3) *E. leucoxylon-E. fasciculosa* occurring with a dense sclerophyll understorey of *Banksia ornata, Spyridium, Xanthorrhoea, A. myrtifolia* and *Leptospermum.*

Between 15-20% of text-defined gum scrub spatially intersect each of the following communities; *E. cosmophylla* very low woodland, *E. fasciculosa* low woodland, *E. ovata* woodland and *E. fasciculosa*

E. leucoxylon woodland (Figure 3. 22). About 24% of gum scrub text records occur on *E. obliqua* - *E. fasciculosa* open forest. This is likely to be as a result of errors in the geolocation process which are emphasised particularly in cases where only small areas between remnant vegetation and historical gum scrub records intersect. In this case only 44 ha of text records spatially overlap and can be compared.

3.3.2.2.7 Grass trees and bush scrub

Numerous sections were recorded as having only grass tree and bushes present without mention of a *Eucalyptus* species being co-present. Their distribution in shown Figure 3. 23. They occupy an area of 3921 ha.

There are no obvious modern analogies in the DENR (1988) classification of remnant vegetation and Boomsma (1948) did not define a vegetation association or type that is without a *Eucalyptus* species. It is possible that, as argued for the scrub description, this description is reflecting a low dense or very low woodland or heath of *E. baxteri* and or *E. cosmophylla* and or *E. fasciculosa* occurring at equal height as the sclerophyll 'understorey' described above. Over 50% of the area classified with historical observations as grass tree and bushes is on present day *E. fasciculosa* low woodland (community10) and about 20% on *E. ovata* woodland (community 34)(Figure 3. 22). Ten and 15% respectively are on Communities 18 and 19, both low woodlands of *E. baxteri* - *E. cosmophylla*. The *E. fasciculosa* woodland community described by DENR does not define *Xanthorrhoea* as a dominant member.

3.3.2.2.8 Grass tree and honeysuckle low and dense scrub

Grass tree and honeysuckle in a low and dense scrub was recorded as being present on several sections in the 1880s surveys classifying an area of 909 ha. Most of this is in the eastern part of the Hundred of Waitpinga. Over 70% of the sections so described, which intersect with remnant vegetation, are on *E. baxteri-E. cosmophylla* low woodland. *Banksia* and *Xanthorrhoea* are components of most of the scrub/low woodland vegetation types described by Boomsma (1948) and present today, so no clear modern analogues can be identified from this description.

3.3.2.2.9 Gum and sheoak

A limited number of field book text observations of gum and sheoak were made during the 1880s survey. The sections on which they occur were described as low gum scrub with sheoak with bushes, and in some cases, acacia. Only 55.7 ha were classified by field book records as such (Figure 3. 24) and of this only 3.75 ha intersected with remnant vegetation. Over 60% of the intersecting communities was *E. fasciculosa-E. leucoxylon* low woodland and the remainder occurred on *E. fasciculosa* low woodland.

3.3.2.2.10 Heath

The term heath was used by surveyors in the 1850 survey period to describe the vegetation cover of sections in diagram books. It is still used as a formation description, referring to scrub that is less than 2 metres in height and of various foliage cover densities. Only five sections constituting an area 408 ha were described as such and they are shown Figure 3. 23. Comparison with remnant vegetation was not possible as none exists on sections so classed. It is likely that the term could be interpreted as being low scrub, however the composition of the species within it is not traceable.

3.3.2.2.11 Grassland

The description 'grassland' was only occasionally used by surveyors in the 1880 surveys and only ever in conjunction with other structural descriptors, indicating that grassland only characterised a part of the section being described. Grassland was a generally used vegetation description during the nineteenth century and the term appears to have equivalent meaning as the modern day savannah woodland (Specht, 1972) or grassy woodland term (Hyde, 1995). Behr (1851) describes a type of South Australian grassland 'one variety of grassland is the pit-land (Bay of Biscay land) consisting of undulating plains or gently inclined slopes which resemble a sea suddenly frozen during the beating of waves'. Stow (1883), in a book describing South Australia's production and resources describes grasslands in 'hilly districts' and they have 'the appearance of occasional hills clothed only with a scanty covering of tussocky grasses, among fragments of ironstone, quartz and sand, destitute of all other vegetation, except the small scattered trees of the *Casuarina stricta (Allocasuarina verticillata), C. glauca* and the peppermint, *Eucalyptus odorata.'* and the 'level tablelands' as being 'covered in grass but deficient in shrubs. Here, scattered are to be seen the most stately and majestic trees of *Eucalyptus.* Such tablelands appearing more like a park - the trees standing seemingly planted at measured distances, single or in small clumps as if planted by the hands of a landscape gardener...'. Only a small area, amounting to 514 ha, of the 1880 survey lands were classed as grassland and the term was used in conjunction with scrub (Figure 3. 23). The regions where the grassland observation would have been likely to be applied over larger areas are those that were first surveyed before section descriptions were made.

Table 3. 4 Vegetation types recorded by surveyors in 1880s survey records in field and diagram books. The number of each observation type and the area they classify are shown. DB = diagram book, FB = field book

Floristic combinations	Observation type	Associated flor. reference	No. obs.	Area
stringy bark forest	DB-section	gt ± bushes	11	2483
	FB-text	-	113	724.6
stringy bark dense forest	DB-section	Gt, bushes ± herbs	23	3774

Floristic combinations	Observation type	Associated flor. reference	No. obs.	Area
stringy bark scrub	BD-section	Gt, bushes ± herbs ± prickly acacia	26	6167
	FB-text	-	90	646.1
stringy bark dense scrub	DB-section	Gt, bushes ± herbs ± prickly acacia	16	2308
stringy bark low scrub	DB-section	Gt ± bushes	2	874
stringy bark low and dense scrub	DB-section	Gt, bushes	2	188
gum scrub	DB-section	± sheoak ± gt, ± bushes ± wattles	15	2173
	FB-text	-	74	302.2
gum dense scrub	DB-section	sheoak, gt, wattles	3	995
gum and stringy bark scrub	DB-section	± sheoak; gt ± bushes ± acacia	17	1842
	FB-text	-	9	111.2
gum and stringy bark dense scrub	DB-section	Gt ± sheoak ± bushes	12	1456
gum and stringy bark low scrub	DB-section	± gt ± prickly acacia	8	730
gum and stringy bark low and dense scrub	DB-section	± gt ± bushes	6	856
Scrub	FB-text		94	596.6
Low scrub	FB-text		22	89.8
grass tree scrub	DB-section		20	2030
grass tree dense scrub	DB-section		1	80
grass tree low and dense scrub	DB-section		12	1326
gum and sheoak	FB-text		10	55.7
grass tree and Banksia low and dense scrub	DB-section	± bushes	7	909
Mallee	DB-section			986
Heath	DB-section			407

3.3.2.3 Indirect information

3.3.2.3.1 Temporal pattern of survey

The preferential selection by early colonists for the grassy woodland systems over the sclerophyll forests and woodlands of highland areas has been frequently noted (Moon, 1969; Williams, 1974; Hyde, 1995). Open areas were preferred over timbered as cultivation could take place without the laborious process of tree clearance. While the first surveys on the Fleurieu Peninsula are devoid of any reference to vegetation, other survey plans in the Adelaide region, from that time, provide specific evidence for selective preference against sclerophyll systems, implying preferential selection for grassy woodlands. Section units delineated in the Green Hills Special Survey were without description of vegetation, however, land directly adjoining surveyed sections, or in between a block of sections was labelled 'scrub and rock' or 'Stringy Bark Ranges' or 'Stringy Bark'. These areas had obviously been deemed unsuitable for immediate uptake and their rejection implies that they were different from those included in the survey. This example illustrates that the first survey boundaries in the Green Hills survey were faithful to the boundary between the grassy woodland and sclerophyll systems at a relatively fine scale. It is likely that the same positive selection for grassy woodland systems would have determined the distribution and extent of first surveys in the Fleurieu Peninsula. Pictorial and documented evidence from the areas delineated in the 1839-40s surveys strengthens this notion. Pictorial records numbers 22-32, (Table 3. 2) occurring on areas delineated in the first survey period depict grassy woodlands. Similarly most of the early descriptions of open woodland type vegetation also occur in regions first surveyed. A total of 756 sections were delineated in the initial surveys amounting to an area of 25 925ha, about 24% percent of the Fleurieu Peninsula region (Figure 3. 25).

Approximately the same area as was delineated in the first surveys was delineated in the 1850 survey period. Vegetation records from this time were scarce and no obvious relationship showing preference for a landscape or vegetation type is apparent.

The remainder of land in the Fleurieu Peninsula, amounting to approximately 50% of the total area of the region, was surveyed in the final 1880s survey period. Nearly all records from this time record the presence of scrub, forest and often the presence of a dense understorey, indicating that they are restricted to the sclerophyll woodland systems of the region.

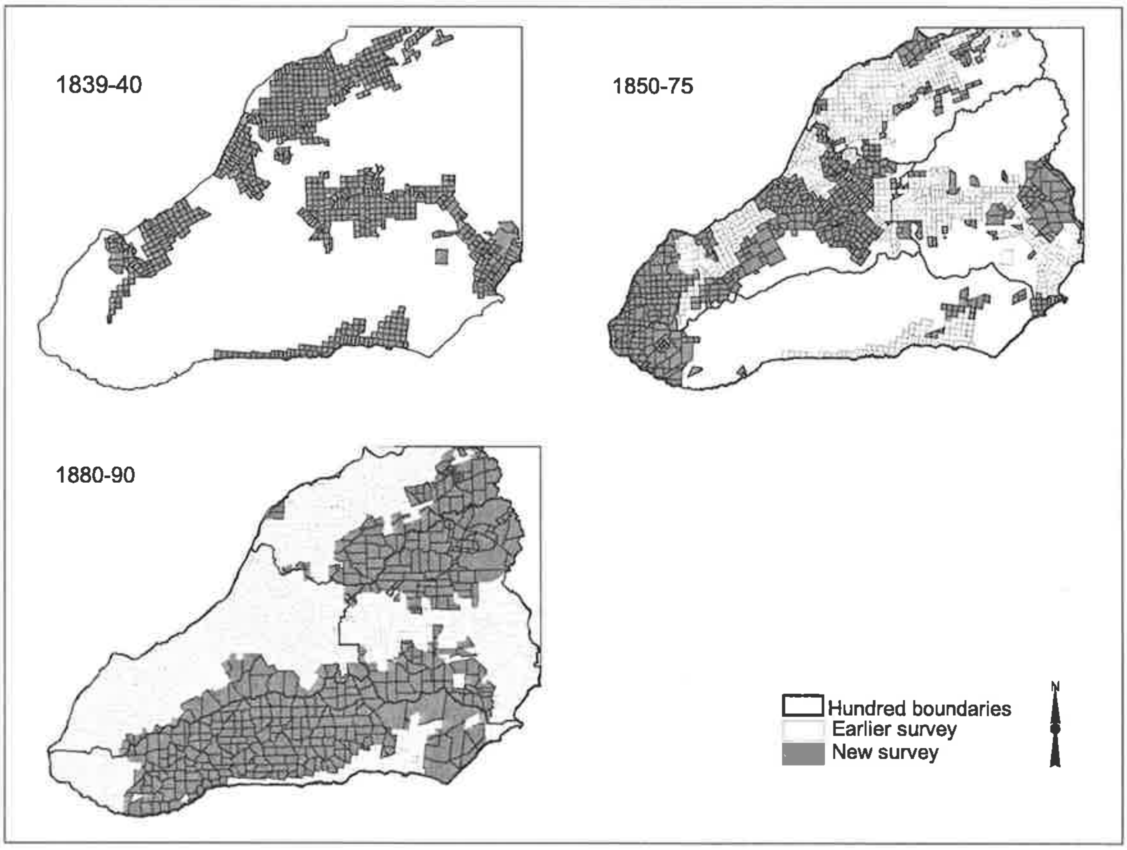


Figure 3. 25 The time period in which sections were surveyed in the Fleurieu Peninsula.

3.3.2.3.2 Agricultural appraisal

Records from the 1841-75 and 1880-90 survey periods contain descriptions of the agricultural potential of individual sections. As agricultural expansion was the abiding interest in land survey and sale, this type of description is found associated with sections more than any other kind of observation. Records classify an area of 34 898 ha (484 records).

Where agricultural assessments were made, sections were categorised into two primary agricultural classes: arable and pasture. Arable refers to the land's suitability for cultivation and cropping, Pasture indicates the land's suitability for grazing. Sections were assessed as being arable, arable in part or unsuited to cultivation. The quality of pasture land was signified with the adjectives: 'indifferent', 'rough' 'poor', 'fair', 'only fair', 'pretty fair', 'medium' to 'good' and 'very good'. These terms were reduced to 3 classes for mapping and analyses (Table 3. 3). Grazing and pasture land were used by surveyors as interchangeable or equivalent terms. Occasionally sections were denoted as being 'Stock' country and this term was interpreted as being equivalent to grazing and pasture land. The distribution of agricultural classification records for sections is shown in Figure 3. 26.

Table 3. 5 Classes of pasture land.

Classification	Quality assessment	'Equivalent' descriptions grouped into classes
Pasture land	Fair	Fair, Only fair, Pretty fair, Medium
	Good	Good, Very good
	Poor	Poor, Rough, Indifferent

Of sections in which observations of agricultural suitability were made, 8 sections were classed as arable (area of 401 ha), 110 sections (an area of 8330 ha) were described as part arable and part pasture and a total of 350 (25640 ha) sections were classed as pasture land. Table 3. 4 shows the relative percent of section historical structural classifications in each agricultural class. Sections classed as 'pasture' and 'arable and pasture' were mostly scrub with a lesser area forest. The arable and pasture classification could indicate variation in the degree of openness of vegetation in the region, that is within the sclerophyll forest and scrub formations more open patches were present. Similarly a few sections classed as arable also had forest and scrub recorded as being present, probably indicating structural heterogeneity within sections.

Table 3. 6 The relative percentages of different structural classifications that occur on each agricultural class.

Historical structural classification	Arable	Arable and Pasture	Pasture
Dense forest	0.0	12.5	16.13
Forest	29.17	24.65	3.63
Scrub (dense, low, low and dense)	0.0	63.2	68.31
Grassland	0.0	0.0	1.89
Open	10.42	0.0	0.0
Other (part scrub, forest and scrub)	47.92	12.15	10.03

The adjectives describing pasture as poor, fair and good were likely to have been referring to the amount of grass apparent on sections. SW Herbert describes a section in the Hundred of Waitpinga as 'poor pasture land' and 'having very little grass'. The words grass and pasture, in particular, can be regarded as synonymous. Records made by S.W. Herbert during the 1880s survey showed that almost 70% of the area which had grass recorded as being present (a total of 51 sections) was classed as good pasture while only 14% of those sections which had no mention of grass, but had a pasture classification, were classed as good.

Table 3. 5 Percentage of sections classed as good, fair or poor pasture with positive and absent grass observations.

Classification	Grass not present	Grass present
Good	14.2	69.8
Fair	72.8	30.1
Poor	12.9	0

'Good pasture land' was not correlated to a particular vegetation structural-type as 'well timbered forest', 'thickly timbered forest', 'lightly timbered' or 'scrub' are all in some cases described as good 'pasture land'. There is a greater association between structural description of vegetation and sections classed as 'poor pasture'. Most being poor pasture sections were described as 'very scrubby' or 'dense scrub'. The term 'fair pasture' is associated with scrub, dense scrub, and forest descriptions of vegetation. The qualification 'only' was sometimes used next to 'fair pasture' and it is possibly a negative conjuncture when accompanying 'fair'. Sections assessed as being 'only fair pasture' generally associated with vegetation descriptions of 'low thick scrub' or 'very thick scrub'.

Land described as 'thickly timbered' or 'scrubby' was not considered arable. It thus follows that land that was lightly timbered or could have been considered arable. Some of the sections described as arable were also recorded as having a cover of sheoaks, 'wood', or 'Belt of Gums'. Very few sections surveyed in the later 1880 phase of survey were classed as arable. Given that the region was a cropping district, that is contained arable land, the low number of arable sections in the later surveys reaffirms the notion that the early surveyors only selected arable sections. The qualification of a section as arable, was probably a comment on the topography as well as vegetation cover.

Most of the area historically classed as pasture is on present day *E. fasciculosa* low woodland. Smaller proportions in *E. obliqua - E. fasciculosa* open forest, *E. obliqua* open forest and *E. baxteri- E. cosmophylla - E. obliqua* low woodland. The majority of sections classified as arable land are on *E. fasciculosa - E. leucoxylon* woodland and *E. obliqua - E. baxteri* open forest. While the relative areas of intersection of historical classes with modern vegetation communities will be influenced by areas of remnant vegetation communities present it can be seen that pasture land is mostly on present-day low woodland ('scrub') communities.

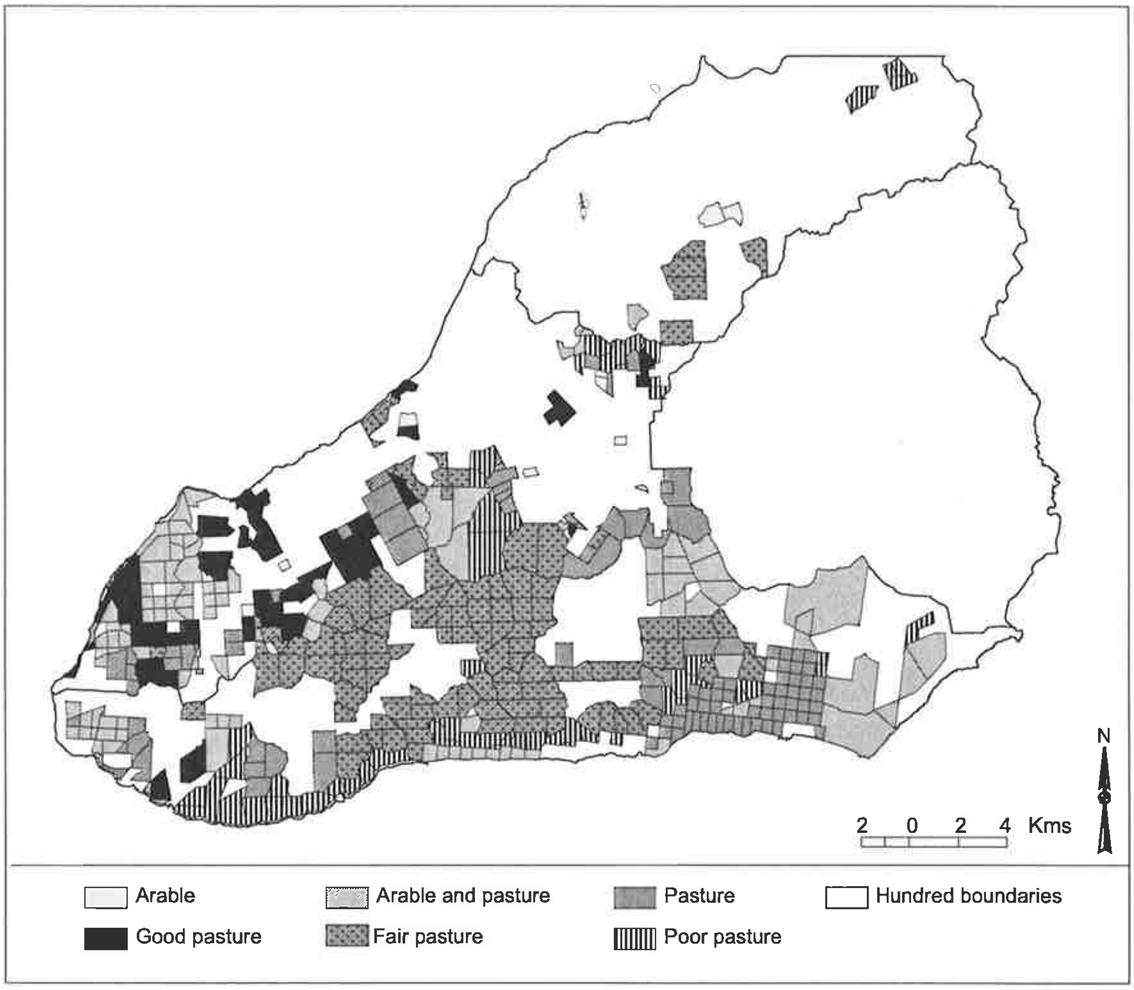


Figure 3. 26 Agricultural classification of sections surveyed in the Fleurieu Peninsula.

3.3.2.3.3 Timber and wooded

Observations of 'timber' or 'timbered' and 'wooded' were made on survey sections in both the 1850-75 and 1880s surveys. The use of the word timber to describe tree cover probably contains inherent assessment of the vegetation's potential utility for construction or as a fuel source and so is likely to be referring to larger sized trees rather than scrub. Licensed collectors in highlands were carrying out timber cutting before and during the time of survey. So appraisal for these ends was likely to have been in surveyors' minds at the time. A few sections were described as 'timber and scrub', indicating that scrub did not contain trees worthy of the timber description. Some sections which were described as being 'forest' were also described as 'thickly timbered', again indicating the term was probably being applied to trees of larger stature. However, 'timbered' was at times used in conjunction with 'scrub'; in the 1880s surveys S.W. Herbert describes a few sections as 'very thickly timbered scrub'. It is possible that the judgement of what constituted valuable timber changed through the survey period due to changes in timber availability and thus relative value. It is not possible to ascribe species or structural information from timber descriptions, however they do at least indicate that the land was not devoid of trees and the trees were probably of large enough stature that they had value for cutting purposes. The description 'wooded' is a similarly vague reference to vegetation which is difficult to interpret. Wooded was applied to sections in the lower elevation regions in the Fleurieu Peninsula and was possibly used to refer to grassy woodland associations. It was similarly used on sections in the higher elevations on which stringy bark was indicated as being present. Figure 3. 27 shows the distribution of the 162 section records described as having timber or being wooded. They classify an area of 11 131 ha.

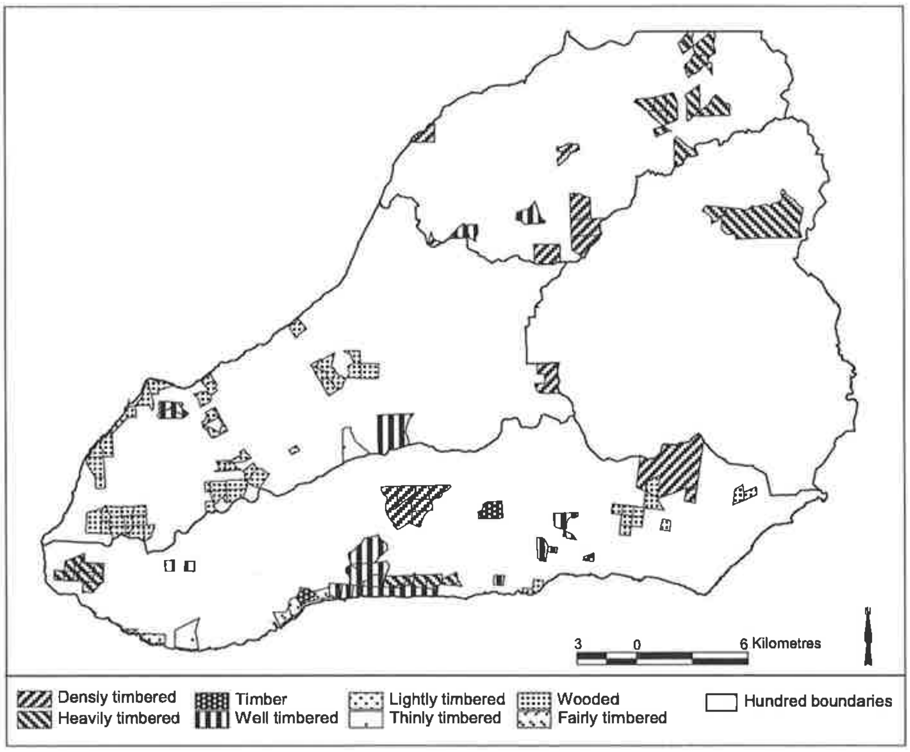


Figure 3. 27 Sections denoted as being wooded or timbered.

3.4 Discussion

3.4.1 Grassy woodlands

Grassy woodlands are well represented by early descriptions and paintings made by explorers, surveyors and early visitors and settlers to the Fleurieu Peninsula region. In part this is due to their proximity to the coast rendering them visible from sea vessels tracking the shore. But it is also because grassy woodlands were considered noteworthy for their perceived agricultural potential, and their 'orderliness' appealing to English sensibilities. These records together, made through the period 1802 to around 1842, provide indication of the importance of grass in the understorey, general information on the structure of grassy woodlands, and a small amount of information on their floristic composition.

The conspicuousness of a grassy understorey is suggested by the number of references to it and in the manner it was described. Baudin in 1802 was struck more by the 'dry straw herbage' covering the land rather than any trees that many have been present, Jones (Napier, 1835) mentioned 'fine grass' at Cape Jervis, Woodforde in 1836 at Rapid Bay 'the grass growing in its natural state is abundant' and Thomas (Thomas, 1925) from the same time and area as Woodforde 'the country...resembled an English park with long grass in abundance'. Further inland, Hutchinson in 1837 described the Hindmarsh Valley as having 'the most luxuriant grass I have ever seen in the colony'. These descriptions are important in that the understoreys of the grassy woodlands are believed to have very rapidly transformed on the establishment of agriculture in the colony. Their demise early in European settlement means that its original importance cannot be gauged from ecological studies carried out earlier this century (such as that of Adamson and Osborn, 1924; Boomsma, 1948). It has been suggested that kangaroo grass (*Themeda triandra*) was the dominant herbaceous species in the woodlands of this area (Specht, 1972; Hyde, 1995; Kraehenbuehl, 1996). But due to the sensitivity of *Themeda* to grazing and changed soil nutrient levels decreasing its competitiveness with other native grasses like *Danthonia* and introduced plants it was rapidly and comprehensively removed from the grassy woodlands (Specht, 1972). Kraehenbuehl suggests that within ten years *Themeda* was significantly removed from the Adelaide region and Hyde suggests that the understoreys of grassy woodlands throughout South Australia had been significantly transformed by the early 1850s. These records suggest that *Themeda* was once a dominant component of the grassy understoreys of the open woodlands of the Fleurieu Peninsula.

Both early paintings and historical descriptions gave some indication of the pre-European structure of the grassy woodland associations in the Fleurieu Peninsula. They suggested that the grassy woodlands areas accorded with the current day definition of an open woodland, and that in some places however tall trees were more densely spaced than in others. The French Angas lithographs from the Carrikalinga to Rapid Bay indicated that the hills and plains of the grassy woodland areas were lightly treed and watercourses more densely treed. They are supported by Skipper's temporally and spatially coincident painting, and approximately concurrently made descriptions of these regions; Thomas described the Rapid Bay area as 'resembling and English Park...with fine trees scattered about but not too many to make it unpleasant' and Light (1836a) around Second Valley and Yankalilla '...there is an abundance of wood all the way, yet not so thick that agriculture might not be persued without the trouble of clearing...' and Morphett similarly commented that, although he has stated the Yankalilla area is well wooded, it would not be necessary to fell a single tree for agriculture. It appears as though some areas were more lightly wooded than others. Morphett did not provide exact locations, but in describing areas north of Cape Jervis he mentions 'plains are both open and elegantly wooded' and Jones (1834) mentioned areas inland from Victor Harbour as not being thickly wooded, with 'open spots of 400-500 acres' frequently occurring.

The majority of early paintings provided little floristic information on grassy woodlands because of the small scale in which they represented scenes, the artist's style and possibly because of deliberate misrepresentation. However documentary records provide a little more information on the components of the grassy woodlands. Gums are most commonly mentioned, and Morphett in 1836 mentions that in the Yankalilla region the principal tree is the 'blue gum, which is a most elegant tree of great magnitude'. Records suggest that *Allocasuarina verticillata* was a principal component of the grassy woodlands at the time of European settlement, particularly between Yankalilla and Cape Jervis. Accompanying a number of the lithographs made from the French Angas paintings and reproduced in the 'South Australia Illustrated' were descriptive text which in some cases provided species information. French Angas writes that Casuarinae or sheoak were the predominant tree in the scene [on the hills] and that *Eucalyptus* were found along the waterways (Carrikalinga Creek). Casuarina is also depicted in his painting The Gorge, situated near the coast approximately two kilometres south of Normanville. Jones (1835) noted that the gum, sheoak and wattle characterised the grassy woodlands around Cape Jervis. Survey records made around the 1850s also suggest Casuarina, again probably *Allocasuarina verticillata*, were extensively distributed in the Southern Fleurieu Peninsula in grassy woodlands (Figure 3. 15). The 'drooping trees' described by Freycinet in 1802, around Yankalilla could well be *A. verticillata.* Wattles are frequently mentioned as components in the understorey of the grassy woodlands of the area (Woodforde, 1836, Jones, 1834; French Angas, 1847) and the wattle is likely to be *Acacia pycnantha*. A descriptions made three miles inland from Rapid Bay by Woodforde (1836) suggests that *Callitris preissii* open woodlands were present at European settlement. *Callitris preissii* woodlands occur as a pure community or mixed with *A. verticillata* on the Adelaide Plains (Kraehenbuehl, 1996). Some *Exocarpus cupressiformis* (also potentially being referred to by Woodforde's description) occurred in these formations. A number of the paintings suggest that the grassy woodlands were without a dense shrub component, but that shrubs were present. Shrubs that are well mentioned or represented are *Xanthorrhoea* and wattle (*Acacia pycnantha*).

The philosophical and aesthetic ideas of a time can influence the manner in which a landscape is described or depicted. Most of the pictorial records depicting the study area were by George French Angas, and were commissioned for the encouragement of immigration to the colony. As such they are likely to be prone towards gentrification of the landscape and depiction of idealised pastoral scenes (Bonyhady, 1985). However the images by French Angas do not contradict the co-located, in space and time, works by Light and Skipper. It can be reasoned that in a broad sense French Angas's paintings were accurate. Similarly, descriptions of the vegetation were infused with the initial enthusiasm for the new colony and the potential it offered for a new and economically prosperous life. Descriptions of landscape and vegetation often related to their amenability to be easily farmed. This was taken in mind when their meaning was interpreted, however it was found a literal approach to interpretation was probably justified given there were no blatantly contradictory observations from the different sources considered.

The ability to spatially locate descriptions and pictorial records varied. Toponyms contained in descriptions and the titles of paintings were useful as was the use of topographic features depicted in the landscape paintings. Most difficulty was had with location of early explorers' descriptions. These documented records only a small amount classified of land in the region, however most records of grassy woodlands were spatially coincident with the sections surveyed in the 1839-40 period of survey. This, combined with other historical documentation of first settlers selective preference for open land which was abundant in herbage and evidence from other early survey plans (this chapter) indicates that early survey data could represent pre-European boundaries of these formation types.

3.4.2 *Sclerophyll forests and woodlands*

At the time of European settlement there was little interest in the sclerophyll woodlands since it had less agricultural value. Their understoreys were mainly composed of sclerophyllous shrubs which were unpalatable to stock and the treed-overstoreys would have taken considerable effort to clear before cultivation could have begun. Consequently very few records from the time of European arrival, that would provide information of their pre-European nature exist. An exception to this was an observation by Woodforde who described the great stature of the stringy bark trees inland from Rapid Bay (Woodforde, 1836). However, indirect information of their distribution was provided from this time. It was argued earlier that the pattern of first survey could be used as a proxy for the pre-European distribution of grassy woodlands, concomitant with this is that the same data is useful in delineating the sclerophyll woodland boundary for the two can be considered to be mutually exclusive. It was not until 50 years after settlement of the colony that lands containing these vegetation types were surveyed. Survey records from this time provide the main source of information of the early European floristic and structural nature, as well as distribution, of components of the sclerophyll forest and woodland associations of the Fleurieu Peninsula.

In order to interpret the survey records to reconstruct historical vegetation pattern and comment on changes, it is necessary to assess the meaning and specificity of the structural and floristic terms employed by surveyors. Although interpretation of historical descriptions using remnant vegetation involves the assumption of constancy through the European period, it was undertaken in cases where reference to independent sources were not available.

Surveyors used the structural terms 'forest' and 'scrub' with a high degree of specificity. This was indicated by consistencies between multiple field book records for the same section and consistencies between field and diagram book records of the same section. Historical dictionary and other documented descriptions of the terms forest and scrub suggested the terms had equivalent meanings to those they infer today. Forest is still used to describe tall vegetation types, while scrub is more precisely characterised as low woodland or very low woodland. Additionally analysis of the geographical intersection of historical records of scrub and forest with remnant vegetation suggested equivalence between historical and modern day usage of the terms. The majority of historical forest observations which occurred on remnant vegetation related to forest and the majority of historical scrub observations were traced to low and very low woodland, 'scrubs'. Forest and scrub were used to describe a particular quality of the vegetation rather than just an impression of vegetation cover *per se*. In the Fleurieu Peninsula 'scrub' and 'forest' descriptions can be taken to indicate the presence of the sclerophyll formation. Both descriptions were often associated with the accompanying description of 'dense bushes' and with overstorey species which occur with sclerophyllous understoreys.

Surveyors made a total of thirteen descriptions containing floristic information. Most were readily interpretable to genus level, and then with reference to regional-remnant vegetation to two to four possible species within that genus. The restriction of a number of these species to the sclerophyll associations in the region allows floristic descriptions alone, that is without structural qualification, to be used to indicate sclerophyll formations in the region.

Repeated combinations of floristic descriptions and the specific usage of the terms 'scrub' and 'forest' allowed historical vegetation communities or associations within the sclerophyll woodland formation to be identified. Surveyors used four combinations of species and structural information in field books and diagram books; stringy bark forest, stringy bark scrub, gum and stringy bark scrub and gum scrub. Descriptions of sections in diagram books provided some additional information on height, density and floristic composition. While the additional information on vegetation height and density was mapped, it was not interpretable in any quantifiable way and so can, at best, be used to indicate relative differences between vegetation types/records.

Geographic analysis of the distribution of historical vegetation communities on modern remnant vegetation communities provided interpretation of communities through a modern analogue approach. The area of overlap of historical and remnant vegetation communities, and thus available for comparison, is dependant upon (1) the area of historical observations spatially intersecting with remnant vegetation classes and (2) the type and relative areas of vegetation classes still remaining. Selective clearance has resulted in some original vegetation types no longer being represented in the modern landscape, or having a restricted occurrence. Other types are over-represented relative to their original distribution. Highly represented remnant vegetation classes are likely to intersect with historical classes more than those with poor representation. So, in the analysis, the highly represented remnant classes could misleadingly appear to be those predominantly designated as the class in question by the surveyor.

'Stringy bark forest' was the historical vegetation class most easily interpreted using the modern analogue approach; for it was the only forest type recorded by surveyors and *E. obliqua* - *E. baxteri* open forest the only forest type extant in remnant vegetation. An obvious modern analogue in the remnant vegetation for 'stringy bark scrub' was not found. It is likely however the description is relating to *E. baxteri* - *E. obliqua* dominated scrubs, which according to Boomsma (1948), once widely occurred in the region but have been much reduced in area by clearance. 'gum and stringy bark scrub' was likely to have been referring to a range of white barked gum and stringy bark combinations that occur in the Fleurieu Peninsula. An *E. baxteri* - *E. cosmophylla* dominated community was the most ubiquitous community type in the *E. baxteri* association defined by Boomsma (1948) thus it is likely that this community was encompassed by the 'gum and stringy bark scrub' description. Most 'gum and stringy bark scrub' text observations occurred on remnant *E. baxteri* - *E. cosmophylla* - *E. obliqua* low woodland. The historical 'gum scrub' community is likely to identify an *E. cosmophylla* and/or *E. fasciculosa* low woodland to very low woodland. Both communities are represented in the remnant vegetation in the region and described by Boomsma (1948). No obvious analogue for the historical class 'grass tree and bush scrub' was found in the remnant vegetation or in Boomsma's 1948 ecological study. The description possibly refers to a low woodland vegetation which does not have an obvious overstorey dominant and in which *Xanthorrhoea* are conspicuous. Similarly the historical classes 'Grass tree and honeysuckle scrub' and 'gum and sheoak' are without obvious analogues in the remnant vegetation or historical literature.

The potential issue of individual historical observers using terminology differently was largely avoided in this study since most the surveyors records from the 1880s surveys, which provided the bulk records used, were made by a single surveyor.

Survey records provide vegetation information at two different spatial scales. Section records in diagram books were located at the spatial resolution of the sections in the ranges. This is, on average, an area of 106 ha. Text records, recorded in field books, of vegetation types or species were more spatially restricted. After transcription into a GIS, individual text records classified an average size of 6.5 ha, with a range of 4-12 ha. Both text and section records infer homogeneity across their entire extent. In the case of some section records this homogeneity is shown to be an artefact of generalisation during the diagram book transcription process, as more than one vegetation type-text record occurs within a single section. Additionally, the resolution of sections in the highland region often encompasses climatic and topographic gradients over which vegetation would vary significantly, further suggesting that in some cases the section scale resolution is too coarse to capture community variation. In contrast, text observations seemed to contain spatial information by way of their placement and size within delineated sections. This suggests that they are more likely correctly classify the vegetation type they are describing. Text-community type observations classify a smaller area of the region (2526 ha compared to 32825 ha of section records). However more confidence in their spatial, and possibly classificatory, veracity is attained.

The use of field book records relied on the assumption that their placement by surveyor's in field books represented their position in the landscape. While this assumption can not be tested, it was not shown to be incorrect; records were geographically consistent and on nearly all occasions where they intersected with remnant vegetation their classifications largely concurred. Locational errors were more likely to be due to loose placement by surveyors rather than in the GIS transcription process. Geolocation errors resulting from the mapping process were minimal as surveyors sketches of topography and boundaries were relatively accurate thus locatable on modern base maps, and allowed for mimicked placement on the GIS.

Indirect information for the sclerophyll woodland formation could also be found through the temporal pattern of survey. Predominantly all sections surveyed in the 1880s were described as being scrub or forest. The agricultural assessments made for individual sections also contained information of vegetation pattern. The arable land-pasture land distinction serves as a general proxy for the sclerophyll-savannah land system boundary. Sclerophyll associations were likely to be present on land deemed as being suitable for pasture as most ‘pasture land’ was scrub or dense forest. Scrubs or forests with a herbaceous component (‘grass’) were graded a better class of pasture land. Land classed as arable was likely to have been open woodland and forests without dense understorey.

3.5 Conclusions

The different historical sources resolved vegetation pattern and composition at a range of classificatory and spatial scales. Survey records have the most potential for further analyses of historical environmental relations for they are botanically explicit, numerous and well distributed across a range of environments. Other records provided valuable supporting information. Pictures and descriptions provided information on the structure and sporadic detail on composition of the grassy woodland formation. Sections of the first surveys potentially represents the distribution of grassy woodlands at the time of first European settlement. Survey records provided information the extent of sclerophyll woodlands in the nineteenth century and of the distribution of some species and vegetation associations within them.

CHAPTER 4

4. MODELLING POTENTIAL VEGETATION DISTRIBUTION FROM HISTORICAL VEGETATION RECORDS

4.1 Introduction

The records of pre-European or early European vegetation mapped in the previous chapter provided a spatially discontinuous representation of a continuous variable. Historical records were mapped as discrete points, localised areas or using the cadastral unit of the section. They only classified a portion of the region, leaving a greater area unclassified. The vegetation boundaries delineated in the mapping process result from implicit assumptions of the transcription methods employed. It is likely that they bear little relation to the boundaries or diffuse ecotones which actually existed in the landscape. However the mapping process revealed patterns in the variation of vegetation types across the landscape of the Fleurieu Peninsula which suggested that relationships between environmental conditions and their spatial distribution may be present and detectable. Relationships may then be used to inform of the actual vegetation boundaries in the region and provide continuous maps of vegetation pattern.

Correlations between vegetation and environment previously have been used to produce continuous chloropleth maps of historical vegetation pattern. Relationships have been established using ‘eyeballing’ approaches involving the overlaying of topographic and soil maps and looking for patterns between historical record distribution and environmental classes (Croft *et al.*, 1997), exploratory data analysis techniques calculating the relative frequency of a historical observation type in the different environmental units present in the region (Lunt, 1997a) and knowledge of environmental correlates of existing remnant vegetation (Fensham, 1989; Fensham and Fairfax, 1997). By inference these relationships have been extended to delineate areas ‘homogenously’ classified by that vegetation type. In practice such approaches are developing models of the relationships between vegetation and environment and making spatial predictions using these models. The models are qualitative mental models where:

historical vegetation = f (one or more readily observed environmental variables).

Such models are usually not explicit, tested or fully recorded. Their accuracy or precision are generally not stated. In addition, they are reliant on the presence of accurate maps classifying the environmental variables correlated to vegetation pattern.

This chapter uses vegetation modelling techniques to empirically examine the extent to which (a) the spatial distribution of historical vegetation records in the Fleurieu Peninsula are correlated with environmental conditions, defined by attributes of climate, soil and topography, and (b) can be used to predict the original distribution of historical vegetation in the region. Historical environmental relations of vegetation are investigated at two classificatory scales. The first is the distribution of the grassy woodland – sclerophyll woodland formation boundary. Their extent in the Fleurieu Peninsula at the time of European settlement, as in most regions where they occur in Australia, has been largely obscured as they have been heavily impacted by agriculture (Prober and Thiele, 1995; Hyde, 1995; Yates and Hobbs, 1997). Knowledge of their former extent is complicated by the hypothesis that grassy woodland boundaries were anthropogenically determined at the time of European settlement (Rolls, 1999). The second is the distribution of communities within the sclerophyll woodland formation. Although sclerophyll woodland communities are the most 'intact' and highly represented in the remnant vegetation of the region, they only amount to around 10% of their former cover. Analysis of historical records of their former extent would provide information on environmental patterns possibly no longer detectable from the distribution of remnant vegetation and inform on the relative impacts on particular associations in the formation.

While historical survey records of vegetation have been used in Australia to map pre-European distributions, their utility as input data in modelling approaches has not been assessed. They were considered to be suitable for modelling due to (1) their amenability to precise geo-location and (2) their similarity to mapped remnant vegetation data for which potential vegetation modelling methods have been developed. They are both incomplete, patchily distributed data sets.

The underlying assumption of the modelling approach adopted in this study is that environmental factors had a principal and controlling effect on historical vegetation pattern. As such the theoretical basis of this investigation is founded in ecological niche theory. The methodological approach adopted in the analyses are those developed in the field of potential vegetation mapping (Franklin, 1995). The chapter begins with an overview of the theories of vegetation pattern. It presents a brief review of the development of, and the methods involved in, potential vegetation mapping. The study first characterises the environment of the Fleurieu Peninsula in terms of environmental regimes affecting plant growth and distribution; spatially continuous models of direct and indirect environmental variables are developed. Empirical models are then used to explore the relationships between historical vegetation records and the mapped environmental variables. GIS mapping techniques are applied to spatially extend any derived relationships to produce predictive maps of vegetation distribution. The predictive ability of the models is then tested.

4.1.1 Vegetation pattern and modelling

The presence of a plant species in a locality, its abundance and the number of other plant species with which it coexists are influenced by physical and biological processes. Habitat factors relating to the water, light, temperature and nutrient status of a site greatly influence plant distribution, dynamics and diversity (Whittaker, 1956). Other physical factors such as disturbance by fire, grazing or erosion and spatial processes such as seed dispersal also influence plant pattern (Bazazz, 1996). Interspecific interactions such as competition, herbivory, mutualism, parasitism and disease may also greatly affect plant dynamics and community structure (Tilman, 1988). Despite the multiplicity of interacting forces on plant distribution in the landscape studies of the relationship between habitat and plants have been successful in explaining vegetation pattern at both global and local scales (Whittaker, 1956; Box, 1981).

The concept of the ecological niche, a description of a species' resource needs, habitat requirements and environmental tolerances, is widely used in classical autecological studies. Ecological niches can be represented by plots of the position and shape of that species response to a single or *n*-dimensional resource gradient. A species genetically programmed and physiologically based response to a single resource gradient is traditionally considered to be a bell-shaped curve[1], defined by the range that that species can adapt to or tolerate, with the maximum occurrence of a species at the optimum of that curve (Austin, 1990; 1999). This area is known as a species *fundamental* or *physiological* niche. Species rarely occupy their entire fundamental niche, rather the competitive presence of other species restricts the range of that response and thus they occupy a reduced area known as the *realised* or *ecological* niche. Plants do not respond to just a single environmental gradient. Rather they respond to several; thus niches are also described in *n*-dimensional space where each attribute vital to the plants ecology may be represented as an axis and the combined axes thus define an abstract multidimensional space (Whittaker, 1973; Austin and Smith, 1989).

The niche concept is also employed in plant community studies as certain niche parameters are fundamental to understanding community attributes such as species co-occurrence and diversity (Whittaker, 1973). A species ecological niche can be considered as the position it occupies in a community in relation to other species. Ecological niche theory suggests that coexisting species are assumed to occupy different niches and are only allowed a minimum of niche overlap. Species occupying the same niche would compete for similar resources and one would simply out compete an other to extinction (Whittaker, 1973). Niche differentiation lead Whittaker (1973) to develop the continuum concept of vegetation organisation, expressed in terms of environmental gradients. The continuum concept proposes that vegetation has a gradually changing species composition along environmental gradients with each species having individualistic and independent distributions in

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[1] Empirical studies by Austin (1984) and examination of results from other vegetation studies (Austin, 1990) have shown that most realised niche curves do not show bell-shaped responses.

space and time. This theory, with foundations in Gleason's 'individualistic' concept of vegetation (Gleason, 1939: Matthews, 1996) was in opposition to Clements 'organismic concept' of community units (Clements, 1928; Kent *et al.*, 1997). The continuum concept argues that communities are not definable groupings of species repeating themselves regularly in space and time. While numerous, competing and fragmented paradigms still characterise the theory of species distributions and community organisation, the continuum concept is currently the most accepted theory of the nature of community organisation (Shipley and Keddy, 1987; Austin, 1999).

4.1.1.1 Potential vegetation mapping

Gradient analyses quantify the relationships between environment and vegetation in an abstract environmental space. Developments in spatial information science technologies, particularly GIS, have facilitated the use and manipulation of large spatial datasets, allowing whole landscape scale analyses of spatially distributed environmental and ecological data to be undertaken. Using such methods vegetation-environment relationships can be quantified and translated to real (geographical) space. One application of the technology has been the development of methods to predict the potential distribution of vegetation and species distributions using inductive models based on an analytical paradigm. This type of procedure has been variously named but such studies were reviewed under the title of predictive vegetation mapping (PVM) by Franklin (1995).

S.R. Kessell and A.H. Strahler have been attributed as founders in the translation of vegetation modelling results from an abstract-environmental to geographic space (Franklin, 1995). Kessell (1976) developed fire management models in Glacier National Park using potential vegetation and animal distribution maps developed from gradient models. Straher (1977) was interested in predicting the composition of montane forests from digital topographic data and wrote:

> 'many ecological and silvicultural studies have shown the importance of topographic parameters of slope angle, aspect and relative elevation in determining vegetation composition...if species composition varies systematically with terrain, topographic variables can be used to improve prediction of species composition through implicit or explicit use of an ecological model' (Strahler, 1977, p. 929).

Box (1981) carried out further seminal work in the field with his study which empirically modelled and mapped the global distribution of plant life forms from macroclimatic variables.

Predictively mapping present day vegetation pattern is only a worthwhile exercise when maps of environmental variables or their surrogates can be obtained more easily than maps of the vegetation itself. Developments over the last few decades in computing and geo-sciences have provided digital maps of topography and other environmental data such as geology and soils and climate which have fuelled an increasing interest in PVM approaches. It thus provides a means of interpolating data from costly vegetation field surveys (Franklin, 1998). Potential vegetation modelling approaches have also been used to predict vegetation composition under different environmental regimes and thus assess the potential impacts of particular environmental changes (Mackey and Sims, 1993; Hughes *et al.*, 1996; Wohlgemuth, 1998).

Potential vegetation modelling approaches have been used to predict species distributions (Franklin, 1998; Zimmerman and Kienast, 1999), plant communities and assemblages (Davis and Goetz, 1990; Brzeziecki, *et al.*, 1993; Brown, 1994; Bolstad *et al.*, 1998; Ostendorf and Reynolds, 1998 and Mackey *et al.*, 1999) and other traits of vegetation or ecosystems such as species richness (Wohlgemuth, 1998) and rainforest vegetation physiognomy and structure (Mackey, 1994). A single study used a PVM approach to predict retrospective vegetation pattern, extrapolating the potential pre-European extent of vegetation types from models derived from remnant community distribution (Commonwealth of Australia, 1997).

The general acceptance of the continuum concept of vegetation has lead to the claim that it is theoretically flawed to design models which assume that discrete communities exist and to a preference for the development of models simulating the behaviour of individual species (Lenihan, 1993; Austin, 1999). Austin and Smith (1989), in a discussion of continua and communities, make the point that the continuum concept applies to abstract environmental space, not to any geographical distance on the ground or to any indirect environmental gradient. They argue that vegetation types can be clearly recognised at particular scales in landscapes and that they are a function of the landscape examined, writing that 'abrupt changes or gradual transitions [in vegetation] may occur depending on the landscape pattern. Co-occurring groups of species can be recognised for any particular region with a recurrent pattern of landscape.' Austin and Smith (1989) assert that labelling these communities is useful for communication and research but that extrapolation of these communities to other regions will be accurate only if the regions have similar patterns of landscape and climate. In contrast species models are more 'biological' and thus more suitable for prediction outside of the geographic area of the original data set. However Austin (1999; Austin and Smith, 1989) warns that the fitting of a model for the realised niche of individual species needs more sophisticated and individual fitting as species' response curves have shown to be context-sensitive, often dependent on other species present and not always Gaussian.

Zimmerman and Keinast (1999) predictively mapped alpine grasslands in Switzerland using a community and a species approach. They found that both modelling approaches yielded vegetation patterns that were significantly correlated with actual patterns. They asserted that communities can be considered to have a narrower realised niche compared to species. As a consequence, the probability of occurrence in a multidimensional ecological space is more uniform for communities. They concluded that advantages exist in modelling communities if real landscape patterns have to be simulated.

Various studies have chosen to develop, and then agglomerate, individual species models to make community-wide predictions (Franklin, 1998; Austin, work in progress). However given the effects of species-interactions, the legitimacy of the agglomeration approach has been questioned (Bazzaz, 1996). In conclusion, while modelling species distributions may be theoretically sound there is a practical need for the prediction of vegetation pattern based on structural and floristic community assemblages. Furthermore such models are theoretically tenable. In either case, predictions should not be extrapolated beyond the geographical area sampled by the data.

4.1.1.2 Environmental gradients for prediction

Environmental gradients provide a convenient means of organising environmental heterogeneity. Various types of environmental gradients can be distinguished (Whittaker, 1973; Austin and Cunningham, 1981; Keddy, 1991). Austin and Cunningham (1980) divided environmental gradients into three types; direct, indirect and resource. Indirect environmental gradients, the equivalent of Whittaker's (1973) complex gradient, are those that have no physiological effect but may influence plant growth indirectly as they are correlated with attributes directly effecting plant growth. Examples of indirect gradients are elevation, slope, aspect, soil texture and soil depth whose location-specific correlation with water availability, wind and temperature are responsible for changes in vegetation response. Direct environmental gradients, for example soil pH, are those which have a direct physiological effect on plant growth. A resource gradient is one where the factor is directly used as a resource for plant growth, for example nitrogen.

4.1.1.3 Characterisation of environmental gradients

Potential vegetation mapping requires the environmental attributes affecting biotic distribution to be quantified on a landscape-wide basis. Efforts to characterise environmental gradients more specifically, and at a finer resolution, have been greatly assisted by the development of computer-based mathematical and computational environmental modelling techniques. These techniques generate spatially distributed values of climatological, hydrological and geomorphological processes in landscapes (Mackey *et al.*, 1988; Moore *et al.*, 1991). A basic component of many of these models is a digital elevation model (DEM). A DEM is an ordered array of numbers that represents the spatial distribution of surface elevations above an arbitrary point in the landscape. Such elevation data can be modelled in numerous ways, with the two most common using grids or Delaunay Triangulation (TINs) using data from a range of sources (Burrough and McDonnell, 1998). A DEM is essentially a mathematical surface so it is possible to derive mathematical derivatives from it at any location. First order derivatives, termed primary terrain attributes, which may be derived from a DEM are slope, aspect, profile and plan curvature, flow path length and specific catchment area (Moore *et al.*, 1991). These surfaces can be combined to form compound attributes such as sediment transport capacity indices and wetness indices which estimate the spatial distribution of specific processes operating in the landscape (Moore *et al.*, 1991). Spatial models of regional climatic indices that are considered to have biological significance, such as mean annual values, seasonal mean conditions and extreme values, have been developed using climate station records and elevation from a digital elevation model (Hutchinson, 1988, 1989; Nix, 1986). Climatic surfaces enable values to be estimated of the key controlling meso-scaled factors in dynamic energy and water balances (Nix, 1986). Radiation is one of the major environmental regimes that directly and indirectly modulates plant response by affecting both the processes of evaporation and photosynthesis. Solar radiation models predicting various radiation measures, and accounting for the effects of topography and other important influencing factors, have been developed at several different scales (Hutchinson *et al.*, 1984; Moore *et al.*, 1991; Dubayah and Rich, 1995).

Various specialised software have been developed to generate the climatic and terrain environmental models, although commercially available GIS software increasingly support environmental modelling functions. In this study environmental models are run whose outputs are then used as source data for the development of a GIS database. The GIS and subsequent analysis and mapping uses ArcInfo 6.0 (ESRI, 1997).

4.1.1.4 Models for the prediction of biotic distribution

Two types of modelling techniques, exploratory and confirmatory, were distinguished by Chatfield (1995). Exploratory techniques are used to study new sets of data which have not been subjected to study. They provide a quantitative analysis of patterns or order in a data set, however do not provide statistical tests yielding confidence limits of model outcomes. Examples of exploratory data analysis (EDA) techniques developed especially to model species distributions are BIOCLIM (Nix, 1986) and Domain (Carpenter *et al.*, 1993). A variety of other EDA approaches; GIS procedures using area calculations, Boolean retrieval based on attributes, classification, overlay and intersection, neighbourhood analysis and trend surfaces, have been adapted to the spatial prediction of biota (For review see Walker, 1991). Multivariate pattern analysis techniques are widely used ordination and correlation methods in ecology (Kent and Coker, 1992) and of these canonical correspondence analysis (CCA, ter Braak, 1987) has received much attention for species prediction. CCA has considerable power provided assumptions of species having unimodal responses to environmental variables, the responses being equally spaced and of equal width or height (ter Braak, 1987) are met. However unimodal responses can not be assumed in the modelling of *Eucalyptus* distribution (Austin *et al.,* 1994). The applicability of such techniques to vegetation modelling is thus questionable.

Confirmatory data analysis approaches, or statistical techniques, are used to test hypotheses from existing results or established theories and involve statistical testing. The data distribution requirements of such techniques are rigorous. Their use involves assumptions that sampling is random, that is each sample measurement should be independent of any other and on every sampling measure each individual should have equal chance of being selected. This is vary rarely the case in vegetation studies due to (1) spatial autocorrelation, which is the inevitable relationship between points in space, particularly if they are close to each other, and (2) the practical difficulties of random sampling. Statistically methods generally involve rigorous ecological assumptions (Austin *et al.*, 1994, but see Yee and Mitchell, 1991). Statistical techniques cannot be carried out on presence-only data, they require presence/absence or abundance data. Examples of confirmatory approaches used for modelling biota in landscapes are the adapted regression models known as Generalised Linear Models (GLMs, McCullagh and Nelder, 1989) and Generalised Additive Models (GAMs, Yee and Mitchell, 1991).

Alternative non-statistical prediction approaches have used computer induction methods including Decision Trees (Lees, 1994), neural networks (Fitzgerald and Lees, 1992) and genetic algorithms (Stockwell and Noble, 1991).

In this study, two types of exploratory data analysis techniques were used to examine vegetation-environmental relations, BIOCLIM (Nix, 1986) and an environmental domain analysis procedure (TEDA, Mullen, 1995). The primary reason for their adoption chosen over statistical methods was related to the nature of the distribution of both the historical and modern data. The assumption of independence of individual records could not be met by either data set.

4.1.1.4.1 BIOCLIM

BIOCLIM is a heuristic modelling method which has been used to predict the theoretical climatic distribution of organisms (Nix, 1986; Busby, 1986). Geocoded specimen records are used in combination with a selected set of bioclimatic variables for the location to estimate the range of each bioclimatic variable within which the species is found. The bioclimatic variables are calculated at each record location. The bioclimatic parameters generated by BIOCLIM are a set of indices considered to have biological significance. They can be considered as surrogates for key controlling factors in dynamic energy and water balances. Applications of BIOCLIM include a continental study of elapid snakes (Nix, 1986), an examination of the bioclimatic domains of *Eucalyptus* species (Lindenmayer *et al.*, 1996; Hughes *et al.*, 1996; Williams, 1991) and an analysis of the biogeoclimatic distribution of *Nothofagus cunninghamii* (Busby, 1986).

For each species location the climatic estimates are aggregated to provide a 'climatic profile' of the taxon. The values for each estimate are ranked in increasing order such that the minimum value, the 5th percentile and 95th percentiles can be defined. Conditions lying between the 5th and 95th percentiles for selected bioclimatic variables are selected to indicate the climatic envelope or 'core domain' for the *potential* occurrence of a species. That is the core domain is defined as where 5-95% of species records occur. Marginal potential environments are defined as those in which values fall outside these values for one or more of the indices, but within the range (upper and lower limits).

While this denotion of core and marginal potential occurrences are arbitrary they are at least explicit (Nix, 1986). From the profile, together with a regular grid of predictions of the bioclimatic variables for a region, a map for the potential occurrence of a species can be generated.

4.1.1.4.2 Environmental Domain Analyses

An environmental domain analyses procedure, TEDA (Topographic Environmental Domain Analyses) developed by Mullen (1995) in a landscape study of *Eucalyptus* rainforest in southeast New South Wales is an exploratory data technique allowing exploration of correlation between vegetation and environment. It has also been applied to a landscape analysis in the boreal forests of Canada (Mackey *et al.,* 2000). The procedure uses patch data of each community type to analyse the environmental domain in which the community occurs. It quantifies the observed probability of a community occurring within a two dimensional domain, which is defined by the combination of two selected environmental variables. The domain analysis requires four gridded data sets for the area as input; (1) gridded estimates of the first environmental variable for the study area; (2) gridded estimates of the second environmental variable for the study area; (3) all occurrences of the target community type; and (4) the distribution of all vegetation types.

The domain analysis involves the generation of a two-way table defined by the selected environmental gradients. Each gradient is divided into 25 equally-spaced classes across its entire range, resulting in 625 discrete environmental domains. The frequency of occurrence of each domain in the whole study area is then calculated. The frequency of occurrence of all grid cells that are labelled as the target vegetation type is then calculated for each domain. An observed probability of occurrence of the target vegetation type is then calculated for each environmental domain by dividing the frequency of occurrence of all grid cells. That is, within each of the 650 two dimensional environmental domains, the total number of grid cells where a species is present is divided by the total number of grid cells in the landscape that occupy that domain. The result is an observed probability of occurrence for each environmental domain in the two way table. The observed probabilities can be interpreted as indicating those environments where the vegetation type is most likely to be present. The models are then used to generate a spatial prediction of the probability of vegetation presence as a function of the two environmental variables under examination.

4.2 Methods

4.2.1 Vegetation data

4.2.1.1 Grassy woodlands and sclerophyll forests and woodlands

It was shown in Chapter 3 that little direct record was made of the distribution or nature of the grassy woodlands in historical survey records. But the distribution of first survey sections (Figure 3.25) is likely to indicate their distribution. In contrast, direct evidence for sclerophyll woodland and forest formations were found in the historical survey records of the region. Records noting 'forest' and 'scrub' with a 'dense understorey of bushes' described communities with sclerophyll understoreys. These communities are the equivalent of, and encompassed by, the sclerophyll landsystem described by Specht (1972). Sections classified as 'forest', 'tall forest', 'scrub', 'low dense scrub', 'scrub', 'dense scrub' and 'low scrub' (Figure 3. 23) were grouped into a single coverage. Sections described as being 'part scrub' were not included. A total of 18 930 hectares were classified in total as sclerophyll woodland.

4.2.1.2 Sclerophyll communities

Digitised text observations (polygons) from surveyor's Field Note Books were used as input data to model the distribution of the pattern of 1) stringy bark forest, 2) stringy bark scrub, 3) stringy bark and gum scrub, 4) gum scrub and 5) low scrub. The data retrieval process is described in Chapter 3 and illustrated by example in Figure 3.1. The distribution of observations is depicted in Figure 3.24. The number of observations and the area they occupy is given in Table 3.5. An interpretation of the vegetation units referred to by each of these historical vegetation classes is also provided in Chapter 3.

4.2.2 Environmental data

Specht and Perry (1948) suggested the microdistributions of the *Eucalyptus* spp. in the Mount Lofty Ranges were sensitive to changes in water-balance induced by variation in rainfall, solar radiation and evaporation potential. Specht (1972) and Sparrow (1991) showed the importance of climate and soil type in defining the distribution of the grassy and sclerophyll woodlands in South Australia. Environmental data directly representing, or as surrogates for, these suggested controlling factors were collected or developed, via modelling approaches, for the study area. Climate variables with biological significance, which vary and influence vegetation pattern at a meso-scale in the landscape, were modelled. The smaller-scaled controls of water-balance and other environmental process, that scale which represents landform and landform elements (Speight, 1988), were modelled using digital terrain analysis approaches. This later scale of variation is hereafter referred to as 'topo-scale'. Topographical factors derived through digital terrain analyses have successfully explained vegetation distribution patterns with both strong (Brown, 1994; Pinder *et al.*, 1997; Bolstad *et al.*, 1998), and modest (Burke *et al.*, 1989; Ostendorf and Reynolds, 1998; Mackey *et al.*, 2000) elevation and topographic gradients.

4.2.2.1 Digital elevation model (DEM)

Obtaining gridded estimates of climate and terrain variables requires the input of a DEM. A regular grid representation of a digital elevation models was built using the ANUDEM program (Hutchinson, 1988) available in *ArcInfo* using the Topogrid command.

Grid based DEMs are the dominant method of representing topography and are preferred as they simplify the application of many terrain based analyses and are compatible with other environmental data sources. A grid based method was chosen over triangulation methods of DEM production as the latter have limitations in representing slope and curvature and do not incorporate ordered descent conditions in streamline data (Burrough and McDonnell, 1998; Hutchinson, 1988). ANUDEM uses an interpolation method especially designed for the creation of hydrologically correct DEMs from elevation and stream coverages. The interpolation method used is a discretised thin plate spline technique using an iterative finite difference interpolation technique (Wahba, 1980), where the roughness penalty has been modified to allow the fitted DEM to follow abrupt changes in terrain, such as are found at streams and ridges. The ANUDEM program imposes a 'global drainage condition' which imposes constraints on the interpolation process and results in the correct representation of ridges and streams. The global drainage condition removes all sink points in the output DEM that have not been identified as sinks in the input sink coverage, thus removing the need for editing or post-processing. The program assumes that all unidentified sinks are errors, since sinks are rare in natural landscapes.

The DEM was built at a grid cell resolution of 20 metres. Terrain attributes are scale dependent quantities, thus appropriate grid cells size choice for the process to be examined is important (Moore *et al.*, 1993b). Scales of 30 metres or less are commonly used to represent hydrological processes. Since vegetation pattern is likely to be related to the distribution of water in the landscape, a grid cell the DEM was built at a resolution of 20 metres. The DEM was interpolated from digitised 5 metre interval contour data. A drainage coverage was also used to build the DEM, as ANUDEM uses the data to ensure more accurate placement of streams. Pre-processing of the drainage coverage was undertaken to ensure correct flow directionality; all arcs were required to be oriented in a down slope direction and lakes and braided streams removed (Appendix 2).

4.2.2.2 Terrain attributes

TAPES-G (Moore *et al.*, 1993; Gallant and Wilson, 1996), a grid based terrain analysis program, was used to calculate the spatial distribution of the primary terrain attributes of slope, aspect and catchment area. The compound terrain attributes of topographic wetness index (Moore *et al.*, 1991), for the hydraulic gradient (Moore *et al.*, 1991). It has been used as a relative index of long-term soil water content for the purpose of predicting vegetation response (Mackey, 1994; Mackey *et al.*, 2000). However there are limitations with its use for such purposes as the model assumes steady state and spatially invariant conditions for both infiltration and transmissivity. It also assumes that there is no deep or complex sub-surface drainage, so that sub-surface flows track surface morphology (Mackey *et al.*, 2000).

It is defined by the equation

TWI = ln (Specific catchment area (A_s) / slope (S)),

Where the specific catchment area (A_s) is the contributing area divided by the flow width. It thereby provides an approximate measure of runoff per unit width,

A_s = the upslope contributing area (A)/the flow width (W).

Upslope contributing area (*A*), sometimes referred to as drainage area or catchment area, measures the area draining out of each cell. The TAPES-G program offers choice in several algorithms which estimate flow direction, to calculate upslope contributing area. The FD8/Frho8 algorithm, which permits drainage from a cell to all nearest down slope neighbours on a slope weighted basis, was selected for it permits the modelling of flow dispersion in upland areas which is important in areas with convex topography (Moore *et al.*, 1993). The flow width (W) is a measure of the width of a landscape element. The TWI index is a non-local topographic attribute. It carries information about the shape of the surface for long distances across the landscape surface. The gridded coverage of TWI is shown in Figure 4. 2.

4.2.2.5 Elevation percentile

The elevation percentile index (E%) is a measure of local topographic position. It was calculated using the program ElevResidGrd (Gallant, 1996), which analyses the properties of each cell in a DEM in relation to cells in a user-defined radius around the centre of each grid cell. A radius of 200 metres was used to capture the average distance from the tops of hills and ridges to adjacent valleys. The elevation percentile index measures the ranking of the elevation of the central point compared to all the points in the context circle, and ranges from 1 to 0. If a point is the lowest in the circle it will be given the value of 0 and if it is the highest, 1. If all points are exactly the same height a value of 0.5 is assigned (Gallant, 1996). The elevation percentile is a relative, dimensionless index (Figure 4. 3).

4.2.2.6 Solar radiation

The amount of solar radiation received at a given point on the Earth's surface is the result of many factors and processes operating at a range of spatial scales. There are three sources of illumination in the solar spectrum; (1) direct irradiance from the sun, the amount received is highly dependant upon latitude, as it affects the illumination angle, and day length, (2) diffuse irradiance which is a function of the scattering and absorbing properties of the atmosphere and clouds, pressure and solar geometry and (3) reflected irradiance from surrounding terrain. These types of radiation incident on a slope are strongly affected by self-shading by the slope itself and shadowing cast by nearby terrain.

Solar radiation models have been developed at a range of spatial scales (e.g. Hutchinson *et al.*, 1984; Dubayah and Rich, 1995). The development of digital elevation models has allowed the incorporation of topo-scale terrain effects in systematic and quantifiable ways to these models. The program SRAD (Wilson and Gallant, 1996), was used to calculate spatially distributed estimates of annual net radiation as a function of location, slope, aspect, topographic shading and time of year. Estimates were modified using average cloudiness and sunshine hours data. SRAD uses a DEM and a locally calibrated parameter file describing surface properties, temperature and average climate on a monthly basis. It includes the effect of shadowing by surrounding topography obscuring the sun as well as slope and aspect.

Wilson and Gallant (1996) fully documented the estimation methods of the SRAD process. In summary the stages involved are: (1) sun position is calculated for user selected time steps using latitude, date and time; (2) transmittance and circumsolar coefficients are used to determine ground level clear sky direct and diffuse irradiance components; (3) horizontal and inclined surface irradiance values are calculated using cloudiness sky-view and albedo values; and (4) temperatures and long wave irradiance using the radiation ratio is calculated.

The parameter file was compiled using local meteorological data and values suitable for south eastern Australia as suggested by Moore (1993). Values used in the parameter file are recorded in Appendix 2. Values used included the average monthly temperature and rainfall data recorded at Parawa on the Fleurieu Peninsula; sunshine fractions measured at Lenswood in the Central Mount Lofty Ranges, estimated monthly values of the circumsolar coefficient (0.25; fraction of diffuse radiation originating near the solar disc), albedo (0.15; - it is assumed to be constant as no snowfall or deciduous forests which strongly affect albedo occur in the region), cloudiness parameter (0.34; ratio of actual radiation to clear sky radiation during cloudy periods), LAI (Leaf area index: 2.25) and monthly elevation lapse rates for minimum and maximum air temperatures (7.30

Correlation of bioclimatic surfaces was investigated using the *correlation* function in ArcInfo Grid (ESRI, 1997) (Table 4. 1). Seasonal minima and maxima for precipitation and temperature were highly correlated with the mean annual precipitation and temperature respectively. Consequently the annual mean values were selected to define the bioclimatic ranges of vegetation types investigated in this study. Mean annual temperature (Figure 4. 6) and annual mean precipitation (Figure 4. 1) provide a gross approximation of total water and energy inputs in a site.

Table 4. 1 Correlation between climate indices derived for the Fleurieu Peninsula. R values are scaled between -1 and 1 with 0 being independent and 1 strongly positively correlated and -1 strongly negatively correlated.

Index 1	Index 2	Correlation coefficient
Annual precipitation	Precipitation of the wettest quarter	-0.9128
	Precipitation of the driest quarter	-0.9927
	Elevation	0.9497
Mean Annual temperature	Mean temperature of the warmest quarter	0.90965
	Minimum temperature of coldest quarter	0.8995
	Maximum temperature of the warmest quarter	0.9267

4.2.2.9 Soil data

Maps of soil types at a scale of 1:50 000 were obtained from Primary Industries and Resources, South Australia. Over 250 soil types have been described in the Mount Lofty Ranges. Soil types were grouped into 14 principle profile forms. Some forms contain textural sub-categories, generating 21 types in total. A map and description of types is presented in Chapter 2, Figure 2.3.

4.2.3 Analytical techniques

4.2.3.1 Grassy woodland-sclerophyll boundary

The program BIOCLIM (Busby, 1986; Nix, 1986) combined with a soil domain model was used to examine the climatic and edaphic domains of grassy woodland and sclerophyll formations woodland as indicated by historical survey data. BIOCLIM was run through a menu driven interface called TkClim version 1.5 (Houlder, 1996). The procedure is documented in Appendix 3 and the major analytical steps are presented in detail by Nix (1986b) and Lindenmeyer *et al.* (1996).

For BIOCLIM modelling a file of the locations and elevations of sites that sample the distribution of the biological entity to be modelled is required. The presence data for historical grassy woodland and sclerophyll woodlands classified areas (polygons), rather than sites (points), as required by BIOCLIM. The mean section size of grassy and sclerophyll woodland records was 34 ha and 108.4 ha respectively. Polygon data were required to be converted into point data. If the conversion of polygon to point data was based on the arbitrary placement of a point within a section polygon, then there is doubt that that the sample point would provide data representative of the whole polygon. To provide a more representative sample of 'observations', the area covered by each polygon was gridded at a resolution of 100m and the centroid of each grid cell was used as a sample point indicating the presence of the observation. Elevations for each site were obtained from a 20m resolution DEM using the ArcInfo/GRID *Sample* command. The sample command outputs a file of AMG coordinates and elevation. This file was edited into the required format and projected into geographic coordinates required by BIOCLIM.

BIOCLIM requires environmental data to be ordinal. Soil is mapped in nominal classes and so an alternative method was required to investigate the soil domains of formation types. A method employing a similar classification approach to BIOCLIM was adopted to define the soil domains occupied by formation types. The observed frequency of soil types was calculated for historical and modern vegetation observations. However, unlike the BIOCLIM procedure which employs site data, gridded areal data was used. The area of intersection of observations of each formation type on each soil type was calculated and the data expressed as a percentage of the total area of all observations of the formation type. The edaphic envelope or domain was then defined using sets of the frequency values. If a formation type did not occur on a soil type it was excluded from the domain. If it occurred at a frequency greater than 0 but less than 10% it was classed as potential marginal domain. Soil types with a frequency of occurrence greater than 10% was classed as potential core domain.

The primary ecological assumption in this modelling approach is that climate and soil type controlled the pre-European distribution of grassy and sclerophyll woodlands. This is a reasonable assumption and is supported by various ecological studies (Specht, 1972; Sparrow, 1991). The modelling approach requires presence only data, and the historical records used to model these boundaries are of this type.

4.2.3.2 Domain analyses

The environmental domain analyses, TEDA, developed by Mullin (1995) were used to explore the spatial distribution of the historical vegetation communities as indicated by 1880s Field Note book records. The TEDA analyses were carried out in GRID, a sub-program of ArcInfo 6 (ESRI, 1997) designed to analyse spatial data in raster format.

4.2.4 Environmental combinations

The combinations of environmental variables selected to examine historical vegetation community distribution are presented in Table 4. 2. Annual precipitation was the only meso-scale variable investigated. Models were initially built with mean annual temperature but the small temperature range in the region resulted in domains of less than 0.1°C. Such small domains are ecologically meaningless and were unable to be resolved by the domain division process. Annual precipitation is reasonable highly correlated with mean annual temperature, so was deemed to sufficiently represent meso-scale climate gradients in the region. Terrain variables were investigated for their correlations with a wide range of environmental processes and attributes affecting biological productivity. The solar radiation model captures topo-scale variation in insolation and thus evaporative potential. Slope and elevation percentile and the topographic wetness index capture aspects of terrain shape and position, which closely controls the way water moves over the landscape, as well as the hydrological potential of a site (Moore, 1993; Gallant and Wilson, 1996).

The effect on soil type on the distribution of sclerophyll woodland vegetation has been discussed (Boomsma, 1948; Northcote, 1977). However, soil indices were not used in the modelling of the sclerophyll woodland vegetation types. Its inclusion would have entailed further development of the TEDA modelling process to accommodate nominal data. Additionally it was thought that the terrain and climate variables may capture some of the variation in the soil types of the region. Soil types can be considered to be functions of geology, topography, climate, time and vegetation (Gerard, 1981). Maud (1972) discussed the relationship between landform and soil type in his study of the soils between Mount Compass and Milang, noting that podzolic soils with high gravel content (Dy3.61) were associated with remnants of the former summit high plain. Climate and soil type relations have been noted in the region. Ward (1966) found that rainfall did not correlate with the soil classes he defined in the County of Adelaide but that the boundary between calcareous and non calcareous soils is determined by the 685 isohyet. Taylor *et al.* (1974) state that the development of acid podzolic soils on all kinds of parent rock, except for calcareous, is tied to the 675 mm isohyet as a minimum rainfall. Similar relationships have been observed in the central Mount Lofty Ranges. Topo-scaled relationships between landscape position and soil type have been observed in the Fleurieu Peninsula. Wright (1973) noted that permeable soils occurred on shale in mid slope positions but waterlogged podzolic soils on the wetter lower, more gently sloping sites. Terrain variables have successfully predicted soil heterogeneity in landscapes in southeastern Australia (Moore, 1993; Gessler *et al.*, 1995).

Table 4. 2 Environmental combinations investigated for their strength of prediction of sclerophyll community pattern from historical data records.

Variable 1	Variable 2	Model reference code
Annual precipitation	Topographic wetness index	APCW
Annual precipitation	annual net radiation	APNR
Annual precipitation	Wetness index	APWI
Annual precipitation	slope	SLAP
Annual precipitation	elevation percentile	EVAP
Elevation percentile	Topographic wetness index	EVCW
Elevation percentile	annual net radiation	EVNR
Elevation percentile	wetness index	EVWI
Elevation percentile	slope	EVSL
Slope	annual net radiation	SLNR
Slope	Topographic wetness index	SLCW

4.2.5 Model assessment

The assessment of the accuracy of predictions from ecological modelling is an important component of the modelling process. The validity of models can be assessed using statistical approaches or more pragmatic approaches involving the testing the model's accuracy and usefulness (Chatfield, 1995). The later approach is adopted in this study. It was chosen for of interest is the utility of such approaches in the prediction of historical vegetation patterns.

Measures of the prediction success of a model can be obtained by (1) a *partitioning* approach, which involves splitting the data set into that which is used to develop the model and that which is withheld and later used to test the predictive success of the model, (2) a *resubstitution* approach, in which the data that was used to generate the model in the first place is used to test the model, or by (3) a *prospective sampling* approach, which involves the testing of the model with a new set of samples specifically obtained for model testing after the model has been developed. The re-substitution method is regarded to give optimistically biased estimates of error rates because of over fitting and a loss of generality (Chatfield 1995). However partitioning methods reduce the size of the data set that is used to build the model, and this can reduce their accuracy. Prospective sampling avoids data loss and the optimistically biased error estimation problems associated with partitioning and resubstitution methods respectively.

Models that predict the presence or absence of a biotic entity can be judged by the number of prediction errors. There are two types of prediction error in a presence/absence model; false positives and false negatives. The performance of a presence/absence model can be summarised in an error matrix that cross tabulates the observed and predicted presence and absence patterns (Table 4. 3).

Table 4. 3 An error matrix. TP = true positive, TN = true negative, F P = false positive and FN = false negative.

	Actual present	Actual absent
Predicted present	TP	F P
Predicted absent	TN	FN

Measures of 'sensitivity' and 'specificity' can be calculated from the error matrix (Fielding and Bell, 1997). Sensitivity is the conditional probability that case X is correctly classified, that is the true positive fraction. Specificity is the true negative fraction.

$$\text{Sensitivity} = TP / (TP + FP)$$

$$\text{Specificity} = TN / (FN + TN)$$

$$\text{Error rate} = (FN + FP)/(TP + FP + FN + TN)$$

Sensitivity and specificity measures are used in a model testing approach which employs a threshold-independent method employing receiver operating characteristic (ROC) plots (Zwieg and Campbell, 1993).

The ROC methodology and its use are discussed by Mackey *et al.*, (In review) and Fielding and Bell (1997). A ROC plot is obtained by plotting all sensitivity values on the *y* axis against their equivalent (1-specificity) values (false positive fraction) for all available thresholds on the *x* axis. The area under the ROC function (AUC) provides a single measure of overall accuracy that is not dependant upon a particular threshold. The value of the AUC is between 0.5 and 1.0. A value of 0.8 for the AUC means that for 80% of the time a random selection from the positive (presence) group will have a score greater than a random selection from the negative (absence case). A value of 0.5 indicates a model with no ability to discriminate since for all decision values the sensitivity is equal to the false positive fraction. A value of 1.0 indicates no overlap between where presences and absences are predicted by the model. Comparisons of model outputs based on ROC plots allows their prediction accuracy to be ranked and provides a comparative measure that is independent of the values in the error matrix. A strength of the ROC method is that the bias that can result from failure to use all the data provided by the model output (classifier) by the dichotomisation of a continuous variable is avoided.

Here, receiver operating characteristic plots curves, giving specificity and sensitivity measures from data used to build the models, were used to assess the relative predictive successes of the various environmental combinations investigated in the prediction of historical sclerophyll community types.

4.3 Results

4.3.1 Grassy woodland – sclerophyll woodlands

4.3.1.1 Bioclimatic domains

The bioclimatic profiles generated from the distribution of historical records of grassy woodland and sclerophyll woodlands are presented in Sclerophyll woodland records, composed of both historical ‘scrub’ and ‘forest’ records, and their individual profiles are also shown in Table 4. 4.The profiles contain the mean, minimum, 5%, 95% percentile and maximum values for the selected bioclimatic indices of annual precipitation, precipitation of the wettest quarter, precipitation of the driest quarter, mean annual temperature, mean temperature of the warmest quarter, minimum temperature of coldest quarter and maximum temperature of the warmest quarter.

Table 4. 4 The mean annual temperature (ºC) and annual precipitation (mm) envelopes of grassy and sclerophyll woodlands generated from the use of BIOCLIM using historical survey observations pertaining to section cadastre. Sclerophyll woodlands were composed of historical 'scrub' and 'forest' records and their bioclimatic envelopes are also shown.

Vegetation type		Mean	S.D.	5%	10%	25%	50%	75%	90%	95%	Max.	Min.
Grassy woodland	Temp.	14.9	0.37	14.3	14.5	14.7	15	15.2	15.4	15.5	15.8	13.8
	Precip.	697	83.24	550	577	634	705	761	804	828	903	502
Sclerophyll woodlands	Temp.	14.1	0.38	13.5	13.6	13.8	14.1	14.4	14.7	14.9	15.6	13.2
	Precip.	826	63.32	702	744	796	837	867	899	914	961	530
"forest"	Temp.	14	0.31	13.6	13.7	13.8	13.9	14.1	14.4	14.7	15.2	13.2
	Precip.	833	44.97	754	790	813	837	862	877	905	961	557
"scrub"	Temp.	14.2	0.39	13.6	13.6	13.9	14.2	14.4	14.8	14.9	15.6	13.2
	Precip.	823	68.92	684	730	788	836	872	903	913	957	530

Cumulative frequency plots for the mean annual temperature and annual precipitation of location of grassy woodland and sclerophyll woodlands records allow comparison of the bioclimatic domains of the two formation types. The cumulative frequency plot for annual precipitation indicates that sites supporting grassy woodlands occupy areas of lower annual rainfall than those supporting sclerophyll woodlands (Figure 4. 8).

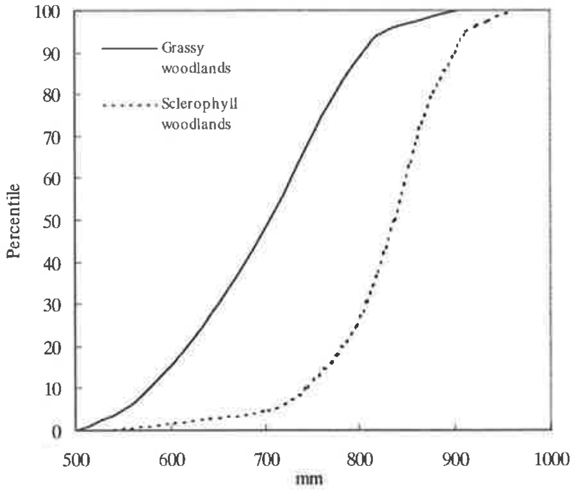


Figure 4. 8 Cumulative frequency plot of the distribution of annual precipitation of sclerophyll and grassy woodland formations as determined by historical data records.

The cumulative frequency plot for mean annual temperature similarly separates the historical distribution of the formation types, with grassy woodlands occupying sites of lower precipitation and higher mean annual temperature than sites supporting sclerophyll woodland (Figure 4. 9)

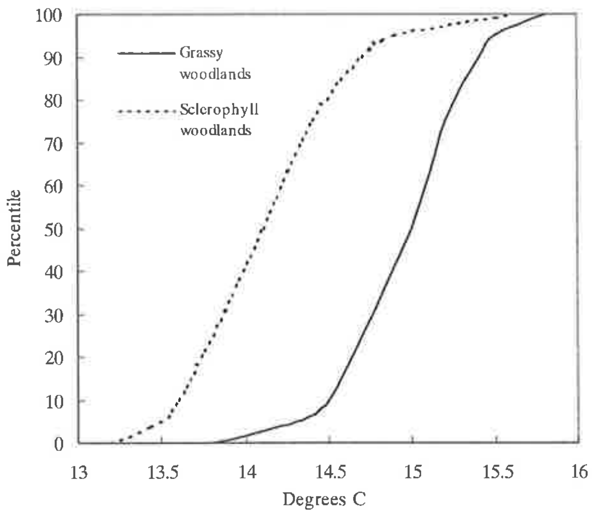


Figure 4. 9 Cumulative frequency plot of the distribution of annual mean temperature of sclerophyll and grassy woodland formations as determined by historical data records.

Maps of the potential bioclimatic domains of the grassy woodland and sclerophyll formations in the Fleurieu Peninsula, as defined by the distribution of historical vegetation records, are presented in Figure 4. 10 and Figure 4. 11. These maps contain a predicted core bioclimatic domain derived from grid matching using the 5th to 95th percentile values in the bioclimatic profile and a predicted marginal bioclimatic domain based on grid matching using the minimum and maximum levels in the bioclimatic profiles. The core and marginal potential bioclimatic domains of grassy woodlands occupies most of the Fleurieu Peninsula, only excluding the highest elevations on the spine of the ranges and small areas fringing the southwest coast. The predicted core grassy woodland bioclimatic domain occupies most of the lower elevations in the region to the mid-elevations of the ranges.

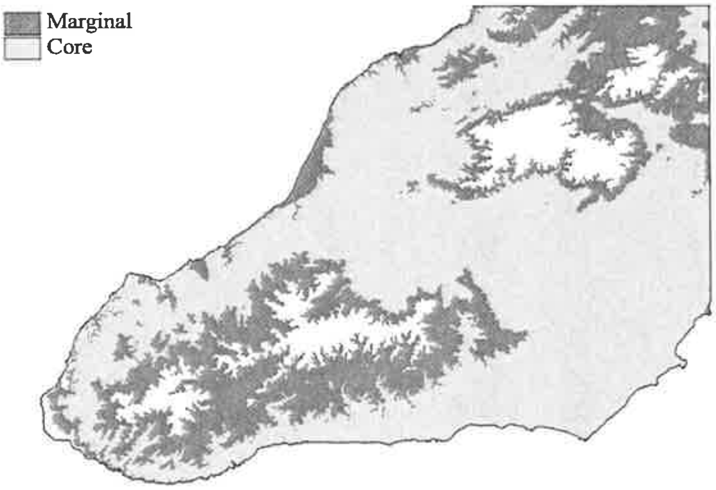


Figure 4. 10 The predicted core and marginal bioclimatic domains of grassy woodlands from historical data records

Most of the Fleurieu Peninsula is classified as being the potential core and marginal bioclimatic domain sclerophyll woodlands, except for low elevation-coastal areas and a small area in the northern uplands. The core domain of sclerophyll woodlands occupies most of the higher and mid elevations found in the region.

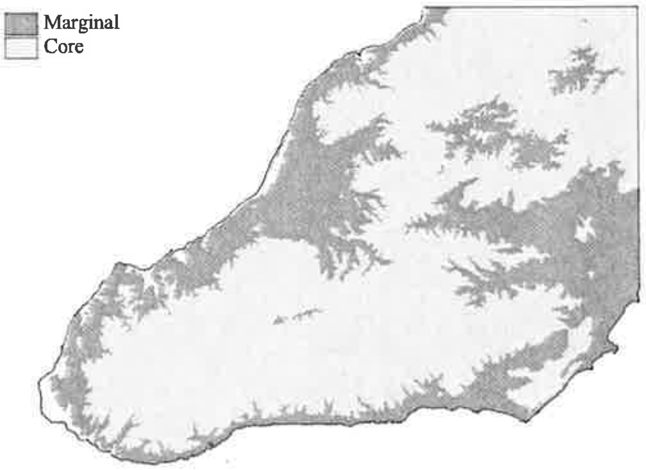


Figure 4. 11 The predicted core and marginal bioclimatic domains of sclerophyll woodland from historical data records

4.3.1.2 Soil domains

Histogram plots of the occurrence of historical observations of grassy woodlands and sclerophyll woodlands on soil classes in the region allow the comparison of the soil domains of the two formation types (Figure 4. 12 and). Sclerophyll and grassy woodland records were represented to varying degrees on most soil types, not being exclusively restricted to a particular soil type or types. However categorical distinctions between grassy and sclerophyll formations were apparent when the most highly represented soil types were considered. More than 30% of grassy woodland communities occur on soil type 302 (Grey or brown sand over clayey subsoils), but only 6% of sclerophyll woodland occurs on this soil type. Conversely over 25% of sclerophyll woodland occurrences were found on type 100 (Grey sandy loams) and type 102 (Grey brown loams), but less than 5% of grassy woodlands were on these types.

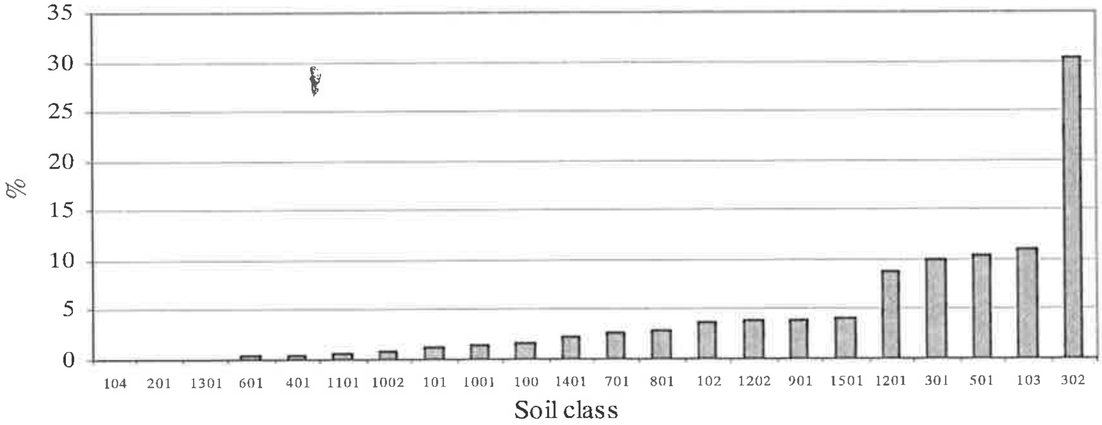


Figure 4. 12 Histogram of the distribution of historical records of grassy woodlands on soil types. Soil types corresponding to soil codes are listed in Figure 2.3.

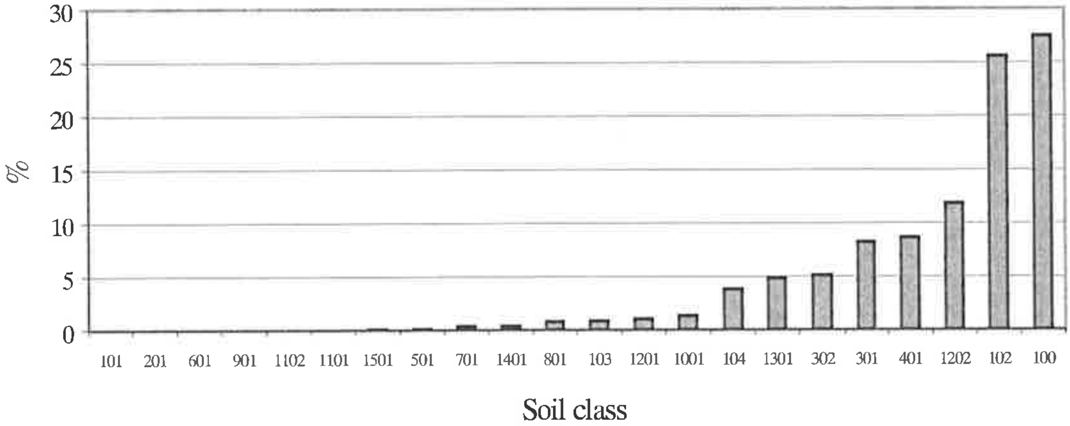


Figure 4. 13 Histogram of the distribution of historical records of sclerophyll woodlands on soil types. Soil types corresponding to soil codes are listed in Figure 2.3.

Analogous to the way in which core and marginal domains were determined by BIOCLIM, frequency of occurrence of formation-records on soil types were used to define the soil-type domains. Soil types on which 10% or more of records occurred were defined as core domain. Soil types on which records occurred but in proportions less than 10% of all records, were defined as marginal domain, and those on which records never occurred were excluded from predictive domains. Maps of the potential soil domains of grassy and sclerophyll woodlands in the Fleurieu Peninsula, defined by historical data, are presented in Figure 4. 14 and Figure 4. 15.

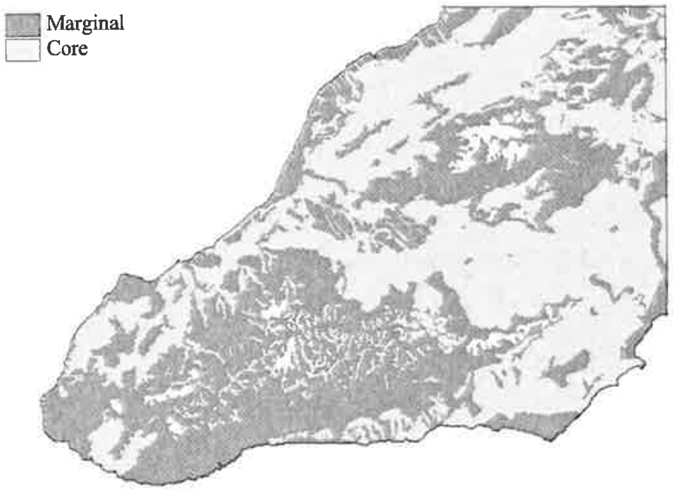


Figure 4. 14 The predicted core and marginal soil domains of grassy woodlands from historical records.

