PALEOFIRE PATTERNS IN TASMANIA: POSTGLACIAL AND HOLOCENE RECORD OF FIRE AND VEGETATION FROM CRADLE MOUNTAIN-LAKE ST CLAIR NATIONAL PARK, TASMANIA, AUSTRALIA

by

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ABSTRACT

On centennial to millennial timescales fire regimes are driven by climate changes, vegetation composition, and human activities. In this study, I reconstructed the vegetation and fire history of Cradle Mountain-Lake St Clair National Park in northwestern Tasmania, and linked vegetation changes to variations in the fire regime, large-scale climate patterns, and anthropogenic activity. Postglacial vegetation and fire dynamics were inferred from five high-resolution pollen and charcoal records from lakes in the montane and subalpine zones of the National Park. Watershed-scale reconstructions of fire and regional trends in vegetation composition were compared to independent records of past climate and the regional archeological record to assess long-term climate-vegetation-fire-human linkages. Pollen and charcoal data indicate that during late-glacial period, the vegetation was largely open and fires were rare. During the Pleistocene-Holocene transition, rainforest taxa and subalpine woody shrubs began to increase in abundance. In the early Holocene, a fire activity maximum occurred at the three lower elevation sites while biomass burning remained low at the higher sites. The elevational differences and basin characteristics likely resulted in climate-controlled differences in vegetation and fuel flammability. The high biomass burning in the early Holocene occurred during the warmest interval of the Holocene as recorded by regional paleoclimate proxy records. The mid-Holocene period featured a multi-millennial phase of cool, temperate rainforest dominance at all sites. The relatively wet conditions of the mid-Holocene likely allowed the rainforest to reach its maximum extent. The late Holocene marks a regional shift toward open sclerophyll woodland associated with increased climate variability and decreased precipitation. A large fire episode occurred at all five sites during this period and hastened the shift in compositional balance from rainforest to a mosaic of sclerophyll woodlands and shrublands, rainforests, buttongrass moorlands, and alpine vegetation. Overall, the vegetation became substantially more open in the late Holocene. The human-fire linkages in Cradle Mountain are tenuous. There is no clear evidence that fire regimes or vegetation were extensively modified by humans prior to European settlement. Climate was the primary driver of fire activity over millennial timescales as explained by the close relationship between charcoal and climate proxy data.

CHAPTER ONE

INTRODUCTION TO DISSERTATION

The forests of Tasmania are a legacy of the vegetation of Gondwana, the supercontinent composed of present-day Antarctica, Australia, South America, Africa, India, and New Zealand. The breakup of this landmass and northward movement of all but Antarctica resulted in restriction and extinction of much of the former cool, temperate biota (Jordan et al., 1997; Kooyman et al., 2014). The surviving Gondwanan rainforest lineages are now confined to temperate rainforests in southern South America, New Zealand, and Tasmania. In Tasmania, the Gondwanan cool temperate biographic element and its iconic tree species are culturally important as a result of their longevity (>1000 years in some cases; Ogden, 1978), size (up to 40 m tall and 1.5 m diameter; Harris and Kitchener, 2005), and status as vestiges of Gondwanaland (Tasmanian Parks and Wildlife Service). Many of the tree species in these forests are endemic to Tasmania (e.g., *Athrotaxis selaginoides*, *A. cupressoides*, *Nothofagus gunnii*, *Phyllocladus aspleniifolius*) or restricted to southeastern Australia (e.g. *N. cunninghammii*). National Park and UNESCO World Heritage Area designations in western Tasmania protect a large portion of these remaining forests. One of the most ecologically rich areas in Tasmania is Cradle Mountain-Lake St Clair National Park (hereafter referred to as Cradle Mountain; Fig. 1.1). The park's diverse vegetation includes one-third of Tasmania's vascular flora (Kirkpatrick and Balmer, 1991) and most of the surviving Gondwanan temperate rainforest lineages in Tasmania. Since European colonization, however, large tracts of the

rainforest have disappeared through deliberate and accidental fires and forest clearance (Johnson and Marsden-Smedley, 2002). Today, these ecologically unique and culturally valued forests remain in areas of the western Tasmanian landscape where wet microclimates and protected topographic settings reduce the likelihood of fire ignition and spread and act as fire refugia (Wood et al., 2011).