The core grassy woodland domain occupies most of the lower elevations of the region and the core sclerophyll woodlands domain occupies the ranges. There is little overlap of areas defined as core by the two formation types, although the areas defined as marginal to both overlap considerably.

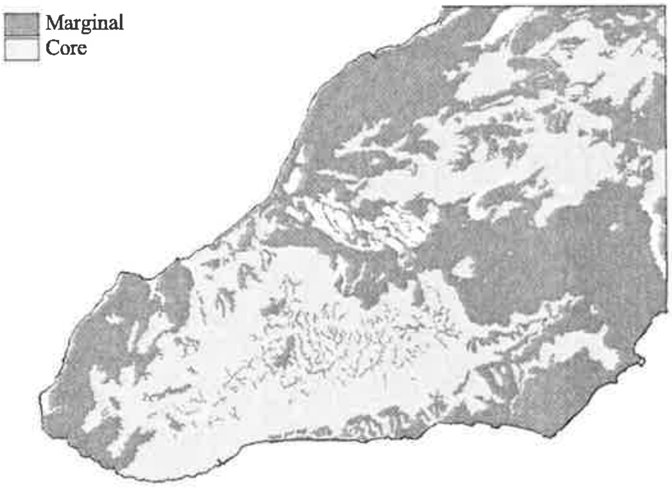


Figure 4. 15 The predicted core and marginal soil domains of sclerophyll woodlands from historical records.

4.3.1.3 Potential domains using soil type and bio-climate

Maps of the potential bioclimatic and soil domains of grassy woodland and sclerophyll woodland formations are presented in Figure 4. 16 and Figure 4. 17. These maps contain a predicted core domain derived from grid matching using the core bioclimatic domain with the core soil-type domain and a predicted marginal domain derived from grid matching using the marginal bioclimatic domain and the marginal soil-type domains. Areas not within the core or marginal domain are shown as white. As with the core domain of grassy woodlands defined by bioclimate alone, the soil-bioclimate core domain predominantly occupies the areas of lower elevation in the region, along the northwestern side of the ranges and through the Inman Valley.

The bioclimate-soil core domain is reduced by an area of approximately 20% from the core domain defined by bioclimate alone by a mosaic of patches of marginal grassy woodland domain. The only area excluded from potential core or marginal grassy woodlands predictions occurred on the highest elevations of the ranges in the southern and northern reaches of the Fleurieu Peninsula. The predicted soil-bioclimate core domain of sclerophyll woodlands is located along the spine of the ranges. The domain defined by soil and bioclimate is not as spatially continuous as that defined by bioclimate alone. The soil-bioclimate core domain is approximately 21% smaller in area than the bioclimatic core domain, with areas of the Inman Valley and the bases of the ranges being excluded. Depressions along creek lines on the plateau of the ranges are also excluded from the core domain. The marginal domain for sclerophyll woodlands included most of the Fleurieu Peninsula with only small parts of the Inman Valley and coastal regions excluded.

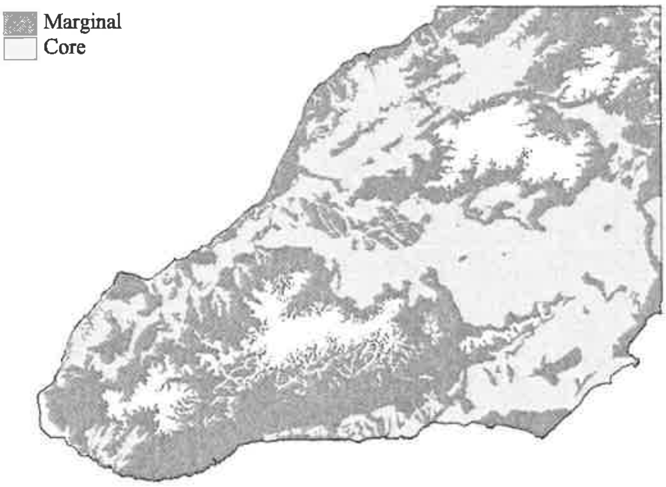


Figure 4. 16 The predicted core and marginal domains of grassy woodlands from historical records. The core bioclimatic and soil domain is based on grid matching at the 5-95% levels in the bioclimatic envelope and >10% representation in the soil envelope.

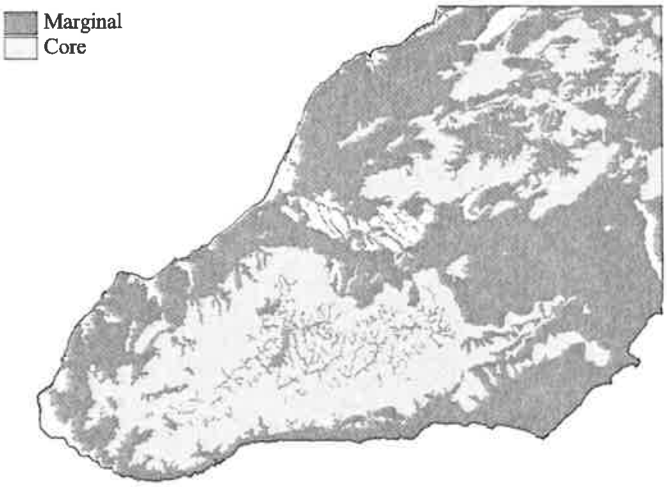


Figure 4. 17 The predicted core and marginal domains of sclerophyll woodlands from historical records. The core bioclimatic and soil domain is based on grid matching at the 5-95% levels in the bioclimatic envelope and >10% representation in the soil envelope.

4.3.1.4 Model assessment

The predictive success of models was assessed using sensitivity and specificity measures generated using the same historical records used to build the model. The model response from BIOCLIM was a prediction of core and marginal domains. The inclusion of both these domains as indicating predictive presence resulted in models which classified almost the entire study region as a type's potential distribution. As interest was in the modelling of the historical boundaries of these types, the predictive potential of the core domains only were tested with the sensitivity measure.

The ability of models to predict true negatives was assessed with the specificity measure using both (1) area outside of the model to indicate predictive absence (2) area predicted as being marginal and area outside of the model to indicate predictive absence (Table 4. 5). The core domain was considered to indicate presence, and the marginal absence, in calculation of specificity and sensitivity measures.

Table 4. 5 Assessment of grassy woodland and sclerophyll woodlands models developed using historical vegetation data. Sensitivity is a measure of the number of correctly classified positive records and specificity a measure of the correctly classified negative records. Negatively classified records were calculated in two ways, (A) records in neither core nor marginal domains and (B) records excluded only from core domains.

Model	Sensitivity	(A) Specificity	(B) Specificity
Grassy woodlands	0.64	0.30	0.92
Sclerophyll woodlands	0.75	0.08	0.89

The grassy woodland model yielded sensitivity values of 0.64, that is 64% of all historical grassy woodland data occurred in the core predicted domain. The sclerophyll woodlands model correctly predicted 75% of historical sclerophyll woodlands. Specificity values were low for all model types when only area excluded from both the core and marginal domain was considered to be the true negative prediction; in reflection of the models predicting most of the area of the Fleurieu Peninsula that is not core domain as being potential marginal domain. However specificity values were high when both the marginal domain and area outside of any predicted domain were considered to represent the true negative fraction.

4.3.2 Sclerophyll communities

4.3.2.1 Selection of predictive variables for TEDA analysis

Analysis yielding ROC plots of sensitivity versus 1-specificity plots from which area under the curve (AUC) values were calculated for the suite of environmental combinations listed in Table 4. 2 for stringy bark forest (Figure 4. 18), stringy bark scrub (Figure 4. 19), stringy bark and gum scrub (Figure 4. 20), gum scrub (Figure 4. 21) and low scrub (Figure 4. 22). The AUC values for all environmental combinations and model types are summarised in Table 4. 6.

Table 4. 6 AUC values from the ROC analysis of predictive success of 2-variable environmental domain models using historical data of vegetation distribution.

Variable 1	Variable 2	Stringy bark forest	Stringy bark Scrub	Stringy bark and gum scrub	Gum scrub	Low scrub
Annual precipitation	Topographic wetness index (TWI)	0.7567	0.6429	0.8228	0.7765	0.7453
	Annual net radiation	0.7557	0.6642	0.8403	0.7925	0.7726
	Wetness index (WET)	0.7619	0.6573	0.848	0.7935	0.7712
	Slope	0.6345	0.5901	0.8142	0.6605	0.5823
	Elevation percentile	0.6305	0.5697	0.8149	0.6255	0.5627
Elevation percentile	TWI	0.5489	0.5697	0.5673	0.5300	0.5380
	Annual net radiation	0.5446	0.5554	0.5848	0.5251	0.5590
	Wetness index	0.5368	0.5600	0.5615	0.5361	0.5559
	Slope	0.5898	0.576	0.6085	0.5590	0.5829
Slope	Annual net radiation	0.5341	0.5425	0.6325	0.5269	0.5404
	TWI	0.5746	0.5634	0.6117	0.5679	0.5177

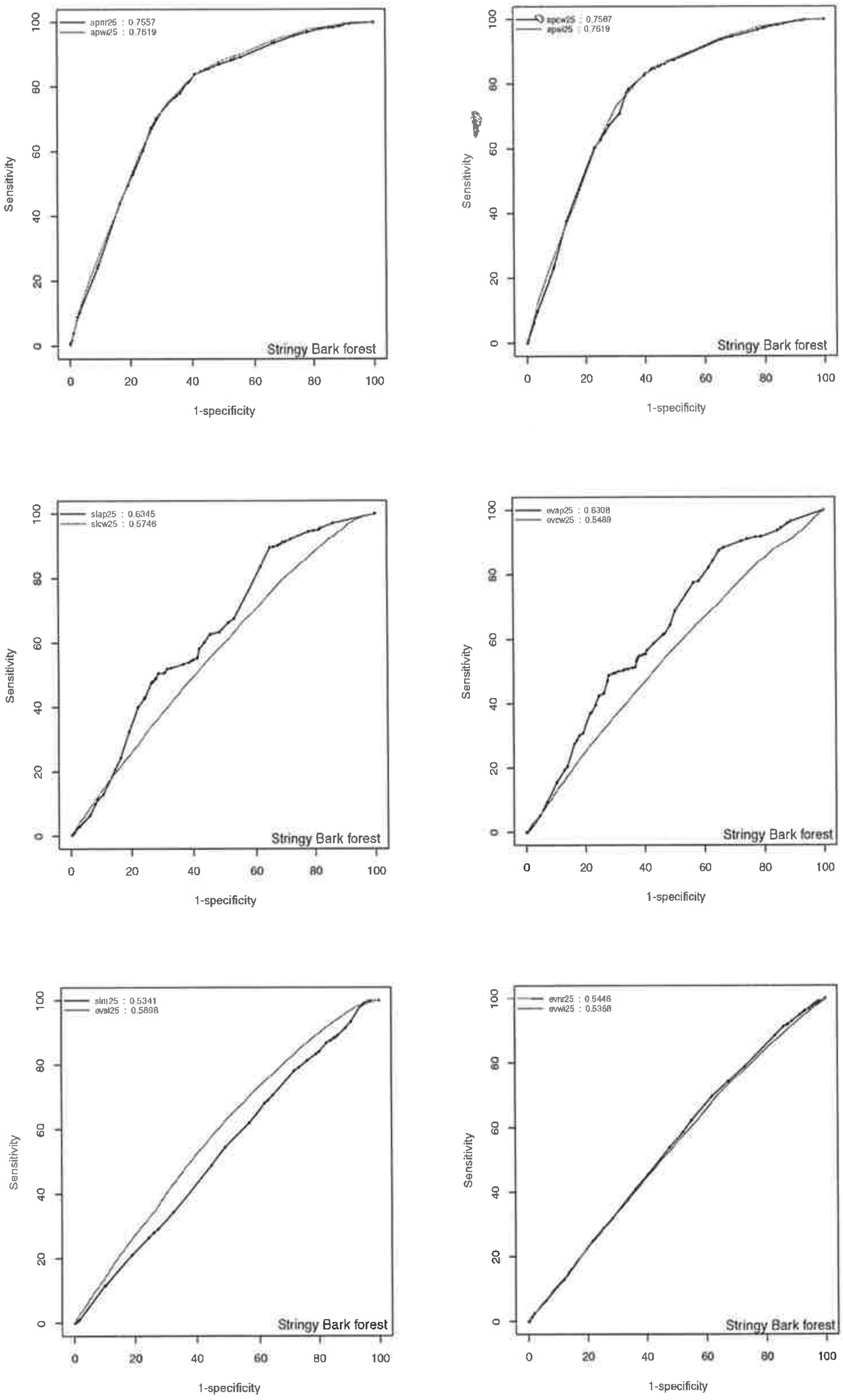


Figure 4. 18 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of a stringy bark forest model.

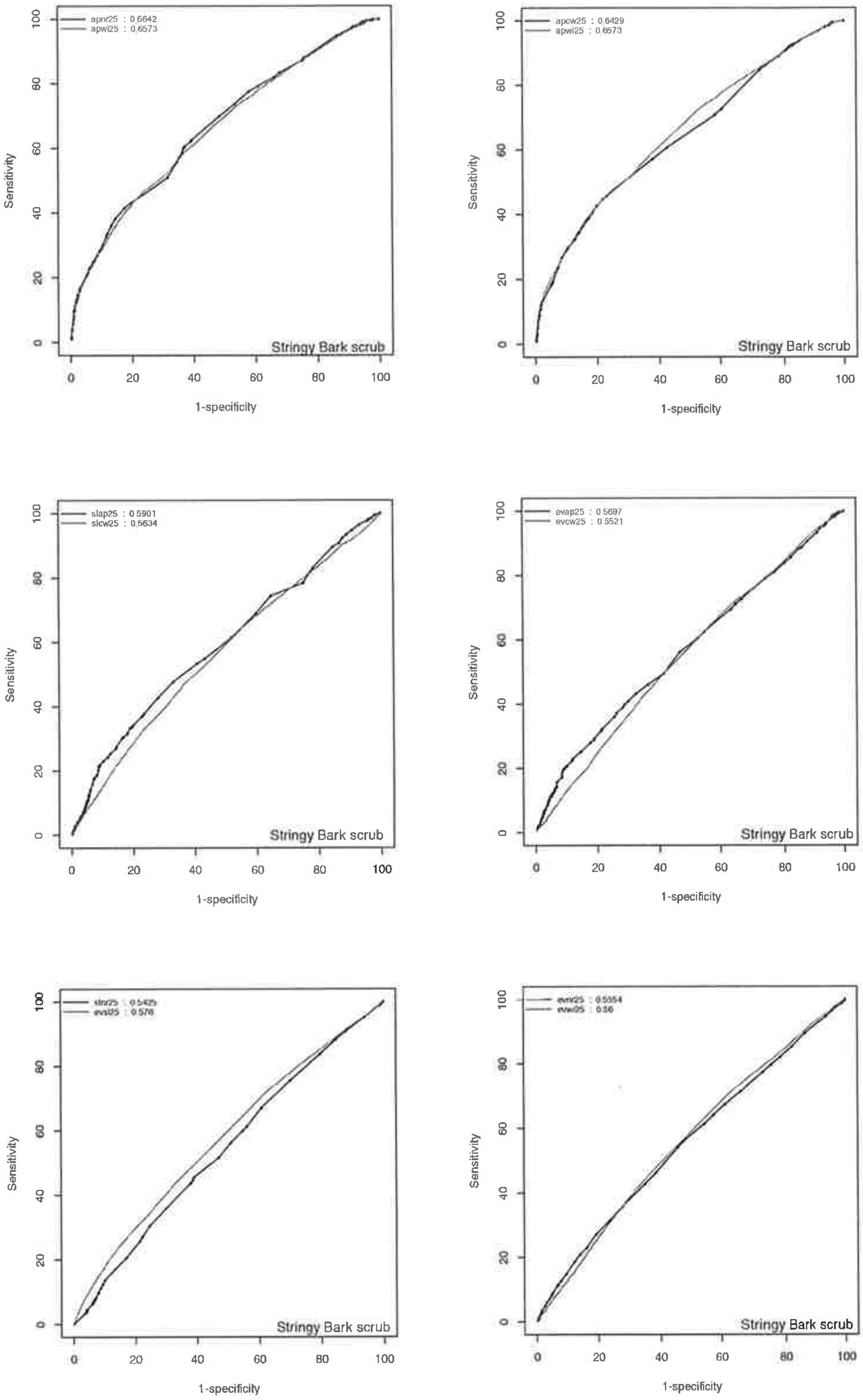


Figure 4. 19 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of a stringy bark scrub model.

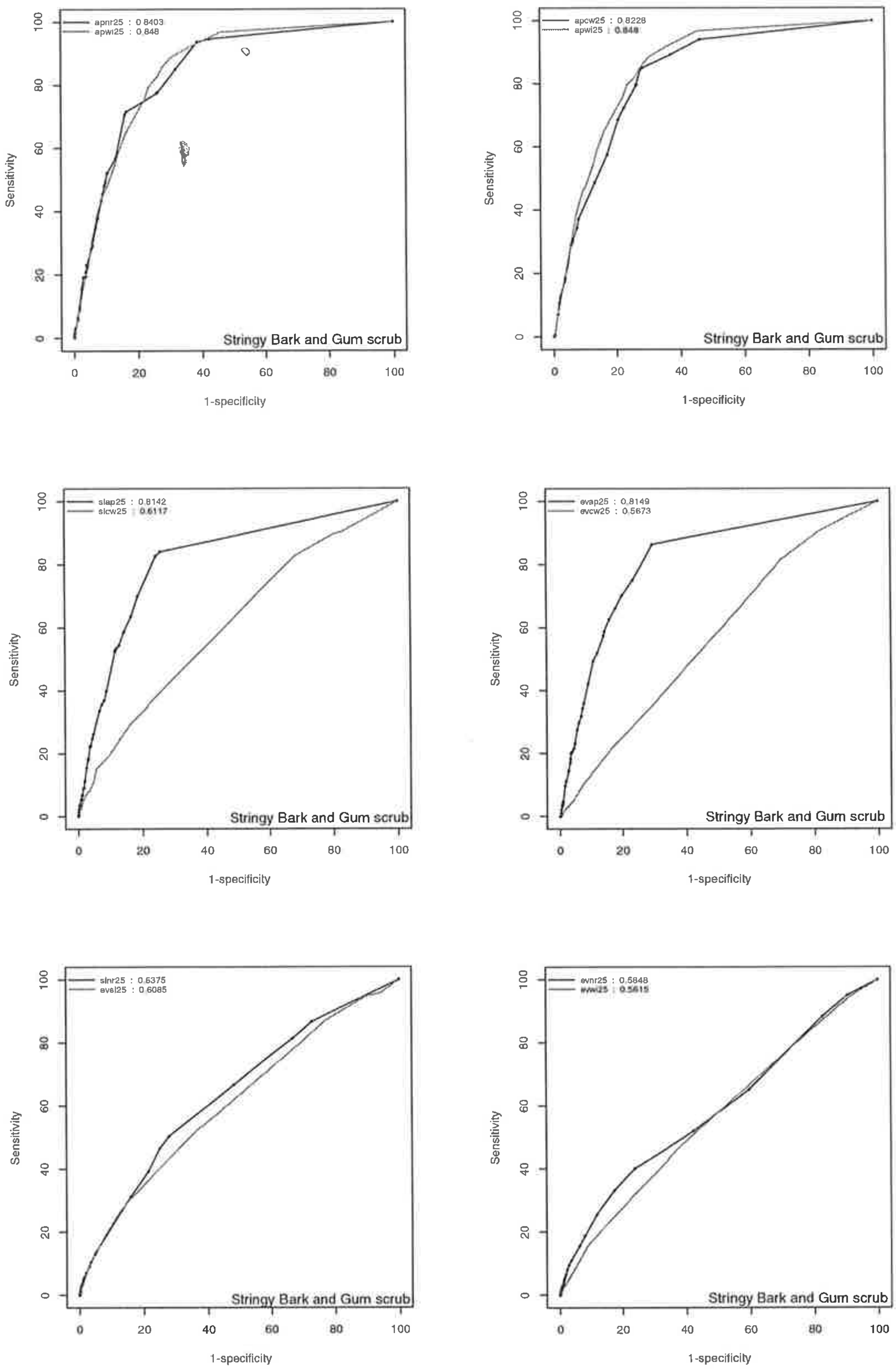


Figure 4. 20 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of a stringy bark and gum scrub model.

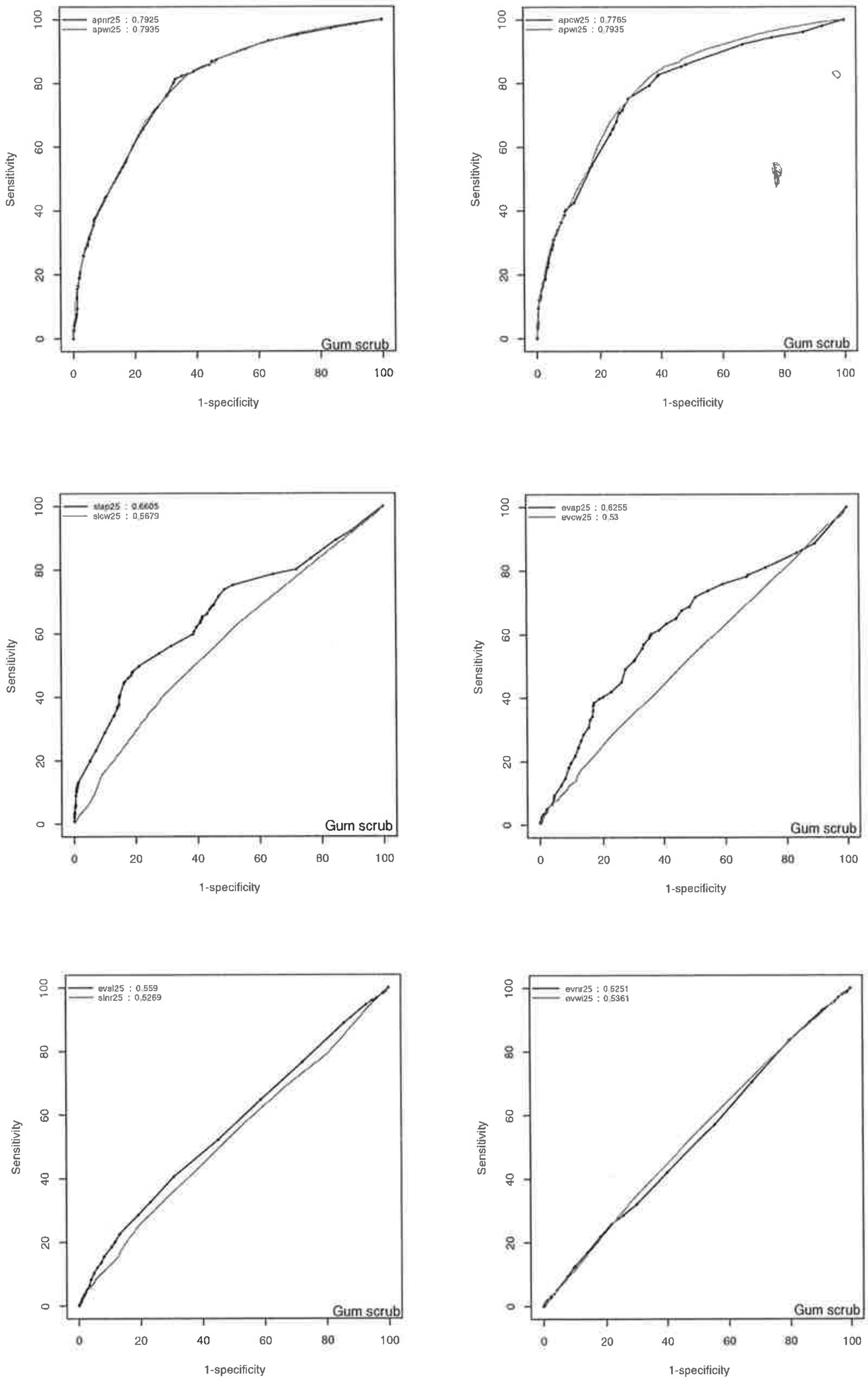


Figure 4. 21 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of a gum scrub model.

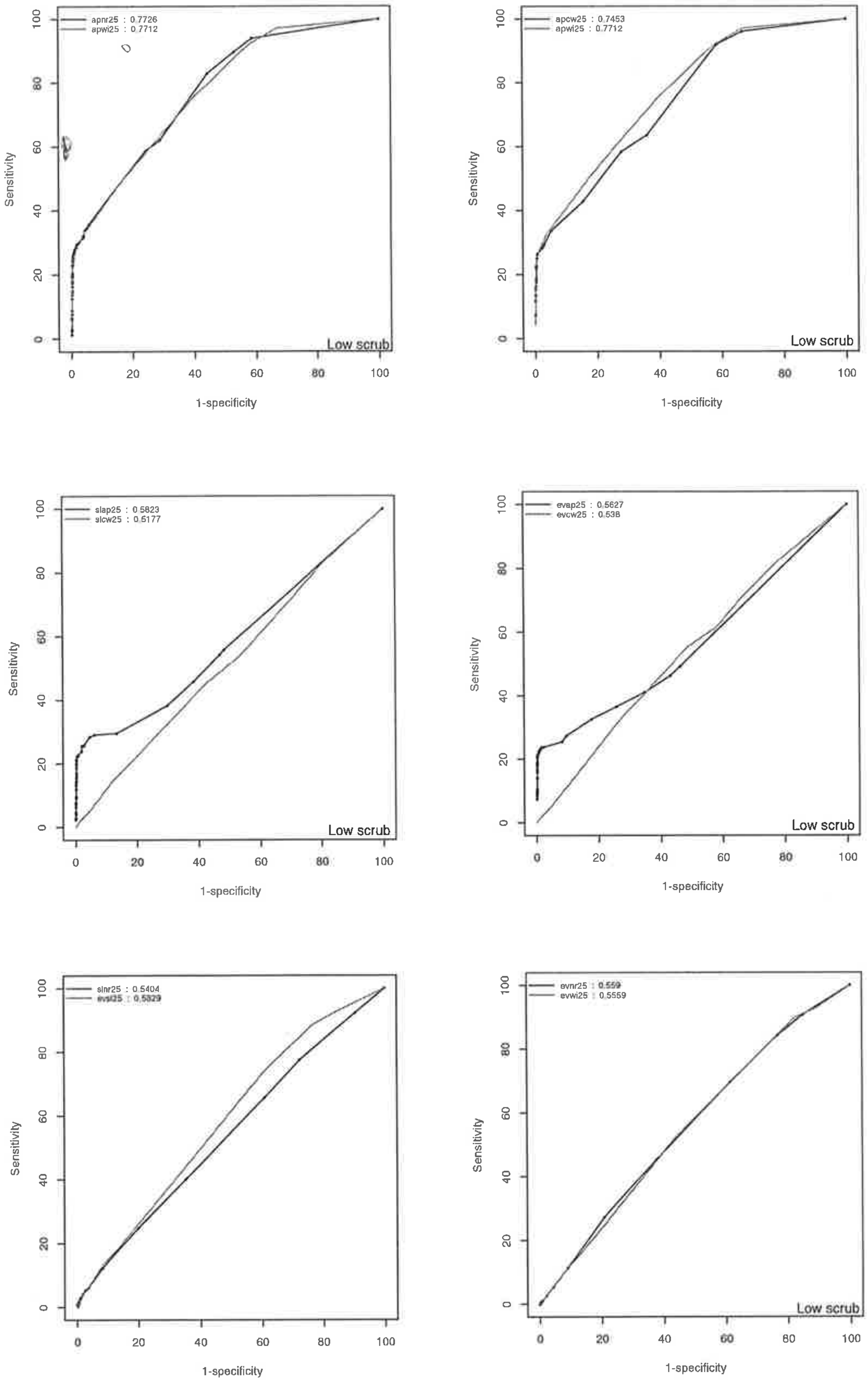


Figure 4. 22 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of a low scrub model.

AOC values ranged from 0.517 - 0.848. Combinations that included annual precipitation with any other variable resulted in models with the highest AUC values and thus predictive ability. Annual precipitation combined with the topo-scaled indices of topographic wetness (TWI), net annual radiation and soil moisture (WET) performed similarly in terms of predictive ability for all vegetation types. These combinations performed substantially better than annual precipitation with the primary topographic indices of slope and elevation percentile for all vegetation types except stringy bark and gum scrub. Annual precipitation with slope and annual precipitation with elevation percentile only performed marginally less well than annual precipitation with the compound topographic indices. Low AUC values of around 0.55 indicated that models combining topo-scale variables had little predictive ability for any vegetation type. Stringy Bark and gum scrub were the only exception to this, with models in which slope was a variable, resulting in AUC values between 0.6 and 0.63. In general slope and elevation percentile were poor predictors of all historical vegetation classes.

These results indicate that the meso-scaled climate variables contribute most strongly to the distribution of all vegetation types. Results also indicated that topo-scaled processes also have some relation to the distribution of historical vegetation types investigated. There was little difference between the performance of the annual precipitation with annual net radiation (APNR) and annual precipitation with the soil moisture (APWI) models. The soil moisture index, generated by the WET program, is more complex than the radiation index. The soil moisture index employs the radiation model as an input and additionally employs a range of other hydrological and climate assumptions. Little testing of the moisture index has been undertaken while the radiation indices generated by SRAD have been shown to be robust (McKenney *et al.,* 1999). Given this, the model combining annual precipitation and radiation was selected over the APWI model for further investigation. The model combining annual precipitation and slope was also chosen for investigation for the predictive potential it showed for stringy bark and gum scrub distribution. Additionally it showed predictive potential for vegetation distribution from modern records, so was chosen to allow comparison of the modern and historical data sets.

4.3.2.2 Observed probability matrices and spatial predictions-APNR model

TEDA analyses, producing observed probabilities in environmental space and predicted probabilities in geographic space, were undertaken for all historical vegetation types. Analyses were calculated for the APNR and APSL models. The observed probabilities of occurrence in environmental space can be shown using two-way matrices. Clusters of cells in the matrices having high probabilities of occurrence of a vegetation type are referred to as 'dominant domains' and indicate the environmental domain a vegetation type is most likely to occupy. The identification of dominant domains can be obscured by randomly scattered domain cells exhibiting high probability values. These domains are likely to be the result of the domains being weakly represented in the landscape and thus having low cell values. An absence of a clearly defined dominant domain may also result from low representation of observations of a particular vegetation type. The area of historical vegetation observations ranged from 89.8 ha for low scrub to 724 ha for stringy bark forest. So high values of probability of occurrence are less likely to be found in the low scrub model. The two-way matrices of observed probabilities of occurrence of all vegetation types modelled using annual precipitation and annual net radiation are shown in (Figure 4. 23). Using the APNR model, the dominant (optimum) domains of some of the vegetation types are distinctive, while the defined dominant domains of others overlap. Precipitation most strongly defines the differences between the dominant environmental domains of low scrub and stringy bark forest, with low scrub most dominantly occurring in areas of low annual precipitation, generally between 550-650 mm, and stringy bark forest occurring in areas with precipitation values between 800-900 mm. Both types occur over a wide range of annual net radiation values, indicating meso-scale climate is responsible for the majority of the variation in their vegetation patterns. Gum scrub and stringy bark and gum scrub are separated by annual precipitation from stringy bark forest and low scrub, with both their dominant domains occurring around 700 mm. A higher proportion of gum scrub sites were in areas of high annual net radiation than were stringy bark and gum scrub (although both span a range of radiation values). The observed probabilities of occurrence indicate that stringy bark scrub is dominant across a wide range of precipitation and annual net radiation values. It shows dominance at precipitation values of 650-700mm and also between 850-900 mm and over a range of annual net radiation values.

The observed probabilities presented in the probability matrices were used to generate spatial predictions of the likelihood of occurrence of each of the vegetation classes. Each grid cell is located in the spatial database within the corresponding domain of the probability matrix and assigned the calculated probability. Probabilities of occurrence were calculated across the whole study region. The resultant maps are a spatial representation of the observed probabilities and indicate where in the landscape the species is most likely to dominate.

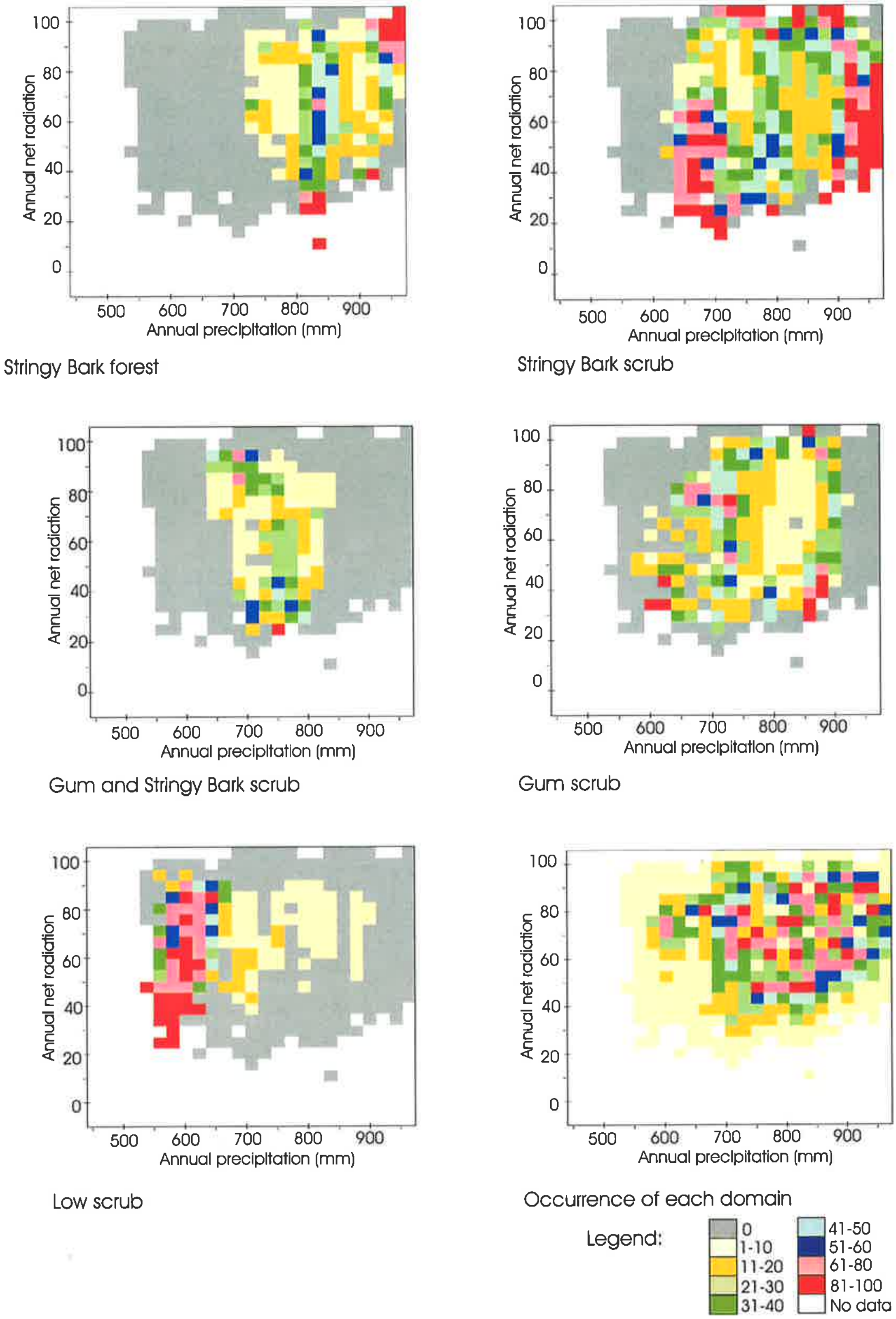


Figure 4. 23 The observed probabilities of (a) stringy bark forest, (b) stringy bark scrub, (c) stringy bark and gum scrub, (d) gum scrub and (e) low scrub as a function of annual precipitation and annual net radiation.

The stringy bark forest model showed high predicted probabilities of occurrence on most of the highland areas while at low probabilities, or not at all, in the lower elevation and precipitation regions (Figure 4. 24). At the topo-scale variation in predicted probabilities are evident. In the southern portion of the ranges, where rainfall is around 800 to 850 mm, south facing or shaded slopes with annual net radiation values around 50-55 have the highest probability of occurrence. In the northern ranges, where rainfall is greater, the highest probability of occurrence is found on exposed sites receiving significantly more radiation (80-90). In the northern region, sites receiving more than 957 mm rainfall per annum were predicted to having low probabilities of occurrence. This is likely to be an artefact of gaps in the stringy bark forest data set in the higher precipitation areas of the ranges.

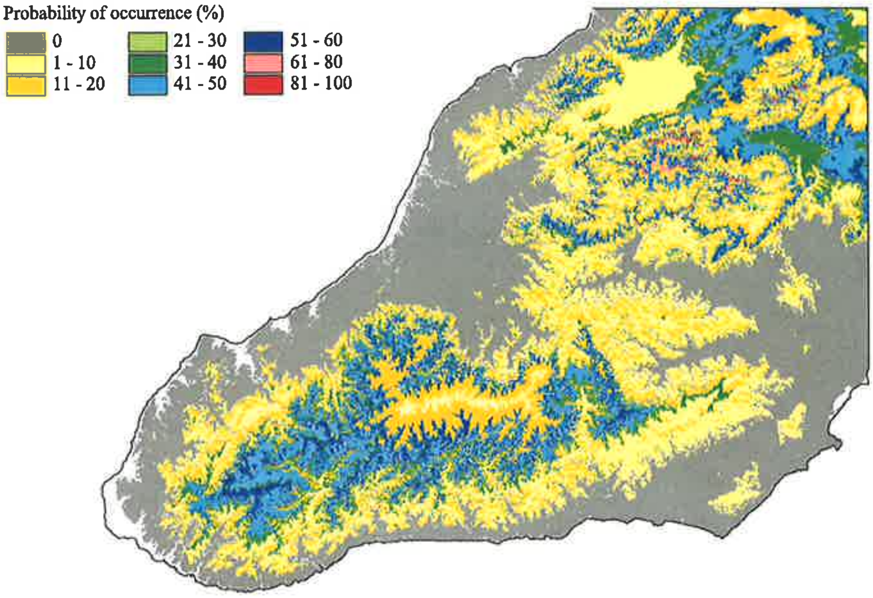


Figure 4. 24 Predicted environmental domain for stringy bark forest based on observed probabilities presented in Figure 4.22 (a).

Stringy bark scrub was predicted as being more likely to occur in two disjunct environmental domains and they translate geographically to the highest elevation and wettest part of the northern part of the ranges and to the moderately high precipitation and elevations of the ranges (Figure 4. 25). Stringy Bark and gum scrub is predicted as likely to occur on the lower elevation slopes and plains in the region and as being unlikely to occur in the wettest regions along the spine of the ranges (Figure 4. 26). Gum scrub is predicted as most likely to occur on areas of low rainfall and high annual net radiation on the eastern sides of the ranges and though parts of the Inman Valley (Figure 4. 27). It is predicted to occur only in small isolated regions in the more highly elevated areas of the region. Low scrub is predicted as most likely to occur in the low rainfall coastal regions in the Fleurieu Peninsula and as being unlikely to occur in the highlands (Figure 4. 28).

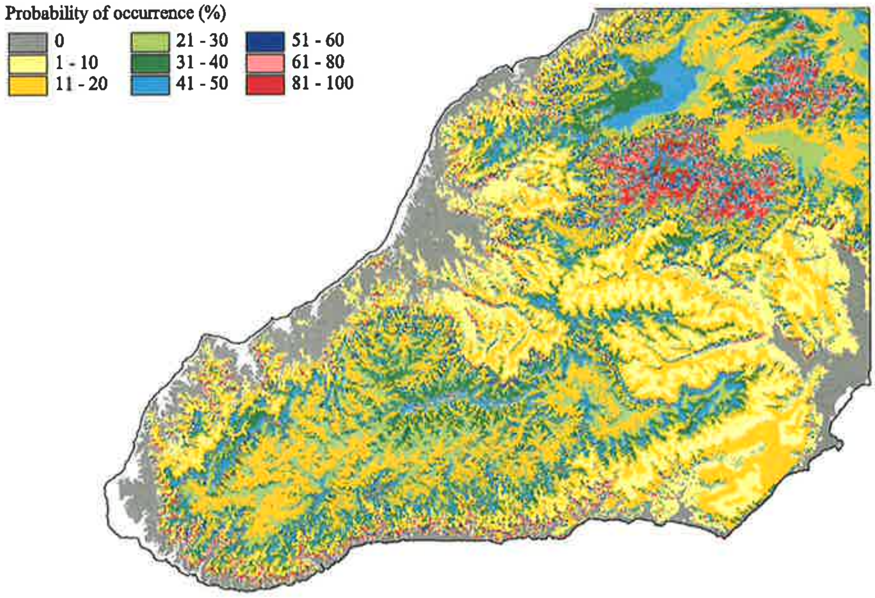


Figure 4. 25 Predicted environmental domain for stringy bark scrub based on observed probabilities presented in Figure 4.22.

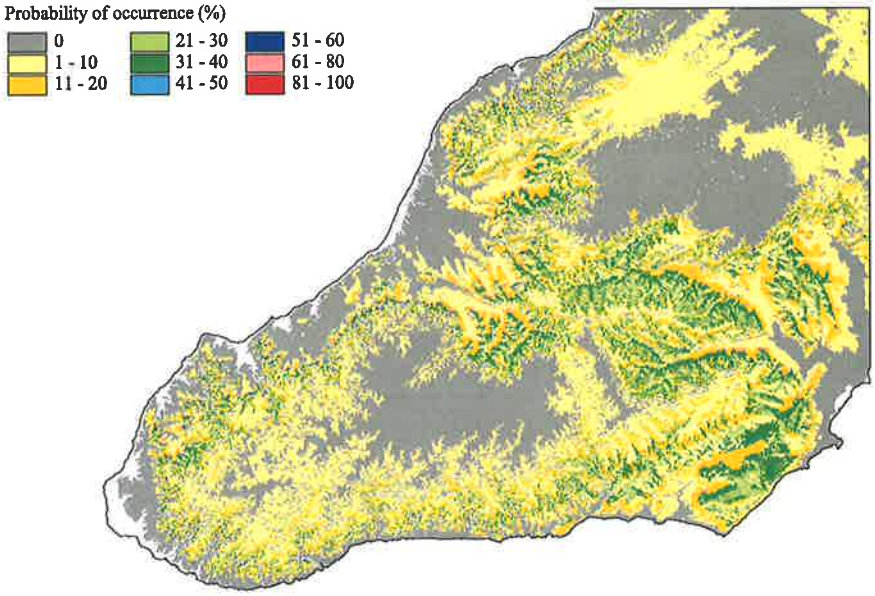


Figure 4. 26 Predicted environmental domain for stringy bark and gum scrub based on observed probabilities presented in Figure 4.22.

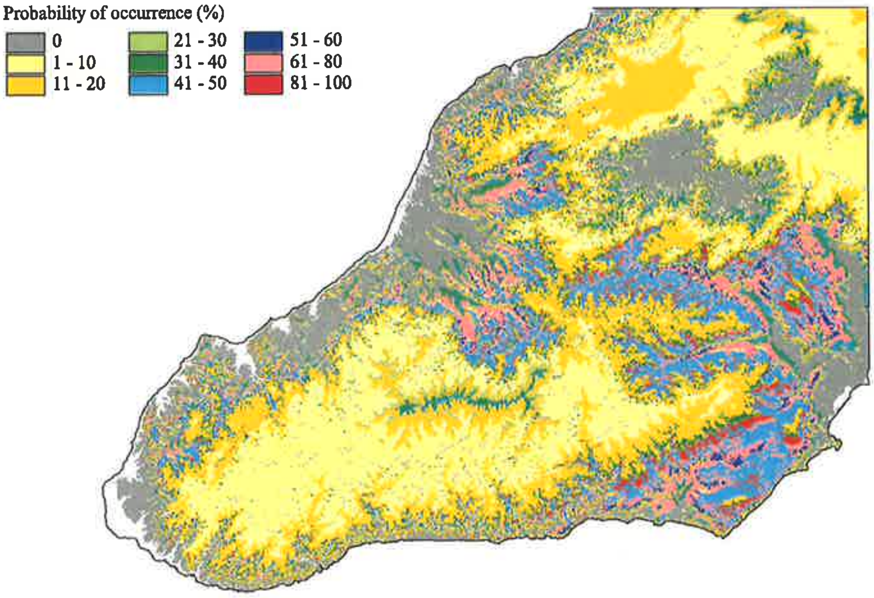


Figure 4. 27 Predicted environmental domain for gum scrub based on observed probabilities presented in Figure 4.22.

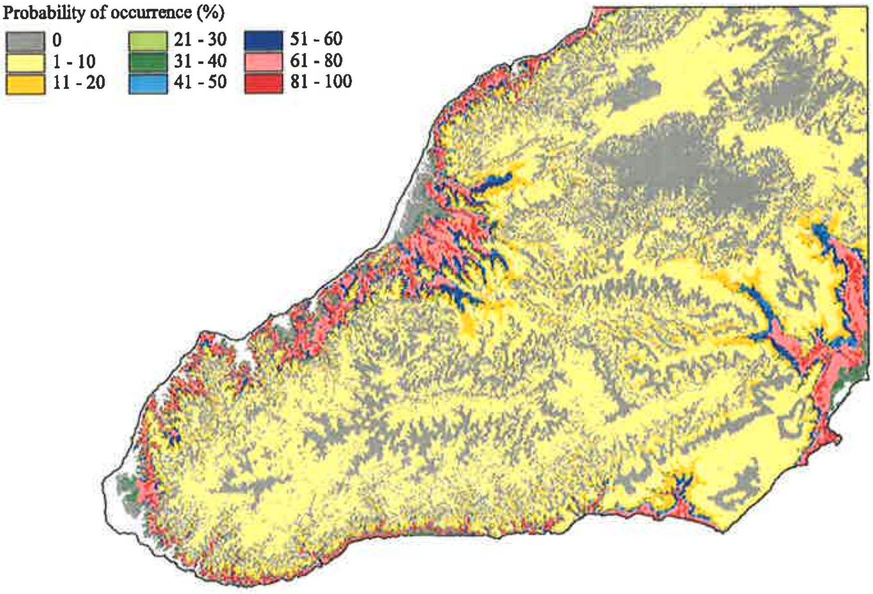
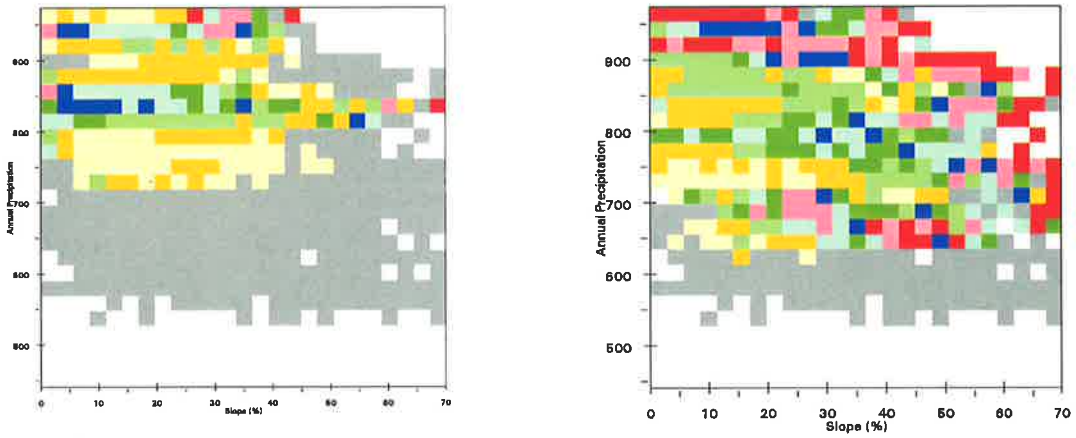
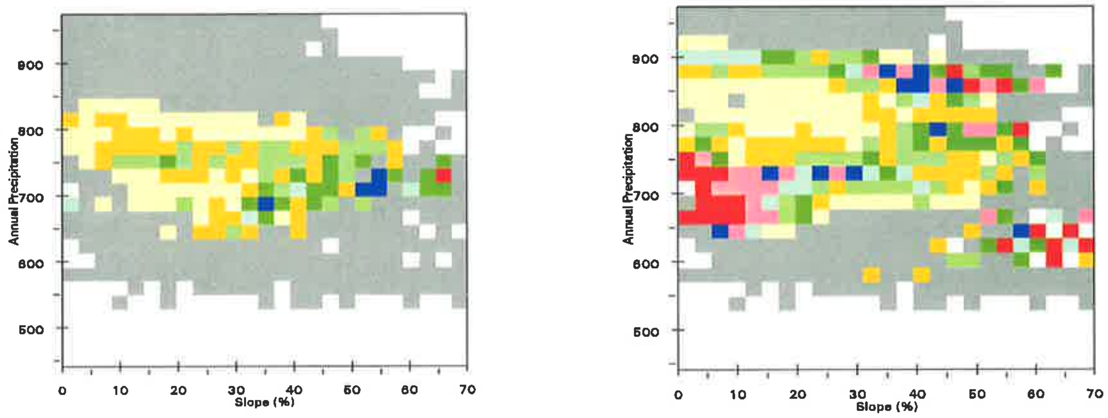


Figure 4. 28 Predicted environmental domain for low scrub based on observed probabilities presented in Figure 4.22.



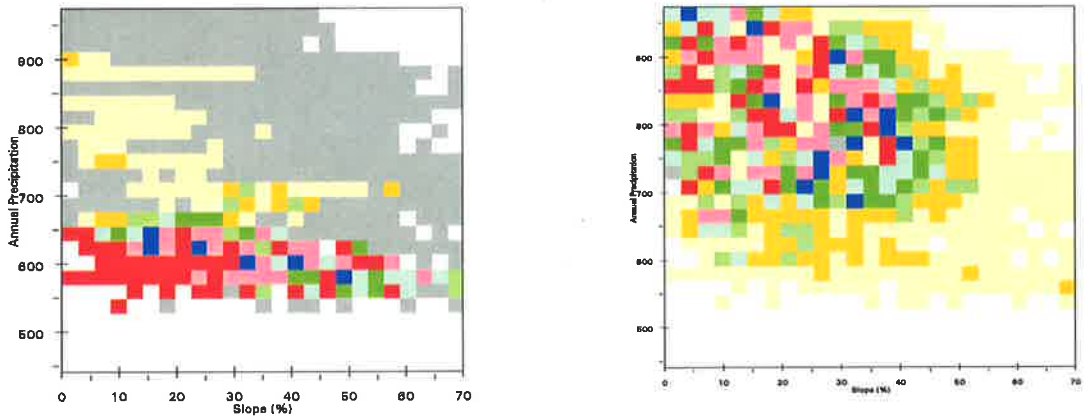
Stringy Bark forest

Stringy Bark scrub



Gum and Stringy Bark scrub

Gum scrub



Low scrub

Occurrence of each domain

Legend:

■	0	■	41-50
■	1-10	■	51-60
■	11-20	■	61-80
■	21-30	■	81-100
■	31-40	□	No data

Figure 4. 29 The observed probabilities of stringy bark forest, stringy bark scrub, stringy bark and gum scrub, gum scrub and low scrub in annual precipitation and slope domains.

4.3.2.3 Observed probability matrices -APSL model

The two-way matrices of observed probabilities of occurrence of all vegetation types modelled using annual precipitation and slope are shown in Figure 4. 29. As with the annual precipitation and radiation model, precipitation is also the stronger gradient and so at the meso-scale APSL are similar to those seen in the APNR model. However stringy bark and gum scrub and low scrub show some relation to slope. The highest observed probabilities of occurrence of stringy bark and gum scrub were on slopes over 30% and low scrub on slopes under 20%. The other historical vegetation types were distributed over a range of slope classes. The APSL probability domains mapped in geographic space are shown in Figures 4.30 to 4.34.

4.4 Discussion

4.4.1 Grassy and sclerophyll woodlands

The modelling undertaken in this section indicates the bioclimatic and edaphic component of grassy woodland and sclerophyll woodland formations' potential physiological domain, or ecological niche, based on the historical distribution of records for these vegetation types. The predictions are based on the premise that if a species naturally occurs at a site then the corresponding environmental conditions must fall within the formation (type) physiological threshold.

The cumulative frequency plots summarise and highlight the major differences in the bioclimatic domains occupied by the formation types. Historical records show that grassy and sclerophyll woodland formations occupy distinctive bioclimatic envelopes, although there is overlap at the upper precipitation and lower temperature ranges of grassy woodland and the lower precipitation and higher temperature range of sclerophyll woodlands. The grassy woodland associations of the Fleurieu Peninsula region are akin to Specht's 'savannah' land system classification and sclerophyll forests, woodlands and low woodlands of the region are included in Specht's 'sclerophyll' landsystem classification. Specht records overlap of the evapotranspiration indices of 'savannah woodland' (occurring on sites with evapotranspiration values between 0.4 and 0.7) and 'sclerophyll' landsystems (occurring on sites with evapotranspiration being greater than 0.5) in South Australia (Specht, 1972). Overlap of their bioclimatic domains is clearly visualised on comparison of the spatial predictions of these domains; areas of intermediate elevation and rainfall were classified as both potentially core sclerophyll and grassy woodland formations. In addition it is seen that areas defined as marginal potential grassy woodland domain largely overlap the core grassy woodland domains and vice versa. The significant overlap, in environmental and thus geographic space, of the core and marginal predicted bioclimatic domains of grassy and sclerophyll woodlands suggests the importance of other variables in defining the realised domains of these formation types. The frequency distribution analysis of historical and modern formation records over soil types suggested the two formations modelled in this study occupied different soil domains, this possibly in part reflecting responses to actual historical extent. The success of the modelling, based on soil and bioclimate, suggests that possibly the grassy-sclerophyll woodland boundary was influenced by these factors as proposed by Specht (1972). Other factors such as burning frequency are known to affect woodland-forest boundaries in Australia. Some authors have proposed that these boundaries have changed position markedly in places in southeastern Australia since cessation of Aboriginal burning (Rolls, 1999). It can not be discounted that pre-European land use patterns affected woodland boundaries, possibly mirroring these edaphic and precipitation gradients and reinforcing pre-European patterns. However elucidating pre-historic human influence from environmental changes and controls remains a confounded problem (Bowman, 1998; Foster *et al.*, 1998).

4.4.2 Sclerophyll communities

The transcription of vegetation records from 1880 survey-field book observations to map form revealed patterns in the variation of types across the Fleurieu Peninsula landscape. The modelling of the distribution of these records suggests that historical vegetation patterns can be correlated to environmental domains characterised by meso-scaled climate and to a lesser degree topography. Interpretation of the environmental domains, where the probability of a given vegetation type is more likely, is complicated by ambiguities in the taxonomic and spatial resolution of the historical data. The probability models for each historical vegetation class are discussed below with regard to their relation to historical environmental niches and issues regarding the taxonomic and spatial resolution of representation of vegetation by the historical data.

Stringy Bark forest was predicted to have the highest likelihood of occurrence between annual precipitation values of 800-950 mm and to occur over a range of radiation values. However its dominant domain is not strongly defined; its domain being somewhat patchy and showing overlap with stringy bark scrub and to a lesser degree gum scrub. Interpretation of this historical vegetation stringy bark forest description in Chapter 3 showed that the class was relatively specific in its classificatory breadth, including only *E. obliqua* open forests. Supporting this interpretation is the agreement between the precipitation domain defined in this model and that recorded for *E. obliqua* forests in the Fleurieu Peninsula (Boomsma, 1948; Mitchell, 1983) and the Mount Lofty Ranges (Specht and Perry, 1948). The complex relation of *E. obliqua* forests to topography has also been discussed and most likely explains the distribution of its modelled environmental domain over a wide range of annual net radiation values. At the lower end of the rainfall limit aspect plays an important role in defining distribution of *E. obliqua* with it particularly occurring on the cooler south-facing slopes (Specht and Perry, 1948). Even in the upper rainfall limits in the Fleurieu Peninsula *E. obliqua* open forest had some preference for shaded gullies (Mitchell, 1983).

Stringy bark scrub was predicted as most likely to occur in two precipitation regions, one receiving 650-800 mm and the other 850-975 mm of rainfall per annum and over a wide range of annual net radiation values. The predictive success rates of the APNR model of stringy bark scrub was lower than those achieved by the other vegetation classes. The simplest interpretation of the stringy bark scrub description is it is representing an *E. baxteri (± E. obliqua)* dominated low woodland (Chapter 3). If it does indeed represent this, then the domains defined in this study only partially confer to recorded *E. baxteri* precipitation limits; Specht and Perry (1948) and Mitchell (1983) suggest *E. baxteri* occurs on sites with annual precipitation 750 mm to 1000 mm. The smaller, but apparent, domain around 650 mm is outside these limits. Regional ecological studies report that, at the lower end of its precipitation limits, *E. baxteri* co-dominates with *E. cosmophylla* and/or *E. fasciculosa* (Boomsma, 1948; Mitchell, 1983). The extension into the drier end of the rainfall range could be explained by European modification of *E. baxteri* distribution between the 1880s, when the historical survey records were made, and the undertaking of the more recent ecological studies. Alternatively it could indicate imprecision by surveyors in use of the stringy bark scrub description; some stringy bark scrub records could have in fact been stringy bark with a less obvious white-barked *Eucalyptus* species.

The dominant environmental domain occupied by stringy bark and gum scrub is characterised by a precipitation envelope of 650-800 mm and over sites with very high radiation values at the low end of the rainfall range and medium radiation levels at higher rainfall values. Probability values are not high, due to stringy bark and gum scrub text records only occupying a relatively small area, but they define a reasonably distinct cluster. They are separated from stringy bark forest and low scrub by precipitation, however overlapping the lower precipitation domains of stringy bark scrub and gum scrub. The precipitation envelope of stringy bark and gum scrub records generally accords with the observations of Boomsma (1948) and Mitchell (1983) that *E. baxteri* combines with *E. fasciculosa* and *E. cosmophylla* at the drier end of its spectrum. However sites with low moisture relations also occur above 800 mm on exposed sites, ridges or on skeletal soils. These sites support associations of *E. baxteri* co-dominant with either or both *E. cosmophylla* and *E. fasciculosa* (Boomsma, 1948; Mitchell, 1983). The model does not predict occurrence in these higher rainfall areas. Assuming that these associations were present at the time the survey records were made this suggests that stringy bark and gum scrub text records are not representative of the full range of communities potentially represented by the description. This notion is supported by the much greater areas classified as stringy bark and gum scrub in section descriptions and many of the text records pertaining to these sections simply reading ‘scrub’, without qualification of species composition. Chapter 3 showed that many of these ‘scrub’ records intersected with remnant *E. baxteri - E. cosmophylla* low woodland. This suggests that the stringy bark and gum scrub text record are an under representation of historical stringy bark and gum scrub presence and so, concomitantly, the environmental domain defined for the type is not likely to be fully representative.

Two separate precipitation domains were defined for gum scrub, one around 650 mm per annum and the other around 850 mm. Both were over a wide range of annual net radiation values. The model predicts high probabilities of occurrence in patches on the highlands, through the slopes of the ranges and extending into the lowland valleys. Gum scrub was likely to have been used to describe *E. cosmophylla* or *E. fasciculosa* dominated communities (Chapter 3). These communities presently occur over a wide range of rainfall values; both *E. fasciculosa - E. cosmophylla* low woodland or *E. fasciculosa* low woodland occurring on ridges, exposed sites in the higher rainfall ranges, and the latter also extending to the low rainfall areas fringing the ranges. The distribution of gum scrub records and their resultant probability domains are probably explained by the fact that more than one community is encompassed by the description and that these communities occupy distinctive environmental domains.

The dominant domain of low scrub is well defined to annual rainfall values between 550-600 mm and as occurring over a range of radiation values. Comparison of the modelled domain with modern remnant communities, or those described by regional ecological studies, is difficult for the lack of floristic specification in this historical vegetation class. The type is predicted as most likely to occur in the driest areas only in the grassy woodland as well as the ranges, suggesting a soil index is required to effectively estimate the historical extent of this class.

Despite the complexity of the environmental domains occupied by historical vegetation types the analysis yielded several important outcomes. First, surveyors records can be used to represent at least meso-scale variation in vegetation patterns. Second, that sclerophyll woodland vegetation pattern, at the classificatory resolution expressed in historical survey records, early in the European period of settlement, was correlated to regional climate gradients. Correlation with topo-scaled environmental variables and processes were less apparent. However, radiation, a surrogate primarily expressing topo-scaled variations in water availability, did improve models to a degree. This lack of correlation could be the result of several factors. It is possible that there were not strong relations between vegetation types and terrain at the time the historical records were made. It is also possible that relationships did exist but lower levels of classificatory/taxonomic resolution than expressed in historical records are required to reveal them. It also can not be discounted that topographic relationships were stronger in historical times than revealed here, but were not able to be resolved due to the spatial scale at which historical records were made, being coarser than the scale at which topography affected vegetation. Surveyors may have been generalising across the landscape when recording observations of vegetation in their text books. A single observation may have encompassed a suite of landform entities and therefore been of insufficiently-fine spatial resolution to detect any possible topo-scaled patterns in the vegetation. If this were the case it would suggest that the assumption that the position of the text record represents the location of the vegetation type it is describing, which was made in the transcription of historical records, is in fact not valid.

Discrepancies between the constructed GIS spatial data base of historical records and the location of text descriptions in field books are unlikely to explain these assumptions; surveyors' sketches of topography and boundaries were accurate, and easily locatable on modern base maps, allowing the data transcription process to be carried out with a fair degree of accuracy.

Other environmental factors not incorporated in this modelling exercise may have contributed to the historical spatial distribution of vegetation types. In which case their inclusion may have improved the predictive performance of models. The importance of soil fertility in the higher rainfall areas of the Mount Lofty Ranges in differentiating *E. obliqua* open forest from *E. baxteri* low woodlands (with *E. obliqua* forest was restricted to deep loamy laterites and as soil fertility declined the forest graded to a *E. baxteri* scrub) has been widely suggested (Adamson and Osborn, 1924; Boomsma, 1948; Specht and Perry, 1948). Mitchell (1983) investigated the distribution of community types in the Fleurieu Peninsula in relation to rainfall, landform and geology. He concluded that clear relationships were difficult to detect and attributed lack of predictive success to the complexity of geology in the region and the complexity of interactions between variables. The importance of soil fertility in separating the sclerophyll woodlands from grassy woodlands associations suggested by Specht (1972), and in the previous modelling analyses of these formations, is further reinforced in this study. The vegetation types with precipitation domains in the lower end of the highland gradient were spatially extrapolated to areas where historical records showed, and models predicted, grassy woodlands to occur. Incorporating a nutrient index into these models, or restricting predictions to the lower nutrient highland regions, would improve its capacity to predict potential historical distributions.

4.5 Conclusions

These analyses are the first study to quantitatively investigate relations between historical (pre-European) vegetation pattern and the environment using historical records of vegetation pattern. The investigation shows that historical environmental patterns at a range of classificatory scales, can be elucidated from surveyors records of vegetation pattern. These relationships potentially represent historical environmental niches. Use of the historical record may be complicated by difficulties of interpretation and the non-specificity of historical records. However, in cases where these can be overcome, they provide a powerful means (and possibly the only means) of examining ecological patterns and relations prior to widespread vegetation clearance by Europeans and environmental transformation. This information has potentially great value in providing a means of assessing European impact and change on environmental distributions of vegetation types.

CHAPTER 5

5. MODELLING HISTORICAL VEGETATION DISTRIBUTION FROM REMNANT VEGETATION

5.1 Introduction

In regions of Australia, where modern vegetation is representative of its pre-European form and distribution, it has provided the most informative and readily interpretable line of evidence for historical vegetation pattern (Fensham, 1989; Fensham and Fairfax, 1997). Remnant native vegetation covers approximately ten percent of the Fleurieu Peninsula but almost all is restricted to the sclerophyll woodland formations in the more highly elevated areas of the region (Williams and Goodwins, 1987). Native vegetation in the lowland areas exists only as isolated paddock trees with predominantly non-native herbaceous understoreys.

This chapter uses the vegetation modelling techniques described in the previous chapter to empirically examine the extent to which (a) the spatial distribution of remnant vegetation records in the Fleurieu Peninsula are correlated with environmental conditions, defined by attributes of climate, soil and topography, and (b) can be used to predict the original distribution of pre-European vegetation in the region. As in the previous chapter the environmental relations of vegetation distribution are investigated at two classificatory scales. First the grassy woodland-sclerophyll woodland boundary and second the remnant communities of the sclerophyll woodland formation.

5.2 Methods

5.2.1 Analytical approach

The same environmental data sets developed and modelling methods used in the previous chapter to model vegetation pattern from historical data were used to model potential historical vegetation from the distribution of modern remnant vegetation; BIOCLIM (Busby, 1986; Nix, 1986), combined with a soil domain model was used to examine the climatic and edaphic domains of grassy and sclerophyll woodlands and TEDA, the environmental domain analyses procedure developed by Mullin (1995), was used to develop potential vegetation models of the remnant communities of the sclerophyll woodlands.

5.2.2 Vegetation data

5.2.2.1 Grassy woodland-sclerophyll boundary

Remnant vegetation data was obtained from the South Australian Department of Natural Resources and Environment (DENR). The DENR vegetation data sets were composed of survey data collected by private individuals, conservation groups and DENR, between 1981-1994 (Table 5. 1). All surveys in the dataset were conducted on remnant vegetation held in reserve on private land, except the Fleurieu Peninsula roadside survey that was conducted along all major roads in the region. Survey methods varied between datasets, with some making only species lists and others additionally recording abundance and structural information. A total of 430 surveys sites pertained to the study area. A GIS database of the location of all survey sites and roadsides surveyed was obtained, along with species lists from those sites.

Table 5. 1 Vegetation surveys conducted in the Fleurieu Peninsula since 1981 for which survey data is available-+/- = presence/absence; A. = relative % cover abundance, S. = structural information.

Survey name	Year	Conducted by	Information recorded	Survey design
SE Coast	1982-7	DENR	+/-, A.	Sites chosen from all main vegetation types
Grassy woodlands	1994	Michael Hyde	+/-	Sites chosen from ground reconnaissance
Kyeema Conservation Park	1981	DENR	+/-	
Mount Lofty Ranges	1981	DENR	A., S.	Selected sites in non NPWS reserves >20Ha in size
Emu Wren	1994	Conservation Council SA.	+/-, A.	Southern Mount Lofty Ranges swamps
MLR Private collectors	1987-91	DENR	+/-; A.	Remnant vegetation and swamps of the Southern Fleurieu Peninsula
Mount Lofty	1988	DENR	+/-; 3 dominant sp.	Sclerophyll systems in the Ranges
Fleurieu Peninsula Roadside survey	1996	Michael Hyde	+/-	All major roads in the region

The potential distributions were modelled of selected dominant overstorey species of the savannah woodland and sclerophyll systems in the Fleurieu Peninsula. The species selected to model the grassy woodland formation were *Eucalyptus leucoxylon, E. camaldulensis* and *E. viminalis*. The sclerophyll woodland formation species selected were *Eucalyptus baxteri, E. obliqua,* and *E. cosmophylla. Eucalyptus leucoxylon* and *E. viminalis* also occur in the sclerophyll landsystems but they more commonly occur as members of grassy woodland associations in the Fleurieu Peninsula (Boomsma, 1948; Specht, 1972). Hence they were included in the grassy woodland data set. *Eucalyptus fasciculosa* is a widely distributed dominant overstorey species in the region, but was not included in the analysis of savannah and sclerophyll boundaries for it is ubiquitously common to both formations. It was thought that the exclusion of this species would not result in an under-representation of the sclerophyll woodland habitats in the region because a substantial number of sites where it occurred were also occupied by one of the other three species representing the formation.

As detailed in Chapter 4, BIOCLIM requires a file of locations and elevations of sites that sample the distribution of the target biological entity. GIS point coverages of survey site locations were compiled for each formation type. Sites files were compilations of survey site point locations and grid-centroid locations derived from gridding the line coverage of roadside vegetation data. Point coverages for the selected species were created from the survey site coverage and associated species lists using ArcInfo/ArcPlot. Line coverages were created from the remnant roadside GIS for each selected species and then gridded at a resolution of 30 m. The centroid location of each cell was taken and converted into a point coverage, each centroid representing a single species observation. In total there were 3776 observation sites indicating savannah woodland presence and 3169 indicating sclerophyll formation presence. Elevations for each site were obtained are described in Chapter 4. The distribution of sites is shown in Figure 5. 1.

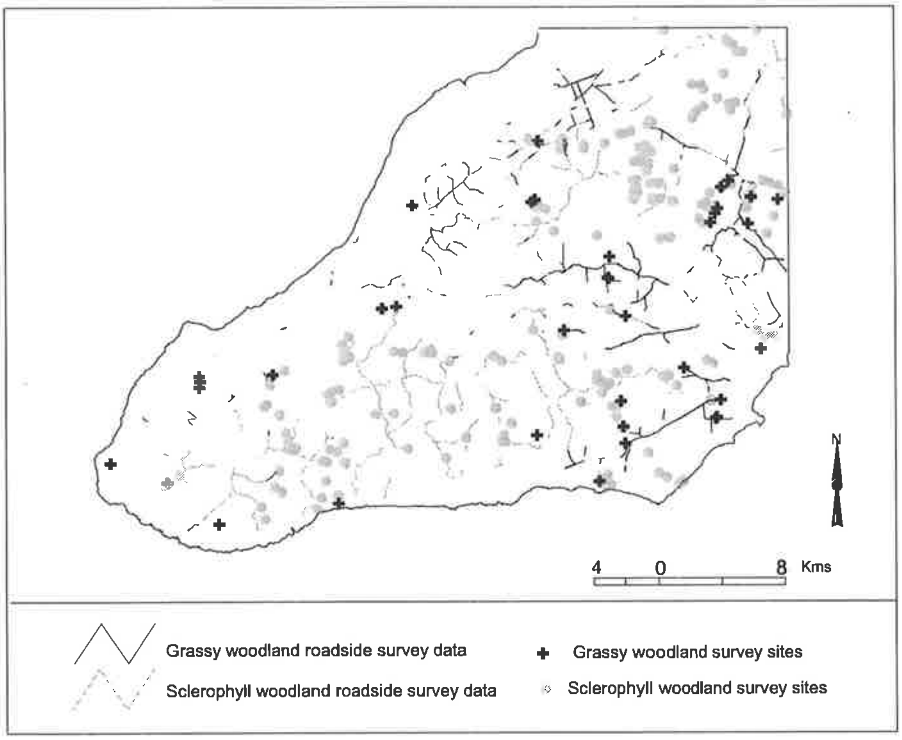


Figure 5. 1 The distribution of the modern data set consisting of survey sites where the dominant grassy and sclerophyll woodland *Eucalyptus* species occur.

Table 5. 2 The number of sites in the Fleurieu Peninsula of *Eucalyptus* species used to generate the bioclimatic profile for savannah and sclerophyll formations

Formation	Dominant species	Number of point survey sites	Number of points from gridded roadside survey	Total number of sites
Savannah	*E. leucoxylon*	26	1918	1944
	E. viminalis	12	165	177
	E. camaldulensis	1	601	602
Sclerophyll	*E. baxteri*	74	2702	2272
	E .obliqua	112	0	112
	E. cosmophylla	92	189	281

5.2.2.2 Sclerophyll communities

The South Australian Department of Environment and Resources (DENR) (1988) classified and mapped the remnant vegetation in the Fleurieu Peninsula using vegetation survey data collected in 1988 and air-photo maps. The classification based on structural and floristic characteristics identified 20 community types and they were mapped at a resolution of 1:50 000. From these community types six of those occupying the greatest area, and potentially comparable with the historical vegetation classes modelled in Chapter 4, were selected for modelling. The classes were 1) *E. obliqua* forest, 2) *E. baxteri* low woodland, 3) *E. fasciculosa* low woodland, 4) *E. fasciculosa - E. cosmophylla* low woodland 5) *E. cosmophylla* very low woodland and 6) *E. ovata* low woodland. The DENR classification separated *E. obliqua* forest into that containing *E. obliqua* with *E. fasciculosa* and that containing *E. obliqua* with *E. baxteri*. There, two forest types share similar understoreys and were amalgamated. The DENR classification identified three types of *E. baxteri – E. cosmophylla* low woodland; one occurring with *E. obliqua* and another with *E. cosmophylla*. They were similarly amalgamated. The dominant species characterising classes and the area they cover are listed in Table 5. 3. Grids of each vegetation group were created at a cell resolution of 20 metres. Their distribution in the Fleurieu Peninsula is shown in Figure 5. 2.

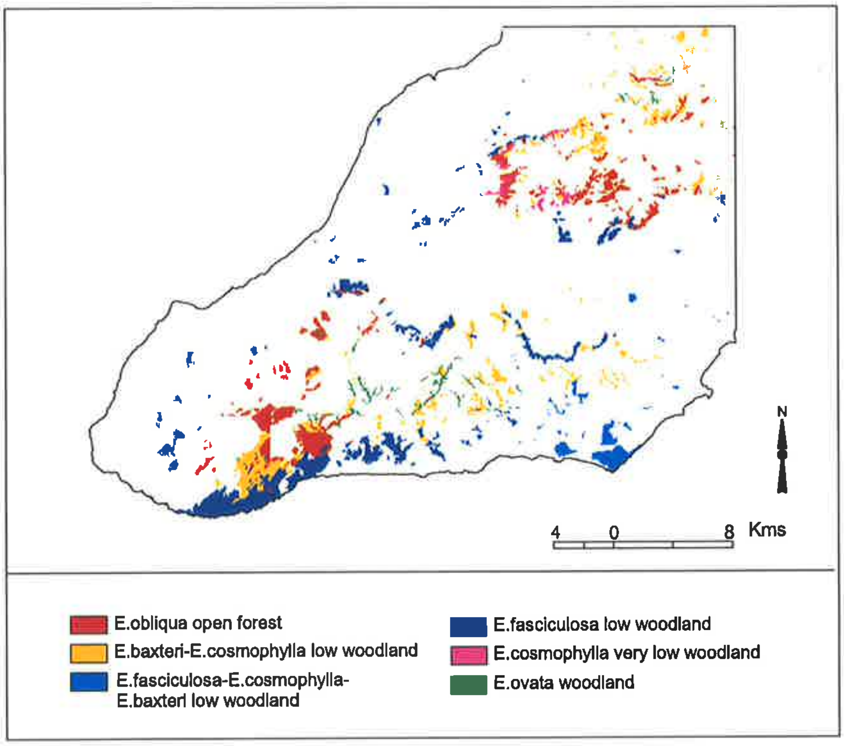


Figure 5. 2. Map of the distribution of remnant sclerophyll woodland communities modelled by domain analyses.

Table 5. 3 The remnant vegetation types modelled using TEDA, the community number and description qualified by the DENR vegetation classification, and the area in hectares encompassed by each type.

Vegetation type	No.	Dominant floristic members	Area (Ha)
E. obliqua forest	16	*Eucalyptus obliqua*, ± *E. fasciculosa* ± *E. baxteri* over *Gonocarpus tetragynus, Xanthorrhoea semiplana, Lepidosperma semiteres, Acrotriche serrulata, Pultenaea daphnoides, Hakea rostrata, Goodenia ovata, Pteridium esculentum*	2812.1
E. baxteri- E. cosmophylla low woodland	18	*Eucalyptus baxteri, E. cosmophylla* ± *E. obliqua* ± *E. fasciculosa* over *Lepidosperma semiteres, Banksia marginata, Pultenaea involucrata, Gonocarpus tetragynus, Hypolaena fastigiata, Leptospermum myrsinoides, Platylobium obtusangulum, Correa reflexa, Lepidobolus drapetocoleus*	2547.9
E. fasciculosa low woodland	10	*Eucalyptus fasciculosa* over *Astroloma humifusum, Chamaescilla corymbosa, Olearia ramulosa, Drosera whittakeri*	3899.7
E. fasciculosa – E. cosmophylla low woodland	20	*Eucalyptus fasciculosa, E. cosmophylla, E. baxteri* over *Hibbertia riparia, Brachyloma ericoides*	816.5
E. cosmophylla very low woodland	9	*Eucalyptus cosmophylla* over *Calytrix tetragona, Hibbertia riparia, Astroloma humifusum, Arthropodium strictum, Allocasuarina muelleriana, Schoenus breviculmis, Goodenia primulacea, Hakea carinata*	394.3
E. ovata woodland	34	*Eucalyptus ovata* over *Goodenia ovata*	485.9
		Total area	10953

5.2.3 *Environmental variable choice and model assessment*

5.2.3.1 Grassy-sclerophyll woodland boundary

As with historical records of grassy and sclerophyll woodland, the climate variables of annual precipitation and mean annual temperature and soil type were used to model the distribution of modern grassy-sclerophyll woodland records. The predictive strength of the spatial prediction models was tested using sensitivity and specificity measures generated using resubstituted data. The model response from BIOCLIM was a prediction of core and marginal domains. The core domain was considered to indicate presence and the marginal absence in the calculation of specificity and sensitivity measures.

5.2.3.2 Sclerophyll communities

Only the combinations of environmental variables that had predictive potential in the analyses of historical records were investigated. Combinations are listed in Table 5. 4.

Table 5. 4 Environmental combinations investigated for their strength of prediction of sclerophyll community pattern from remnant vegetation distribution data.

Variable 1	Variable 2	Model reference code
Annual precipitation	Topographic wetness index	APCW
Annual precipitation	Annual net radiation	APNR
Annual precipitation	Slope	SLAP
Annual precipitation	Elevation percentile	EVAP
Elevation percentile	Slope	EVSL

5.3 Results

5.3.1 Grassy – sclerophyll woodlands

5.3.1.1 Bioclimatic domains

Bioclimatic profiles containing the mean, minimum, 5%, 95% percentile and maximum values for all bioclimatic indices derived by BIOCLIM for grassy and sclerophyll woodlands and the species aggregated to form the formation profiles are shown in Table 5. 5. The profiles contain the mean, minimum, 5%, 95% percentile and maximum values for the selected bioclimatic indices of annual precipitation, precipitation of the wettest quarter, precipitation of the driest quarter, mean annual temperature, mean temperature of the warmest quarter, minimum temperature of coldest quarter and maximum temperature of the warmest quarter.

Table 5. 5 The bioclimatic envelope of grassy woodlands and sclerophyll woodlands derived from the use of BIOCLIM using remnant vegetation survey data. The grassy woodland profile was composed of site data for *E. camaldulensis, E. viminalis* and *E. leucoxylon* and the sclerophyll profile was composed of site data for *E. baxteri, E. obliqua* and *E. cosmophylla*. The individual envelopes of these species are also shown. All values are in ºC and mm.

		mean	sd	5%	10%	25%	50%	75%	90%	95%	max	min
Grassy woodlands	Temp.	14.9	0.37	14.3	14.4	14.6	15.0	15.2	15.3	15.5	15.6	13.2
	Precip.	720	69.09	614	629	669	716	773	816	830	966	525
E. camaldulensis	Temp.	15.0	0.32	14.6	14.6	14.7	15.1	15.3	15.4	15.5	15.5	14.3
	Precip.	694	69.9	598	606	634	680	779	793	798	825	566
E. viminalis	Temp.	14.5	0.2	14.2	14.3	14.5	14.5	14.6	14.7	15.0	15.2	14.0
	Precip.	809	29.22	745	787	804	814	826	835	846	873	691
E. leucoxylon	Temp.	14.9	0.36	14.2	14.4	14.7	15.0	15.1	15.3	15.4	15.6	13.2
	Precip.	720	64.6	621	641	675	714	761	813	831	966	525
Sclerophyll woodlands	Temp.	14.1	0.41	13.4	13.6	13.8	14.0	14.4	14.6	14.8	15.3	13.1
	Precip.	842	53.86	751	780	806	842	878	915	939	972	586
E. obliqua	Temp.	14.1	0.35	13.6	13.7	13.9	14.1	14.3	14.6	14.7	15.3	13.4
	Precip.	844	50.31	772	788	807	849	877	907	927	947	625
E. baxteri	Temp.	14.0	0.39	13.4	13.5	13.7	14.0	14.3	14.5	14.7	15.1	13.1
	Precip.	848	49.51	770	786	815	847	878	914	940	972	687
E. cosmophylla	Temp.	14.5	0.38	13.8	14.0	14.2	14.4	14.7	15.0	15.2	15.3	13.3
	Precip.	790	66.96	667	697	747	796	838	874	897	956	586

Figure 5. 3 and Figure 5. 4 are cumulative frequency plots showing the relationship between different percentile values of the precipitation and mean annual temperature of sites occupied by grassy and sclerophyll woodlands. Sites supporting grassy woodlands have lower annual precipitation values and higher mean annual temperature values than those supporting sclerophyll woodlands. Cumulative frequency plots for annual precipitation and mean annual temperature of the individual structural dominant *Eucalyptus* of the grassy woodland and sclerophyll woodland formations are shown in Figure 5. 5 and Figure 5. 6. Of those that dominate the sclerophyll formation, *E. baxteri* and *E. obliqua* occupy the wettest and coolest regions and their domains largely concur. *E. cosmophylla* is separated by occupying slightly drier and warmer sites. Of species

constituting the grassy woodland formation in the region *E. camaldulensis* and *E. leucoxylon* show almost indistinguishable temperature and precipitation domains and *E. viminalis* occupies a narrow domain on sites that have a lower mean annual temperature and higher annual rainfall than the other two species.

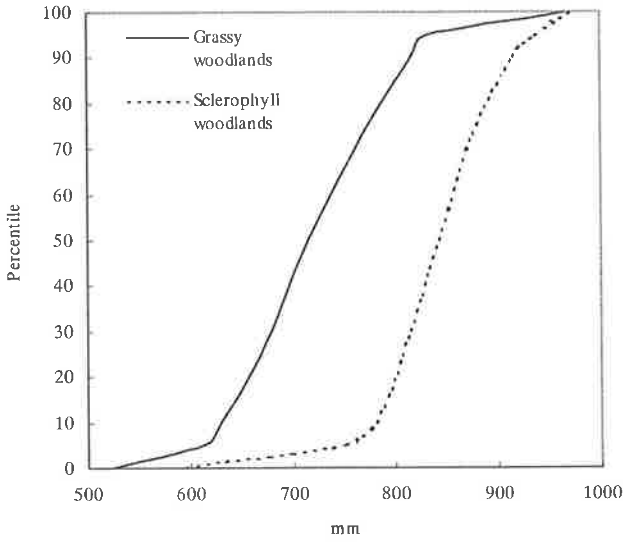


Figure 5. 3 Cumulative frequency plots of the distribution of annual precipitation of sclerophyll and grassy woodland formations as determined by modern data records.

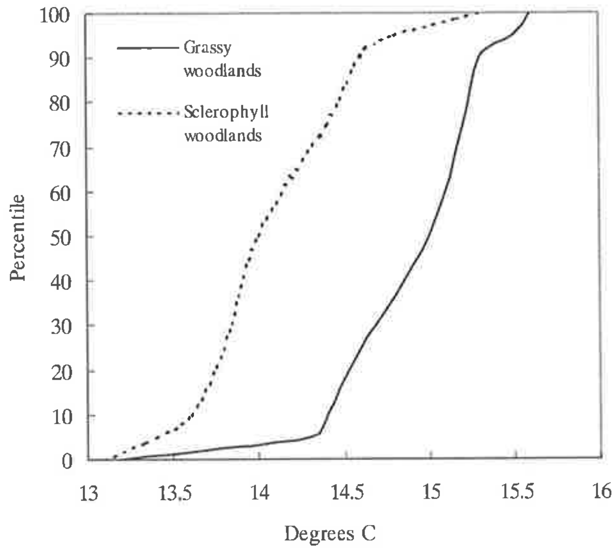


Figure 5. 4 Cumulative frequency plots of the distribution of annual mean temperature of sclerophyll and grassy woodland formations as determined by modern data records.

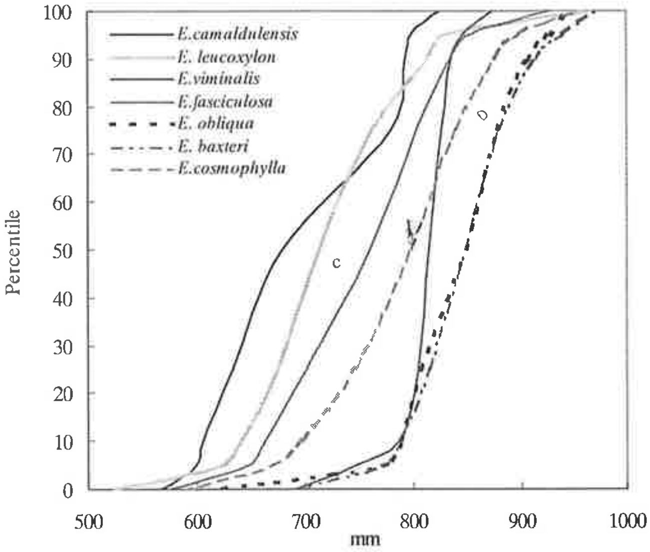


Figure 5. 5 Cumulative frequency plots of the distribution of annual precipitation of *Eucalyptus obliqua, E. baxteri E. cosmophylla, E. fasciculosa, E. leucoxylon, E. camaldulensis* and *E. viminalis* as determined by their modern distributions.

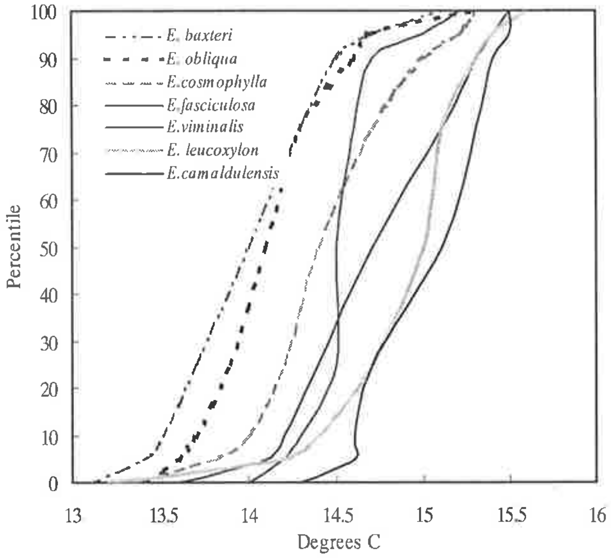


Figure 5. 6 Cumulative frequency plots of the distribution of annual mean temperature of *Eucalyptus obliqua, E. baxteri E. cosmophylla, E. fasciculosa, E. leucoxylon, E. camaldulensis* and *E. viminalis* as determined by their modern distribution.

The potential core and marginal bioclimatic domain of grassy woodlands defined by the distribution of remnant vegetation records is shown in Figure 5. 7. The marginal domains extend over almost the entire Fleurieu Peninsula, excluding only small regions fringing the coast. The core domain encompasses about half of this area, over the mid-elevations of the region. The potential core and marginal bioclimatic domain of sclerophyll woodlands defined by the distribution of remnant vegetation records is shown in Figure 5. 8. The core domain encompasses the most highly elevated regions in the Fleurieu Peninsula, excluding a small region in the northern part of the ranges. The coastal fringe is excluded from any potential domain for this formation type. The marginal domain extends through mid-elevations flanking the ranges and extending through the Inman Valley.

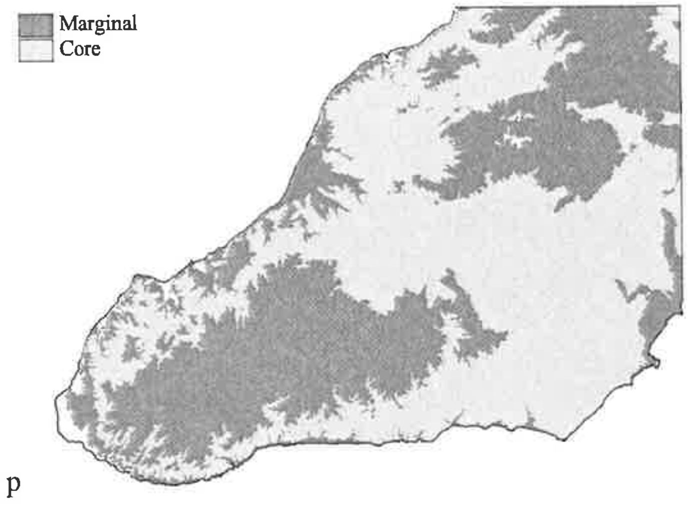


Figure 5. 7 The predicted core and marginal bioclimatic domains of grassy woodlands from modern vegetation distribution data records

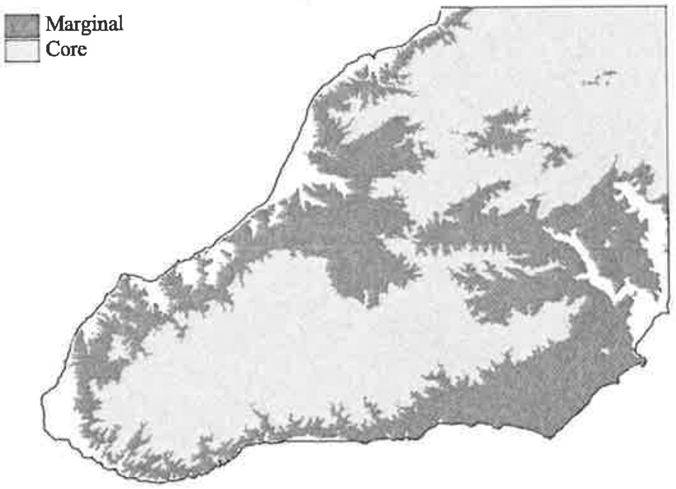


Figure 5. 8 The predicted core and marginal bioclimatic domains of sclerophyll woodland from modern vegetation distribution data records.

5.3.1.2 Soil domains

Plots of the occurrence of historical observations of grassy and sclerophyll woodlands on soil classes in the region allow comparison and definition of the soil domains of the two formation types (Figure 5. 9 and Figure 5. 10). The greater proportion of grassy woodland records occurred on soil type 302 (grey or brown acid to neutral sand over clay subsoils) and on class 301 (acid to neutral grey sand over white sand overlying a yellow and brown strongly acidic sandy clay) with only minor occurrences on other soil types. Sclerophyll woodland records were more evenly distributed over a wider range of soil types with classes 401 (Ironstone gravelly sandy loam over brown, yellow and red clay), 1202 (very shallow or shallow to moderately deep, gravelly and stony sand to sandy loam), 102 (Grey brown loams over friable brown and red clays on shale and schist), 100 (Grey sandy loams over yellow brown clay subsoils, moderately shallow on sandstone or schist) and 302 all accounting for more than 10% of the sclerophyll woodlands records.

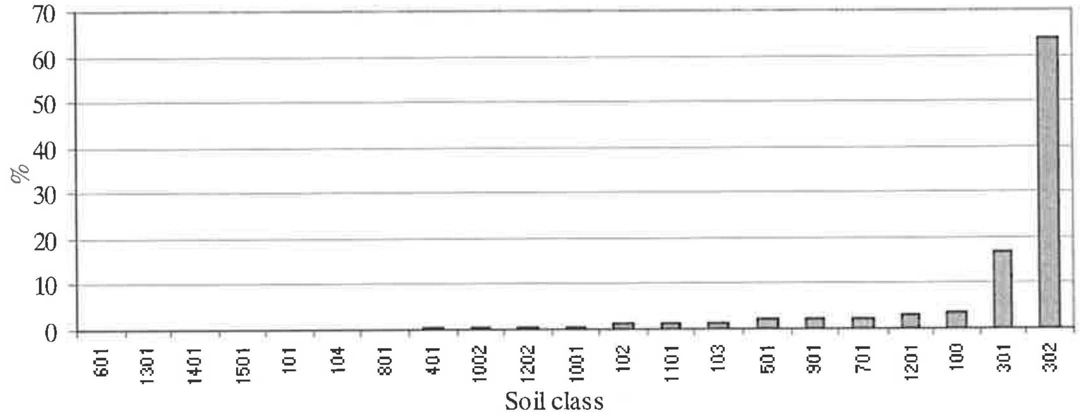


Figure 5. 9 Histogram of the distribution of remnant vegetation records of grassy woodlands on soil types.