Paleoecology is the field of biogeography that utilizes environmental proxy evidence to investigate the response of species, populations, communities and ecosystems to past environmental change. The field is multidisciplinary drawing on techniques from biogeography, geochemistry, and archaeology to reconstruct past environmental conditions, biotic responses, and climate and nonclimatic forcings. Paleoecological research into the long-term roles of climate and people on fire and vegetation in Tasmania has been an active area of investigation for decades. Work by Macphail and Colhoun among others was instrumental in establishing the sequence of postglacial vegetation development in western Tasmania (e.g. Macphail 1979; Colhoun and van de Geer, 1986; Colhoun et al., 1999). This work showed that vegetation of the last glacial period Tasmania was primarily alpine grassland and herbfields and that as the climate warmed forest taxa expanded from pockets of glacial refugia to cover large areas (Colhoun and van de Geer, 1986; Colhoun et al., 1999; Colhoun and Shimeld 2012). In the Holocene, a long period of rainforest dominance followed by an increase in wet sclerophyll taxa was identified in montane sites in central and western Tasmanian (Macphail 1979). The timing of the vegetation changes identified by these studies are not well constrained due to the method of radiocarbon dating employed, but the studies are

important for their pioneering role in outlining broad patterns of ecosystem change. More recent paleoecological studies with better chronologic control have been published from Lake St Clair (Hopf et al., 2000), southwest Tasmania (Fletcher and Thomas, 2007, 2010), the Hartz Mountains (Fletcher et al., 2014), Frenchmans Cap (Fletcher et al., 2015), north-central Tasmania (Beck et al., 2017), Flinders Island (McWethy et al., 2017), Mount Field National Park (Rees, et al., 2015), and western Tasmania (Anker et al., 2001). The findings of this collection of work describe the timing of vegetation changes in certain montane and low elevation settings and suggest the importance of both climate and human drivers of fire regimes in the Holocene. Many montane sites have evidence of a mid-Holocene temperate rainforest maximum between ca. 9000-5000 cal yr BP and an increase in wet sclerophyll vegetation in the late Holocene after ca. 5000 cal yr BP (e.g. Hopf et al., 2000; Anker et al., 2001; Fletcher et al., 2014; Beck et al., 2017). Fletcher and Thomas (2007, 2010) demonstrated that many low elevation sites in southwestern Tasmania were occupied by buttongrass moorland for the entirety of the Holocene. They argued deliberate burning by Aboriginal peoples would have been necessary in order to maintain buttongrass vegetation, and thus these areas constitute "an ancient cultural landscape." The vegetation and fire activity reconstructions from Flinders Island also suggest the importance of anthropogenic burning in shaping vegetation during the Holocene (McWethy et al., 2016). However, studies from temperate forests have found evidence that climate was the primary driver of both fire activity and vegetation change during the Holocene (Fletcher et al., 2014, 2015; Rees, et al., 2015).

I employed paleoecological methodologies and approach to investigate the changes in vegetation and fire activity since the last ice age with the aim of better understanding the drivers of changes and shifts in Tasmanian montane and subalpine ecosystems. The paleoecological perspective adopted in this dissertation allows for the assessment of Tasmania's cool, temperate plant communities over a long time period at a high spatial resolution and helps clarify the historical range of variability in this system, improves our understanding of the natural and anthropogenic legacies that shape the present landscape, and reveals the sensitivity of ecosystems to a range of environmental conditions. My research questions are: (1) what is the postglacial history of fire activity and vegetation change in Cradle Mountain-Lake St Clair National Park; and (2) to what extent have prehistoric fire regimes shaped by climate, landscape and fuel arrangements, and human activities.

Objectives

This research aims to better understand the fire-vegetation-climate-human linkages in the Tasmanian cool, temperate rainforest and subalpine system in the Cradle Mountain region through an examination pollen, charcoal, lithologic records from sediment cores taken from five lake sites. Lakes serve as excellent repositories of past environmental change by collecting and preserving in sediment charcoal produced by fires and pollen from local and regional vegetation (Whitlock and Larsen, 2001). Local and regional trends in vegetation were inferred from fossil pollen data. Watershed-scale trends in fire activity were inferred from fossil charcoal records. My overarching goal is

to disentangle the climatic and anthropogenic drivers of past vegetation change and fire activity over the last 16,000 years. Specifically, the objectives were to (1) reconstruct the postglacial history of vegetation and fire activity at decadal to centennial scales based on a single site; (2) evaluate the spatiotemporal patterns of climate-fire-vegetation linkages and identify the importance of regional and local controls on Holocene ecological history by comparing multiple records; and (3) assess the role of Aboriginal Tasmanian land management in driving environmental change.

To address the objectives, I undertook a study of the fire and vegetation history of Cradle Mountain since the end of last glacial period (ca. 17,000 cal yr BP). I compared the results of fire activity and vegetation reconstructions to independent proxies of past climate and human presence through the regional archeological record. This study produced the first high-resolution reconstructions of local-scale fire activity in Cradle Mountain. The sites from north to south are (Fig. 1.1):

- Wombat Pool (41.650°S 145.950°E; 998 m elev., 0.4 ha area) is a glacial lake that provides the longest paleoenvironmental record from this study. Sediments from this small lake have a basal age of ca. 16,500 cal yr BP. The present-day vegetation around the lake is a mosaic of wet sclerophyll forest and shrub communities, areas of buttongrass (*Gymnoschoenus sphaerocephalus*), mixed forest containing rainforest and *Eucalyptus* species, and alpine shrubland. *A. cupressoides* of different age classes grow directly on the edge of this small lake. Within 100 m of the lake, a woodland community with *Eucalyptus coccifera* overstory and shrub understory is present.

- Lake Lilla (41.652°S; 145.955°E; 933 m elev., 7.2 ha area) is a glacial lake surrounded by wet sclerophyll forest and shrubland, buttongrass, and mixed forest containing rainforest trees (*N. cunninghammii*, *A. selaginoides*, *P. aspleniifolius*) and *Eucalyptus* species. A small outlet stream, Lilla Creek, flows out of Lake Lilla at its northern end. This site has a 14,000-year-long record of fire and vegetation.
- Lake Hanson (41.663°S 145.973°E; 1007 m elev., 8.4 ha area) is a glacial lake. Near the head of Hanson Valley a glacial trough descends in two rock steps within 2 km, the first of these steps dams Lake Hanson (Thrush, 2008). Today the site is surrounded by a mature cool, temperate rainforest, areas of mixed forest, and *N. gunnii* stands. Lake Hanson provides a 13,000-year-long history of fire and vegetation.
- Lake Wilks (41.673°S 145.955°E; 1060 m elev., 2.7 ha area) is a valley head cirque thought to be one of two initial locations of ice accumulation during the last glacial advance (Thrush, 2008). This steep-sloped basin is today home to *Athrotaxis* rainforest, substantial patches of *N. gunnii*, *Eucalyptus* woodland, and coniferous alpine heathland.
- Suttons Tarn (41.683°S 145.934°E; 1099 m elev., 2.0 ha area) is a cirque lake dammed by a terminal moraine of last glacial maximum age (Thrush, 2008). The basin contains a mix of coniferous alpine heath and *N. gunnii*-dominate cool, temperate rainforest.