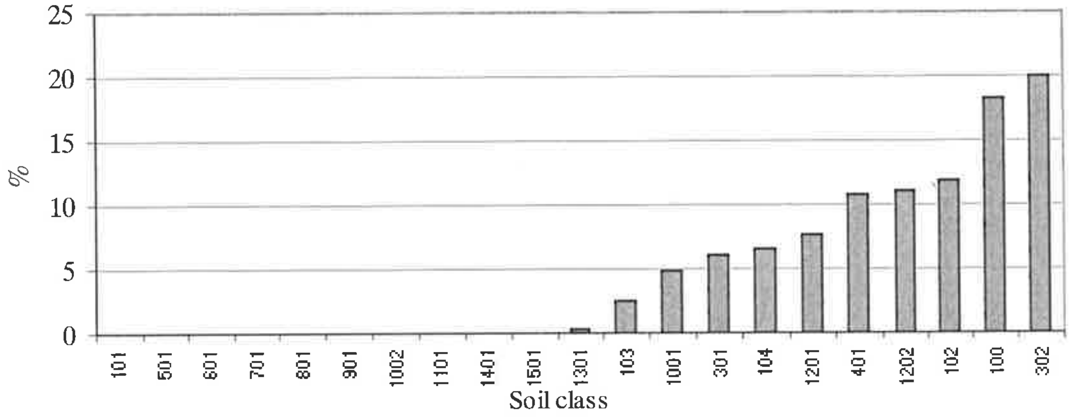


Figure 5. 10 Histogram of the distribution of remnant vegetation records of sclerophyll woodlands on soil types.

Soil type domains were defined as those described for historical records in Chapter 4 and used to produce maps of the potential soil domains of grassy woodlands and sclerophyll woodlands (Figure 5. 11 and Figure 5. 12). The core grassy woodland soil domains are mainly restricted to the Inman Valley region and on areas of mid elevation on the western side of the ranges. Areas excluded from the any sclerophyll woodland domain on the western side Fleurieu Peninsula were classed as marginal or also excluded from any grassy woodland domain. Most of the highland regions, classed as being core sclerophyll woodland soil domain, were classed as being marginal soil domains for grassy woodlands. The core soil domain of sclerophyll woodlands occupies most of the highlands regions but also extends through the Inman Valley in patches of the lower elevated regions on the eastern and western sides of the ranges. The core soil domains of grassy and sclerophyll woodlands show significant overlap with the models both defining the widely distributed type 302 as being core.

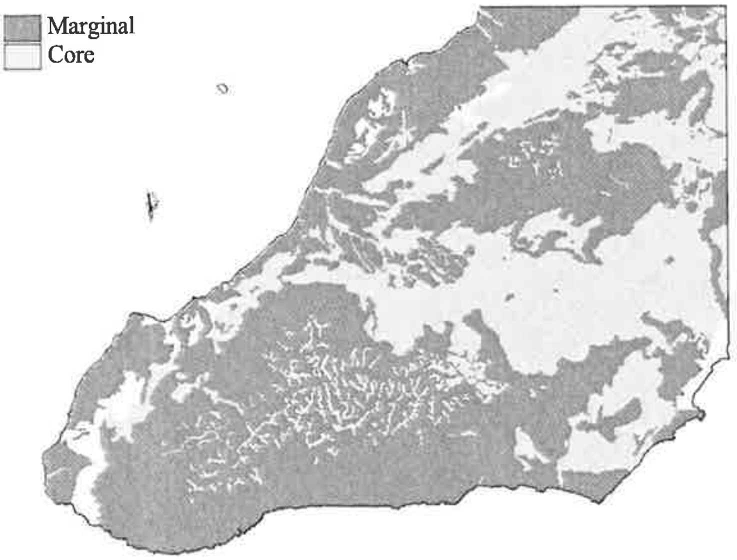


Figure 5. 11 The predicted core and marginal soil domains of grassy woodlands from remnant vegetation records.

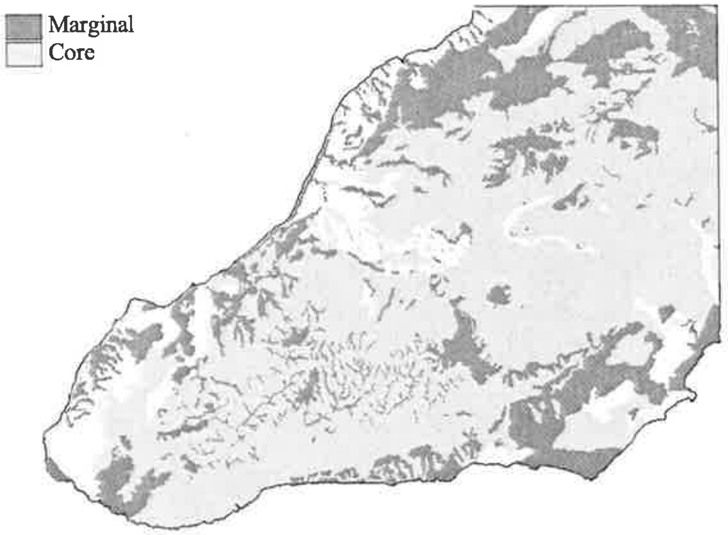


Figure 5. 12 The predicted core and marginal soil domains of sclerophyll woodlands from remnant vegetation records.

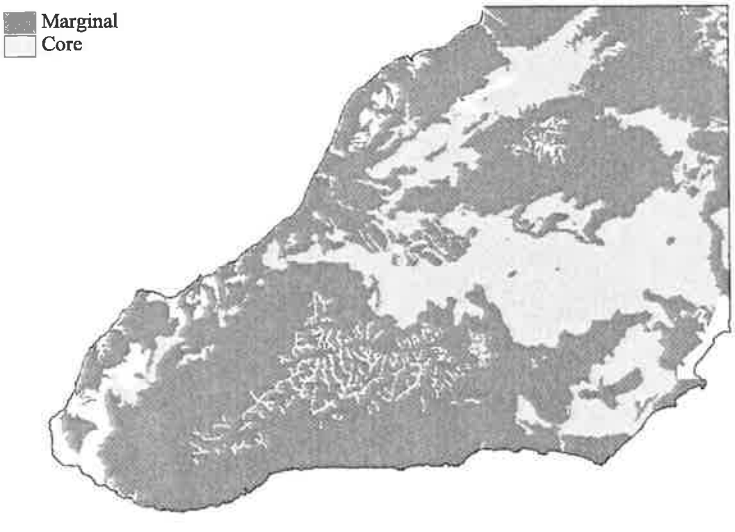


Figure 5. 13 The predicted core and marginal domains of grassy woodlands from remnant vegetation records. The core bioclimatic and soil domain is based on grid matching at the 5-95% levels in the bioclimatic envelope and >10% representation in the soil envelope.

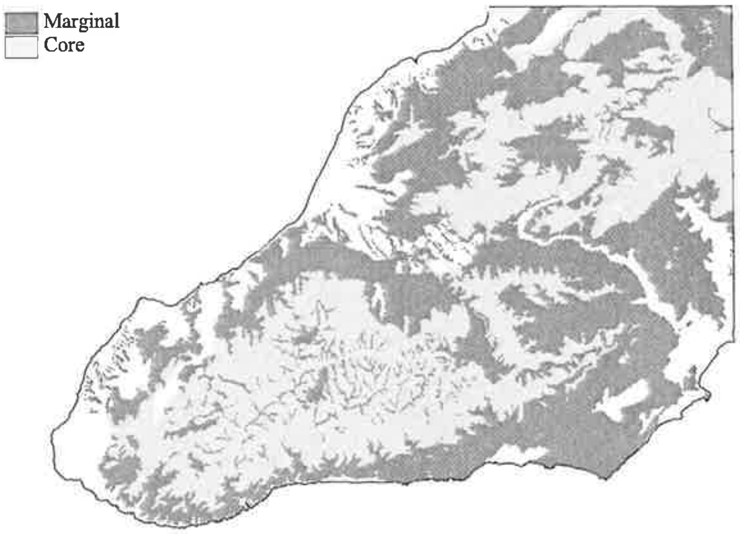


Figure 5. 14 The predicted core and marginal domains of sclerophyll woodlands from remnant vegetation records. The core bioclimatic and soil domain is based on grid matching at the 5-95% levels in the bioclimatic envelope and >10% representation in the soil envelope.

5.3.1.3 Potential domains using soil type and bio-climate

Maps of the potential domains of grassy and sclerophyll woodland formations derived from combination of the potential bioclimatic domains combined with soil domain are presented in Figure 5. 13 and Figure 5. 14. These maps contain a predicted core domain derived from grid matching using the core bioclimatic domain with the core soil-type domain. A predicted marginal domain is derived from grid matching using the marginal bioclimatic domain and the marginal soil-type domains. Areas excluded from any domain are shown as white. The core domain of grassy woodlands is approximately halved in extent from the prediction using climate alone. Its location is restricted to the Inman Valley region and patchily along the western side of the ranges. Most of the western areas of lower elevation around Rapid Bay and Yankalilla are classed as being marginal with patches of land in these areas excluded from any potential domains. The predicted core domain of sclerophyll woodlands defined by modern data is situated in the upper and mid-regions of elevation and is fragmented by areas classed as marginal. The core domain also extends in patches through areas of the Inman Valley region. In total the core domain occupies about 38% of the region, about 15% less area than the core area defined using bioclimate alone. About 16% of the region, situated predominantly around the coastal areas and through parts of Inman Valley, is excluded from any predicted domain.

5.3.1.4 Model assessment

Grassy and sclerophyll woodland models developed using remnant vegetation records were assessed using sensitivity and specificity measures generated using the same records. Core areas were used to indicate predictive presence in the calculation of the sensitivity measure, while predictive absence was calculated using (1) only areas outside any domain and (2) marginal areas and areas outside any domain.

Table 5. 6 Assessment of grassy woodland and sclerophyll woodlands models developed using historical vegetation data. Sensitivity is a measure of the number of correctly classified positive records and specificity a measure of the correctly classified negative records. Negatively classified records were calculated in two ways, (A) records in neither core nor marginal domains and (B) records excluded only from core domains.

Model	Test data	Sensitivity	(A) Specificity	(B) Specificity
Grassy woodlands	Remnant vegetation	0.73	0.02	0.87
Sclerophyll woodlands	Remnant vegetation	0.80	0.35	0.79

The grassy woodland model has a specificity value of 0.73, that is correctly predicting 73% of grassy woodlands remnant vegetation records and a relatively high specificity value of 0.87. The sclerophyll woodland model performed better than the grassy woodland model as indicated in its ability to predict historical sclerophyll woodlands records, having a sensitivity value of 0.80 when tested with remnant vegetation records and a higher specificity value.

5.3.2 Sclerophyll communities

5.3.2.1 Selection of predictive variables for TEDA analysis

ROC plots of sensitivity versus 1-specificity, from which area under the curve (AUC) values were calculated for the suite of environmental combinations for the six remnant vegetation types modelled are shown in Figure 5. 15 to Figure 5. 17.

Table 5. 7 AUC values from the ROC analysis of predictive success of 2-variable environmental domain models using modern data of vegetation distribution.

Variable 1	Variable 2	Code	*E. obliqua* Open forest	*E.baxt.* - *E.cosmo* low woodland	*E. ovata* woodland	*E.fasc.*- *E.cosmo* - *E.baxt.* low woodland	*E. cosmo* very low woodland	*E. fasc.* low woodland
Annual precipitation	Topographic wetness index	apcw	0.7636	0.7082	0.852	0.9224	0.7992	0.7733
	Annual net radiation	apnr	0.7902	0.7273	0.8218	0.9275	0.8435	0.7831
	Slope	apsl	0.7718	0.7469	0.8598	0.9622	0.8676	0.8196
	Elevation percentile	evap	0.7391	0.6623	0.8507	0.8946	0.7655	0.7551
Elevation Percentile	Annual net radiation	evnr	0.5458	0.5792	0.8125	0.7225	0.6883	0.6128

The AUC values for all environmental combinations and model types ranged from 0.5458 to 0.9622 (Table 5. 7). The models which incorporated annual precipitation with slope model (APSL) resulted in the highest AUC values for all communities types except for *E. obliqua* open forest. There was variation however, amongst the AUC values for APSL models; *E. baxteri* - *E. cosmophylla* low woodland showed the lowest predictive success with an AUC value of 0.74 and *E. fasciculosa* - *E. cosmophylla* - *E. baxteri* low woodland the highest at 0.96. The annual precipitation and net annual radiation (APNR) model was the most successful at predicting *E. obliqua* forest and it yielded the second highest AUC values for all other vegetation types except *E. ovata* woodlands. Instead, the second best model according to the AUC analysis for *E. ovata* woodlands was annual precipitation with the topographic wetness index (APCW) which had an AUC value of 0.7636.

Models combining the two topo-scale variables of elevation percentile and annual net radiation, did not perform as consistently well as combinations incorporating the meso-scaled predictor of precipitation. However they were reasonable successful at predicting *E.ovata* woodland and *E. fasciculosa* - *E. cosmophylla* - *E. baxteri* low woodland. They showed AUC values of 0.8125 and 0.7225 respectively while other communities resulted in AUC values between 0.5458 and 0.6883.

Models of annual precipitation and a topographic wetness index (APCW) resulted in predictive values similar to both APSL and APNR models. Elevation percentile and annual precipitation showed reasonably high AUC values for most community types although values were less than models with precipitation and the other variables investigated. The APSL and APNR models were selected for further analysis, given their overall higher rates of predictive success for all vegetation classes.

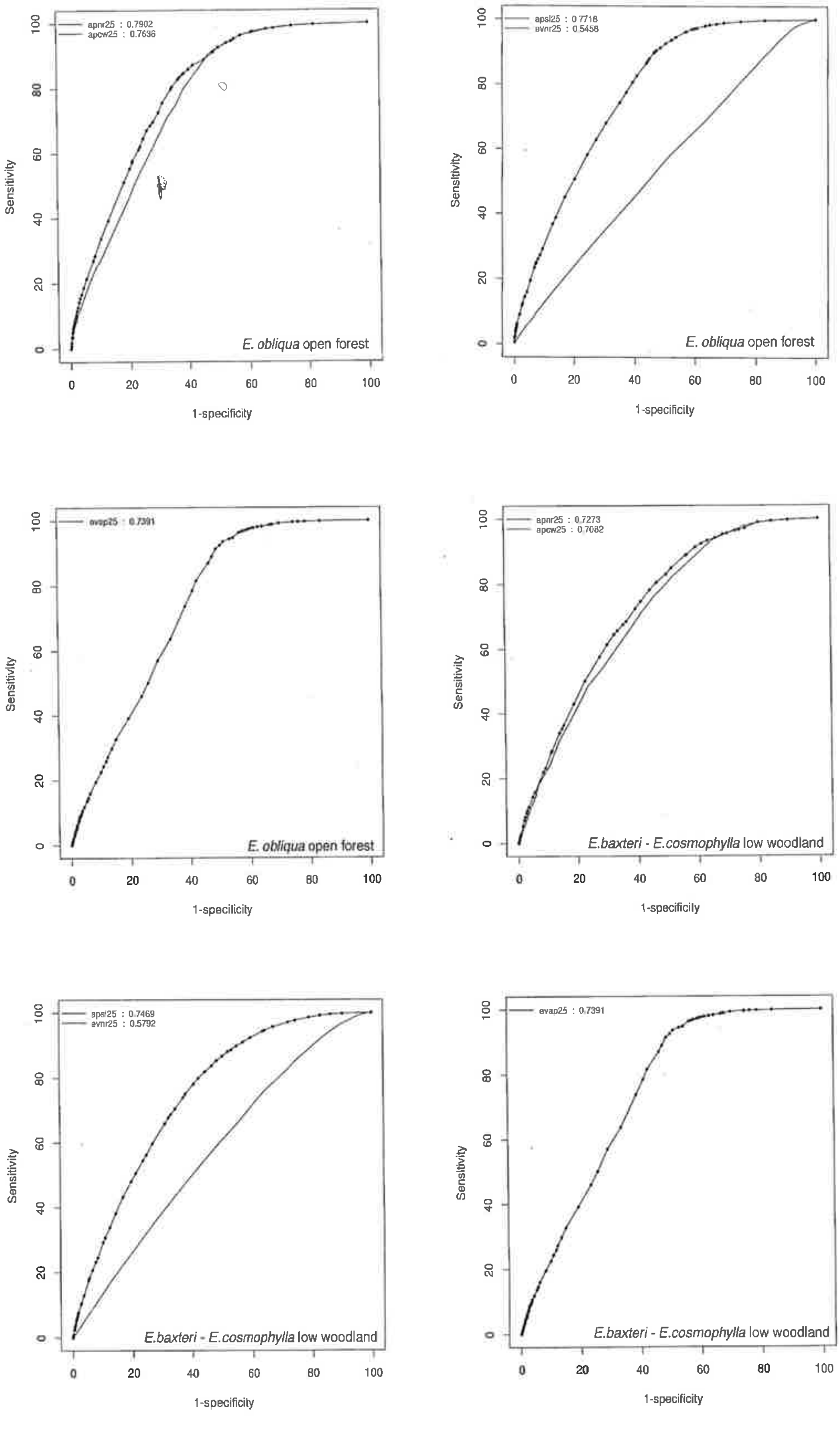


Figure 5. 15 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of a (1) *E. obliqua* open forest and (2) *E.baxteri* - *E.cosmophylla* low woodland model.

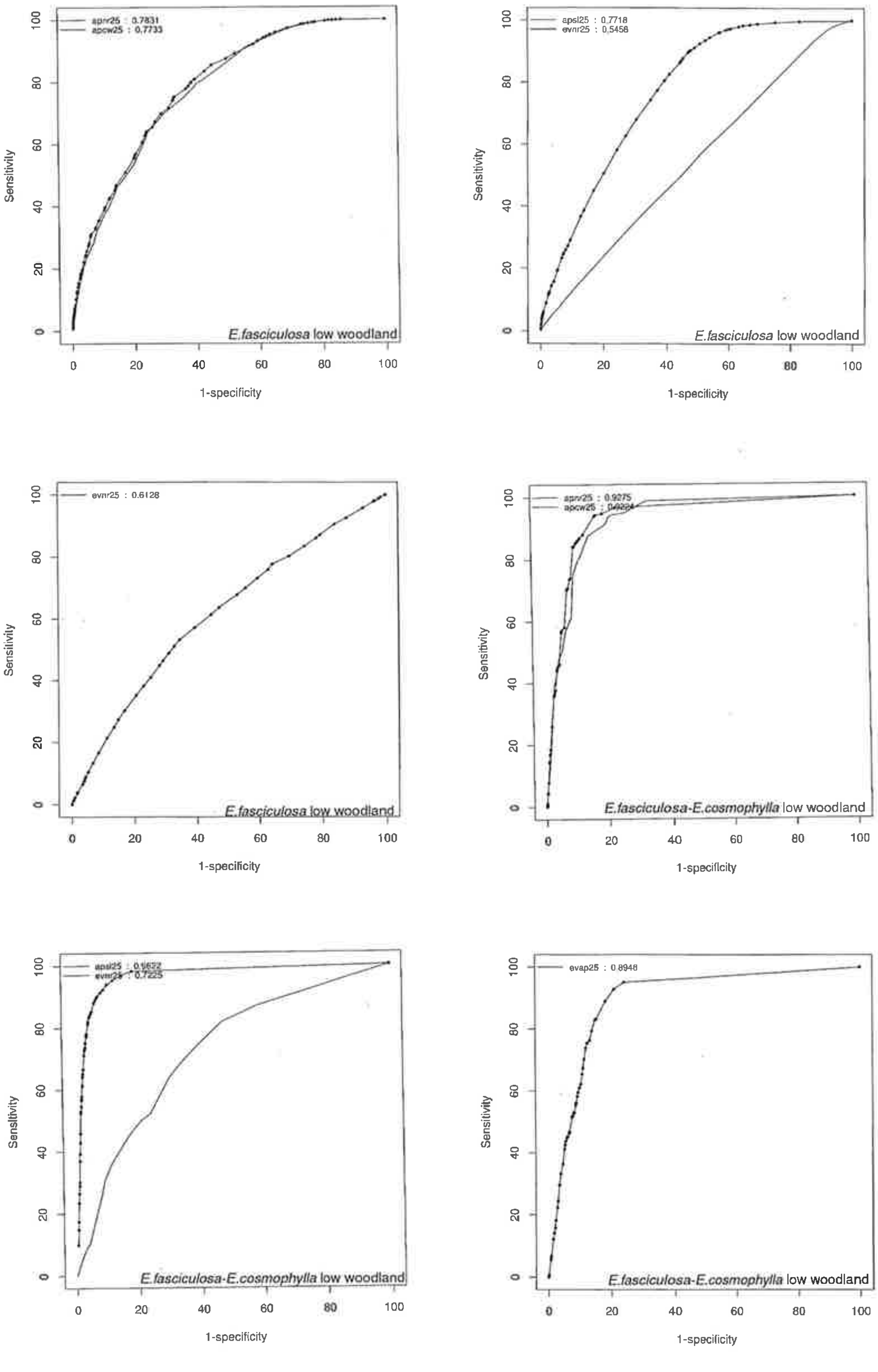


Figure 5. 16 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of (1) *E. fasciculosa* low woodland and (2) *E. fasciculosa- E. cosmophylla* models.

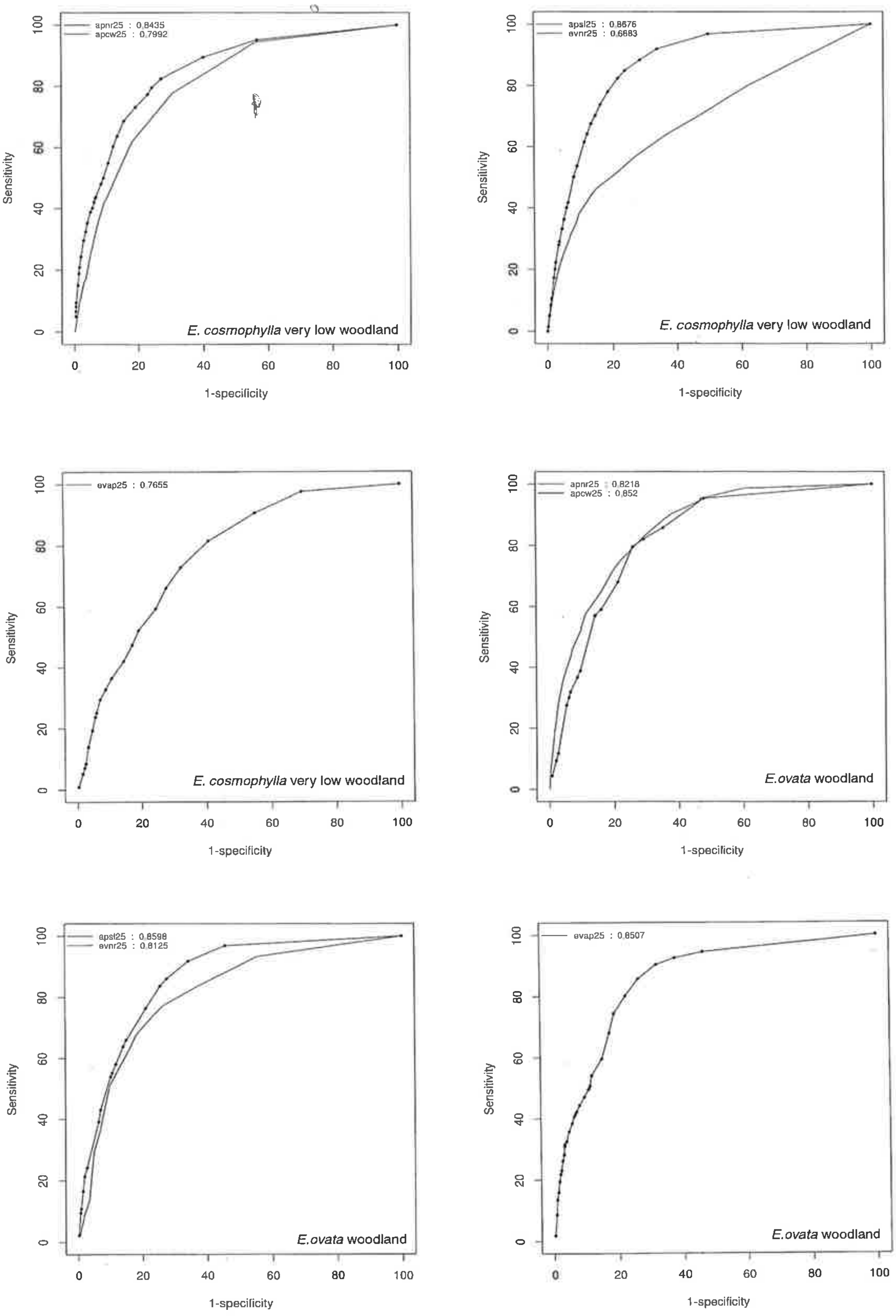
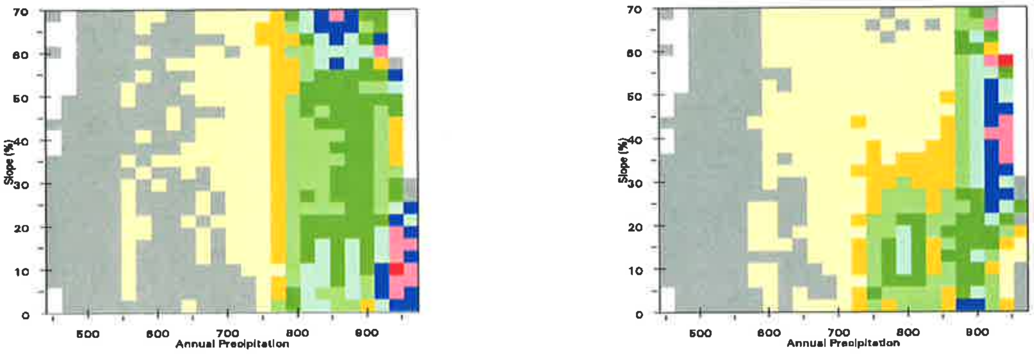
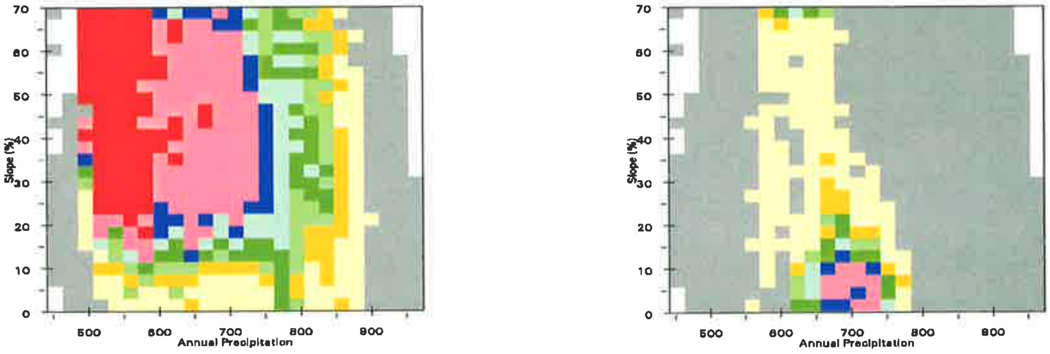


Figure 5. 17 Two-dimensional ROC plots yielding AUC values for models generated using all environmental combinations investigated for their predictive strength in development of (1) *E. cosmophylla* very low woodland and (2) *E. ovata* woodland models.



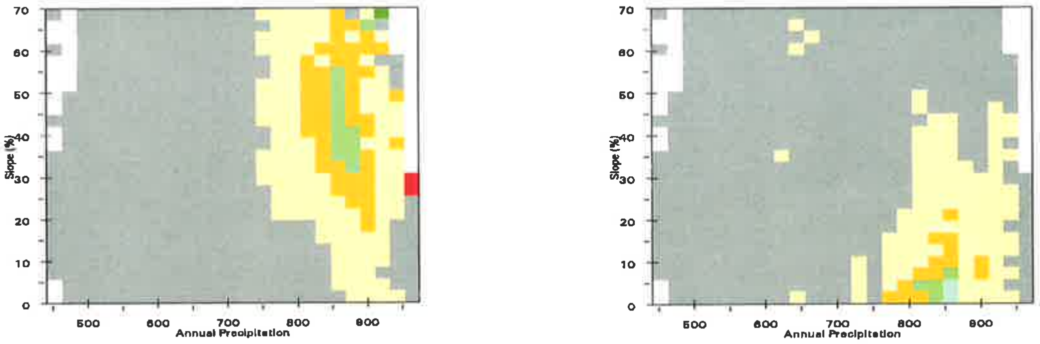
E.obliqua open forest

E.baxteri - *E.cosmophylla* low woodland



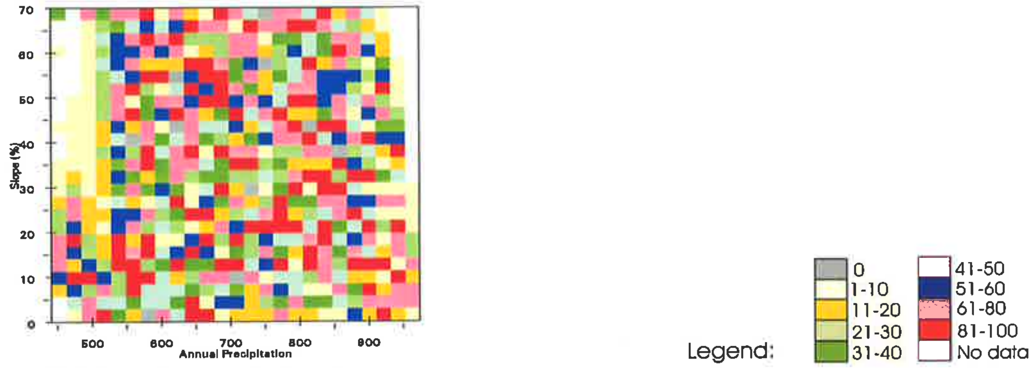
E. fasciculosa low woodland

E. fasciculosa - *E. cosmophylla* low woodland



E. cosmophylla very low woodland

E. ovata woodland



Occurrence of each domain

Figure 5. 18 The observed probabilities for *E. obliqua* open forest, *E. baxteri* low woodland, *E. fasciculosa* low woodland, *E. fasciculosa-E. cosmophylla* low woodland, *E. cosmophylla* low woodland and *E. ovata* woodland as a function of annual precipitation and slope.

5.3.2.2 Observed probability matrices and spatial predictions-APSL model

The observed probabilities for modern vegetation classes as a function of slope and annual precipitation are shown in Figure 5. 18. The highest probability domain revealed for *E. obliqua* open forest is at precipitation values greater than 800 mm and on slopes of less than 20%, although it also shows a disjunct dominant domain at the same precipitation values but with very steep slopes. This domain shows some overlap with the dominant domains of *E. baxteri* - *E. cosmophylla* low woodland. They are weakly separated by slope with *E. baxteri* – *E. cosmophylla* low woodland occurring more frequently on mid-steepness to steep slopes than *E. obliqua* open forest. Also at the higher end of the rainfall gradient in the region are the dominant domains of *Eucalyptus ovata* woodland and *E. cosmophylla* very low woodlands. The dominant domain of *E. ovata* woodlands has an annual precipitation range between 800-850 mm and on very gradual slopes (less than 5%). *Eucalyptus cosmophylla* also most frequently occurs in regions with annual precipitation values around 850 mm, although it dominates on slopes with steepness greater than 30%. The observed probabilities for *E. ovata* woodland and *E. cosmophylla* low woodland are markedly lower than the other four community types reflecting their relative scarcity in the landscape. However domains having relatively higher probability values can still be distinguished. *Eucalyptus fasciculosa* low woodland is dominant on positions with steep slopes, ranging from 20-70%, and having annual precipitation values between 500-700 mm. *Eucalyptus fasciculosa* - *E. cosmophylla* low woodland similarly occurs in areas precipitation values between about 650 and 750 mm, but on gentler slopes (less than 10%).

The observed probabilities presented in the APSL-model probability matrices were used to generate spatial predictions of the likelihood of occurrence of each of the modelled vegetation classes. High probabilities of occurrence of *E. obliqua* open forest occurred on low slopes of the wettest part of the Fleurieu Peninsula in the northern part of the ranges (Figure 5. 19). Much of the southern rangeland areas were classified as having moderately high probabilities of occurrence. The coastal plains and the Inman Valley region had low probabilities of *E. obliqua* open forest occurrence. The APSL model predicted high probabilities of occurrence of *E. baxteri* - *E. cosmophylla* low woodlands on the steeper slopes of the northern ranges in the Fleurieu Peninsula (Figure 5. 20). Moderately high probabilities of occurrence were predicted on the steep to moderately steep slopes of the northern and southern ranges and on the lower slopes on the eastern side of the ranges. *Eucalyptus fasciculosa* low woodland was predicted at high probabilities on the steep slopes in the lower rainfall areas of the region and as having little likelihood of occurrence over the more highly elevated parts of the ranges (Figure 5. 21). *Eucalyptus fasciculosa* - *E. cosmophylla* - *E. baxteri* low woodlands was predicted as being mostly likely to dominate in small patches on the edges on the ranges and on the more gentler sloped areas of the Inman Valley and Victor Harbour regions (Figure 5. 22). *Eucalyptus cosmophylla* low woodland has a higher predicted probability of occurrence in the elevated high rainfall regions, predominantly on steep slopes in the northern highly elevated regions (Figure 5. 23). *Eucalyptus ovata* woodland is predicted as potentially occurring over the whole of the upland region but with higher probability of dominating in low lying flat bottomed valleys (Figure 5. 24).

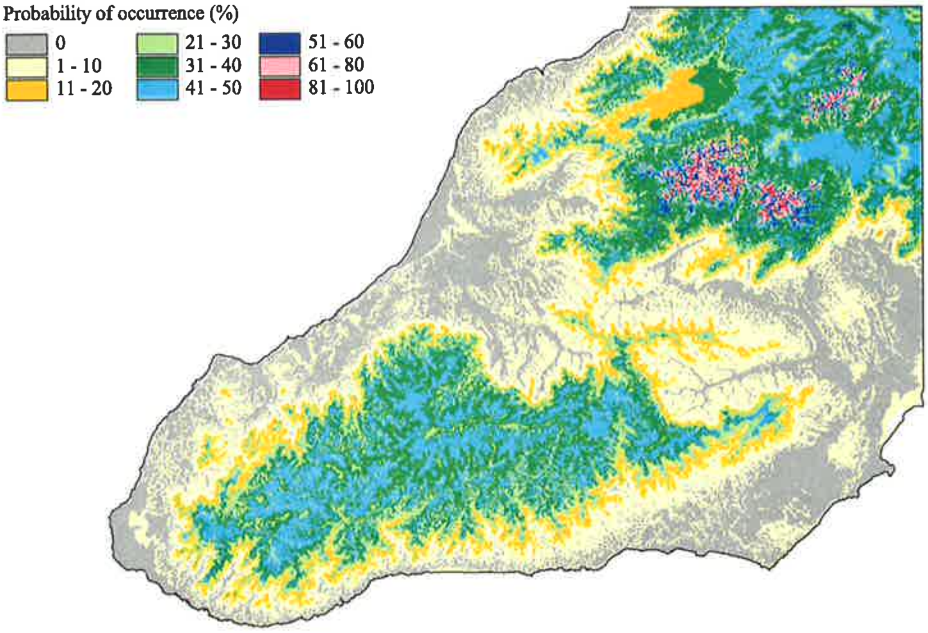


Figure 5. 19 Predicted environmental domain for *E. obliqua* open forest based on observed probabilities presented in Figure 5.18.

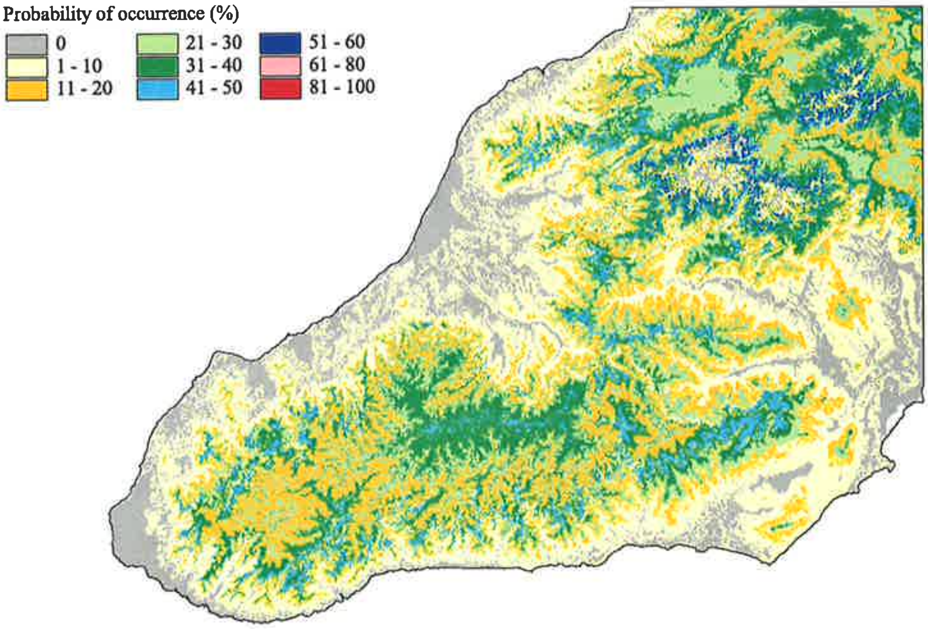


Figure 5. 20 Predicted environmental domain for *E. baxteri* - *E. cosmophylla* low woodland based on observed probabilities presented in Figure 5.18.

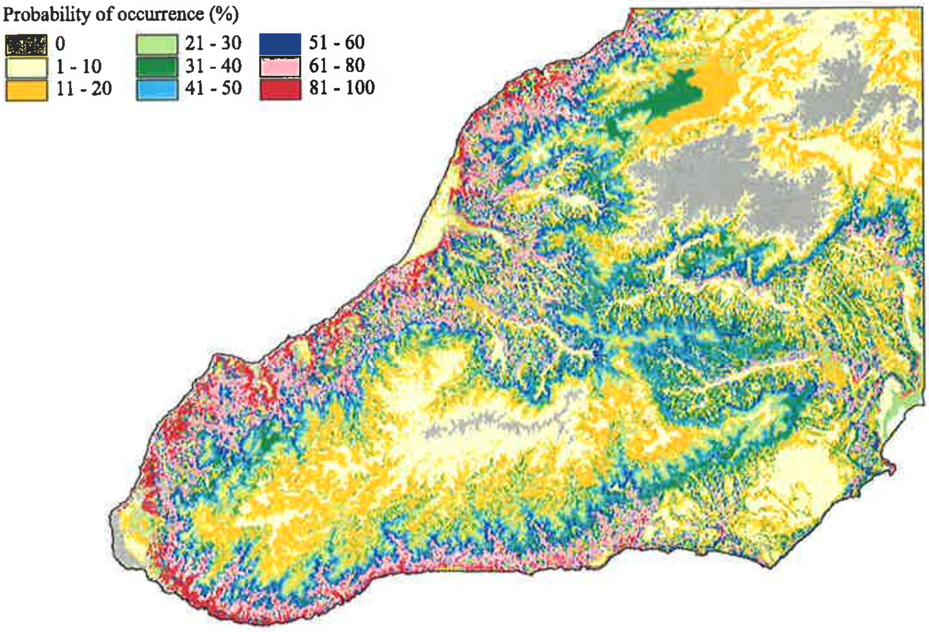


Figure 5. 21 Predicted environmental domain for *E. fasciculosa* low woodland based on observed probabilities presented in Figure 5.18.

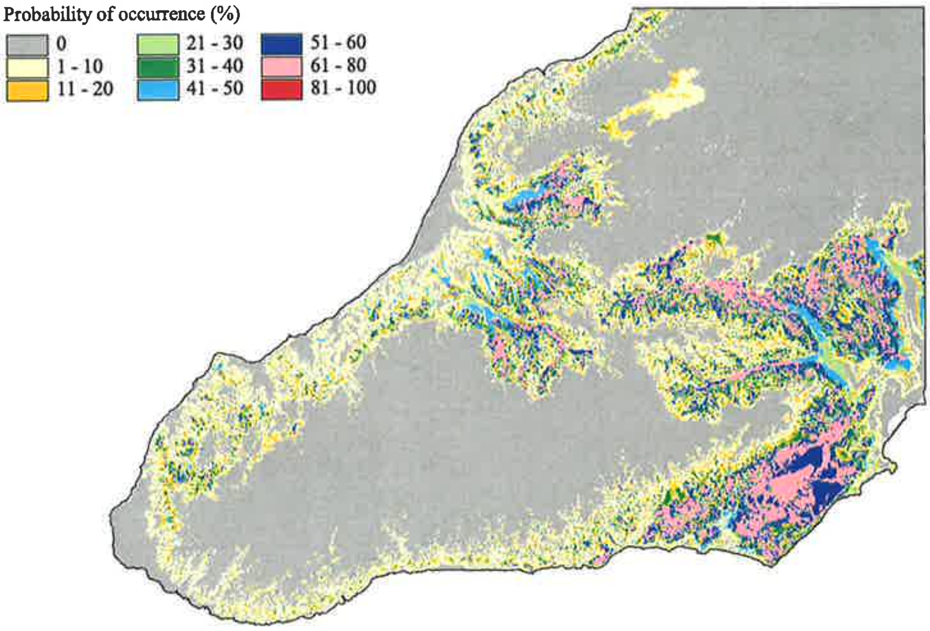


Figure 5. 22 Predicted environmental domain for *E. fasciculosa – E. cosmophylla-E. baxteri* low woodland based on observed probabilities presented in Figure 5.18.

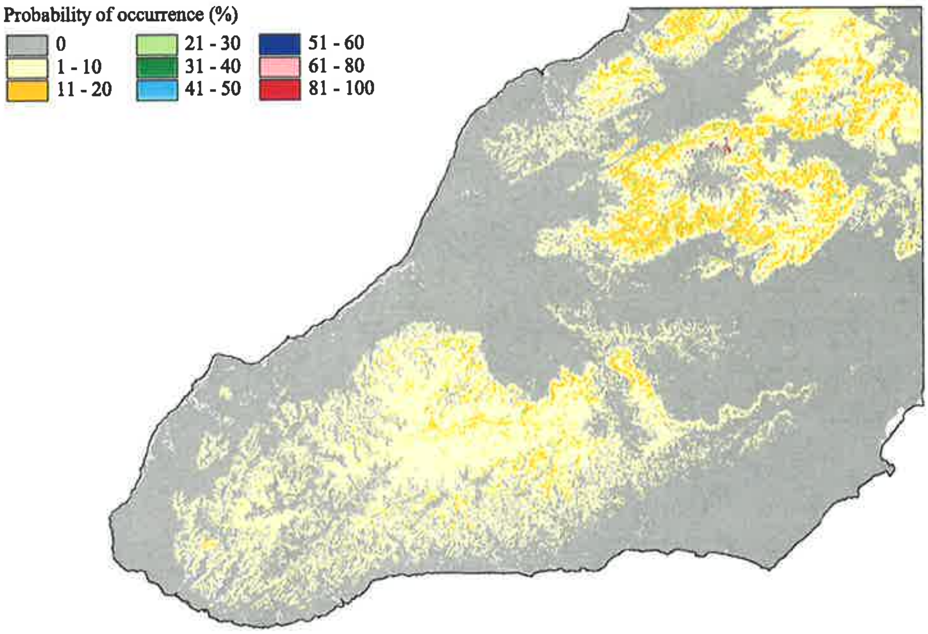


Figure 5. 23 Predicted environmental domain for *E. cosmophylla* very low woodland based on observed probabilities presented in Figure 5.18.

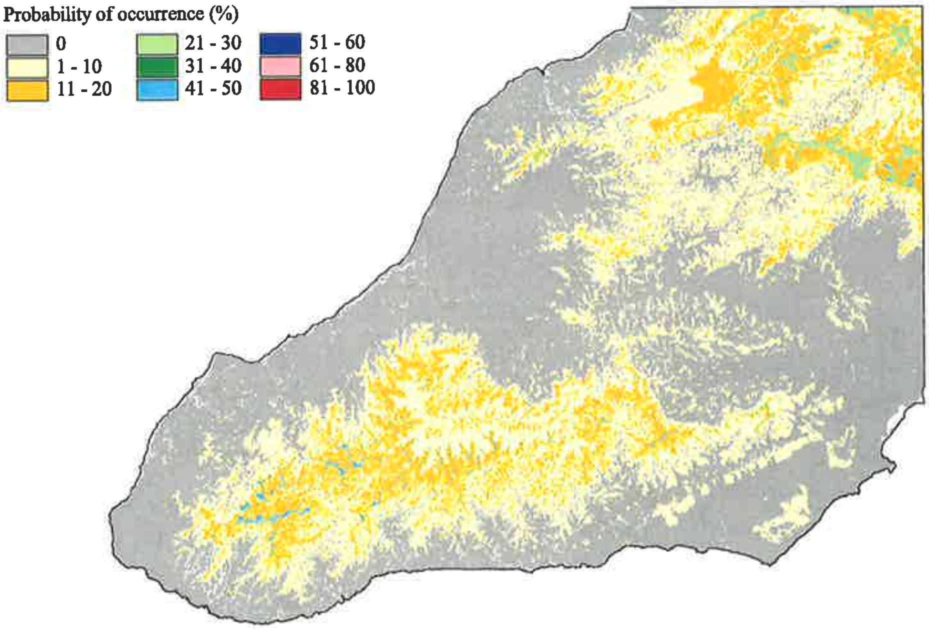
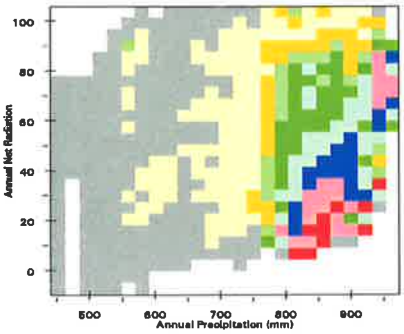


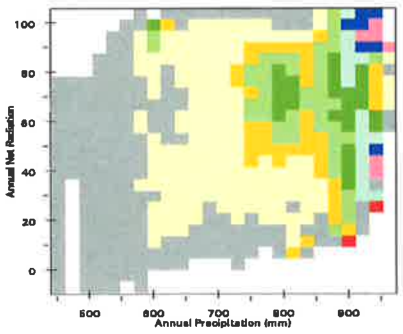
Figure 5. 24 Predicted environmental domain for *E. ovata* woodland based on observed probabilities presented Figure 5.18.

5.3.2.3 Observed probability matrices -APNR model

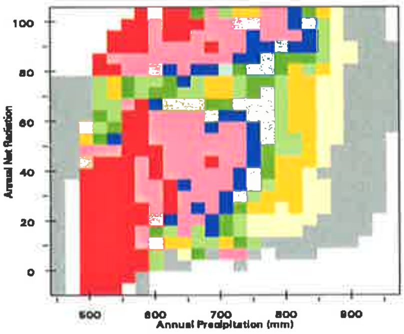
Figure 5. 25 shows the observed probability for modern vegetation communities in environmental space defined by annual precipitation and annual net radiation. The precipitation domains occupied by the types are as described in the APSL model and so description is restricted to differences in the radiation domains occupied by community types. *Eucalyptus obliqua* open forest most frequently occurs in domains where radiation is around 20 MJ/m^2/yr. The dominant domains of *E. baxteri* –*E. cosmophylla* low woodland occur across the range of annual net radiation values occurring in the



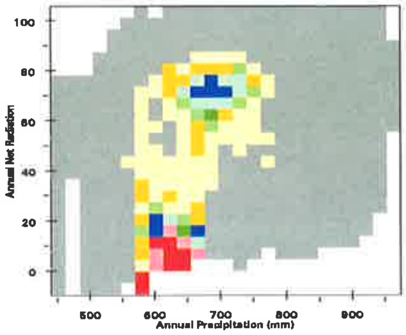
E.obliqua open forest



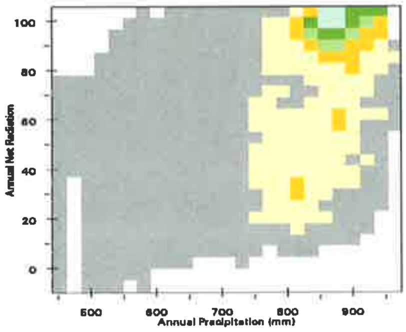
E.baxteri - *E.cosmophylla* low woodland



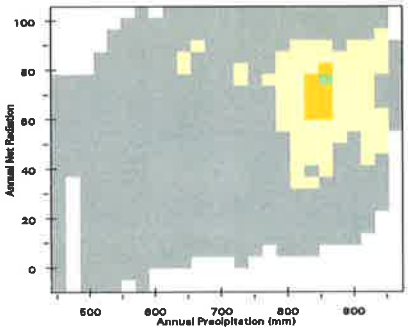
E. fasciculosa low woodland



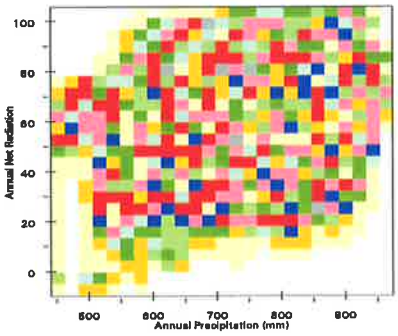
E. fasciculosa - *E. cosmophylla* low woodland



E. cosmophylla very low woodland



E. ovata woodland



Occurrence of each domain

Legend:

▨	0	▨	41-50
▨	1-10	▨	51-60
▨	11-20	▨	61-80
▨	21-30	▨	81-100
▨	31-40	☐	No data

Figure 5. 25 The observed probabilities for *E. obliqua* open forest, *E. baxteri* low woodland, *E. fasciculosa* low woodland, *E. fasciculosa* - *E. cosmophylla* low woodland, *E. cosmophylla* low woodland and *E. ovata* woodland as a function of annual precipitation and annual net radiation.

study region. Similarly, *E. fasciculosa* low woodland shows little correspondence to specific annual net radiation values. *Eucalyptus fasciculosa* - *E. cosmophylla* low woodlands were found to occur in two discrete dominant domains, one with annual precipitation values between 600-650 mm and low net annual radiation values, and the other with precipitation values 650-700mm and with high radiation values. As with the slope and annual precipitation model, the observed probabilities for *E. cosmophylla* low woodlands and *E. ovata* woodlands are low. However the highest probabilities for *E. cosmophylla* low woodlands are in areas of high annual net radiation (80-100 MJ/m^2/yr), and *E. ovata* woodland occupies positions with moderately high annual net radiation (~60 MJ/m^2/yr). Spatial predictions of the likelihood of occurrence of each of the modelled vegetation classes using the APNR model are shown in Figure 5. 25. The APNR probability domains mapped in geographic space are shown in Figures 5.26 to 5.31.

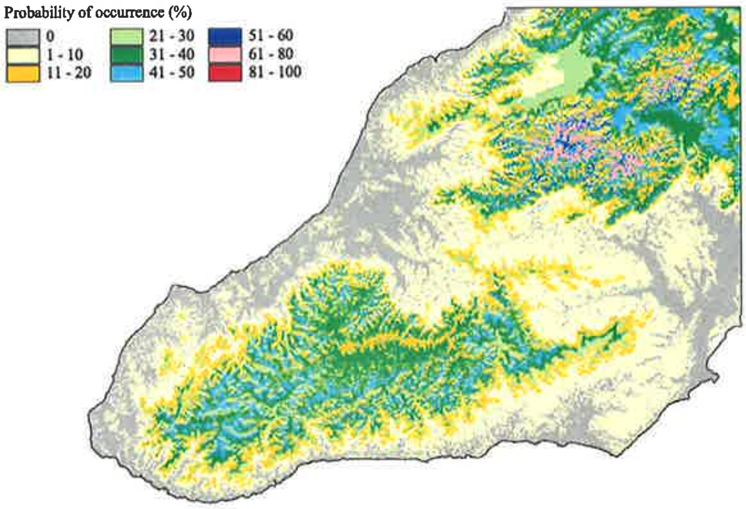


Figure 5. 26 Predicted environmental domain for *E. obliqua* open forest based on observed probabilities presented in Figure 5.25

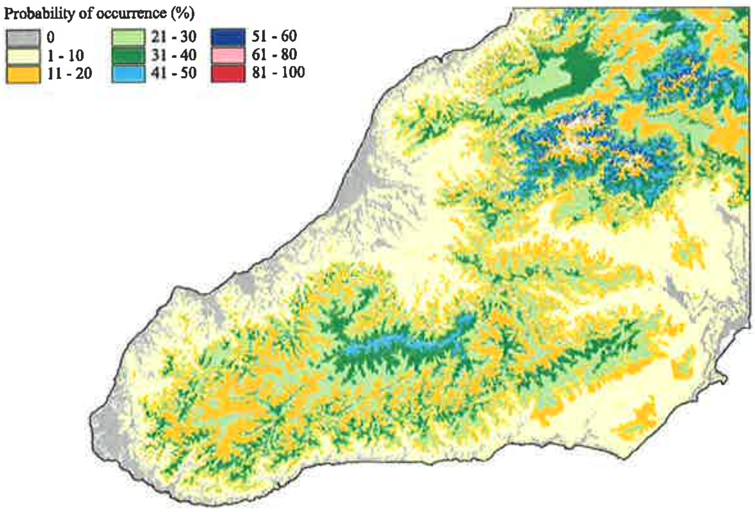


Figure 5. 27 Predicted environmental domain for *E. baxteri* - *E. cosmophylla* low woodland based on observed probabilities presented in Figure 5.25

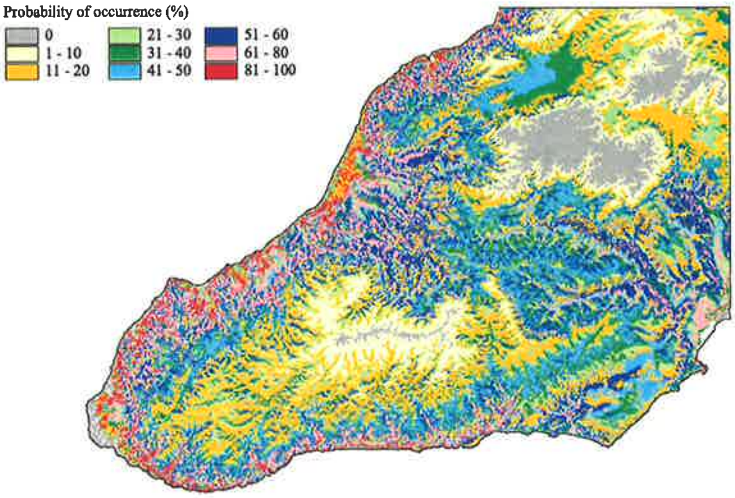


Figure 5. 28 Predicted environmental domain for *E. fasciculosa* low woodland based on observed probabilities presented in Figure 5.25

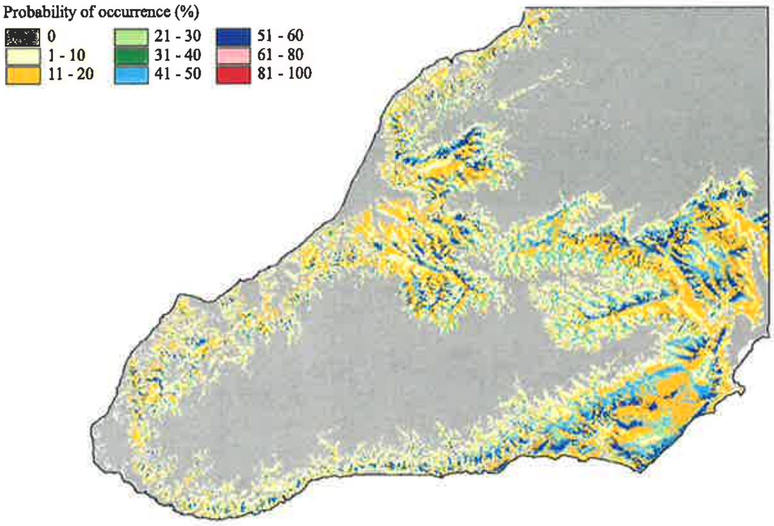


Figure 5. 29 Predicted environmental domain for *E. fasciculosa – E. cosmophylla* low woodland based on observed probabilities presented in Figure 5.25

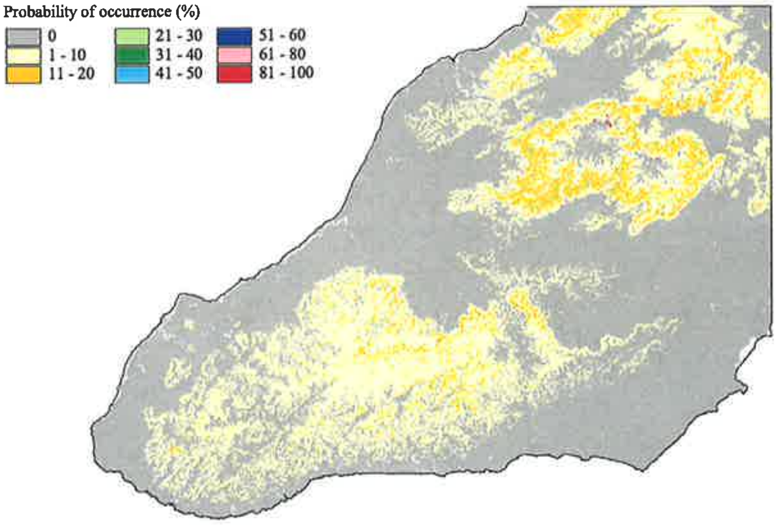


Figure 5. 30 Predicted environmental domain for *E. cosmophylla* very low woodland based on observed probabilities presented in Figure 5.25.

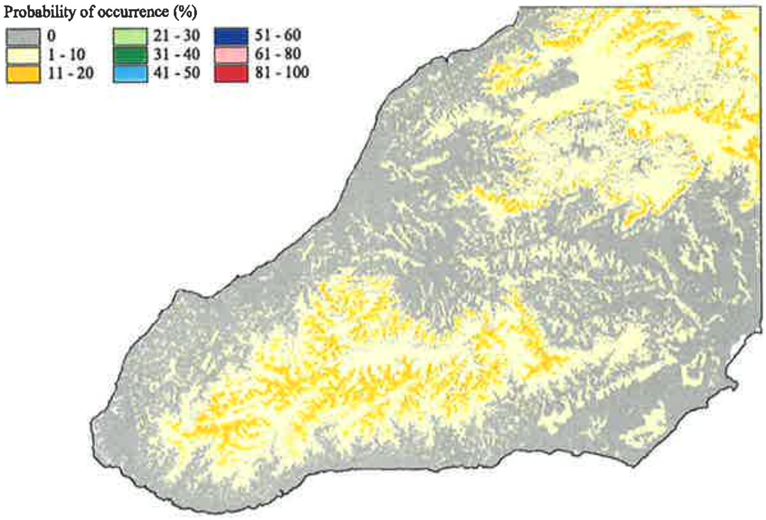


Figure 5. 31 Predicted environmental domain for *E. ovata* woodland based on observed probabilities presented 5.25.

5.4 Discussion

5.4.1 Grassy - sclerophyll woodlands

The potential physiological bioclimatic domains for the grassy and sclerophyll woodland formations, based on the remnant distribution of dominant overstorey species, appear substantially different. However a small proportion of grassy woodlands records extend into the precipitation and temperature domains occupied by the high proportions of sclerophyll woodland records. This is expressed in the spatial predictions of bioclimatic domains by the *marginal* domain of grassy woodlands extending well over the most highly elevated regions—areas that are classed as *core* sclerophyll woodland regions. Although this overlap is in agreement with the climatic ranges recorded in the ecological literature (Specht, 1972), it is probably in part also explained by imprecision in the data sets used to represent the formation types. *Eucalyptus leucoxylon,* one of the species selected to represent grassy woodlands, also occurs in sclerophyll woodland formations and its occurrences in areas of higher elevation are indicated by the upper end of its precipitation domain encompassing climate values typical of sclerophyll woodland formations. The overlap could also represent selective vegetation removal from particular environments. *Eucalyptus viminalis,* although principally an overstorey dominant of grassy woodlands formations on sites between *E. camaldulensis* and *E. leucoxylon* associations (Boomsma, 1948; Specht and Perry, 1948), also occurs on pockets of more fertile soils in the wetter and more elevated regions (Boomsma, 1948). The bioclimatic envelope of *E. viminalis* shows a narrow range of precipitation values more characteristic of the domains occupied by sclerophyll woodland species. It is possible that the present day occurrences are possibly relatively skewed towards more highly elevated regions as these areas have been less impacted by European vegetation removal. Such trends would be accentuated by the fact that *E. viminalis* was probably not historically highly represented in the vegetation of the region (Boomsma, 1948) and has limited present day occurrence.

Comparison was made between annual precipitation values recorded in the ecological literature for species used to model grassy and sclerophyll woodland and those derived by BIOCLIM. Comparison indicated that the *core* precipitation domains (ranges) concur more closely with those documented in ecological studies than values defining marginal domains (Table 5. 8). Differences between precipitation values recorded in the literature and derived by the BIOCLIM analysis are found mainly on the upper end of the precipitation limit. This is likely to be due to differences between precipitation in the southern Mount Lofty Ranges (Fleurieu Peninsula) and the central and northern Mount Lofty Ranges where the ecological studies were undertaken. It could also be due to imprecision in the methods used by Specht and Perry (1948) and Green (1994) to estimate rainfall.

Table 5. 8 Comparison of annual precipitation ranges recorded in ecological studies of the Mount Lofty Botanical Region, of which the Fleurieu Peninsula is part of, and BIOCLIM-derived annual precipitation measures. The BIOCLIM values given are the range and the 5 and 95 percentiles.

	BIOCLIM-range	BIOCLIM core	Boomsma (1948)	Specht and Perry (1948)	Green (1994)
E. leucoxylon	525-966	621-831	475-625 ('optimum')	625-1000	-
E.camaldulensis	566-825	598-798		> 700mm wide areas <700 mm creek lines	<800
E. viminalis	691-873	745-846		750-1000	>600
E. fasciculosa	572-928	646-853		500-1000	-
E. obliqua	625-947	772-927		750-1250	>800
E. baxteri	687-972	770-940		750-1250	
E. cosmophylla	586-956	667-897		875-1125	

Soils of the ranges and plains in the Fleurieu Peninsula are a complex mosaic of different types. The soil domain analyses method excluded certain soil types, or classed them as being marginal, for both grassy and sclerophyll woodlands. This particularly was the case with certain soil types in the lowland areas on the western side of the ranges. As the two formations represent the only alternative classes in the region the exclusion of particular soil types, or their marginal classification by both models, indicates poor performance of one or both models. The exclusion of a particular soil type from both core and marginal domains indicates absence, or low relative proportions of records, on that soil type. This could be due to environmental limits imposed by that soil unit or may be the result of the removal of that vegetation type from the soil unit. Additionally the inclusion of a record on a particular soil type will be related to the area of that soil type. Unless stratified sampling strategies have been implemented, soil categories covering a greater areal extent will have more *chance* of being included in sample sets. While data distribution is important over continuous variables, the exclusion, for example, of a particular rainfall range which may not be greatly represented in a landscape may be compensated by the presence of records on values directly above and below it. So a general picture of total range is still derived. However this 'smoothing effect' cannot operate with categorical variables where little can be inferred from the inclusion of records of one type but their exclusion from another due to inadequate sampling. Red brown loams of the western embayments were been defined as carrying grassy woodlands (Specht, 1972). However the model did not predict grassy woodland to occur on these soils, indicating poor performance of the soil models. Poor model performance is likely to be due to the sensitivity of the analytical approach to the areal representation of individual soil categories, the removal of vegetation from these areas, or both factors operating in tandem. The definition of soil domains could be improved by the application of 'rules' of inclusion or exclusion, based on prior knowledge of the biotic units ecological preference if such information is available. It could also possibly be improved by the inclusion of categories in the core domain that are unique to a particular formation, even if their frequency of representation is low.

Error analyses, using the data that was made to build them as a test, indicate that potential domains identified for grassy and sclerophyll woodlands predicted remnant grassy woodland and sclerophyll woodland data relatively well. Sclerophyll woodlands showed slightly higher sensitivity and specificity values than grassy woodlands, suggesting the sclerophyll woodland model was the better model. However this testing does not provide indication of how well the modelled distributions reflect pre-European formation distributions because vegetation removal has likely resulted in the modelled domains only representing a portion of the physiological domains formerly occupied by these formation types. That this is the case is suggested by the fact that some areas in the region are not represented in the potential domains of either model. The models developed in these analyses as lines of evidence for historical grassy woodland and sclerophyll woodland boundaries are further considered in Chapter 9 where outputs are tested with independent evidence from other sources.

5.4.2 Sclerophyll communities

The analyses indicate that the remnant vegetation communities of the sclerophyll formation in the Fleurieu Peninsula occupy distinctive environmental domains. Annual precipitation clearly distinguishes the environmental domains of *E. fasciculosa* dominated low woodlands from those dominated by *E. obliqua*, *E. ovata*, *E. baxteri,* and *E. cosmophylla*[1]. The precipitation domains occupied by *E. cosmophylla* very low woodlands and *E. obliqua* open forests are also distinct, although not as clearly so as *E. fasciculosa* woodlands and the other vegetation types modelled. While, like the historical vegetation classes, remnant vegetation distribution showed some affinity to differences in net annual radiation, all remnant vegetation classes, except for *E. obliqua* open forest, were more highly correlated with slope angle. Slope angle particularly improved the predictive success of *E. fasciculosa* low woodlands, *E. cosmophylla* very low woodland and *E. fasciculosa - E. cosmophylla - E. baxteri* low woodlands models.

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[1] The *E. cosmophylla* low woodland and, *E. ovata* woodland models show distinctive domains but the domains exhibit low probabilities of occurrence values due to the relatively low areal representation of these types in the landscape. To allow comparison with the domains of other vegetation types with relatively higher representation in the landscape, and thus exhibiting a higher probability values, actual percentage values of domains were not considered. Rather areas of relatively high and low probability were compared.

Distinctive and defined domains could be evidence for environmental control of the spatial distribution of the sclerophyll communities in the Fleurieu Peninsula. That is, the results here in part suggest that niche theories of vegetation pattern could be invoked to explain their distribution. Domains thus represent the limiting primary environmental resources that relate to biological productivity and vegetation distributions. However it is beyond the scope of models that indicate correlation to prove causality. Other factors that could possibly explain the correlations revealed by these analyses ought be considered.

The spatial distribution of records is critically important to any modelling study of relationships between environment and vegetation. Data records should represent the range of possible environmental domains in a study region (Austin and Heyligers, 1989; Neldner, 1994). The modern vegetation data set that was used to develop these models is likely to principally represent environments that were not deemed worthy of clearing for agriculture and as such could be expected to correlate with particular environmental gradients or domains in the region. Agriculturists selected for soil types which were perceived to be more fertile, terrain which was most easily accessed, and for climates optimising productivity. Thus land clearance patterns reflected the selection for particular soil types, slopes and climates and against others. So the remnant vegetation data set is highly representative of particular environmental domains and exclusive of others. This can be illustrated by analysis of *Eucalyptus fasciculosa* low woodlands. These were correlated with sites receiving annual values between 500 and 700 mm precipitation per annum and on intermediate to very steep slopes (20-70%). Ecological studies report that *E. fasciculosa* occurs over precipitation values from 400-1000 mm per annum, but on soils of low moisture relations throughout the Mount Lofty Ranges (Specht and Perry, 1948; Mitchell, 1983). The community extends over this reported high range of precipitation values but the model shows that it has a much higher probability of occurrence in the lower end of its precipitation spectrum and on steep slopes. Although speculative, it can not be discounted that the defined domain is accentuated by selective land-clearance and it may have once have had greater representation in higher rainfall areas and on more gradual slopes with poor moisture relations. Similarly, the optimum portion of the *E. baxteri* - *E. cosmophylla* low woodlands domain was in steep sloped areas. *Eucalyptus baxteri* is reported to replace *E. obliqua* open forests as moisture and soil relations decline in the highlands regions of the Fleurieu Peninsula (Boomsma, 1948). While slope is likely to have been a contributing factor in *E. baxteri* – *E. cosmophylla* distribution, in that steeper slopes are generally characterised by shallower soils with poor moisture relations as with the *E. fasciculosa* woodlands, it can not be discounted that *E. baxteri* – *E. cosmophylla* low woodlands once had greater occurrence on gentler slopes but with impoverished soils and the defined domain is partially representing a footprint of land clearance patterns.

Of all the vegetation types modelled *Eucalyptus ovata* woodlands were most strongly correlated with topographic position, being the only vegetation type which was successfully predicted by the model incorporating elevation percentile. *Eucalyptus ovata* woodland distribution correlated strongly to low lying areas, with low slope in the higher rainfall regions. The model is thus useful in characterising potential distribution in other low lying areas in the region where wetlands may have been drained and the vegetation removed. But it can not be discounted that these woodlands may have once covered wider environmental domains as it could be conceived that selection against low lying swampy areas for vegetation clearance occurred and may contribute to the domain defined using remnant data and these analyses.

Regional ecological studies record that *Eucalyptus cosmophylla* low woodlands tend to develop on very skeletal soils which restrict other *Eucalyptus* species. Also, direct insolation is a marked controlling factor of its distribution, being only found on sunny slopes at both the upper and lower limit of its precipitation range (Specht and Perry, 1948). Both the precipitation with slope, and net radiation, reasonably well predicted *E. cosmophylla* low woodland distribution with the dominant domain on sites with annual precipitation values around 850 mm, and on slopes with steepness greater than 30% or with very high net radiation values. The dominant domain generally concurs with current distribution and ecological literature. Such environments would have been selected against for clearance and agricultural improvement. It is possible that vegetation types with such environments, remain as remnant vegetation. If this were the case, the modelled domain adequately represents the pre-European realised niche of this vegetation type. As such the modelled domains where *E. cosmophylla* dominates may represent environmental controls rather than clearance patterns.

The environmental variables adopted in these models either directly or indirectly represent a wide range of environmental regimes related to ecological process. The meso-scale precipitation variable is a function of elevation lapse rate affects and terrain shadowing (in relation to the direction of moisture bearing air masses) and was shown to be highly correlated with temperature gradients in the region. Terrain variables were investigated for their correlations with a wide range of environmental processes and attributes affecting biological productivity. The solar radiation model captures topo-scale variation in insolation and thus evaporative potential. Other terrain variables capture terrain shape and position which closely control the way water moves over the landscape and as such is related to soil toposequences (Moore *et al.*, 1993a; Gessler *et al.*, 1995) as well as the hydrological potential of a site (Moore, 1993; Gallant and Wilson, 1996). However geological substrate or soil type, which can play a significant role in determining the nutrient availability at a site and affect the horizontal transmissivity of subsurface water, were not included in these models. Their exclusion possibly represents an important, unaccounted component of the primary environmental regimes affecting vegetation pattern in the region. *Eucalyptus baxteri* is reported to replace *E. obliqua* as soil nutrients become less available (Boomsma, 1948). Also, the dominant domains of *E. baxteri – E. cosmophylla* low woodlands and *E. obliqua* open forests both occurred in the higher rainfall regions with only slight differentiation by slope and net radiation. This indicates that other processes or environmental variables are required to explain the niche separation of these two types. Similarly the areas of predicted high probability of occurrence of *E. fasciculosa - E. cosmophylla - E. baxteri* low woodlands and *E. fasciculosa* low woodlands extended through much of the area designated as carrying remnant grassy woodlands. As discussed in the grassy-sclerophyll woodland analyses soil nutrients are a controlling factor of their distribution. So improvement of the spatial predictions of these types in the Fleurieu Peninsula could be achieved by either restricting analyses to upland soil types or the inclusion of a soil fertility index.

While the role of disturbance and vegetation composition is little studied in the region, or in regions with similar vegetation types, both human and natural disturbances have been shown to potentially influence, and are influenced by, complex environmental gradients. The two may be difficult to distinguish. For example Mackay *et al.* (2000) suggested that spatial heterogeneity in fire regimes, which could be explained by local topographic gradients, could account for topographically correlated species distributions in Canadian boreal forests. The possibility that disturbance gradients affecting vegetation composition are paralleling, or complicating, physical environmental gradients in the vegetation types investigated additionally confounds interpretations of environmental causality of sclerophyll community distribution in the Fleurieu Peninsula.

5.5 Conclusions

These analyses provided a basis for identifying environmental domains where vegetation types were more likely to occur in the landscape, based on their present day distributions. The domains of some of the vegetation types overlapped while others were clearly distinct, showing show strong correlation with environment. Issues of the representativeness of the remnant vegetation data set complicate interpretation of distinctive domains as evidence for environmental control of vegetation patterns in the region. The defined dominant domains could be subsets of their pre-European domains, exaggerated towards specific domains, due to correlation between land with least potential for intensive land use and environmental gradients. The remnant vegetation in the region constitutes a biased data set and so is restricted in its ability to reveal historical environmental relations. In cases where domains indicate correlation with land clearance patterns, the modelling is useful in revealing landscape effects of European land use. If combined with historical data on community distribution, such information provides a means to measure relative impacts on particular vegetation types.

Vegetation types that are strongly and *specifically* correlated to environmental domains that have not been cleared, are likely to be representative of their pre-European distribution. In these cases an environmental modelling approach provides a powerful way of predicting potential historical vegetation. However predictions can really only be applied to areas with environmental characteristics well represented in the data set. In this case, for example, other steep sloped areas.

Remnant vegetation has some application as a reliable source for the reconstruction of pre-European vegetation pattern. However its utility is restricted to only those environments/vegetation types well represented in the remnant vegetation. These landscapes correlate with those which are unsuitable for intensive agriculture. Vegetation types, which correlated to land selected for intensive agriculture, are poorly (or unrepresented) represented in the data set and using remnant vegetation to predict their historical environmental domains could lead to incorrect ecological conclusions.

CHAPTER 6

6. MODERN POLLEN DEPOSITION IN THE FLEURIEU PENINSULA

6.1 Introduction

Studies of the relationships between modern pollen deposition and extant vegetation are fundamental as aids to the interpretation of fossil pollen assemblages. Their importance has become all the more paramount with the adaptation of palynological techniques to address questions about ecological patterns and process operating at decadal and century scales, from the more traditional questions of broad scale palaeoclimatic reconstruction (Birks, 1996).

Knowledge of modern pollen deposition allows consideration of the relative representation of the pollen from species within a vegetation community, reveals pollen source area and the nature of pollen transfer. Modern pollen studies provide an essential key to the reconstruction of historical vegetation communities from fossil pollen spectra. One of the central questions in modern pollen studies is whether different vegetation types can be sufficiently well characterised by their pollen spectra. While these questions have been thoroughly studied in the European context, the complexity of the Australian vegetation, coupled with a lack of information on the pollen morphology and production of community dominants, has resulted in only a few Australian studies and much less well understood pollen-vegetation relationships.

Australian modern pollen studies have been carried out in southeastern and central New South Wales in *Eucalyptus*-dominated sclerophyll forests and woodlands and rainforest communities, *Callitris* woodlands and *Acacia*-chenopod shrublands (Dodson, 1983; Kodela 1990), in a variety of formations from coastal and central Victoria (Hope, 1968); in mangrove, freshwater wetland and rainforest formations in Queensland (Crowley, 1994) in shrub, heath and *Eucalyptus* woodland communities in semi-arid southwestern Australia (Newsome, 1999). A single study has been carried out in South Australia. Dodson (1977b) considered pollen deposition in a closed lake in the southeast of that state. Most of these studies have been in the form of percentage representation of taxa in surface sediments or moss polsters that have accumulated for unknown periods of time. Exceptions to this have been of Hope (1968) who considered aspects of seasonal and absolute pollen production and Newsome (1999) who used Tauber pollen traps over a two year period.

These studies show that in general Australian vegetation types can be distinguished at the formation level by their pollen spectra. This is particularly the case where dominant components of formations represent individuals from different Families. Where community and formation shifts represent changes at the genus level, within a Family, the identification of distinctive pollen spectra has been more difficult

(Kodela, 1990; Dodson, 1993). In a large part this is due the widespread dominance of members of the family Myrtaceae in Australian vegetation and to the morphological similarity of the pollen of members within this family. It is also due to the poor representation in the pollen record of many of the understorey components of Australian vegetation because of their low levels of pollen productivity and poor dispersive properties. Dodson (1983) estimated that about 70% of Australian taxa fall into the group having 'local' dispersion only, that is dispersing no more than about 10m, and this group is generally under represented in pollen records.

Differentiation of Myrtaceae pollen in fossil assemblages where attempted, has generally been limited to the separation of major taxonomic groups such as *Eucalyptus*, *Melaleuca* and *Leptospermum*. Few studies have attempted more detailed subdivision of Myrtaceae pollen, and these have concentrated on the separation of *Eucalyptus* pollen types (eg Dodson, 1974; Dodson, 1977a; Dodson and Wilson, 1975; Ladd, 1979b). Several recent studies have considered whether or not the pollen of certain Myrtaceae species might be identified to the specific level however none of these studies considered the dominant Myrtaceae species extant in the Fleurieu Peninsula (Chalson and Martin, 1995; Pickett and Newsome, 1997). The results of a study of the morphology of the dominant Myrtaceae species of the Fleurieu Peninsula are presented in Appendix 4. Morphological features or combinations of features were identified which allowed the distinction of the eight dominant *Eucalyptus* species to six classes. These species were also clearly distinguishable from other extant Myrtaceous members in the local flora.

Moss polsters are expected to represent both local and regional components of the pollen rain and provide pollen spectra relatively similar to atmospheric traps and represent several years of pollen accumulation (Fall, 1992; Moore *et al.*, 1991). They may also incorporate water-borne pollen from sheet wash, this being related to topographic position of the polster site. The veracity of using pollen spectra from moss polsters and surface soil samples to characterise modern vegetation communities and then interpret pollen spectra from lakes and swamps depends upon the pollen spectra from moss polsters providing an analogue for wet depositional environments. It has been asserted that small bogs and moss polsters both accumulate most of their pollen through atmospheric deposition and provide records of local vegetation. They have thus been shown to be comparable suggesting that moss polsters provide useful modern analogues for pollen from small swamps/bogs (Fall, 1992).

This chapter investigates how modern pollen assemblages from vegetation communities in the Fleurieu Peninsula, deposited on moss polster and wetland surfaces, reflect variations in the vegetation. It aims to determine the degree to which the modern vegetation communities of the Fleurieu Peninsula could be characterised by their pollen rain. Such a study was deemed to be a necessary to the enable the positive detection of historical vegetation stability or change through the fossil pollen record. In relation to discussion of pollen dispersal, the following terminology is adopted; local types are those which travel only about 10m, extra-local pollen is usually deposited within 100m and regional pollen is pollen that occurs in relatively large numbers at greater distances (*sensu* Janssen, 1973).

6.2 Methods

6.2.1 Sample collection and preparation

The modern pollen sites investigated were sampled from the three dominant vegetation formations in the Fleurieu Peninsula; dry sclerophyll forest, dry sclerophyll scrub and grassy woodland. Sites were located on a range of vegetation types, having different dominant overstorey or combinations of dominant overstorey species, from within these formation types. The sclerophyll forest and scrub types, as classified, named and used as mapping units in the DENR (1988) floristic and structural community classification of the remnant vegetation in the region were;

E. obliqua dry sclerophyll open forest,
E. obliqua - *E. fasciculosa* dry sclerophyll open forest,
E. obliqua semi-sclerophyllous woodland,
E. fasciculosa - *E. leucoxylon* semi-sclerophyllous woodland
E. fasciculosa - *Callitris pressei* semi-sclerophyllous woodland,
E. obliqua - *E. baxteri* - *E. cosmophylla* low sclerophyll woodland,
E. fasciculosa very low dry sclerophyll woodland and
E. baxteri - *E. cosmophylla* low sclerophyll woodland.

The species used to describe the community were the dominant *Eucalyptus* species found at all sites except for the site mapped by DENR (1988) as *E. fasciculosa* very low dry sclerophyll woodland. This site was instead was dominated by *E. cosmophylla.* The descriptions of vegetation types used through this chapter relate to the dominant species present in the ten meters surveyed around the collection site. The DENR classes are derived from numerous survey sites within the mapping units so provide a useful indicator of the vegetation mix around sample sites.

The grassy woodlands have been highly impacted by European land use practices in the region so that only scattered native overstorey species with understoreys of introduced pasture grasses and weeds remain. Moss polster samples were collected from agricultural paddocks supporting tall and scattered *E. leucoxylon* and *E. leucoxylon* - *E. fasciculosa* trees. These areas possibly once supported these species with native grassy and open shrub understoreys.

A total of 12 moss polster samples were collected and 3 swamp surface samples. The location of the modern pollen sites is shown in Figure 6. 1. In most cases, single samples of community types were taken and as such results from these samples are indicative only. Where possible several polsters of different moss species, and from different areas of the plot, were taken and combined for processing. This approach was intended to reduce bias from differential entrapment of pollen taxa by mosses of differing growth form (Boyd, 1986) and for reduction of the influence of factors such as seasonal fluctuations in pollen abundance and relative pollen quantities. At each site the dominant overstorey and understorey taxa were recorded in a ten metre radius around the collection site. The location, sample type, vegetation formation and DENR floristic and structural community classification, and common species occurring around the sites are given in Table 6. 1.

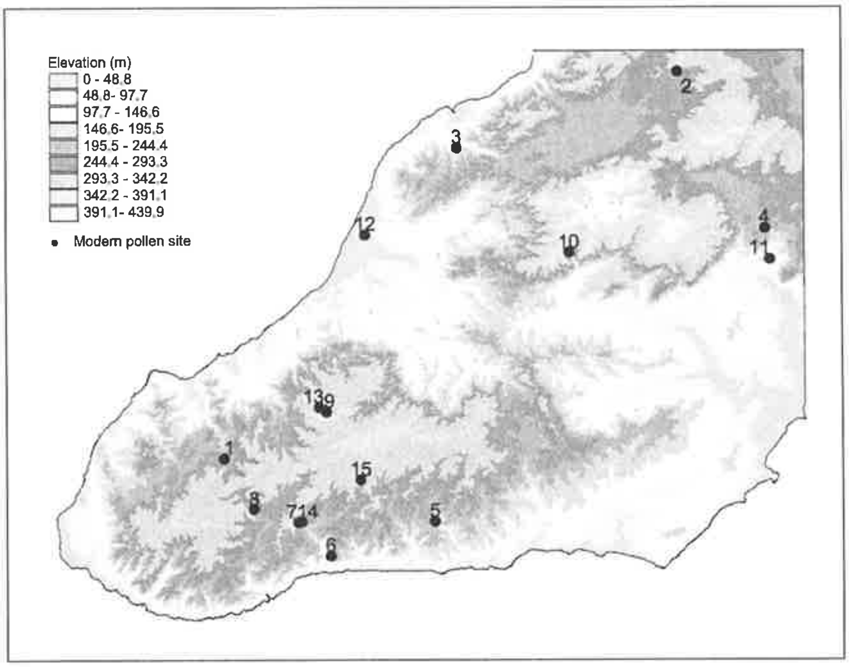


Figure 6. 1 The location of modern pollen collection sites on the Fleurieu Peninsula and extant remnant vegetation communities as defined and mapped by DENR (1988)

The moss polster and swamp surface samples were processed using standard pollen extraction and processing techniques (Faegri and Iverson, 1989 and described in Appendix 5). Samples were first soaked overnight in a 5% solution of Calgene, then soaked overnight in 10% KOH solution followed by a final overnight treatment in hydrofluoric acid (HF). Following the HF treatment samples were subjected to standard acetolysis treatment and mounted in glycerine jelly. The samples were counted under x 400 magnification with a Zeiss photo-microscope with a pan-apochromatic objective lens. Pollen and spores were identified throughout this study with the aid of a reference collection of modern pollen and spore types held at the Department of Archaeology and Natural History, Australian National University. Additional reference materials were prepared from staminate material collected from flowering material or from collections at the Herbarium of South Australia. Results from the morphological study of the dominant Myrtaceae species in the region (Appendix 4) were used to class Myrtaceae grains.

Where possible at least 200 native pollen grains were counted per slide. The actual numbers counted averaged 302 grains, with a range from 88 to 447 grains per slide. Pollen derived from native taxa accounted for an average of 201 grains per slide with a range from 50 to 335 grains. A total of 69 taxa were recognised and 11 of these were determined to be from non-native introductions. A range of 16 to 396 (mean 101.4) exotic pollen grains were present per sample. Pollen types are described in Appendix 6.

The pollen sum used to interpret fossil pollen assemblages was based on the native taxa to allow for the comparison with Holocene fossil assemblages. Exotic pollen was excluded from the sum so that the native pollen signals were not diminished by the high abundances of exotic types such as *Asteraceae* and *Pinus*. Indeterminant and unknown taxa were included in the pollen sum. Cyperaceae from the moss polster samples were included in the pollen sum as in this region, they generally represent terrestrial vegetation. The pollen types identified in moss polster pollen, their ecological groupings and information on their distribution or habitat in the Fleurieu Peninsula, is given in Table 6. 2.

Table 6. 1 Modern pollen samples: sample identification number, sample type (MP = moss polster, SS = surface sample), vegetation formation, vegetation classification if the site was located in a patch of mapped remnant vegetation (DENR, 1988), and the dominant tree and understorey taxa in a 10 metre radius around the collection site. Grid references are from 1: 25000 topographic maps; T, 6526-1-N Torrens Vale, C, Cape Jervis 6526-N; Y, Yankalilla South 6527-2-S.

ID	Type	Location (lat, long, nearest landmark)	Vegetation formation	Floristic Class (DENR, 1988)	Dominant tree taxa	Dominant shrub and understorey taxa
1	MP	6059856 247051 Delamere	Open woodland (grazing land)	-	*E. leucoxylon*	Introduced grasses
2	MP	276631 6084666 Myponga	Open woodland (grazing land)	-	*E. fasciculosa* *E. leucoxylon*	Introduced grasses, legumes, *Taraxacum, Acacia melanoxylon*
3	MP	262517 6079787 Myponga Beach Road	Open woodland (Grazing land)	-	*E. fasciculosa* *E. leucoxylon*	Introduced grass and weed understorey of *Taraxacum* sp., and rye grass. Nearby in small strip on roadside: *Xanthorrhoea semiplana, Platylobium obtusangulum, Dianella revoluta,, Allocasuarina verticillata, Sparaxis* sp.*
4	MP	282242 6074641 Mount Billy	Sclerophyll scrub	*E. baxteri* - *E. cosmophylla* low woodland Community 19	*E. baxteri* *E. cosmophylla*	*Xanthorrhoea semiplana , Banksia ornata, B. marginata, Hypolaeana fastigata, Pteridium esculentum, Leptospermum myrsinoides, Isopogon ceratophyllus, Lepidosperma semiteres*
5	MP	6055751 261002 Tunk Head Road	Sclerophyll scrub	*E. baxteri* - *E. cosmophylla* - *E. obliqua* low woodland Community 18	*E. baxteri* *E. cosmophylla* *E. obliqua*	*Banksia marginata, Spyridium thymifolium, Pultenaea involucrata, Epacris impressa, Leptospermum myrsinoides, Hibbertia riparia, Danthonia* sp., *Xanthorrhoea semiplana.*
6	MP	2534455 6053527 Boat Harbour Road	Sclerophyll scrub	*E. fasciculosa* low woodland Community 10	*E. cosmophylla* *E. fasciculosa* *Allocasuarina verticillata*	*Isopogon ceratophyllus, Hakea rostrata, Dillwynia hispida, Spyridium thymifolium, Hibbertia sericea, Xanthorrhoea semiplana, Gonocarpus* spp., *Pultenaea largiflorens*
7	MP	252269 605570 Deep Creek Conservation Park	Sclerophyll open forest	*E. obliqua* – *E. fasciculosa* open forest Community 16	*E. obliqua*	*Acacia myrtifolia, Pultenaea daphnoides, Pteridium esculentum, Drosera whittakeri, Hibbertia exutiacies, Spyridium thymifolium, Billardiera bignoniaceae, Xanthorrhoea semiplana.*

ID	Type	Location (lat, long, nearest landmark)	Vegetation formation	Floristic Class (DENR, 1988)	Dominant tree taxa	Dominant shrub and understorey taxa
8	MP	249456 6056569 Raywood	Sclerophyll open forest	*E .obliqua - E. baxteri* tall open forest Community 17	*E. obliqua*	*Xanthorrhoea semiplana, Pultenaea daphnoides Lepidosperma semiteres, Pteridium esculentum, Hibbertia riparia, Hakea rostrata, Acacia myrtifolia, Daviesia leptophylla, Goodenia ovata, Acrotriche serrulata*
9	MP	254105 6062836 Springs Road	Sclerophyll open forest	*E. obliqua-E. baxteri* open forest Community 17	*E. obliqua* *E. baxteri*	*Hakea rostrata, Allocasuarina striata, Xanthorrhoea semiplana, Pultenaea involucrata, P. daphnoides, Banksia ornata, Tetratheca pilosa, Spyridium thymifolium, Banksia marginata, Isopogon ceratophyllus*
10	MP	269674 6073070 Town Hill	Sclerophyll Woodland	*E. obliqua* woodland Community 14	*E. obliqua*	*Pultenaea daphnoides, Hibbertia* sp., *Stipa* sp., *Danthonia* sp., *Xanthorrhoea, Acacia myrsinoides*
11	MP	282527 6072629 Mount Billy- Open forest	Sclerophyll Woodland	*E. fasciculosa - E. leucoxylon* woodland Community 36	*E. fasciculosa* *E. leucoxylon*	*Acacia pycnantha, A. paradoxa, Leptospermum myrsinoides, Chamescilla* sp. *Glossidia major, Dianella revoluta, Hibbertia exutiacies, Cheilanthes austrotenuifolia, Astroloma humifusum, Gonocarpus tetragynus*
12	MP	256 654 6074212 Yankalilla - Jervois St	Sclerophyll scrub	*E. fasciculosa Callitris* open woodland Community 8	*E. fasciculosa* *Allocasuarina verticillata*	*Callitris preissii, Briza* sp., *Hibberia riparia, Dodonaea viscosa, Acacia rupicola, A. pycnantha, Olearia* sp.
13	SS	253663 6063137 Springs Road	Sclerophyll open forest	*E. obliqua – E. baxteri* open forest Community 17	*E. obliqua* *E. ovata*	*Acacia myrtifolia, Olearia* sp., *Epacris impressa, Hakea rostrata, Pultenaea daphnoides, Thysanotis patersonii, Stylidium graminifolium, Stackhousia aspericocca, Stipa* sp., *Hibbertia riparia*
14	SS	252496 6055740 Deep Creek Tapanappa	Sclerophyll open forest	*E. obliqua – E. baxteri* open forest Community 17	*E. obliqua* *E. ovata*	*Goodenia ovata, Acacia myrtifolia, Olearia ramulosa, Poa* sp., *Pteridium esculentum, Gonocarpus tetragynus, Billardieria bignoniaceae*
15	SS	256306 6058442 Boat Harbour Creek	Swamp in Grazing land	-	*E. ovata*	Swamp is fringed by *Acacia retinoides* and *Leptospermum spp.* and surrounded by introduced rye grasses and leguminous pasture species

Table 6. 2 Pollen types identified in moss polster pollen spectra analysis. Ecological groupings T= tree; S=Shrub; H= herb are given for each pollen type. Two ecological groupings are denoted for some types where the members of the class have variable habit. The first listed group was used in the pollen sum. The distribution data has been gathered from DENR species and abundance lists (DENR, 1988); Dashorst and Jessop (1990), Boomsma (1981). E.ob=*E. obliqua* E.ba= *E. baxteri*, E.fa = *E. fasciculosa*, E.co = *E. cosmophylla* E.leu = *E. leuxoxylon* GW= grassy woodland, SW = Sclerophyll woodland.