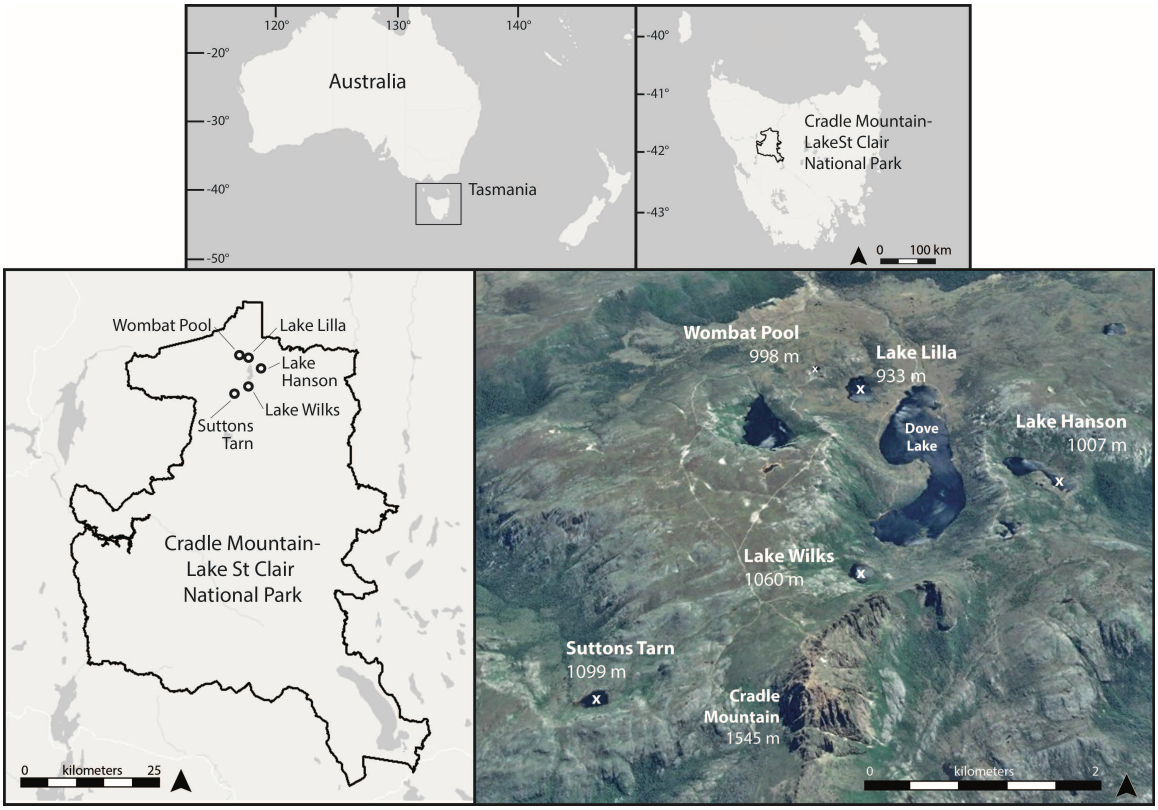


Figure 1.1 Map of study sites.

In order to assess the climate-fire-vegetation linkages and regional-versus-local drivers of fire and vegetation patterns, paleoclimate proxy data and regional archeological information were compared to reconstructed fire and vegetation histories. Regional climate history was inferred from a number of independent paleoclimate datasets including: two lake level reconstructions from Victoria, Australia (Wilkins et al., 2013); a record of speleothem growth rate from Lynds Cave in northern Tasmania (Xia, et al., 2001); sea-surface temperature reconstructions from Murray Canyons off the coast of South Australia (Calvo et al., 2007) and the Southern Ocean south of Tasmania (Sikes et al., 2009); air temperature reconstruction based on oxygen isotope ratios from Taylor Dome, Antarctica (Grootes et al., 2001); Southern Hemisphere Westerly Wind strength

over Tasmania inferred from multiproxy sources (Fletcher and Moreno, 2012; Rees et al., 2015); and reconstructed El Niño-Southern Oscillation events (Moy et al., 2001).