Pollen Taxon	Family	Ecological group	Distribution notes; DENR Communities in which taxon are major components
Allocasuarina <28μm	Allocasuarinaceae	T	Rocky sites and mixed or single species stands in grassy woodands
Allocasuarina >28μm	Allocasuarinaceae	T/S	*A. striata* is common understorey in E.ob-E.ba-E.co low woodland; E.fa E.leu low woodland
E. baxteri type	Myrtaceae	T	E.ob-E.ba-E.co low woodland; E.ob-E.ba open forest; E.ba-E.co low woodland
E. cosmophylla type	Myrtaceae	T	Ranges on acid, leached or infertile soils; E.ob-E.ba-E.co low woodland; E.ba-E.co low woodland; E.fa E.co-E.ob low open woodland
E .fasciculosa type	Myrtaceae	T	Ranges and foothills; E. fasciculosa very low woodland; E.fa E.leu low woodland- MB; E.fa E.leu low woodland-DC; E.fa E.co-E.ob low open woodland
E. leucoxylon type	Myrtaceae	T	Ranges, foothills and plains; E.fa E.leu low woodland- MB; E.fa E.leu low woodland-DC; E.fa E.co-E.ob low open woodland
E. obliqua type	Myrtaceae	T	Predominantly ranges; E.ob-E.ba-E.co low woodland; E.ob-E.ba open forest; E.fa E.co-E.ob low open woodland
Banksia marginata	Proteaceae	T	Tree or shrub; major component of sclerophyllous understorey. E.ob-E.ba-E.co low woodland E.ob-E.ba open forest; E.ba-E.co low woodland
Banksia ornata	Proteaceae	T	Tree or shrub; E.ba-E.co low woodland
Acacia 2 (8 poly)	Fabaceae	T/S	Either *A. myrtifolia* or *A. paradoxa.*- E.ob-E.ba open forest; E.ba-E.co low woodland. *A. paradoxa*; forest to mallee
Acacia 3 (16 poly- large)	Fabaceae	T	Probably *A. pycnantha;* woodlands and forests
Amyema preissii	Loranthaceae		Parasite; host plant usually *Acacia*
Callitris preissii	Cupressaceae	T	Widespread
Exocarpus cupressiformis	Santalaceae	T	Widespread- parasitic .. E.fa E.leu low woodland- MB
Hakea spp.	Proteaceae	T	Three species in region; *H carinata* and *H. rostrata* are common as sclerophyllous understorey; E.ob-E.ba-E.co low woodland; E.ob-E.ba open forest; E.fa very low woodland; E.ba-E.co low woodland; E.fa E. cosmophylla-E.ob low open woodland
Leptospermum myrsinoides	Myrtaceae	S	E.ob-E.ba-E.co low woodland; E.fa very low woodland; E.ba-E.co low woodland. E.fa E. cosmophylla-E.ob low open woodland
Melaleuca sp.	Myrtaceae	T/S	
Xanthorrhoea semiplana	Liliaceae	S	Widespread sclerophyllous understorey; B-E.ba-E. cosmophylla low woodland; E.ob-E.ba open forest; E.fa very low woodland; E.ba-E.co low woodland; E.fa E.leu low woodland- MB; E.fa E.leu low woodland-Deep Creek Tapanappa
Bursaria spinosa	Pittosporaceae	S/T	E.fa E.leu low woodland- MB E.fa E.co-E.ob low open woodland
Calytrix tetragona	Myrtaceae	S	E.ba-E.co low woodland E.fa E.leu low woodland-Deep Creek Tapanappa
Chenopod <20μm	Chenopodiaceae	S	Without local distribution
Chenopod >20μm	Chenopodiaceae	S	
Comesperma	Polygalaceae	S	Probably *C. calymega*; small milkwort
Correa reflexa	Rutaceae	S	Understorey shrub; E.ba -E.co low woodland
Dodonaea	Sapindaceae	S	Probably *D. viscosa* (most widespread sp.) shrub; E.fa E.leu low woodland- MB; E.fa E.leu low woodland-Deep Creek

Pollen Taxon	Family	Ecological group	Distribution notes; DENR Communities in which taxon are major components
			Tapanappa
Leucopogon spp.	Epacridaceae	S	Sclerophyllous understorey species
Acrotriche/Epacris type	Epacridaceae	S	Sclerophyllous understorey species E.ob-E.ba-E.co low woodland; E.ob-E. baxteri open forest; E.fa very low woodland; E.ba-E.co low woodland; E.fa E.co-E.ob low open woodland
Astroloma type	Epacridaceae	S	Sclerophyllous understorey species; E.fa very low woodland; E.ba-E.co low woodland; E.fa E.leu low woodland- MB; E.fa E.leu low woodland-DC; E.fa E.co-E.ob low open woodland
Gyrostemon australasicus	Gyrostemonaceae	S	
Lamiaceae		H	
Fabaceae 1	Fabaceae	S/H	There are 18 genera in the family. They occur as shrubs and herbs through the GW and SW formations
Fabaceae 2	Fabaceae	S/H	
Fabaceae 3	Fabaceae	S/H	
Fabaceae 4	Fabaceae	S/H	
Fabaceae M1	Fabaceae	S/H	
Fabaceae M2	Fabaceae	S/H	
Polygonaceae-Muellen?		S	Lignums;
Spyridium spp.	Rhamnaceae	S	Common scleropyllous understorey; E.ob-E.ba-E. cosmophylla low woodland; E.ob-E.ba open forest; E.fa very low woodland; E.fa E.co-E.ob low open woodland
Apiaceae		H/S	Seven genera and 10 species in region along Ranges and plains
Asteraceae T1		H	Well represented family of herbs; Twenty one native genera and 35 species. Very widespread in sclerophyllous and savannah woodland communities as understorey herbs
Asteraceae T2		H	
Asteraceae T3		H	
Asteraceae T4		H	Probably introduced herb;
Asteraceae-*Cirsium* type		H	Agricultural weed
Cyperaceae-*Lepidosperma* type		H	Rush; E.ob-E.ba-E.co low woodland; E.ob-E.ba open forest; E.fa very low woodland; E.ba-E. cosmophylla low woodland
Empodisma minus	Restionaceae	H	Rush-
Euphorbiaceae (unk11)		S	Possibly *Micrantheum demissium* which is a small coastal shrub.
Gonocarpus spp.	Haloragaceae		Probably *G. mezianus*; Stringy Bark -E.ba open forest E.fa very low woodland; E.fa E.leu low woodland-DC; E.fa E.co-E.ob low open woodland
Goodenia 2	Goodeniaceae	H	Herbs of woodlands and sclerophyllous communities; E.ob-E.ba-E.co low woodland; E.ob-E.ba open forest; E.fa very low woodland
Hibbertia spp.	Dillenaceae	H	E.ob-E.ba open forest; E.ba-E.co low woodland E.fa E.leu low woodland- MB; E.fa E.leu low woodland-DC; E.fa E.co-E.ob low open woodland
Liliaceae1- *Lomandra* type		H	E.fa very low woodland; E.fa E.leu low woodland- MB; E.fa E.co-E.ob low open woodland; E.ob-E.ba-E.co low woodland; E.ob-E.ba open forest; E.ba-E.co low woodland
Liliaceae3		H	
Plantago lanceolata	Plantaginaceae	H	Agricultural weed
Poaceae-barley		H	Introduced
Poaceae<20um		H	Possibly native
Poaceae20-30um		H	Possibly native

In many cases the pollen produced by native and introduced Poaceae species is indistinguishable at the level of magnification used in this study. However size has been used as an approximate measure to distinguish between native and exotic Poaceae types, with the larger size grains being attributed to those from plants with non-native origins (McPhail, pers.comm.). In this instance Poaceae grains with a diameter greater than 30μm were excluded from the native pollen sum, although it was possible that a number of grains with diameters greater than 30μm could have been produced by native plant species.

A constrained incremental cluster analysis was performed on the percentage data using the Tilia2 (Grimm, 1991) sub-program CONISS. The percentage data was transformed using a square root transformation (Edwards and Cavalli Sforza's chord distance) and results were viewed graphically in the form of a dendrogram showing relationships between samples.

In addition the distinctiveness of pollen signatures investigated was viewed by using the ordination technique, Principal Components Analysis (PCA). Ordination is an attempt to reflect similarities between communities by defining them in meaningful spatial patterns by the best fitting plane through a multi-dimensional species space. Results from the analysis are plotted on a 2 or 3 dimensional plane and nearby points have similar communities and points far apart have few species in common or the same species at different levels of abundance. PCA was used in this chapter and later in Chapter 8 to summarise information contained in detailed pollen diagrams and present relationships between modern and fossil samples in an easily interpretable format. The method uses a square root transformation of the data to reduce the influence of over represented taxa. The resultant data set of eigenvalues are displayed as biplots on the first and second axes. Only taxa with a value of more than 5% in at least one sample were analysed in the PCA analysis.

Pollen percentage diagrams and PCA analysis were implemented within the PSIMPOLL program developed by Bennett (1993) for plotting and analysing pollen data.

6.3 Results

The pollen taxa from samples 1-15 are presented in Figure 6. 2 as relative percentages of the native pollen sum. It can be seen from these spectra that most pollen types occur only in low numbers, with only approximately one quarter of the taxa identified present at a value of 5% in at least one sample. Samples have been ordered with those with a value of 5% in at least one sample appearing first and taxa with more minor representation following. Comparison of the dominant species around modern pollen

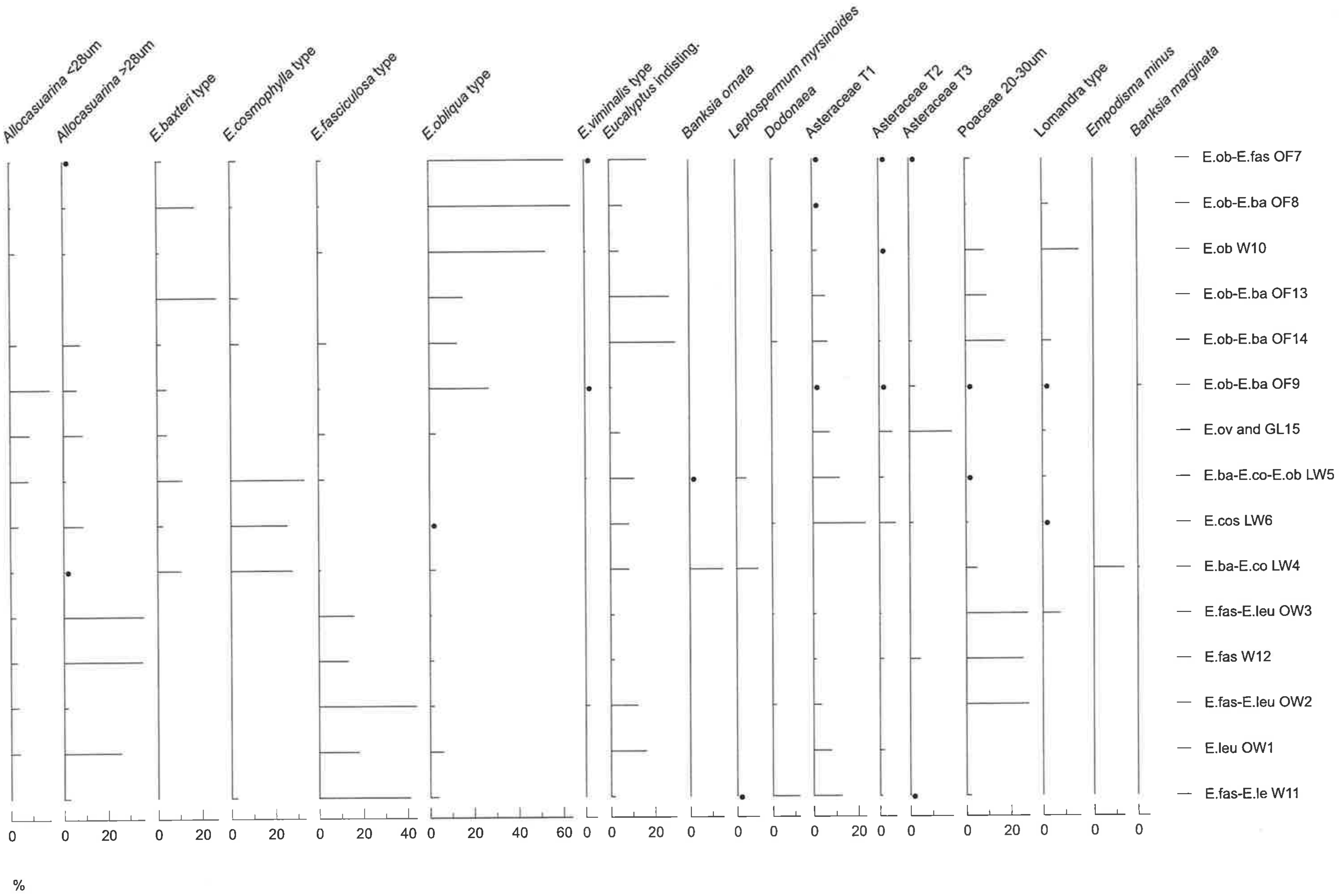
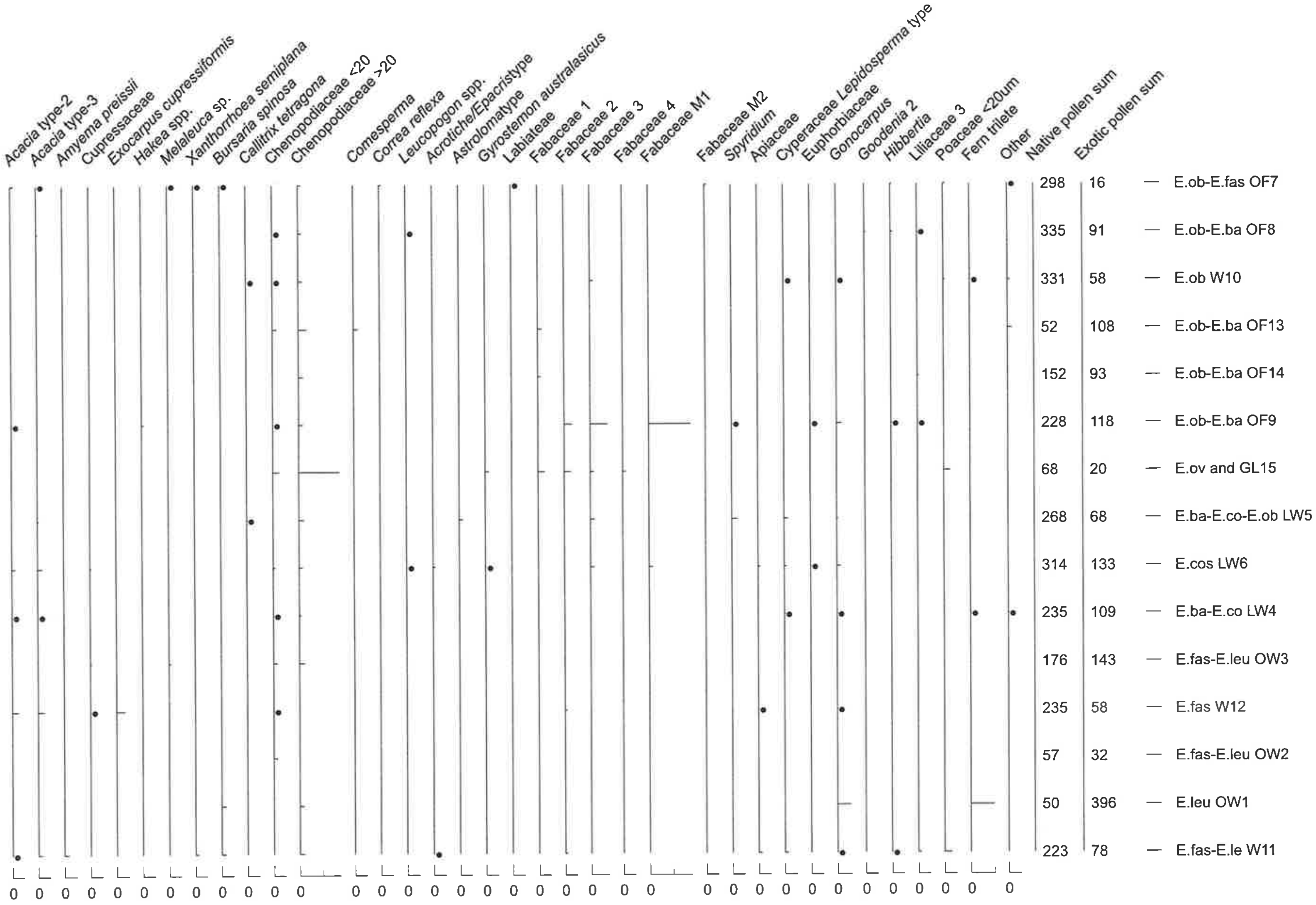


Figure 6.2 The pollen spectra from moss polster and modern sediment samples. Counts are expressed as percentages of the native pollen sum.



%Figure 6.2 The pollen spectra from moss polster and modern sediment samples. Counts expressed as percentages of the native pollen sum.

collection sites with pollen taxa present shows that many species are not represented in the pollen spectra, and this is likely to be due to low production and or low dispersal of pollen from the vegetation. Despite this, comparison of spectra from similar vegetation communities shows that similarities of pollen representation within formation types is seen and that some signatures are possibly distinctive enough to define community types within formations.

Modern samples in the pollen diagram were ordered according to the divisions produced by cluster analysis. The dendrogram produced by the cluster analysis, showing relative similarities of samples to each other, is given in Figure 6. 3.

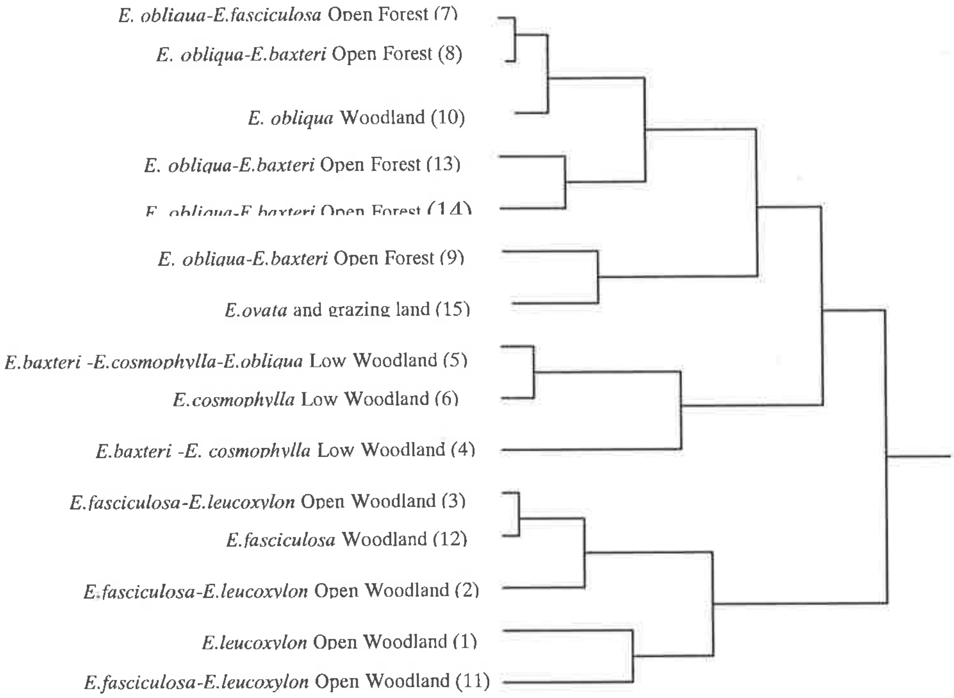


Figure 6. 3 The classification of modern pollen samples using CONISS.

Similarity of samples was also examined through PCA analysis. Axis 1 and 2 of the PCA analysis explained 50.7% of the original variability in the data set and axis3 contributed another 15% (Table 6. 3).

Table 6. 3 Results of PCA analysis. The proportion of variation in the modern pollen spectra explained by axes. Axes marked with * are considered to be significant in explaining variation.

Axis	Value	Proportion	Cum. prop.
1	0.133	0.289*	0.289
2	0.100	0.218*	0.507
3	0.067	0.146*	0.653
4	0.039	0.085	0.739
5	0.031	0.067	0.806
6	0.022	0.048	0.854

After inspection of the third axis plots it is apparent that the first two axes adequately illustrated relationships between samples. Samples are displayed on these axes as a bi-plot (Figure 6. 4). The vectors for principal taxa leading to the sample plots values in the PCA analysis are shown in Figure 6. 5. The first component (axis1) is driven by high positive values for *E. fasciculosa* type, *Allocasuarina* <28μm and Poaceae <30μm and high negative values for *E. obliqua* type and *E. baxteri* type reflecting the difference between open woodland and sclerophyll forest conditions. The second component (axis 2) is defined by high negative loadings for *E. cosmophylla* type, moderately high values for Asteraceae and high positive values for *E. obliqua* type, reflecting the less distinctive but still apparent separation of forest and scrub communities.

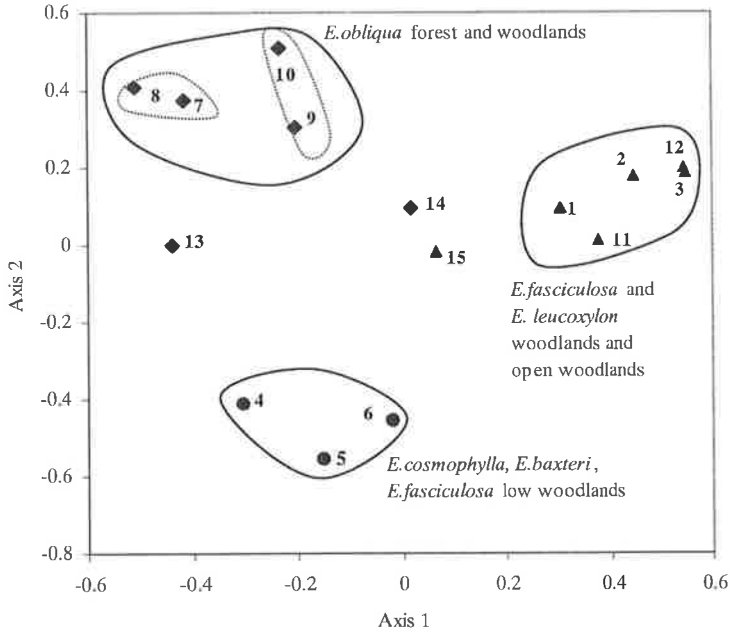


Figure 6. 4 Principal Components Analysis (PCA) biplots for samples in the modern pollen data set. Eigenvalues are expressed as proportions of the total variation with the bi-plot centred on the origin. Sample numbers relate to those used in Figure 6.3.

Both PCA and the cluster analyses group samples into formation categories and then indicate the presence of sub-categories within formation groups. The first division of the cluster analysis separated the *E. fasciculosa* and/or *E. leucoxylon* dominated open woodlands (2 and 3), low woodland (12) and woodland formations (11) from the rest. The second division separated the low woodlands containing *E. cosmophylla* in combination with *E. fasciculosa* and/or *E. baxteri* (4, 5 and 6) from *E. obliqua* containing open forests (7,8,9, 13 and 14), *E. obliqua* woodland (10) and *E. ovata* and grazing land (15). Formation categories are seen as loose but distinctive clusters on the PCA plot (Figure 6. 4). The pollen characteristics of distinctive groups are described below.

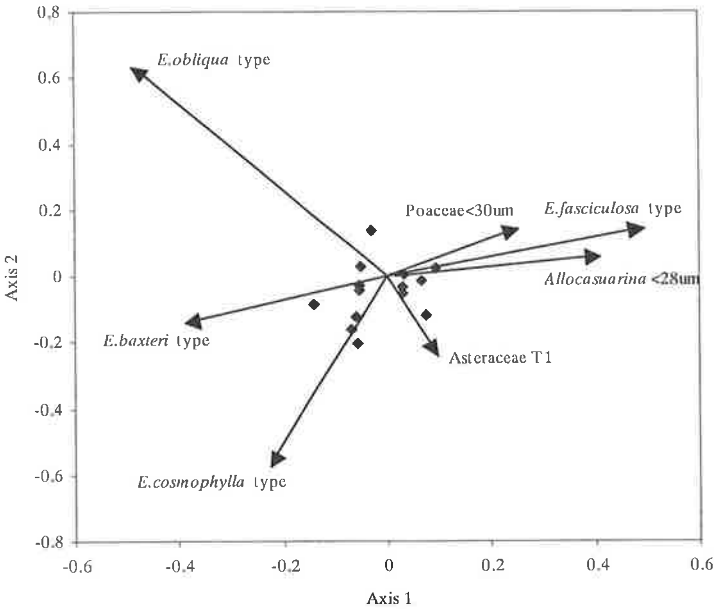


Figure 6. 5 Principal Components Analysis (PCA) biplots for taxa in the modern pollen data set. Only taxa accounting for the most variation in spectra (that is with the most distinctive eigenvectors) are labelled.

6.3.1 E. obliqua open forests and woodlands with sclerophyllous understoreys

Pollen assemblages 7, 8, 9 and 10 were derived from moss polster samples, and 13 and 14 from surface samples. These were taken from communities dominated by *E. obliqua* in pure stands or with *E. baxteri*. These species clearly dominate the pollen rain. Despite their grouping in the cluster analysis, sites are only grouped loosely in the PCA analysis with the moss polster samples of *E. obliqua* ± *E. fasciculosa* open forest forming one sub-cluster and the surface samples *E. obliqua* open forest 14 and 15 another.

6.3.1.1 *E. obliqua* open forest - moss polsters, sites 7 and 8

Sites 7 and 8, both collected from the southern Fleurieu Peninsula from *E. obliqua* dominated stands, have the most similar pollen assemblages. *Eucalyptus* pollen comprises an average of 90% of the pollen present and *E. obliqua* type pollen accounting for most of that value; averaging 62% of the sum. *Eucalyptus baxteri* type pollen is present in varying frequencies in the two samples, only 2% at the Deep Creek site 7 and 17% at the Raywood site 8. A small amount of the tree pollen is from *Allocasuarina* and *Acacia* species (1 - 2.4% and 0.6 - 1.9% respectively). The remaining ~10% of the pollen sum is comprised mainly of Asteraceae, Tubuliflorae type (5 to 9%), Poaceae (0.6 to 2%) Chenopodiaceae (1.3 to 1.8%) and in site 8, Liliaceae (3%). The understorey of sclerophyllous shrubs and herbs which are predominantly in the Epacridaceae, Fabaceae and Asteraceae families were not represented in the pollen spectra.

6.3.1.2 *E. obliqua* open forest - moss polsters, site 9

The Springs Road moss polster sample (9), also from *E. obliqua* - *E. baxteri* open forest, was grouped in the *E. obliqua* cluster. However it shows greater similarity to the surface samples from *E. obliqua* open forest than the moss polster samples from those communities. In the spectra from this site *E. obliqua* is still present in relatively high amounts (26% of the sum) however *Allocasuarina* pollen, predominantly of the smaller grained type, is present at almost the same frequency. *Allocasuarina striata* is well represented as a component of the local understorey at this site. The frequency of shrub pollen represented in the spectra was significantly higher than in the other *E.obliqua* sites, totalling 32% of the sum. Most of it is derived from Fabaceae species. The herb component was composed of pollen from Liliaceae (1%), Gonocarpus (2%), Chenopodiaceae (2%) and Asteraceae (3.4%).

6.3.1.3 *E. obliqua (+ E. ovata)* open forest - surface samples, sites 13 and 14.

Sites 13 and 14 were similarly from *E. obliqua* and *E. baxteri* dominated open sclerophyll forests however they were surface samples rather than moss polsters. While *Eucalyptus* pollen still dominates, the signature *E. obliqua* dominance is not so clear as with the moss polster sites. An average of 27% of the pollen was identifiably of *Eucalyptus* origin, however degradation prevented identification to type. *Allocasuarina* pollen comprised 11% of the Deep Creek sample but was absent from the Springs Road sample. Herbs comprised 30% of the Deep Creek sum and 15% of the Springs Road sum and were mainly from the families of Asteraceae (average of 6.5%), Poaceae (an average of 14%), and Liliaceae in the Deep Creek site only (4.6%). As with the moss polster sites, the shrub components of the vegetation were poorly represented in the spectra, comprising 9.6% of the Springs Road site and 6% of the Deep Creek site. Half of the pollen from shrubs in the Springs Road site was from Chenopodiaceae and is not likely to be of local origin.

6.3.1.4 *E. obliqua* woodland, site 10

Site 10 was from a northerly located *E. obliqua* dominated stand with a more open herbaceous understorey than that which characterised the southern sites. Its pollen spectra was similar to that of the southern *E. obliqua* open forest sites, with the main difference being a higher representation of pollen derived from herbaceous species. *E. obliqua* type pollen accounted for 52% of the pollen sum and herbaceous pollen, predominantly Liliaceae and Poaceae, 29% with small amounts of *Gonocarpus* and *Lepidosperma* (each 0.3%). A small amount of pollen from shrub species was found; Fabaceae 1.5% and *Dodonaea* 0.9 %.

6.3.1.5 *E. ovata* in cleared agricultural land, site 15

The cluster analysis groups a surface sample from Boat Harbour Creek with the larger *E. obliqua* division. Low counts of terrestrial pollen were obtained in this sample (only 68 grains of native origin) so percentages must be viewed with caution. Unlike other spectra in the grouping tree, shrub and herb pollen is present in almost equal proportions. Here *Allocasuarina* (17%) and *Eucalyptus* types (15%) dominate the tree proportion, Chenopodiaceae (20%) and Fabaceae dominate the shrub component and

Tubuliflorae type-Asteraceae (32%) dominate the herb proportion. *Allocasuarina*, *Eucalyptus* and Chenopodiaceae are probably representing the regional pollen rain from both aerial and waterborne sources.

6.3.2 E. cosmophylla - E. baxteri - E. fasciculosa *very low woodlands- 'scrubs'*

Modern pollen spectra from the *E. cosmophylla - E. baxteri - E. fasciculosa* low woodland, 'scrubs', form a reasonably discrete and tight groups in both the PCA and cluster analysis. Sites 5 and 6 are the most similar to each other and are discussed together. Site 4, *E. baxteri - E. cosmophylla* low woodland, is described separately.

6.3.2.1 *E. cosmophylla - E. baxteri - E. obliqua* very low woodland, site 5 and *E. cosmophylla* very low woodland site 6

E. cosmophylla is the predominant overstorey species represented in the pollen spectra from sites 5 and 6 (33% and 54% respectively). *Eucalyptus baxteri* type is also present accounting for 11% of the sum in site 5 and 2.5% in site 6. *Allocasuarina* <28μm pollen, probably mostly derived from *A. striata*, a dominant component of the communities' understorey, contributed to 10% and 3% of the sums of sites 5 and 6 respectively. The larger grained *Allocasuarina* was also present in both spectra, in trace amounts in site 5 but in greater amounts (13%) in site 6. *Leptospermum myrsinoides* accounted for 4% of the pollen rain at site 5 but was absent from site 6. As with the forest communities, the shrub component of the vegetation was not well represented in the pollen spectra with only small amounts of Epacridaceae (1.5%), Fabaceae (2%), *Acacia* sp. (1%) and *Spyridium* sp. (2.6%) noted. The herb components were higher than seen in the spectra from the *E. obliqua* communities (18% of all types for site 5 and 37% for site 6) largely due to an increase in the representation of Tubuliflorae-type Asteraceae pollen (Asteraceae type T1 and T2) and less than 5% of *Gonocarpus* and Cyperaceae-*Lepidosperma* type.

6.3.2.2 *E. cosmophylla - E. baxteri* - site 4

The pollen spectrum of this community, as represented in moss sample 4, is dominated by tree species (78%), with members of the Myrtaceae family, most notably *E. cosmophylla* (28%), *E. baxteri* (11%) and *Leptospermum myrsinoides* (10%), accounting for the greatest proportion of tree types. High numbers of Proteaceae pollen occur in this sample; *Banksia ornata* (15%) and *Hakea* spp.(10%). Shrub type and *A. verticillata* type *Allocasuarina* pollen was only present in trace amounts. The herb pollen component of the spectrum (20%) is comprised of the Restionaceous rush *Empodisma minus* (14%), which was prevalent in the vegetation, Tubuliflorae type-Asteraceae (3%) and Poaceae pollen (7%).

6.3.3 E. leucoxylon - E. fasciculosa *open woodland and woodland types*

The cluster and PCA analysis reveal similar relationships within this reasonably tight group. *Eucalyptus fasciculosa - E. leucoxylon* open woodland with modified understorey (site 3) and *E. fasciculosa* low woodland (site 12) are most similar to each other. *Eucalyptus leucoxylon* open woodland with modified understorey (site 1) and *E. fasciculosa - E. leucoxylon* woodland (site 11) are also closely grouped. *E. fasciculosa-E. leucoxylon* open woodland with modified understorey (site 2) is situated between the two sub-clusters. The wide range of structural and floristic vegetation types responsible for these spectra have been largely unified due to their high levels of *E. fasciculosa* type pollen, which includes *E. leucoxylon*, and in some cases, high levels of *Allocasuarina* >28μm type pollen.

6.3.3.1 *E. fasciculosa - E. leucoxylon* woodland-site 11

Tree pollen accounted for 57% of the pollen sum in this community, shrub pollen 19% and the remainder was derived from herbaceous species. *Eucalyptus leucoxylon* and *E. fasciculosa* (42%) type pollen are the most abundant tree types. *Allocasuarina* pollen is present in low numbers only. *Dodonaea* pollen constitutes most of the shrub component. Various Tubuliflorae-type Asteraceae pollens account for most of the herb sum, with only small percentages of Poaceae (5%), Cyperaceae (1%) and Liliaceae pollen (1%) being present.

6.3.3.2 *E. fasciculosa* woodland, site 12

The most abundant taxon represented in the pollen sum for this community was *Allocasuarina* >28μm type pollen, amounting to 38% of the total sum. Other tree species represented were *E. fasciculosa* (13%), *E. obliqua* (2%), *Acacia spp.* (5%) and *Exocarpos cupressiformis* (4%). Shrub species were barely represented in the spectrum (1%), yet pollen from herbaceous types was quite well represented with Poaceae 20-30μm pollen comprising 25% and various Tubuliflorae-type Asteraceae pollen 8% of the sum.

6.3.3.3 *E. leucoxylon* open woodland - *E. fasciculosa* and *E. leucoxylon* open woodland (understories modified), sites 1, 2 and 3.

There are no intact examples of savannah woodland communities in the region but dominant overstorey species remain as isolated trees. The original native understoreys have been completely replaced with introduced weeds and agricultural species. The pollen counts were dominated by introduced taxa and native pollen counts were low (50 and 57) in samples 1 and 2. Pollen from tree species dominated the native sums accounting for an average of 65% of all types. At all sites *Eucalyptus* spp. were the dominant overstorey tree type, however Eucalyptus pollen only dominated the pollen spectra of site 2, where *E. fasciculosa* pollen was the most abundant type (43%). The tree component of the spectra of sites 1 and 3 were dominated by *Allocasuarina* pollen (34%) and *E. fasciculosa* type, (derived from *E. leucoxylon* and/or *E. fasciculosa)* counted for approximately 15% of the total sum. Shrubs were poorly represented in pollen spectra from all open woodland sites. The non-tree component of pollen sums was mostly composed of Poaceae (an average of 27% sites 2 and 3 but absent from site 1), Liliaceae and native Tubuliflorae-type Asteraceae pollen. The Poaceae percentages must be viewed with caution due to the partially arbitrary nature of the size class separation applied to separate native species derived types from non-native.

6.4 Discussion

While this study did not attempt to correlate the relative abundances of components of the local vegetation and the relative abundances of their pollen spectra, general relationships can be determined. This study clearly demonstrates that the majority of taxa in the Fleurieu Peninsula are under-represented in the pollen rain and have local distribution only. That is they may be at or near a sampling site but are absent, or poorly represented, in the pollen spectrum. Where their representation is high it is due to a proximally-located parent plant. Many of the native taxa contributed no pollen to the pollen rain. This finding is in accordance with other studies of pollen distribution from sclerophyllous communities in Australia (see Dodson, 1983 for a summary). Taxa which were well represented to over-represented are *Allocasuarina* spp. and *Eucalyptus* sp., *Dodonaea* spp., *Empodisma minus*, *Pinus* and members of both the Tubuliflorae and Liguliflorae-types of Asteraceae.

The presence of a pollen type in a modern sample but the absence of that taxon in the local vegetation indicates the regional dispersion of the pollen of that species. Regional pollen acts to dull the relationship between pollen and vegetation assemblages at a site. As widely recorded in other pollen studies Chenopodiaceae and *Allocasuarina* >28μm pollen (*Allocasuarina verticillata* type) were regionally dispersed and thus represented in all sites except one (surface sample Springs Road-site 13). *Allocasuarina* >28μm achieved highest levels of representation in sites where it was growing locally or where stands were located nearby the site. With all but a single exception (site 2) open woodland sites showed higher levels of *Allocasuarina* >28μm pollen than forest sites. This is possibly due to differences of relative extra-local production and that deposition of *Allocasuarina* >28μm pollen may have been restricted in forest sites due to the filtering effect caused by their more dense overstoreys and shrubby understoreys.

Not all open woodland sites showed similar levels of *Allocasuarina* >28μm which suggests that the strength of the regional *Allocasuarina* >28μm signal in the Fleurieu Peninsula is in part dependant upon proximity to source plants. Thus, although *Allocasuarina* pollen is regionally dispersed, the local presence of source plants is indicated in the pollen spectrum by relatively higher levels of representation. This is in accordance with the finding that the decline of the dispersion curve of most pollen types is

Chenopodiaceae family are not represented in the local vegetation around any of the sample sites, however its pollen was present at values less than 10% in nearly all samples. This supports other studies which indicate that Chenopodiaceae pollen is broadly regionally dispersive (Dodson, 1983). However its low representation reinforces the interpretation that the moss polster and surface samples sites are predominantly representing the local vegetation. *Eucalyptus,* Proteaceae, Liliaceae, Fabaceae and Asteraceae pollen appeared to be predominantly of local origin. The study reinforced the belief that moss polsters in closed canopy forests provide more local records of vegetation than moss polsters from open vegetation (Fall, 1992).

The pollen assemblages obtained reflect the floristic composition of the surrounding vegetation in a sufficiently consistent way that it is possible to ascribe typical pollen characteristics for vegetation at the association level of classification, and in some instances, the community level of classification in the Fleurieu Peninsula. *Eucalyptus obliqua* forests are clearly distinguishable from *E. cosmophylla* - *E. fasciculosa* and *E. baxteri* low and very low woodland or 'scrub' communities in the region. *E. fasciculosa-E. leucoxylon* woodlands are also distinct from the 'scrubs' and open forests. The similarities between the groupings obtained by cluster analysis and PCA analysis of the pollen data confirm the strength of the relationship between pollen and local vegetation.

Eucalyptus obliqua forests and woodlands are distinguished by high proportions of *E. obliqua* type pollen in the moss polster samples (>50%) and moderate amounts of *E. obliqua* type pollen in the surface samples. Although surface samples have only moderate amounts of *E. obliqua* type pollen, they have higher levels of *Eucalyptus* pollen that is indistinguishable to a type which is probably also *E. obliqua* pollen. Also characteristic of the spectra from *E. obliqua* forests and woodlands are low to medium levels of *Allocasuarina* pollen. The maximum representation of *Allocasuarina* pollen in a single sample is 18% of the smaller grained variety and it was likely to have been locally derived from *A. striata*. Shrub species were very poorly represented in the pollen spectra from *E. obliqua* forests and woodlands. Herbs too were generally poorly represented, although the *E. obliqua* open forests are distinguishable from *E. obliqua* woodland by differences in representation of pollen from herbaceous species; the woodland association showed higher amounts of Poaceae and Liliaceae and these components were more highly locally represented around the woodland moss polster site.

The pollen spectra from *Eucalyptus cosmophylla* - *E. fasciculosa*- *E. baxteri* low woodland communities were distinguished from those from *E. obliqua* forest and woodland communities mainly by differences in their dominant *Eucalyptus* taxa, but also by higher abundance of pollen from *Leptospermum myrsinoides* and *Banksia ornata*, understorey species characteristic of these drier community types. The presence of *E. cosmophylla* pollen is particularly useful for separating these formations as the other common 'scrub' dominants, *E. baxteri* and *E. fasciculosa*, also occur in forest communities in the region.

The pollen spectra from the low woodland communities showed more diversity of taxa than those from forests. This finding is in accordance with classical pollen rain studies and models which suggest that the pollen rain in forests is dominated by canopy species while this domination is not so evident in vegetation with lower canopies (Tauber, 1967). Distinction of floristic community types within the scrub formation may be possible by considering taxa restricted to particular vegetation types. For example *Banksia ornata* is generally restricted to *E. baxteri* - *E. cosmophylla* low woodlands and was present in relatively high levels in the pollen spectrum from this community.

The pollen spectra of *E. fasciculosa* and *E. leucoxylon* open woodland and woodland sites are distinguished by the reasonably high levels of *E. fasciculosa* type pollen (20-40%) in conjunction with either one or both high levels of Poaceae (25%) and or *Allocasuarina* >28μm type pollen (>25%). The *E. leucoxylon* and *E. fasciculosa* open woodland sites considered in this study had heavily modified understoreys, and so spectra can not be taken to be indicative of the spectra produced by this formation in its pre-European form. The spectra of *E. fasciculosa and/or E. leucoxylon* woodland and *E. fasciculosa and/or E. leucoxylon* open woodland communities are indistinguishable.

The pollen spectra from all communities in the region were dominated by *Eucalyptus* pollen and so paramount to the delineation of formations and communities was the correct classification of *Eucalyptus* pollen to types which related to species or groups of species. This is in part due the fact that the shrub component of the sclerophyllous understoreys of these communities were very poorly represented (accounting for less than 10% of the sums) in the pollen assemblages despite their high representation in the vegetation. Where shrubs were represented they were generally in amounts which constituted less than 5% of the sum, making their use as reliable indicators in interpretation of spectra problematic. An exception to this was *Leptospermum myrsinoides* and *Banksia ornata* pollen in the spectra of *E. baxteri – E. cosmophylla* low woodland. In addition, in the region, there is much overlap between the composition of the understorey between scrub and forest communities in the Fleurieu Peninsula (Specht, 1972; Mitchell, 1983) with relative abundances of shared species being distinctive. As such their detection in the pollen record is problematic.

Forest formations had higher amounts of *Eucalyptus* pollen (>60%) than did either 'scrub' or open woodland (not greater than 40%). This could be a reflection of the degree of openness of the overstorey taxa of the open woodland communities (productivity differences) and a reflection on different taphonomic processes (dispersability and deposition) operating in the scrub communities. The degree of openness in the woodland communities could not be distinguished. Inference of structural composition of vegetation from the pollen assemblages is not unequivocally possible.

This study concurs with other pollen studies (Newsome, 1999; Kodela 1990; Dodson, 1983) in that *Eucalyptus* pollen dominates pollen spectra from *Eucalyptus*-sclerophyll forests and woodlands and scrubs. Dodson (1983) noted that small differences in understorey representation were important in discerning associated species, and hence formation types. This was found to be the case in the Fleurieu Peninsula formations also, however the resolution of the overstorey dominants to type level revealed distinctive pollen signatures for these types. These results concur with suggestions made by other researchers (Janssen, 1967; Birks, 1996) that reconstructions of vegetation at a more detailed ecological scale of classification, for example at the association level, are more suited to the use of indicator species.

6.4 Conclusions

The utility of pollen spectra for revealing differences in the vegetation from the Fleurieu Peninsula region has been demonstrated. The main formations within the region may be clearly distinguished and the composition of pollen spectra also has the potential to distinguish vegetation a finer scale of ecological classification. The majority of taxa were of local and extra-local origin and were unrepresented in the pollen rain. Differences in *Eucalyptus* pollen types were largely responsible for the distinction of spectra, and thus vegetation types, although their association with less abundant understorey components was also important. Most pollen spectra contained clear indicators of European presence.

CHAPTER 7

7. VEGETATION DYNAMICS SINCE EUROPEAN SETTLEMENT

7.1 Introduction

Studies have indicated that the effect of the imposition of European agricultural practices on the Australian landscape can be detected using palaeoecological records. The European period is characteristically marked by pollen signatures showing a substantial decrease in *Allocasuarina* with a concomitant increase in grasses (Kershaw, 1994; Mooney, 1997), decrease in Myrtaceae tree cover (Crowley, 1994; Dodson *et al.*, 1994), a decline in floristic diversity (Crowley, 1994) and appearance of European crop and weed species (D'Costa *et al.,* 1989; Mooney, 1997). Detection of this time period usually relies on analyses being conducted at finer taxomomic scale than just considering broad taxonomic groups (Kershaw, 1994).

However, fewer studies have considered vegetation dynamics through the European period at scales that are able to detect changes other than wholesale clearance. Palynological studies carried out at finer temporal, spatial and taxonomic resolutions than traditionally applied in palaeoecological research have been successfully used to reconstruct long term plant community dynamics in Europe and North America (Davis *et al.*, 1993; Calcote, 1995; Ritchie, 1995) and indicated human impacts on vegetation (Hicks and Birks, 1996; Fuller *et al.*, 1998; Atherden and Hall, 1999). A handful of fine resolution palynological studies have indicated that these techniques also have potential to answer questions about vegetation change and recent European impact in Australian environments. Gell *et al.* (1993) investigated the impacts of changing settlement and land use pattern on the Delegate River catchment in the East Gippsland region of Victoria using pollen, charcoal and sediment records. Significant changes to the forest understorey with shrubs and herbs being replaced with grasses as a result of increased incidence of fire was found as well as evidence for shrub re-colonisation after a period of introduction of fire suppression measures. Dolman (1988) investigated the dynamics of Sydney's urban bush land using a fine resolution pollen and sediment approach. Vegetation changes observed in the European period were increases in the abundance of taxa of mesic communities, increases in exotic species and an increase in the number of trees at the expense of shrubs. Harle *et al.* (1999) detected evidence of European logging activities in Huon Pine forests of the Gordon River Valley in South West Tasmania. Kenyon (2000) considered landscape and vegetation changes in the *Eucalyptus camaldulensis* forests on a section of the Murray River floodplain. She found that the pollen record corroborated documented-historical records of increases since European settlement in the density of *Eucalyptus* forests and *Carex appressa* in the understorey and declines in other elements of the vegetation including Cupressaceae.

This chapter aims to use pollen and charcoal fossil records to investigate wetland and terrestrial vegetation dynamics of remnant vegetation and an agricultural catchment in the higher elevation regions of the Fleurieu Peninsula over the European period. It begins with a review of the principles and assumptions of palaeoecological evidence. The chapter then reports on the study of three sedimentary cores, and their microfossil records, spanning the European period.

7.2 Principles and assumptions of environmental evidence

7.2.1 Sediment records and peat swamps

Peat swamps and bogs have been shown to yield palaeoecological records that are chronologically sequential and at fine resolutions (Green *et al.*, 1988; Goudie *et al.,* 1990). Their deposits are primarily autochthonous and as such are relatively free of the resorting, redeposition, episodic slumping, seasonal turnovers and sediment focussing evident in lake environments. Pollen grains deposited in swamps and bogs under sedentary and undisturbed conditions have been shown to maintain stratigraphic integrity irrespective of subsequent shifts in the water tables, bioturbation or cryoturbation (Polach and Singh, 1980). Small basins and swamps primarily record local and extra local pollen input (Jacobson and Bradshaw, 1981; Prentice, 1985) and as such are suitable for reconstructing vegetation histories of the wetland itself and the catchment surrounding it.

7.2.2 Pollen

There are a number of processes involved in the production of final pollen assemblages from the original vegetation that must be taken into account in the reconstruction of vegetation. Taphonomic factors such as pollen production rates and dispersal methods of taxa affect the amount of pollen represented in fossil samples (Chapter 3). Tauber (1967) produced a model outlining the range of mechanisms by which pollen can arrive at a site. Fossil pollen may be a product of any of the following components; 1) trunk space component, pollen which falls from the canopy and is carried by sub canopy air movements, 2) canopy component, pollen which is carried in air currents above the canopy, 3) rain component, or pollen fall out from the atmosphere, 4) local component, pollen produced by local aquatic taxa and 5) secondary in-washed component, pollen from the surrounding catchment. The proximity of plants to a depositional basin, and the size of that basin, also significantly influences pollen representation. Basin size has been recognised as one of the most the important variables influencing pollen deposition. Stream influx and outflow, air input, sedimentation processes and factors in the local environment such as hydrogeology, basin orientation, local climate and topography are all relevant (Jacobson and Bradshaw, 1981; Prentice, 1985). Adopting the model of pollen deposition constructed by Prentice (1985) for Northern Hemisphere forest types to Australian vegetation, Dodson (1988) asserted that basins with a diameter greater than one to three hundred metres are likely to have pollen influx dominated by long distance transported types. Basins of about 100 metre diameter would contain regional, local and extra-local pollen types and particular vegetation stands would be represented in sediment sites up to 50 metres in diameter. Small basins will primarily record local and extra local pollen input.

7.2.3 *Charcoal*

Reconstruction of fire history from fossil charcoal is based on the assumption that the amounts of charcoal in sediment preparations reflect past fires; that is aerial fallout and post-fire erosion of charcoal produced by fires close to a sedimentary site will result in increased charcoal abundance in sediments (Patterson *et al.*, 1987). Microscopic charcoal on fossil pollen microscope slides is of the order of $50\mu m^2$ to $10\ 000\mu m^2$ in area and records both local and regional fire activity (Clark, 1983, Patterson *et al.*, 1987). Macroscopic charcoal analysis has attracted interest for its usefulness in reconstruction of local fire regimes being based on the assumption that large fragments of charcoal will not travel long distances and thus are indicative of local fires (Clark, 1988; McDonald *et al.*, 1991). The process of macroscopic charcoal analysis involves sieving fragments of charcoal from about $2500\ \mu m^2$ to $50\ 000\ \mu m^2$ in size from sediments and counting under a low power microscope. Macroscopic analysis avoids some of the problems of the difficulty in separation of charcoal from unburned plant material (Clark, 1988) and the effects of physical and chemical procedures used in the preparation process on the amount of charcoal in a sample, encountered in microscopic analysis (Clark, 1984).

The assumptions and difficulties in relating the charcoal record to past fire regimes and fire-vegetation relationships have been well discussed (Clark, 1983; Clark, 1988; Patterson *et al.*, 1987; McDonald *et al.*, 1991). Critical among them are; the charcoal catchment may not be the same as the pollen catchment; a peak in a charcoal curve may represent one fire or several; input into the sedimentary basin may take place over a very long time following the processes of breakdown, transport, deposition, resuspension, further redeposition which may continue after the time of deposition (Whitlock and Millspaugh, 1996); most charcoal is transported to lakes and swamps by water rather than wind and thus charcoal in sediments provides not only a record of fire, but fire rainfall events (Clark, 1983); more charcoal in one sediment sample may represent more or less frequent fires, depending on the number of years of sediment in each sample, the rate of fuel build up and the interval between fires (Clark, 1983).

Comparison of the charcoal record with independent sources, such as dendrochronological or historical records, of past fire regimes have shown good correlation between fire events and charcoal particle abundance in a peat swamp sites analysed at an annual resolution. Green *et al.* (1988) showed that the charcoal signal was not significantly biased by the processes of transport and preservation. Using cross correlograms this study found significant relationships between species abundances and fire events, thus indicating the ability to detect fire-driven changes to vegetation pattern from fossil records.

7.2.4 Chronologies

7.2.4.1 Holocene

Radiocarbon dating, a radiometric dating method based on the isotope carbon-14, is the most important method for dating organic material from the Holocene to *ca* 30 000 to 50 000 years (Gupta and Polach, 1985; Goudie *et al.*, 1990; Roberts, 1989). The method is not suitable for dating samples from the last 150 years due to problems arising from atomic testing and the burning of fossil fuels since the Industrial revolution, acting to inject geologically old carbon into the atmosphere.

7.2.4.2 European period

Lead-210 has a short half life, of 22.26 years, and as such is suitable for establishing chronologies over the past 150 years. Methodology and models of ^{210}Pb accumulation rates are discussed in Appleby and Oldfield (1992). Lead-210 is removed from the atmosphere principally by precipitation and part of this radioactive fall out is adsorbed onto sedimentary particles. Atmospherically deposited lead in sediments is known as unsupported or excess lead and it supplements continuous ^{210}Pb production from uranium incorporated into *in situ* sediments, referred to as supported lead. The dating of excess lead involves application of the law of radioactive decay to the excess lead fraction and the subsequent application of a dating model that is in accordance with the processes governing ^{210}Pb accumulation. The stratigraphy of ^{210}Pb depends on the amount of parent nucleotides in the sediment, the supply to the depositional site of unsupported lead (usually constant over period of a few years), reworking of sediments within the depositional environment, the source of sediment inputs (Wasson *et al.*, 1987) and the decay of the unsupported ^{210}Pb.

Caesium-137 (^{137}Cs) is an artificial radioisotope, the presence of which in the environment is the result of fallout from atomic bomb testing. Caesium-137 first appeared in the atmosphere in globally detectable quantities in 1954-55 and its first appearance marks this time (Goudie *et al.*, 1990). Caesium-137 dating has been applied to peats with varying degrees of success. Oldfield *et al.* (1979) showed that in some ombrotrophic mires it was subject to downward diffusion and to active uptake by living plants.

Pollen from introduced weeds, plantation trees and agricultural crops have the potential to be used as stratigraphic markers for the beginning of the European settlement, or in conjunction with land use histories of a region as markers for periods within European settlement. The native Australian flora is without plants from the genus *Pinus* and its pollen is readily recognisable due to its distinctive morphology. *Pinus* pollen is regionally distributed and trees exhibit high pollen production rates. As such it has been successfully used as a marker for European settlement (Ogden, 1996). Other widely used European markers are from the agricultural weeds, *Echium, Rumex* spp., *Plantago lanceolata* and Poaceae. In some cases use of these types is confounded due to difficulties in separation from morphologically similar native pollen types. However sustained increases in one or more of these have been used to infer changes to land use regimes.

7.3 Core sites

European impacts are not likely to have been homogenous across the Fleurieu Peninsula, but related to different environments and vegetation types and different land use histories. Consequently, the Fleurieu Peninsula was surveyed for suitable swamp sites across the range of environmental and land use areas in the region. No lakes are present in the study region although numerous swamps are present in areas of higher elevation, most being on the flat plateau of the ranges where drainage is impeded. A primary criterion for site selection was the integrity of the site in relation to disturbance of the sediment record. Sites with evidence of gross disturbance by swamp clearance, draining, or stock trampling were avoided. The few extant lowland swamp sites in the region were found to be highly disturbed and were considered unsuitable for core extraction. A further criterion applied to the selection of the highland swamps was the number of in-flowing and out-flowing drainage lines. Those with few stream inputs were preferred to ensure that the swamps had mainly a local pollen source area. Numerous sites in the higher elevation sclerophyll land system were investigated and three yielded sedimentary cores, which were believed to provide an undisturbed sequence (Figure 7.1). Two of the sites, Deep Creek Tapanappa and Springs Road, were small peat swamps in creek lines in patches of remnant native vegetation and one, Boat Harbour Creek, a peaty swamp within a catchment cleared of its original vegetation cover.

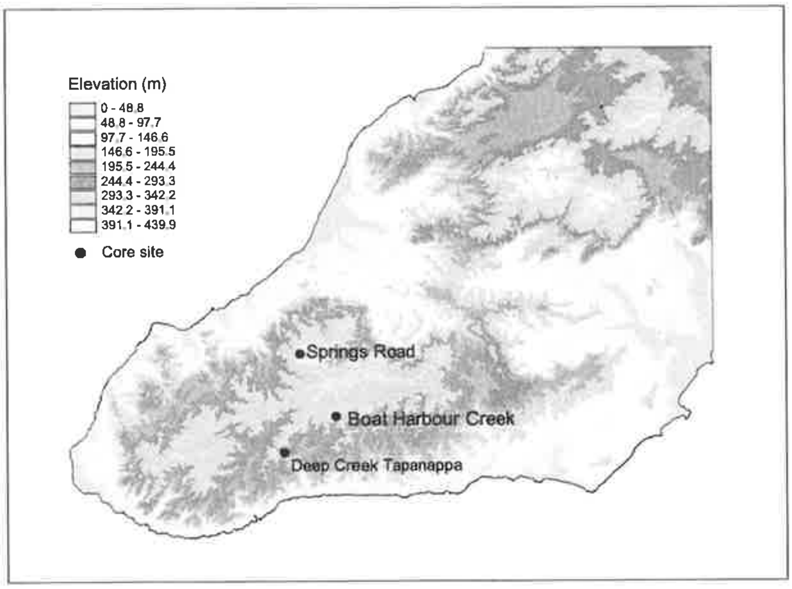


Figure 7.1 Location of core sites on the Fleurieu Peninsula.

7.3.1 Boat Harbour Creek

The Boat Harbour Creek swamp (Figure 7.2) is relatively large cyperaceous and shrub peatland, or swampy meadow, which lies in a relatively gentle valley on the highland plateau of the Fleurieu Peninsula (35° 34'00''S, 138°18'30''E, elevation 290 m. a.s.l.). The swamp is topogenous, being dependent on surface run off and ground water to maintain waterlogged conditions. A tributary of the Boat Harbour Creek enters the swamp 2.5 kilometres from its headwaters, being fed by catchment area of 103ha before reaching the core site.

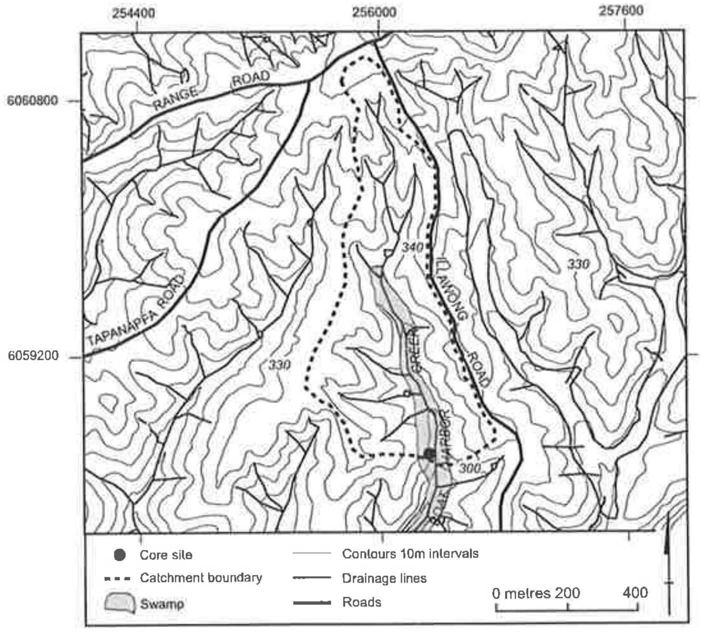


Figure 7.2 Catchment, surrounding topography and drainage of Boat Harbour Creek core site.

The soils of the swamp are dark brown sandy to clay loam with a paler coloured and gravelly A2 horizon. Soils of the catchment of the swamp are grey-brown sandy loams overlying ironstone-rich gravelly yellow-brown to red clays. Soils have been formed on the highly weathered and kaolonised metasandstones and metasiltstones of the Backstairs Passage Formation. The site receives an average annual rainfall of 843 mm with a winter and summer rainfall of 361 mm and 86 mm respectively. The mean annual temperature is 13.9^{0}C (values derived from ANUCLIM12 climate models generated for the region, Chapter2).

Since native vegetation clearance in the catchment in 1953, pasture grasses (perennial ryegrass and subterranean clover) have been the predominant land cover type surrounding the Boat Harbour Creek swamp (Figure 7.3). Weed species, notably *Plantago* spp., *Rumex* spp. and Asteraceae, grow interspersed with the pasture grasses. Isolated *Eucalyptus baxteri* trees remain on hill slopes and along the roadside of the western boundary of the catchment. A small strip of *E. baxteri* - *E. cosmophylla* - *E. obliqua* over *Lepidosperma semiteres, Banksia marginata, Hakea rostrata* and *Pultenaea involucrata* low woodland is extant on the eastern ridge of the catchment. Down stream from the swamp is a small patch of *E. baxteri-E. cosmophylla* low woodland. The majority of land in the vicinity of the catchment is agricultural or planted to *Pinus radiata*. Flanking the swamp is an *Eucalyptus ovata* open wet heath community with an overstorey of *Acacia retinoides, Leptospermum continentale, L. lanigerum, Melaleuca decussata* and *E. ovata* and an understorey of numerous reed and other swamp taxa, most commonly *Baumea rubiginosa, Baumea tetragona, Empodisma minus, Shoenus* spp. and *Villarsia umbricola* (Table 7-1).

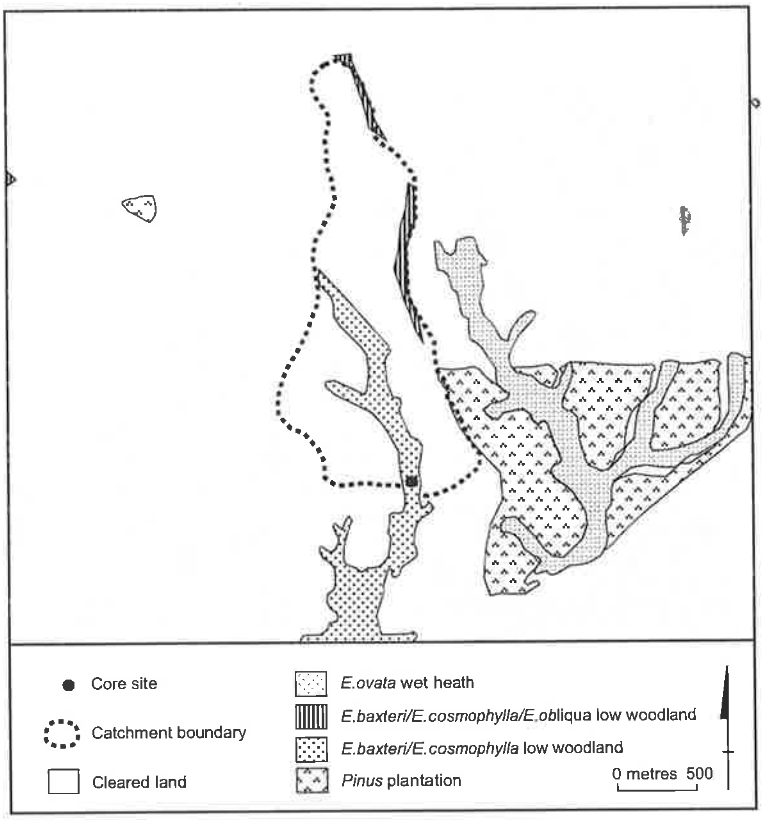


Figure 7.3 Vegetation in the catchment and nearby the Boat Harbour Creek swamp.

Table 7-1 Swamp species recorded at the Boat Harbour Creek swamp

Site	Species	
1	*Acacia retinodes* var. *retinodes* (swamp form)	*Gahnia sieberiana*
	Baumea rubiginosa	*Juncus articulatus*
	Baumea tetragona	*Leptospermum continentale*
	Blechnum minus	*Leptospermum lanigerum*
	Eleocharis gracilis	*Triglochin procerum*
	Empodisma minus	*Villarsia umbricola* var. *umbricola*
2	*Acacia verticillata*	*Lepidosperma longitudinale*
	Baumea juncea	*Leptospermum continentale*
	Baumea rubiginosa	*Leptospermum lanigerum*
	Baumea tetragona	*Melaleuca decussata*
	Blechnum minus	*Olearia ramulosa*
	Bossiaea prostrata	*Patersonia fragilis*
	Cassytha glabella	*Patersonia occidentalis*
	Centella cordifolia	*Platylobium obtusangulum*
	Cryptostylis subulata	*Prasophyllum frenchii*
	Deyeuxia quadriseta	*Pultenaea laxiflora*
	Drosera auriculata	*Schoenus breviculmis*
	Drosera binata	*Sprengelia incarnata*
	Empodisma minus	*Spyridium thymifolium*
	Eucalyptus ovata	*Villarsia umbricola* var. *umbricola*
	Gonocarpus tetragynus	*Schoenus carsei*

7.3.2 Deep Creek Tapanappa

The Deep Creek Tapanappa core was taken from a peaty swamp in a creek line in the Deep Creek National Park (35° 37'S, 138°16') at an elevation of 240 metres above sea level. The Deep Creek Tapanappa swamp was composed of a dense cover of ferns, most prominent of which were

Blechnum minus and *Gleichenia microphylla* and sedges and rushes including *Lepidosperma longitudinale, Juncus planifolius, Baumea juncea, Shoenus carsei* and *S. apogon. Acacia verticillata, Leptospermum continentale* and *L. lanigerum* and *Melaleuca decussata* lined swamp margins and extended over the swamp itself. *Eucalyptus ovata* and *Acacia retinoides* var. *retinoides* also occur along swamp margins. The swamp is 400m downstream of the headwaters of a tributary of Boat Harbour Creek, which runs from the elevated plateau of the Peninsula along valley floors of relatively steep sided dissected ranges, concluding at the Southern Ocean. The site is subject to run off from a local catchment area of 75.7 ha (Figure 7.4). Five drainage lines, of each of approximately 400 metres in length, enter the main streamline traversing the swamp. The stream channel was 2 metres wide and 20 centimeters deep in January, 1996. The swamp had an average width of 33 metres and length of 67 metres thus being approximately 2.2 ha in area.

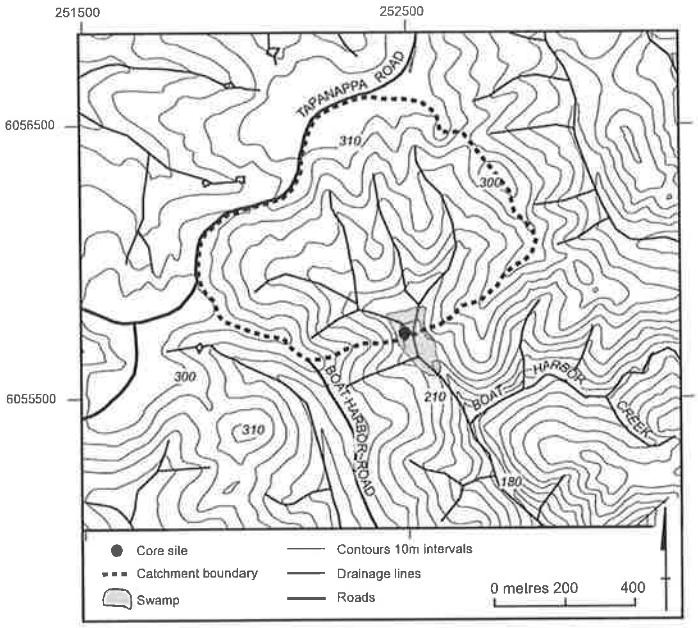


Figure 7.4 Catchment, surrounding topography and drainage pattern of Deep Creek Tapanappa swamp

It was developed on soils which are generally referred to as 'creek line soils', being dark brown sandy to clay loams with paler coloured and gravelly A2 horizons overlying grey-brown heavy clays. The soils of the surrounding catchment are moderately shallow, dark brown loams, also with paler brown A2 horizons overlying yellowish red to orange clays. Weathering metamorphosed siltstones or phyllites from Kanmantoo metasediments occur within 50-100 cm from the surface. The site receives an average annual rainfall of 811 mm with almost half of this falling in the winter months and only 82 mm in the summer months. The mean annual temperature is 14.2°C (Values derived from ANUCLIM12 climate models generated for the region, Chapter 4).

Three vegetation communities, as defined and mapped by DENR (1988), and a small amount of cleared land and are found within the catchment of the Deep Creek Tapanappa swamp site. Figure

7.5 shows vegetation community distribution in the catchment and a list of species present in these communities is given in Table 7-2.

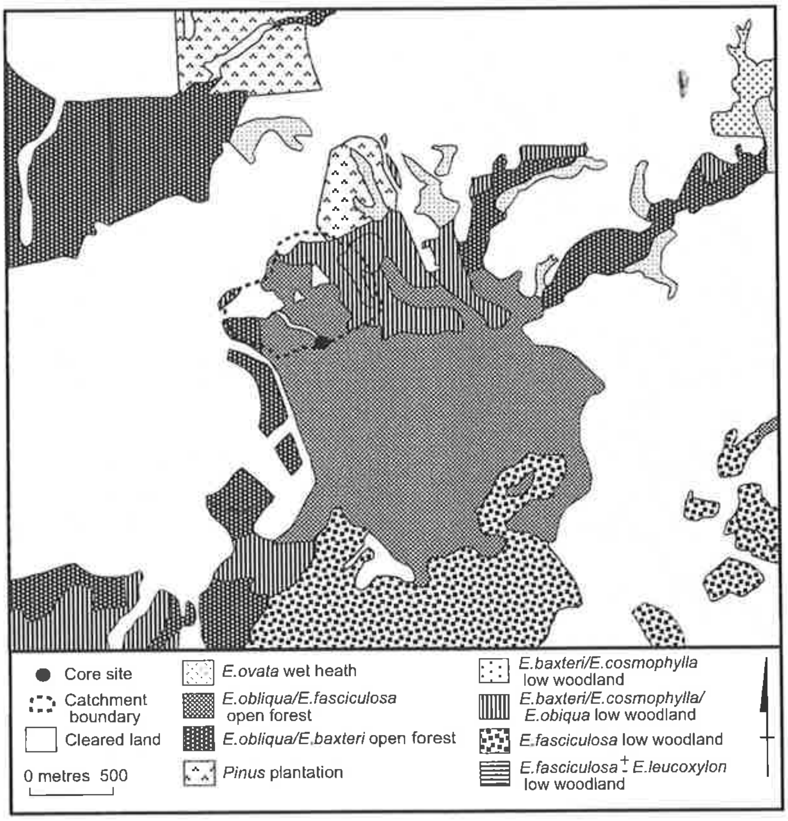


Figure 7.5 Vegetation of Deep Creek Tapanappa swamp catchment

Swamp vegetation was classified as *Eucalyptus ovata* woodland and mapped as part of an area of 20.4 ha, running along the creek line upstream from the core site. An open forest of *Eucalyptus obliqua - E. fasciculosa* over *Gonocarpus tetragynus, Xanthorrhoea semiplana* and *Lepidosperma semiteres* occupies 345 ha - the majority of the area of the catchment. A small patch of *E. obliqua - E. baxteri* open forest over *Acrotriche serrulata, Pultenaea daphnoides, Hakea rostrata, Lepidosperma semiteres, Goodenia ovata* and *Pteridium esculentum* occupies the top reaches of the western side of the catchment. A low woodland of *E. baxteri - E. cosmophylla - E. obliqua* over *Lepidosperma semiteres, Banksia marginata, Pultenaea involucrata* occupies approximately 80 ha of the eastern side of the upper reaches of the catchment.

Land to the south of the Deep Creek Tapanappa catchment is native vegetation and is under Conservation Park management. Other nearby land uses include grazing on cleared land which has been sown to non-native pastures grasses and *Pinus radiata* plantation forestry. The closest *Pinus* plantation to the Tapanappa site, in an adjacent catchment, 1km to the north-west of the core site, was established in 1970.

Table 7-2 Species in catchment of Deep Creek Core site.

E. obliqua – E .fasciculosa open forest

Acacia myrtifolia
Billardiera bignoniacea
Briza minor
Correa sp. aff. *Calycina*
Epacris impressa
Eucalyptus obliqua
Gonocarpus tetragynus
Goodenia ovata
Hibbertia exutiacies
Ixodia achillaeoides ssp.
Leucopogon parviflorus
Olearia ramulosa
Olearia teretifolia
Opercularia sp.
Pimelea stricta
Poa sp.
Pteridium esculentum
Pultenaea daphnoides
Stipa muelleri
Viola hederacea
Xanthorrhoea semiplana ssp. *tateana*

E.baxteri-E.cosmophylla low woodland

Allocasuarina muelleriana
Banksia marginata
Cassytha glabella
Drosera macrantha ssp. *planchonii*
Drosera whittakeri
Epacris impressa
Eucalyptus baxteri
Goodenia blackiana
Hakea rostrate
Hibbertia riparia
Hibbertia sericea var. *sericea*
Lepidosperma carphoides
Lepidosperma semiteres
Leptospermum myrsinoides
Leucopogon concurvus
Persoonia juniperina
Pimelea octophylla
Pimelea phylicoides
Pimelea sp.
Platylobium obtusangulum
Poranthera ericoides
Pultenaea involucrata
Schoenus breviculmis
Spyridium thymifolium
Stipa muelleri
Stylidium graminifolium
Tetratheca pilosa ssp. *pilosa*
Viola hederacea
Xanthorrhoea semiplana ssp. *tateana*
Xanthosia pusilla

E. ovata open woodland

Acacia retinodes var. *retinodes*
Acacia verticillata
Baumea juncea
Baumea rubiginosa
Billardiera bignoniacea
Cassytha glabella
Centrolepis fascicularis
Eleocharis gracilis
Epacris impressa
Gahnia trifida
Gonocarpus micranthus
Hibbertia sp.
Juncus planifolius
Lepidosperma longitudinale
Leptospermum continentale
Leptospermum lanigerum
Leucopogon hirsutus
Leucopogon lanceolatus
Melaleuca decussata
Moss
Myriophyllum amphibium
Patersonia occidentalis
Pultenaea daphnoides
Schoenus apogon
Schoenus carsei
Sprengelia incarnata
Villarsia umbricola

7.3.3 Springs Road

The Springs Road core was taken from a peaty swamp in a patch of remnant native vegetation owned by ForestrySA (35°33’S, 138°17’) at an elevation of 315 metres above sea level. The swamp is covered in Cyperaceae species, most commonly *Baumea juncea, Juncus pauciflorus* and *Carex tereticaulis,* and is surrounded by a 14 ha strip of *E.ovata* low woodland with the overstorey dominants being *Eucalyptus ovata, E. fasciculosa, Melaleuca decussata, Acacia verticillata* and *Leptospermum continentale*. The swamp occupies a small flat along a valley incised by a creek line (Figure 7.6). The swamp is approximately 10 metres wide and 25 long in the direction of the creek line which feeds in and out of it. The swamp is situated approximately 500 metres from the head of the creek line which is one of the main stream lines feeding into the River Anacotilla running to the coast at Yankalilla Bay on the Gulf of St Vincent. It has a local catchment area of 79.7 ha with four short stream lines in the catchment running into the main creek.

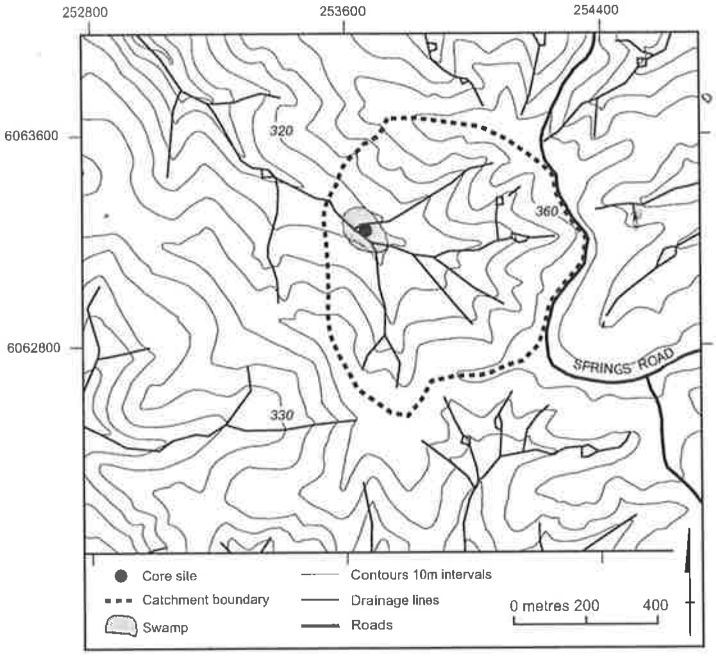


Figure 7.6 Catchment, surrounding topography and drainage pattern of Springs Road swamp

The soils of the immediate swamp region are dark clay loams over grey and yellow clays and moderately thick grey-brown sandy loams to clay loams with a paler coloured and gravelly A2 horizon. These soils overlie an ironstone gravelly yellow sandy clay loam which grades to a yellow-brown and red clay below 70 centimeters. These soils have been formed on highly weathered and kaolinized metasandstones and siltstones of the Backstairs Passage Formation. The site receives an average annual rainfall of 862 mm with 366 mm of this total falling in the winter months and 87mm falling in the summer months. The mean annual temperature is 13.9°C.

Most of the local catchment of the Springs Road swamp has a cover of native vegetation however a small proportion is agricultural land and *Pinus radiata* plantations. Seventy eight ha of *E.obliqua - E. baxteri* open forest over *Acrotriche serrulata, Pultenaea daphnoides, Hakea rostrata, Lepidosperma semiteres, Goodenia ovata* and *Pteridium esculentum* surrounds the *E. ovata* swamp community. A small area of *E. baxteri, E. cosmophylla, E. obliqua* low woodland over *Lepidosperma semiteres, Banksia marginata, Pultenaea involucrata* occupies a south west portion of the swamp catchment. The distribution of vegetation communities and cleared land in the catchment of the Springs Road site is shown in Figure 7.7 and a list of species present is given in Table 7-3.

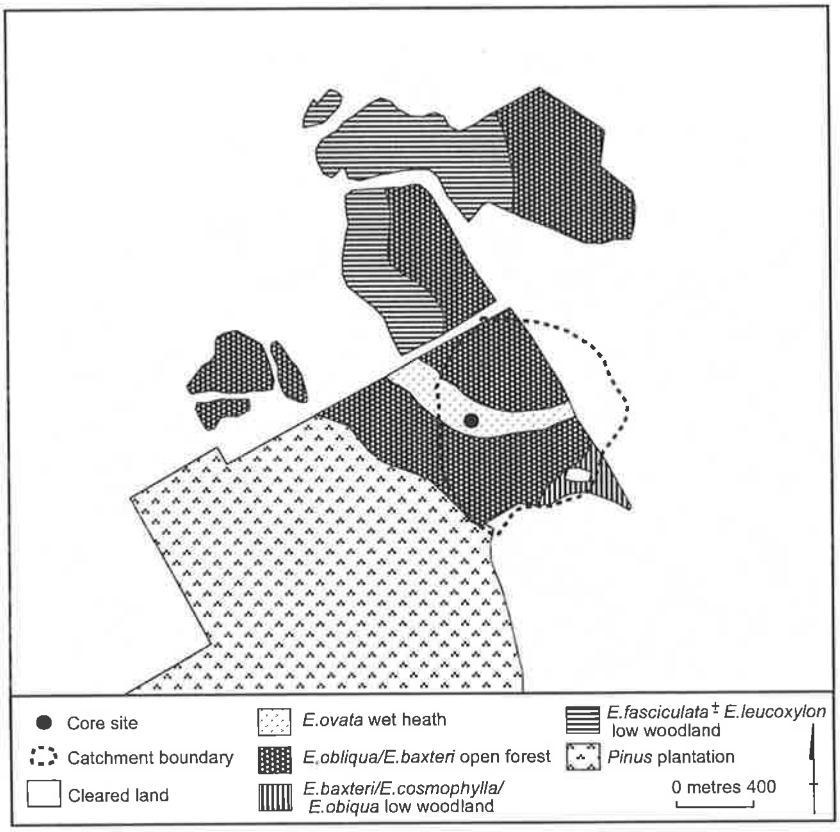


Figure 7.7 Vegetation of Springs Road swamp catchment

Table 7-3 Species in catchment of Springs Road site

E.ovata woodland

Acacia verticillata
Acaena novae-zelandiae
Banksia marginata
Baumea juncea
Carex tereticaulis
Epilobium billardierianum
Eucalyptus fasciculosa
Eucalyptus ovata
Gahnia trifida
Goodenia ovata
Gratiola peruviana
Juncus pauciflorus
Leptospermum continentale
Melaleuca decussata
Olearia teretifolia
Pteridium esculentum
Senecio sp.

E.obliqua/*E.baxteri* open forest site1

Acacia myrtifolia
Acacia pycnantha
Acianthus caudatus
Astroloma humifusum
Banksia marginata
Burchardia umbellata
Caladenia carnea
Centrolepis aristata
Chamaescilla corymbosa var. *corymbosa*
Craspedia glauca
Cyrtostylis reniformis
Danthonia sp.
Daviesia leptophylla
Drosera auriculata
Drosera whittakeri
Isopogon ceratophyllus
Epacris impressa
Eucalyptus obliqua
Glossodia major
Gonocarpus tetragynus
Goodenia blackiana
Hakea rostrata
Hibbertia riparia
Hydrocotyle callicarpa
Lepidosperma semiteres
Leucopogon concurvus
Logania recurva
Lomandra fibrata
Olearia grandiflora
Olearia teretifolia
Opercularia varia
Platylobium obtusangulum
Pterostylis vittata
Pultenaea daphnoides
Pultenaea involucrata
Rutidosis multiflora
Schoenus apogon
Stackhousia aspericocca
Stipa sp.
Stylidium graminifolium
Thelymitra ixioides
Thelymitra pauciflora
Thysanotus patersonii
Tricoryne elatior
Viola sieberiana
Wahlenbergia stricta
Xanthorrhoea semiplana ssp. *tateana*
Xanthosia pusilla

Table 7-4 Land tenure and use in the catchments surrounding cores sites at Boat Harbour Creek, Deep Creek Tapanappa and Springs Road.

Year	Land tenure	Land use
Boat Harbour Creek:		
1841-	Crown Land	Unregulated grazing/ grazing under Council License
1884	Survey, Section 194, Hundred of Waitpinga	
1885	William Begg Sells, (miscellaneous lease)	Grazing
1889-89	Charles Williss –local Delamere labourer. Leased 4168 acres, which included section 194	Grazing and possibly wattle bark collection
1899	Williss lease is cancelled for non-payment (he probably walked off the land).	
1899-1945	9 leasees, usually farmers or local labourers, some for only a few months (6 to 9 months). Longest lease through this time was 7 years, high turnover of leases, 'small' farmers and probably wattle bark collectors	Grazing, wattle bark collection, yacca gum collection
1950?		
1953	Land cleared, Whitlock Jones, trace elements and superphosphate added, sown to improved pastures	
1955- (?)	Property freehold Ian Robinson	Grazing on improved pastures annual fertilisation
Deep Creek Tapanappa		
1841-	Crown Land	Unregulated grazing/ grazing under Council License, timber collection
1884	Survey, Section 48, Hundred of Waitpinga	
1889	Charles William Collins (RPL lease) –adjoining sections 59, 50, 51 and 52 also RPLs at ½ d per acre.	Sheep grazing
~ 1890	Charles William Collins	Wattle collection
1906	James Norman (Delamere farmer, purchased RPL- restructured rent)	Sheep grazing
1935	Part of section cleared, Fissell Brothers (three consecutive ploughs and burning)	Sheep grazing (low stocking rates 300-600 wethers)
1949	James Norman	
1973	Second Valley Forest	*Pinus* plantations- Boat Harbour Block, 1973, Martins Block, 1980
1982	Deep Creek National Park	Conservation park
Springs Road		
1841-	Crown Land	Unregulated grazing/ grazing under Council License/timber collection
1850	Survey, Section 1636 Hundred of Yankalilla	
1854	Section granted to Edward Stephens (by Gov. Sir Henry Fox Young)	Grazing/timber collection
1874	James Flemming (Painter in Adelaide)	
1879	William Begg Sells (perpetual lease)	Grazing
1881	George Anstey, William Gilbert, Thomas Giles, LG Browne, A. Ferguson (Adelaide land speculators—presumably an investment holding)	Timber collection (and grazing?)
1896	William Briggs Sells	Grazing and wattle bark
1908	Hugo Charles Cave (Freehold)	Grazing
1911	Crown repurchase land for forest reserve	Native Timber collection
1914	Road put through section	
1957-1959	Land within section and catchment cleared and planted to *Pinus*	Native vegetation clearance and *Pinus* plantation
1959-1962	Land 2km from site, at Mount Hayfield, cleared and planted to *Pinus*	
1950/1960	Patch of land in catchment cleared for improved pasture grazing	Grazing

7.3.4 *European land use history of the catchments of core sites*

The phases of occupancy and development in the highland regions, where all core sites are found, were discussed in Chapter 2. The land survey, tenure and use of the catchments directly surrounding the core sites at Boat Harbour Creek swamp, Deep Creek Tapanappa and Springs Road are listed in

Table 7-4. Information was obtained from the Land Titles section of the South Australian Department of Environment and Natural Resources.

7.4 Methods

Sediment cores of 4 centimeter diameter were taken using a D-Section (or 'Russian') corer at the approximate centre point of each swamp, away from regions of obvious channel incision. Cores were placed in PVC tubing, wrapped in plastic film and aluminum foil and stored in the dark at 4° C. Sub-samples of sediment were taken at 1-5 cm intervals for fossil pollen, spores and micro-charcoal. Macroscopic charcoal content was analysed at 1-3 cm intervals from a second core taken adjacent to the first. Material from a core taken adjacent to the Deep Creek Tapanappa core was used for ^{210}Pb and ^{137}Cs dating. Material from core BH2 was dated using ^{210}Pb. Samples were processed at the CSIRO Division of Land and Water in Canberra.

7.5 Boat Harbour Creek core-BH2

7.5.1 Results

7.5.1.1 Stratigraphy

Peats of varying degrees of humicity are the predominant sediment type in the upper 42 cm of core BH2. From 42-35 cm sediments are a combination of humic and herbaceous reed peats. These peat sediments are interrupted by a 6 cm clay intrusion from 34-29 cm. Sediments from 29 cm to the top of the core are herbaceous reed peats.

7.5.1.2 Radiometric dating

Nineteen sediment samples were taken from the top 65 cm, and two from near the base of the core, for Lead-210 (^{210}Pb) dating. Log excess ^{210}Pb has been plotted against depth (Figure 7.8). Depth has been calculated as cumulative ashed sediment to eliminate the effects of compaction and variable sediment grain size. Figure 7.8 does not show a continuous linear decrease of excess ^{210}Pb with depth, which is the relationship expected if the assumption of a constant sediment accumulation rate holds. Two regions of approximate linearity are shown, corresponding to the 0-11 cm and 13-21 cm depth sections. Between them there is a large positive shift in $^{210}Pb_{ex}$ concentration. Increasing concentrations are also observed near the base of the plot (equivalent to 21-24 cm depth). Negative $^{210}Pb_{ex}$ are seen at greater depths (below 26 cm). Positive shifts in concentration with increasing depth have been attributed to periods of accelerated accumulation, perhaps following changes in catchment land management (Appleby and Oldfield 1992). Negative $^{210}Pb_{ex}$ values are less commonly reported. In this case they may be due to the intrusion of groundwater; in particular saline groundwater, which often carries high dissolved concentrations of Radium-226 (^{226}Ra). If this intrusion was recent (within the last few decades) ^{210}Pb in the sediment would yet to have re-established radioactive equilibrium with the new ^{226}Ra activity of the sediment, and the ^{210}Pb activity of the sediment would be lower than ^{226}Ra. The relative constancy of sediment ^{226}Ra activities in the upper core profile suggests that groundwater has not elevated ^{226}Ra concentrations above 24 cm, and that ^{210}Pb dating can be applied in this section of the core.

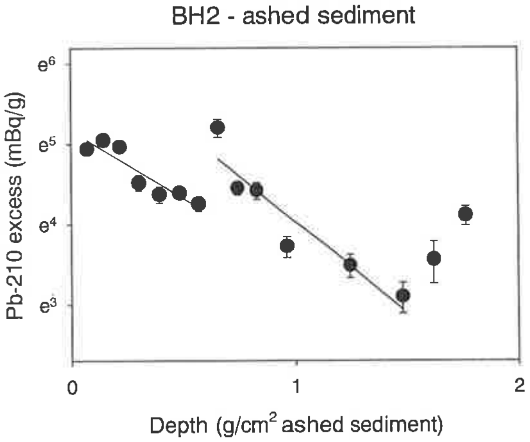


Figure 7.8 Excess Lead-210 plotted against cumulative dry sediment from core BH-2

Lead-210 results were modelled using the constant rate of ^{210}Pb supply (CRS) model, a variable accumulation rate model, and the age-depth curve produced is shown in Figure 7.8. The CRS model assumes a constant transfer function, resulting in a constant rate of supply to the accreting material (Appleby and Oldfield, 1992). In this model the initial unsupported ^{210}Pb activity varies inversely with the mass accumulation rate. The CRS model has been considered to be the most appropriate for lead dating of organic rich matter (Appleby and Oldfield, 1992) and, where the ^{210}Pb concentration does not monotonically decrease, CRS ages (t) are given by $t = 1/\lambda \ln(A_0/A)$ where A_0 is the total residual excess ^{210}Pb in the sediment column ($^{210}Pb_{ex}$ inventory, equal to 130 mBq/cm^2 in core BH2). A change in slope is visible at a depth of about 12 cm. The lead model provides an estimated date for this depth at *ca* 1988. Accumulation rates according to the CRS model from 0-12 cm are 0.31 cm/year and from about 14 to 24 cm a lower accumulation rate of 0.21 cm/year.

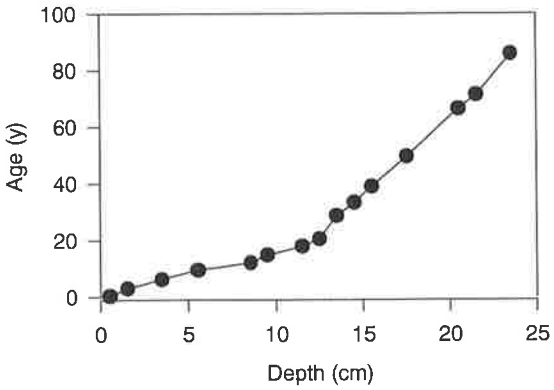


Figure 7.9 Age versus depth plot for core BH-2 derived using the CRS model

7.5.1.3 Microfossil markers

Most of the *Pinus* found was in the top 10 cm of sediment where terrestrial pollen counts were low. *Pinus* pollen counts were similarly low. The maximum number of *Pinus* grains recorded in any sample was four, at 4 cm. The nearest *Pinus* plantation to the core site is on the adjoining ridge between Tunkalilla and Illawong Roads. This plantation was established in 1980 and significant pollen production from it would have occurred by approximately 1985. Local forester Albert Jones (pers. comm.) estimated that *Pinus radiata* planted with modern soil preparation practices in the region takes between 3-4 years to produce pollen and for those grown earlier in the century, establishment and maturation was slower and pollen production took 7-8 years. Given that the site looks to be mainly representing local vegetation and that *Pinus* pollen representation and distance from the source is correlated (Appendix 7), the upper 10 cm have probably accumulated since *ca* 1985. Two grains and a single grain of *Pinus* were recorded at 30 and 32 cm respectively. Markers suggesting older ages above these depths preclude the interpretation that these *Pinus* grains represent pollen production from the most proximal plantation in *ca* 1985.

Single grains of pollen from weed species; *Rumex, Plantago* and *Cirsium* were found at 4, 10 and 35 cm respectively. *Cirsium* sp. had established itself as a problematic weed by the 1860s in the Fleurieu Peninsula (RBCMB, 1856-1878). *Rumex* was introduced as a garden vegetable very early in settlement and escaped soon afterwards (Kloot, 1983). *Plantago* spp. had established as weeds by 1851 in South Australia (Kloot, 1983). Brassicaceae has the potential to be a useful marker of European settlement in this region as there are no extant members of the family in the native flora. Brassicaceae pollen first appeared at 25 cm and is present in small proportions in the top 10 cm. Its appearance could mark *ca* 1910 as at this time the swamp was partially cleared to grow vegetables (Williams, 1985). However there are many exotic weeds in the Brassicaceae family (Kloot, 1983) and this pollen could also be sourced from one of them. Larger grained Poaceae pollen is often attributed to cultivated cereal grasses and other European grasses. There is a rise in the number of Poaceae in the size range 30-50μm at 20 cm. Also there is a clear rise in the number of Fabaceae type-1 pollen at 20 cm. As Fabaceae pollen is known to have limited dispersal (Dodson, 1983), it is likely that this pollen was derived from plants on the swamp. Land owners reported a marked increase in abundance of *Viminaria juncea* after vegetation clearance in the catchment (Robertson, pers.comm.). The pollen of *Viminaria juncea* confers to the Fabaceae type-1 morphological class. Thus the increase in the abundance of pollen of this type at 20 cm could mark sediments accumulating in 1954.

As macroscopic charcoal is derived from the swamp or local catchment, observed peaks in its abundance may be correlated with dates of local fires. The catchment of the swamp was cleared and burned in 1953. There is an uniquely large macroscopic charcoal peak at 22 cm, which just precedes the rise in grass pollen, a decline in *Eucalyptus* pollen and rise in Fabaceae type-1 pollen. Together these markers strongly suggest that the sediments at 22 cm were deposited at the time of clearance of the catchment in 1953. Markers, the depths which they occur and the potential times they signify are shown in Figure 7.10.