Aboriginal peoples entered Tasmania at least 40,000 years ago (Cosgrove, 1999) and used fire to enhance hunting success and facilitate travel (Cosgrove et al., 1990; Bowman, 1998; Gott, 2005; Gammage, 2008; 2011). Anthropological research, the accounts of European colonizers, and landscape structure analysis suggest that Aboriginal peoples actively managed parts of the Tasmanian landscape through deliberate burning (Bowman, 1998; Marsden-Smedley and Kirkpatrick, 2000; Gott, 2005; Gammage, 2008, 2011; Onfray, 2012). In order to address my objective of assessing the role of humans in driving environmental change, I investigated the archeological record from sites near Cradle Mountain. Three well-studied archeological sites are situated within ca. 25 km of Cradle Mountain: Mackintosh Cave, Warragarra Rockshelter, and Parmerpar Meethaner Rockshelter. Analysis of these sites provides evidence of human occupation in two ways: (1) radiocarbon dates on occupation layers—strata that contain human-made tools and animal bones with evidence of human butchery, and (2) discard rates—the number and kind of discarded bones and tools throughout the archeological deposits (Lourandos, 1983; Stern and Marshall, 1993; Cosgrove, 1995; Allen and Porch, 1996). Not every occupation layer has been radiocarbon dated so discard rates fill in the gaps between dates as well as provide more information about how and with what intensity sites were used over time (Jones, 1995; Cosgrove, 1999). While acknowledging the difficulty and limitations of comparing human fire ignitions to paleoenvironmental reconstructions, we

consider human presence in the Cradle Mountain region as evidence of a potential anthropogenic fire-ignition source.

Cradle Mountain has ecologically diverse vegetation composed of a mosaic of pyrophytic and pyrophobic assemblages. The pyrophytic plant communities include plants with high flammability, meaning they have the capacity to burn throughout the year, not only in the summer (Pyrke and Marsden-Smedley, 2005); as well as adaptations such as post-fire resprouting and epicormic buds, which allow for quick recovery after fire disturbance. Pyrophobic plant communities include plants with low flammability but extreme fire-sensitivity, meaning the ecological impact from a single fire has a high probability of drastically changing the ecology of the community (Pyrke and Marsden-Smedley, 2005). Some of the best-preserved vestiges of the Gondwanan temperate rainforests are found in Cradle Mountain, including the culturally and ecologically important endemic conifer trees *Athrotaxis selaginoides* and *A. cupressoides*. Cradle Mountain is also one of the few areas in Tasmania where all of the island's coniferous subalpine shrub species co-occur (*Podocarpus lawrencii*, *Microcachrys tetragona*, *Diselma archeri*, and *Microstrobus niphophilus*; Kirkpatrick and Bridle, 2013). Both of Tasmania's *Nothofagus* species are there: *N. cunninghammii*, a very large temperate rainforest tree, and *N. gunnii*, a short-statured temperate rainforest plant with both shrub and tree forms. In addition to these cool, temperate rainforest and subalpine plants, several fire-tolerant, sclerophyll forest and scrub taxa persist. The most important of which are two species of *Eucalyptus*. Wet sclerophyll woodlands of *E. subcrenulata* interspersed with open scrub, and forest woodlands of *E. coccifera* are present. Other wet

sclerophyll plants include *Leptospermum*, *Melaleuca*, *Monotoca*, *Banksia*, and *Richea*. Moorland areas dominated by the very fire-tolerant perennial sedge buttongrass are also widespread in the area. Cool temperate rainforest, coniferous subalpine shrubland, wet sclerophyll woodlands and shrublands, and buttongrass moorland form a mosaic landscape cover at Cradle Mountain (Kirkpatrick and Balmer, 1991).