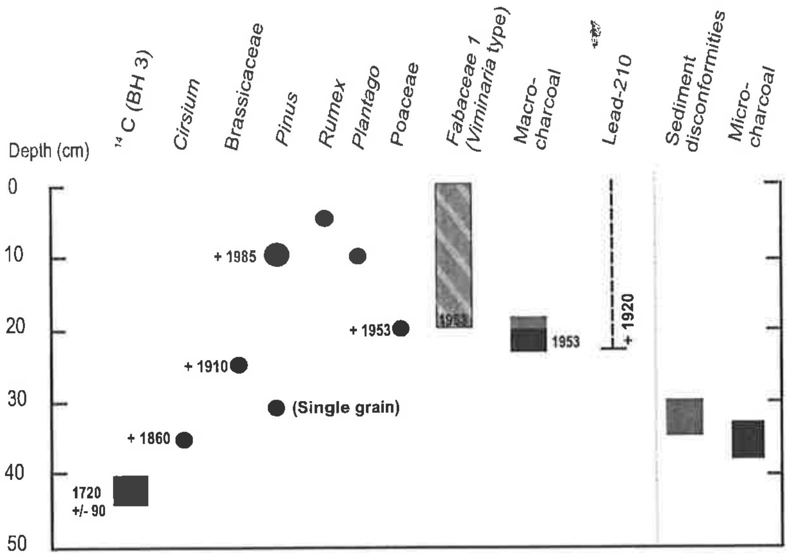


Figure 7.10 Summary of the chronological markers present in the upper 40 cm of core BH-2

7.5.1.4 Microfossils

The summary curves of the ecological groups within the terrestrial pollen complement identified in the upper 45 cm of BH2 sediments are presented in

Figure 7.11. The abundance of individual terrestrial taxa expressed as percentages of the terrestrial pollen sum, aquatic taxa as percentages of the aquatic pollen sum and the numbers of terrestrial and aquatic pollen types counted in each sample are also shown on

Figure 7.11. Most terrestrial pollen counts from sediments above 35 cm were under 100 grains. The same sediments had much higher numbers of aquatic pollen types (mean 591 ± 403). A zonation of the terrestrial pollen types revealed significant changes in the terrestrial pollen spectra at 31.5 and 42 cm. The upper two zones, pertaining in most part to the European period, are described below. Zone B-1 is described in Chapter 8.

Zone B-2 42-31.5 cm

The pollen of tree taxa is more numerous than that of shrub or herb, accounting for over 60% of the terrestrial sum. *Allocasuarina* <28 μm composes almost 30% of the sum at 41 cm but declines thereafter. *Allocasuarina* >28 μm is present at values of around 10%, except for a small rise to 20% at 32 cm. *Eucalyptus baxteri* type, *E. obliqua* type, *E. fasciculosa* type and *E. cosmophylla* type pollen are each represented at values between 5-10%. Chenopodiaceae pollen constitutes the greatest part of the shrub component. Trace amounts of *Xanthorrhoea*, *Leucopogon* type, *Banksia ornata* and

Fabaceae type 1 pollen are also present. Asteraceae (Types 1, 2 and 3) pollen dominates the herb component.

Carex type and *Baumea* type Cyperaceae together account for about 50% of the aquatic pollen sum at the bottom of the zone but decline to approximately half that value at the top. *Acacia* type 1 pollen rises dramatically in this zone from around 10% to 60%. *Leptospermum* spp. pollen is present at about 10% throughout the zone. *Goodenia* pollen is present at 20% at the base of the zone but declines to less than 5% by the top. *Myriophyllum* pollen are stable at values less than 10%.

Zone B-3 31.5-0 cm

Terrestrial pollen counts are low through this zone. Tree taxa decline, while shrubs increase slightly and herbs more markedly from the previous zone. All types of *Eucalyptus* pollen that were present in the previous zone, except *E. baxteri* type pollen, decline in representation. Both size classes of *Allocasuarina* pollen are present throughout the zone but show a small decline towards the top of the core. The shrub component of the zone is represented by sporadic occurrences of Proteaceae type-1 pollen, *Leucopogon* type, *Dodonaea*, *Muehlenbeckia adpressa*, *Boronia parviflora*, *Plageanthus* type pollen, Rhamnaceae and Liliaceae type-1 pollen. Chenopodiaceae and *Xanthorrhoea* pollen are consistently present through the zone. Poaceae increases from the previous zone, particularly that in the 30-50 μm size class. Asteraceae types 1, 2, and 3 are present in proportions similar to the previous zone, while Asteraceae type-4 and Liguliflorae increase. Exotic pollen is more abundant in this zone than below (refer to section 7.5.1.3).

Acacia type-1 pollen, which rose dramatically towards the top of the previous zone, continues to dominate the aquatic pollen spectra in the lower part of Zone B-1. It declines markedly at about 20 cm, where the representation of *Leptospermum* pollen dramatically rises sustaining high values to the top of the core. *Goodenia* and Cyperaceae pollen types decline from the previous zone. Monolete fern spores show a small but unsustained rise in representation at 20 cm. As with the previous zone *Myriophyllum* pollen is a persistent component of the aquatic pollen spectra, but it never accounts for more than greater than 12% of the sum.

7.5.2 Interpretation, core BH-2

7.5.2.1 Chronology

There is agreement between ^{210}Pb ages and the inferred ages from marker pollen types in the top 10-15 cm of the core. They both indicate that the top 10 cm represents the last ~20 years of deposition. The large macroscopic charcoal peak at 24 cm preceding a rise in Fabaceae type-1 and the decline in *Eucalyptus* and increase in Poaceae pollen are interpreted as reflecting catchment clearance in 1953. The ^{210}Pb CRS age model shows that sedimentation slowed above 20 cm and

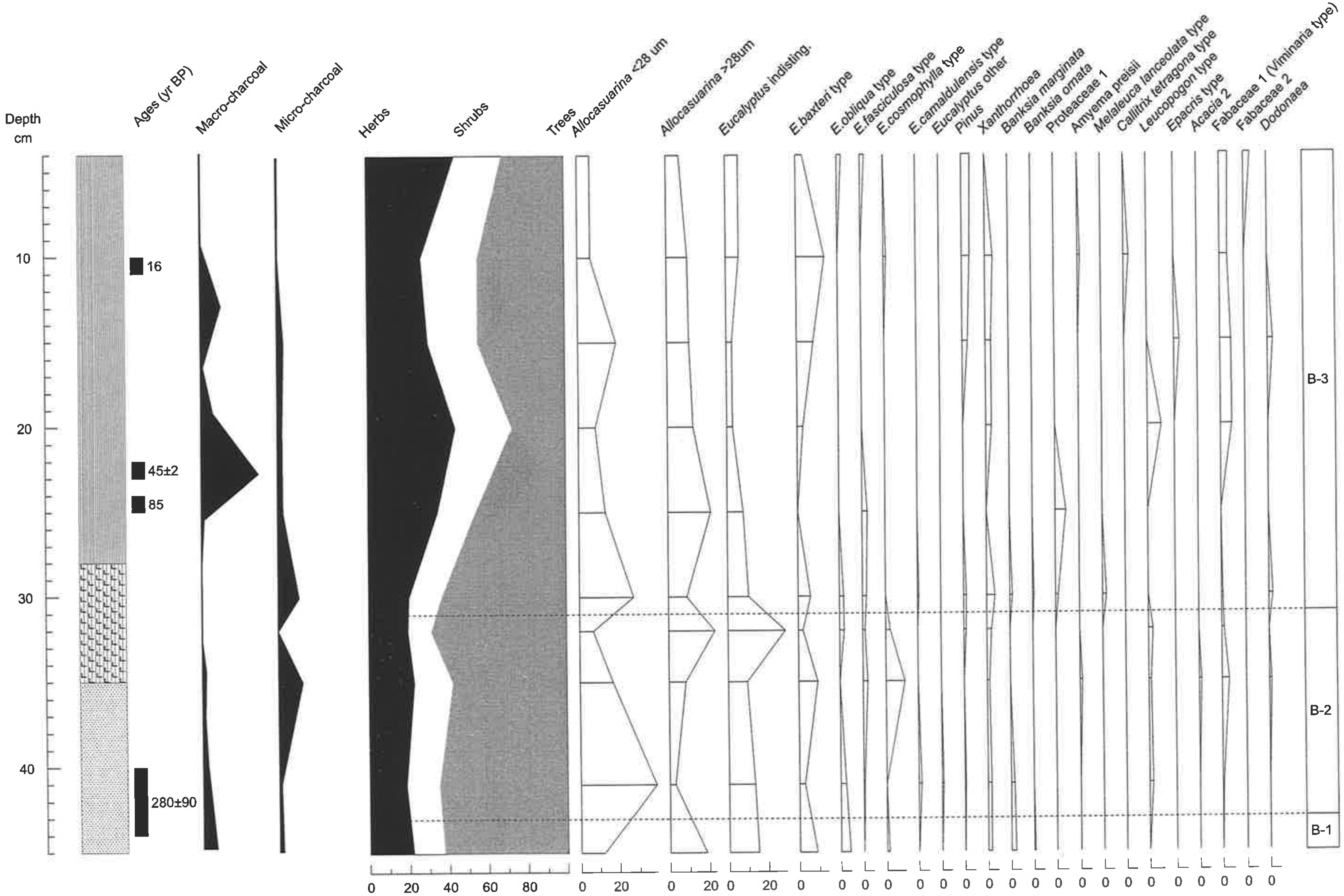
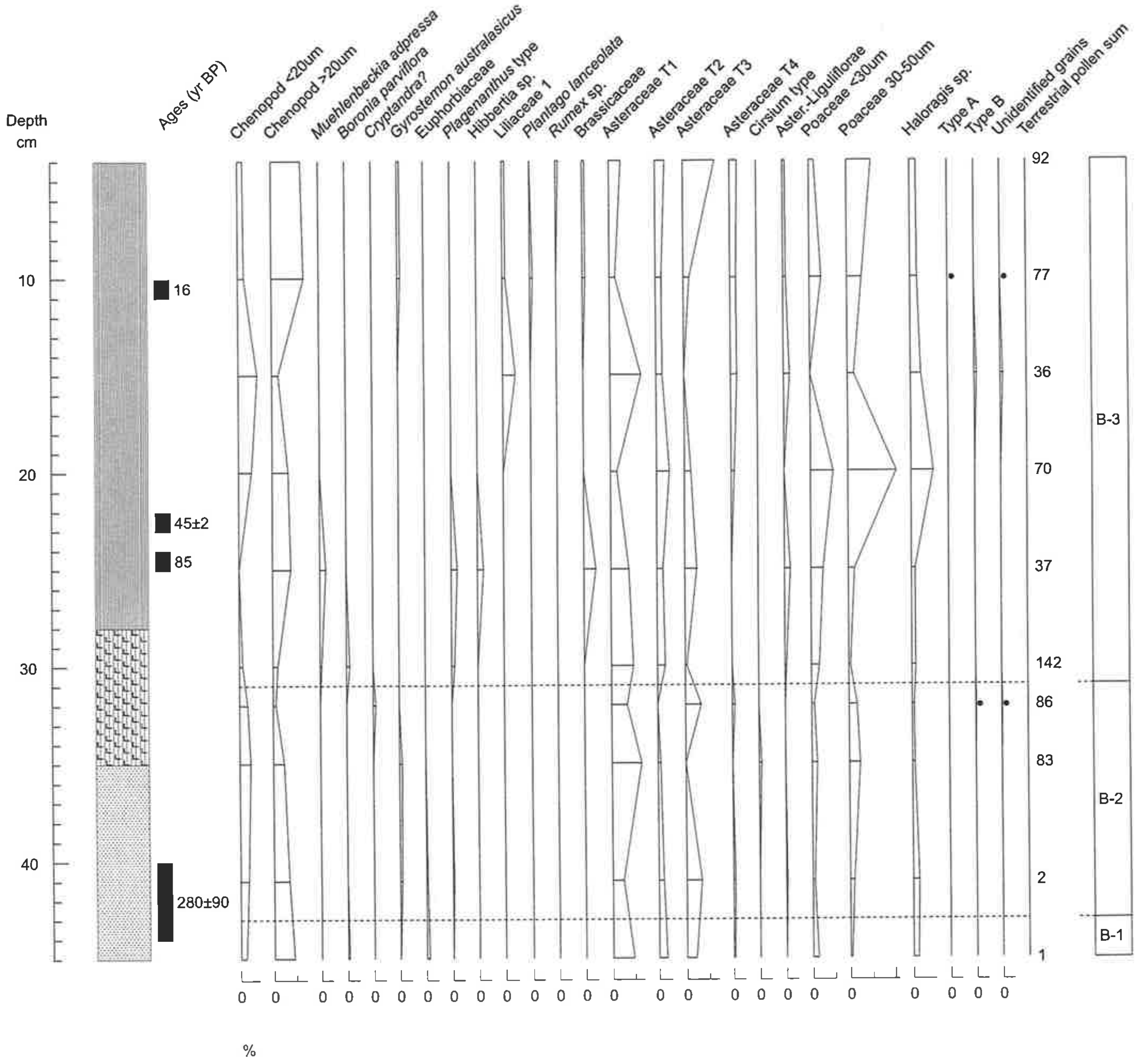
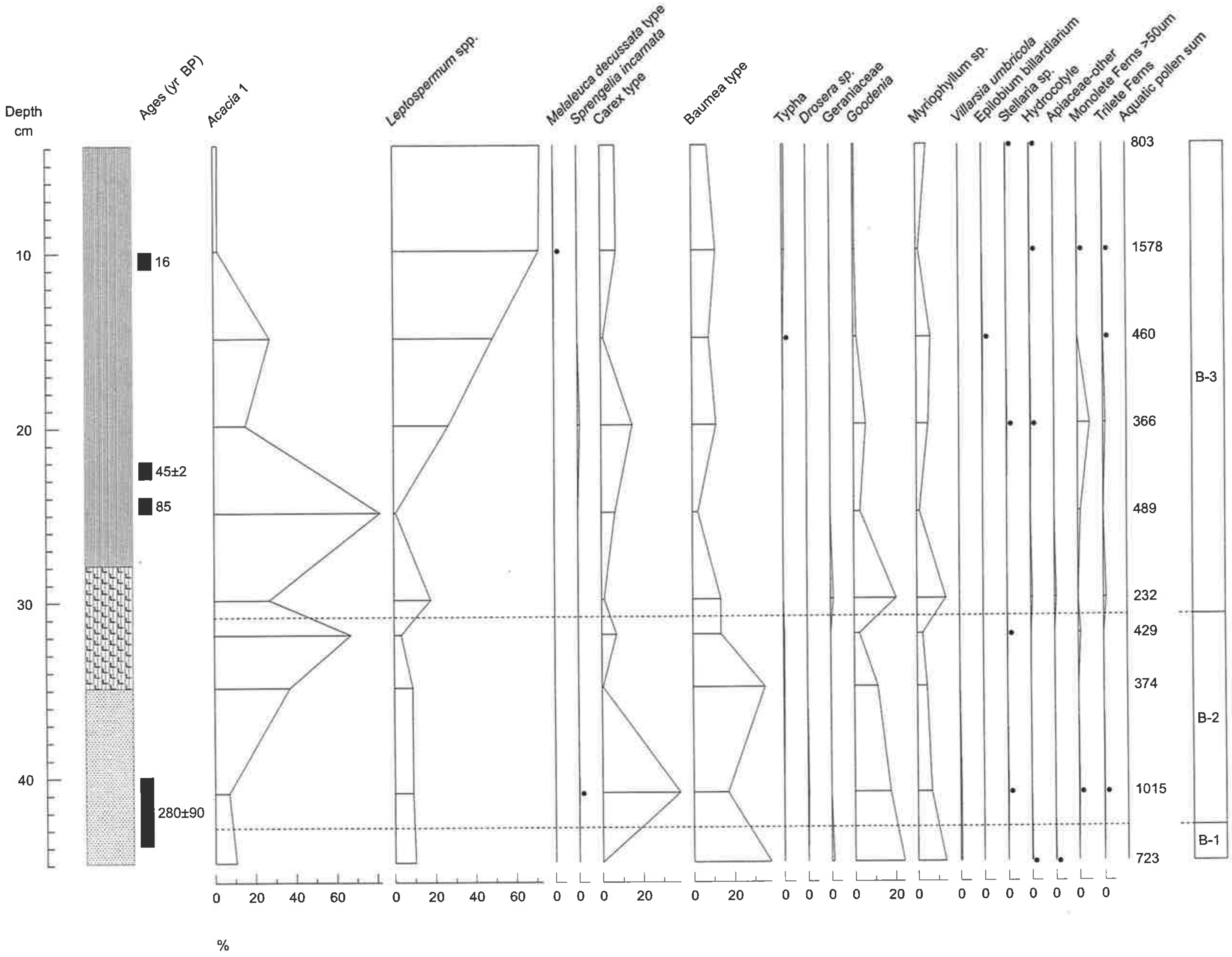


Figure 7.11 Pollen diagram of Boat Harbour Creek core BH-2 (0-45cm)


Depth
cm
10
20
30
40
Ages (yr BP)
16
45±2
85
280±90
Chenopod <20um
Chenopod >20um
Muehlenbeckia adpressa
Boronia parviflora
Cryptandra?
Gyrostemon australasicus
Euphorbiaceae
Plagenanthus type
Hibbertia sp.
Liliaceae 1
Plantago lanceolata
Rumex sp.
Brassicaceae
Asteraceae T1
Asteraceae T2
Asteraceae T3
Asteraceae T4
Cirsium type
Aster.-Liguliflorae
Poaceae <30um
Poaceae 30-50um
Haloragis sp.
Type A
Type B
Unidentified grains
Terrestrial pollen sum
92
77
36
70
37
142
86
83
2
1
B-3
B-2
B-1
0
%


Depth
cm
10
20
30
40
Ages (yr BP)
16
45±2
85
280±90
Acacia 1
Leptospermum spp.
Melaleuca decussata type
Sprengelia incarnata
Carex type
Baumea type
Typha
Drosera sp.
Geraniaceae
Goodenia
Myriophyllum sp.
Villarsia umbricola
Epilobium billardiarium
Stellaria sp.
Hydrocotyle
Apiaceae-other
Monolete Ferns >50um
Trilete Ferns
Aquatic pollen sum
803
1578
460
366
489
232
429
374
1015
723
B-3
B-2
B-1
0 20 40 60
0 20 40 60
0 0 0 20
0 20
0 0 0 0 20 0
0 0 0 0 0 0 0
%

dates suggest that the deposition of sediments at 24 cm occurred approximately 20 years earlier at *ca* 1930. ^{210}Pb could reach the swamp site in two ways: by deposition from the atmosphere and attached to in-washed sediments. Older ages could be explained by older sub-soil sediments being mixed with swamp peats (Wasson *et al.,* 1987). Exotic pollen types indicate that the sediments above 35 cm were deposited post-European settlement. Sediments marking European settlement are likely to be between 40-35 cm depth. That these sediments date to this time is further strengthened by the BH-3 radiocarbon date of 280 ± 90 years derived from the same stratigraphic section as matches to 44-40 cm in core BH2.

A preferred age-depth model derived from stratigraphic markers, lead and carbon dates and used to construct the vegetation history in the European period of the Boat Harbour Creek site was developed (Figure 7.12).

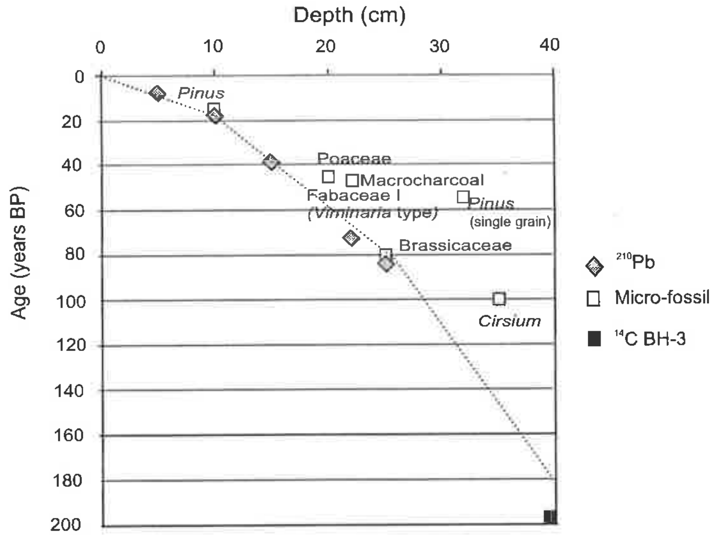


Figure 7.12 Preferred age-depth model for BH2 core using microfossil markers, ^{210}Pb and ^{14}C ages.

7.5.2.2 Terrestrial vegetation and fire history

Total terrestrial pollen counts are lower in the European period of core BH-2. Several reasons operating singly or possibly in conjunction with each other could explain this. Reduced pollen input could be due to increases in density of the swamp-margin shrubs *Acacia* and *Leptospermum* acting as a filter for trunk-space pollen. The pollen record indicates expansion of both these species in the European phase. Reduced terrestrial pollen inputs could also be a result of a decline in extra-local pollen production due to the removal of the terrestrial vegetation in the catchment. The catchment was cleared in 1953. Alternatively decreased pollen concentrations could be an artefact of higher sedimentation rates and which are evident in the upper section of the core. Most of the terrestrial pollen taxa identified were of local and extra-local origin the following record predominantly provides evidence of vegetation of the catchment surrounding the core site.

The record suggests that prior to European settlement the Boat Harbour Creek catchment supported a sclerophyllous woodland in which *Eucalyptus cosmophylla* was a dominant component. It may also have supported *E. baxteri* however the *E. baxteri* type pollen in the record could also be derived from *E. ovata* (Swamp Gum), which presently grows on the margins of the swamp. *Eucalyptus fasciculosa* and *E. obliqua* were represented, but to a lesser degree. The interpretation of the relative mix of the *Eucalyptus* types constituting the woodland from the relative abundances *Eucalyptus* pollen in the pollen record must be viewed with caution for the majority of grains were unable to be identified to type due to degradation of distinguishing features. Shrub forms of *Allocasuarina*, probably *A. muelleriana,* were present in the understorey. *Xanthorrhoea* and *Banksia marginata* were also shrubby components of the vegetation. Asteraceae were well represented in the understorey, while grasses had little representation. At this time microscopic charcoal levels were high and suggest changes to the regional and or local fire regimes, however this phase of high charcoal is not concurrent with significant changes in the vegetation.

Allocasuarina > 28μm pollen, attributed to *A. verticillata* (Kershaw, 1970), is present in relatively high percentages in pre-European sediments and then declines before increasing in representation in sediments that date to post catchment clearance. This pollen is likely to be regionally derived. The early peak and decline of *A. verticillata* suggests a regional decline in the species early in European settlement. Later increases in *A. verticillata* abundance are likely to be an artefact of low pollen counts in upper sediments. *Eucalyptus camaldulensis* pollen is present in low numbers early in European settlement, but is absent in later sediments. The record could be representing a regional decline of this species in the early phases of European settlement. Clearance of catchment vegetation is evident in the pollen record by marked declines in *Eucalyptus cosmophylla, E. baxteri* or *E.ovata* (*E. baxteri* type pollen), *Banksia marginata* and Asteraceae type 2 pollen and increases in grass pollen likely to be from non-native species which were planted after vegetation clearance. Various native species show localised peaks of abundance and these peaks are more likely to be artefacts of very low terrestrial pollen counts in these sediments than representing actual vegetation dynamics in the catchment. The proportional increase in shrub pollen is seen in the post-clearance phase period is largely due to a rise in Chenopodiaceae pollen. This increase is probably an artefact of regionally dispersed pollen showing a relatively increased signal due the decline in local vegetation extent, rather than an increase in local or regional Chenopodiaceae populations.

7.5.2.3 Swamp history

Prior to European settlement the Boat Harbour Swamp was a Cyperaceae-dominated wetland in which *Goodenia, Acacia* and *Leptospermum* were components. Early in European settlement *Acacia* begins to assume greater representation. The increase in *Acacia* is likely to be representing the expansion *of A. retinoides* on the swamp itself. Its increase is concurrent with the highest peak of macroscopic charcoal and phase where microscopic charcoal levels are at sustained and substantially higher levels than elsewhere. *Acacia* regeneration through seed germination is stimulated by fire and so its relative expansion is probably a direct response to intensified European firing of the swamp and or swamp fringes. Firing of the swamp surface itself may have been deliberately carried out, as it was in many other Fleurieu Peninsula swamps to provide fodder for stock (Duffield, 2000) or occurred incidentally as the surrounding catchment vegetation was regularly burned during the grazing phase of occupancy. Although the *Acacia*, due to the locally dispersive properties of its pollen, has been interpreted to represent swamp vegetation, some of the pollen may have been sourced extra-locally and represents an expansion of other *Acacia* species (*A. myrtifolia*) in the surrounding terrestrial vegetation. Wattle bark collection formed a major enterprise on the property containing the Boat Harbour Creek site from 1899 and regular burning was carried out to stimulate the expansion of *Acacia* (Williams, 1985). *Acacia* declines markedly at a time that is interpreted to be around that when the native vegetation of local catchment was cleared. From this time other Fabaceae increase (likely to be *Viminaria juncea*) and *Leptospermum* rises markedly. The expansion of *Leptospermum* and decline in *Acacia* could be marking a successional process after early European disturbances or reflecting responses to hydrological and or nutrient changes following vegetation clearance. The presence of *Viminaria* suggests that disturbance by fire was still being in operation as *V. juncea* is a short lived legume that requires fire for regeneration and unburned swamps have been noted to carry only dead or dying *Viminaria* (Murphett and Taplin, in Duffield, 2000). The expansion of *Leptospermum* could reflect hydrological changes to the swamp. *Leptospermum* favours drier ground and has been observed to expand at the expense of plants requiring more waterlogged conditions in swamps in the Fleurieu Peninsula in response to swamp drying (Duffield, 2000). While it could be surmised that vegetation clearance may have resulted in increased water input in the swamp through increased run off, and possibly a raising of the water table, the clearance of vegetation at Boat Harbour was at a time of regional agricultural development and expansion in the sclerophyll highlands. Increased water inputs may have been off set by over all declines in water availability though water diversion and abstraction by such processes as farm dam establishment. The dramatic increase in *Leptospermum* pollen could also be accounted for in part by the reduction in *Acacia* in the wetlands and surrounding vegetation following clearance and the cessation of regular burning.

Sedimentation rates through the European period as demonstrated in core BH-2 have not been constant. Those in the early part of European settlement are approximately 0.75 cm/annum, higher than those occurring after catchment clearance. It appears that over the early phase of settlement, when the land was subject to regular burning and rough grazing, increased sediment input from surrounding catchment resulted. The clay intrusion at around 33 cm is likely to be reflective of disturbance from this phase of occupancy and land use somewhere between 1890 and *ca* 1940. Sedimentation rates over the last 50 years have varied between 0.2 and 0.3 cm/annum. A lower sedimentation rate could reflect a decline in sediment inputs from the catchment or a decline in swamp productivity.

7.6 Deep Creek Tapanappa - Core DCT-1

7.6.1 Results

7.6.1.1 Stratigraphy

A 46 cm core was extracted from the Deep Creek Tapanappa site. The stratigraphy of the core and results of sediment analysis is shown in Figure 7.13. Dark silts and humic peats extended from the base of the core to 33 cm, only interrupted by a narrow dark sand intrusion at 42 cm. From 33 cm to 12 cm the herbacous peat content of the sediments began to increase as silt and humic peat content decreased. The sediments from 12 cm to the top of the core were composed of dark brown herbaceous and fibrous peats. Loss on ignition values increased up the core, with values rising markedly at 25cm. The dry weight of material increased with depth. These measures reflect an increase in inorganic material with depth.

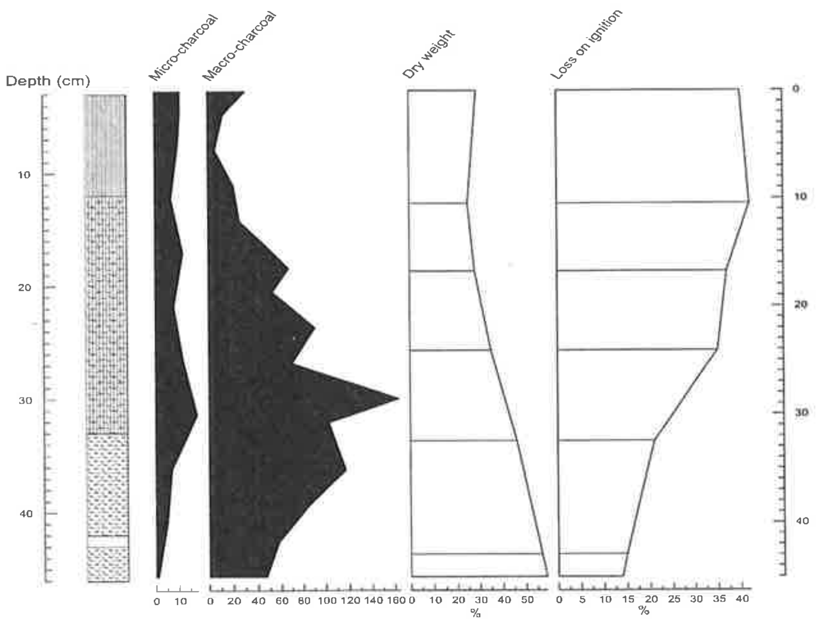


Figure 7.13 Lithology, microscopic charcoal, macroscopic charcoal and sediment characteristics of core DCT-2. (Percentage dry weight and loss on ignition).

7.6.1.2 Radiometric dating

Results of the ^{210}Pb and ^{137}Cs analysis of sediments are given in Table 7-5. The ^{210}Pb$_{ex}$ decreases rapidly in the upper 13 cm, reaching a value consistent with zero in the 13.5-18 cm section (˜ 2 g/cm^2 mineral sediment). However, significant ^{210}Pb$_{ex}$ is also observed at 25 cm depth (25±5 mBq/g), and significant negative values are observed at 20 and 33cm. Using the constant rate of ^{210}Pb supply (CRS) model, sediment at 2 cm dates at *ca* 1990, and sediment at 6.75 cm at *ca* 1958. Sediment ages then increase to *ca* 1896, at 20.25 cm. Younger sediments, *ca* 1962, are then seen at 24 cm depth.

Table 7-5 Depth profile values of excess ^{210}Pb and ^{137}Cs , ^{226}Ra gamma and age of sediments calculated using the CRS model from core DCT-3. Results are given against depth and ashed weight (cumulative mineral sediment (g/cm^2)).

Depth	^{137}Cs	Cum ash wt g/cm^2	SE	^{210}Pb$_{ex}$ (ash)	SE	^{210}Po$_{ex}$ (ash)	SE	^{226}Ra gamma (ash)	SE	cum Pb-Po ave extrapolated	Age (Po-Pb CRS)
0-4.5	14.7	0.20	1.2	142.80	10.16	115.45	8.57	101.2	1.8	39.86	8.68
4.5-9	2.8	0.46	1	42.00	9.77	27.08	5.29	100	1.8	15.04	39.64
9-13.5	0.4	1.07	0.7	2.30	7.06	9.72	3.83	99.8	1.5	7.06	63.65
13.5-18	-0.3	1.85	0.5	-0.60	5.02	-3.23	2.74	95.5	1.1	2.11	102.02
18-22.5	-1.5	2.96	1.1	-7.10	15.36	-11.71	3.47	92.4	2.2	3.60	85.01
22.5-27	0.1	3.72	0.5	4.10	5.32	25.26	4.54	76.7	1.1	14.06	41.77
27-31.5	-0.9	4.54	0.7	1.50	6.84	2.55	3.66	102.2	1.4	1.67	109.48
31.5-36	2.9	5.66	1.3	-60.70	9.62	-39.36	4.39	135.1	2.8		
36-40.5	-0.5	6.87	1.2	-5.70	8.25	4.03	3.57	85.7	2		
40.5-45	-2.2	8.01	0.8	-8.40	11.72	-1.91	2.64	99.5	1.7		

The presence of detectable ^{137}Cs in sediment below 9 cm suggests an age of pre-1958, the year corresponding to the first appearance ^{137}Cs in the sediment profile (Olley, 1988).

7.6.1.3 Microfossil markers

The core site is approximately 3km north-west of the sections surveyed in the 1840s Waitpinga Survey and approximately 8-10 km from the Rapid Bay and Yankalilla colonial-period settlements. It is approximately 8km from the core site from the forest plantations in the Fleurieu Peninsula of *Pinus radiata* which were established in 1912 and between 4-6 km from the large plantations established in 1934-45 on the Range Road. There are two plantations within 1-2 km from the core site which were planted in 1973 (Boat Harbour Block) and 1980 (Martins Block). A single grain of *Pinus* first appears in the core at 40 cm. Small but greater amounts were identified at 35 cm. Its presence rises from about 25 cm increasing to about 10 cm and increasing markedly from 5 cm. This most recent rise is likely to be reflective of pollen release from the most proximal planting to the core site. This was established in 1970 and would have been producing pollen by *ca* 1975. The relatively constant levels of *Pinus* pollen between 10 cm and 25 cm are likely to have been derived from more distant *Pinus* plantations, such as those on the Range Road which would have been producing substantial amounts of pollen between the years of 1940-1950 and after. The variations in the frequency of fossil *Pinus* pollen provides evidence for basis of an estimation of the age of the basal sediments of the core. The trace presence at 40 cm could be a contaminant, or mark the 1912 forestry plantations or trees planted by early agriculturists in the region. *Pinus* is absent at 45 cm and so it can be argued that the basal sediments are, at their youngest, late nineteenth century in age. They may however be older and have been deposited before European settlement.

Other pollen types which provide evidence to establish a chronology for core DCT2 are Poaceae 50-80μm, which is possibly rye grass, *Artemesia vulgare*, an introduced Asteraceae weed, *Cirsium*, likely to be *C. vulgare*, Brassicaceae and exotic Fabaceae types, likely to be Subterranean and White Clover. All appear in, and are exclusive to, zone D-4. They are indicators of either disturbance or agriculture and thus suggest that these sediments were deposited after the clearance of native vegetation and the cultivation of the land in the catchment in 1938.

Markers, the depths at which they occur and the estimated date they signify are shown in Figure 7.14.

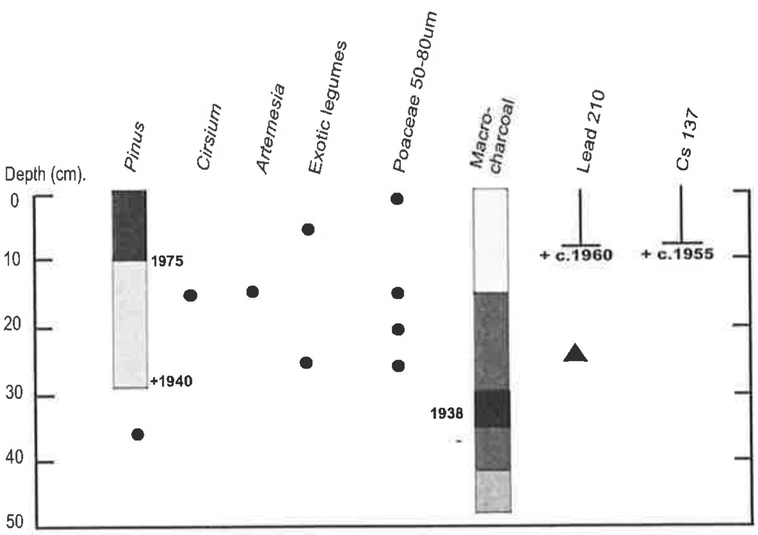


Figure 7.14 Summary of the chronological markers present in core DCT-2.

7.6.1.4 Microfossils

Concentrations of microscopic charcoal fluctuated along the entire DCT2 core, however the record is distinguished by a significant and unparalleled rise between 30-32 cm. Macroscopic charcoal levels are relatively high at the base of the core, increase to a maximum level around 30-32 cm, and remain high to about 17 cm, from which point they decline markedly.

Fossil pollen was reasonably well preserved throughout core DCT-2, although preservation was better and concentrations higher in the more organic-rich top 25 cm. An average of 326 ± sd 110 grains per sample were counted comprising a total of 74 pollen and spore taxa. Most taxa were present in low numbers accounting for less than 5% of the pollen sum. Of these, 17 taxa (22.6%) were of aquatic or aquatic-terrestrial ecotone origin. Unidentified pollen types accounted for 2.6% of all taxa. The remaining ~75% of pollen recovered were from terrestrial plants. Six of the terrestrial taxa could be confidently identified as originating from non-native introduced species: *Pinus, Plantago lanceolata, Artemesia vulgarae,* Brassicaceae, Asteraceae-*Cirsium* type and leguminous pasture types. A survey of the flora near the core site and in the catchment of the swamp (Table 7-2) revealed that the majority of the fossil pollen taxa had a local origin (pollen travelled up to 10 m), or extra-local origin (pollen travelled within 100 m) and so were derived from the vegetation surrounding the swamp and that on the slopes directly surrounding the core site respectively. About one third of aquatic pollen taxa identified in the upper sediments were not found present in the swamp vegetation directly surrounding the site (eg *Opercularia* sp., *Stellaria* sp., *Epilobium* sp., *Calystegia* sp.) yet commonly occur in swamps and watercourses in the region, suggesting a proportion of pollen has a water borne and regional origin.

The pollen diagram (

Figure 7.15) presents summary curves of the relative components of terrestrial ecological groups, individual terrestrial types expressed as percentages of the total terrestrial pollen sum (herbs, shrubs and trees) and aquatic types as percentages of the aquatic pollen sum (ferns and swamp plants). Four statistically significant zones, taking into account terrestrial herb, shrub and tree taxon, excluding *Pinus* pollen, were delineated. The zones are as follows:

Zone D-1 46- 42.5 cm

A single sample is represented in this zone. Tree and herbaceous taxa are present in similar proportions each accounting for about 40% of the terrestrial pollen sum. Shrubs account for the remaining 20%. *Allocasuarina* and *Eucalyptus* pollen types comprise the bulk of the tree component and 27% and 23% of the terrestrial sum respectively. The majority of *Eucalyptus* grains were indistinguishable to type. *Banksia marginata* pollen was recorded in low numbers. The shrub component of the sum was made up of low percentages of Proteaceae type-1, derived from either *Hakea* or *Grevillea*, *Isopogon ceratophyllus, Xanthorrhoea*, *Epacris*-type, Euphorbiaceae, *Dodonaea* and *Acacia* type-2. Of these *Xanthorrhoea* was the most abundant. Proteaceae-type1 and *Isopogon ceratophyllus* are unique to this zone. The herbaceous component of zone D-1 is composed primarily of various classes of Tubuliflorae-type Asteraceae and Liguliflorae-type Asteraceae. Poaceae pollen was poorly represented.

Ferns spores occupy 65% the wetland sum in this zone and this percentage is composed almost wholly of trilete spores (likely to be derived from *Adiantum aethiopicum* and/or *Gleichenia microphylla*). *Acacia*-type-1 and Cyperaceae pollen are the major components of the non-fern components of the aquatic spectra, while *Leptospermum* pollen is virtually absent.

Zone D2 42.5-32.5 cm

The proportions of tree (40-60%), shrub (20%) and herb (30%) taxa in the terrestrial pollen sum are very similar to those in zone D-1. *Eucalyptus* pollen types account for approximately 40% of the terrestrial sum and *Allocasuarina* (>28 μm), the other major tree type, approximately 10%. *Allocasuarina* (>28 μm) shows a decline in representation from the previous zone. *Eucalyptus baxteri, E. fasciculosa and E. cosmophylla* types are present and each represent less than 10%. Indistinguishable *Eucalyptus* grains are present in equal number to the sum of all *Eucalyptus* grains identified to type. *Xanthorrhoea* and Chenopodiaceae (>20 μm) pollen are the main shrub taxa represented, however *Banksia marginata* is present in the lower section of the zone. As with Zone D-1, the herbaceous component of this zone is composed primarily of Tubuliflorae-type and

Liguliflorae-type Asteraceae and they show little change in representation from the previous zone or within this zone. Poaceae pollen represents less than 10% of the terrestrial sum.

The aquatic sum is dominated by trilete fern spores, however they decline toward the top of the zone and monolete fern spores appear for the first time. *Baumea* type Cyperaceae increases in this zone (from 20-28%). *Acacia*-type1 is consistently present at approximately 10% of the aquatic sum and *Melaleuca decussata* type, *Leptospermum* spp. and *Myriophyllum* are present in small amounts only. *Goodenia* is present at 5%.

Zone D-3 32.5-27.5 cm

The proportion of shrub taxa declines from the previous zone while tree taxa show an increase. The herbaceous component of the spectrum remains largely unchanged. Zones are distinguished by differences in *Allocasuarina* pollen of both size classes. It is less abundant here than in lower zones. Undetermined-type *Eucalyptus* grains are more frequent, while proportions of other *Eucalyptus* types remain largely the same, with the exception of the appearance a few *E. camaldulensis* pollen grains. Chenopodicaceae (>20 μm), *Acacia* type 2 and *Xanthorrhoea* pollen account for the bulk of the shrub component. Poaceae (<30 μm) pollen shows a slight increase, while Asteraceae remains generally unchanged from zone D-2 in types and frequency.

The components of the aquatic taxa, and their relative abundances, in this zone are also similar to the lower zone with the exception the rise in monolete fern spores and a marked decline in the number of trilete fern spores from zone D-2. *Carex*-type Cyperaceae and *Goodenia* and *Hydrocotyle* pollen are represented in higher proportions than lower zones.

Zone D-4 27.5 cm- 0 cm

Tree taxa dominate the upper 15 cm of this zone but decline to almost equal proportions with herbaceous taxa in the lower 7 cm. Shrub taxa comprise only 10-15% of the pollen sum which is markedly lower than in previous zones. *Eucalyptus* dominates the tree component of the pollen sum and *Allocasuarina* is present in only small proportions (~5%). *Eucalyptus obliqua*-type and *E. baxteri*-type are the dominant classed *Eucalyptus* types present (8-10% each). *Eucalyptus fasciculosa* and *E. cosmophylla* were consistently present through the zone but never accounted for more than 5% of the sum. Indistinguishable *Eucalyptus* grains comprised 20-30% of the pollen sum. Small numbers of various shrub types are sporadically recorded in this section eg. *Epacris*-type, *Dodonaea*, Pea-types 1 and 2, *Muehlenbeckia adpressa, Gyrostemon australasicus*. Poaceae types and Liguliflorae-type Asteraceae were the best represented herbaceous components of the pollen spectra. Poaceae (<30 μm) increased between 15 and 27.5 cm to levels higher than in zone D1 or the upper-most sample of this zone. Non-native pollen types are more numerous in this zone than previously, with *Artemesia vulgaris*, exotic Fabaceae types, *Plantago lanceolata* and *Cirsium*-type Asteraceae grains all appearing sporadically. *Pinus* is well represented to 25 cm but its presence increases markedly in the upper 10 cm.

The swamp component of this zone is distinguished by increasing representation of *Leptospermum* spp., fern spores and high proportions of Cyperaceae. Other herbaceous swamp species, such as *Myriophyllum, Opercularia* sp., *Stellaria* sp. were infrequently observed. *Baumea* pollen is present throughout this zone but to a lesser degree from 40 cm. *Euphrasia collina*, *Calystegia sepium* and *Sprengelia incarnata* appear in low numbers for the first time in this zone for the record.

7.6.2 Interpretation, core DCT-2

7.6.2.1 Chronology

The ^{137}Cs and ^{210}Pb -based chronology suggests that the top approximately 10 cm of sediments were deposited prior to 1962. These dates are in agreement with the *Pinus* peak at 5 cm marking *ca* 1970-1980. Sediments between 13.5-18 cm have virtually no lead signal suggesting a pre-1880 date. Extrapolation of the sediment accumulation rate of the upper 13 cm (0.18 cm/y) over greater depths yields ages which are much older than indicated by *Pinus* and other chronological marker pollen types in the top 25 cm. It is possible that the apparent ^{210}Pb accumulation rates in the top 9 cm are not typical of accumulation rates prior to 1958. Faster sediment accumulation rates prior to 1958 would not only explain pollen and charcoal data, but provide explanation of the appearance of $^{210}Pb_{ex}$ at 24 cm depth. Rapid accumulation prior to *ca* 1960 could have diluted concentration and so activity of fallout ^{210}Pb in sediment below 9 cm, making it undetectable between 13 and 27 cm. The appearance of $^{210}Pb_{ex}$ at 25 cm depth could be then explained by a period of less rapid accumulation or by input of top soil with a higher lead signal from elsewhere in the catchment (Wasson *et al.*, 1987). However it cannot be discounted that sediment mixing could account for the appearance of $^{210}Pb_{ex}$ at 25 cm.

Exotic pollen types suggest that sediments above 40 cm post-date the arrival of Europeans. The presence of high levels of macroscopic charcoal from around 40 cm supports this interpretation as the charcoal probably reflects the regular firing carried out during the grazing phase of occupancy. The relatively steep slopes surrounding the swamp would have ensured that much charcoal would in-wash during rainfall events that followed catchment fire. Burning for grazing purposes has not occurred in the district since 1960 and sediments younger than 1960 show low amounts of macroscopic charcoal. The largest peak of macroscopic charcoal, present at 31 cm, could mark catchment burning during the partial clearance of native vegetation cover in 1938 or the large wild fire the region experienced in 1934. The subsequence appearance of exotic pollen types indicative of

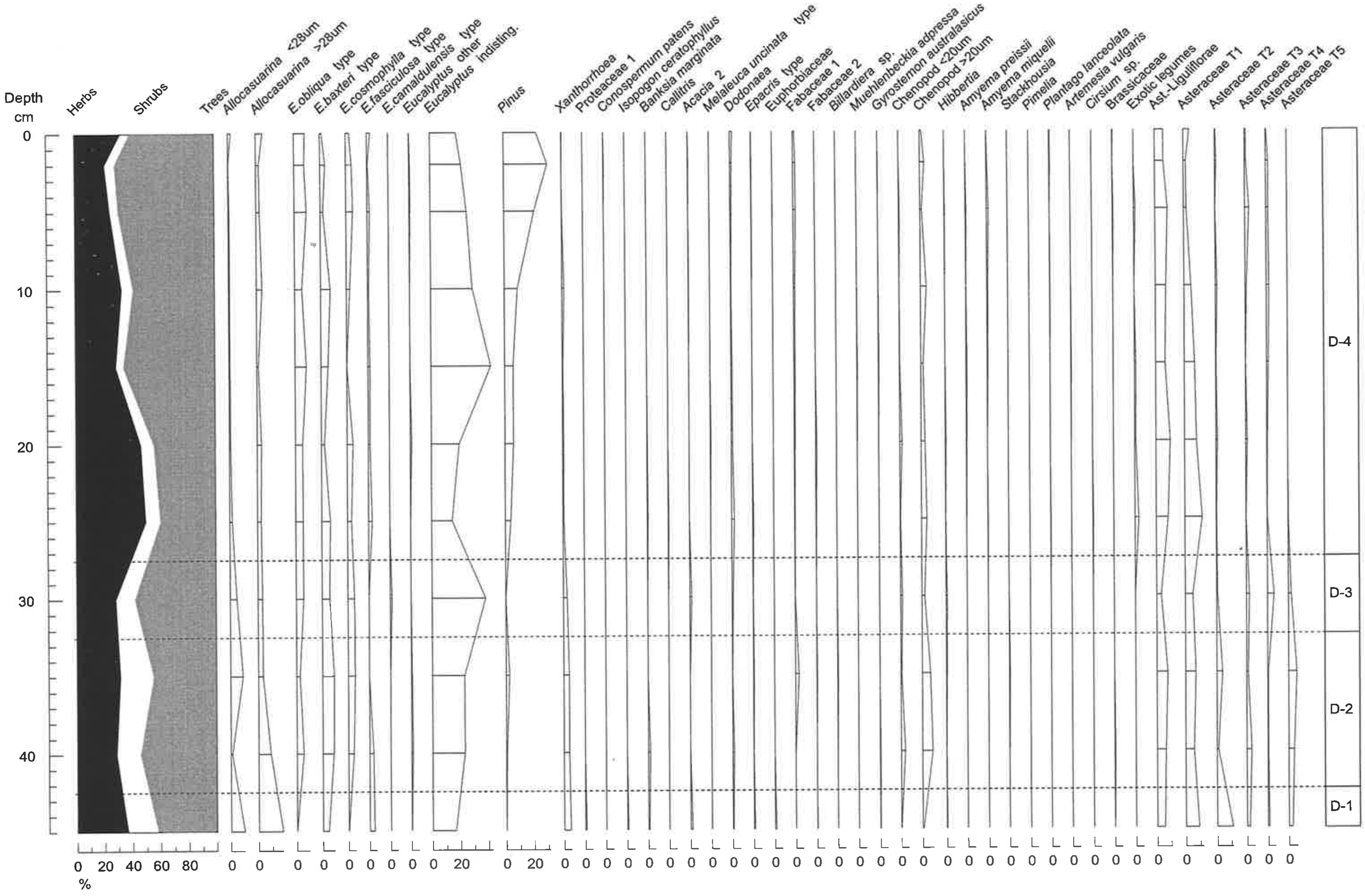
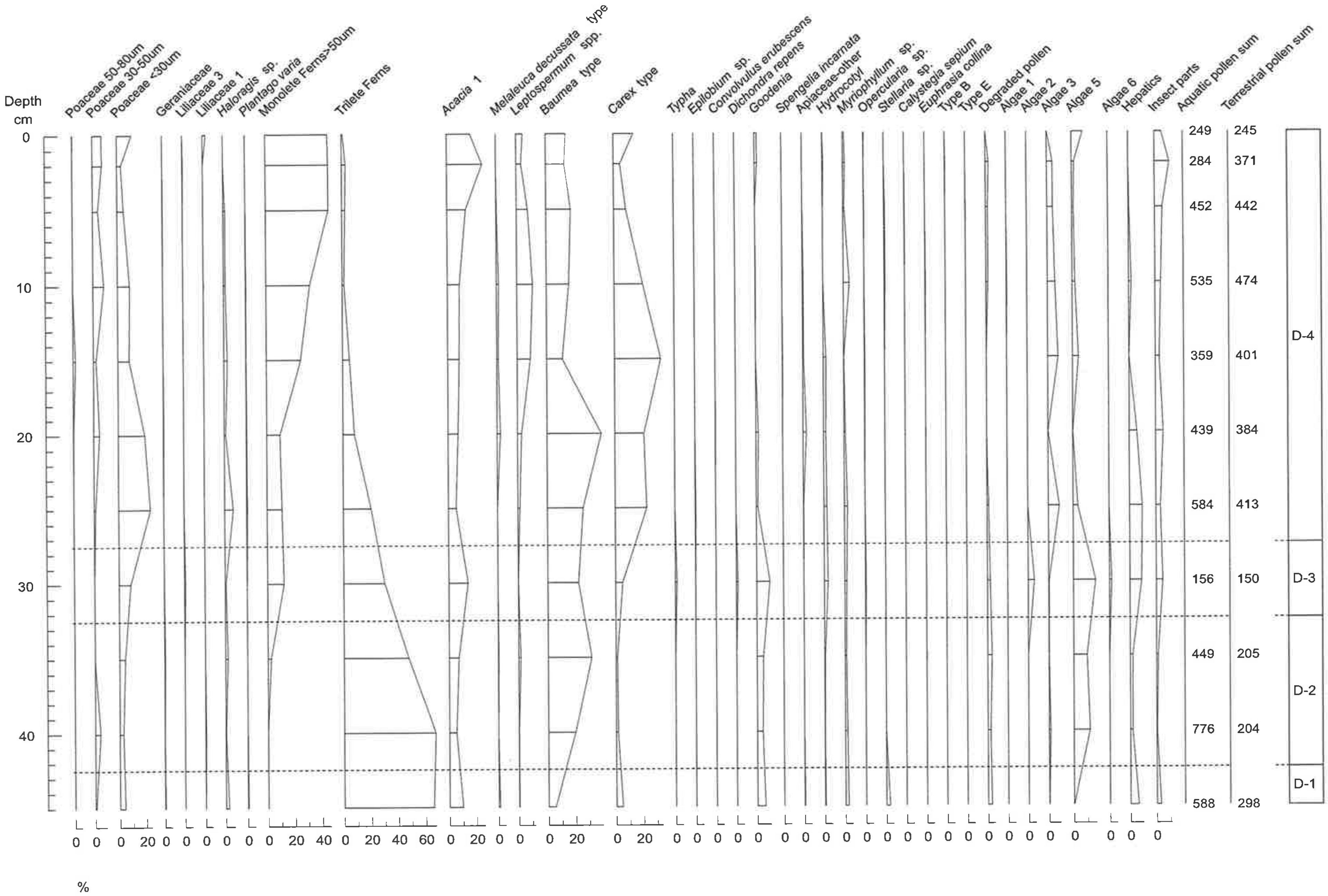


Figure7.15 Pollen diagram from the Deep Creek Tapanappa core DCT-2.


Depth
cm
0
10
20
30
40
Poaceae 50-80um
Poaceae 30-50um
Poaceae <30um
Geraniaceae
Liliaceae 3
Liliaceae 1
Haloragis sp.
Plantago varia
Monolete Ferns>50um
Trilete Ferns
Acacia 1
Melaleuca decussata type
Leptospermum spp.
Baumea type
Carex type
Typha
Epilobium sp.
Convolvulus erubescens
Dichondra repens
Goodenia
Spengelia incarnata
Apiaceae-other
Hydrocotyl
Myriophyllum sp.
Opercularia sp.
Stellaria sp.
Calystegia sepium
Euphrasia collina
Type B
Type E
Degraded pollen
Algae 1
Algae 2
Algae 3
Algae 5
Algae 6
Hepatics
Insect parts
Aquatic pollen sum
Terrestrial pollen sum
249 245
284 371
452 442
535 474
359 401
439 384
584 413
156 150
449 205
776 204
588 298
D-4
D-3
D-2
D-1
0 0 0 20 0 0 0 0 0 0 20 40 0 20 40 60 0 20 0 0 0 20 0 20 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
%

cultivation reinforce the interpretation that the peak marks this time. If it does then it indicates that between that between *ca* 1930 and *ca* 1960 sediments accumulated at a rate of 0.84 cm per year. This is an accumulation rate almost 8 times greater than has occurred over the last 40 years. This sedimentation rate agrees with the proposed explanation for the lack of lead signal in these sediments. If the bottom sediments, dating around European settlement, are used to calculate a sedimentation rate, a lower pre-1960 rate is obtained than that calculated using the macroscopic charcoal peak marking 1930. However this rate is still higher than that evident post-1960.

A preferred age-depth model for core DCT-2 is presented in Figure 7.16. Neither radionucliotide dating or stratigraphic markers provide an unambiguous chronology for the length of core DCT-2. The upper 10 cm are dated with relative surety. Pollen and charcoal records suggest that the bottom-most sediments are pre-European, but the chronology of the middle part of the core between 40-10 cm is tentative.

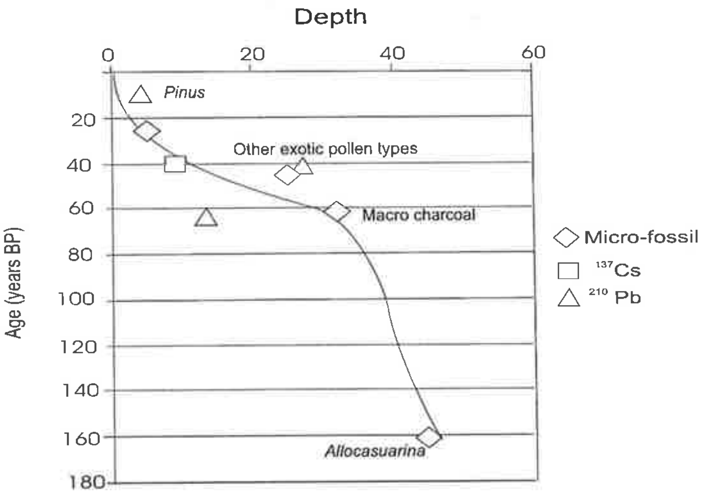


Figure 7.16 Preferred age-depth model for DCT-2 core using microfossil markers, ^{210}Pb and ^{137}Cs dates.

7.6.2.2 Terrestrial vegetation and fire history

As with the Boat Harbour Creek Core, DCT-2 predominantly provides evidence of vegetation of the catchment surrounding the core site. For the time span covered by the core, the vegetation has been dominated by mixed *Eucalyptus* forest and scrub. The relative proportions of *Eucalyptus* pollen types, *E. obliqua*-type, *E. fasciculosa*-type, *E. baxteri*-type and *E. cosmophylla*-type, do not vary greatly in the pollen record suggesting that the *Eucalyptus* forest and low woodland mix has been relatively stable throughout the period of European occupation. Unlike the tree taxa, shrub taxa do not remain constant through the sequence. Shrub taxa are more highly represented in the early European and pre-European sediments. Shrub representation declines to a steady 10% value in the post-clearance phase, possibly indicating a reduction in the proportion and diversity of shrub taxa in the vegetation. It should be noted that this reduction in shrub taxa is coincident with major changes to swamp flora and so it is also possible that the reduction in shrub-derived pollen is due to changes to taphonomic processes. However, on consideration of the local fire history of the site, it would not be unreasonable to interpret changes to the fire sensitive components of the shrub pollen spectra as reflecting actual changes in the vegetation. Proteaceae type-1 pollen, likely to be from *Hakea rostrata*, and *Isopogon ceratophyllus* are both unique to the pre-European period. Proteaceae pollen is generally under-represented in the pollen record (Chapter 3 and Dodson, 1988). The decline in these taxa is concurrent with increases in fossil charcoal from both the microscopic and macroscopic record. These magnitude of these charcoal peaks, particularly that in the macroscopic record, suggests they are the result of the large, hot, local fires (Clark, 1983) could be expected to have occurred during the grazing phase of occupancy when deliberate and regular burning which was carried out. *Xanthorrhoea* pollen declines from the pre-European to the post clearance phase. This decline is possibly reflecting impacts of the yacca harvesting industry, strongly active between 1880-1920, on local *Xanthorrhoea* populations.

A number of Asteraceae pollen types and *Goodenia* (possibly *G. ovata*) declined in representation from the early to more recent phases. It is not possible to determine whether the decline reflects changes to swamp fringe or catchment vegetation as taxa in both areas could be represented by these pollen types. If the pollen types are of extra-local origin swamp changes, from a more open creekline to a closed sedge and *Leptospermum* swamp, could explain their displacement.

Allocasuarina pollen of both size classes changes substantially between the pre-European and the clearance phase. It is likely that the larger size class *Allocasuarina,* derived from *A. verticillata,* is of regional origin and its decline represents regional clearance of this species in the nineteenth century. The decline in representation of the smaller grained *Allocasuarina* occurs most prominently at the clearance phase (zone D-3). *Allocasuarina muelleriana* is a dominant understorey component of *E. baxteri - E. cosmophylla* low woodland which covers part of the upper reaches of the core-site catchment and this community is likely to have experienced reduction in extent through clearance in 1938. It is possible that this reduction is reflected in the pollen record.

7.6.2.3 Swamp history

Prior to European settlement, and in the early phases of settlement, the site appears to have been a small silty wetland and more creek-like than it is today. It was fringed by some *Acacia*, Cyperaceae and by the creek bank colonising *Adiantum aethiopicum* (common maiden hair fern) and *Gleichenia microphylla* (coral fern). The basal sediments from this time are characteristic of those which accumulate in creek line terraces; being mainly fine and black alluvial silts containing coarse grained sand unconformities. Domination of the flora by *Gleichenia* is often characteristic of swamps that have been ungrazed and unburned for long periods in the Fleurieu Peninsula (Taplin and Murfett, 1993). At a time which has been interpreted as likely to be that when the upper reaches of the catchment was burned and cleared, as macroscopic charcoal is at its greatest abundance and sedimentation rates are high, the swamp flora dramatically changes; *Blechnum* spp. ferns (water ferns) replace *Adiantum* and *Gleichenia, Leptospermum* spp. colonise the site and Cyperaceae expands. Concurrent with these vegetation changes, sediments become more peaty and characteristic of those formed in sedge and fern swamps. *Blechnum*, Cyperaceae, *Leptospermum* and *Acacia* continue to persist to the present day.

7.7 Springs Road, core SR-2

7.7.1 Results

7.7.1.1 Stratigraphy and chronology

The stratigraphy and results of the sediment analysis of Springs Road core (SR2) are shown in Figure 7.17. The bottom 6 cm were composed of dark brown clays. From 40-30 cm humic peats are mottled with orange clays. Sediments from 30-24 cm are humic peats and dark brown silts. Dark brown herbaceous peats dominated the top 24 cm of the core with coarse humic matter increasing to the surface. The top 8 cm of peats were mottled with orange clays. Rootlets and preserved stems were found throughout these strata. Loss on ignition values are low in the deeper silty and clay dominated sediments, but distinctly increase from 24 cm to the top of the core. The dry weight shows a strong inverse trend with the more inorganic sediments of the lower strata having higher dry weight values.

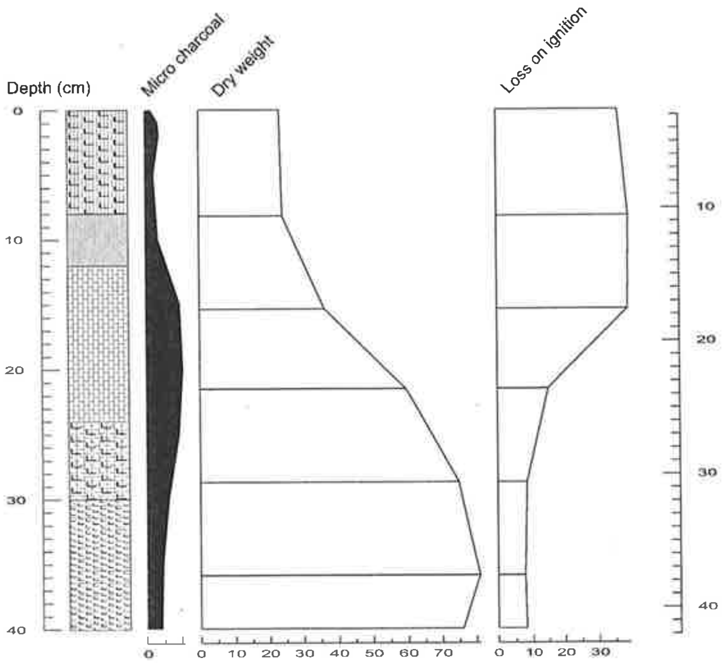


Figure 7.17 Lithology, microscopic charcoal and sediment characteristics of core SR-2. (Percentage dry weight and loss on ignition).

A tentative age model for the core is derived using chronological-marker pollen types. The *Pinus* plantation directly adjacent to the SR2 catchment was planted between 1959-1962 and this time could be expected to be marked in the record with a substantial increase in *Pinus* pollen. *Pinus* pollen rises markedly at 15 cm and thus sediments above this were probably deposited over the last

35 years. *Cirsium*, Brassicaceae and *Plantago lanceolata* pollen, were also recorded in the upper 15 cm, and exotic legume pollen at 20 cm, supporting this chronology. Rye-type Poaceae pollen has the potential to be a useful marker as it was first widely planted in the region from *ca* 1950. It is found with small amounts of *Pinus* and *Rumex* at 25 cm, suggesting sediments at this level are not likely to be older than 50 years (*ca* 1950). The higher levels of *Allocasuarina* >28 μm below 35 cm suggests that these sediments date to early in the European period, and are possibly pre-European. A single and well preserved grain of *Cirsium* pollen occurred at 40 cm, yet the sample at 35 cm is without exotic pollen of any type. This grain could be a contaminant or mark early European-period sediments as *Cirsium vulgare* was first recorded in the Yankalilla district in 1850, and declared a noxious weed in 1851 (Kloot, 1983). Core depth and marker pollen presence are shown in Figure 7.18 and an inferred age-depth model derived from marker pollen is shown in Figure 7.19.

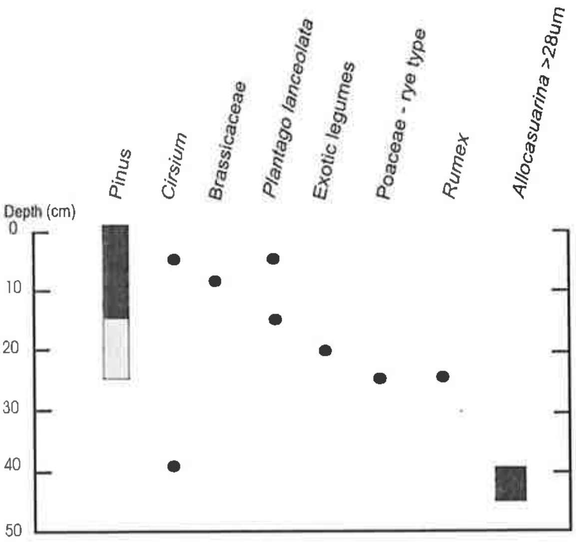


Figure 7.18 Chronological marker pollen types in core SR2

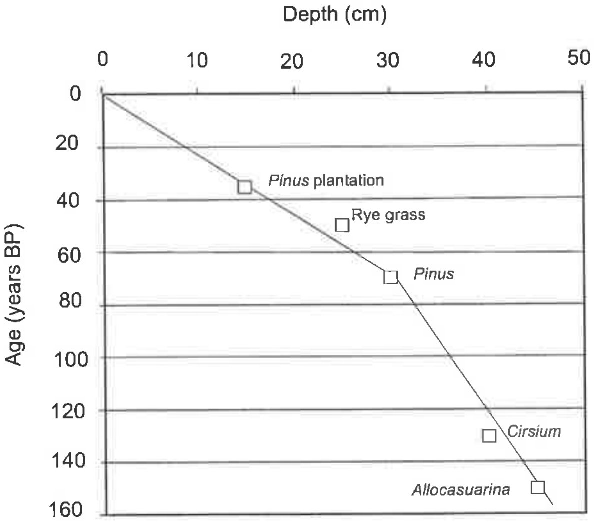


Figure 7.19 Inferred chronology of core SR2.

7.7.1.2 Microfossils

Microscopic charcoal was recorded in all samples, with levels highest between the depths of 15 and 25 cm.

Entire slides were counted for pollen, resulting in an average count of 226 ± sd 112 pollen grains from terrestrial species and 58 ± sd 38 from aquatic species. Fossil pollen was well preserved in sediments above 35 cm but poorly preserved below this depth. A total of 65 pollen and spore taxa were identified from SR-2. Most of these taxa accounted for less than 5% of the pollen sum of most samples. Figure 7.20 presents (1) summaries of the ecological groups, herbs, shrubs and trees and (2) individual terrestrial taxa as percentages of the terrestrial pollen sum and aquatic taxa as a percentage of the aquatic sum. *Pinus* pollen was excluded from the terrestrial pollen sum and also excluded from the zonation analysis given that local vegetation dynamics are the focus of interest. Three statistically significant zones in the Springs Road sequence were distinguished. The zones are described below.

Zone S-1 40-37.5 cm.

Trees, mostly *Eucalyptus* types and *Allocasuarina*, accounted for over 80% of the pollen sum. Few of the *Eucalyptus* grains were identifiable to type as the preservation of the pollen was poor. *Allocasuarina* (>28 μm) pollen is at its highest level of abundance in the core, accounting for about 10% of the terrestrial sum. *Allocasuarina* (<28 μm) is also present at about 10%. Shrub taxa were not numerous, accounting for only 10% of the sum and *Xanthorrhoea* type pollen contributed to most of this component. Traces of Proteaceae type-1 pollen were recorded. Herbs also were poorly represented in this zone, contributing to only 8% of the sum. The herb component was composed of Poaceae 30-50 μm and Tubuliflorae-Asteraceae types. Exotics were largely absent from this zone, with the exception of a single grain of *Cirsium*-type Asteraceae pollen.

Aquatic taxa were not present in high numbers, only 23 grains in total were counted. Cyperaceae, *Baumea*-type and *Carex*-type, monolete and trilete fern spores, and *Epilobium* are the major constituents of the sum.

Zone S-2 37.5-27.5 cm

Tree taxa accounted for 71-72% of the pollen sum in this zone and shrub and herbaceous taxa 3-8% and 19-25% respectively. Tree taxa were dominated by *Eucalyptus* types, accounting for 40-45% of the terrestrial sum. *Allocasuarina* (> 28 μm) shows a marked decline through this zone while the smaller grained *Allocasuarina* shows a small decline. Herb and scrub components are largely unchanged from the previous zone S-1. Smaller grained Poaceae are in greater abundance than larger grain types. Tubuliflorae-type Asteraceae T3, the only member of this group to show different proportions between zones, increases here. A single grain of *Pinus* pollen was found at 30 cm, but the zone is largely without confidently-identified pollen from exotic taxa.

Aquatic pollen counts were much higher in this zone than the previous. *Baumea*-type Cyperaceae is the most abundant aquatic taxon. *Leptospermum* spp. appear for the first time in the core and increases in representation through this zone. Trilete fern spore numbers were variable. *Haloragis, Stellaria* and *Myriophyllum* were all present in low amounts accounting in total for less than 5% of the sum.

Zone S-3 27.5-2 cm

As with zone S-2, the pollen spectra of this zone is dominated by tree taxa. The tree sum is composed of mostly *Eucalyptus* types, the frequency varying slightly within this zone with *E. viminalis* type pollen first appearing at 20 cm and *E. obliqua* and *E. baxteri*-type pollen increasing at 15-20 cm. *Eucalyptus cosmophylla* type pollen is present in fairly uniform proportions through the zone. Unclassified *Eucalyptus* ('*Eucalyptus*-other' type) pollen increase at 25 cm. A small number of *E. camaldulensis* grains were recorded at 20 cm. *Allocasuarina* (> 28μm) pollen is virtually absent in this zone and *Allocasuarina* (<28 μm) pollen is present in slightly higher proportions but is also poorly represented compared to previous zones. *Banksia marginata* pollen appears in low proportions in this zone. *Acacia* type-2, Chenopodiaceae > 20μm, Fabaceae type 1, and *Muehlenbeckia adpressa* constitute the shrub component. *Muehlenbeckia adpressa, Acacia* type-2 and Fabaceae type-1 are unique to the zone. Herbaceous pollen types account for 15-28% of the terrestrial pollen sum and this component is mainly composed of Poaceae and Asteraceae pollen types, with the Liguliflorae type showing a rise in representation at the top of the core.

Pollen from European-introduced species was found throughout this zone. *Pinus* pollen representation rose dramatically. *Plantago lanceolata*, Brassicaceae, *Cirsium*-type, exotic legumes (most likely to be *Trifolium* sp.) and Rye-type Poaceae pollen were all found in low numbers between 0 - 25 cm.

The pollen spectra of aquatic and swamp-surrounding species is characterised by a dominance of *Leptospermum* spp., *Melaleuca decussata* type, *Goodenia* and *Baumea*-type Cyperaceae. Lesser proportions of *Acacia* type-1, *Carex*-type Cyperaceae, *Haloragis* sp., *Opercularia*, *Stellaria* sp. and *Villarsia umbricola* are present. A small number of monolete fern spores were recorded in the top 10 cm. A few trilete fern spores were recorded below 10 cm.

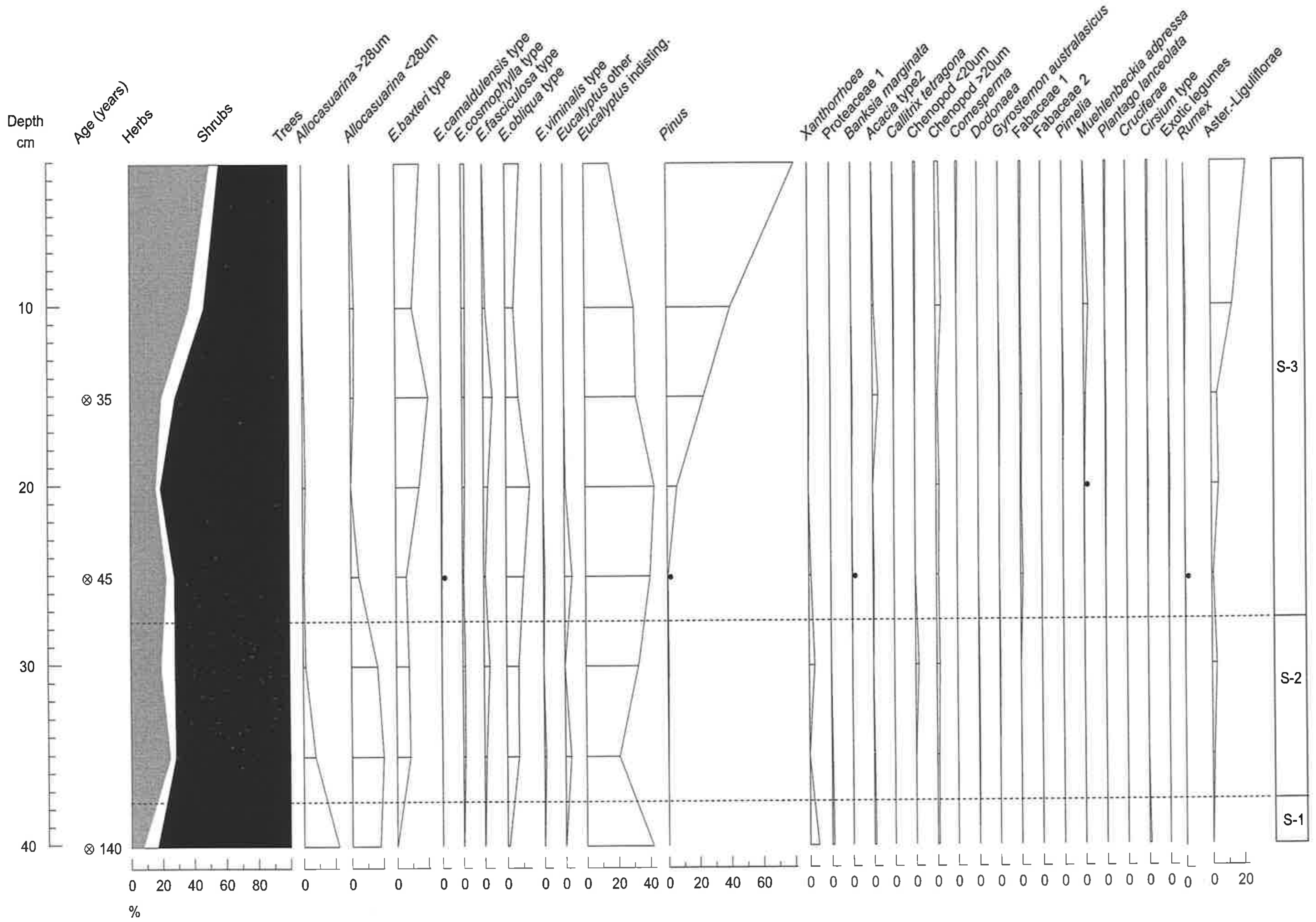
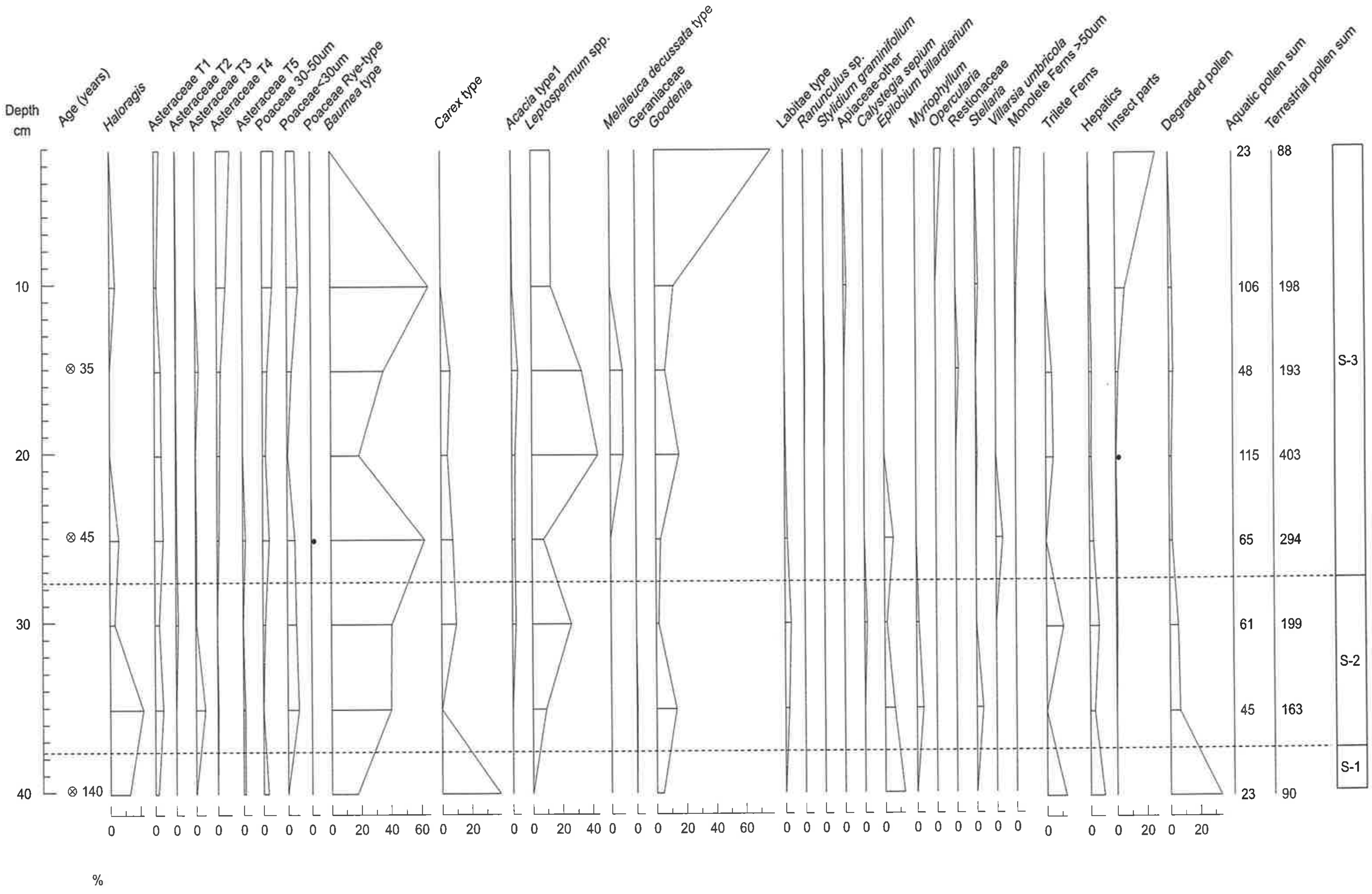


Figure 7.20 Pollen diagram from Springs Road core SR-2


Depth cm
Age (years)
Haloragis
Asteraceae T1
Asteraceae T2
Asteraceae T3
Asteraceae T4
Asteraceae T5
Poaceae 30-50um
Poaceae<30um
Poaceae Rye-type
Baumea type
Carex type
Acacia type1
Leptospermum spp.
Melaleuca decussata type
Geraniaceae
Goodenia
Labitae type
Ranunculus sp.
Stylidium graminifolium
Apiaceae-other
Calystegia sepium
Epilobium billardiarium
Myriophyllum
Opercularia
Restionaceae
Stellaria
Villarsia umbricola
Monolete Ferns >50um
Trilete Ferns
Hepatics
Insect parts
Degraded pollen
Aquatic pollen sum
Terrestrial pollen sum
10
20
30
40
⊗ 35
⊗ 45
⊗ 140
23 88
106 198
48 193
115 403
65 294
61 199
45 163
23 90
S-3
S-2
S-1
0 20 40 60
0 20
0 20 40
0 20 40 60
0 20
0 20
%

7.7.2 Interpretation, core SR-2

7.7.2.1 Terrestrial vegetation and fire history

Eucalyptus is the dominant tree species throughout the time period examined at Springs Road and the record suggests that there have not been any shifts in overstorey species dominance. *Eucalyptus obliqua* and *E. baxteri* pollen-type percentages remaining relatively constant throughout the core and thus it is likely that the gross nature of the *E. obliqua - E. baxteri* open forest presently characterising most of the Springs Road catchment was in place at the time of European settlement. *Eucalyptus cosmophylla* type pollen is persistent but present in low numbers, suggesting that overstorey stability has similarly been maintained in the *E. baxteri - E. cosmophylla - E. obliqua* low woodland community occurring in part of the catchment. The record suggests that *Allocasuarina verticillata* (>28 μm) declined early in the European settlement phase around the site and the understorey shrub species *A. striata* has similarly declined. *Xanthorrhoea* has declined over the period represented by the core. *Muehlenbeckia adpressa* is uniquely present in the younger core sediments. Its presence has been found to be an indication of disturbance (McPhail, pers. comm.). The increase in exotic taxa in modern vegetation is possibly representing both the presence of weeds in the cleared area of the catchment and an increase in the introduced components in the native vegetation.

The microscopic charcoal curve shows moderately high levels of charcoal in the bottom sediments, a peak between 25-15 cm before a decline from 10 cm to the top of the core. Microscopic charcoal can represent both local and regional fires (Clark, 1983). The inability to distinguish the source renders uncertain the interpretation of the relationship between the catchment vegetation represented in this pollen record and local fires.

7.7.2.2 Swamp history

Marker pollen suggests that the core spans the period from early or just prior to European settlement to the present. Changes to the sedimentary environment occur over this time as indicated by sediments shifting from being clay and silt to peat-dominated. An increase in the peatiness of sediments suggests hydrological changes to the system have occurred over the time span of the core. An absence of peat could represent an environment where water was more free flowing, or one which was not permanently or near permanently waterlogged. The presence of Cyperaceous pollen, fern spores (trilete fern spores likely to be *Adiantum aethiopicum* (common maiden hair fern) and *Gleichenia microphylla* (coral fern) and aquatic pollen types, *Myriophyllum* sp. and *Stellaria* suggests that the early environment was a more free flowing silty swamp or swampy creekline. The presence of silts in the sediments (30-24 cm) support this. The swamp changes from a silty swamp to a peat swamp around 25 cm: the timing of this event is speculative however the *Pinus* record suggests that it did not occur before 1965 but possibly occurred sometime around 1945. Rye-type Poaceae in the record at 25 cm supports this tentative date. Widespread vegetation clearance, and its replacement with pasture grasses began at this time in the highland region of the Fleurieu Peninsula. The removal of native vegetation may have acted to raise the water table and swamp wetness inducing an expansion of the swamp around the creekline. Three dams were established on tributaries of the creek which traverse the swamp. With the building of upstream dams, flow rates and the amount of free flowing water, detrimental to swamp peat development, through the swamp would have declined and possibly further encouraged swamp expansion. *Leptospermum* and *Melaleuca decussata* presence increased. This possibly indicates that the net effect of *increased* water inputs, due to vegetation clearance and changes to the water table, and the *decline* in stream flow, due to damming and diversions, was to increase wetness. However wetness was not increased to levels so high that the more-dry environment preferring *Leptospermum* could not establish. Riparian trilete ferns were replaced with water ferns (*Blechnum*) and *Epilobium billiardiarum* (a creekline, swamp fringe herb*)* declined. The relative proportions of cyperaceous species changed also, with *Baumea* becoming more prevalent than in lower sediments.

7.8 Discussion

7.8.1 Terrestrial vegetation

Through the European period there has been compositional stability in the overstorey of remnant *E. obliqua - E. baxteri* open forests in the Fleurieu Peninsula. This is despite burning regimes that were probably more frequent than experienced just prior to European settlement. Fire frequency, intensity and seasonality is an important factor in determining the growth, survival and persistence of many plant species in sclerophyll woodland and forest vegetation (Gill *et al.*, 1981). Ethnohistoric evidence, and the charcoal record (although more ambiguously), suggest that sclerophyll vegetation in the region was subject to intense fires of high fire frequencies in the grazing phase of occupancy between 1850-1930. The pollen record corroborates short term ecological studies that have suggested that pyric-succession in *Eucalyptus obliqua* forests is only seen in the understorey plants and the relatively fire-insensitive overstorey composition is maintained (Cochrane, 1963).

Pollen records suggest, however, that stability through the European period has not been maintained in the shrub components of the sclerophyll forests. The decline of Proteaceous species in the pollen record early in European settlement, at both the Deep Creek Tappanapa and Springs Road sites, probably reflects their decline as components in the vegetation. Woody shrubs, many being obligate seed regenerators, are the component of sclerophyll vegetation types likely to be negatively affected by relatively short inter-fire intervals. In contrast, herbaceous and semi-woody species are relatively resilient to reduced fire intervals as they have comparatively short juvenile periods allowing them to complete their life cycle. An interval of 7 years of low-intensity fires significantly reduced the abundance of *Banksia* sp. and *Hakea* spp. in sclerophyll woodlands in New South Wales, resulting in a less shrubby understorey (Morrison *et al.*, 1996). Thus the 2-5 year fire frequency during the grazing phase of occupancy could be expected to have significantly reduced the Proteaceaous component of the vegetation and, most likely, other fire sensitive components that were not detected in the pollen record.

Xanthorrhoea pollen similarly becomes less abundant over the European period, and although it is an under-represented pollen type, its decline in the DCT and SR sites, both surrounded by remnant vegetation, suggests that there has been a reduction in its cover. Survey descriptions suggest that *Xanthorrhoea* was a very conspicuous, even dominant component of the *E. obliqua* - *E. baxteri* forests. Section descriptions of Stringy Bark forest were nearly always accompanied with records of a grass tree understorey (Chapter 3). The yacca gum harvesting industry of the 1910-20s and vegetation clearance probably strongly contributed to the reduction of this component of the vegetation. Additionally fire has been shown to have a long term deleterious effect on large plants of *Xanthorrhoea australis* (Curtis, 1998) and it is possible that *Xanthorrhoea semiplana* shows a similar response. The high fire frequencies of the grazing phase may also have contributed to a reduction in *Xanthorrhoea* in the region.

A decline in shrub *Allocasuarina* is also seen in both remnant vegetation sites and is less easily explained as a response to frequent firing. While information on the fire ecology of *A. striata* and *A. muelleriana*, the dominant shrub components in the region, was not found, Ladd (1988) recorded that many shrub *Allocasuarina* species regenerate from basal lignotuber structures. Most fire sensitive species occur in environments not prone to burning such as river valleys and arid areas (Ladd, 1988). This, and the timing of its decline in the pollen records, suggest the decline is more likely to be reflecting its local and regional depletion in the vegetation due to wholesale land clearance.

Fire frequency has declined in the catchment since the phase of vegetation clearance, the establishment of improved pastures and plantation forestry. The low macroscopic charcoal levels found in upper sediments of this period reflect this decline. However the pollen records from sites in remnant vegetation do not show a return of original fire-sensitive shrub components to the vegetation. This is despite 'vegetation thickening' having occurred in the understorey since the reduction in the frequency of fires. The density of the present-day understorey vegetation in the catchment would not allow 'bullock passage' as it did in the late nineteenth century. This could be explained by changes to taphonomic process resulting from changes to the wetland vegetation or that different successional sequences and resultant relative proportions of species have occurred subsequent to the shift to less frequent firing regime.

Given that *Allocasuarina verticillata* is not a particularly fire sensitive species, and is in fact advantaged by low intensity firing (Kirkpatrick, 1986), it is likely that its decline at all core sites, early in European settlement, reflects direct clearance through selective browsing by cattle and by early settlers for firewood and construction timber. The timing and nature of this decline is in agreement with that revealed by numerous other pollen records in south-eastern Australia (for example Clark on Kangaroo Island, 1983; Boon and Dodson in eastern Victoria, 1994).

7.8.2 Wetlands

All the swamp sites investigated showed substantial shifts in composition of the wetland vegetation through the European period.

Hydrology is the most important factor influencing wetland function. The removal of native vegetation in the region and its replacement with firstly pasture grasses is likely to have raised water tables and increased inputs into particularly groundwater fed wetlands. However concurrent with vegetation clearance was an intensification of agriculture which probably resulted in increased water abstraction and diversion from the building of farm dams and wetland drainage. Both of which would have reduced water availability. Ground water levels in some areas would have been lowered as *Pinus* plantations matured. Thus the overall water balance of wetlands through the European period is difficult to reconstruct but is likely to be much impacted by regional and local modifications of vegetation cover and surface waterways. *Leptospermum* abundance is possibly an indicator of the hydrological status of wetlands. Its expansion could indicated a drying of the wetland or onset of a peaty wetlands. *Leptospermum* pollen greatly increases in the upper sediments of the Boat Harbour Creek site (replacing *Acacia*), possibly indicating overall later drying of the swamp. Its expansion relative to *Acacia* could also represent a decline in firing regimes at this site.

Increases in sediment input conceivably occurred through the rough grazing phase of the highlands when they were regularly burned to stimulate palatable grasses for stock. Anecdotal evidence suggests that this was so. That erosion from this period was substantial is supported by a recollection made by Albert Jones, local farmer involved in clearing much of the native vegetation in the southern Fleurieu Peninsula from the 1940s. Jones recalled that on occasion when ripping the soil after vegetation removal, buried 'recent' timber was found in gullies under ‘as much as 3 feet of top soil’ (Jones, pers. comm.). The process of vegetation removal (1930-1960) also could be expected to be accompanied by substantial soil instability and loss from slopes. That this was the case was also supported by evidence from Jones who recalled that much top soil was lost after ripping the soil, particularly if a large rain event took place before pasture was established (Jones, pers. comm.; Williams, pers. comm.).

Two of the wetlands sites studied, Boat Harbour Creek and Deep Creek Tapanappa have undergone shifts from higher-energy silty wetlands to lower energy peat-dominated wetlands. Invoking causal associations to these changes with certainty is not possible, due to the chronology of cores being too poorly constrained. However it appears that the change from a silty creekline swamp to peat-swamp changes at the Springs Road and Deep Creek Tapanappa sites occurred around the time of catchment clearance. The changes were probably due to both increases in sediment input from erosion and shifts in both surface and ground water inputs. *Leptospermum* increases at the Deep Creek Tapanappa site suggesting wetland expansion, as it is coincident with increases in water ferns and change to peats from silts. Historical survey diagrams additionally suggest that the Deep Creek Tapanappa site expanded to a swampy peatland after European settlement. Surveyor, S.W. Herbert delineated swamps with precision in his field book sketches, as demonstrated by the delineation of swamps in neighbouring catchments (Hundred of Waitpinga FB 1390, 1882), but did not indicate the presence of a swamp at the Deep Creek Tapanappa site.

Records suggest that these wetlands were responding to European disturbances prior to land use changes of the early to mid-twentieth century. Concurrent with the increased sediment input during the grazing phase of land use would have been an increase in wetlands burning and disturbance by cattle. All wetlands show expansion of disturbance related species. In the Boat Harbour Creek site *Acacia* expands greatly early in European settlement and this is interpreted as a response to increased fire levels in the catchment and possibly on the swamps themselves. The 1884 survey records, made during the grazing phase, note that tea-tree (*Leptospermum*) was present along the Boat Harbour swamp, so it is unlikely that the *Acacia* expansion was at the expense of *Leptospermum.* Rather, pollen records are probably reflecting an expansion of *Acacia retinoides* around the already-present *Leptspermum.* The decline in pollen likely to be sourced from *Gleichenia*, an indicator of an undisturbed (by burning and possibly grazing) wetlands in the Fleurieu Peninsula, is seen to occur in the early part of European settlement in core DCT-2. Little is known about the ecological relations between wetlands and fire (Duffield, 2000). Murphett and Woolcott (in Duffield, 2000) note that all components of a southern Fleurieu Peninsula peatland were resilient to a fire, with most re-establishing after two years and no components were lost. Most wetland species regenerate from lignotubers, tubers and rhizomes and are able to regenerate from superficial burning of above ground vegetation. However it is has been suggested that under dry conditions, or when fires are intense, oxidation of the surface peat layers can occur, destroying underground organs and seed stores. It has been suggested that too frequent burning may lead to temporary stability of wetlands communities but with long term degradation of the habitat through nutrient losses and soil and peat erosion. If wetlands were subjected to very frequent burning it is possible that certain sensitive components were lost and the wetlands of today are the fire resilient relics of past European burning practices.

Results from the Deep Creek Tapanappa and Boat Harbour Creek sites suggest that the accumulation of recent sediments was slower than rates occurring during the early phase of European settlement. This pattern of the most significant European-impacts occurring in the initial contact period, and being followed by a phase of relative stability, has been recorded in other regions of Australia. Franklin *et al.* (2000) found very high increases in sedimentation rates in the early contact period at Red Head Lagoon in East-Central New South Wales and that sedimentation rates have steadily declined since 1897. Prosser (1996) showed that extensive and dramatic gullying in south eastern Australia occurred concurrently with the expansion of grazing in the nineteenth century.

Macroscopic charcoal records show that fire regimes have varied over the historical period. The European phase of occupation appears to be characterised by more intense and frequent fires in the region. It can at least be said that fire has been more prevalent during this time and that the regime post-European contact is different to that in place prior to settlement. Boon and Dodson (1992) at Lake Curlip and Gell *et al.* (1993) in East Gippsland similarly found increased charcoal levels in post European sediments and interpreted it as relatively intensified burning by Europeans. Clark (1983) similarly found an intensification of firing on Kangaroo Island in the historical period. Other sites in Australia (Dodson *et al.,* 1994) have found suppressed burning regimes since European settlement.

7.9 Conclusions

Microfossil and sediment studies provide a sequent history of vegetation and environmental dynamics of the sclerophyllous regions of the Fleurieu Peninsula through the European period. They provide otherwise unobtainable information on the composition of the vegetation at the time of European settlement. The sequences suggest that substantial changes to the environment and terrestrial and wetland vegetation occurred in the initial phase of European settlement, at the time of the expansion of grazing and native timber collection. Increased fire regimes, selective harvesting and grazing particularly had effect on understorey composition. Pollen suggests that there has been no obvious response in floristic composition of the overstorey of *E. obliqua* forests. Species have responded in individualistic ways to European perturbations due to their different ecologies and according to whether or not they were selectively targeted. Wetland vegetation underwent further dramatic changes later in the European period. These changes are likely to be related to broad scale vegetation clearance carried out from the 1940-60s, causing shifts in hydrological and nutrient regimes. Lower sedimentation rates are seen in recent sediments dating to post land clearance suggesting that there has been more stability in catchment soil processes since that time.

CHAPTER 8

8. HOLOCENE VEGETATION HISTORY

8.1 Introduction

Substantial changes in vegetation composition occurred in southern Australia through the Holocene, and dramatic changes through the Late Pleistocene. The nearest Pleistocene records to the study region are located in the south east of South Australia at Lake Leake and Wyrie Swamp and they provide intermittent records for the last 50000 years (Dodson 1974a; 1975, 1977a). They show that open *Eucalyptus* woodland was replaced by *Eucalyptus* woodland and wet heath by *ca* 50000 years BP. The wet heath of this time was composed of shrub *Allocasuarina*, Myrtaceous scrub types and low amounts of Poaceae. At *ca* 39 000 years BP the vegetation reverted to an open formation with a high Asteraceae and Poaceae component. By 38000 years BP *Eucalyptus* and heath formation returned. Conditions were dry from 35000 years BP with the *Eucalyptus* woodland becoming more open but still with a heath understorey, although the heath was replaced with Asteraceae and Poaceae in more arid periods. Vegetation changed significantly at around 10000 years BP when conditions became wetter than at anytime in the previous 50000 years and *Allocasuarina verticillata* migrated into the region. *Allocasuarina verticillata* did not replace *Eucalyptus*, its abundance remaining relatively unchanged (Dodson, 1974). The vegetation changes from the Lake Leake and Wyrie Swamp cores are similar to those from other southeastern Australian sites (Singh and Geissler, 1985; D'Costa, *et al.,* 1989).

Numerous palaeoecological records of Holocene environmental change have been studied from southeast of South Australia and western Victoria. Lake Keilambete is considered to provide the best guide to climate of south eastern Australia during the Holocene. A precipitation curve constructed by Bowler and Hamada (1971; Bowler *et al.,* 1976) show both wetter and drier periods than present through that time. The curve defines a Holocene wet period which peaked at 6000 years BP but extended from 7500-4500 years BP. A significant dry and climatically unstable period occurred between 3500–2500 years BP, before conditions became wetter again at about 2000 years BP. More recently fine resolution palaeoclimatic analysis of sediments from the last 2000 years at Lake Keilambete (Mooney, 1997) showed that it is likely that climate over this time has been variable, with certain periods receiving relatively higher effective moisture than others. The periods 2000 to 1800 years BP and 1415-1320 years BP received higher moisture; 1750-1425 years BP was a time of increased instability in the catchment and possibly of decreased moisture availability. Considerable environmental change was detected at 1450 years BP; 1150-800 years BP was a time of temperature variability and 400 years BP to AD 1840 was a time of increased moisture availability.

The climatic trends at Lake Keilambete are largely reflected throughout Holocene sites in southeastern Australia. However the timing and significance of these events vary between sites. These differences can be accounted for by regional variations of climate. Holocene records of Lake Leake show that conditions from 10 000 years BP became increasingly wet with the period between 7860 and 2940 possibly being wetter than today and maximum effective precipitation occurring between 6900 and 5000 years BP (Dodson, 1974). After this time conditions became drier and then marginally wetter again at 2000-1300 years BP. The period was defined by a cover of *Eucalyptus* woodland (dominated by *E. baxteri, E. obliqua and E. ovata*). However, during the wettest phase (7860-2960) an expansion of wet heath communities occurred, as indicated by an increase in *Allocasuarina* <28 μm type pollen. The record also shows a decline in *A. verticillata* at *ca* 5500 years BP from its *ca* 9400 years BP maximum.

The nearby Marshes Swamp record largely substantiates that from Lake Leake with swamp initiation occurring at approximately 8500 years BP followed by a maximum period of peat formation between 7500 and 5200 years BP (Dodson and Wilson, 1975). After 5200 years BP conditions became drier; peats became partially oxidised, pollen increasingly degraded. Deflation of sediments may also have occurred. Wet heath characterised the vegetation at Marshes Swamp during the wettest phase of the Holocene (7000-5240 years BP). From 5240 years BP to present *Allocasuarina* and *Eucalyptus* dominated the land pollen with levels of both showing minor fluctuations to the present.

The most substantial Holocene history from central-southern South Australia is from Lashmar's Lagoon on Kangaroo Island (Clark, 1983). Lashmar's Lagoon provides a continuous record of the past 7000 years and showed quite dramatic vegetation changes through that period. Between 7000 and 6400 years BP the vegetation was more open than any other time during the record until European clearing and was dominated by *Allocasuarina verticillata* with an understorey of taxa in the families Chenopodiaceae, Asteraceae and Poaceae understorey. *Allocasuarina verticillata* woodland persisted from about 6400 to 4800 years BP. *Allocasuarina verticillata* and grasses declined dramatically at *ca* 4800 years BP and were replaced with *Eucalyptus* and woody species, possibly due to a drier climate or a change in human activity. At about 1300 years BP Asteraceae and *Allocasuarina* shrub species increased and persisted to European settlement when grasslands increased and *A. verticillata* disappeared from the record almost completely.

Two Holocene records from the Mount Lofty Ranges, South Australia, have also been investigated. Creek bed sediments near Palmer on the eastern side of the Mount Lofty Ranges suggested that conditions were moister from about 8000 years BP to sometime after 6600 years BP. However at the generic level vegetation has been relatively stable for the past 8000 years, the site being characterised by an *Allocasuarina, Banksia* and *Eucalyptus* woodland (Grubb, 1978). Lang (1976) investigated sediments in a swamp near Crafers in the Central Mount Lofty Ranges. Only a single date of *ca* 6000 years BP was obtained at this site. The sequence was dominated by *Eucalyptus* pollen and proportions of *Eucalyptus* types identified did not change through the core. Lang (1976) concluded that over the span of the core climatic conditions were invariant.

There are no well preserved, dated and continuous records of vegetation and environmental change in the Mount Lofty Ranges through the Holocene. This chapter aims to investigate such changes by considering sediment and microfossils from a peat swamp in the Fleurieu Peninsula. It will provide a means to compare and therefore better understand the post-European changes investigated in this thesis.

8.2 Methods

The Boat Harbour Creek site was described in Chapter 7. A 200 cm long core was taken using a Russian Peat corer from the middle of the swamp. Cores were placed in PVC tubing, wrapped in plastic film and stored in the dark at 4° C. Sub-samples of sediment were taken at 5-10 cm intervals along the core for fossil pollen, spore and micro-charcoal extraction. Macroscopic charcoal content was analysed at 2-5 cm intervals. Fossil pollen was prepared using standard methods of preparation (Faegri and Iverson, 1989; Appendix 6). Macroscopic charcoal was prepared using a method developed by McDonald *et al.* (1991). Microscopic charcoal was counted using the point count technique developed by Clark (1982) on slides prepared for pollen examination.

Where pollen concentration was sufficient at least 200 terrestrial pollen grains were counted for each sample. Pollen taxa were placed into broad ecological groups (Chapter 5). Pollen counts are expressed as percentages of two distinct sums; one consisting of terrestrial herb, shrub and tree taxa and the other aquatic and swamp fringe taxa. Numerical zonation, employing optimal splitting by sums of squares, was performed on pollen data to identify sections of similarity and difference in pollen spectra. Analysis was performed only on major taxa whose pollen values exceeded at least 5% in one sample. All numerical analyses and pollen diagram production were carried out using the PSIMPOLL program (Bennett, 1993).

Fossil pollen data were compared with modern pollen data in order to examine whether or not any of the pollen spectra from modern communities provide analogues for historical communities. The modern analogue approach relies on the assumption that if two spectra are similar, and are sourced from equivalent depositional environments, then it can be concluded they were produced by a similar vegetation type. If no modern analogue for the fossil spectrum can be found it may be concluded that either the past vegetation has no modern analogue or that the modern information is inadequate and analogues should be sought elsewhere.

8.3 Results

8.3.1 Stratigraphy and dating

The stratigraphy of core BH-2 and dry weight and loss on ignition curves for core BH-2 are shown Figure 8.1. Sediments from the base of the core to 183 cm were light grey clays. Sediments from 183 to 176 cm were grey sands. Grey-brown clays, containing some humic material, occurred from 176 to 156 cm and from 156 to 135 cm the grey-brown clays were mixed with humic peats. From 135 cm the peat content of sediments increased while the clay content decreased. From 117 to 88 cm sediments were humic peats. Grey clays mixed with humic peats between 88-78 cm. From 78 cm to 68 cm organic sediments return, being a combination of herbaceous and humic peats. At 68 cm peat sediments were less humic and more herbaceous. From 50 cm to 35 cm peats return to being predominantly humic. Peat sediments are interrupted by a grey-brown clay intrusion between 30-35 cm. Herbaceous peats occurred from 30 cm to the top of the core.

Radiocarbon dating was carried out on four bulk sediment samples from core BH-2 and two from an adjacent core, BH-3. Samples were processed at the Quaternary Dating Research Centre of the Australian National University. The pre-treatment and dating procedure is outlined in Gupta and Polach (1985). Pre-treatment of whole sediment samples entailed first sieving, to retain material between the sizes 100μm and 250μm, the acid washing of this material in 10% hot HCl and finally the solvent extraction of two an insoluble and soluble fraction for dating with NaOH at 80°C. The NaOH soluble fraction includes humic acids and degraded cellulose and the NaOH insoluble fraction includes plant remains.

Results of carbon dating of the BH2 core are presented in Table 8-1. The ages yielded by the soluble fraction of the material decrease almost linearly with depth while the insoluble fraction shows a less ordered relationship with the least shallow sediments yielding the oldest age. The insoluble fraction yielded from the pre-preparation process of sediments was considered to be of insufficient volume to generate reliable results.

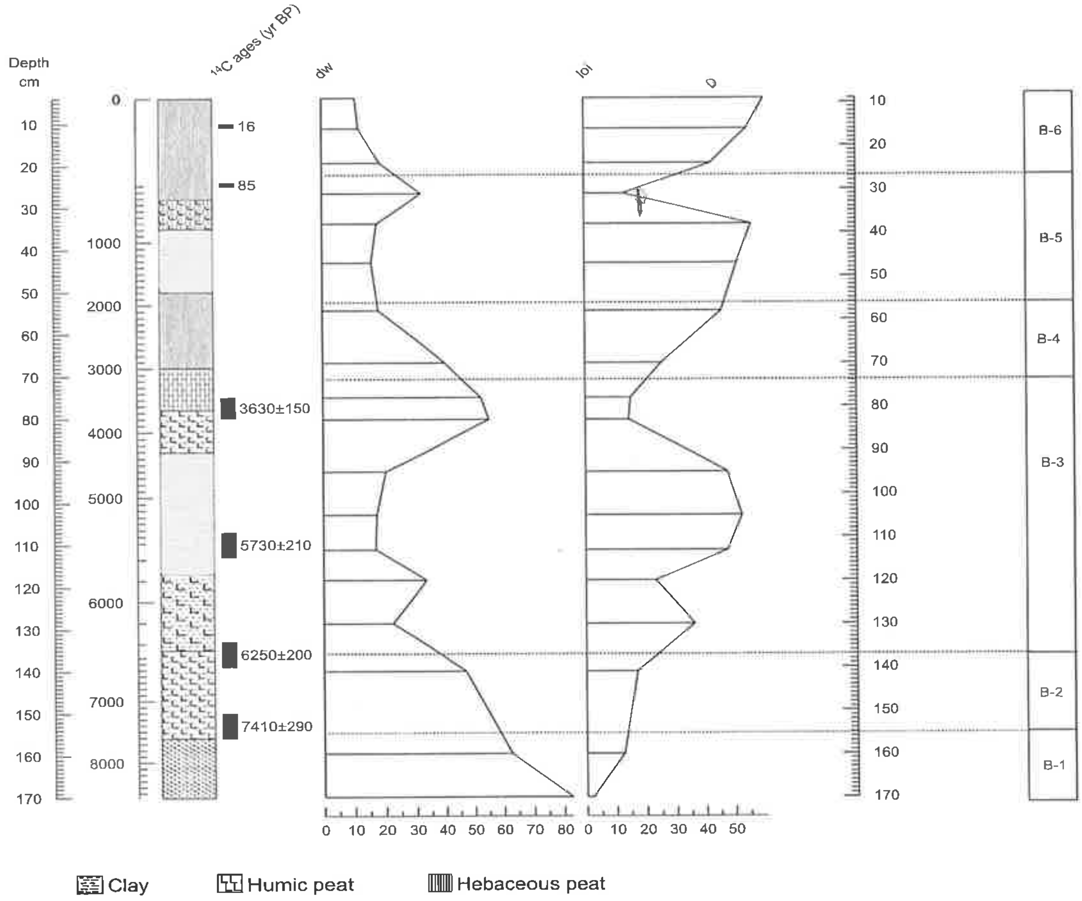


Figure 8.1 Stratigraphy and sediment analysis (dry weight and loss on ignition) of core BH-2

Table 8-1 Sediment material from core BH-2 radiocarbon dated and the ages (years BP) resulting.

Depth of material	ANU Laboratory Code	Code	Fraction	Age (Years BP)	Sample material
75-80 cm	ANU-10888 B	BH2-1	Insoluble	6230 ± 190	Peat
75-80 cm	ANU-10888 C	BH2-1	Soluble	3630 ± 150	Peat
107-113 cm	ANU-10887 B	BH2-2	Insoluble	650 ± 180	Peat
107-113 cm	ANU-10887 C	BH2-2	Soluble	5730 ± 210	Peat
133-139 cm	ANU-10885 B	BH2-3	Insoluble	5540 ± 270	Peat
133-139 cm	ANU-10885 C	BH2-3	Soluble	6250 ± 200	Peat
150-156 cm	ANU-10886 B	BH2-4	Insoluble	5060 ± 380	Peat
150-156 cm	ANU-10886 C	BH2-4	Soluble	7410 ± 290	Peat

In core BH-2, the date of 650 ± 180 for ANU-10887B from 107-113 cm is likely to be unreliable due to small fraction size. It could represent a sediment inversion in the core but this interpretation is not preferred as the pollen sequence shows internal integrity. Additionally there was no evidence of disturbance in the sediments at this depth. It is likely that the date of 6230 ± 190 years BP for date ANU-10888B from 77 cm is also spurious and an artefact of insufficient dating material. The soluble fraction representing the matrix from the same depth yielded a younger age of 3630 ± 150 years BP. Although the insoluble fraction can sometimes be less reliable, in this case it provides a more coherent chronology. Using the dates derived from the insoluble fraction the core represents at least a 7410 ± 154 year time span.

Due to uncertainties in dating results, particularly of the upper sediments, another core, core BH-3, was taken from the Boat Harbour Creek swamp near to where the BH-2 core was extracted. Sediments of core BH-3 at 200 cm to 192 cm were light grey clays. Clays are replaced by black-brown humic and herbaceous peats to 155 cm. The herbaceousness of sediments increases at the expense of humic material from 155 cm and they remain predominantly herbaceous to 100 cm. From 100-50 cm sediments remained peaty but contained more humic material than those below. From 50-36 cm peat sediments became herbaceous and then from 36-26.5 cm, more humic. Sediments between 26.5 and 21 cm were grey-brown clays. Sediments from 21 cm to the top of the core were herbaceous and humic peats. Stratigraphies were matched between the cores to enable extrapolation of dates between cores (Figure 8.2). The clay band intruding the predominantly herbaceous peats and humic peat sediments of the upper part of BH2 at 28-35 cm was present in BH3 but at 21-26.5 cm. A sample 6 cm below this band was dated. A second sample was taken of humic material at 54-60 cm. Carbon-14 dates from the soluble and insoluble fractions were obtained and are presented in Table 8-2. Due to differences in core stratigraphy below 40 cm, it was thought that only the dates from the upper sediments (33-41 cm) of ANU-11096 could be confidently extrapolated using stratigraphy using the uppermost clay band common to both cores.

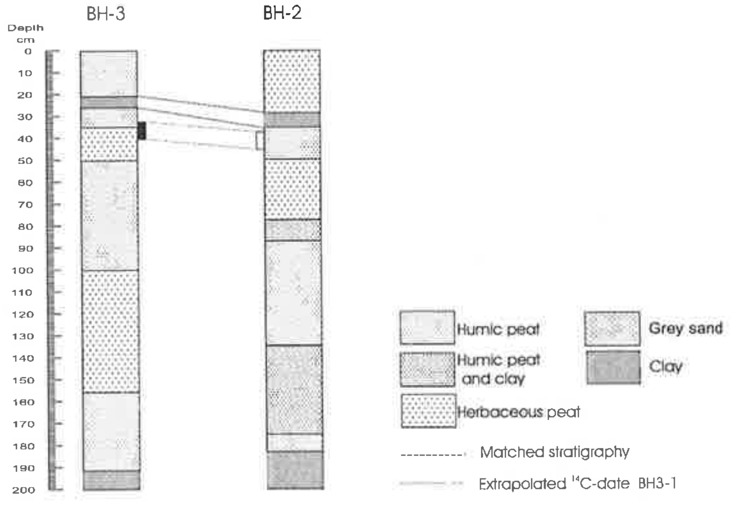


Figure 8.2 Stratigraphic matching of sediments of cores BH-2 and BH-3

Table 8-2 Sediment material from core BH-3 radiocarbon dated and the ages (years BP) resulting.

Depth of material	ANU Laboratory Code	Code	Fraction	Age (Years BP)	Sample material
33-41 cm	ANU-11096 B	BH3-1	Insoluble	280 ± 90	Peat
33-41 cm	ANU-11096 C	BH3-1	Soluble	300 ± 120	Peat
54-61 cm	ANU-11097 B	BH3-2	Insoluble	5060 ± 80	Peat
54-61 cm	ANU-11097 C	BH3-2	Soluble	4570 ± 140	Peat

Nineteen sediment samples were taken from the top 65 cm, and two from near the base of core BH-2, for ^{210}Pb dating. The core provided sufficient sediment material to carry out alpha spectrometry only. Insufficient sediment material precluded gamma spectrometry, and the measurement of ^{137}Cs, from being undertaken. The ^{210}Pb results are presented and discussed in detail in the previous chapter, where the European sequence from core BH-2 is considered in more detail. Results indicate that at least the top 24 cm of the core were deposited in the European phase of settlement.

Pollen from exotic plant species was present in the top 35 cm of the core. *Pinus, Rumex, Plantago lanceolata, Brassicaceae* and *Asteraceae*-Liguliflorae type were identified, but were only present in low numbers. Single grains of *Pinus* pollen were found in sediments at 70 and 90 cm. These grains were considered to have been the result of contamination during the coring or preparation process as sediments are clearly indicated to be of pre-European origin by ^{14}C dating. Macroscopic and microscopic charcoal concentrations potentially serve as additional markers of the post-European settlement period. Macroscopic charcoal was present at unprecedentedly high concentration in sediments at 24 cm depth and could be the result of catchment burning during the grazing phase of occupation of catchment burning and clearance in 1953. Microscopic charcoal shows a similar unparalleled increase in concentration in sediments between 40 and 26 cm depth.

An age model for core BH-2 was developed using the soluble ^{14}C dates from BH-2 sediments and the stratigraphically matched ^{14}C date BH3-1 and ^{210}Pb dates using a linear logistic regression (Figure 8.3).

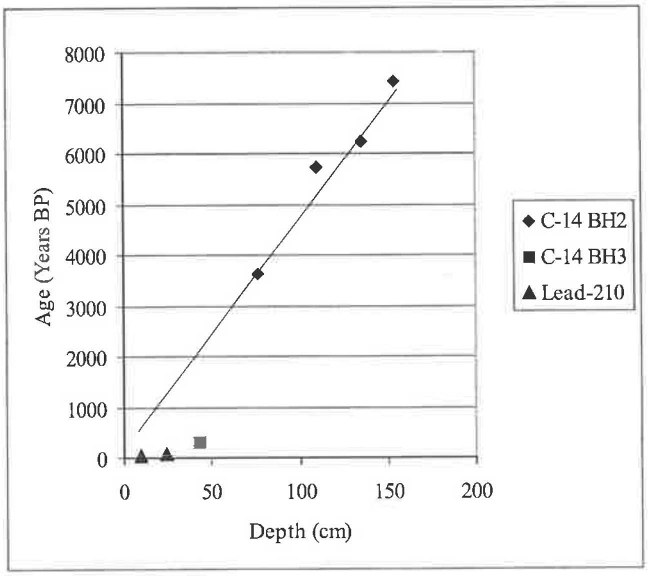


Figure 8.3 Age-Depth curve of the preferred chronology of core BH2 Core 2 (BH2) from the soluble fractions C-14 dating from core BH2, the insoluble fraction of date BH3-1 from core BH3 and Lead-210 ages derived using a CRS model (Chapter 3). The age-depth curve is modelled using a linear logistic regression ($r^2 = 0.9254$).

8.3.2 *Microfossils*

The relative abundance's of the dominant pollen types in the record of core BH-2, calculated as percentages of the sum of both aquatic and terrestrial pollen types (this sum is referred to as the 'total pollen sum'), are presented in Figure 8.4. Microscopic and macroscopic charcoal and the concentration of pollen through the sequence are also depicted. The relative abundances of all pollen and spore types in core BH-2, using a terrestrial pollen sum and an aquatic pollen sum are shown in Figure 8.5. As in Chapter 6, the aquatic pollen sum was composed of both aquatic and swamp margin plants. Zonation analysis of terrestrial pollen types identified six distinctive zones in core BH-2. The zones are shown on both pollen diagrams and are described below.

Zone B-1 ? -7410 BP - Depth 176-156 cm

Sediments of this zone are dark brown to grey clays. Pollen preservation was poor. Macroscopic and microscopic charcoal levels were consistently relatively low, except for a slight rise in the microscopic fraction at 160 cm. *Eucalyptus*, Cyperaceae and *Allocasuarina* pollen dominated the total pollen sum.

Trees compose between 75-85% the terrestrial pollen sum, with *Eucalyptus* types clearly dominating the tree pollen input. Most of the *Eucalyptus* pollen in this zone was not identifiable to type due to poor preservation. Of those identifiable was *Eucalyptus cladocalyx*, occurring at the top of zone B-1. *Allocasuarina* (<28μm) increased from 7% to 25% in the zone but *Allocasuarina* (>28 μm) values remained steady at about 10%. Poaceae and Asteraceae levels are less than 6% and 10% throughout the zone. *Banksia marginata* pollen accounts for 5% of the terrestrial pollen sum in a single sample in the zone. The aquatic pollen spectra was dominated by Cyperaceae pollen, which could be derived from aquatic or terrestrial species. Low percentages of *Leptospermum* were present throughout zone B-1. *Acacia* type-1 levels were low at the bottom of the zone but increased throughout. *Myriophyllum*, *Stellaria* and *Epilobium billardiarium* pollen were present indicating that conditions were moist.

Zone B-2 7410 BP -6250 BP Depth 156-135 cm

The sediments in this zone are grey brown clays mixed with humic peats. The organic content of sediment increases through the zone. Both microscopic and macroscopic charcoal levels remained low through the zone.

As a proportion of the total pollen sum, *Eucalyptus* is lower than in the bottom of zone B-1, Cyperaceae is relatively unchanged at 20%, *Allocasuarina* slightly lower at about 8% and *Acacia* type-1 pollen increases, reaching proportions of 18-22%.

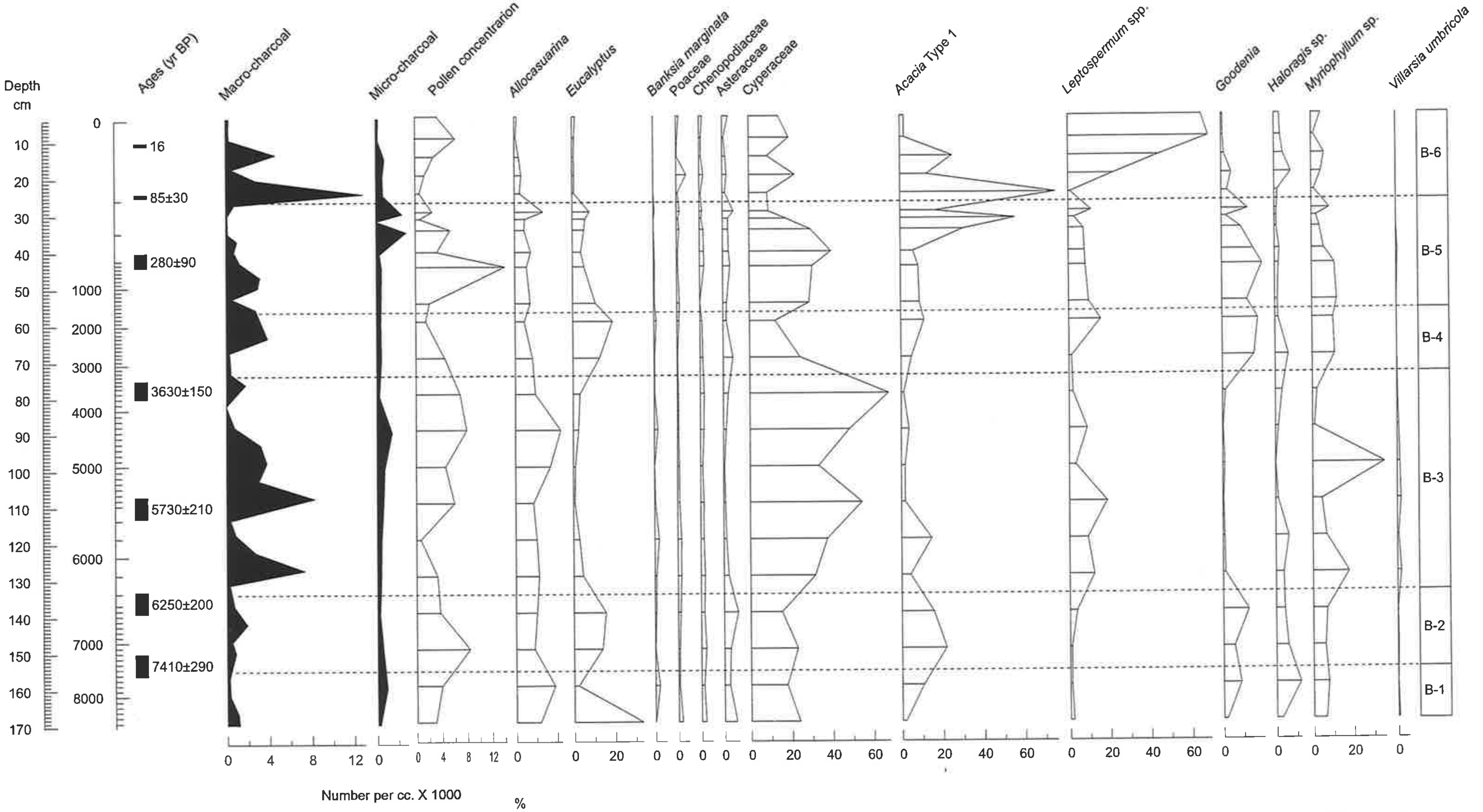


Figure 8.4 Microscopic and macroscopic charcoal concentrations and pollen diagram of the dominant types in core BH-2 expressed as percentages of the total pollen and spore sum.

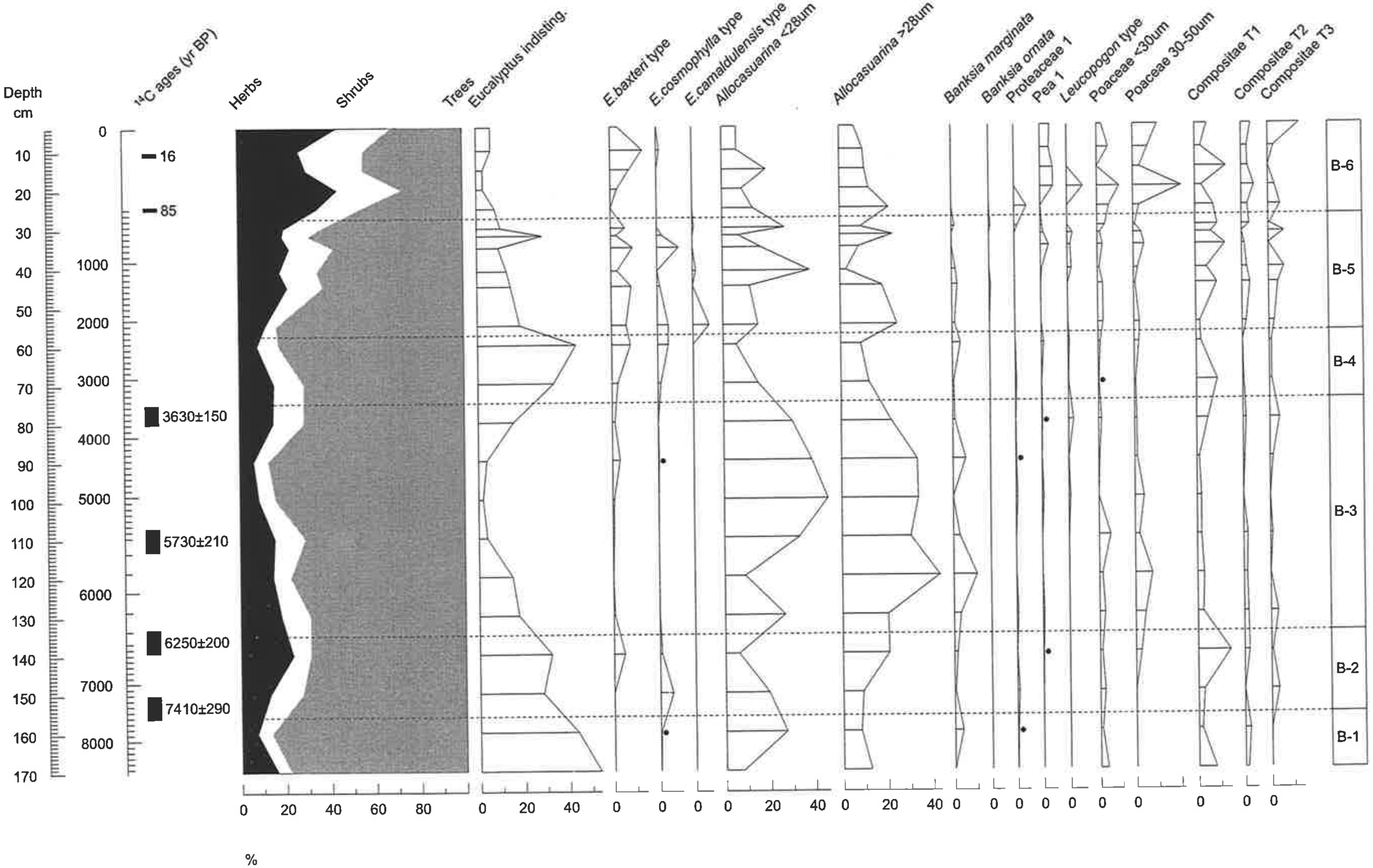
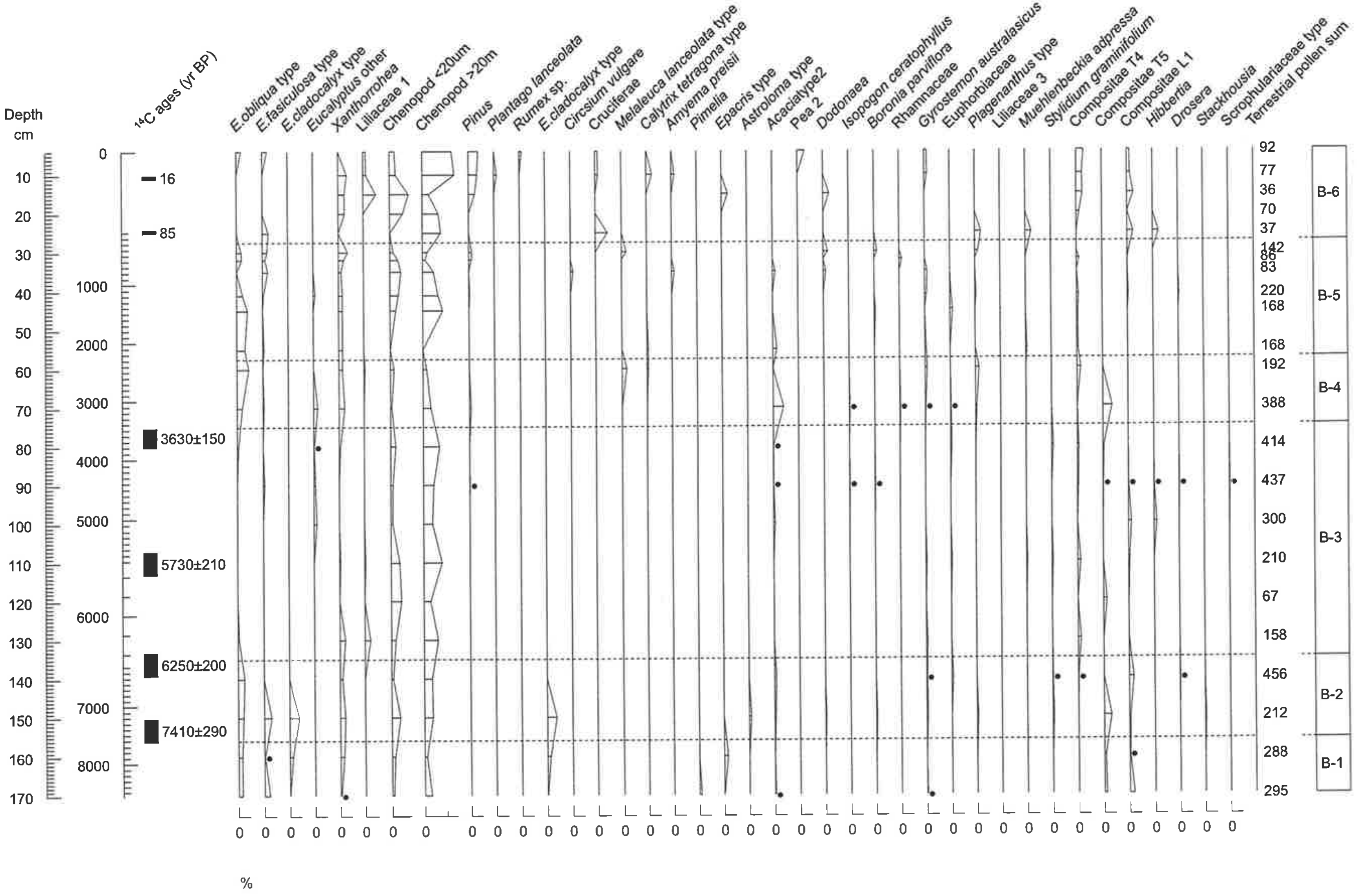


Figure 8.5 Pollen diagram of the relative percentages of all terrestrial and aquatic pollen taxa from core Bh2 as percentages of the terrestrial and aquatic pollen sum respectively.


Depth
cm
0
10
20
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100
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120
130
140
150
160
170
¹⁴C ages (yr BP)
0
1000
2000
3000
4000
5000
6000
7000
8000
16
85
3630±150
5730±210
6250±200
7410±290
E.obliqua type
E.fasiculosa type
E.cladocalyx type
Eucalyptus other
Xanthorrohea
Liliaceae 1
Chenopod <20um
Chenopod >20m
Pinus
Plantago lanceolata
Rumex sp.
E.cladocalyx type
Circsium vulgare
Cruciferae
Melaleuca lanceolata type
Calytrix tetragona type
Amyema preisii
Pimelia
Epacris type
Astroloma type
Acaciatype2
Pea 2
Dodonaea
Isopogon ceratophyllus
Boronia parviflora
Rhamnaceae
Gyrostemon australasicus
Euphorbiaceae
Plagenanthus type
Liliaceae 3
Muehlenbeckia adpressa
Stylidium graminifolium
Compositae T4
Compositae T5
Compositae L1
Hibbertia
Drosera
Stackhousia
Scrophulariaceae type
Terrestrial pollen sum
92
77
36
70
37
142
86
83
220
168
168
192
388
414
437
300
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B-1
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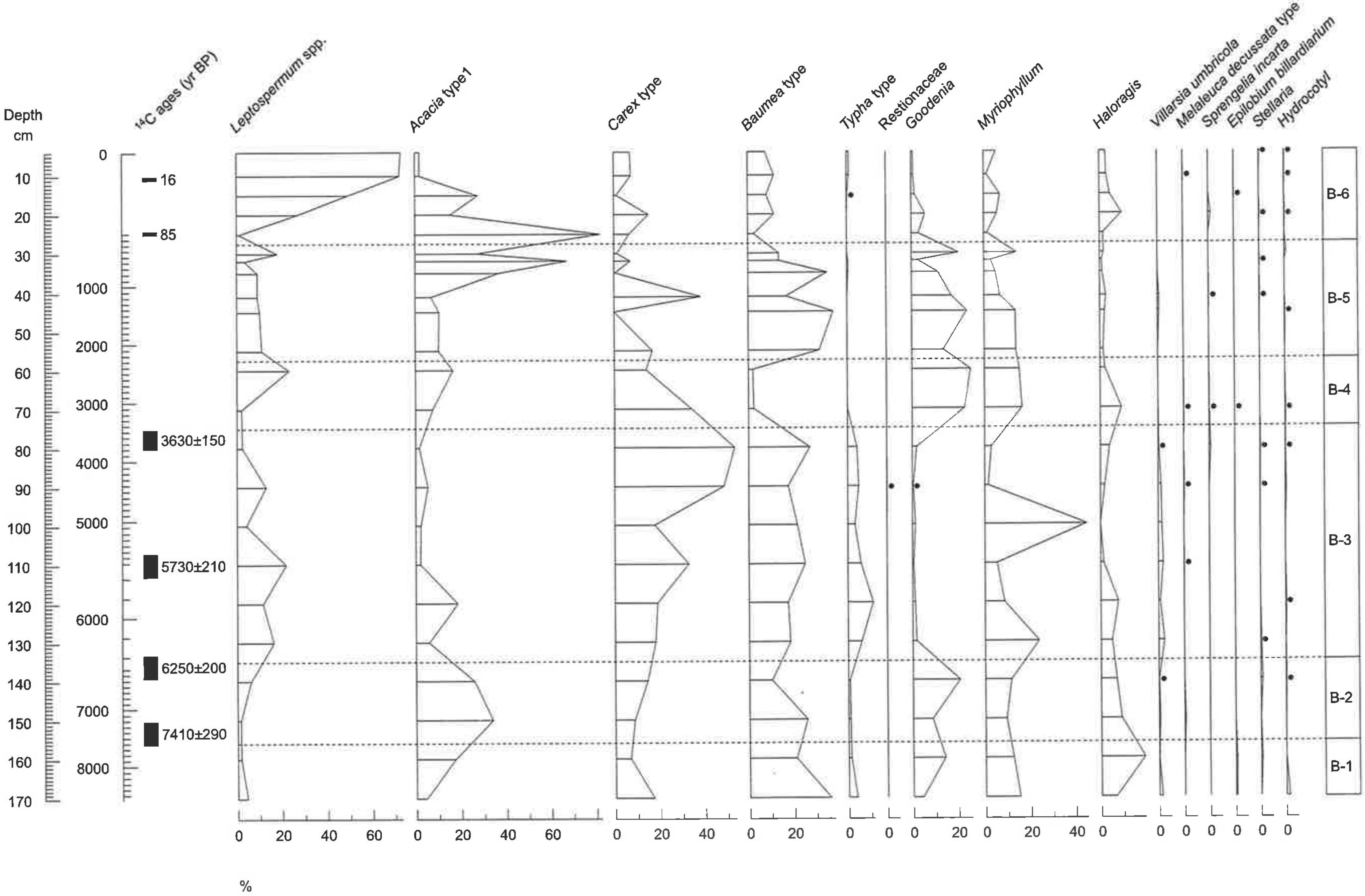
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^{14}C ages (yr BP)
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2000
3000
4000
5000
6000
7000
8000
16
85
3630±150
5730±210
6250±200
7410±290
Leptospermum spp.
Acacia type1
Carex type
Baumea type
Typha type
Restionaceae
Goodenia
Myriophyllum
Haloragis
Villarsia umbricola
Melaleuca decussata type
Sprengelia incarta
Epilobium billardiarium
Stellaria
Hydrocotyl
B-6
B-5
B-4
B-3
B-2
B-1
0
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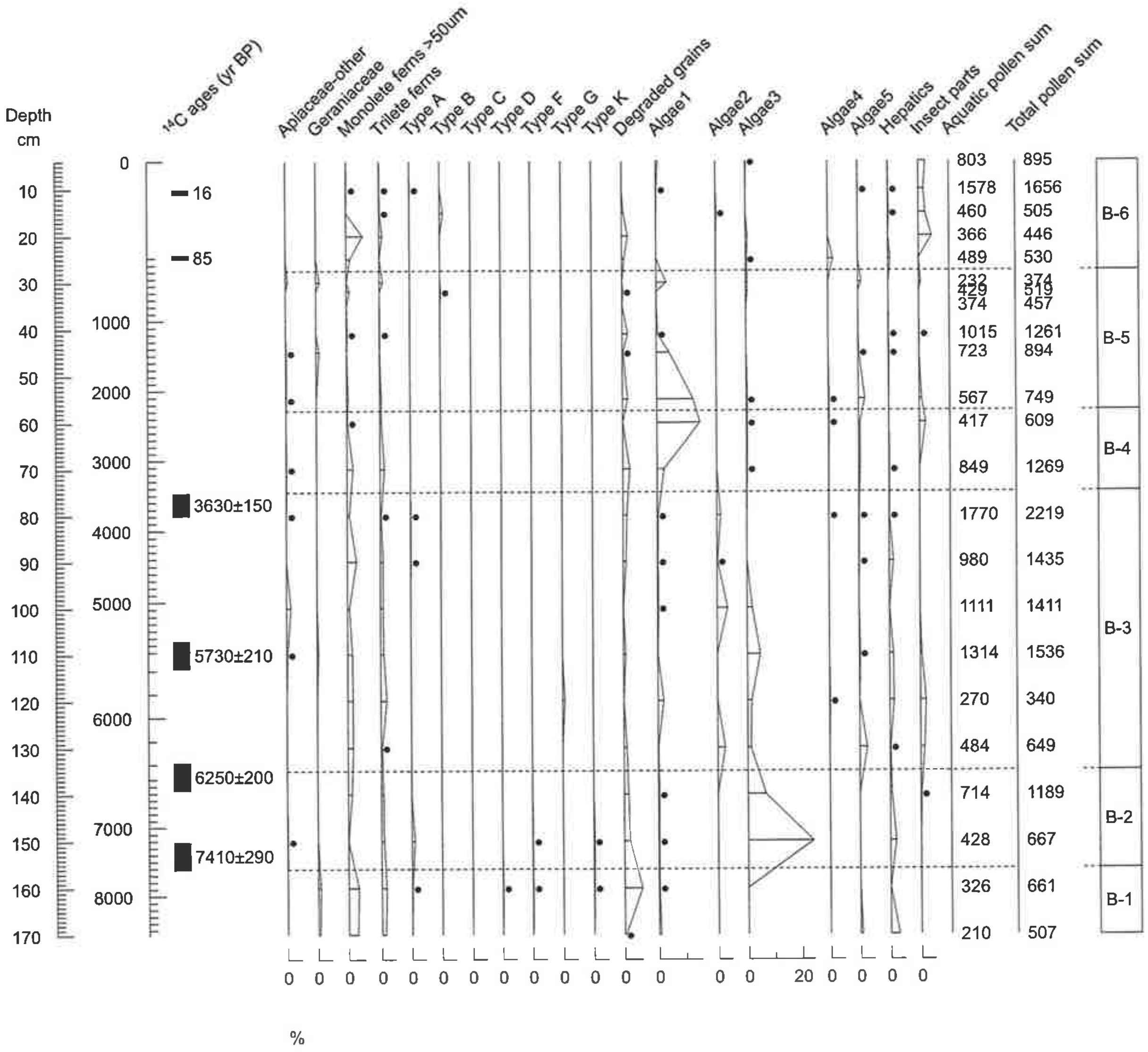
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4000
5000
6000
7000
8000
16
85
3630±150
5730±210
6250±200
7410±290
Apiaceae-other
Geraniaceae
Monolete ferns >50um
Trilete ferns
Type A
Type B
Type C
Type D
Type F
Type G
Type K
Degraded grains
Algae1
Algae2
Algae3
Algae4
Algae5
Hepatics
Insect parts
Aquatic pollen sum
Total pollen sum
803
1578
460
366
489
232
429
374
1015
723
567
417
849
1770
980
1111
1314
270
484
714
428
326
210
895
1656
505
446
530
374
519
457
1261
894
749
609
1269
2219
1435
1411
1536
340
649
1189
667
661
507
B-6
B-5
B-4
B-3
B-2
B-1
0
20
%

Eucalyptus continues to dominate the tree types of the terrestrial pollen sum, with a representation of about 45%, and *Allocasuarina* (combined <28μm and >28μm classes) about 25%. Shrubs represent 7-12% of the terrestrial sum and herbs commence at 13% at the bottom of the zone increasing to 23% at the top. Most of the *Eucalyptus* pollen were not distinguishable to type, but, of the morphologically intact grains, *E. cosmophylla* type and *E. baxteri* type were most prevalent. *E.cladocalyx* type pollen was restricted to the lower region of this zone. Shrub components were dominated by less than 5% representation for each of *Xanthorrhoea*, *Dodonaea* and Chenopodiaceae pollen. The increase in herbs was mainly due to an increase in *Asteraceae* Type1. Poaceae levels remained consistantly below 5% throughout the zone. The aquatic pollen spectra largely resemble that of zone D-1 with the exception of higher levels of *Acacia* type-1 pollen and a small increase in *Leptospermum* spp. pollen.

Zone B-3 6250 BP-3500 BP Depth 135-75 cm

Sediments in zone B-3 were predominantly peats with some clay appearing at discrete levels. Macroscopic charcoal substantially increases in sediments in the upper part of the zone. Microscopic charcoal levels are constant and low throughout the zone.

The total pollen sum is dominated by Cyperaceae. The representation of Cyperaceae pollen steadily increases in this zone and is present in significantly higher levels than in the lower two zones. Cyperaceae pollen is most likely to be from aquatic species as Cyperaceae pollen is only a minor component of modern pollen spectra from dryland vegetation communities containing plants in this family (Chapter 3). *Allocasuarina* also forms a significant component of the total pollen sum, yet *Eucalyptus* pollen contributes relatively little and is in much lower proportions than previous zones.

Allocasuarina pollen (from both <28μm and >28μm size classes) dominates the terrestrial pollen sum, having a minimum representation of 69% and a maximum of 87%. Both the small grained and the large (probably *A. verticillata*) grained types rise markedly in frequency. *Eucalyptus* pollen accounts for less than 5% of the terrestrial pollen sum. *Banksia marginata* pollen expands to maximum levels in the record (10%) suggesting its local expansion at this time. *Xanthorrhoea* type pollen is present but in reduced numbers from the previous zone. Chenopodiaceae pollen is present in largely unchanged proportions through zone B-3 and in similar proportions to previous zones. The herb pollen spectra is dominated by Poaceae and Asteraceae. Poaceae is more highly represented than in lower zones. Asteraceae is slightly less well represented in this zone than in previous, largely due to a reduction in Asteraceae-type1. The swamp flora is dominated by Cyperaceae, which shows an overall rise from 40% to 80% at the top of the zone. Typhaceae, likely to be *Typha domingensis*, is more prevalent in this zone than any other, accounting for a maximum of 10% of the aquatic pollen sum. *Leptospermum* forms between 10-20% of the aquatic pollen sum. *Acacia* type-1, probably derived from swamp species *A. retinoides* or the dryland *A. verticillata*, accounts for 20% of the sum at the bottom of this zone but declines to represent less than 5% above 110 cm. *Myriophyllum* levels fluctuate through the zone. *Villarsia umbricola* is more consistently present in this zone than any other.

Zone B-4 3500 - 1750 BP Depth 55 cm -75 cm

Sediments in this zone are herbaceous peats. Macroscopic charcoal is consistently present in the zone in moderately high amounts and microscopic charcoal is present in lower amounts than zone B-3.

The total pollen sum shows declines in the amount of Cyperaceae (from 65%-25%) and *Allocasuarina* pollen and increases in the amount of *Goodenia*, Asteraceae and *Eucalyptus* pollen. *Myriophyllum* is constantly present at approximately 10%.

Trees account for 71% of the terrestrial pollen sum at 70 cm and this rises to 82% at the top of zone B-4. *Eucalyptus* replaces *Allocasuarina* as the dominant type. *Eucalyptus* increases in representation from 30-61% in the zone. Most *Eucalyptus* grains were indistinguishable to type due to grains being degraded. Of recognisable grains *E. baxteri* type, *E. cosmophylla* type and *E. obliqua* type were present in approximately equal proportions (~4-12% each). *Eucalyptus fasciculosa* is present in trace amounts throughout the zone. The shrub component of the terrestrial pollen sum declines from 13% to 5% through this zone and is predominantly composed of *Banksia marginata*, *Xanthorrhoea*, *Acacia* type-2 (likely to be *A. myrtifolia*) and Chenopodiaceae pollen. At 70 cm *Acacia* type2 pollen comprised 4.6% of the pollen sum, higher levels than in any other zone of the core. *Xanthorrhoea* pollen is present again in the record, accounting for 2% of the terrestrial sum. Herbs comprise between 8-15% of the terrestrial pollen sum. Asteraceae pollen accounts for most of the herb pollen, with Asteraceae Type 1 showing the most significant rise in representation in the lower samples of this zone. Poaceae pollen is poorly represented accounting for less than 5% of the terrestrial pollen sum.

Cyperaceae pollen is present in reduced proportions from zone B-3, comprising a low of 20% of the aquatic pollen sum at 60 cm before rising to 40% at 55 cm. *Goodenia* pollen increases markedly from less than 5% to 25% in zone B-3. *Leptospermum* also shows an increase in this zone from 5% at the base to 30% at the top.

Zone B-5 1750 - 110 BP- Depth 55 cm -27.5 cm

Sediments of zone B-5 are mostly humic peats. Peats are interrupted by clays between 35-30 cm. Macroscopic charcoal levels fluctuate being relatively high between 42-50 cm and low in the clay mottled sediments. The highest levels of microscopic charcoal in the sequence occurs at 30 and 35 cm.

The total pollen sum shows a rise, then decline, of Cyperaceae pollen from lower zone. The decline is due to rapid and dramatic relative increase in the amount of *Acacia* type-1 pollen in the record at this time. *Eucalyptus* and *Allocasuarina* are present in almost equal proportions in the total sum (~10% each).

Trees decline in representation by approximately 20% in this zone from the top of zone B-4. They account for about 65% of the terrestrial pollen sum. Shrubs and herbs are present in similar proportions, each fluctuating between 11-22% of the sum. Herbs increase in representation from the bottom to the top of zone B-5. The decline in tree representation is largely due to a decrease, from 50-25%, in the total amount of *Eucalyptus* pollen. The different size classes of *Allocasuarina* pollen vary throughout the zone, however if considered together the overall amount of *Allocasuarina* pollen here accounts for approximately 35% of the terrestrial pollen sum. A higher percentage of *Eucalyptus* grains were identifiable to type in this zone. *Eucalyptus baxteri*-type was the dominant class present. *Eucalyptus obliqua*-type, *E. fasciculosa*-type and *E. cosmophylla*-type were consistently recorded although none in proportions not greater than 10%. *Eucalyptus camaldulensis*-type pollen is recorded for the first time in the core in this zone, representing a maximum of 7% of the sum at 55 cm but is rarely recorded elsewhere. Chenopodiaceae, *Xanthorrhoea* and *Banksia marginata* compose the bulk of the shrub taxa, the latter two in relatively constant and low (less than 5%) percentages. *Banksia ornata* pollen is uniquely represented in this zone, although at less than 1%. Poaceae pollen comprises a relatively constant 10% of the pollen sum and all types of Asteraceae pollen totalled approximately 20%. Both are present in slightly greater proportions than the previous zone.

The aquatic pollen sum is dominated by Cyperaceae, *Goodenia, Leptospermum* and *Acacia* type-1 pollen. *Acacia* type-1 pollen increases greatly at 35 cm. Cyperaceae pollen declines in zone B-5 however this is due to relative increase in *Acacia* type-1 pollen, as when Cyperaceae was considered in a sum without the swamp fringe *Acacia* and *Leptospermum,* it remained relatively constant. *Baumea*-type Cyperaceae is the most consistently dominant Cyperaceae pollen type, although *Carex*-type is present at atypically high levels at 40 cm. *Leptospermum* is similarly constant at approximately 10% throughout the zone, although also declines in percentage representation when *Acacia* greatly increased. *Myriophyllum* accounts for 14% of the aquatic pollen sum at 55 cm and declines to 3% at 32 cm and then increases to 14% at 30 cm. *Villarsia umbricola* is present at less than 1% in the bottom of the zone.

Zone B-6 110 BP - present Depth 27.5 cm -0 cm

Sediments of this zone were loosely compacted herbaceous reed peats. Terrestrial pollen counts were low, with a minimum of 37 grains and a maximum of 92. Aquatic pollen counts were much greater with a mean count of 806 grains. The high aquatic counts are largely due to a large increase in the amount of *Acacia* type-1 at 25 cm, and then after 25 cm, *Leptospermum* pollen in the total pollen sum.

Due to low counts terrestrial pollen counts caution must be taken in interpretation of the relative percentages of terrestrial pollen types in this zone. The decrease in terrestrial types could represent the clearance of native vegetation or changes to the pollen depositional characteristics of the swamp. The relative proportions of trees, shrubs and herbs alters substantially from the rest of the core. Trees decline to account for a maximum of 45% of the sum and a minimum of 27%. Herbs increase to unprecedented values showing a maximum value of 44% (mean 36%), and the mean representation of shrubs in the zone is 24%.

Eucalyptus and *Allocasuarina* continue to dominate the tree component of the sum but display lower percentages than in zone B-5. *Eucalyptus* declines to less than 10% of the pollen sum at 20 cm but increases in the surface samples to 15-20%. *Pinus* pollen accounts for 3% of the pollen sum at 15 cm and increases to 4.3% in the surface sample. Chenopodiaceae pollen increases in this zone to an unprecedented 15% of the terrestrial pollen sum. *Epacris*, *Dodonaea*, *Leucopogon*, *Plageanthus*-type, and *Muehlenbeckia adpressa* pollen are present in higher percentages than previously recorded. This does not necessarily reflect an increase in their distribution but rather a relative increase due to tree pollen decline. Poaceae, particularly the larger sized grains, increase markedly in this zone; from 2% at 25 cm to 20% at 20 cm. Pollen from the non-native species in Brassicaceae, *Plantago* spp. and *Rumex* spp. also contribute to the herb component of the terrestrial sum. Asteraceae-Tubuliflorae types in total have similar percentage contribution to the sum as zone B-5, whereas Asteraceae Liguliflorae pollen has increased representation.

The aquatic pollen sum is strongly dominated by *Acacia* pollen (80%) at 25 cm and then *Leptospermum* pollen from 20 cm to the top. Cyperaceous pollen shows a relative decline in representation. *Myriophyllum* declines in this zone. When the highly represented *Acacia* type-1 and *Leptospermum* types are removed from the aquatic pollen sum *Myriophyllum* and Cyperaceae levels do not show this decline. *Goodenia* pollen is present in much reduced percentages from zone B-5, at levels less than 10%.

8.3.3 Combined PCA analysis

Comparison of modern pollen samples from vegetation communities in the Fleurieu Peninsula (Chapter 3) and fossil samples from core BH-2 was carried out using PCA analysis. About 39% of the variability in the combined pollen data was able to be explained by the first two component axes of a PCA (Table 8-3).

Table 8-3 The proportion of variation in the modern pollen and fossil pollen spectra explained by component axes as calculated by PCA analysis.

Axis	Value	Prop.	Cum. prop.
1	0.038	0.254*	0.254
2	0.021	0.141*	0.396
3	0.018	0.121	0.518
4	0.012	0.081	0.600
5	0.009	0.064	0.665
6	0.009	0.061	0.726

The eigenvectors for the principal taxa leading to the sample plot values in the PCA analysis are shown in Figure 8.6. The first axis is driven by high positive values for *Allocasuarina* <28 μm and *Allocasuarina* >28 μm and high negative values for *E. obliqua* type pollen. The second axis is defined by high positive values for *E. cosmophylla* and *Eucalyptus* indistinguishable to type grains and high negative values for *E. fasciculosa*, and Poaceae type 30-50 μm and moderately high negative loadings for Poaceae, type 20-30 μm, and Asteraceae type-4 pollen.

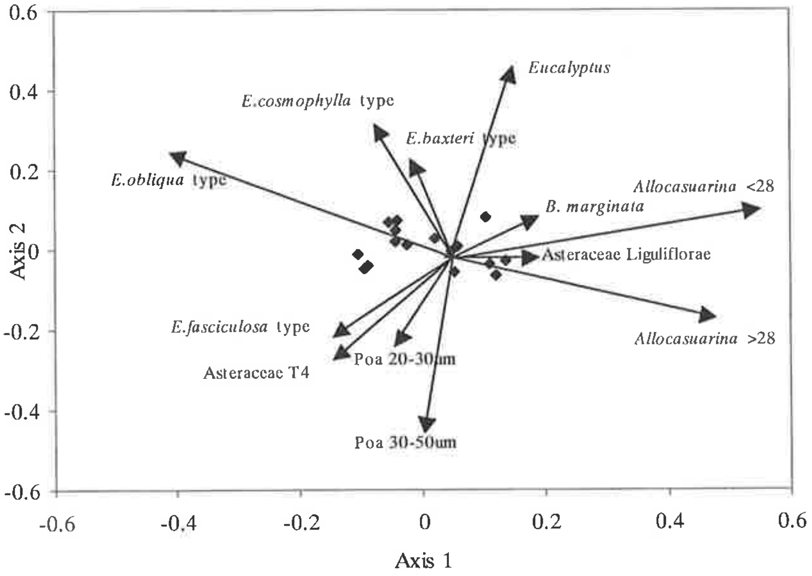

Figure 8.6 Principal component analysis biplot for taxa in the combined modern pollen and Boat Harbour creek fossil pollen data sets. Vectors have been drawn to those taxa accounting for the most variation in the data set.

The plots for fossil and modern samples show modern pollen samples show division along the primary component axis of modern and fossil samples (Figure 8.7). Early and late Holocene samples (zones B-1, B-2, B-4 and B5) form a reasonably tight cluster, the mid Holocene samples, zone B-3 out lie as a distinctive group along the first axes and European period samples form a distinctive, but loose, cluster. The dark arrowed lines from midpoints of each zone reveal small vegetation changes which occurred in the early Holocene, a large shift to mid-Holocene *Allocasuarina*-dominated heath, a return to *Eucalyptus*-dominated vegetation types that were more similar in composition to early Holocene vegetation, and finally a large shift to vegetation post-European vegetation. Modern pollen samples in comparison are only loosely grouped with little affinity for fossil samples, suggesting that no modern analogue is provided by this modern pollen data set.

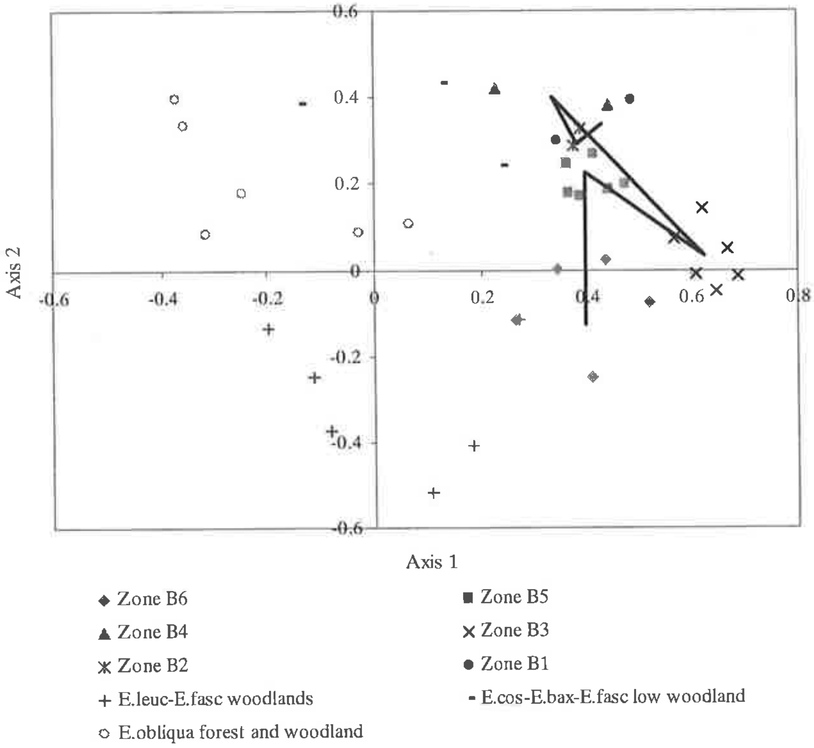

Figure 8.7 Principal component analysis bi-plot for combined modern pollen and Boat Harbour creek fossil pollen data sets. Eigenvalues are expressed as proportions of total variation. Fossil samples are identified according to their respective zones and modern samples to their respective vegetation group. The midpoints of fossil samples (mean of principal component) from a single zone are joined in stratigraphic order by the dark line. E.leuc. = E.leucoxylon, E.cos. = E.cosmophylla, E.bax.= E.baxteri, E.fasc = E.fasciculosa.

8.4 Interpretation core BH-2

Modern pollen spectra from Fleurieu Peninsula vegetation communities (Chapter 3) suggest that the fossil pollen spectra from Boat Harbour Creek is primarily of local (swamp and swamp margin) and extra-local origin (surrounding catchment), with a lesser proportion of regionally dispersed pollen types. The consistently low abundance of Chenopodiaceae pollen in the sequence, a regionally dispersed pollen-type which is commonly present in south-eastern Australian pollen records, provides added weight to the interpretation that this swamp record is primarily reflecting local and extra-local vegetation. As such, this site is in agreement with Tauber's (1967) observation that regional pollen is generally more prevalent in open water sites than in swamps, where it is filtered by swamp margin or swamp vegetation. The record also suggests, through the low presence of *Pinus* pollen despite the large regional plantings of *Pinus radiata,* that the representation of regional pollen in sediments of the European-phase may be further reduced due to shrub-thickening on the swamp.

Microscopic charcoal in sediments is considered to represent charcoal from both local and regional sources, while macroscopic charcoal is likely to be only sourced locally from fires that burned within the drainage basin or on the swamp surface itself (Clark, 1983; Patterson *et al.*, 1987; Macdonald *et al.*, 1991). That the macroscopic charcoal record from the BH-2 core is reflecting local or *in situ* burning events is substantiated by the fact that low amounts of macroscopic charcoal were present in sediments in zone B-1, prior to the expansion of the swamp. On the basis that macroscopic charcoal reflects local fire events and microscopic both local and regional, it could be expected that the major peaks in the macroscopic record would be reflected in the microscopic. Overall there is little agreement between the two charcoal records, except for large peaks in upper sediments. These peaks probably reflect European burning. While it is believed that no charcoal measure provides unequivocal measures of catchment fire events, so perfect matches between records are unlikely (eg McDonald *et al.* 1991), the difference in sampling intervals between methods used here most likely explains the absence of the swamp or local catchment burning events evident in the macroscopic record, but undefined in the microscopic.

The core indicates that the Boat Harbour Creek swamp began to form some time between 7-8000 years BP. The lowermost clay sediments contain only small amounts of pollen of the swamp-margin species, *Leptospermum* and *Acacia,* and the proportion of Cyperaceae pollen in these sediments is much lower than in upper more organic sediments. Cyperaceae pollen comprises 20% of the total pollen sum compared with between 35 and 65% of upper sediments. The presence of *Myriophyllum, Villarsia* and *Stellaria* pollen in the bottom clays indicate local conditions were moist at this time but not wet enough for peat preservation. *Eucalyptus* woodland, with a sclerophyllous-shrub understorey of species including *Banksia marginata,* shrub *Allocasuarina* and *Xanthorrhoea,* characterised the vegetation of the catchment at this time. Poaceae pollen is present in low numbers only which adds weight to the interpretation that the surrounding understorey was composed of sclerophyllous shrubs. *Goodenia* spp. pollen was present in relatively high numbers, representing the distribution of wetland species around the swamp or its presence in the terrestrial vegetation at that time. It is difficult to determine the floristic composition of the *Eucalyptus* overstorey as only small numbers of *Eucalyptus* pollen were identifiable to type. However of them *E. obliqua, E. fasciculosa and E. cosmophylla* types and *E. cladocalyx* pollen were distinguished confirming that at least these species were components of the extra-local and possibly regional overstorey vegetation at that time.

The organic content of sediments increases steadily from swamp inception to about 5700 years BP except for a temporary decline at about 5900 years BP. Zone-B3, starting around 6250 years BP, represents a period of reed swamp establishment and the lateral expansion and colonisation by the swamp-fringe shrub species *Leptospermum*. The swamp was probably permanently wet as indicated by consistent levels of *Typha* pollen in this phase. *Typha* spp. do not tolerate more than one season of drying and generally grow in open water up to 1 metre to 1.5 metres deep (Gott, 1982). However the fact that *Carex*-type and *Baumea*-type Cyperaceae constantly dominate the aquatic spectra at this time indicate that it is unlikely that water depths were significantly greater than at present, as decline in these types would be expected if water levels deepened (Dodson and Wilson, 1975; Crocker and Eardley, 1939). *Myriophyllum* abundance varies throughout this zone possibly suggesting that there were fluctuations in water levels through this period.

During this time of Cyperaceae-swamp expansion, *Allocasuarina* pollen dominates the terrestrial pollen spectrum. Both *Allocasuarina* < 28μm and *Allocasuarina* >28μm pollen show an increase in representation, with *Allocasuarina* <28μm, a shrub type, increasing a little more than the type generally attributed to be from *A. verticillata*. *Banksia marginata* and *Leptospermum* pollen are also well represented. Spectra from this time are strongly separated on the first axis from modern scrub, forest and open woodland samples by PCA analysis (Figure 8.7), suggesting there is no modern analogue in the extant vegetation of the region.

High *Allocasuarina* presence has been interpreted as representing *Allocasuarina* woodland (Clark, 1983). *Allocasuarina verticillata* woodlands were recently extant in the lower rainfall areas of the Fleurieu Peninsula, but largely disappeared after European settlement. Remnant stands of *A. verticillata* are now restricted to sites of low moisture availability. Consideration of the present day moisture relations at the Boat Harbour Creek swamp catchment, and the ecological habitat of *A. verticillata,* suggests that the spectra at this time is not representing a local vegetation dominated by *A. verticillata* woodland. The increase in *Allocasuarina* pollen at Boat Harbour Creek therefore must be explained by an expansion in another species of the genus. *Allocasaurina striata, A.muelleriana* and *A.mackliniana* are shrub components of the sclerophyll landsystem in open forest, scrub and heath formations in the Mount Lofty Ranges. All three are most commonly found to occur on depauperate soils with low moisture relations. Modern pollen spectra from communities with *Allocasuarina* components show that *Allocasuarina* pollen does not account for more than 20% of the pollen sum (Chapter 6). Drier conditions could be expected to favour expansion of the shrub *Allocasuarina* understorey component of sclerophyll communities, so the expansion of these species is unlikely to explain the *Allocasuarina* rise in this record. It is more likely that the expansion of a wetland-habitat species of *Allocasuarina* is responsible for this change in the spectra. *Allocasuarina* species do not feature strongly in the modern wetland vegetation in the Fleurieu Peninsula. Very limited occurrences of *A. robusta* have been reported on swamps in the Mount Compass region, 20km to the north of the study site (Jessop, pers. comm.). *Allocasuarina robusta* is morphologically and ecologically similar to *A. paludosa*, a commonly occurring component of wet and dry heath communities in the lower and upper southeast of South Australia (Specht, 1972). Until the recent revision of the Casuarinaceae family (Johnson, 1982), *Allocasuarina robusta* was considered to be the same species as *A. paludosa*. Dodson and Wilson (1975) describe a wet heath community in the lower southeast of South Australia, occupying open areas in water logged regions, and propose that it dominated the Mount Burr site at Marshes Swamp from 7160-5240 years BP. The community has an overstorey of shrubby forms; *Leptospermum continentale*, (formerly *L. juniperum*), *Allocasuarina paludosa* and *Banksia marginata* over, or interspersed with, rushes and sedges (Restionaceae and Cyperaceae). At this time in the Boat Harbour Creek site, *Banksia marginata* pollen attains higher percentages than elsewhere in the core. An increase in the locally dispersed pollen from *B. marginata* indicates its expansion nearby or within the swamp. *Leptospermum* pollen also significantly increases. Pollen spectra from this time in the core BH-2 could be representing a Cyperaceae, *Leptospermum, Allocasuarina* and *Banksia*-dominated wet-heath community similar to that occurring today in the lower south east of South Australia. *Eucalyptus* pollen is virtually absent from the spectra at this time suggesting that either the catchment was largely devoid of *Eucalyptus* or regional pollen was diluted due to the local expansion of the scrub-heath community. It is possible that it was too wet for *Eucalyptus* establishment. *Eucalyptus ovata* (Swamp Gum) may have been patchily located in the swamp or on its fringes and *E. baxteri* may have been confined to less wet patches or on surrounding ridge tops.

From 3630 years BP a drier period is evident. The organic content of sediments declines and peats show less humification than those in zone B-3, except for a brief return of humic dominated peats between 50 and 35 cm. The extra-local terrestrial vegetation changes from *Allocasuarina*, *Banksia*, *Leptospermum* and *Cyperaceae* wet heath to a *Eucalyptus*-dominated association with a sclerophyll/heath understorey as indicated by rises in *Xanthorrhoea, Banksia ornata* and *Acacia* type-2 (probably *A. myrtifolia*). The identifiable *Eucalyptus* pollen types, *Eucalyptus baxteri*-type, *E. cosmophylla*-type, *E. obliqua*-type pollen were identified in this phase and comprised the upper strata of the surrounding vegetation. The PCA suggested some affinity between the composition of vegetation of this period and the modern *E. cosmophylla-E. baxteri-E. obliqua* low woodland or ‘scrub’ communities presently extant in the region. *Eucalyptus camaldulensis* pollen was also identified in this zone.

Eucalyptus remains the dominant overstorey tree type until declining markedly at the time of European settlement. The post-European sediments are organic-rich, herbaceous peats, except for an incursion of clay sediments at around 28 cm. Sediment accumulation rates are substantially higher than at any other time in the core. The aquatic pollen spectra from this time is distinguished by dramatic increases in *Acacia* type1 and *Leptospermum* pollen, probably indicating expansion of these components on the swamp. The terrestrial pollen spectra from this time are more akin in composition to the open woodland modern pollen samples than those from forest or scrub (Figure 8.7). This is likely to be due to the fact that fossil samples of the European phase are reflecting vegetation clearance so the pollen spectra resemble the more open woodland community types. The modern open woodlands communities are the most modified of the modern communities sampled in the modern pollen study. It is thus also possible that pollen spectra from this phase could be reflecting a general footprint of European transformation, as well as a local record of vegetation change. It should be noted however, that terrestrial pollen counts were low, so analysis of their composition needs to be made with caution. Chronology, sediments and pollen from this phase of the core are considered in more detail in the following Chapter.

8.5 Discussion

8.5.1 Wetland history and climate

The formation of the Boat Harbour Creek swamp around 7500 years BP is coincident with a major phase of peatland initiation, or sediment change in existing peatlands, in southeastern Australia (Kershaw *et al.*, 1993; Kershaw, 1995). This phase of peat initiation is concurrent with, and has been explained by (Kershaw *et al.*, 1993), the attainment of maximum precipitation values in the Holocene in western Victoria (Bowler *et al.*, 1976) and southeastern South Australia (Dodson, 1974). The present day climatic gradient between western Victoria, southeastern South Australia and the Mount Lofty Ranges is not great and, on that basis, it has been supposed that conditions were wetter than present as far west as the Mount Lofty Ranges in the mid-Holocene (Dodson, 1974). The Boat Harbour Creek sequence supports this assertion. High levels of peat formation (sedimentation rates of 0.025 mm/yr between 6200 and 4800 years BP) are seen in the Boat Harbour Creek record, suggesting conditions were highly suitable for peat formation to at least 4800 years BP. While increased moisture due to wetter climatic conditions is likely to be a necessary requisite for swamp initiation, it is conceivable that various other autochthonous changes, and changes related to human activity, may have facilitated swamp development and expansion at this time. The soils of the catchment are podzolic with loamy A-horizons overlying ironstone-rich gravelly clays. The increased moisture level at this time could have lead to increased podzolisation of these soils. Podzolised soils, being poorly drained, would have resulted in increased water logging in the catchment and paludification of lower lying areas. Anthropogenic removal of trees has been attributed as being a likely cause for localised and blanket peat development in the mid-Holocene in parts of Europe (Simmons, 1990) and as a major cause of a raising of ground water levels in southern Australia since European settlement (McTainsh and Broughton, 1993). The record suggests aboriginal occupation and manipulation of vegetation by burning in the mid-Holocene. While speculative, Aboriginal burning may have acted to create more open vegetation in the catchment. A more open vegetation would have fewer deep-rooted *Eucalyptus* species whose transpiration processes strongly contribute to maintaining water table depth. Water tables may have risen as a result and lead to increased water logging.

In thc mid Holocene phase of maximum peat development, sediments are interrupted by an incursion of inorganic of sediments at 5900 years BP. These sediments are most likely derived from short term fluvial transport rather than representing a temporary shift to drier conditions. The low pollen concentrations in these organic sediments is consistent with the idea that they represent a phase of relatively rapid accumulation.

Effective precipitation values and temperatures declined in southeastern Australia in the mid- to late Holocene. Evidence of drying, as indicated by a decline in the organic content of sediments, less humified peats and the shifts in terrestrial vegetation from a wet heath to *Eucalyptus* woodland dates to *ca* 3630 years BP in the Boat Harbour Creek record. The shift in the surrounding vegetation provides the best evidence for a drier phase. Water level changes in peat basins can be the result of successional processes operating independently within the basins themselves. Shallowing, independent of climate change, can occur as a result of the natural evolution of the hydrosere resulting in peat build up and drying. Clark (1983) interpreted a decline in Cyperaceae pollen and fern and bryophyte spores at 4800 years BP at Lashmar's Lagoon as an onset of drier conditions on coastal Kangaroo Island. The disparity in the timing of this drying event, and that at Boat Harbour Creek, could be explained by the two sites occupying opposite ends of the climate gradient established by the Mount Lofty Ranges. Alternatively the differences could be more apparent than real and due to the relative sensitivities of the respective vegetation types at Lashmar's Lagoon and Boat Harbour Creek to temperature and precipitation change. Conditions became drier in the western Victorian lakes from 3500 years BP (Bowler and Hamanda, 1971; Bowler *et al.*, 1976) and remained wet for longer, not drying until 2960 years BP, in the more easterly situated Lake Leake (Dodson, 1974). The timing of the drying phase at Boat Harbour Creek is in general agreement with these records.

Dodson and Wilson (1975) proposed that deflation of sediments occurred at Marshes Swamp in the later part of the Holocene when conditions became drier. A more constricted chronology of the upper part of core BH-2 would be required to ascertain whether deflation occurred in the Boat Harbour Creek swamp. However from 3630 ± 150 at 75 cm to just prior to European settlement, the age-model adopted indicates that sedimentation rates are lower than at any other time in the record (0.01 mm/year) and so may be representing net accumulation rates rather than deposition rates. Peats become more humic once again between 50 and 35 cm. Variability in precipitation and temperature are thought to have occurred over the last 2000 years in southeastern Australia. Water levels were higher between 2000-1300 years BP at Lake Leake (Dodson, 1974). Bowler *et al.* (1976)

demonstrated that conditions became wetter at Lake Keilambete in the late Holocene recorded at *ca* 2000 years BP at Lake Keilambete and Mooney (1997), considering the record from Lake Keilambete in fine resolution over the last 2000 years, proposed that climate fluctuated through this period with 2000-1880 years BP and 1415-1320 years BP being periods of increased moisture supply. It is possible that the fluctuations between herbaceous and more humic peats in upper sediments of the Boat Harbour core are also reflecting Late Holocene climate fluctuations.

8.5.2 Holocene vegetation history

The lowermost sediments suggest that *Eucalyptus* woodland was extra-locally, and possibly regionally, present at the inception of the Boat Harbour Creek peatland. In southern Australia *Eucalyptus* and *Casuarina* forest and woodland expanded between 12000-9000 years BP after being restricted in localized favourable patches during the last glacial (Kershaw, 1995). Although a firm basal date was not obtained for the record it is likely that the sequence is in agreement with other southern Australian records and the bottom sediments, demonstrating *Eucalyptus* woodland, were deposited in the early Holocene. Notable in *Eucalyptus* grains present in lowermost sediments was *E. cladocalyx* type pollen. This species is no longer growing naturally on the Fleurieu Peninsula but occurs in a localised areas on the Eyre Peninsula, in the Southern Flinders Ranges and on Kangaroo Island (Boomsma, 1981). This record indicates that this species once had a more continuous distribution extending to the Fleurieu Peninsula prior to *ca* 7000 years BP. Other identifiable *Eucalyptus* types present in the record prior to *ca* 7000 years BP are from species with present day distributions in the region. *Eucalyptus baxteri* type, which includes *E. baxteri* and the swamp gum *E. ovata,* are not detected in the record until *ca* 6300 years BP. This was at the time that climatic conditions were becoming wetter and so could be indicating expansion of *E. ovata* at that time.

Moisture relations in the catchment around 6250 years BP changed to the extent that the threshold supporting *Eucalyptus* woodland was crossed and it was replaced by a more moisture-tolerant heath of *Leptospermum, Allocasuarina* and *Banksia*. As the Boat Harbour site principally represents the extra-local and local vegetation, the extent of this heathland is questionable. With relation to conditions critical for vegetation change during climate changes, local environmental conditions, particularly related to landform, are important (Smith, 1965). The broad gentle valleys and lateritic soils of the upland plateau characterising the southern Fleurieu Peninsula would have been particularly susceptible to moisture changes. Increases and decreases in regional precipitation would, in effect, be locally amplified in such landscapes. It could be reasoned that the *Allocasuarina* wet heath could have covered extensive areas of the plateau of the southern Fleurieu Peninsula and conditions may have been too swampy over broad areas on the plateau for the establishment of even the present day wetland-fringing *Eucalyptus* species (*E. ovata* and *E. baxteri*). This is supported by the almost complete lack of *Eucalyptus* pollen, which is well dispersed, in the record at this time.

Substantial amounts of *Eucalyptus* type-4 pollen (attributed to *E. baxteri or E. ovata)* were found in the *Allocasuarina, Banksia* and *Leptospermum* wet heath assemblage at Mount Burr swamp in southeastern Australia at a similar time (Dodson and Wilson, 1975). This suggests that taphonomic processes associated with this heath type vegetation are unlikely to be responsible for the exclusion of *Eucalyptus* pollen. The wettest areas of the Fleurieu Peninsula are currently occupied by *Eucalyptus obliqua* forests (Chapter 5; Boomsma, 1948) and an increase in precipitation in this area could conceivably have favoured the expansion of this forest type. There is no evidence for this occurring near the Boat Harbour Creek core; modern pollen samples from *E. obliqua* forest and woodland sites are clearly separated in the PCA analysis of modern and fossil assemblages. This may reinforce the suggestion that conditions were too swampy in broad areas for the persistence of eucalypts. It could also indicate that edaphic factors exert a controlling influence on *E. obliqua* distribution in the region. The soils in the catchment are considered depauperate, being low in nitrogen, phosphorus and trace elements and *E. obliqua* forests occur on more fertile soils in the region (Boomsma, 1948). The uplands of the central Mount Lofty Ranges are characterised by steeper gradients (Laut, 1977) and so it is unlikely that the wet heathland of the southern Fleurieu Peninsula extended over the central and northern Mount Lofty Ranges.

Wet heathlands and swamps of *Leptospermum, Allocasuarina* and *Banksia* are still found in the southeast of South Australia (Dodson and Wilson, 1975) but no longer feature in the remnant vegetation on the Fleurieu Peninsula. The wetland vegetation of the Fleurieu Peninsula is considered distinctive from others in southeastern Australia (Duffield, 2000). This record suggests that perhaps there were more similarities between more easterly vegetation in the mid Holocene than there is at present and that diversification occurred in the later half of the Holocene.

Allocasuarina declines markedly in the Boat Harbour Creek record after 3650 years BP, and eucalypts, once again, become more prominent. A decline during the Holocene in *Allocasuarina,* and its replacement by *Eucalyptus* as the dominant sclerophyllous taxon, has been discussed as a significant regional pattern and a fundamental vegetation change marking the Late Quaternary in southeastern Australia (Kershaw *et al.*, 1991). Although the Boat Harbour Creek record does show a substantial decline in *Allocasuarina,* interpreting it as representing a regional event should be done with caution. The inability to identify the species with any surety, and the fact that the species within the *Allocasuarina* family exhibit such a diverse range of ecologies, makes the search for regional trends a false exercise. That the pollen spectra from the Boat Harbour core has been interpreted to be mainly representing local and extralocal vegetation further suggests that it would be inappropriate to juxtapose this record with other regional records and search for unifying causality of the decline. The decline in the Boat Harbour record is thus discussed as a local phenomenon. Nevertheless, the various explanations purported to explain *Allocasuarina* declines; changed human and climate-affected fire regimes (Singh *et al.*, 1981; Hooley *et al.*, 1980, Kershaw, 1988), a change to a wetter climate (D'Costa *et al.*, 1989), competitive replacement by eucalypts (Dodson, 1977a) and responses to ground water levels and soil salinity (Crowley, 1994) are discussed.

It is unlikely that an anthropogenically-altered fire regime is the primary forcing agent of *Allocasuarina* decline in the Boat Harbour Creek record. While the microscopic charcoal record is of only sufficient resolution to detect major changes, there does not appear to be any major shifts in the fire regime in the catchment through the Holocene until European settlement. The microscopic charcoal record remains reasonably low and constant until it dramatically increases in the European period. Low and constant levels of microscopic charcoal, have been interpreted as reflecting a high frequency of low intensity fires (Clark, 1983; Hope, 1999) and being indicative of regimes in place in regions under continual Aboriginal occupancy (Clark, 1983). Holocene sea levels reached their present level at about 6600-6400 years ago (Belperio *et al.*, 1983) and archaeological studies conducted in the 1970s argue for an occupation of the eastern coastline of St. Vincent's Gulf soon after this time through to modern times (Cane, 1977). However given the antiquity of aboriginal occupation in areas proximal to the Fleurieu Peninsula the area could have been occupied and deliberately burned for considerable time prior to this time (Lampert, 1981; rock shelter Kangaroo Island 16 000 years BP). That changes in the fire regime, anthropogenic or natural were not responsible for the decline in *Allocasuarina* is further suggested by the fact that there is little evidence that the *Allocasuarina* species likely to have been represented in the mid-Holocene pollen spectra are disadvantaged relative to *Eucalyptus* under intensified fire regimes (Ladd, 1988; Kirkpatrick,1986; Crowley, 1994).

Crowley (1994) examined 20 late-Quaternary pollen records from southeastern Australia and suggested that, in most records, *Allocasuarina* decline was synchronous with rises in groundwater and soil salinity. From this she argued that declining *Allocasuarina* spp. were salt-sensitive and that the relationship between groundwater levels, salinity and *Allocasuarina* decline was causal. She noted that coincident with *Allocasuarina* decline in most sites, were increases in salt tolerant Chenopodiaceae. She used this as further evidence that salinity was the principal controlling factor. The Boat Harbour Creek record does not substantiate Crowley's hypothesis; for *Allocasuarina* is maintained when groundwater levels would have been at their highest, that is in the wettest period of the Holocene, and the Chenopodiaceae count remains largely stable through the entire sequence. In addition, present day groundwater salinity levels are less than 1000 mg/L total dissolved salts, below critical levels affecting plant growth.

A drying, and an increasingly variable climate, are the preferred explanation for the decline in *Allocasuarina* in the Boat Harbour Creek record. As remarked earlier, there was a regional shift to drier conditions in the late Holocene and evidence for climatic variability at that time, possibly beginning *ca* 5000 years BP and becoming more evident in the last 3000-4000 years (MacPhail and Hope, 1985; McGlone *et al.*; 1992; Schulmeister, 1999). The fact that the *Allocasuarina* community dominance in the Boat Harbour record is in phase with the wettest period in the Holocene and its decline is around the time of reported regional climate deterioration suggests that climate has been important. A decline in groundwater and reduced precipitation would have resulted in reduced water logging on the broad flat areas of the plateau of the southern Fleurieu Peninsula and conditions would have became suitable for the establishment of the less moisture-requiring eucalypts and sclerophyllous understorey species. Clark (1983) also concludes that climate was the primary driving force for the replacement of *Allocasuarina* woodland by *Eucalyptus* on Kangaroo Island at *ca* 4800 years BP. She argues that the onset of drier conditions resulted in more intense fires which would have facilitated *Eucalyptus* dominance.

Comparison of modern and fossil pollen spectra showed that the fossil record was largely without a close modern analogue. Several reasons could explain this. It could be that the historical vegetation was very different and has no modern analogue. Also possible is that the modern pollen data set is inadequate and a full suite of possible analogues would have arisen with wider sampling. Selective clearance of vegetation types by Europeans has resulted in the remnant communities from which moss polster samples were taken, not being representative of the breadth of community types present on settlement. Additionally it could be that remnant vegetation has been altered so extensively by European settlement that that fossil vegetation can not be characterised by a modern analogue approach. A recurrent problem facing the modern analogue approach to fossil pollen interpretation is that basins of deposition of core sites and moss polsters are likely to have different properties and spectra will reflect their individual properties. For example moss polster communities are more likely to represent local communities whereas swamps with in flowing streams and large catchments are likely to be an integration of the pollen rain of surrounding communities.

8.5.3 Aboriginal wetland use

The greatest macroscopic charcoal concentrations in the sequence are present in the post-European sediments and in the wettest phase of the record, zone B-3. The presence of high microscopic charcoal levels from 6800 years BP in a coastal swamp at Discovery Bay in western Victoria has been used as evidence for Aboriginal wetland use (Head, 1988). It is possible that the large macroscopic charcoal peaks represent deliberate anthropological burning of the swamp surface in the mid-Holocene. Local landowners report that the swamps in the region do not burn easily, rarely igniting during wild fires and often only burning with difficulty after deliberate ignition. This suggests that the *in situ* burning, that macroscopic charcoal indicates, might have anthropogenic origin. Adding strength to this interpretation is the unique appearance of *Typha* spp. pollen in the record at this time. *Typha* pollen is present in greater abundance between 140 and 180 cm than anywhere else in the record. *Typha* pollen has been reported to be poorly represented in the pollen record, except beneath very large stands (Head and Stuart, 1980), suggesting that the levels of representation of this taxa in the pollen record suggest it was ubiquitous in the swamp at that time. The roots of *Typha* spp. are a staple of many of the southern Aborigines diets (Gott, 1982; Clarke, 1988) and ethnographic records indicated that Aborigines burned swamps to facilitate the harvest process. Eyre (1845) writes that the rhizome was used throughout the year on the lower Murray River, but that it was best 'after the floods have retired and the tops have become decayed and been burned off'. Clarke (1988) considers *Typha* spp. to be one of the staple food resources for the southern Australian Aborigines and quotes Angus (1847) 'the staff of their existence is the bulrush root which the women gather amongst the reeds'. Little is known of the Aboriginal use of the uplands of the Fleurieu Peninsula areas (Gara *et al*, 1999) as little survey or dating of Aboriginal sites in these areas has been undertaken. This is in contrast to coastal regions, where many aboriginal sites have been recorded. The high frequency of sites in coastal regions has lead to arguments that the coast was the focus for Aboriginal occupation in the Adelaide region (Ellis, 1976; Campbell, 1988; Clarke, 1996) and the upland forests and scrubs were used for sheltering, firewood collection and hunting primarily in the winter months (Tindale, 1974; Ellis, 1976). The reduced size of the coastal plains, and thus the proximity of the ranges to the coast in the southern Fleurieu Peninsula, might have meant that the inland areas were more intensively used after sea levels reached their maximum.

8.6 Conclusions

The record provides evidence for the dynamic nature of sclerophyll vegetation of the Fleurieu Peninsula during the Holocene. It reveals a transition from an early Holocene-*Eucalyptus* dominated woodland to an *Allocasuarina* dominated wet heath in the mid-Holocene and a return to *Eucalyptus* dominated woodland in the drier Late Holocene, probably reflecting responses of the vegetation to Holocene climate changes. Charcoal and pollen records from this study suggest that Aborigines have occupied and utilised the highland forested regions of the Fleurieu Peninsula throughout the mid-late Holocene. Substantial vegetation changes occurred through the Aboriginal period of occupation but these changes seem to be in response to changing climate regimes rather than being anthropogenic in nature.

CHAPTER NINE

9. EVALUATION OF DATA SOURCES

9.1 Introduction

This chapter evaluates the different types of evidence used in this thesis. The spatial, taxonomic and temporal level of resolution of each approach is assessed. Where lines of evidence meet in time and space they are compared. The chapter examines the relative strengths and weaknesses of evidence types in relation to their ability to reveal former vegetation patterns, change and human impact.

9.2 Scales and Resolution

The integration of the palaeoecological and historical records examined in this study required (1) the basic taxonomic units of each approach to be equivalent, (2) the spatial units of each to be of comparable scale/resolution and (3) the temporal resolution of the records to be comparable. The extent to which this was achieved, or is possible, with the available data for historical environments in this region is discussed here.

9.2.1 Taxonomic and classificatory resolution

Identification of pollen to a resolution which discriminated pollen fossil assemblages to the plant formation and the community level allowed comparison of pollen data with modern vegetation and documented historical records. Discrimination of *Eucalyptus* species to genus or type-classes, using multiple, fine-resolution morphological features facilitated the differentiation of open grassy woodlands from sclerophyll forests and low woodlands. Similarly, formation units were clearly recognisable in documented historical records. The use of well-represented *Eucalyptus*-types, and less well-represented understorey types, as indicator species allowed recognition in the pollen record of some heterogeneity at the association/community level. Some variation at this scale of classification was also discernible in the documented historical record.

The historical and modern vegetation classes, whose potential distribution was modelled, varied in their comparability. Historical 'scrub' and 'forest' records indicated the presence of sclerophyll woodlands (Chapter 3) and the modern data set consisting of *E. obliqua, E. baxteri* and *E. cosmophylla* survey site records represented most of the extent of sclerophyll woodland in the region today (Chapter 5). The first surveyed sections which were taken as evidence for the distribution of historical grassy woodlands (Chapter 3) could not be compared with such certainty to modern grassy woodland records because of the indirect nature of the historical records. Comparability was also complicated due to the modern grassy woodland data set containing *Eucalyptus leucoxylon* (as well as

E. camaldulensis and *E. viminalis*) which also occurs in sclerophyllous communities. Historical reference to stringy bark forest was readily identifiable as being the equivalent of *E. obliqua* open forest and *E. obliqua* ± *E. fasciculosa* open forest (Chapter 3). The historical descriptor stringy bark scrub was most likely used to describe *E. baxteri* dominated low woodlands, which were once extensive in the region but were largely removed by 1948 (Boomsma, 1948) and no longer occur. Historical reference to gum and stringy bark scrub referred to a wide range of vegetation types combining *E. baxteri,* and to a lesser degree *E. obliqua* with either, or combinations of, *E. cosmophylla, E. leucoxylon* and *E. fasciculosa*. *Eucalyptus baxteri* – *E. cosmophylla* low woodlands were the only obvious modern equivalent. Historical reference to gum scrub probably represented a range of white-barked gum-dominated communities including *E. cosmophylla* very low woodland, *E. fasciculosa* low woodland, and *E. fasciculosa* *E. leucoxylon* woodland.