Overview of Dissertation

My dissertation research uses fossil pollen and charcoal data from lake sediments to reconstruct the sequence of vegetation and fire activity changes that have occurred in the postglacial and Holocene periods and compares it to independent proxies of climate and the regional archeological record to disentangle climatic and nonclimatic drivers of fire and vegetation dynamics in Cradle Mountain. To address my study objectives, I first provide a review of approaches used in terrestrial paleoecology (Chapter 2). The common approaches and data used to reconstruct terrestrial ecosystem change are described. Dr. Cathy Whitlock co-authored this chapter. This chapter was published in *Key Methods in Geography* (Sage, 2016).

A detailed postglacial and Holocene environmental history from Wombat Pool is provided in Chapter 3. Wombat Pool is close to the Cradle Mountain terminal Pleistocene moraine and is today surrounded by a mosaic of wet sclerophyll woodlands, mixed forest, alpine heathland, and buttongrass moorland. Pollen, charcoal and lithological analyses resulted in a high-resolution reconstruction of environmental changes for the last ca. 17,000 years. These reconstructions were compared with other paleoecological records to

better understand postglacial and Holocene vegetation, fire, and climate dynamics in western Tasmania. Dr. Cathy Whitlock and Dr. Simon Haberle (Australian National University) co-authored the paper, which was published in *Frontiers in Ecology and Evolution* on July 7, 2016 (Volume 4, 1-17).

In Chapter 4, fire activity was reconstructed at five sites and vegetation history at three sites in Cradle Mountain in order to examine the long-term history of climate and human drivers of environmental change in the region. This paper reconstructs the vegetation and fire history in Cradle Mountain based on new, high-resolution paleoecological records from lakes in close proximity. These reconstructions are compared to independent archeological and paleoenvironmental evidence in order to interpret the environmental history of the region in light of past changes in climate and human activity, and examine the influence of Holocene vegetation change on land-use strategies as a way of exploring past human-fire interactions. Dr. Cathy Whitlock and Dr. Simon Haberle co-authored the paper. It has been prepared for submission to *Quaternary Science Reviews*. Finally, in Chapter 5, I provide a summary of the major findings of the research conducted in each chapter and how it influences our understanding of the environmental history of western Tasmania, including Holocene vegetation dynamics, fire history, and climatic and anthropogenic impacts on fire and vegetation history.

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CHAPTER TWO

GETTING INFORMATION FROM THE PAST: PALEOECOLOGICAL STUDIES OF TERRESTRIAL ECOSYSTEMS

Contribution of Authors and Co-Authors

Manuscript in Chapter 2

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Synopsis

In this chapter, we examine some of the approaches and data used to reconstruct terrestrial ecosystem change. Research employing these methods comes under the auspice of ecological biogeography, which is concerned with the factors that have lead to the current distribution of plants on the landscape. Palaeoecology is the field of biogeography that utilizes environmental proxy data to investigate the response of species, populations, communities and ecosystems to past environmental change. Palaeoecological research usually concerns ecosystem dynamics during the Quaternary period (the last 2.58 million years), and in particular over the last 21,000 years, which includes the last glacial maximum (LGM) and the Holocene (the current interglacial period that began 11,700 years ago). Environmental proxy data are sensitive to ecosystem change at particular temporal and spatial scales and describe aspects of the environment to which the organism or physical property is sensitive. We outline the approaches taken to reconstruct terrestrial ecosystem change and review some of the common proxy data used to reconstruct past terrestrial ecosystem change, including tree rings, pollen, plant macrofossils, packrat middens, charcoal and dung fungal spores, as well as supporting palaeolimnological information from diatoms, chironomids, and lake-sediment lithology, geochemistry and mineralogy. Proxy records can be used alone, but fuller understanding is achieved by combining and comparing multiple proxy data from single or groups of sites. Alternatively, developing geographic networks of records from a single proxy type, such as charcoal or pollen data, provides insights about patterns of environmental change over broad spatial scales.