9.2.2 *Spatial resolution*

Comparison of different lines of evidence requires their spatial conjunction. As well as overlapping in space they must conform to the same spatial resolution. Constructed spatial frameworks are implicit in each line of evidence. In the case of palaeoecological evidence spatial frameworks are based on experimental or conceptual models of pollen and charcoal transport and deposition. The spatial data bases built on historical documented records of vegetation involved different assumptions about the area classified by each record type (Chapter 3). Mapped remnant vegetation community data are derived from models of distribution developed using classified site data and aerial photographs (DENR, 1988). The spatial unit used to interpret pollen data was, for most components of the spectra, the catchment surrounding the swamp and the swamp itself. Surveyors Field Notebook records of vegetation were of a similar spatial scale. Often one or more records were contained within a catchment. This is in contrast to the Diagram Book records which classified larger units and more appropriately represented meso-scale variations. The scale at which remnant vegetation was mapped captured topo-scaled changes. This allowed the parallel use of palaeoecological and documented Field Book evidence for defining vegetation pattern and remnant vegetation.

9.2.3 *Temporal resolution*

While most documented historical data was resolvable with precision to a particular year, it was time transgressive and represented the first 50 years of European settlement, rather than just the time of settlement. Sclerophyll woodland records were made in the 1880s while most of the grassy woodlands' data used in the reconstructions were made around that time, or within the first 10 years, of settlement. It is possible that boundaries may have been obscured or shifted in that interval. The survey data used to map and model sclerophyll woodland communities were collected over a short time period and therefore provided a static, single sample of vegetation that may be dynamic at stand to regional scales.

In the European period, chronological resolution of palaeoecological records provided the biggest challenge to their interpretation and comparison with documented records. Radioisotope (lead-210) dating of peat sediments did not provide easily interpretable chronologies or chronologies extending over the full 130 years for which they have the potential. Pollen and charcoal markers, used in conjunction with documented land use histories and information on exotic species introductions, were useful indirect dating methods in this study. They provided potential pre-European markers as well as verification for the radiometric dating. Although chronologies were not tightly constrained in the post-European period, they were at least of sufficient resolution to associate with particular occupancy and land use phases through that time. The pre-European pollen and charcoal records were resolved at a coarser temporal scale than through the European period. Ideally, finer resolution sampling should be adopted to allow more definite conclusions through cross comparison of rates of change through the European period with the Holocene changes.

9.3 Cross testing and comparison

Where two independent lines of evidence are coincident by spatial, temporal and classificatory parameters, then they may be used as tests for each other. Where they are taxonomically commensurable, but temporally disjunct, they may also be compared. In such cases comparison allows the assessment of change or stasis over that time period represented by the two data sets. In cases where it can be independently shown that change has not occurred over the time period of two temporally disjunct data sets, then the data sets also have the potential to be tests for each other.

9.3.1 Pollen, survey records and remnant vegetation

The historical vegetation pattern revealed by survey records in the catchments concurred with the pattern indicated by fossil pollen records. While pollen data were only available at three sites, two presently supporting *E. obliqua* forests and the other *E. cosmophylla (± E. baxteri)* low woodland, they provided a positive check on the veracity of both lines of evidence. Comparison of the remnant vegetation and pre-European fossil pollen spectra indicated there has been stasis in the dominant overstorey species in *E. obliqua* forests, although there have been significant changes in the frequencies of understorey species. This check indicates that it was probably not unreasonable to use remnant vegetation to assist in the interpretation of historical survey terminology and descriptions, for change in the overstorey features which are recorded in these descriptions is not likely to have occurred. It also indicates that the assumption of remnant vegetation being representative in composition of pre-European vegetation, and therefore providing a valid data source for modelling pre-European vegetation pattern, is from that perspective, reasonable. However this check only pertained to *E. obliqua* forests and the overstorey of other community types may have been more susceptible to change following European settlement.

9.3.2 *Predictive vegetation models*

An aim of the thesis was to explore methods for the extrapolation of records of historical vegetation to produce spatially continuous maps of historical vegetation patterns. Modelling analyses resulted in probability maps indicating where in the landscape vegetation types were more likely to occur. Probability values were based on relationships between the environment and remnant vegetation or historical vegetation record. If the assumptions that the environment exerts a primary control of vegetation pattern, both presently and *historically*, is correct and the models developed adequately characterise those relationships, then areas of high probability might also reflect the pre-European vegetation pattern. To this point, the success of model predictions has only been assessed using a data re-substitution approach which indicates how effectively output models predict the data that were used to build them. This does not provide a good test of the model's capacity to represent pre-European vegetation patterns. This is because re-substitution tends to give optimistically biased estimates of error rates (Chatfield, 1995) and in the case of the models developed from remnant vegetation, test analyses show that the data set is unrepresentative of pre-European distribution due to a bias in vegetation clearance. Temporally disjunct, but taxonomically commensurable data sets provide an independent test set and are used to appraise model output using the sensitivity and specificity measures described in Chapter 4.

9.3.2.1 Grassy and sclerophyll woodlands

The historical grassy woodland model correctly predicted a high number of modern grassy woodland records, demonstrating a sensitivity value of 0.83. It also correctly classified a high percentage of sclerophyll woodland as demonstrated by a high specificity value of 0.86 (Table 9. 1). The modern model did not successfully predict a high percentage of grassy woodland historical records, the error analyses resulting in a sensitivity value of only 0.36, although it achieved a higher specificity value (0.94).

Table 9. 1 Assessment of grassy and sclerophyll woodlands models developed using 'prospective' test data sets. Sensitivity is a measure of the number of correctly classified positive records and specificity a measure of the correctly classified negative record values. (1) not core or marginal (2) not core. Multiplication of these values by 100 results in percentage correctly predicted (sensitivity) and percentage correctly excluded (specificity) values.

Model	Input data	Test data	Sensitivity	Specificity (1)	Specificity (2)
Grassy woodlands	Historical first survey sections	Remnant *E. leucoxylon, E. viminalis, E. camaldulensis*	0.83	0.39	0.86
	Remnant *E. leucoxylon, E. viminalis, E. camaldulensis*	Historical first survey sections	0.36	0.05	0.94
Sclerophyll woodlands	Historical scrub and forest sections	Remnant *E. obliqua, E. baxteri, E. cosmophylla*	0.69	0.03	0.82
	Remnant *E. leucoxylon, E. viminalis, E. camaldulensis*	Historical scrub and forest sections	0.69	0.33	0.89

These results suggest that the historical data model of grassy woodland boundaries better predicts pre-European boundaries than the modern data model. This is despite the fact that the remnant vegetation data set is probably an under-representation of its pre-European distribution, which would have the effect of favourably biasing sensitivity values for the model, derived using the historical data set. The historical model predicts a much greater area in the Inman Valley and on the western side of the ranges as being potential core grassy woodland than do the modern data. Historical survey data suggest these areas were likely to have supported grassy woodlands. That the western side of the ranges did support grassy woodlands, and so were erroneously predicted by the modern data model, is further suggested by pictorial and early description records (Chapter 3).

The sclerophyll woodland model derived from modern data correctly predicts 69% of historical sclerophyll woodland records and correctly excludes 89% of historical grassy woodland records. The historical sclerophyll woodland model shows similar correct prediction and over-prediction values when tested with remnant vegetation data (Table 9. 1). The specificity value is slightly lower and this could be a result of the inclusion of *E. leucoxylon,* which also occurs in sclerophyll communities, in the modern test data set. These analyses show that both modern and historical data models predict sclerophyll woodland boundaries reasonably well. Comparison of the core domains from historical and modern data indicate that the modern model over-predicts in the Inman Valley region (area designated as grassy woodland by historical records) and that the historical data model predicts less area of the northern highlands as core than does the modern. Historical survey records were not as well represented in this region. The exclusion of these areas may in fact be an under estimate of historical sclerophyll woodland boundaries due to uneven data distribution.

9.3.2.2 Sclerophyll community models

Error analysis values produced by cross testing sclerophyll community models with temporally distinct data sets, are presented in Table 9. 2. The degree of equivalence of data sets varies and is discussed in Chapters 3 and 4 and section 9.2.1 of this chapter.

Table 9. 2 Models generated from historical vegetation observations and the 'prospectively sampled' modern vegetation data used to assess their predictive strength. APNR is the annual precipitation with net annual radiation model and APSL is the annual precipitation with slope model.

Output model	Prospective test data set	APNR		APSL	
		sens	*spec*	*sens*	*spec*
stringy bark forest	*E. obliqua* open forest	29.5	87.14	35.8	83.11
stringy bark scrub	*E. baxteri* - *E. cosmophylla* low woodland	30.64	73.31	29.2	73.4
stringy bark and gum scrub	*E. baxteri-E. cosmophylla* low woodland	0.26	98.94	0.4	99.14
gum scrub	*E. fasciculosa* low woodland and *E. cosmophylla* very low woodland	15.09	86.31	13.17	85.93
Low scrub	*E. cosmophylla* very low woodland	0.0	94.6	0.0	96.8
E. obliqua forest	stringy bark forest	22	89.1	34.9	73.2
E. baxteri – *E. cosmophylla* low woodland	stringy bark scrub	8	95.9	12.1	95
	gum and stringy bark scrub	0.0	94.3	10.8	92.8
E. fasciculosa low woodland	gum scrub	24	86	18.7	89.8
E. fasciculosa – *E. cosmophylla*- *E. baxteri* low woodland	gum and stringy bark scrub	1.6	98.6	0.2	98.1
E. cosmophylla very low woodland	Low scrub	0.0	98	0.0	95

9.3.2.2.1 Stringy bark forest - *E. obliqua* open forest

Cross testing resulted in similar sensitivity (between 20 and 30%) and specificity values (between 73-78%) for both APNR and APSL models built using both modern and historical data. This suggests that both modern and historical data sets have the potential to predict historical boundaries. However the high probability environmental domains, and resultant location of areas of high predicted probability of occurrence of historical and modern records differ. The modern data had a higher predicted likelihood of occurrence at sites with high precipitation-low radiation values than did historical records. This possibly indicates a skewing of remnant *E. obliqua* forests to southward facing slopes. The annual precipitation-slope model supported this interpretation. The APSL model of remnant *E. obliqua* forest shows two domains with higher probabilities of occurrence, one exhibiting high slope values and the other low. Neither of these domains exhibit high probability values in the APSL model of historical stringy bark forest distribution. The domain in the steeper sloped area is likely to be explained by a greater proportion of *E. obliqua* forest occurring on steep-sloped areas, relative to pre-European times, due to preferential vegetation clearance on less steep slopes. The low slope domain is possibly an artefact of a relatively low representation of areas with low slopes in the entire remnant vegetation data from which the probability values are generated. This suggests clearance has had the effect of skewing the relative representation of the range of environments in which *E. obliqua* forest once occurred. The forest occupies the same climate domain as it did in the

1880s, but it is now better represented in certain topographic positions in the landscape. This skewing was significant enough to affect the modelling outcome using remnant vegetation records. A combination of historical and modern records would provide a less skewed data set from which to model the historical environmental domain of *E. obliqua* forests.

9.3.2.2.2 Stringy bark scrub – *E. baxteri* low woodlands

Stringy Bark scrub records were considered predominantly to represent a bygone vegetation community of *E. baxteri* low woodland (Chapter 3), as well as possibly some *E. baxteri* ± *E. cosmophylla* ± *E. fasciculosa*. Consequently no modern vegetation type provides a good cross test for this model. However, its ability to predict correctly low woodlands of *E. baxteri* ± *E. obliqua* co-occurring with *E. cosmophylla* ± *E. fasciculosa* was tested as historical records did intersect with a portion of this vegetation type (Chapter 3). Both the APNR and APSL models successfully predict around 30% of historical *E. baxteri – E. cosmophylla* low woodlands, however specificity values were not particularly high for either models (around 73%). The only partial representativeness or compatibility of this test data set renders it difficult to assess the stringy bark scrub model's alikeness to pre-European distribution patterns. The overlap of the environmental domains of stringy bark scrub with stringy bark forest, in the upper precipitation ranges, suggested that other environmental variables or determining factors than those considered in this study were responsible for determining its historical distribution. The historical records have much value in reconstructing historical patterns for they represent the only way of investigating this locally extinct vegetation type.

9.3.2.2.3 Gum and stringy bark scrub – *E. baxteri* ± *E. cosmophylla* ± *E. leucoxylon* ± *E. fasciculosa* low woodlands

Gum and stringy bark scrub models, of both precipitation with slope and with net radiation, when cross tested with *Eucalyptus baxteri – E. cosmophylla* produced low sensitivity values. This is due to most gum and stringy bark scrub probability values being less than 40% and a dichotomising threshold of 40% being applied during the testing procedure. Re-scaling the percentage prediction values or the application of a lower error threshold may have resulted in higher sensitivity and specificity values. The modern-data APSL model of *E. baxteri –E. cosmophylla* low woodlands correctly predict about 10% of gum and stringy bark scrub records and 12% of stringy bark scrub records. The low probability values derived for this vegetation class are in a large part due to the small number of text gum and stringy bark scrub records, and therefore the small area so classified. It seems that text records underestimate the real historical extent of this vegetation class; *Eucalyptus baxteri,* and to a lesser degree *E. obliqua,* with *E. cosmophylla* account for almost 20% of the remnant vegetation today. Also Boomsma (1948) documented that *E. baxteri - E. cosmophylla* dominated scrubs were the most ubiquitous community types in the highlands. Text and section records map gum and stringy bark scrub as occurring on the mid to high elevations of the southern spine of the ranges, extending more to the east than *E. baxteri* low woodlands, although with some patches on the southwestern part of the Fleurieu Peninsula. A small amount also is recorded the on the spine in the northern ranges. The historical records describe an area in a relative narrow precipitation range (700-800 mm) and form a relatively clear domain defined mainly by precipitation in the APNR probability model. In contrast, the modern distribution of *E. baxteri - E. cosmophylla* records extends over a greater precipitation range (750-975mm) and on higher annual net radiation and slope values. The probability models for this type define its dominant domain as being around 900 mm and with higher probabilities of occurrence on steep slopes. Comparison of these environmental domains additionally demonstrates that the stringy bark and gum scrub text description probably underestimated the distribution of the association actually present in the landscape. Although comparison of environmental domains must be done with caution due to the suggested under-representation of this vegetation class in the historical record, the modern distribution of this class dominates more strongly on steep slopes while no such pattern is apparent in the historical record. This suggests that this vegetation type may once have characterised a greater range of landform types than it does today and clearance has restricted it to certain places in the landscape. In conclusion, the lack of records and their classificatory imprecision with regard to a single community type means that the historical model for this vegetation type probably has limited predictive strength. Historical ecological relations are more likely to be understood using modern records, although they probably represent an environmentally biased set of this vegetation type's original distribution.

9.3.2.2.4 Gum scrub - *E. fasciculosa* ± *E. cosmophylla* low woodlands

Low woodlands dominated by *E. fasciculosa* constitute the most widely represented class of sclerophyll woodland vegetation in the Fleurieu Peninsula region today. They are predominantly situated on steep slopes at the lower end of the rainfall spectrum and form a strong and well defined dominant domain in the APSL environmental model. Their predictive model was tested with historical gum scrub records and 24% of these records were correctly predicted by the model and 86% correctly excluded. Confidence in the test is weakened by the historical gum scrub class also including the environmentally separated *E. cosmophylla* low woodlands. Despite difficulties in using the error values the modelled environmental domain for *E. fasciculosa* low woodland, using modern vegetation distribution, may be akin to that it occupied at European settlement. The fact that *E. fasciculosa* low woodlands are highly represented in the vegetation and highly correlated with steep slopes receiving low precipitation suggests that selective clearance may have spared this vegetation type.

Remnant *E. cosmophylla* low woodlands were correlated with steep slopes but in areas receiving higher annual precipitation. Their nearest historical analogue was also the gum scrub historical class. The problem of non-specificity of this class also confounded valid comparison with modern records and models. Very low correct and incorrect prediction values were obtained. Low probability values derived from the *E. cosmophylla* low woodland model, due to its low representation in the landscape, would also have contributed to these low values. Consequently, comparison of the temporally disjunct records in environmental space can not be made.

The non-specificity of the gum scrub models, defining higher probability domains in both high and low rainfall areas suggests they do not have strong potential to model pre-European vegetation patterns. Gum scrub models correctly predicted around 15% of the distribution of both *Eucalyptus cosmophylla* low woodlands and *E. fasciculosa* low woodlands.

9.3.2.2.5 Low scrub - *E. cosmophylla* low woodlands

The only identifiable prospective test for the historical 'low scrub' class were *E. cosmophylla* very low woodlands. Neither modern nor historical models predicted the distribution of respective temporally separated data sets. This is most likely to be due the low probability ranges of both models.

9.3.2.2.6 *E. ovata* woodlands

There was no historical equivalent for *Eucalyptus ovata* woodlands so cross testing was not possible. However, *Eucalyptus ovata* woodlands occupied a very distinctive environmental domain in areas with low slope and high precipitation. Ecological information suggests that *E. ovata* is restricted to low lying areas prone to water logging. The terrain modelling using remnant vegetation may adequately represent historical environmental relations.

9.4 Discussion

Remnant vegetation proved to be an essential starting point in the interpretation of all forms of historical evidence types. Remnant vegetation records are taxonomically unambiguous and spatially accurate. While it was the intention to analyse independently the different lines of evidence, without the taxonomic detail that remnant vegetation provided it would have been very difficult to interpret pollen or documented historical records. Pollen spectra from remnant vegetation communities provided a means to interpret fossil pollen spectra. Remnant vegetation provided the main source for interpretation of terminology in documented historical records. However, issues of environmental distribution and representativeness impinge on the utility of remnant vegetation to provide a comprehensive reconstruction of pre-European vegetation patterns. The fact that there is very little vegetation left and clearance has been selective, means that remnant vegetation is unable to provide evidence for the presence or former distribution of certain vegetation types as they have been completely removed from the landscape. In addition, in cases where remnants of former community types are present they are often not representative of their former environmental distribution. Where reconstructions are based on environmental relationships, conclusions about former environmental domains/niches can be erroneous for the remnant vegetation represents an incomplete data set which is biased.

The value of written sources obviously depends upon their availability; and this depends upon the location of the study site. In this region, in contrast to remnant vegetation records, historical records were much more taxonomically/classificatory ambiguous and this had bearing on the scale at which vegetation could be reconstructed with accuracy, and the subsequent scale at which change could be assessed. Where terms were non-specific, encompassing more than one species or vegetation type, then investigation of environmental relations is problematic. Unless the agglomerated vegetation units occupy the same position in environmental space (and actual distribution is determined by other factors) then environmental domains will be lumped and similarly non-specific. In this area stringy bark forest records were classificatory specific, and it was argued that the majority of stringy bark scrub records were also, but gum scrub and gum and stringy bark scrub records were less so. However, where records were taxonomically specific, they provided an invaluable resource for uncovering past vegetation patterns and environmental relations. Locational accuracy is also paramount to the utility of historical records in reconstruction, particularly in reconstructions that utilise environmental relationships. Field Book records in particular were made at scales and with locational precision useful to topo-scale (and meso-scale) reconstruction. Field Book records captured more environmental variation than did section records from Diagram Survey Books, consequently they accurately represented the historical heterogeneity of sclerophyll woodlands. Section records adequately resolved formation level variation in the Fleurieu Peninsula.

In some cases documented historical records revealed pre-European environments, but in most cases records were made in the mid to late 19th century. They therefore reflect a former state; but as this thesis showed it was not necessarily a state that was without European impact. However, it was prior to widespread vegetation clearance and from that perspective documented historical records provided the only record of vegetation pattern on sites where no remnant vegetation exists. When interpreted with the same concern for bias as any form of historical evidence (Chapter 3) they provide a vital resource in historical reconstructions where remnant vegetation and scientific ecological knowledge is scant. The issue of records not reflecting the historical state of interest is more pertinent to the use of remnant vegetation records. The degree to which the assumption that their composition and distribution reflects that of the historical time frame under comparison is discussed in 9.3.1.

When mapped, both remnant vegetation and historical records qualified only a small area of the Fleurieu Peninsula, leaving most part of the region without evidence of former vegetation cover. The predictive vegetation modelling undertaken in this study potentially provided a means of characterising former vegetation cover of unclassified areas. Model success was qualitatively gauged by (1) assessing the ability of different models to define distinctive and unique domains, and (2) using error analyses which considered how well the output models predicted the distribution of records used to build them, and (3) error analyses using commensurable, but temporally distinct, data sets. The models showed varying degrees of predictive success. However in both historical and modern data sets correlation to environment at meso- and, to a lesser degree, topo-scales was apparent. This supports the adoption of a modelling approach, which was based on the fundamental assumption that environmental factors are able to explain a significant proportion of historical and modern vegetation pattern. The models do not prove causality, they can only show correlation which could also be the result of disturbance variables similarly relating to environmental disturbance regimes. This was argued to be the case for some of the modern vegetation models; slope was a much more important variable in the modern models than in historical ones. This was so because European land use (disturbance) was correlated with slope grades in this region. Similarly, historical environmental patterns may have been affected by fire regimes, which possibly in part were determined by topographic gradients. The importance of the incorporation of other environmental variables was discussed in relation to improvement of the sclerophyll community models (Chapters 4 and 5).

The quality of data was considered to be the greatest impediment in the use, and success, of modelling approaches in vegetation reconstruction. The historical record was beset with issues relating to classificatory specificity or resolution while the modern data set was beset with issues of environmental representativeness. The analysis of both modern and historical data sets in environmental space provided a useful medium to comment on data representativeness and interpret model outputs. For example it was concluded that both historical and modern data sets had the potential to predict the historical distribution of *E. obliqua* forests although the modern environmental domain was somewhat different to the historical. While this could just be due to 'sampling' differences in the data, it could also represent a less representative modern domain due to selective removal from particular environments. Only with the use of the historical 'baseline' data can such deductions on selective impact be made or incorrect ecological conclusions on environmental relations be avoided. Historical data provided a vital adjunct to the use and interpretation of modern vegetation records. However, the limiting factor to the degree, and the scale, with which they could be compared to evaluate each other or assess change was ultimately decided by the classificatory resolution of the historical data records.

A quantitative assessment of whether or not the potential vegetation distribution models represent pre-European vegetation pattern was difficult to make. The testing with temporally disjunct data sets, investigated in this chapter, was limited by the degree to which classes were commensurable and the different ranges of probability values predicted for different model types. Direct comparison of the error analysis values to rank relative predictive successes of different models can not be validly achieved. Despite this the models, if they are successful in defining environmental niches, can be viewed as useful as they do show where a species could potentially grow. Such information may have practical value in the design of conservation reserves or revegetation strategies.

It was considered that the use in this research of quantitative methods to analyse historical evidence and remnant vegetation, was a worthwhile process. Much was revealed about former vegetation patterns and European impact on the vegetation, from the analysis of the spatially disjunct nominal maps of historical records and of remnant vegetation in environmental space. The integrative nature of GIS technologies facilitated the derivation of environmental variables, the development of historical vegetation spatial databases, the spatial alignment of data sets, the reformatting of data to meet modelling requirements and the spatial examination of modelling results. Hence different data sets could be compared in environmental space which characterised climate and landscape conditions related to energy and moisture regimes affecting vegetation patterns. Modelling through a GIS medium provided a useful way of investigating historical data, if, as with all forms of data, its shortcomings are acknowledged so that interpretation boundaries can be set.

The palaeoecological records provided information on processes that operate on time scales beyond the reach of the historical record, thus providing a means to assess recent changes against their immediate antecedents. Despite the challenges of establishing a chronology, identifying pollen types and interpreting the communities pollen spectra represent, pollen records provide the only means of acquiring direct evidence of vegetation composition and dynamics prior to the earliest historical-observations. Retrospective modelling, using past climate records and tolerances of present day species, is an alternative approach for reconstruction of past vegetation patterns (Busby, 1986). This work shows that, beyond about 3600 years BP historical vegetation at the Boat Harbour Creek site is without a regional modern analogue. Retrospective prediction of vegetation, for example, at the time of the wettest period in the Holocene, would predict a cover of *Eucalyptus obliqua* forest, as this type presently occupies the wettest sites in the region. The pollen record revealed little evidence of *Eucalyptus* presence but instead a wet heath of *Allocasuarina*, *Banksia* and *Leptospermum*.

Issues of distribution and representativeness pertained to all the evidence types investigated in this thesis but were particularly pertinent to palaeoecological records. Fossil records predominantly represented local wetland and catchment histories. Their distribution was restricted to the upland areas of the study region, which have distinct and different physiography and probably environmental histories, to the lowland areas. However sites providing records in these areas were not present. Additionally, the fossil sites studied in the highland region did not represent the heterogeneity revealed by documented records and remnant vegetation. Study of a greater number of palaeoecological records, covering the main environmental gradients and landforms within them, would have greatly strengthened the reconstruction of pre-historic vegetation dynamics in the region.

9.5 Conclusions

The historical records investigated were fragmentary in space and time and resolved vegetation pattern and change at a range of different scales. No single source was without omissions, bias or ambiguities in interpretation. However the analytical methods adopted in this study facilitated a degree of comparison and integration of different record types. The cartographic transcription of text records from early survey Field Books allowed them to be interfaced with contemporary remnant vegetation. The fine resolution identification of fossil pollen allowed its comparison with both remnant vegetation and documentary records. Comparison of environments over diachronic, or multiple points in time, in combination with information of land use history in the region provides some insight into the specific causes and effects of European actions through this time. In cases where sources provided record of vegetation and or change at different scales, direct comparison of records was not possible. However the multi-scaled resolution of environments and change provides a richer history in the sense that ecological phenomena and significant human impacts similarly operate on a range of scales.

The combined use of historical sources provides information on the early nineteenth century nature and/or distribution of the major vegetation types in the Fleurieu Peninsula; the *E. obliqua* forests, the sclerophyll low woodlands, the highland swamps and the grassy woodlands. It also provides a long term record of vegetation change in the sclerophyll woodlands. The following chapter integrates the different lines of evidence into a chronological sequence and discusses European impacts in relation to Holocene vegetation dynamics.

CHAPTER 10

10. HISTORY OF THE VEGETATION OF THE FLEURIEU PENINSULA

10.1 *c.* 8000 years BP- 1836

Palaeoecological data indicate that prior to European settlement, through the Holocene, the wetland and sclerophyll woodland vegetation of the Fleurieu Peninsula was dynamic, responding to regional Holocene climate changes. The formation of the Boat Harbour Creek wetland was contemporaneous with a major phase of peatland development in southern Australia (Dodson and Wilson, 1975; Kershaw *et al.*, 1993), occurring sometime around, or just before, the period of maximum Holocene precipitation in South Eastern Australia (about 7000-6000 years BP). At that time the Boat Harbour Creek vegetation changed from *Eucalyptus*-dominated woodland to an *Allocasuarina* dominated wet heath which persisted through the mid-Holocene. The *Allocasuarina* heath was replaced by a *Eucalyptus* dominated sclerophyll woodland later in the Holocene, around 3600 years BP. This later phase is characterised by reduced production, and possible loss of peat sediments, indicating synchrony with the documented regional shift to drier and more variable climatic conditions (Dodson, 1974; Mooney, 1997). *Eucalyptus* dominated woodland persisted until European times. The current day vegetation communities in the Fleurieu Peninsula are less than 4000 years old.

Throughout the time span covered in this study, archaeological evidence suggests that the region was occupied by Aboriginal people (Lampert, 1981). The extent to which vegetation patterns through the Holocene, and at earlier times, were a product of Aboriginal burning remains poorly understood (Bowman, 1998) due to the difficulties in distinguishing anthropogenic impacts from 'natural'. Clark (1983 p.160) encapsulated this well when she wrote, 'The complex interaction and interdependence of fire, climate, soils and vegetation make it extremely difficult to distinguish the effects of Aboriginal burning'. Kershaw *et al.* (in press) suggest that by the Holocene a balance between Aboriginal land use and burning had been achieved, as the major vegetation changes and burning activity through the Holocene are consistent with the inferred patterns of climate change. Kershaw *et al.* (in press) were discussing vegetation patterns occurring on large biogeographic and/or evolutionary scales. The synchrony of the major changes in the Fleurieu Peninsula pollen record with regional climate changes supports their interpretation.

At the time of European settlement Aboriginal burning was a major disturbance variable in the Mount Lofty Ranges (Ellis, 1976) as it was elsewhere in Australia (Jones, 1969; Hallam, 1975). It would not be unreasonable to extrapolate retrospectively and suggest that fire was similarly important through the Holocene. However, how and where fire was used is likely to have varied through that time. The significant ecosystem changes evidenced through the Holocene would have changed the resource base available to Aboriginal people, and thus have influenced population distribution and how the landscape was used. This proposition is supported in this thesis by evidence for deliberate burning of the wetlands, possibly to facilitate the harvest of *Typha* in the wettest phase of the Holocene. This was a time when swamps were likely to have been wetter and possibly more extensive than today and thus provided more resources than in the drier late-Holocene. Archaeological evidence in the Fleurieu Peninsula region suggests that at the time of European settlement the coast was the focus for Aboriginal occupation (Gara *et al.*, 1999). Luebbers (1978) conducted extensive archaeological investigations of the coastal and inland areas around the Coorong and Beachport regions. He found that coastal occupation was intensified in the late Holocene as conditions became drier, but prior to this, during the wettest phase of the Holocene, occupation was more widespread, primarily because inland wetlands were more ubiquitous and productive. This study suggests that Leubbers' model of resource use and occupation during the Holocene may hold true for the more westerly situated Mount Lofty Ranges.

A greater number and extent of palaeoecolgical records, analysed at finer resolutions, would be required to determine the effect of burning on the terrestrial vegetation through the Holocene. Given that Aborigines were present and fire constituted an important land use technology, topo-scale gradients of vegetation structure, and relative species abundance related to fire frequency would have been evident, although temporally and spatially variant with the ecosystem changes that occurred through the Holocene. The treed, but very open, nature of the grassy woodlands of the Fleurieu Peninsula first encountered by Europeans were likely to be demonstrating one effect, at a point in time, of Aboriginal burning. An increase in overstorey densities after the cessation of Aboriginal burning would more conclusively suggest that this vegetation was indeed a cultural construct, but this did not occur in the Fleurieu Peninsula due to European land uses also acting to prevent tree thickening. However, Aboriginal burning has been implicated in maintaining open tree densities of grassy woodlands elsewhere in temperate Australia (Jones, 1969; Barr and Cary, 1992; Bowman, 1998; Rolls, 1999).

The palaeoecological record demonstrates that the species patterns present at the time of European settlement were transitory assemblages that have changed in abundance, distribution and association in response to the climate changes of the Holocene. Although the smaller scale impacts of Aboriginal land use practices on the landscape remain unclear, micro-fossil data suggest Aboriginal use of the uplands of the Fleurieu Peninsula in the mid Holocene. The effects of a long and changing history of anthropogenic disturbance would have been implicit in the vegetation patterns at European settlement in 1836.

10.2 1836 – Present

10.2.1 Grassy woodlands

The grassy woodlands of the Fleurieu Peninsula first encountered by Europeans were treed, but open, and carried a grassy understorey (Chapter 3). *Eucalyptus camaldulensis* was found along the fertile Hindmarsh, Inman, Congeratinga and Bungala valleys, but was absent from the steep sided valleys containing little alluvium between Cape Jervis and Victor Harbour (Boomsma, 1948). *Eucalyptus leucoxylon* woodlands occurred along the eastern side of the ranges from Myponga to Cape Jervis and flanked the Inman River through the Inman Valley (Boomsma, 1948). *Eucalyptus viminalis* had restricted original occurrence in the Fleurieu Peninsula, confined to sites between *E. camaldulensis* and *E. leucoxylon* associations, and typically occurred as a co-dominant with these species. Open woodlands of *Eucalyptus fasciculosa*, occurring in places with *Allocasuarina verticillata* or *E. odorata,* occurred through the Inman Valley and between Cape Jervis and Rapid Bay (Boomsma, 1948). *Allocasuarina verticillata* was interspersed though the grassy woodlands and dominated on the southwestern lowlands of the Fleurieu Peninsula (Chapter 3). In places, the open woodlands contained *Callitris preissii* as a tree component. *Themeda triandra* was most likely to have been a dominant and conspicuous component of the understorey (Chapter 3).

European transformation of grassy woodlands in the Fleurieu Peninsula was rapid, occurring shortly after the region's initial settlement in 1839. Their understoreys were probably significantly altered in the first 10 years of settlement during the initial phase of subsistence farming and grazing. Carmichael (1973) records that by 1842 'all the palatable grasses had been removed' and some first settlers were already moving on to new frontiers in the colony. Grazing favoured herbaceous species such as *Stipa* and *Danthonia* (Adamson and Osborn, 1924) which rapidly replaced the original dominating *Themeda*. A much greater area than that accounted for by the first sections officially purchased was likely to have been altered, with each section owner given the right to rent commonage, and undoubtedly uncontrolled grazing on non-sanctioned land also occurred. Disturbance by cattle trampling and overgrazing would have provided opportunities for exotic weed establishment and historical accounts suggest that many species became naturalised within the first 20 years of settlement (Kloot, 1983). The grassy woodlands were then extensively and intensively cultivated between the years 1850 to 1870. This phase would have seen overstorey tree clearance and the removal of those components that were initially resilient to grazing. The 'lands' cultivation practices, which were widely used in the area, created wide downslope running furrows which were likely precursors for much soil loss through sheet and gully erosion. Cultivated lands were abandoned before mixed farming, dominated by grazing and wattle bark collection was practiced in the grassy woodlands. These disturbed and abandoned areas would have been extremely susceptible to weed invasions (Sutherland, 1889; Kloot, 1983).

Overstorey removal was affected by ring barking and cutting to clear for cultivation, cutting for building materials and, in the case of *Allocasuarina verticillata*, for fodder. It would have occurred from early settlement (Chapter 2) and opened the vegetation further. In some cases the attack on the overstorey helped to completely remove particular grassy woodland associations from the landscape; *A. verticillata* was removed by about 1870. Boomsma (1948) wrote that the overstorey of grassy woodlands had changed from 'scattered stands' at pre-European times to a 'few trees' in 1948. Today, only the *Eucalyptus* components of these woodlands survive as isolated paddocks trees over introduced pasture species and weeds. This was similarly the case in 1924 when Adamson and Osborn (1924) wrote that 'very few of these forests are without obvious traces of interference' and that there had been an 'almost a total removal of the native flora and its replacement with aliens which are either annuals or plants….that withstand pasturage'. Tree decline due to old age, ringbarking by stock, root trampling, insect defoliation and current land use practices which preclude regeneration has resulted in continuing decline, despite less timber collection occurring through the twentieth century (Newman, 1995). A 30% reduction in the area of tree cover occurred between the years of 1936 and 1979 in the *E. camaldulensis* – *E. leucoxylon* woodlands in the southern Mount Lofty Ranges (Sullivan and Venning, 1984). Analysis of the environmental distribution of historical and modern distributions of grassy woodlands reflects this contraction. The climatic domain occupied by the remnant records represents a subset of that occupied at the time of European settlement. The core, and, in areas, the marginal bioclimatic domain of grassy woodlands defined by remnant data did not extend to coastal regions on the western part of the ranges, yet these regions were included in the domains defined by historical data. Similarly the omission or low frequency of representation of remnant grassy woodland sites on many soil classes, (soil classes which were represented by historical grassy woodland sites), indicates the effects of European selection for soil types that were perceived to be favourable for agriculture.

10.2.2 Forests

The pre-European forests of the Fleurieu Peninsula were dominated by *Eucalyptus obliqua* as they are today. They covered at least 6500 ha, mainly situated along the western spine of the northern and southern ranges and in patches on the plateau. *Eucalyptus obliqua* occurred either as a sole overstorey dominant or probably in places with *E. baxteri* or *E. fasciculosa*. The forests were selectively logged from the time of settlement but most intensively between 1850-1880 (Chapter 2). While an absence of records precludes estimation of how much timber was removed at this time, Government concerns about rapid timber depletion (Chapter 2), so that by 1880 most of the timber was only good for 'fencing material and telegraph poles' (Albert Jones, pers. comm.), suggests that this early phase of timber collection would have severely depleted and changed *E. obliqua* forests. Logging companies collecting native timber remained operative in the Fleurieu Peninsula until 1923 (Blum, 1985), presumably cutting regrowth timber from the early intensive harvest phases. Structurally, the present-day forests are young and even-aged, and are the legacy of intensive and repeated logging from the time of European settlement in the region. The early targeting of this resource means that reconstruction of their original structure is difficult. Boomsma (1948), considering the density of remnant stumps, suggested they were more open, with only a few (8-18) mature dominant trees per acre. Mature trees were larger than examples presently found in the forests. Stringy Bark trees were described in 1836 as being 'of immense size', with the diameter of fully grown trees commonly '3-4 feet' (Woodforde, 1836).

The composition and density of the understorey of forests was likely to have been influenced by changes to burning regimes, the introduction of sheep and cattle and the harvesting of certain components. Fire frequencies increased markedly on European arrival, the grazing of forest regions occurred from the time of European settlement, and the collection of *Acacia pycnantha* and *Xanthorrhoea* constituted substantial industries in the region. Fire sensitive species in the Proteaceae family, and possibly shrub *Allocasuarina,* declined in response to increased deliberate firing (Chapter 7). *Xanthorrhoea* also declined in frequency, probably in response to the yacca gum collection which was conducted through the sclerophyll woodlands and forests in the early 1900s (Chapter 7). Shifts in the frequencies of understorey species were expressed as changes in understorey density. In some places, increased burning maintained already open understoreys, or resulted in further opening. In the *E. obliqua* forests in 1870 it was possible to "drive a bullock through anywhere" (Albert Jones, pers.comm.). Oral recollections are supported by photographs taken in 1913 of *E. obliqua* forests in the Hundred of Waitpinga, which show a relatively open understorey of bracken fern, *Xanthorrhoea* and many *E. obliqua* trees that appear to have suffered the effects of burning (Gill, 1913). However, understorey densities probably varied with spatial variation in fire regimes and patterns. The 1880s surveyors commonly describe the forest and scrub in the region as having a 'dense undergrowth' and other areas in forested sections as being 'part arable' or 'open'. The present day understoreys of *E. obliqua* forests are dense, and dominated by *Xanthorrhoea semiplana, Lepidosperma semiteres, Pultenaea daphnoides, Hakea rostrata, Goodenia ovata, Pteridium esculentum* and *Gonocarpus tetragynus*. Boomsma (1948) and the pollen cores examined in this study (Chapter 7) suggest that *Xanthorrhoea, Leptospermum myrsinoides, Hakea*, and *Banksia marginata* were components pre-European components. This suggests that the understoreys have been generally resilient to changing disturbance regimes but have undergone changes in composition and density through this time.

Pinus plantations in the region were established from 1912. Locations supporting *E. obliqua* forests were favoured and native forests were clear felled. This diminished their original extent by at least two thirds and, at a topo-scale, changed the representation of the forest type on its original range of environments. The more gentle slopes were favoured for *Pinus* plantations and so the *E. obliqua* forest remaining has much higher relative representation on steep slopes than previously. It can be surmised that clearance has removed some of the former diversity (heterogeneity) this forest type expressed at pre-European times and that the structure and composition of the remnant forests must be interpreted in the light of their intensive and changing European land use histories.

10.2.3 Low woodlands

Prior to European settlement, the low woodlands of *E. fasciculosa, E. baxteri, E. cosmophylla,* with some *E. leucoxylon* and *E. obliqua,* extended over much of the poorer soils of the uplands of the southern and northern Fleurieu Peninsula. They are largely unremarked upon in the historical record becausethey lacked grass; their stunted timber and dense undergrowth, provided little attraction for the first settlers. Consequently their pre-European form and distribution is the most enigmatic of all vegetation types in the region. The 1880s surveyors' records indicate that *E. baxteri* (± *E. obliqua*) low woodlands extended over most of the higher rainfall areas of the southern side of the ranges on the southern Fleurieu Peninsula and in the northern upland areas. Low woodlands of *E. baxteri,* combined with *E. cosmophylla* and *E. fasciculosa,* occurred over the mid and high elevation areas of the southern and northern uplands. *Eucalyptus fasciculosa* and/or *E. cosmophylla* low woodlands occurred on the steep southerly slopes of the southern uplands and in patches in the northern uplands. Ambiguity in interpretation of historical 'scrub' classes, and consideration of the heterogeneity of modern low woodland communities in the region (Mitchell, 1983), suggests that the taxonomic resolution of survey records captures only a portion of their true original heterogeneity. By the time of the 1880s survey the woodlands had been subject to frequent (at least once every five years, but probably more frequently) deliberate burning to facilitate the licensed and illegal grazing of cattle and sheep. Compositional and structural changes to these woodlands could have been expected to have occurred with increased firing regimes (Chapter 7). They were released for sale and lease after the 1880s survey. High frequencies of ownership changes of many of the holdings indicates the difficulty in deriving income from grazing, wattlebark collection and yacca gum collection in these areas. After the second world war the discovery that soils carrying these vegetation types were lacking in various trace elements, and demand for land for soldier settlement schemes, resulted in the broad scale removal of these vegetation types. They were cleared and replaced with exotic pasture grasses. Clearance correlated with landscape domains deemed more suitable for improved agriculture. Low woodland vegetation types similarly correlated to these environments and so are poorly represented, or are without representation, in the remnant vegetation. The vegetation community types which remain are those correlated to positions in the landscape with undesirable slopes, nutrient and hydrological regimes.. Sheep grazing and burning regimes varied through the European period and most likely impacted shrub compositions of these formations in ways discussed for *E. obliqua* forests of the region. To summarise; the European impact on the low woodland vegetation of the Fleurieu

Peninsula has been to remove particular types present at European settlement from the vegetation completely, and drastically alter the relative representation of remaining vegetation types

10.2.4 Wetlands

Both the silty-creekline and peat-dominated wetlands of the Fleurieu Peninsula have undergone substantial changes through the European period. Changes to surface and subsurface water flows and sediment changes due to increased erosional inputs can dramatically affect water relations of wetlands. These studies suggest that disturbance of vegetation and soil by intensive firing and the introduction of ungulates increased the rate of redistribution of soil and sediment early in European settlement in the highlands (Chapter 7). The effect of this was to shift the higher-energy silty wetlands, supporting creek bank colonising *Adiantum aethiopicum* and the disturbance intolerant *Gleichenia microphylla,* and some Cyperaceae and *Acacia,* to lower energy peat-dominated wetlands, supporting the water fern *Blechnum*, and increasing amounts of Cyperaceae and *Leptospermum.* At the time of European settlement the gentle, broad-bottomed valleys of the upland plateau of the southern Fleurieu Peninsula supported Cyperaceous and *Leptospermum* swamps. While these environments still support such wetlands, dramatic successional processes have continued through the European period, probably in response to changing firing regimes, hydrological regimes and nutrient relations. As with the silty-creekline type wetlands, changes began early in European settlement., and from 1940 to 1960 widespread native vegetation clearance, and conversion to agriculture in the region, most likely prompted another phase of soil loss through erosion and dramatic shifts in hydrological regimes, and further effected change in peatland ecosystems. The sediment records and vegetation histories of these sites suggest that soil redistribution and catchment hydrology has stabilised somewhat in the last 30 years.

10.3 The Nature of European Disturbances

European settlers regionally transformed the vegetation of the Fleurieu Peninsula. They acted to create completely new ecosystems from the interaction between European activities, the original organisms, immigrant organisms and changed environmental factors. The timing and nature of this transformation varied between vegetation types in the region. The understoreys and *Allocasuarina verticillata* components of the grassy woodlands were dramatically transformed within the first thirty years of settlement by grazing and cultivation. The rapidity of this transformation following settlement strongly parallels that which occurred to grassy woodlands elsewhere in Australia (Moore, 1970; Barr and Cary, 1992; Lunt, 1997a; Rolls, 1999). Nineteenth century intensive burning, grazing and forestry modified the structure and composition of the forests and low woodlands of the sclerophyllous vegetation of the uplands, before widespread vegetation clearance from the 1940s to 1960s reduced these areas to unrepresentative fragments. The hydrology and vegetation composition of wetland environments has undergone substantial changes with changing European land uses. The modern vegetation in all biophysical regions in the Fleurieu Peninsula is compositionally and structurally distinct from pre-European. At a community level it is much less heterogeneous than at pre-European times with clearance resulting in the complete removal of particular communities which were present at the time of pre-European settlement. Remaining vegetation communities are not representative of the former range of environments they once occupied, due to vegetation clearance being highly selective to specific sites. Vegetation patterns that formerly reflected climatic and edaphic gradients now reflect past land uses and selection. All environments in the region are responding to changed environmental factors Although not directly investigated in this study, it can be assumed that fundamental changes to soil chemistry have occurred with cultivation and the establishment of improved pasture grasses. Original nutrient soil recycling processes have been changed, and the addition of nitrogen- and phosphorus-rich fertilisers, to which many Australian native plants have developed particular strategies to exist without, have created new nutrient balances.. Agricultural practices have also changed the physical nature of the soil through the use of modern machinery and "European" tillage practices (Hamblin, 1987). Changes to the sub-surface and surface hydrological regimes have occurred (Jenkin, 1986) The removal of native animal and bird populations have removed important components of nutrient and plant reproductive cycles. Immigrant plant species became established, and continue to expand, different ecosystems of the region of the region. Today they account for approximately 10% of the species of the flora of the Fleurieu Peninsula (Dashorst and Jessop, 1990). Their expansion has altered the biotic environment in ways that are difficult to assess (Williams, 2001) but in general affect it results in the assembly of a new flora. Adamson and Fox (1982) described European impacts on vegetation in Australia as 'revolutionary transitions' that can be viewed as single or multiple step functions causing the original vegetation to alter to completely novel qualitative states (

Figure 10. 1). On a millennial time scale the impact of European settlement can be compressed into a nearly vertical step. On the scale of hundreds of years or decades the events can be resolved into multiple steps and each has a time-based slope that reflects the rate of change. The multiple steps (y–axis) reflect the amount of change the ecosystem has undergone.

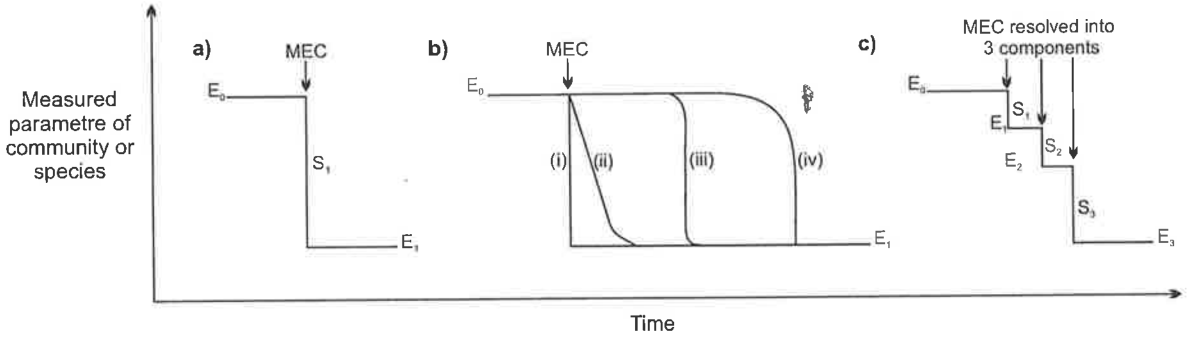

Figure 10. 1 A model of change in ecosystems responding to post-European impacts. The response of ecosystems (S) to major environmental changes (MEC) can be represented as a one step (a) or a multiple step (c) depending upon the time-scale of observations and the complexity of responses. There is no return to the original ecosystem (E_o) with time, but new ecosystems (E_1 to E_n) are established. In (b (i)) the change is almost instantaneous, in (b(ii)) change is progressive and the slope is resolved on the time scale used; in (b(iii)) change is delayed but is sudden when ultimately triggered, usually by a some predictable environmental fluctuation like a drought or by some change in the ecosystem which reached a threshold or (b(iv)) change is delayed but inevitable, for example by the death of a long lived individuals whose reproduction was blocked by an earlier change.

The sequent ecosystem changes due to spatially and temporally variant European land uses, demonstrated in this historical study support Adamson and Fox's hypothetical model of ecosystem change. The changes recorded to the Fleurieu Peninsula through the European period were step-wise, occurred at different rates and have resulted in completely new vegetation states. Figure 10.2 shows application of Adamson and Fox's model to the history of change of the vegetation types of the Fleurieu Peninsula. Adamson and Fox (1982) stress that in the Australian context no new steady state has emerged. This assertion is supported by this study. The effects of widespread clearance to remnant sclerophyll vegetation appear to be still in play, with species extinction and the invasion of non-native species continuing (Lang and Kraeheunbuel, 1987, Murphett, pers comm.). Tree death of the overstoreys of grassy woodlands are still occurring and are a delayed consequence of earlier environmental changes. Ongoing grazing disturbance is preventing overstorey regeneration. The effects of the almost-instantaneous imposition of agricultural and industrial technologies on the Fleurieu Peninsula landscape are still being played out. New 'stable' ecosystems have not yet been formed. In fact the likelihood of an ecosystem state that is a result of original European disturbances finally manifesting in the landscape when earlier impacts have run their course is unlikely to occur. It is likely that continuing human affected environmental changes, such as anthropogenically accelerated climate changes, will continue to provide a shifting stage to which vegetation will respond.

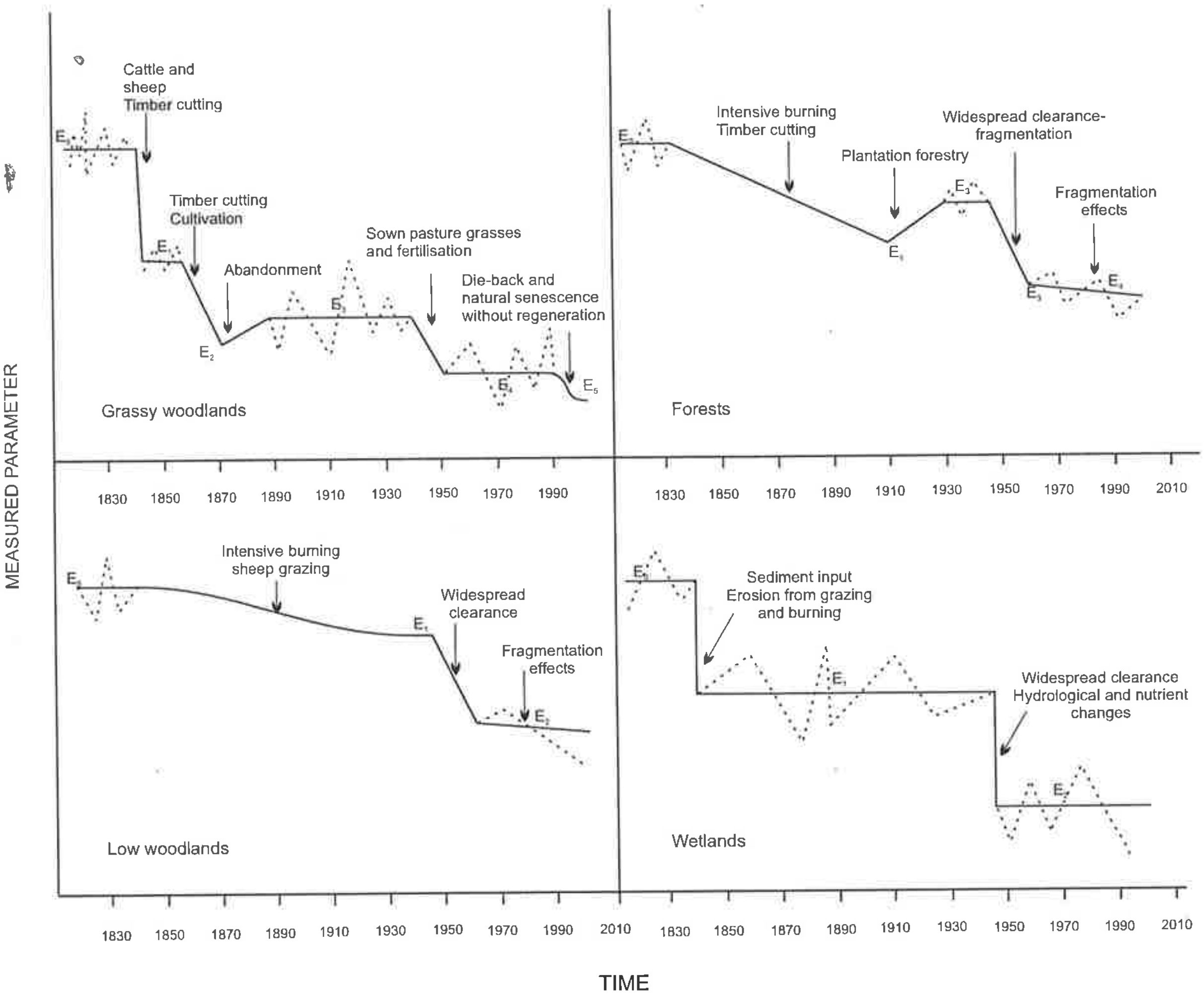

Figure 10. 2 Application of a model of ecosystem change developed by Adamson and Fox (1982) to the grassy woodlands, forests, low woodlands and wetlands in the Fleurieu Peninsula through the European period of settlement. The model shows the stepwise alteration of ecosystems to new states (E_1 to E_n). These states are described through the thesis and summarised in section 10.2 of this chapter. The parameters of change indicated on the y-*axis* could include vegetation structure, biomass, the ratio of native to exotic species, the ratio of perennial to annual species and changes in native species composition.

The vegetation changes documented in this thesis that occurred through the Holocene prior to European arrival, involved the replacement of one ecosystem with another. These changes occurred on much greater time scales in response to regional climate changes. In striking contrast, the ecosystem replacements in the European period occurred over decades. The rate of recent European changes is unprecedented. The type of ecosystem change between the periods is also different. The response of Australian vegetation to climate change is likely to be one of restriction to environmentally suitable refuges in times of deleterious environmental change and re-expansion as conditions ameliorate (Kershaw, 1995). Regional species extinction and forecasted future extinctions are a feature of European disturbance in the region and the dedication of land to agriculture, forestry or settlement preclude recolonisation in a way it could have occurred in the past. Pre-historic vegetation changes involved the substitution of one 'native' vegetation type with another, however shifts in the European period largely involve the replacement of the more structurally and compositionally diverse deep rooted-perennial species with agricultural and pasture species, which are non-native shallow- rooted annuals. The overall effect on whole ecosystem function would be much more dramatic than occurred with changes through the Holocene.

Fire, both natural and anthropogenic, and drought have long been components of influential natural disturbance regimes to which the Australian flora has adapted. Such changes would have been experienced more locally and had shifting loci. Natural disturbances are characterised by a pulse of damage which is followed by a period of recovery (Pickett and White, 1985). Viewed at a landscape or regional scale, where vegetation is continuous a dynamic equilibrium is maintained, with an overall stable distribution of patches among various age classes within the landscape mosaic of community types (Pickett and White, 1985). At a particular site natural disturbances probably resulted in large temporary fluctuations in plant populations; at decadal scales the vegetation may have been dynamic but over centuries the vegetation would have maintained a steady state about which fluctuations occurred. In periods of climatic stability, overall vegetation stability is maintained despite disturbances. Response to these types of natural disturbances contrast markedly to European disturbances where regeneration cannot, or has not, been allowed to occur. Ongoing agriculture and forestry in the region has prevented a period of regeneration. However even if regeneration could occur, it has been questioned whether traditional successional theories, invoked to explain sequential changes in vegetation induced by disturbances, are adequate to explain responses to recent human disturbances (Bazzaz, 1996). This is because recent disturbances are so different in nature. Foster (1997) discussed how, in general terms, post-industrial period human disturbances differ from antecedent natural disturbances. Recent human disturbances (1) are new in evolutionary context of the organism or system, (2) may reach intensities rivalling the most severe natural disturbances, (3) are relatively homogenous across broad areas that naturally differ in disturbance regimes, and (4) alter the biotic and abiotic environment and alter natural disturbance regimes. His distinctions usefully characterise European impacts in the Fleurieu Peninsula. The extraordinary nature of recent human changes necessitates a greater focus on the type disturbance/environmental changes (either historical or future). Understanding the history of recent changes, as done in this study, and investigation of the direct consequences of those changes, may help to develop new models which more adequately explain phenomena of this type.

Changing vegetation patterns through times of continuous human occupancy are common to both the time periods examined in this thesis. However the rate, the magnitude, the nature of disturbances affecting those changes and response to disturbances, are very different between the time periods. Collectively European disturbances have resulted in the complete elimination of components of the pre-European vegetation; a skewing of the environmental distribution of surviving vegetation types, permanent changes to the biotic and a biotic environment and the absence of a period of recovery for most types. Such changes are without precedent in the Holocene and probably not in the time periods before.

10.4 Historical Perspectives and Conservation

Extensive loss of native vegetation, changed disturbance regimes and changes to the abiotic environment present considerable challenges to both the conservation of regional biota and sustainable land use. Conservation of regional biota depends almost entirely on the retention and management of these remnant patches of vegetation. Unlike the very large or contiguous areas in which natural processes may continue to function as before, remnants are subject to a variety of exogenous disturbances which may disrupt normal processes. Successful conservation of species requires the conservation of interactions between species, and therefore the maintenance of natural processes within areas of native vegetation. It is doubtful that what remains is sufficient to retain functioning ecosystems which will maintain viable faunal and plant populations in the long-term (Saunders *et al.*, 1991). Habitat reconstruction, to extend the size of existing remnants, or on areas devoid of vegetation, to reconstruct a regional framework representing original landscape heterogeneity, has been viewed as the only possibility by which conservation goals in such regions can be met (Saunders *et al.*, 1987; Saunders and Hobbs, 1995; Reid, 2000; Williams, 2000). The unquestioned starting point for most habitat reconstruction is establishing what the landscape looked like before development and degradation and reconstruction of these vegetation patterns and processes (Commonwealth of Australia, 1997; Radeloff *et al.*, 2000). In many parts of Australia that implies its pre-European state, but most reconstructions work back from evidence provided in the form of remnant vegetation in the present landscape (Saunders and Hobbs, 1995; Commonwealth of Australia, 1997).

This thesis particularly raises some of the difficulties and limitations in using remnant vegetation alone to reconstruct the nature of pre-European vegetation. It shows modern vegetation types are a subset of the community types present at the time of pre-European settlement and many that remained are only representative of a portion of the environmental domains they formerly occupied. Remnant vegetation thus represents an incomplete and biased data set from which to predictively model pre-European vegetation patterns by considering environmental distribution and niches. In the case of the Fleurieu Peninsula, at a meso-scale, the environmental domains occupied by modern vegetation pattern were similar to those at the time of European settlement. However at scales more relevant to landscape reconstruction, the topo- scale, the effects of selective clearance and land use are compelling. The modern vegetation at this scale neither comprehensively represents pre-European types nor is representative of the full range of environments and thus diversity formerly occupied by each forest type. The findings support the vegetation scientist Grieg Smith (1983, p129) when he wrote that for all levels of ecological classification '....correlation between present environmental differences and present vegetation may break down owing to past changes in environment and vegetation, so that the determining variables are primarily historical ones'. This pattern is not peculiar to the Fleurieu Peninsula; selective removal of vegetation types that correlated with particular environments favoured for agriculture probably occurred throughout the agricultural belt in Australia (Hobbs *et al.*, 1993; Yates and Hobbs, 1997; Williams, 2000).

Even where the environmental distribution of remnant vegetation is sufficient to allow reconstruction of former domains by modelling, or *ad hoc* extrapolation approaches, both make the assumption that the vegetation at these sites is representative of its pre-European composition. While this assumption may hold true for particular components of the vegetation which have been resilient to changed disturbance regimes (for example the upper strata of *E. obliqua* forests in the Fleurieu Peninsula) it is unlikely to be so for the vegetation as a whole (Chapter 7).

Representativeness of composition, distribution and diversity can only be assessed by comparison with independent historical data sources. While these data sources may not be always be available, when present, they may provide sufficiently detailed ecological information, and if they are well distributed, an invaluable resource which should be used in conjunction with remnant vegetation. Where actual records of distribution of historical vegetation are not available, histories of settlement and exploitation can provide indirect information on impact and potential former states. Settlement and land use records provide another valuable adjunct to the correct use and interpretation of remnant vegetation records in environmental reconstruction. Historical data and an appreciation of the extent to which historical processes have shaped present patterns is required to avoid erroneous ecological interpretations.

The use of vegetation-environment relationships forms the basis of most environmental reconstruction projects. This is despite the recognised importance of disturbance regimes and historical cultural factors in determining vegetation pattern. In one sense the omission of disturbance factors can be considered to represent a disregard for the notion that the 'natural' state of vegetation is one where change or flux is inherent (Botkin, 1997). The focus on environmental/vegetation relationships is presumably because they are more easily revealed, and at least explain a portion of variation in landscapes, while past disturbances are difficult to establish. Palaeoecological records, applied at a sufficiently fine resolution, provide a means of revealing past disturbance regimes and characterising the natural range of historical variation. Such information may assist to further explain vegetation at a point in time (for example at the time of European settlement) or be used as a guideline to determine whether our future activities maintain vegetation within its 'natural' historical ranges.

Even if pre-European vegetation patterns are elucidated then the question of whether or not they can be reconstructed remains. This thesis suggests that at least local and possibly regional environments in the Fleurieu Peninsula had been altered by Aboriginal people. Prehistoric ecosystem balances have been replaced by new sets of relationships, with their own balances and trajectories that include ongoing European impacts. Gross changes to biotic and abiotic processes have occurred. The factors that give rise to the condition at any one point in time are so complex that it would appear that attempting to reconstruct former conditions in the present would be an unachievable goal.

At the time of arrival of Europeans in Australia the vegetation was undoubtedly more diverse and ecosystems were more functional than they are today. From this perspective the goal to reconstruct pre-European conditions, or the duplication of some of their characteristics in a new form, is worthy. However, the Holocene record analysed in this thesis highlights that pre-European conditions were but a single frame of a long history of varying vegetation states. Pre-European conditions can be considered to represent a somewhat arbitrary point in time. As the vegetation of the Fleurieu Peninsula was sensitive to the relatively small Holocene fluctuations in climate it is not unrealistic to assume that it will be sensitive to future anthropogenically accelerated climate changes. Biological reserves designed under present day conditions may be obliterated by later climatic changes. Reserve systems that accommodate a wide spectrum of environment types are required to allow species to move to survive inevitable environmental changes. This work showed that remnant vegetation, and thus reserve systems, are restricted to a small subset of the environment types present in the heterogeneous Fleurieu Peninsula landscape. Revegetation and conservation strategies should possibly consider more than community conservation but also the identification and protection of a variety of environments. Reconstruction strategies, which accommodate predictions of future climate changes, are more likely to successfully place species under some sort of environmental protection that will ensure their long-term survival.

CHAPTER 11

CONCLUSIONS

The intent of this thesis was to use retrospective inquiry to investigate the nature of European impacts on the vegetation of the Fleurieu Peninsula. To achieve this the study setout to qualify vegetation changes through the European period and understand them, by comparing them to long term environmental and vegetation changes which have been operative in the landscape long before European arrival. Vegetation change was the focus of the study, for vegetation was seen to act as a bridge between biotic, abiotic and human systems and so provides a focus for an interconnected history of all components.

Paramount to the assessment of the type and magnitude of European impacts was information on the status of the vegetation at the time of European arrival. Multiple-sources were investigated for their potential to provide information on pre-European impact conditions, and changes to them through that time. Methods for the use of the various types of evidence for these means were investigated. In the Fleurieu Peninsula, a region in which most of the original vegetation has been removed, the adoption of multiple sources was essential for reconstruction of this time period. This was primarily because no single source represented the range of former ecosystem types. Neither did any one line provide information that could be unambiguously interpreted without the help of another. Evidence was patchy in its distribution and specificity. Individual qualities of evidence types directly determined the extent to which pre-European impact environments could be reconstructed.

Methods to extend the spatial distribution of restricted remnant vegetation and historical survey records were investigated using a potential vegetation modelling approach, founded on gradient analyses and ecological niche theory. While the approach did not result in a 'verified' pre-European vegetation map, it suggested the potential of qualitative examination of former ecological relations in environmental space for both the reconstruction of historical vegetation patterns and qualification of specific impacts. The analyses showed that in highly disturbed environments, remnant vegetation patterns correlate to past land uses rather than former habitats. Remnant vegetation records integrated with historical records provided a measure of what had disappeared from those environments no longer represented by remnant vegetation.

Microfossil records from the European period provided a sequential history of wetland and terrestrial vegetation dynamics through the European period. Analysis was at a sufficiently fine temporal and classificatory resolution to detect responses to European impacts. Key to their application was the use of fine resolution taxonomic identification methodologies. The study suggested the utility and further potential of these techniques, in the Australian context, to consider historically operative vegetation dynamics.

Historical data provided insights into the nature and distribution of the pre-European vegetation otherwise unobtainable from remnant vegetation or current ecological knowledge. They provided information on the presence and distribution of components of the pre-European vegetation. This in turn allowed for analysis of the nature of changes to that vegetation. Land use histories were integrated to the vegetation histories to reveal potential causes of change. The integration of sources and human histories allowed for a qualitative and in places semi-quantitative history of impact and response. A European-period history of the forests, the sclerophyll low woodlands, the highland swamps and the grassy woodlands was reconstructed. It was shown that the timing of changes in the European period varied between environments with different land use histories. Ecosystems were transformed at different rates according to the ecology of the individual components within them and their different responses to imposed disturbances. However in aggregate, all the vegetation types of the Fleurieu Peninsula have been grossly modified from their pre-European form by conversion to agriculture, or by sequent phases of altered disturbance regimes and exploitation. European impact has been to displace pre-European ecosystems with completely new ecosystems from the interaction between the original organisms, new immigrant organisms, changed environmental factors and human activities. It has acted to remove some communities from the region altogether and strongly restrict others to particular environments in the region.

Holocene records revealed the dynamic nature of vegetation prior to European settlement. At millennial scales, over which regional climate changes occurred through the Holocene, components of the Fleurieu Peninsula vegetation underwent whole ecosystem replacements. It is probable that the vegetation was dynamic in response to fire and other natural disturbances over shorter time periods, but these changes were not revealed in this study due to the temporal resolution of pre-European records. These smaller scale disturbances were probably localised in extent and despite them, overall regional compositional stability of the vegetation was maintained. Changes through the European period contrast strongly to antecedent dynamics by their unprecedently fast rate and the grossly different nature of the causes and effects of change. No new steady state has been reached with the effects of earlier changes still in play.

The extraordinary nature of recent human impacts brings into focus the importance of understanding them and their effects better. Different regions with different biogeographies and settlement histories obviously have individual histories of human development and ecosystem change. This regional historical study provided empirical evidence for the nature of recent impacts, and some information on the timing and nature of ecosystem responses to those changes, in a particular area. To discover how common these responses are and to determine what are the major controls of change more studies are required to fully document examples of other regions. A significant outcome of this work was to indicate that the integration of different types of evidence operational across a range of spatial and temporal scales is possible and rewarding in the type of environmental histories it can reveal. Further methodological development of palaeoecological, documentary, and environmental data towards this outcome is required and the benefits and potentials of doing so are suggested in the methods developed in this thesis.

The utility of the historical inquiry in revealing past environmental relations and patterns at scales relevant to landscape conservation and reconstruction efforts additionally suggests that more regional histories are required to provide useful direction in the formulation of conservation strategies. This study suggested that multi-disciplinary and innovative analyses of historical data could elucidate historical environmental relations at scales relevant to current day issues. Additionally, recent vegetation histories are required to interpret contemporary ecological patterns and ongoing anthropologically-affected dynamics, as this thesis indicates, components of these undoubtedly have explanations in the past.

As well as providing necessary information for highly pertinent contemporary environmental issues, the environmental history of this region provides a useful perspective communicable and relevant to every person. The condition of Australia before and after European contact is of interest to both the indigenous and non-indigenous people in this country. The revelation of former cultural-environmental relationships is important to Aboriginal notions of place and identity. It similarly relates to the ideas that European Australia was built upon and who we are today. Former environments are no longer clearly evident in present environments. Their former nature and history of change allows for understanding of what we have done. This historical perspective may have great power in providing motivation and direction for present day action towards conservation of what is left, and amelioration of former damages. This work moves towards confirming that all histories are now environmental histories. The environmental component of human endeavour and the impacts of humans on the landscape are of such a scale that the relationships are irrevocably and crucially entwined.

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Held by the Department for Administrative and Information Services (DAIS)—Land Services Group, Lands Title Office

Hundred of Waitpinga Book 1, Book2
Hundred of Yankalilla Book 1, Book 2
Hundred of Myponga, Book 1, Book 2
Hundred of Encounter Bay Book 1, Book 2

Field Books

Held by the Department for Administrative and Information Services (DAIS)—Land Services Group, Lands Title Office

128, Hundred of Myponga, 1840, M. Baker
134, Hundred of Myponga, 1853, A. Brooking
143, Hundred of Myponga, 1854, 1863, A. Brooking, W. Pearson
212, Hundred of Myponga, 1880, 1881, 1883, S.W. Herbert, Ferguson, W.G. Evans
242, Hundred of Encounter Bay, 1863, 1874, 1863, G. Moore, A.H. Suite, A. Cooper , Pearson
1145, Hundred of Encounter Bay, 1880, N. Shaw
1276, Hundred of Encounter Bay, 1883, A. Poeppel
1296, Hundred of Encounter Bay, 1883, A. Poeppel
1310, Hundred of Encounter Bay, 1883, A. Poeppel
1368, Hundred of Encounter Bay, 1883, A. Poeppel
1350, Hundred of Encounter Bay, 1883, A. Poeppel
245, Hundred of Waitpinga, 1856, J.M. Painter, G. Moore
580a, Hundred of Waitpinga, 1870, A.M. Mitchell
1390, Hundred of Waitpinga, 1882-1886 , S.W. Herbert
1484, Hundred of Waitpinga, 1882-1886 , S.W. Herbert
134, Hundred of Yankalilla 1854, Corp. Brooking ,J.M. Painter
169, Hundred of Yankalilla 1854, 1860, 1862, Brooking, Dowling, G. Moore, M. Pearson
1270, Hundred of Yankalilla 1882-6, 1900, S.W. Herbert, A.W. Pethick, W. Wadham

Maps

Held by the Mortlock Library 'C' maps.

Plan of 76 sections west of Encounter Bay Districts D and F. 1840, Corp. Moulton R. and Miners
Plan of 268 Sections in the Vallies [sic] of the Myponga District D. 1840,, Corprals Ide and Baker,
Plan of the District of Yankalyilla [sic], 1839 Messers Kentish and Poole
Plan of 15 Sections in the county adjoining Rapid Bay. District F, 1839
Plan of the Settled Districts D and F near Rapid Bay., 1839
Outline of the Plan of the Sections in the Vale of Inman District E Plan 195 sections on the Inman, 1839 Corporal Baker and Ide.

Held by Department for Administrative and Information Services (DAIS)—State Records of South Australia

Hundred of Waitpinga, 1875, GRG 35/586
Hundred of Waitpinga, 1884, GRG 35/586
Hundred of Waitpinga, 1896, GRG 35/586
Hundred of Yankalilla, 1875, GRG 35/586
Hundred of Yankalilla, 1887, GRG 35/586
Hundred of Myponga, 1875, GRG 35/586
Hundred of Myponga, 1896, GRG 35/586
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Pictorial works

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Other sources

Census data

1841, The Original Districts A to C, South Australian Statistical Register

1846 Abstract of Census returns, March 1, The South Australian Government Gazette

1850, 1855, 1860, 1861, 1871, 1876, 1881, 1891 Issued in SAPP in South Australian Statistical Returns

State Government Records

South Australian Parliamentary Papers, "Statistical Register of the Province of South Australia", years 1860, 1871, 1881, 1890, 1900, 1910, 1920, 1930, 1940.

SAGG, 1850

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SAGG, 1864

Local Government Records

Held by the Yankalilla District Council

Yankalilla Council Minute Book, 1856-78

Rapid Bay Council Minute Book (RBCMB), 1864-1878

RBCMB, 1878-1914

Historical notes

Held by Department for Administrative and Information Services (DAIS)—State Records of South Australia

Research Note 160 On the Hundred of Waitpinga (Newland, R.W., April, 1840)

Research Note 309 vol. 7 Capt.Collett Barker

Research Note 831 Hutchinson, Y. Trip to Lake Alexandrina, November 27, 1837. South Australian State Records, Adelaide.

Newspapers

South Australian Government Gazette, 1839

Observer Oct.3rd. 1914

Personal communications

Ian Robertson, Albert Jones, Roy Williams, Professor Geoff Hope, Dr. Michael McPhail.

APPENDIX 1

PALEOGRAPHIC TRANSCRIPTION OF HISTORICAL VEGETATION OBSERVATIONS IN A GIS

Production of historical Hundred plans

Aim: To edit the contemporary land section digital coverages (DCDB plans) to resemble the sections depicted in the hard copy 1935 Hundred Plans, which are the sections delineated in original survey's of the region. This was necessary to do as most vegetation information recorded in the Diagram books drawn up from early surveys was done using the section as a identificatory geographical unit and would thus allow geolocation of these descriptions. In additionally this coverage was required to assist the geo-location of vegetation descriptions contained within section units in surveyors' field note books.

Clipping South Australian DCDB coverage to study area

Arc/Info
Clip DCDB coverage with study area boundary coverage.

```
usage: clip <in_cover> <clip_cover> <out_cover> {coverage type} {fuzzy_tolerance}
eg Arc: clip dcdb coast_fp dcdb_fp poly #
```

Editing study area DCDB coverage to produce digital coverages of each historical Hundred plan

The editing process involved visual comparison of the historical Hundred maps with the on screen digital coverage. The coverage of all land parcels in the study area was large, taking much time to draw and redraw in *ArcEdit*. It was decided that for ease of comparison one Hundred plan at a time would be reconstructed. To do this the DCDB coverage of the study region was copied four times and named according to the particular Hundred map it was to be edited to resemble. All sections not encompassing the Hundred being edited were selected and deleted. Most original section boundaries were still present in the modern DCDB coverage. However, many original sections had been subdivided and roads had been added. The editing process largely involved removing subdivision-arcs and roads. Roads were between most of the historical sections, thus two parallel arcs divided most sections. One of these arcs was removed and where this left un-intersected arcs, the arcs were joined.

Coverages were edited using *Arc/tools edit* a program within *Arc/Info*
At arc prompt type **arctools edit**
From **arctools menu** select the **file** drop menu
Select **open** from the **file** menu
Select the coverage to be edited.
Select the feature to be edited. In this case it was arcs.
Note: the open coverage becomes the current edit object. The selected feature to edit becomes the edit feature and the Edit feature Menu and Feature selection menus appear.

Selecting arcs using the lh mouse button and **select arrow** from the feature selection menu
Deleting arcs using the lh mouse button and **delete** command button on the Edit feature menu
Moving arcs was done by first selecting the arc to be moved and then selecting the **move** command button on the Edit feature menu
Nodes were added to arcs using the Edit nodes command buttons (**split**)on the Edit feature menu. (this was done to allow new arcs to be joined at the correct place along an arc.
Adding arcs- new arcs were digitised from the screen. From the Edit feature menu **add** arcs command button was selected. The middle mouse button begins an arc with a node and the left hand mouse button creates the arc.

Cleaning/building polygon coverages.

From the **Arctools menu** select Tools drop menu
Select topology/clean from the topology drop menu
Select topology/build from the topology drop menu

Assigning section numbers to the newly constructed section polygons

It was necessary to assign the original section numbers to section polygons so that vegetation information that was recorded for each section could be added/imported. This was done in **Arctools edit**, polygons were selected one at a time and with reference to the section number of the hardcopy historical Hundred map numbers were assigned to the Section_no item field.

Adding polygon items

1. From the edit polygons menu select the Table Manager command button
2. From the Table manager drop menu select **additem**
3. Add item by naming and defining Item type, Item width, Display width and Decimals.

Adding records to items

1. Select the polygon/s the record is to be added to
2. From the edit polygons menu select the Table Editor command button
3. From the Table Editor drop menu select Edit command button (drop menu with attributes appears and their values appears)
4. Add the record to the appropriate attribute field.

Adding attribute information to historical section coverages

1. Original sections surveyed (1839-1840)

Copies were taken of the first Survey maps pertaining to the study region. The boundaries of the sections delineated on these maps were those drafted in the 1935 Hundred plans, that is remained unchanged through that time.

> The sections drawn in the early maps were selected on the historical hundred section coverages and put to a new cover. **Arcedit edittools**
> Historical sections were given attribute first survey and all polygons delineated in the first survey were designated a value of 1.

2. Importing excel data files in to **Arcinfo INFO**

Formatting excel data files to importable format

1. Replace all spaces between text strings with underscores using **Excel** Find and Replace commands.
2. Save excel files as ascii comma separated value files (.csv)
3. ftp .csv files to network
4. edit imported file using **textedit** to remove column headings
5. Create info file template with fields matching those of excel data file (this file was copied and used for importing all Hundred data files)

An info file template can be created in **arcinfo** or in **INFO.**

```
arcinfo additem command
INFO modify command
```

5. Import records in to INFO template file in INFO using by selecting the template file and using the import command

```
(arc: INFO
info: sel <file name>
info: import <file name.csv> sdf)
```

6. In **INFO** relate the template info file to the .pat file by the item section_no for the coverage containing the sections for which the records pertain to and transfer the records across to the .pat file.

```
info: sel <.pat file records to be added to>
info: relate <info file with imported records> by section_no
```

7. Use the move command to transfer text items and the calculate commands to transfer numeric items

for example:

```
calc sb =$1sb
move $1agricultural_ref agricultural_ref
```

Digitising field book vegetation descriptions

Setting up edit coverage

Setting up back ground images to allow correct location of text descriptions

To view image as background

1. From **Arctools** menu select **Display** drop menu
2. Select **Back environment general image**

Note: this displays the image environment menu used to specify which back images are to be drawn and the methods for drawing each.

3. Select cover using rh mouse button at **add back** option
4. Select feature of coverage to be drawn at **feature** window
5. Select drawing style and colour under **symbols** in **back options** window and back cover **on**
6. Click on **draw** and **apply** and back coverage is drawn up.

To view text as background

1. From **Arctools** menu select **Display** drop menu
2. Select **Back textitem**
3. Select coverage which contains text to be displayed from **Backobject** window
4. Select feature relating to text item from **feature** window (polygon)
5. Select **Text item** (section number)
6. Click on **apply**

The following back covers were drawn up to allow the on screen digitising of historical field book text records,

Section boundaries
Contour lines
Drainage lines
Section numbers

Joining Hundred Coverages

For ease of analysis historical Hundred coverages were joined to form a single layer for the study area.

1. Ensure that coverages .pat files with identical items. The items must have the same name, definitions and be in the same order. (editing was done in ArcInfo INFO).
2. ArcInfo mapjoin command

```
(usage: mapjoin <out_cover> {feature_class ... feature_class | template_cover} {NONE | FEATURES | TICS | ALL} {CLIP_COVER}.
Prompt for          enter the first cover:
                    enter the second cover
etc. to all covers are entered. )
```

APPENDIX 2

CONSTRUCTION OF ENVIRONMENTAL COVERAGES

Digital Elevation Model

A regular grid representation of a digital elevation models was built using the ANUDEM program (Hutchinson, 1988; Hutchinson and Dowling, 1991) available in *ArcInfo* using the **Topogrid** command. The program requires elevation data and optionally stream network data for the area to be modelled. Elevation data was obtained from contour, and stream data from drainage, coverages of region developed and held by the Department for Administrative and Information Services, South Australia.

Editing stream coverage to use as input into ANUDEM/ TOPOGRID

The inclusion of stream data in the generation is recommended for a quality output DEM as the data is a powerful way of adding additional topographic information to interpolation process. The coverage must be in the form of single arc streams with all arcs orientated to point downstream. This required pre-processing of the drainage coverage. The pre-processing process is presented below.

ArcInfo:

```
Arc: Copy <drain_fp> <drain>
build <drain> node
Info: sel DRAIN.NAT
calc drain_id = drain_no
```

Converted nodes in to a point coverage

```
arc: nodepoint <drain> drainpoint
```

Interpolate elevation values for each point from a TIN DEM for the region, created previously

```
arc: tinspot <tin> <drain_point> elev linear
```

The PAT for the coverage drain_point now contains an item 'elev' with elevation values in it. Copy this .pat twice to two attribute files dp_to.pat and dp_from.pat.

```
arc: copyinfo drain_point.pat <out_info_file>
```

drop all items except the drain_point# and elevation value

```
arc: dropitem < dp_to.pat> <dpto.pat> area perimeter drain_point-id
arc : dropitem <dp_from.pat> <dpfrom.pat> area perimeter drain_point-id
```

Alter item names, 'drain_point#' to 'TNODE#' in modified info file dpto.pat; 'drain_point#' to 'FNODE#' in dpfrom.pat; 'elev' to 't_elev' in dpto.pat and 'elev' to dpfrom.pat

```
info: sel < DRAIN_POINT.PAT>
> alter
item name >
end
```

These files now have elevation and a Tnode# only - join them to the drainage cover so that each FNODE and TNODE has respective elevation values.

Join the item files with elevation values to the arc attribute table of the drain cover <drain>

```
Usage: arc: joinitem <in_info_file> <join_info_file> <out_info_file> <relate item> {start_item} {linear|ordered|link}
arc: drain.aat dpfrom.pat drain.aat FNODE# drain-id linear
```

In arc edit draw drainage lines with directionality arrows, select all arcs where the t_elev (former tnode) is greater than the f-elev (former fnode) and use the flip command to alter directionality of these selected arcs.

```
Arcedit
disp 9999
editcover <drain>
editfeature arc
Drawenvironment arc arrows
sect t_elev >f_elev
flip
```

Dams and braided streams were edited manually in **arcedit**. Arcs forming dams were selected, deleted and stream lines were reconnected using add arc function.

Running the TOPOGRID command

Usage of **Topogrid**

```
Arc: TOPOGRID <outgrid> <cell size>
```

Subcommands:

Datatype: contour (the primary type of input data)

Contour: <in_cover> <elev_item>(input coverage in this case was a 5m. interval contour coverage of an area slightly larger than desired DEM boundary to ensure correct interpolation of edges was used. The elev_item the name of the numeric item in the AAT which store the elevation attributes.

Boundary: <in_cover> (single polygon-polygon coverage representing the outer boundary of the output DEM)

Stream: <in_cover> (input of a line coverage representing streams.)

Tolerances: {RMS} {tol1} {tol2} (a set of tolerances use to adjust the smoothing of input data and the removing of sinks in the drainage input)

RMS; represents accuracy and density of the elevation points and was set at 0.05 the recommended setting for 5 m. contour data. The other tolerances were set at 2.5 and 0.5 respectively representing elevation tolerances.

Output: {sink_cover} {drainage_cover} {diagnostic_file}- optional outputs providing information used to evaluate the quality of the input data and output DEM. Created sink_fp, stream_fp and diag_fp. The sink cover consisted of 614 sinks and were sinks that were not specified in the input sink coverage and were not cleared during the drainage enforcement. They were overlain on the DEM and contour coverage used to generate the DEM to indicate sinks resulting from mis-labelled contour lines. The number of sinks can be reduced by the adjustment of tolerance values, however this was not done. It was thought not to be necessary after comparing sink elevations with

surrounding contour data and the output DEM as nearly all sinks were along drainage lines or in positions where dams had been removed from the stream cover to make it suitable for input use or were only minor depressions in the surface.
Margin: <value> - a value indicating that interpolation should extend by a specified distance beyond xyz limits and boundary. This is required to edges of DEM are correct, that is built with the same amount of information as internal regions. A value of 200m was used.
Enforce: <on|off> - turns drainage enforcement routine on or off. Selected to use drainage enforcement to ensure removal of spurious sinks and create a hydrologically correct DEM.
Iterations: < value> The number of iterations for each grid resolution. The default value of 30 was used.
End

Correcting errors in contour coverage for accurate DEM construction

The building process was iterative in that a DEM was built, used to check for errors in the input contour data, errors in data were corrected and then the DEM was rebuilt with corrected contour data.
Contours were derived from the DEM using the ArcInfo **latticecontour** command and derived contours viewed for errors. Areas where contours changed in a non natural way were highlighted and located on original contour coverage. Incorrect elevation values on original contour coverage was found to be responsible for errors. The elevations on mislabeled contours were corrected in arcedit.

Usage: Arc: latticecontour <in_lattice> <out_cover> <interval> {base contour} {contour_item} {weed_tolerace} {z_factor}
Arc: latticecontour <dem> deriv_contour 15

The GRID **hillshade** command, which creates a shaded relief from a grid by considering the illumination angle and shadows was also created from the DEM as another means of highlighting any obvious errors.
Usage; <out_grid> = hillshade (<in_grid>, {azimuth}, {altitude}, {all|shade|shadow}, {z_factor})
Grid: <hill_1> = hillshade (dem, 270, 30, all, 10)

Terrain variables

Inputs in to TAPES-G program (Moore *et al.*, 1993; Gallant and Wilson, 1996)
Grid cell size : 20m
Critical area slope: 50 000
Drainage calculation: D8 algorithm
Catchment area computation: Multiple direction drainage method FD8
Slope output using: finite difference algorithm

Solar radiation

Inputs into SRAD (Moore, 1993; Wilson and Gallant, 1996).

Parameter	Value used	Units	Data souce
Latitude	-35.57	decimal degrees	
Circumsolar Coefficient (fraction of diffuse radiation originating near the solar disc)	0.25	none	ANU estimate
Albedo (fraction of sunlight refracted from the surface)	0.15	none	ANU estimate
Cloudiness parameter	0.34		ANU estimate
Sunshine fraction (Ratio of actual sunshine hours to theoretical maximum day length)	Monthly average values	none	Sunshine hours from Lenswood Meterological station Mean day hours - ASLIG
Maximum air temperature	Monthly average values	C	Parawa Met records (5 years of record)
Min air temperature	Monthly average values	C	Parawa Met records (5 years of record)
Average surface temperature	Monthly average values	C	Parawa Met records (5 years of record)
Min air temperature lapse rate	7.30	C/1000 m	ANU estimate
Max air temperature lapse rate	6.00	C/1000 m	ANU estimate
Maximum leaf area index	10	none	Typical value
Surface emissivity	0.96		Typical value
Transmissivity lapse rate	0.00008	1/m	Typical value
Elevation of reference station (required for temperature extrapolation)	320		Parawa station
Atmospheric transmittance (fraction of solar radiation transmitted by the atmosphere)	monthly values		ANU estimate

APPENDIX 3

METHODS USED IN BIOCLIM ANALYSIS

BIOCLIM program calculates bioclimatic values at nominated sites and on regular grids. From the bioclimatic values at a set of sites it can generate a bioclimatic profile. A schematic summary of the process is presented.

Vegetation Site Data

a) Formation classifications : Scrub, Forest and Savannah Woodland

Create individual coverages for each formation type

From the section level resolution historical survey coverages, new coverages were built with only those sections classed as scrub and forest respectively in the attribute type 'Structural reference'.

Created Scrub and Forest coverages in Arc/tools edit. At arc prompt type **arctools edit**
From **arctools menu** select the **file** drop menu
Select **open** from the **file** menu
Select the coverage to be edited. In this case 'FP_SECT'
Select the feature to be edited. In this case it was polygons.
Select the **Edit** drop down menu. Select **Attribute selection**.
Chose attribute "Struct_class" and select polygons of values desired.
Values 'scrub', 'dense scrub' 'low scrub', and 'low dense scrub' were selected and **put** to cover named 'sect_scr'.
Values 'forest' and 'dense forest' were selected and **put** to cover named 'sect_forest'.
Coverages were built as polygons in *ArcInfo.*
The first survey coverages, comprising only of those sections surveyed in the 1839-40 surveys were already built (see above) and were copied and renamed 'woodland' coverage.

Cover name	No. sections
sect_scrub	142
sect_forest	56
woodland	756

Check mutual exclusivity of the vegetation classification types
To check for mutual exclusivity of the vegetation classification types the coverages were investigated for any points of overlap. This could possibly occur between sections denoted in the first surveys and then resurveyed and classified in the second period of survey.
Arcview
Create view with the three formation coverages as themes.
From the **Analysis** drop down window select **Tabulate areas.**
Row theme: Name of formation cover
Row field: Polygon-id
Column theme: Name of second formation cover
Column field: Polygon id

Produce site data input file for BIOCLIM from polygon coverage

To generate the bioclimatic profile for a species BIOCLIM requires a file with location of site in geographical decimal degree coordinates, elevation of the site and an identificatory number. This file interrogates the climatic surfaces generated by ANUSPLIN.

It was decided that a single point site placed arbitrarily with in a section polygon to provide elevation and thus bioclimatic values for the whole polygon region may not provide data representative of the whole polygon. Thus several sites were sampled from each section polygon by gridding the coverage using the **polygrid** command in **GRID** and then using the centroid of each grid cell that fell with in a polygon as a sample point in the Site data input file. Elevations for each site were obtained from the DEM previously created for the region using the **GRID** command **Sample**. The sample command outputs an ascii file of AMG coordinates and elevation. This file was edited into the required format and projected into geographic coordinates.

Running BIOCLIM through the TkClim interface.
TkClim is a graphical user interface to BIOCLIM and other bioclimatic modelling programs developed by CRES, ANU. TkClim version 1.5 was used.
From the ANUCLIM menu select BIOCLIM.-generate bioclimatic profile -
options - from site data
- from DEM
For generation of species/vegetation profile chose **site data.**
A window with input options appears. **Select SURFLIST** (file which contains the specifications of all Australian climate surface coefficient files to be used by BIOCLIM). The standard SURFLIST file for Australia was used. (/opt/tk-clim-1.6/surfaces/surflist).
Select region : Australia
Select species site file that profile is required from the scrolling list on menu.
Indicate format of site data in the data format popup menu.
Indicate name of output file.
Set BIOCLIM options in pop up menu.

Periods/quareters consist of	months
Max soil water availability	150 mm
Soil type	Clay loam

Select Australian Climatic surfaces to use to generate bioclimatic parameters (there are sixteen to chose from in this program; those listed below were selected)
maximum temperature ^{0}C, minimum temperature ^{0}C, rainfall mm.
Select program Run
The program produces a *.bio file which contains the bioclimatic parameters for each individual site location and contains frequency graphs for each individual bioclimatic parameter.
The parametres generated from the above selected surfaces were

Annual mean temperature, Mean diurnal range, Temperature seasonality (C of V), Max. temperature of the warmest period, Min temperature of the coldest period, Temperature annual range, Mean temperature of the wettest quarter, Mean temperature of the driest quarter, Mean temperature of the warmest quarter, Mean temperature of the coldest quarter, Annual precipitation, Precipitation of the wettest period, Precipitation of the driest period, Precipitation seasonality, Precipitation of the wettest quarter, Precipitation of the driest quarter, Precipitation of the warmest quarter, Precipitation of the coldest quarter

BIOCLIM also produces a *.pro file, which is a statistical summary of the bioclimatic parameters from each location and contains the following values for each BIOCLIM parameter; 1) mean, 2) 2.5 percentile 3) standard deviation of the mean, 4) 5th percentile 5)10th percentile 6) 25th percentile 7) median, 8) 75th percentile 9) 95th percentile 10) maximum value 11) minimum value.

Running TkClim Utilities

Generating graphical display of the distribution of bioclimatic parameters for site files.

Select **Utilities** pop down menu
Select **Show BIOCLIM parameter profiles**
Select species/veg types to profile from scrolling menu of profile files
Chose graphical display type- **histogram** or **percentile plot**
Run.

Graphs were viewed through Ghostview, printed and saved as postscript files. The percentile mode produce lazy-S curves---these curves can be used to indicate any problems in data (deviations could indicate several species recorded in one file).

Generating bioclimatic parameter surfaces for entire region from DEM.

BIOCLIM program was run through ANUCLIM and the generation of a command file (copy of file in appendix?). The inputs were as with the generation of the site files (above) but a 20m DEM was input into the program and bioclimatic parameters calculated for each cell. BIOCLIM output was in the form of individual variables in ascii files. These files were converted into floating point grids in *ArcInfo* GRID with the **asciigrid** command and projection files copied to them from original DEM using *ArcInfo* **projectcopy** command.

Test for correlations between bioclimatic parameters

ArcInfo Grid
Use the correlation command which calculates the cross correlation between two input grids
usage; correlation <grid 1> <grid 2>
Resultant correlation coefficients range from 1 to -1 with grids that are highly positively correlated with a value equal to one, if they are independent 0 and a strong negative correlation the output value will equal -1.

Mapping sites of predicted occurrence

Combine and reclassify bioclimatic profile grids *ArcInfo* GRID.

Values of the minimum and maximum limits (the range) and the 5 and 95 percentile limits of individual bioclimatic variables were read from the each vegetation types .pro files. Cells in bioclimatic variable grids were reclassified using according to the limit class their value fell in.

Cells outside the range were given a value of 0.
Cells between range the range limits and 5 and 95 percentile values were given a value of 1 (in range but not 'core' distribution).
Cells with values between the 5 and 95 percentile values were given a value of 2 ("core" distribution).

Grids were then overlayed with the **COR** command - 'combinatorial or' which performs a combinatorial -OR operation on two input grids o a cell by cell basis. The command interprets the input as Boolean values. A combinatorial operator assigns a different number to each unique combination of input values to the VALUE item in the VAT output.

Usage Grid : outgrid = <grid> cor <grid>

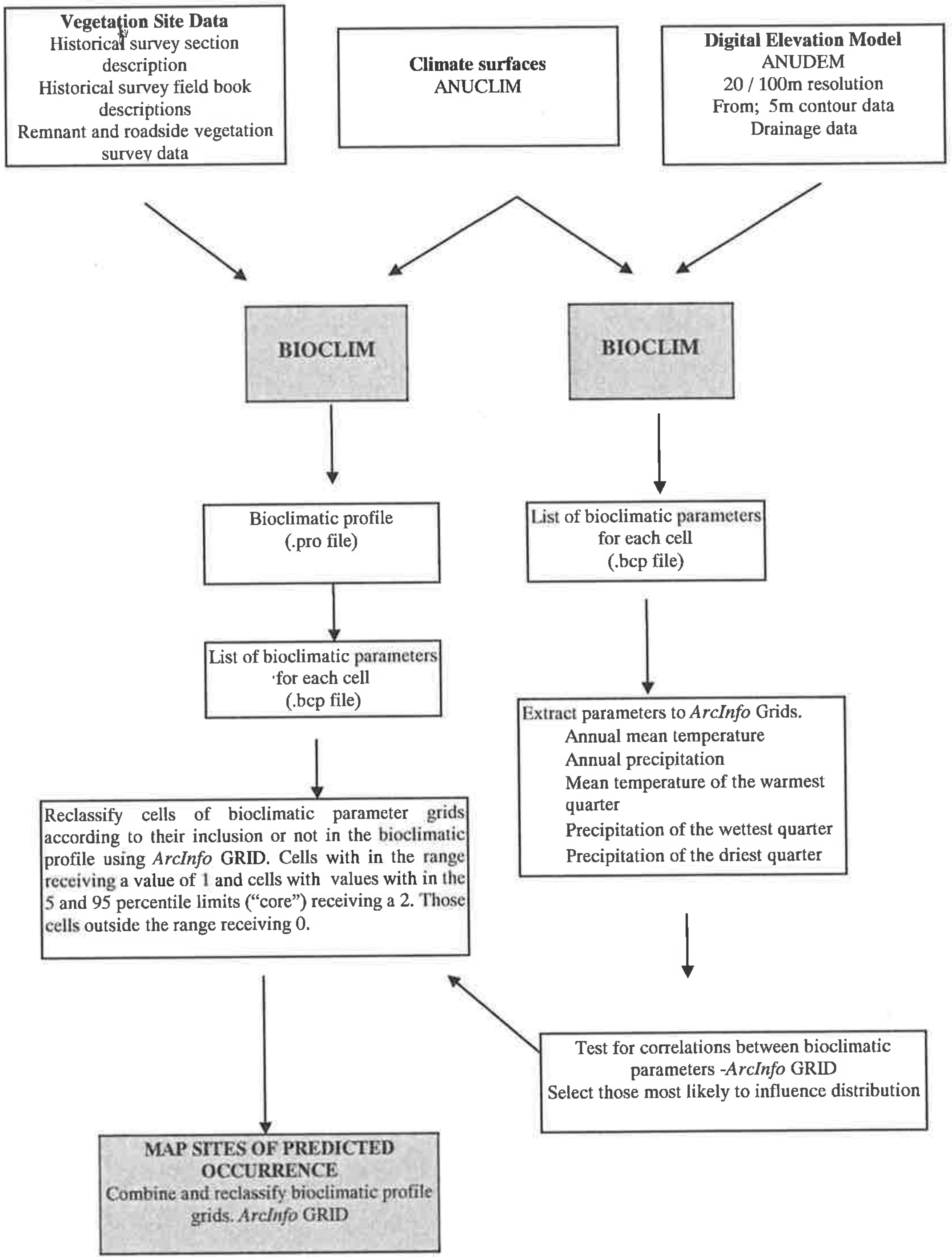
Values (combinations) of the resultant grid were then reclassified.

The following combinations were possible and were reclassified as follows;

Combinations		Reclassification value
0	0	0 - not present
0	1	0 - not present
0	2	0 - not present
1	1	1 - in range but not in core
1	2	1 - in range but not in core
2	2	2 - core of distribution

The core potential distribution occurred where both bioclimatic parameters for a given location fall with in the core (5 to 95 percentile limits) for that species or vegetation class and were given a value of 2. Locations where one bioclimatic parameter fell in the 5 to 95 percentile limits and the other only in the range were given a value of 1, and considered to be locations of potential distribution but the species or vegetation type not as likely to be present as in locations classified as core. If one bioclimatic parameter was outside of the range for a location the site was excluded from the potential distribution map.

Outline of the BIOCLIM procedure



APPENDIX 4

POLLEN MORPHOLOGY *EUCALYPTUS* SPP. *LEPTOPSPERMUM*, SPP *MELALEUCA* SPP. *KUNZEA* SP. AND *CALYTRIX* SP. OF THE SOUTHERN MOUNT LOFTY RANGES

Introduction

The high level of species diversity within the Australian flora and the morphological similarity of the pollen produced by many of the dominant species present particular difficulties in the successful application of fine resolution palaeoecological studies in Australian environments. The pollen of members of the most diverse and one of the most important components of the Australian vegetation, the Myrtaceae family, is superficially very similar. Without the morphological separation of dominant species, shifts from one community or formation to another are undetectable in the fossil record and so vegetation or environmental histories are limited in detail.

Differentiation of Myrtaceae pollen in fossil assemblages, where attempted, has generally been limited to the separation of major taxonomic groups such as *Eucalyptus*, *Melaleuca* and *Leptospermum*. Few studies have attempted more detailed subdivision of Myrtaceae pollen, and these have concentrated on the separation of *Eucalyptus* pollen types (eg Dodson, 1974; Dodson, 1977; Dodson and Wilson, 1975; Ladd, 1979). Several recent studies have considered whether Myrtaceae pollen might be identified to a species level. Pickett and Newsome (1997) investigated this question with regards nine *Eucalyptus* species from a region in south-western Western Australia, in both modern preparations and in fossil sequences. Chalson and Martin (1995) considered the morphology of modern pollen of twenty New South Wales Myrtaceous species. These studies suggest that species level identification is possible for most of the species studied when both gross morphological and fine detailed characters were employed.

Both the sclerophyll and grassy woodlands of the Fleurieu Peninsula, and the nearby mallee formations, are structurally dominated by *Eucalyptus* species. Other species in the Myrtaceae family are important components of their understoreys. Eight *Eucalyptus* species occur as dominant overstorey species, either on their own, or in association with other *Eucalyptus* species. The species are; *Eucalyptus leucoxylon* sub sp. *leucoxylon*, *E. viminalis* sub sp *.cygnatensis*, *E. obliqua*, *E. baxteri*, *E. fasciculosa*, *E. camaldulensis*, *E. cosmophylla* and *E. ovata*. Other *Eucalyptus* species with limited contemporary distributions in the study region are, *E. cnerifolia*, *E. incrassata*, *E. rubida*, *E. leptophylla* and *E. diversifolia*. In addition, *E. socialis*, *E. oleosa*, *E. odorata*, *E. microcarpa*, *E. porosa* and *E. congoldbata* are found within the central and northern Mount Lofty Ranges. *Eucalyptus anceps*, *E. cladocalyx*, *E. foecunda*, and *E. rugosa* have distributions on nearby Kangaroo Island but not in the Fleurieu Peninsula.

Species of *Melaleuca*, *Leptospermum*, *Kunzea*, *Baeckia* and *Calytrix* are common understorey components of the sclerophyll communities or as overstorey components of swamp communities in the Fleurieu Peninsula. Three *Melaleuca* species, *M. decussata*, *M. squamea* and *M. lanceolata*, occupy a range of habits from swamplands to low woodland. *Melaleuca decussata* and *M. squamea* are the most commonly occurring species in the region, both preferring swampy environs. *Melaleuca lanceolata* is found in woodland and mallee formations along the southern and western coast of the Peninsula. *Melaleuca brevifolia* occurs in the region however is not common. *Melaleuca uncinata* and *M. halmaturorum* do not presently occur in the study region however are distributed nearby the region, on the eastern side of the Mount Lofty Ranges. Three *Leptospermum* species have present day wide distributions in the Fleurieu Peninsula. *Leptospermum myrsinoides* is a common understorey plant in the sclerophyllous communities. *Leptospermum continentale* is found in forests, wet gullies or in swampy sands. *Leptospermum lanigerum* is restricted to swamp surrounds and creek beds. Other Myrtaceae in the region with broad distributions are *Kunzea pomifera*, *Baekea ramosissima* and *Calytrix tetragona*.

This study explores the feasibility of specific identification of pollen of the eight dominant *Eucalyptus* species in the Fleurieu Peninsula. It also investigates the morphology of pollen of other myrtaceous species to ensure no overlap with the dominant *Eucalyptus* classes, and to investigate their potential for specific identification.

Methods

Pollen collection and preparation

Pollen was obtained from either herbarium specimens at the South Australian Herbarium, collected from flowering species on the Fleurieu Peninsula or examined from the pollen reference collection at the Australian National University, Department of Archaeology and Natural History. Collection of pollen from herbarium and living material involved sampling from at least three individuals for each species, sampling across the geographical range where possible. Mature flowers only were sampled. Type slides were prepared in the same way as fossil material, using standard pollen preparation techniques (Faegri and Iverson, 1989), with the omission of the hydroflouric acid (HF) treatment. HF treatment is reported to cause grain shrinkage (Moore and Webb, 1991), however this was considered when comparing fossil and modern size measurements. The mounting media used for pollen from fresh material and herbarium specimens was glycerine and that used on the Australian National University reference slides was silicon. Gylcerine jelly mounts are reported to cause grain swelling. The apex to base length of pollen from the same species was compared between silicon mounted ANU type slides with those mounted in glycerine. It was found that on average pollen on glycerine mounted slides were 20% greater than those mounted in silicon. To allow the comparison of size measurements, measurements of pollen on silicon slides were multiplied by 1.2. Measurements were made on a light microscope at x 400 magnification on a minimum of ten grains per sample for the *Eucalyptus* species studied in detail and on at least 5 grains other species considered. Photographs of each type were taken at x 1000 magnification.

Table 1 Pollen sources and preparation mounting media.

Species	Source	Slide mount
Eucalyptus obliqua	*Herbarium* (Victor Harbor, Waitpinga)	Glycerine
E. baxteri	*Fresh* (Fleurieu Peninsula)	Silicon
E. ovata	*Herbarium* (Parawa, Fleurieu Peninsula)	Glycerine
E. cosmophylla	*Fresh* (Fleurieu Peninsula) ANU (225-3-153)	Silicon
E. fasciculosa	*Fresh*-Fleurieu Peninsula; ANU (225-3-156, se South Australia)	Silicon
E. leucoxylon sub sp. *leucoxylon*	*Herbarium*- (Fleurieu Peninsula) ANU (225-3-222 se South Australia)	Glycerine (herbarium) Silicon (ANU)
E. viminalis sub sp. *cygnatensis*	*Herbarium* (Fleurieu Peninsula)	Glycerine
E. camaldulensis	ANU 225-3-86c; Victoria	Silicon
Melaleuca squamea	ANU (225-9-28a/b South Australia)	Silicon
M. decussata	Herbarium (Fleurieu Peninsula)	Glycerine
M. lanceolata	ANU (225-9-27a)	Silicon
Leptospermum myrsinoides	ANU 225-12-13b	Silicon
L. lanigerum	ANU 225-12-3	Silicon
L. continentale	ANU 225-6-223	Silicon
Kunzea pomifera	ANU 225-1-4	Silicon
Baeckia ramosissima	ANU 225-11-4a	Silicon
Calytrix tetragona	ANU 225-10-1f	Silicon

Morphological characteristics examined

Typically grains of the Myrtaceae family are isopolar, radially symmetric, tricolporate, triangular in polar view and oblate, Grains may be parasyncolpate, with a distinctive apocolpial field or syncolpate. *Eucalyptus* pollen usually has a distinct vestibulum formed by the splitting of the endexine and ectexine in the region of the pore. A generalised diagram of a Myrtaceae pollen grain is presented Figure 1. The choice of morphological features studied was guided by previous studies of the Myrtaceae pollen morphology (Chalson and Martin, 1995; Pickett and Newsome, 1997). The characteristics examined were 1) *grain shape*; a) grain walls - were they straight, convex, concave in polar view (Figure 2) (b) amb angle - were ambs sharply rounded, rounded, slightly rounded or very rounded (Figure 3), (2) Types of colpi and apocolpial fields - were grains syncolpate or parasyncolpate and if parasyncolpate were apocolpial fields arcuate, angular or intermediate between arcuate and angular (Figure 4) (3) apocolpial edges - may range from smooth, irregular to rough (Figure 5) (4) Polar islands, which is the presence of ectexine over the apocolpial field was noted as being present, not present or in the form of granules 5) floor of vestibulum - was it flat, concave or convex (Figure 6), 6) roof of vestibulum - was it unthickened, slightly thickened, distinctly thickened (Figure 6) and 7) surface patterning - psilate, scabrate, granulate, verrucate, according to the sculpturing types defined by Moore and Webb (1991, p.76). Pollen grain size measurements of apex to base, wall thickness and pore height and wall thickness, were taken (Figure 7).

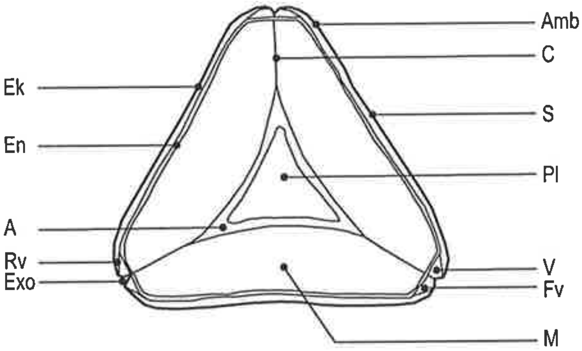


Figure 1 Generalised Myrtaceae pollen grain in polar view. Ek. Ektexine; En, Endexine; A, Apocolpium; Ex, Exopore; Amb, The amb; C, Colpus; S, Sides of the Amb; P I Polar Island; V, Vestibule; M. Mesocolpal region; RV, Roof of vestibule; FV, Floor of Vestibule.

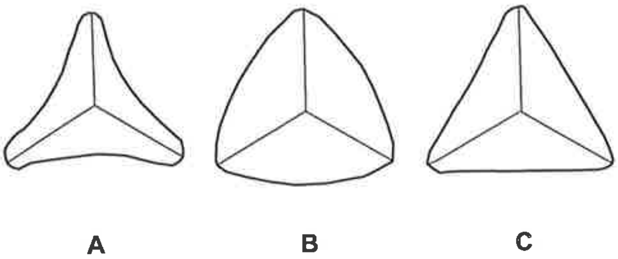


Figure 2 Pollen grain shape; Sides of pollen grains A) concave; B) convex; C) straight. (from Chalson and Martin, 1995).

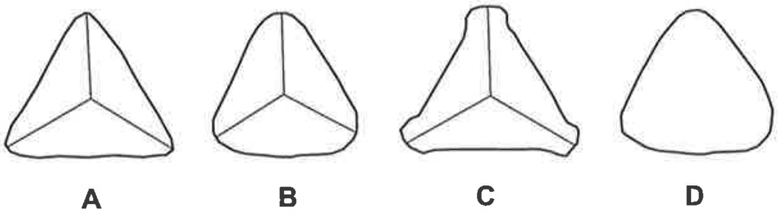


Figure 3 Pollen grain shape; Angle of the amb A) sharply rounded angle, B) rounded angle, C) slightly rounded angle, D) very rounded angle.

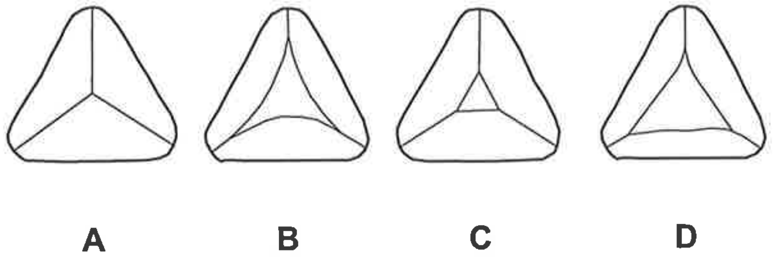


Figure 4 Types of colpi; A) syncolpate, B) parasyncolpate with arcuate colpi, C) parasyncolpate with angular colpi, D) parasyncolpate with angular-arcuate colpi.

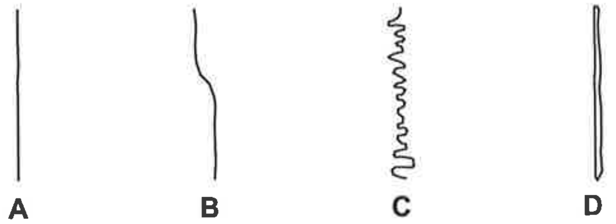


Figure 5 Types of colpal edges; A) smooth, B) irregular, C) rough D) thickened

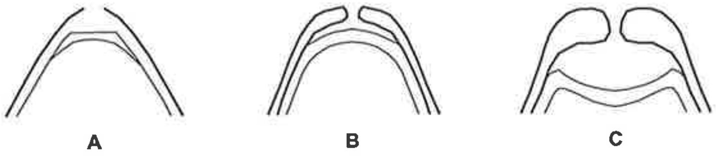


Figure 6 Types of vestibulum roofs and floors A) unthickened roof and straight floor, B) Slightly thickened roof and straight floor, C) distinctly thickened roof and concave floor

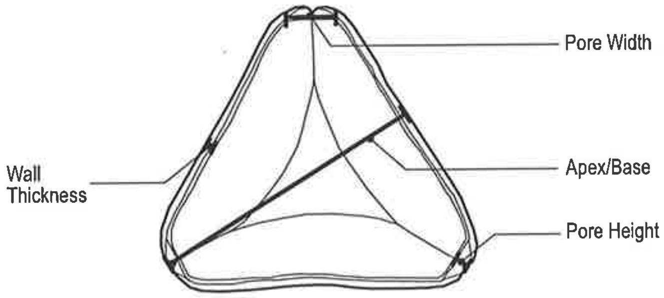


Figure 7 Size measurements made on pollen grains

Results

Characteristics of modern Eucalyptus *pollen*

Photographs of each pollen type are presented on Plate 1. The size and morphological features of *Eucalyptus* pollen types are summarised in Table 2 and Table 3.

Eucalyptus obliqua

E. obliqua grains ranged in size from 24 to 30 µm. The sides of most grains are straight (85%) in polar view although some (15%) were slightly concave. The amb angle is rounded. Grains are parasyncolpate and the apocolpial field maybe arcuate, arcuate/angular or angular. The apocolpial field is generally distinctive and relatively large. Apocolpial edges are generally irregular or rough. Polar islands are present only on 20% of the grains, 45% of grains being without an island and 35% having scattered granules in the apocolpial field. The vestibulum floor may be flat or concave. The roof of the vestibulum is generally distinctly or slightly thickened, only 10% of the grains not showing any thickening. Exine patterning was not evident.

Eucalyptus baxteri

E. baxteri grains ranged in size from 26 to 30 µm. Most, 73.3%, of grains were straight sided with the rest being slightly concave. The amb angle is rounded. The grains are parasyncolpate with distinct angular or angular/arcurate apocolpial fields most of which have either a polar island or granules present. The apocolpial edges are commonly rough but may be smooth and are thickened. The floor of the vestibulum is usually flat, although in 13.3% of the grains was concave and the vestibulum roof is always thickened although grains varied in the degree of thickening. Surface pattern of grains was psilate to scabrate.

Eucalyptus ovata

E. ovata grains range in size from 26 to 32 µm with a mean of 29.5 µm. Grains sides were either straight or convex. The angle of the amb were rounded. Grains are parasyncolpate. The apocolpial field varied in size from small to being large and prominent. The apocolpial field was angular in 60%, angular/arcuate in 45%, and arcuate in 5% of the grains. Polar islands were present on only 30% of the grains, most of the grains being without an island. Granules are sometimes present in the apocolpial field. The floor of the vestibulum was flat in most of the grains considered and convex in 20% of the grains. The roof of the vestibulum was slightly thickened.

Eucalyptus cosmophylla

E. cosmophylla grains ranged in size from 25 to 40 µm with a mean size of 31 µm. Grains sizes varied almost equally between being straight, convex and concave. The amb angles were rounded. The grains were parasyncolpate with arcuate and medium sized apocolpial regions. Polar islands were present on 39% of grains and the other 61% of the grains were without an island. The vestibulum floors were usually flat and vestibulum roofs were slightly thickened. Grain patterning was psilate.

Eucalyptus fasciculosa

E. fasciculosa grains ranged in size from 19 to 25 µm with a mean size of 19.4 µm. Most grains were straight sided (81%), and if not straight they tend to convex. The angle of the amb is rounded to very rounded. Grains are parasyncolpate and most have small to medium sized arcuate apocolpial regions, however some grains have arcuate/angular or angular colpi. Apocolpial edges may be smooth, irregular or rough. Polar islands are present on 27.5% of the grains, 45.5% are without any island and 27.25% have a granulated apocolpial field. The floor of the vestibulum was either flat or concave. The roof of the vestibulum was predominantly without thickening, although slight thickening was seen in 19.2% of grains. Surface pattern of grains was scabrate.

Eucalyptus leucoxylon subsp. leucoxylon

E. leucoxylon grains ranged in size from 25 to 28 µm with a mean size of 26 µm. Half of the grains were straight sided, 38.8% had convex sides and a small number had concave sides. Half of the grains were found to have very rounded amb angles and the ambs of the other half were rounded. Grains are parasyncolpate with small arcuate apocolpial fields. Apocolpial edges on 70% of grains were smooth with the remainder being rough edged. Polar islands were not present on any of the grains. The floor of the vestibulum maybe concave or flat. The roof of the vestibulum were unthickened. Surface patterning of grains was psilate.

Eucalyptus viminalis subsp. cygantensis

E. viminalis grains ranged in size from 20 to 30 µm with a mean size of 27.4 µm. The majority of grains were straight sided but convex sided grains were also observed. The angle of the amb was in most cases rounded but tended to sharply rounded in 20% of the grains observed. The grains were parasycolpate with an obvious apocolpial region that was usually large and most commonly angular however arcuate/angular and arcuate fields were found on some grains. Apocolpial edges were irregular on 60% of the grains and rough on 40%. Eighty percent of grains had distinct polar islands and 20% granules in apocolpial field. The floor of the vestibulum was usually straight, although was convex in 30% of the grains. Thickening of the roof of the vestibulum was slight in 30% of grains, distinct in 20% of grains and absent in the 50% of grains. Surface patterning on the grains was finely reticulate.

Eucalyptus camaldulensis

E. camaldulensis grains ranged in size from 18 to 20.5 µm with a mean size of 19.1 µm. Grain sides were either straight or convex. The angle of the amb was mostly rounded although 10 % of grains had sharply rounded amb angles. The grains were parasyncolpate with commonly medium sized angular apocolpial fields. Colpi edges were rough or irregular and slightly thickened. A small percentage of grains had angular to arcurate apocolpial fields. Polar islands were present on 10% of grains, granules found on 30% of grains and the rest of grains were with out a polar island. Apocolpial edges were either rough or irregular. The floor of the vestibulum was generally flat although tended to convex on 10% of the grains. The roof of the vestibulum was generally distinctly thickened. The surface patterning on grains was verrucate.

Table 2 *Eucalyptus* pollen grain size variation. Measurements are in µm.

Species	Grain size		Pore Height		Pore width	
	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
E. camaldulensis	18 - 20.5	19.08 ± 86	2.6 - 3.6	3.31 ± 0.27	6 - 6.6	6.17 ± 0.2
E. fasiculosa	19 – 25	22.2 ±1.43	1.9 - 3.2	2.6 ± 0.29	8.4-10.5	8.96 ± 0.67
Eucalyptus leucoxylon	25-28	26 ± 0.8	2.22 -2.4	2.24 ± 0.06	4 – 8	7 ± 1.2
E. odor ata	22.5 - 29.5	26.4 ±1.12	1.9 - 3.5	2.4 ± 0.41	7 - 9.8	8.82 ± 0.84
E. viminalis	20-30	27.4 ±3.12	3.5-6	4.3 ± 0.68	7 – 8	7.8 ± 0.32
E. baxteri	26 - 30	28 ± 0.84	2.8 - 5.6	3.63 ± 0.62		
E. obliqua	24 – 30	28 ± 1.20	2 - 6	3.65 ± 0.85	6 – 8	7.1 ± 0.9
E. ovata	26-32	29.5 ± 1.6	3-5	4.07 ± 0.34	7-10.5	8.35 ± 0.69
E. cosmophylla	25.2 - 40	31 ± 3.47	2.8 - 4.2	3.37 ± 0.52	8 – 14	10.9 ± 1.68

Table 3 Pollen morphology of the *Eucalyptus* species examined. (Percentage values have been rounded to nearest whole number- for sample numbers and values) St = Straight, Cv=concave, Cx=convex; Arc= clearly arcuate, Arc-Ang=between arcuate and angular, angular = distinctly angular.

Species	Grain walls	Amb angle	Apocolpial field shape	Apocolpial field size	Apocolpial edges	Thickening of colpi edges	Polar islands	Vestibulum floor	Vestibulum roof	Surface pattern
E. obliqua	St 85% St-Cv 15%	Rounded	Arc-Ang 40% Arc 50% ang 10%	large	irreg or rough	no	absent. 45% present 20% granules 35%	flat 50 % concave 50%	dist 50% sl 40% un 10%	none
E. baxteri	St 73% sl Cx 27%	Rounded	Ang 73 % Arc-ang 27%	Mostly medium	Rough 86 % smooth 14%	yes	granules 53% present 33% absent 14%	flat 86% concave 14%	sl 71% dist 21 % un 8%	psilate 80% scabrate 20%
E. ovata	st 50% cx 50%	Rounded	ang 60% arc-ang 45% arc 5 %	all sizes	irreg 70% rough 30%	no	absent 60 % present 30 % granules 10%	flat 80% convex 20%	sl 100%	psilate 90% scabrate 10%
E. cosmophylla	st 38 % cv 31 % cx 31 %	Rounded	arcuate	Mostly small	rough 54.8% smo 45.2%	no	absent 61% granules 39%	flat 85% cv 7.5% cx 7.5%	sl 100%	scabrate 90% psilate 10%
E. fasciculosa	st 81 % cx 19 %	vr 63.6% rounded 36.4%	arc 63.9% ang 27.3% arc-ang 9.1%	Small and medium	rough 54.4% smooth 36.4% irr 9.1%	no	abs 45.5 % pres 27.25 % granules 27.25%	flat 54.4% cv 45.5%	un 81.1% sl 19.2%	scabrate
E. leucoxylon	st 50 % cx 38 % cv 13 %	rounded 50% vr 50%	arcuate	Mostly small	smo 70% rough 30%	no	absent	cv 56.6% str 44.4%	un 100%	psilate
E. viminalis	st 75% sx 25%	rounded 80% sh r. 20%	ang 70% arc-ang 20% arc 10%	Mostly large	irreg 60% rough 40%	no	present 80% absent 20%	cv 70% cx 30%	un 50% sl 30% dist 20%	reticulate
E. camaldulensis	cx 60% st 40%	rounded 90% sh r. 10%	ang 90% arc-ang 10%	Mostly medium and small	rough 60% irreg 40%	slight	absent 60% granules 30% present 10%	cv 90% cx 10%	dist 90% sl 10%	verrucate

Characteristics of modern Melaeuca *and* Leptospermum *pollen*

Photographs of each pollen type are presented on Plate 1. The size of both *Melaleuca* and *Leptospermum* pollen types are summarised in Table 4, the morphological features of *Melaleuca* pollen types are summarised in Table 5 and the morphological features of *Leptospermum* pollen types are summarised in Table 6.

Melaleuca squamea

Grain size ranged from 21.6 to 30 µm with a mean size of 22.67 µm. Grain walls are straight with angular to slightly rounded ambs. Colpi edges were smooth or irregular and distinctly thickened. Colpi were parasyncolpate with small and angular apocolpial regions which may or may not enclose a polar island. The amb has a distinct vestibule with a flat floor and thickened floor and slightly thickened roof. The exine has a distinctive faveolate/reticulate pattern.

Melaleuca decussata

Grains ranged in size from 20-26 µm with a mean size of 22.67 µm. Grain walls were either convex or straight and ambs were slightly rounded. Colpi were mostly syncolpate, although some grains have small apocolpial regions, thus the grains could be described as parasyncolpate. Colpi edges were smooth and thickened. The pore is vestibulate, the vestibulum is distinctive with flat floor and unthickened roof. The exine was characterised by a faint faveolate patterning.

Melaleuca lanceolata

Grains ranged in size from 12-14 µm with a mean size of 12.2 µm Grains had concave sides and slightly rounded ambs. Grains were parasycolpate with angular and very small apocolpial fields which contained a polar island. Apocolpial edges were smooth and slightly thickened. Pores were notch-like exopores. The pores were without a vestibulum and there was no obvious thickening of the ektexine at the pore region. The exine was characterised by a faint faveolate patterning.

Leptospermum myrsinoides

The grains ranged in size from 14.4 to 15.6 µm with a mean of 14.88 µm. Grains had straight walls and sharply rounded ambs. Colpi are smooth and syncolpate. Gaps in the colpi were not apparent. The exene had a reticulate/granulate pattern. The pore is non-vestibulate, is very small, and there is no thickening of the ektexine at the pore opening.

Leptospermum lanigerum

The grains ranged in size from 13.2 to 15.6 µm with a mean size of 14.5 µm. The walls of most grains were concave (85%) with the remaining 15% being straight. The ambs were slightly rounded and colpi syncolpate with smooth apocolpial edges. The amb has no distinct vestibule and pore is a notch like exopore. The exine is reticulate.

Leptospermum continentale

The grains ranged in size from 14.4 to 16.8 µm with a mean size of 15.8 µm. Grains had straight/concave sides and sharply rounded ambs. Colpi were sycolpate with smooth apocolpial edges. The amb had a narrow vestibulum with a concave floor and unthickened roof. The exine pattern was scabrate.

Table 4 *Melaleuca* and *Leptospermum* pollen grain size variation. Measurements are in µm.

	Grain size		Pore height		Pore width		Exine width	
Species	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
M. decussata	20-26	22.67 ± 2.0	2.4-3.0	2.73±0.22	4.0-6.0	5.17 ±0.56	1-1.2	1.07±0.17
M. squamea	21.6-30	25.8 ± 2.55	2.16-4.8	3.27 ± 0.69	7.2-8.4	7.8 ± 0.6	0.96-1.8	1.3 ± 0.2
M. lanceolata	12-13	12.2 ± 2.0	1.4 - 1.6	1.55± 0.15	4.0-4.5	4.4± 0.4	0.8-1.0	0.96±0.04
L. continentale	14.4 – 16.8	15.8 ± 1	1.2 -1.8	1.34 ± 0.19	4.2-4.8	4.5±0.3	0.96-1.2	1.12±0.11
L. lanigerum	13.2-15.6	14.5± 0.53	1.2 -1.8	1.42 ± 0.15	3.6-4.8	4.2± 0.4	0.96-1.44	1.24 ±0.13
L.myrsinoides	14.4 – 15.6	14.88± 0.58	0.96-1.2	1.08± 0.1	3.6-4.2	3.84 ±0.29	0.84-0.96	0.94±0.04

Other local Myrtaceae

Descriptions and size measurements of *Kunzea pomifera, Baeckia ramosissima* and *Calytrix tetragona* were primarily made in order to assess whether or not they were distinct from the dominant *Eucalyptus, Melaleuca* and *Leptospermum* types examined. The size ranges and morphological features of genera are summarised in Table 7.

Kunzea pomifera

Grains ranged in size from 18-20.5 µm with a mean size of 26.8 µm. Grains had convex sides, were triangular in polar view with sharply rounded ambs. Colpi were sycolpate, and mesocplpial regions were well defined with thickened colpial walls. Pores were notched and vestibulate; the floor of the vestibulum was concave and the roof slightly thickened. The grain's exine was not patterned.

Baeckia ramosissima

Grains ranged in size from 16.8-18 µm with a mean size of 0.96 µm. Grains walls were straight or slightly convex, and ambs were rounded to flat with a notch like exopore. Grains are syncolpate with smooth apocolpial edges. Pores were notch - like and non - vestibulate without exine thickening. Grains were patterned with a coarse reticulum.

Calytrix tetragona

Grains ranged in size from 20.4 to 21.6 µm with a mean size of 21.3 µm. Grain sides are concave and amb angle is broad, rounded to flat. Grains are syncolpate with smooth to rough apocolpial edges. Pores are non vestibulate without exine thickening. Grains show fine reticulate patterning.

Eucalyptus *pollen types*

Eucalyptus fasciculosa type

This class includes pollen from both *E. fasciculosa* and *E. leucoxylon*. Both species can be differentiated from other taxa on the basis of a very rounded to rounded amb angles, small to medium sized arcuate apocolpial fields, unthickened pore roofs and grain size (19-28 µm). The two differ in some characters, however these were not consistent and it was doubtful whether they could have been reliably resolved in fossil material. *Eucalyptus leucoxylon* tends to be larger than *E. fasciculosa* and it never has a polar island, whereas *E. fasciculosa* grains may have complete polar islands or granules in the apocolpial field area. *Eucalyptus fasciculosa* grains showed scabrate patterning where as *E. leucoxylon* grains were unpatterned. *Eucalyptu. cosmophylla* grains also have arcuate shaped apocolpial windows but can be distinguished by their thicker vestibulum roof.

Eucalyptus baxteri type

This class includes pollen from *E. baxteri* and *E. ovata* and can be distinguished from other species by their rounded amb angles, angular or angular to arcuate apocolpial fields, slightly to distinctly thickened vestibulum roofs and scabrate patterning and size range from 26-32 µm. The presence and absence of polar islands varied at the same frequency between species. Differences between the nature of the apocolpial edges between species, *E. baxteri* grains commonly showed thickening of colpial edges, and the coarseness of the scabrate patterning was recorded between species but these differences were not considered to allow confident division of the grains into different types.

Eucalyptus viminalis type

This type can be distinguished from other species on the basis of having by having straight sided grains with rounded to sharply rounded amb angles, 20-30 µm in size, large and angular apocolpial windows which mostly hold close fitting polar islands, unthickened or slightly thickened vestibulum roof and scabrate patterning.

Eucalyptus camaldulensis type

This type can be distinguished from other species on the basis of grains having distinctly thickened vestibulum roofs, small size (18-20.5 µm), rounded to sharply rounded amb angles, concave vestibulum floor and an angular apocolpial field-shape.

Eucalyptus cosmophylla type

E. cosmophylla type can be distinguished from other types by its rounded amb angle, arcuate shaped apocolpial field, slightly thickened vestibulum roof and its size (25- 40 µm). The potential overlap with *E. fasciculosa* type has been discussed.

Eucalyptus obliqua type

Eucalyptus obliqua can be distinguished from other types by its arcuate-angular/arcuate apocolpial field, the majority of its grains having distinctly thickened or slightly thickened vestibulum roof and its size (24-30 µm). There is overlap with characters of *E. baxteri* type but *E. obliqua* generally has a larger apocolpial field, which is more often arcuate/arcuate-angular, where the field of *E. baxteri* types is smaller and more often angular.

*Non-*Eucalyptus *Myrtaceae pollen types*

Leptospermum myrsinoides type

Leptospermum myrsinoides type can be distinguished from other *Leptospermum* species on the basis of grains the having straight sides, sharply rounded amb angle and reticulate exine patterning.

Leptospermum lanigerum type

Leptospermum lanigerum type is distinguished by its concave grain sides, slightly rounded amb angle, reticulate exine patterning and distinctive notch like exopore. *Leptospermum continentale* also has concave grain sides however it can be distinguished on the basis of grain patterning, the exine of *L. lanigerum* showing a scabrate patterning.

Leptospermum continentale type

Leptospermum. continentale type is distinguished by its predominantly concave grain wall sides, slightly rounded amb angles and scabrate exine patterning. *Melaleuca lanceolata* type also show these features but the types can be differentiated by their colpi. *Melaleuca lanceolata* grains are parasycolpate displaying small apocolpal windows containing small polar islands whereas the colpi of *L. continentale* grains were syncolpate.

Melaleuca decussata type

This type includes *M. decussata* and *M. squamea*. The type is characterised by their thickened colpal edges and vestibulate pores which show no roof (ektexine) thickening. The grains may, however, show some thickening on the vestibulum floor. Grain sides are convex or straight. Colpi are parasyncolpate with small and angular apocolpial regions. They may be distinguished from *M. lanceolata* by their vestibulate pores and reticulate patterning, the pores of *M. lanceolata* grains being non vestibulate and the exine displaying a feint scabrate patterning. They are distinguished from all *Eucalyptus* types described by their thickened colpal edges and distinctly small apocolpial areas.

Melaleuca lanceolata type

Melaleuca lanceolata type is characterised by its concave grain wall sides, slightly rounded amb angles, parasyncolpate colpi displaying a very small apocolpial area, slightly thickened ektexine near the pore opening and scabrate patterning. Its possible overlap with *L. continentale* is discussed above.

Kunzea pomifera type

Kunzea pomifera type grains may be distinguished from other Myrtaceae types by their concave grain sides, unpatterned exine surface, sharply rounded amb angles and thickened apocolpial edges. Their apex to base grain size measurement is significantly larger than *Leptospermum* types however its size range overlaps with that of the *Melaleuca* size range. The type can be distinguished from potential overlap with *M. lanceolata* type by the distinctly thickened colpal walls, which are absent in *M. lanceolata*, concave endexine in the pores region and more acutely angular ambs.

Baeckia ramosissima type

Baeckia ramosissima type is characterised by its coarse reticulate exine patterning, straight to convex grain sides, rounded amb angle, syncolpate colpi and non vestibulate pore. This type is most similar to *L. myrsinoides* type however its grain size is significantly larger, the surface reticulum is more course and the amb angle more rounded and broader than *L. myrsinoides*.

Calytrix tetragona type

Calytrix tetragona type is distinguished by its rounded to flat amb angle, distinctly concave sides, non vestibulate pore, syncolpate colpi and fine reticulate patterning. It is most morphologically similar to *L. continentale* yet it can be differentiated by size as its grain apex to base measurements are significantly larger (*C. tetragona* mean apex to base size being 21.36 µm, *L. continentale* 15.8 µm.).

Table 5. Pollen morphology of the *Melaleuca* species examined. (Percentage values have been rounded to nearest whole number- for sample numbers and values). St = Straight, Cv=concave, Sl = slightly, Cx=convex; Ang = distinctly angular.

Species	Grain walls	Amb angle	Para/syncolpate	Apocolpial field shape	Apocolpial field size	Polar island	Pore type	Apocolpal edges	Thickening of Apocolpial edges	Vestibulum floor	Vestibulum roof	Surface patterning
M. decussata	St (50%) Cx 50%	sl. rounded	parasyncolpate	Ang	small	no	vestibulate	smooth	thickened	flat	unthickened	reticulate/ faveolate
M. squamea;	St	angular to sl. rounded	parasyncolpate	Ang	small	yes	vestibulate	smooth-irregular	thickened	flat and thickened	unthickened	faveolate/ reticulate
M. lanceolata	Cv	sl. rounded	parasyncolpate	Ang	very small	yes	non - vestibulate	smooth - sl. thickened	thickened	flat	thickened	scabrate

Table 6 Pollen morphology of the *Leptospermum* species examined. (Percentage values have been rounded to nearest whole number- for sample numbers and values) St = Straight, Cv=concave.

Species	Grain walls	Amb angle	Para/syncolpate	Pore type	Apocolpal edges	Ektexine at pore	Surface patterning
L. continentale	80% St-Cv, 20% st	sl rounded	syncolpate	notch (exopore)	smooth	unthickened	scabrate
L. lanigerum	85% Cv, 15% St	sl rounded	syncolpate	notch (exopore)	smooth	unthickened	reticulate
L. myrsinoides	St	sharply rounded	syncolpate	notch (exopore)	smooth	unthickened	reticulate

Table 7 Comparison of size and morphological features of pollen of the Myrtaceae genera within the Fleurieu Peninsula.

Genera	Size (um)			Grain shape		Colpi		Colpi			Pore type			Surface patterning
	A-B	Pore height	Pore width	Grain walls	Amb angle	Para/syncolpate	AF shape	AF size	Ap. edges	Polar island	Exo or endo pore	Vest. floor	Vest. Roof	
Eucalyptus	18.0 – 40.0 mean 26.8 sd 4.01	1.9 – 6.0	4.0 –14.0	Straight Concave Convex	Very rounded Rounded Sharply rounded	Parasyncolpate	Arcuate Arcuate-angular Angular	Small Medium Large	Irregular Rough Smooth	Present Absent Granular	Vestibuate pores	Flat Concave Convex	Unthickened Sl. Thickened Dist. Thickened	Psilate Scabrate Verrucate Reticulate
Melaleuca	16.8 – 30.0 mean 21.82 sd 4.16	1.92 – 4.8	4.0 – 8.4	Straight Concave	Sharply rounded Slightly rounded Rounded	Parasyncolpate Syncolpate	Angular	Very small Medium Large	Smooth Irregular Thickened	Present Granular	Exopore	Flat	Unthickened Sl. Thickened	Scabrate Faveolate
Leptospermum	13.2 – 16.0 mean 15.07 sd 0.86	0.96 – 1.8	3.6 – 4.8	Straight Concave	Sharply rounded Slightly rounded	Syncolpate	-	-	Smooth	-	Exopore	Flat Concave	Unthickened	Scabrate Verrucate Reticulate
Kunzea	18 - 20.5 mean 19.1 sd 0.89	2.4 - 3 mean 2.62 sd 0.35	4.8 - 6.0 mean 5.3 sd 0.5	Concave	Sharply rounded	Syncolpate	-	-	Smooth-thickened	-	Exopore- vestib.	Concave	Unthickened	No pattern
Baeckia	16.8- 18 mean 17.2 sd 0.69	0.96 mean 0.96 sd 0.0	3.0 - 3.6 mean 3.2 sd 0.5	Straight/convex	Rounded	Syncolpate	-	-	Smooth	-	Exopore- non vestib.	Flat	Unthickened	Coarse reticulate
Calytrix	20.4 - 21.6 mean 21.3 sd 21.36	1.7 - 2.2 mean 1.85 sd 0.2	9.6 - 10.8 mean 10.1 sd 0.66	Concave	Rounded to flat	Syncolpate	-	-	Smooth/rough	-	Exopore- non vestb.	Concave	Unthickened	Fine reticulate

Discussion

Pollen from the species in the Myrtaceae family is superficially very similar. In many cases gross morphological features cannot distinguish it. Fine-detail morphological features showed variation between the Myrtaceous species considered in this investigation. A combination of both fine detail characters in conjunction with gross morphological features enabled the separation of the different myrtaceous genera in the Fleurieu Peninsula and the distinction of most of the pollen of *Eucalyptus*, *Melaleuca* and *Leptospermum,* investigated in this study, to species level. Where character states overlapped species were grouped into a type; no type contained more than two species.

Many of the fine-detail characters examined showed intra-specific variation. Whether or not this variation was due to variation *between individuals* or from the *same individual* could not be discerned as most of the modern preparations were composed of pollen from more than one individual.

Intra-specific variation could also be present at a population level, rendering some of the results of this study specific to genetic material studied. Individuals from different populations may have slightly different pollen morphologies. While in cases the material used in this study was from different areas, and hence possibly populations, in a region or from different regions results may not represent the full variation within all species. That this could be the case in some types is suggested by comparison of Dodson's (1974) description *Melaleuca squamea* pollen collected in the Victoria as non-vestibulate, where that sourced from plants from the Fleurieu Peninsula was clearly vestibulate.

The methods described here were time consuming but as the most of the vegetation communities of the Fleurieu Peninsula are dominated by these species, their identification greatly enhances the resolution at which vegetation pattern can be identified in the region using pollen spectra. As such the potential for fossil pollen spectra to be used in the investigation of Holocene environments in the Fleurieu Peninsula is also enhanced.

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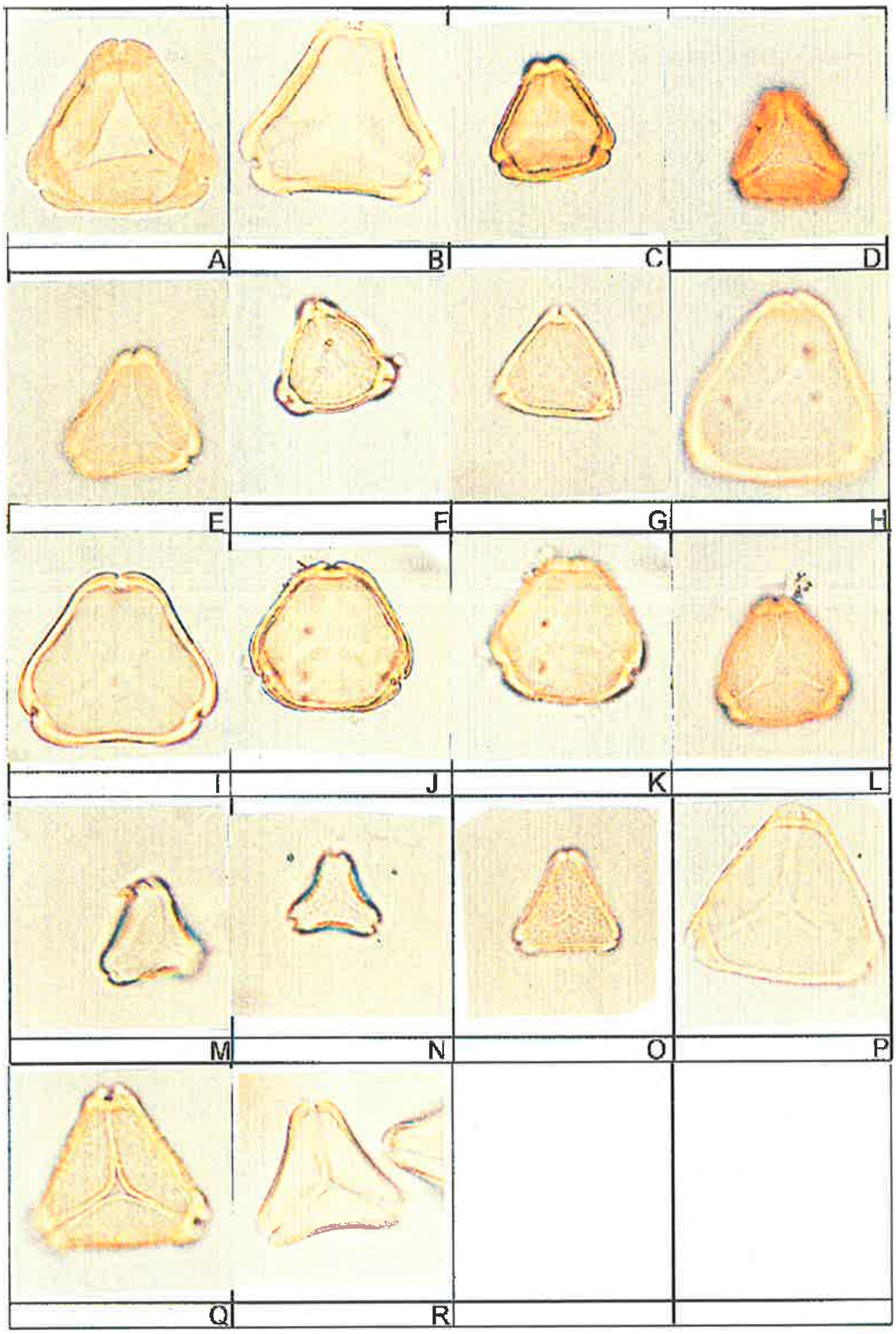
Plate 1.

Key:

A. *Eucalyptus obliqua* (x 1000, Adelaide Herbarium, Glycerine)
B. *Eucalyptus obliqua* (x 1000, Adelaide Herbarium, Glycerine)
C. *Eucalyptus baxteri* (x 1000, SB, Silicon)
D. *Eucalyptus baxteri* (x 1000, SB, Silicon)
E. *Eucalyptus ovata* (x 1000, Adelaide Herbarium, Glycerine)
F. *Eucalyptus camaldulensis* (x 1000, ANU, Silicon)
G. *Eucalyptus viminalis* sub. sp. *cygnatensis* (x 1000, Adelaide Herbarium, Glycerine)
H. *Eucalyptus viminalis* sub. sp. *cygnatensis* (x 1000, Adelaide Herbarium, Glycerine)
I. *Eucalyptus leucoxylon* sub. sp. *leucoxylon* (x 1000, Adelaide Herbarium, Glycerine)
J. *Eucalyptus fasciculosa* (x 1000, SB, Silicon)
K. *Eucalyptus fasciculosa* (x 1000, SB, Silicon)
L. *Eucalyptus cosmophylla* (x 1000, SB, Silicon)
M. *Leptospermum continentale* (x 1000, ANU, Silicon)
N. *Leptospermum lannigerum* (x 1000, ANU, Silicon)
O. *Leptospermum myrsinoides* (x 1000, ANU, Silicon)
P. *Melaleuca decussata* (x 1000, Adelaide Herbarium, Glycerine)
Q. *Melaleuca squamea* (x 1000, ANU, Silicon)
R. *Melaleuca lanceolata* (x 1000, ANU, Silicon)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APPENDIX 5

FOSSIL POLLEN PROCESSING- volumetric preparation technique

Pollen analytical methods follow the standard acetolysis methods described by Faegri and Iverson (1989) and adapted by The Division of Archaeology and Natural History, Australian National University.

Place 2-2.5 ml of sediment sample into a 250ml plastic beaker.
Add exotic marker pollen tablet if required.
Add 10ml of 10% HCl to dissolve marker pollen tablet and to remove any calcium carbonates present.
Once reaction stops fill beaker with distilled water and leave to settle for at least six hours, then decant.
Add 50ml of HF and leave for at least 20 hours, decant.
Place sample in to a 50 ml centrifuge tube. Wash with distilled water, centrifuge 3500 RPM, decant.
Add 20-40 ml of 10% KOH to samples and place in boiling water bath for 10 minutes.
Repeat wash in distilled water.
Course sieve through terylene (mesh size approximately 180 microns).
Add 20 mls glacial acetic acid, centrifuge, decant.
Add 20 ml freshly made acetolysis solution (1:9 conc sulphuric acid: acetic anhydride). Place in 80° C hot water bath for 3-5 minutes. Top up with glacial acetic acid, centrifuge and decant.
Wash sample with 10-20 mls of glacial acetic acid . Centrifuge and decant.
Wash samples in distilled water, centrifuge and decant.
Sieve sample through 10 micron sieving material. Collect top fraction and add a small amount of absolute ethanol to preserve sample.
Slides were mounted in both silicon oil and glycerol (glycerine) jelly. Glycerine jelly provides a fixed mount with long lasting properties.

MOSS POLSTER POLLEN PREPARATION
As above except material was soaked over night in 5 %Calgene solution and HF step was omitted?

POLLEN TYPE SLIDES
Preparation of pollen type slides from herbarium and fresh specimens followed essentially the same procedure as carried with fossil material except the HF treatment was omitted as no siliceous material was present.

Appendix 6

DESCRIPTION OF FOSSIL POLLEN TYPES

Fossil type: Hydrocotyl FAMILY: APIACEAE
Description: Tricolporate grains 16 x 20μm. Exine fine reticulate pattern. Long narrow colpi, widening at mid latitudes of the grain. Pore circular; grain is prolate with bulge at the equatorial region. Exine is 3.5 μm hick with nexine equal in thickness to sexine.
Comments: There are three Hydrocotyl species in the regions *H. callicarpa, H. foveolata* and *H. verticillata* and all aquatic species found in swamps in the region.
Ecological grouping: Aquatic herb

Fossil type: Apiaceae other FAMILY: APIACEAE
Description: Tricolporate, sub prolate grains 24 x 30 μm. Colpi are wider at both ends pores are eliptical and wider than the colpi. Fine surface patterning on the exine.
Comments: *Centella cordifolia* is common in swamps in the region recorded in 37 swamps in the region. This type could also represent *Platysace heterophylla.*
Ecological grouping: Aquatic; *Centella*- Herb, *Platyscace* herb or shrub

Fossil type: *Stellaria* FAMILY: CARYOPHYLLACEAE
Description: Periporate (~16 pores), spheroidal, 40μm diametre. Pores large and annulate, 4-5μm in diametre. Exine is 5 μm thick and punctitegillate, baculate.
Comments: *S. palutris* (chickweed) and *S. media* (swamp starwort) are in region.
Ecological grouping: Aquatic herbs; introduced.

Fossil type: *Allocasuarina* < 28μm FAMILY: CASUARINACEAE
Description: Grain size 28-40 μm, pore size 6μm. Mainly triporate, but some 4-porate and 5-porate. Grains are oblate to apiculate in lateral view and wounded to semi angular in polar view. Each pore is on a raised protrusion with a circular base and flattened folding top. Exine is 2-3 μm in thickness and the surface psilate to scabrate.
Comments: There are 5 species native to the study area; *A. verticillata, A. striata (t or s), A.pusilla, A.meulleriana (s)* and *A. paludosa.* Confident identification of species of Casuarina pollen is not considered to be realisable by most analysts (Boyd, 1992). However Kershaw (1981) comments that although confident identification of species may not be possible, systematic changes in grain sizes through time probably reflect species compositional changes and so grain size ought to be recorded. The grain size classes denoted by Dodson (1975) were employed here; Dodson records that generally *A. verticillata* grains are > 28μm and *A. striata, A. meulleriana* and *A. paludosa* pollen falls into the less than 28μm category.
Ecological grouping: Tree or shrubs

Fossil type: *Allocasuarina* > 28μm FAMILY: CASUARINACEAE
Description: Grain size 20-28 μm, pore size 4μm. Mainly triporate. Morphological description as with *Allocasuarina* < 28μm.
Ecological grouping: Tree

Fossil type: Asteraceae T1 FAMILY: ASTERACEAE - Group Tubuliflorae
Description: Tricolporate or tricolpate echinate, spheroidal 16-20 μm ; Spines are numerous with up to 26 per face ,small, short ,conical, broad based and are uniformly spaced; medium thickness exine 1-2μm showing granular patterning.
Comments: Possibly belonging to sub-tribe Asteraceae which is represented by species from the following genera in the Fleurieu Peninsula; *Brachycome, Logenifera, Minuria,* and *Olearia.*
Ecological grouping: Herbs and shrubs

Fossil type: Asteraceae T2 FAMILY: ASTERACEAE - Group Tubuliflorae
Description: Tricolporate or tricolpate echinate grains with broad copli and circular pores and diametre of 20 to 30 μm ; spheroidal to slightly prolate echinate with spines being broad and short and 10-15 per face. spheroidal 22-26 u; very thick exine (5-6μm) which is granular.
Comments: Possibly belonging to sub-tribe Anthemideae, which has members from *Cotula* and *Centipeda* genera in the Fleurieu Peninsula (fits Boyd, 1981) description of the subtribe p90)
Ecological grouping: Herbs.

Fossil type: Asteraceae T3 FAMILY: ASTERACEAE - Group Tubuliflorae
Description: Tricolporate, echinate and spheroidal 20-26 μm in diametre; spines are short (2μm) broad based but finely pointed at their ends and number approximately 15 per face; exine medium thickness of 2-4 μm and with a granular pattern.
Comments: Possibly sub-family Inuleae which includes species in the genuses; *Calocephalus, Cassinia, Gnaphalium, Helichrysum, Ixiolaena, Ixodia, Millotia, Podolepsis, Podotheca, Pogonolepis* and *Rutidosis.*
Ecological grouping: Herbs and small shrubs.

Fossil type: Asteraceae T4 FAMILY: ASTERACEAE - Group Tubuliflorae
Description: Triporate, echinate with spines being relatively long (4 to 6 μm in length) and with sharply pointed ends and there being approximately 15 per face. Pores can be difficult to see. Grains are spheroid and 15 to 20 μm in diametre. Exine thickness varies from being relatively thin to relatively thick and a feint reticulate patterning is visible between spines.
Comments: Genera undetermined.
Ecological grouping: Herbs/shrub

Fossil type: Asteraceae T5 FAMILY: ASTERACEAE - Group Tubuliflorae
Description: Tricolpate prolate and echinate grains measuring 30μm x 26 μm. Echina are short (2 μm), pointed with wide bases and numerous, with about 60 per face. Exine is relatively thin (1.5 μm) and granularly patterned.
Comments: Separate on size and grain shape from Asteraceae T1. These grains are larger and prolate.
Ecological grouping: Herbs/shrub

Fossil type: Cirsium sp. FAMILY: ASTERACEAE – Group Tubuliflorae

DESCRIPTION: Tricolporate, spheroidal and echinate grain, 50 μm in diameter. Relative to grain size echina are short and collumella are longer under each echina and arranged slantingly (vis x1000), so a radiating pattern is seen. Exine is relatively thick and granular.
COMMENTS: Possibly *Cirsium vulgare. C. vulgare was* recorded as a weed in 1860s in region (Kloot, 1983).
ECOLOGICAL GROUPING: Herb - exotic.

FOSSIL TYPE: Ast.-Liguliflorae FAMILY: ASTERACEAE- Group Liguliflorae
DESCRIPTION: Grains are fenestrate, tricolpate, echinolophate, with 12 to 20 lacunae; the ridges are hight and vertically striate. Echinae are arranged in ridges and are sharply pointed and conical. Grains are 30 -35 μm in diametre.
COMMENTS: There are three native species in the region which produce Liguliflorae type pollen; *Microseris lanceolata* (yam daisy) *Sonchus hydrophyllus* and *Picris squarrosa*. Numerous weedy introduced Asteraceae also produce Liguliflorae type pollen including *Hypochoeris* sp (very widely distributed weedy herbs -catsears- recorded in regions 1855 Kloot, 1983), *Sonchus* sp (sow thistles)., *Taraxacum officienale*, *Cichorium intybus* (1855 recording), *Picris echiodes* (1855 recording). Native and introduced types were unable to be distinguished.
ECOLOGICAL GROUPING: Herbs - native and exotic

FOSSIL TYPE: *Artemesia vulgare* FAMILY: ASTERACEAE
DESCRIPTION: Tricolporate, scabrate. Distinctive collumella varying in thickness very coarse collumella occupy the centre of the mesocolpia and shorter collumella near the colpus margins.
ECOLOGICAL GROUPING: Herb- exotic.

FOSSIL TYPE: *Calystegia sepium* FAMILY: CONVOLVULACEAE
DESCRIPTION: Spheroidal and polyporate large grains measuring 80μm in diametre Exine punctitegillate, gemmate, exine 9 μm and pores measure 12μm with poorly defined and irregular edges.
ECOLOGICAL GROUPING: Aquatic; Greater bindweed- perennial vine.

FOSSIL TYPE: *Dichondra repens* FAMILY: CONVOLVULACEAE
DESCRIPTION: Tricolpate with long and ragged edged colpi. Distinct clavae 2 μm in length. Grain measures 26 x 28 μm and is spheroid prolate in shape.
ECOLOGICAL GROUPING: Aquatic herb

FOSSIL TYPE: Chenopod < 20μm FAMILY: CHENOPODIACEAE
DESCRIPTION: Polyforate, spheroidal and grains 20 μm or less in diameter. The number apertures varied, ~ 40 was common.
COMMENTS: Recognised as a stenopalynous family so did not attempt to class beyond size groupings
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: Chenopod > 20μm FAMILY: CHENOPODIACEAE
DESCRIPTION: Polyforate, spheroidal and grains > 20 μm or less in diametre but no larger than 30 μm. The no. apertures varied ~ 40 was common.
COMMENTS: Recognised as a stenopalynous family so did not attempt to class beyond size groupings The following generaare found in the region, most having species with coastal distributions except the widespread ruby saltbush *Enchylaena tomentosa; Atriplex spp., Chenopodium spp., Einadia spp,, Halosarcia spp., Marienana spp., Rhagodia spp., Sarcocornia spp.*
ECOLOGICAL GROUPING: Shrubs

FOSSIL TYPE: Cruciferae FAMILY: CRUCIFERAE
DESCRIPTION: Tricolpate elliptic grains, with thin copli that do not extend to poles. Two pollen types placed in this group one with exine 1.2 μm thick grains 26 μm diametre and distinct reticulate with columellae distinct in surface view, the other having the same morphological features but 38μm diametre.
COMMENTS: No native species in the flora of the region. Numerous introduced species however. The larger grain. 2-7 is likely to be *Frankenia* sp. (bindweed).
ECOLOGICAL GROUPING: Herbs

FOSSIL TYPE: *Baumea* type FAMILY: CYPERACEAE
DESCRIPTION: Spheroidal grains with either distinct granular or indistinct exines, 1- 4 porate, Size 25- 30μm.
COMMENTS: This class most likely is composed of pollen from *Baumea*, *Lepidosperma* (predominantly terrestrial origin), *Gahnia* and *Shoenus* species. The extant wetland genera found on the Fleurieu Peninsula are Cyperaceae are *Baumea* (8 species), *Carex* (5) species, *Cyperus* (2 species), *Eleocharis* (3 species), *Gahnia* (2 species), *Isolepis* (7 species), *Schoenus* (7 species) and *Tetraria* (1 specie).
ECOLOGICAL GROUPING: Aquatic- rushes

FOSSIL TYPE: *Carex* type FAMILY: CYPERACEAE
DESCRIPTION: Pear or bell shaped grains with granulate, scabrate or unpatterned exines; apetures either not apparent or 1-4 colpus 25-32μm in length.
Likely to include- *Elocharis*, *Carex* and *Shoenus*
COMMENTS: *E. gracilis* is very common and is pear shaped with pores near base but there are many other possible species also represented in this class.
ECOLOGICAL GROUPING: Aquatic- rushes

FOSSIL TYPE: *Typha* FAMILY: CYPERACEAE
DESCRIPTION: Bell shaped to spheroidal grains with a distinctly reticulate patterned exine. 2-3 ulceroid like apetures sometimes apparent. Grains 40- 45 u length.
COMMENTS: *T. domingensis* and *T.orientalis* are the only two *Typha* species native to Australia. *T. domingensis* is found in swamps in the Southern Mount Lofty region, but is not currently found in the Boat Harbour Creek swamp. The morphology of this type conforms to both *Typha domingensis or T. orientalis* pollen.
ECOLOGICAL GROUPING: Aquatic- rushes.

FOSSIL TYPE: *Hibbertia* FAMILY: DILLENACEAE
DESCRIPTION: Tricolpate, oblate- spheroidal small 24 diametre. Exine 2 μm thick and sexine is as thick as nexine and shows reticulate to striate patterning.
COMMENTS: The following species are widely distributed on the Peninsula; *Hibbertia exutiacies, Hibbertia riparia, Hibbertia sericea, Hibbertia virgata* and could be represented by this class.
ECOLOGICAL GROUPING: Shrubs

FOSSIL TYPE: *Drosera* FAMILY: DROSERACEAE
DESCRIPTION: Tetrad grains with 12 apertures per grain. Tetrad diametre 60 μm and grain diametre 43 μm. Exine is 4 μm thick and covered with dimorphic spinules.
COMMENTS: The following species are found on the Fleurieu Peninsula; *Drosera auiculata, Drosera binata, Drosera glanduligera, Drosera macrantha, Drosera pygmaea* and *Drosera whittakeri.*
ECOLOGICAL GROUPING: Herbs

FOSSIL TYPE: *Sprengelia incarta* FAMILY: EPACRIDACEAE
DESCRIPTION: Tetrad 26 μm total diametre with each grain 15 μm diametre. Exine finely reticulate.
COMMENTS: Common in swamps
ECOLOGICAL GROUPING: Aquatic - shrubs

FOSSIL TYPE: *Leucopogon* type FAMILY: EPACRIDACEAE
DESCRIPTION: Spherical to lobed tetrads 28-40 μm diametre grains are tricolporate with indistinct furrows and exine surface is scabrate.
COMMENTS: This class includes *Leucopogon concurvus, Acrotiche affinis* and *A. fasciculiflora.*
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Epacris* type FAMILY: EPACRIDACEAE
DESCRIPTION: Lobed tetrad with a diametre ranging from 47 to 55 μm. Each grain is tricolpate with transverse furrows which are unclear in outline. Exine has endocracks, is 2μm thick and psilate.
ECOLOGICAL GROUPING: Shrub
COMMENTS: *Eparcis impressa* is presently recorded in and near swamps, grain also resembles *Acrotiche serrulata.*

FOSSIL TYPE: *Astroloma* type FAMILY: EPACRIDACEAE
DESCRIPTION: Tetrads, grain diametre 72 μm, exine wall thick and scabrate. Grains are tricolporate, with colpi and pores being indistinct and 'furrow' like.
COMMENTS: Type conforms to *Astroloma conostephoides* or *Brachyloma ericoides.*
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: Euphorbiaceae FAMILY: EUPHORBIACEAE
DESCRIPTION: Croton type- periporate, grains are spheroidal, numerous small pores sharply pointed clavae; grains 43μm diametre and exine thickness of 2.5μm.
COMMENTS: Most likely to be *Beyeria lechenaultii,* which has a coastal distribution or *Micrantheum demissium* which is the sole common terrestrial form in the region.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Goodenia* FAMILY: GOODENIACEAE
DESCRIPTION: Tricolporate grains with lalongate pores, oblate-spheroidal to prolate. Sexine is tegillate and baculate, being thicker at the poles than else where.
COMMENTS: This class is likely to contain pollen from several species as there was size and morphological variation with in the class. All extant Scaveola; *Scaevola albida and S. linearis* and Goodenia; *Goodenia albiflora, G. amplexans, G blackiana, G. geniculata, G. humilis, G. ovata, G. pinnatifida* could be included in this class however much of the pollen is likely to be from *G. ovata*, the common swampland species.
ECOLOGICAL GROUPING: Aquatic (Herbs)

FOSSIL TYPE: Poaceae < 30μm FAMILY: GRAMINAE
DESCRIPTION: Monoporate spheroid and oblate grains ranging in size from 18-30 μm in diametre, pores with annuluses and ranging in size from 3-5 μm. Surface patterns scabrate or verucate. The class included grains with distinct exines and thin and less distinct exines.
COMMENTS: There are at least 33 native grass species in 16 genera in the Southern Fleurieu Peninsula. Graminae is noted for its intra-family uniformity and so class sizes were recorded only with out any attempt to morphologically differentiate to subgroups. This class probably contains a mixture of introduced and native species, however native species characteristically have smaller pores and smaller sized grains than exotics, both characters characterising this class, thus it could be argued that this class is likely to be composed of predominantly pollen from native grass species.
ECOLOGICAL GROUPING: Herb; aquatic and terrestrial- *Phragmites australis, Microlaeana stipoides, Glyceria australis, Deyeuxia semiannularis* and *Danthonia semiannularis* are frequently recorded swamps in the Fleurieu Peninsula. A number of these species also have terrestrial distributions.

FOSSIL TYPE: Poaceae 30-50μm FAMILY: GRAMINAE
DESCRIPTION: Monoporate spheroid and oblate grains ranging in size from 30-50 μm in diametre, pores with annuluses and ranging in size from 3-5 μm. Surface patterns scabrate or verrucate
COMMENTS: Class probably contains a mixture of introduced and native species.
ECOLOGICAL GROUPING: Herb

FOSSIL TYPE: Poaceae 50-80 μm FAMILY: GRAMINAE
DESCRIPTION: Monoporate, spheroidal or ovoidal grains, distinct annulus around pores ranging in diametre from 4-6 μm, exine smooth, psilate or or faintly reticulate.
COMMENTS: The major cultivated cereal grasses are species in the genera *Triticum*, *Avena*, *Hordeum* and *Secale*. Cereal grains are usually larger with bigger annuli, than native grass pollen (McPhail, pers. comm.) ECOLOGICAL GROUPING: Exotic herb

FOSSIL TYPE: Poaceae Rye-type FAMILY: GRAMINAE
DESCRIPTION: Monoporate grain with oblong outline. Grain measures 40 x25μm and annulus diametre 8-10μm, exine surface is scabrate.
COMMENTS: Most probably *Secale* sp.
ECOLOGICAL GROUPING: Exotic agricultural grass.

FOSSIL TYPE: Geraniaceae FAMILY: GERANIACEAE
DESCRIPTION: -Tricolpate spheroidal grains with short colpi and ranged in size from 45-60μm. Exine is semitectate and coarsely reticulate.
COMMENTS: Members of *Pelargonium* and *Geranium* genera conform to this type. grouped in this type. Plate 2-16 is probably *Geranium* sp. and 2-17 *P. australe*.
ECOLOGICAL GROUPING: Herb

FOSSIL TYPE: *Gyrostemon australicus* FAMILY: GYROSTEMONACEAE
DESCRIPTION: Tricolpate and at times four-colpate; spheroidal to prolate, 20μm in diametre well delimited colpi thick walled (3μm) and exine psilate.
COMMENTS: Dispersed distribution over the region.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Myriophyllum* sp. FAMILY: HALOGORACEAE
DESCRIPTION: Sub-oblate and peritreme (25x 30μm); 4 and 5 porate with pores protruding 3-4 μm and exine 2 - 2.5 μm thick and thickened at pores. Tectum is punctate.
COMMENTS: There are two native species in the region; *M. amphibium and M. simulans* and the introduced *M aquaticum.* The description fits grains from all species.
ECOLOGICAL GROUPING: Aquatic

FOSSIL TYPE: *Haloragis* sp. FAMILY: HALOGORACEAE
DESCRIPTION: 4-6 pororate paraisopolar, suboblate, 30-38 x 25-30 μm, radially symetrical, pertectate. Apetures not protruding. Tectum notably puncate, exine comparatively thin.
COMMENTS: Pollen of *Gonocarpus* and *Haloragis* conform to this type. *Gonocarpus micranthus* and *G. tetragynus* commonly occur in wetlands of the region.
ECOLOGICAL GROUPING: Herb

FOSSIL TYPE: *Amyema miquelii* FAMILY: LORANTHACEAE
DESCRIPTION: Tricolpate, with long narrow colpi. Grains are triangular and peroblate (14x30 μm) with concave sides. Exine patterning is feint but reticulate.
COMMENTS: Parasite, host is usually *Eucalyptus.* Box mistletoe

FOSSIL TYPE: *Amyema preissii* FAMILY: LORANTHRACEAE
DESCRIPTION: Tricolpate, with long narrow colpi. Grains are triangular (10 x 23μm) and peroblate with markedly concave sides. Exine patterning is obscure.
COMMENTS: Parasite, host usually *Acacia.* Wire leafed mistletoe.

FOSSIL TYPE: *Villarsia umbricola* FAMILY: MENYANTHACEAE
DESCRIPTION: Peroblate 30 x 40 μm in size and triangular in polar view. Colpi are narrow with apices that fuse at the poles making grains parasycolpate. The exine is this and striate.
ECOLOGICAL GROUPING: Aquatic, colonises open water ponds.

FOSSIL TYPE: Fabaceae 1 FAMILY: LEGUMINOSAE
DESCRIPTION: Grains are tricolpate or tricolporate and prolate in shape (16 - 20 x 20-24 μm). Colpi broaden at the equatorial region and are often unconstricted. Exine pattern may be fine or moderately coarse and distinctly reticulate.
COMMENTS: This description is general and fits a number of members in the family including the common swamp and terrestrial species *Viminaria juncea, Daviesia ulicifolia* and *Pultanea daphnoides.*
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: Fabaceae 2 FAMILY: LEGUMINOSAE
DESCRIPTION: Grains are tricolpate or tricolporate and spheroidal to sub-prolate in shape with diametres 16-20μm. Exine is 1μm in thickness and with a fine reticulate pattern.
COMMENTS: As with Fabaceae1 this description is vague how ever encompasses common species including *Platylobium obtusangulum.*
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: Fabaceae 3 FAMILY: LEGUMINOSAE
DESCRIPTION: Grains are tricolpate with deep invaginated colpi; prolate (30 x 20μm) in shape. Exine is 2.5μm thick and sexine is equal in thickness to nexine. Exine is patterned with coarse reticule and clavae are distinctive.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: Fabaceae 4 FAMILY: LEGUMINOSAE
DESCRIPTION: Grains are tricolporate and rhombic with truncate ends in the equatorial view (29 x 46 μm). Pores are lalongate and protrude. Exine is 1.5 μm in thickness, tectate, columellae are distinctly visible and in plan showing a fine reticule.
COMMENTS:
ECOLOGICAL GROUPING: Shrub

Fossil type: Acacia 1 Family: LEGUMINOSAE
Description: Grains occur in polyads of 12. Apetures on individual grains are not distinct. Individual grains are 6-12μm in size and polyads 42 - 54 x 38 - 60μm in size in equatorial view. Grain surface is smooth or verrucate. Polyads in polar view are rounded-cubical or regular rectangular.
Comments: Attempt was made to separate the major watercourse and terrestrial species on rain size and morphology however it was not successful. There was much intraspecific variation and overlap between species. Since the pollen does not travel far from its source plant most Acacia1 in swamp samples is likely to be from *A. retinoides, A. verticillata* and *A. melanoxylon.*
Ecological grouping: Aquatic. *A. retinoides* tree or shrub; *A. verticillata;* shrub *A. melanoxylon;* tree.

Fossil type: Acacia 2 Family: LEGUMINOSAE
Description: Grains occur in polyads of 8. Apetures on individual grains are not distinct. Individual grains are 6-10μm in size and polyads 34 x 28μm in size in equatorial view. Grain surface is smooth.
Comments: *A. myrtifolia* and *A. armata* are the only two 8 celled polyads in the local flora. Most grains are probably from *A. myrtifolia* as it is more likely to be proximal to waterways.
Ecological grouping: Shrub

Fossil type: Acacia 3 Family: LEGUMINOSAE
Description: As with Acacia 2
Comments: Put in separate class from Acacia 2 as found in moss polster samples and therefore not likely to be sourced from swampland species. Most likely to be *A. pycnantha A. myrtifolia*
Ecological grouping: Shrub

Fossil type: Exotic legumes Family: LEGUMINOSAE
Description: Two types of pollen included in this class - 1) tricolpate spherical to oblate, with short colpus and large circular pore (6μm diametre) reticulate to foveolate. 2) Trizonocolporate foveolate Pori less well defined indicated by the constriction to the colpus. Colpi narrow.
Comments: Most likely to be *Trifolium* spp. and *Medicago* spp.
Ecological grouping: Herbs

Fossil type: Liliaceae 1 Family: LILIACEAE
Description: Monosulcate grains elisoidal shaped grains 8-14 to 10 -22 μm in with fine reticulate patterning, exine 0.8- 1μm thick.
Comments: This type is likely to be pollen from *Burchardia*. *B. umbellata* is commonly found in swamp areas in the region. Non spinulose species of *Lomandra* also could be included in the class.
Ecological grouping: Herbs. *Burchardia*- herbs; *Lomandra* -rushes.

Fossil type: *Xanthorrhoea* Family: LILIACEAE
Description: Monosulcate grains 15-18 μm x 30-35. Furrow is long, running more than half way around the grains. Grains are elisoidal often slightly flattened dorsally and may have one truncate end. Exine is 2 μm thick with a reticulate patterning.
Ecological grouping: Shrub

Fossil type: Liliaceae 3 Family: LILIACEAE
Description: Large mososulacate grains 30 x 60 μm with very distinctive coarse reticulate patterning. The grain is elipsoidal in polar view with pointed ends.
Comments: Likely to be *Chamescilla corymbosa* or *Thysanotis* sp.
Ecological grouping: Herbs.

Fossil type: *Plagianthus* type Family: MALVACEAE
Description: Polyporate spheroidal grain 32μm in diametre and with c16 pores per face. Pores 1.5-4μm in diametre. Exine 5 μm thick and spinuliferous pointed and 2-4 μm in length.
Comments: *Lavatera plebeia* and *Plagianthus specatus* are the only two extant types. Too small to be introduced weed *Malva parvifora* or *M. verticilillata*?
Ecological grouping: Shrub

Fossil type: *Epilobium billardiarium* Family: ONAGRACEAE
Description: Peroblate grains 60 x 55μm, triporate, triangular in polar view with large and protruding vestibulate pores. Exine is tegilate baculate and exine finely granular. Viscin threads are sometimes present.
Comments: Likely to be the common swamp plant *E. pallidiflorum.*
Ecological grouping: Aquatic herb.

Fossil type: *Billardiera* sp. Family: PITTOSPORACEAE
Description: Spheroidal, 3-colporate, sexine is as thick as nexine and reticulate. Diameter size 30μm.
Ecological grouping: Shrub

Fossil type: *Plantago lanceolata* Family: PLANTAGINACEAE
Description: Spheroidal, periporate, pores with distrinct opercual exine surface is verrucate are large and irregular. diametre size 26μm.
Ecological grouping: Herb- exotic

Fossil type: *Plantago varia* Family: PLANTAGINACEAE
Description: Spheroidal, periporate, pores with annulus exine surface is verrucate. Diameter size20μm.
Ecological grouping: Herbs

Fossil type: *Pinus* Family:
Description: Grains are saccate, with 2 separate sacci with irregular reticulum on their inner surfaces. Length of body of grain 40-60μm, sacci constricted at their point of attachment to the body.
Ecological grouping: Exotic tree

FOSSIL TYPE: *Comesperma* sp. FAMILY: POLYGALACEAE
DESCRIPTION: Grains are polycolporate (approximately 14 colpi) suboblate with a bulge at poles where colpi meet. measuring 48 x 40μm. Exine is 4μm thick, although thickening more towards the poles. Pores form a ring around the central equatorial area.
COMMENTS: There are two *Comesperma* species in the region *C. calymega* and *Comesperma volubile*.
ECOLOGICAL GROUPING: Shrub/creeper.

FOSSIL TYPE: *Rumex* sp. FAMILY: POLGONACEAE
DESCRIPTION: Trizonocolporate, Surface is tectate-perforate, colpi are relatively short narrow and unconstricted. Exine is 0.8 μm and of even thickness over whole grain. Grain shape is circular to slightly lobed in polar view and 22μm in diametre.
COMMENTS: *R. crispus, R. conglomeratus.* Also *Emex australis*—records of spread since 1855 (Kloot, 1983) all conform to class description.
ECOLOGICAL GROUPING: Introduced weed—Dock and Three Corner Jack.

FOSSIL TYPE: *Polygonum aviculare* FAMILY: POLGONACEAE
DESCRIPTION: Trizonocolporate grains elliptic to rectangular obtuse in shape, being longer from pole to pole than across equitorial region. The surface is tectate and columella fine, surface columellae longer at poles.
COMMENTS: *P. aviculare, P. salicifolium* are common weeds and there are records of their presence since 1855 (Kloot, 1983)
ECOLOGICAL GROUPING: Herb-exotic; distributed largely on plains.

FOSSIL TYPE: *Muehlenbeckia adpressa* FAMILY: POLGONACEAE
DESCRIPTION: Tricolporate grains which are spheroidal in polar view but subprolate in and 22μm (PxE = 24x20μm) in diametre, colpi are short and with diamond shaped lalongate pore. Surface patterning is fine reticulate. Exine is 1.8μm thick and the sexine is thicker than the nexine with columellae being straight in both.
COMMENTS: *Muehlenbeckia aspressa*
ECOLOGICAL GROUPING: Herb -twining plant; Climbing lignum

FOSSIL TYPE: *Banksia marginata* FAMILY: PROTEACEAE
DESCRIPTION: Bilateral, elongated bi-porate with pores at each end, apetures are almost circular covered by convex membranes; exine is 1.5μm thinning to ends. 34 x 20μm. Exine surface is smooth
ECOLOGICAL GROUPING: Tree or shrub

FOSSIL TYPE: *Banksia ornata* FAMILY: PROTEACEAE
DESCRIPTION: Grains are bilateral, elongated bi-porate with pores at each end, apetures are almost circular covered by convex membranes; exine is 1.5 μm thinning to ends. 50 x 22μm. Exine surface is smooth.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Isopogon ceratophyllous* FAMILY: PROTEACEAE
DESCRIPTION: Grains are triporate oblate, isopolar, and rounded triangular, 50μ in length in polar view. Exine is 2.5μm thick but thins towards the pores which are 8μm in diametre. The exine surface is reticulate.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: Proteaceae 1 FAMILY: PROTEACEAE
DESCRIPTION: Grains are isopolar, tricolpate, oblate and triangular in polar view. Pores are circular and a collar may or may not be present around pore and pores measure 18-24μm in diametre. Exine is ornamented with raised reticules. Grains measure 54-75 μm along the longest axis. Sides are straight to convex.
COMMENTS: This class includes the *Hakea* species of the region, *H. carinata, H. rostrata* and *H. rugosa* and the single native Grevillea species, G. *lavendulaceae*.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Conospermum patens* FAMILY: PROTEACEAE
DESCRIPTION: Grains are triporate with circular apertures whose margins are unclear. Grains are subisopolar and 75μm in diameter. The exine is thick and its surface is reticulate.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Opercularia* sp. FAMILY: RUBIACEAE
DESCRIPTION: Grains are tricolporate, colpi are invaginated and brevicolpate and pores also narrow and lalongate, Grains appear lobed but can be described as oblate-spheroidal (20μm on longest side) in polar view. Exine is relatively thick with both sexine and nexine layers being easily recognised and of equal thickness. Surface patterning is scabrate.
COMMENTS: Most likely to be *Opercularia varia*. It is the only recorded *Opercularia* sp. in wetlands of the region today.
ECOLOGICAL GROUPING: Aquatic

FOSSIL TYPE: *Boronia parviflora* FAMILY: RUTACEAE
DESCRIPTION: Tricolporate spheroidal grains 27 μm diametres. Exine 2.5μm thick with nexine being significantly thinner than sexine. Colpi extend to poles and pores are 3μm in diametre and lalongate. Columellae are clarly visible pilate.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: Rhamnaceae FAMILY: RHAMNACEAE
DESCRIPTION: Grains are tricoplporate, sub oblate and almost triangular in polar view. Pores are lalongate and diamond shaped. Grains measure 16 x 20μm. Exine patterning is obscure and surface appearing smooth.
COMMENTS: Grains are too large to be *Spyridium* although could possibly be *Cryptandra hispidula* or *Pomaderris oraria*
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Ranunculus* sp. FAMILY: RANUNCULACEAE
DESCRIPTION: Grains are tricolpate, colpi are obscure. Grains are spheroidal and exine is distinctively patterned with 'ringed spots', the tectum undulates and is cracked in places and is 4μm thick.
COMMENTS: Possible species are *Clematis microphylla, R. amphitrichus, R. involucrata, R. lappaceus* and *R. sessiflorus.* Aquatic. A number of naturalised introduced exotic species; R.*muricatus, R. trilobus.* Has been reported to under represent or well represent sources.
ECOLOGICAL GROUPING: Aquatic herb

FOSSIL TYPE: *Exocarpus* FAMILY: SANTALACEAE
DESCRIPTION: Grains are 3-colporate, subprolate and small (17x13um). Surface pattern is not apparent.
COMMENTS: Probably *E.cupressiformis*, as morphology conforms to type (Boyd, 1992) and although other species (*E. glomeratum* and *E.sparteus*) are native to the region it is the most widely distributed in the southern Fleurieu Peninsula.
ECOLOGICAL GROUPING: Tree

FOSSIL TYPE: *Dodonaea* FAMILY: SAPINDACEAE
DESCRIPTION: Tricolporate with long and broad pores; prolate spheroidal, subtriangular in polar view with pronounced apertural zone where the endexine thickens. The exine is mainly 2μm thick, tectate with a very thick tectum and psilate with tiny pits. Size 26-30 μm.
COMMENTS: *Dodonaea viscosa* and *D. baueri* are the only local species in this genera. The species were not distinguished so the class could represent both although *D. viscosa* has the more abundant distribution of the two species.
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Euphrasia collina* FAMILY: SCROPHULARIACEAE
DESCRIPTION: Tricolpate prolate-spheroidal grains 40 x 38 μm in diametre. Colpi are long and have rough edges, Exine is thin 1μm and scabrate.
ECOLOGICAL GROUPING: Aquatic herb

FOSSIL TYPE: *Stylidium graminifolium* FAMILY: STYLIDACEAE
DESCRIPTION: 4 -5 Colpate grains, oblate spheroidal in shape, colpi have rough edges, are 12μm in length and meet at the poles. The grain is 35-40μm in size. Exine is thin (1.8μm) and spinuliferous.
ECOLOGICAL GROUPING: Herb

FOSSIL TYPE: *Stackhousia* FAMILY: STACKHOUSIACEAE
DESCRIPTION: Tricolpate or tricolporate (unable to distinguish) grains almost circular in polar view measuring 24 x 22 μm. Exine is stronly patterned; semitectate, rugulate.
COMMENTS: Probably *Stackhousia aspericocca* or *Stackhousia monogyna*
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Pimelia* FAMILY: THYMELIACEAE
DESCRIPTION: Polyporate spheroidal grain with croton exine patterning, spheroidal 50μm in diametre. Exine is 4μm in thickness and sexine is significantly thick than nexine.
COMMENTS: Class possibly includes *Pimelia curviflora, Pimelia flava, Pimelia glauca, Pimelia humis, Pimelia linifolia, Pimelia octophylla, Pimelia phylicoides, Pimelia stricta.* Probably not *P. linifolia* as too small
ECOLOGICAL GROUPING: Shrub

FOSSIL TYPE: *Empodisma minus* FAMILY: RESTIONACEAE
DESCRIPTION: mono apeturate grains with a centrolepidoid pore (15-20μm diametre) which have a relatively large diametre 40 x 30μm. Exine is rigid, 2.5μm thick, smooth, tectate foveolate with lumina c 1.5 μm across.
ECOLOGICAL GROUPING: Herb

FOSSIL TYPE: Type A/H FAMILY: Pittosporaceae or Logoniaceae
DESCRIPTION: Tricolporate and prolate 40 x 27 μm grains. Exine 3 μm with nexine thinner than sexine, surface is reticulate with sculpturing types being semitectate pilate. Colpi run length of grain.
COMMENTS: Also looks like *Scaevola* spp. but morphology did not fit any extant species of this genus.
ECOLOGICAL GROUPING: Unidentified

FOSSIL TYPE: Type B
DESCRIPTION: Pentazonoporate grains that are elliptic in equatorial view. Grains measure 22x11μm. Exine surface is foveolate with lumina arranged almost in lines running from pole to pole. Pores are circular and 1μm diametre.
ECOLOGICAL GROUPING: Unidentified

FOSSIL TYPE: Type C
DESCRIPTION: Tricolpate spheroid grains 18μm in diametre. Very strong reticulate pattern with lumina measuring 2-3μm in length. Exine 2.5 μm thick.
COMMENTS: Resembles *B. spinosa* however characteristic circular pore of this type was not present
ECOLOGICAL GROUPING: Unidentified

FOSSIL TYPE: Type D
FAMILY: Leguminosae?
DESCRIPTION: Tricolporate prolate grains 40x23μm in size. Colpis meet at poles and pre is feint and lalongate. Exine is 2μm thick and sexine is equal thickness as nexine. Surface pattern is fine reticulate.
ECOLOGICAL GROUPING: Unidentified

FOSSIL TYPE: Type E
DESCRIPTION: Tricolporate, sub-prolate grains measuring 16 x 12μm p x e. Exine is relatively thick 2μm and strongly reticulate. Colpi are broad.
ECOLOGICAL GROUPING: Unidentified

FOSSIL TYPE: Type F
DESCRIPTION: Hexazonocolporate prolate grains Colpi are invaginated 24 x 18μm. Surface pattern is psilate and exine 2.5 μm thick.
ECOLOGICAL GROUPING:

FOSSIL TYPE: Type G FAMILY: Goodeniaceae or Lobeliaceae
DESCRIPTION: Tricolporate and polate to acuminate with acute ends shaped grains measuring 40x28μm p x e. Grains appear lobate on polar view. Colpi join at poles. Exine surface is reticulate with clearly pilate columellae and 3μm thick.
ECOLOGICAL GROUPING: Unidentified

FOSSIL TYPE: Type H
DESCRIPTION: Tricolporate and spheroidal grains 22μm in diametre, colpi broad but constricted at equator. Colpal membrane is unpatterned. Exine is 2μm thick and finely reticulate.
ECOLOGICAL GROUPING: Unidentified

FOSSIL TYPE: Trilete fern spore
DESCRIPTION: Radiosymetrical trilete spores, triangular in shape in polar view, with straight or concave sides and rounded angles. Exine is thin 1.5 μm and surface is smooth. Laesurae arms are 15μm long and taper towards the ends. Spores size *c*35x40μm (equatorial diametre).
COMMENTS: Most common trilete fern spore recorded. (some others were seen, not classed separately however). Other common extant swamp land fern species producing TFSs are *Pteridium esculentum, Gleichenia microphylla, Adiantum aethiopicum*
ECOLOGICAL GROUPING: Fern

FOSSIL TYPE: Monolete fern spore
FAMILY: Blechnaceae or Schizeaeceae
DESCRIPTION: Ansiopolar, bilateral monolete fern spore 40 x 60μm. Perispore sometimes present and forming a wing around spore.
COMMENTS: Most likely to be *Blechnum minus* or *B. nudum.* Some size variation in this class so probably includes both species of *Blechnum. Schizea bifida* is another a monolete spore of similar size class so could be in the class. (*S. fistulosa* also present but characterised by gemmate exine so is easily distinguished)
ECOLOGICAL GROUPING: Fern

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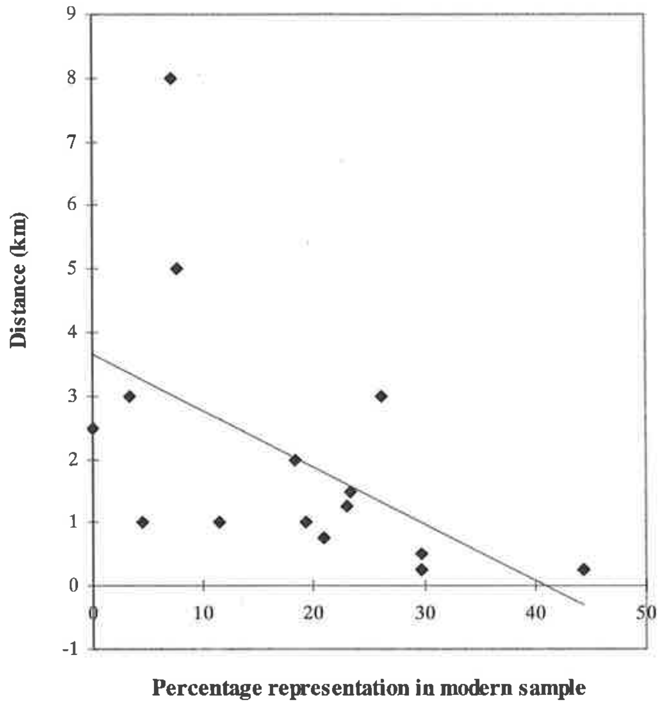
PINUS POLLEN DISTRIBUTION



The relationship between Pinus pollen abundance and distance from deposition site in the Fleurieu Peninsula as determined by analysis of modern pollen from moss polster and surface samples.