This chapter is organized into the following sections:

- Introduction
- Palaeoecological approaches and data
- Types of proxy data in palaeoecological studies
- Multi-proxy records and global syntheses
- Conclusion

Introduction

The present is considered the key to understanding the past, but historical and prehistorical data conversely play a critical role in informing the present and the future. The past provides information on the historical range of variability, improves understanding of the natural and anthropogenic legacies that shape the present landscape, and reveals the sensitivity of ecosystems to a range of environmental conditions. Knowledge of the past comes from many sources. Real-time and near real-time data are acquired from field and remote instruments; aerial photography and satellites provide information about the past few decades. Historical data come from centuries of human observation and measurement. Information about the period before observational and instrumental data is obtained from environmental proxy evidence, such as those preserved in tree rings and lake sediments (Figure 2.1).

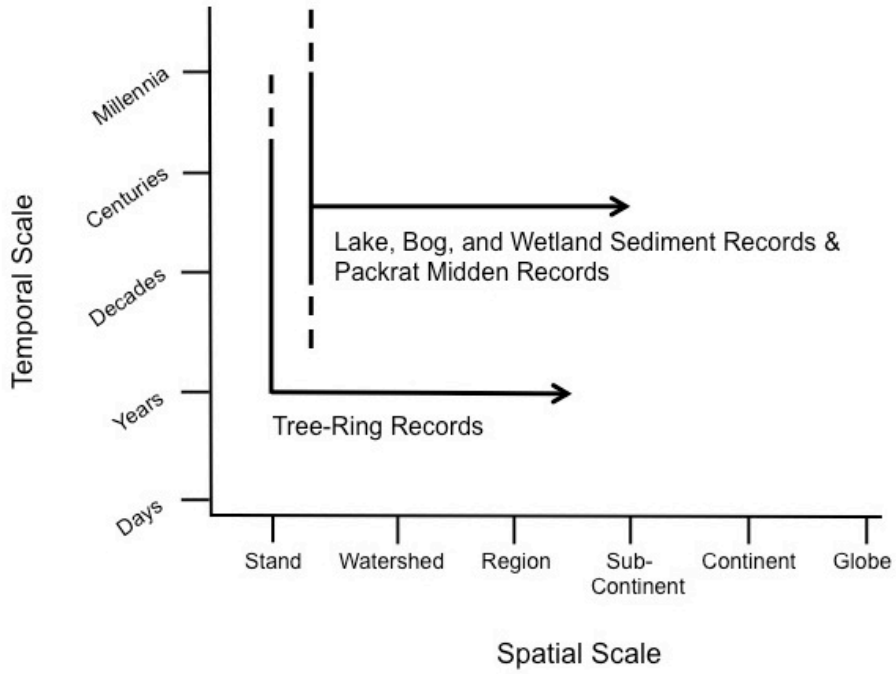


Figure 2.1 Temporal and spatial scales of proxy data discussed in this chapter. The primary scale that these proxy data operate at is shown with solid lines. The dashed lines indicate scales that can be achieved in certain unique cases.

Palaeoecology is the field of biogeography that utilizes such proxy data to investigate the response of species, populations, communities and ecosystems to past environmental change. The field is multidisciplinary drawing on techniques from biogeography, palaeontology, geochemistry, and archaeology in order to reconstruct past environmental conditions, biotic responses, and climate and nonclimatic forcings. While palaeoecology has been applied to marine settings and even the cryosphere, our focus is on examining reconstructions of the terrestrial biosphere.

Most palaeoecological research concerns ecosystem dynamics during the Quaternary period (the last 2.58 million years), when vast ice sheets cyclically expanded and contracted likely in response to small variations in the configurations of the Earth's

orbit around the sun (Figure 2.2). Of this body of literature, most attention is given to the last 21,000 years of history, starting with the time of the last glacial maximum (LGM) and extending through the current interglacial period, the Holocene, which began 11,700 years ago. In this chapter, we describe some of the types of data used in terrestrial palaeoecology. Our examples come from work in which we have been involved and published studies that we admire for their detail or approach. Our coverage of this topic is not meant to be comprehensive in concept or geography, and for that we refer to other helpful references.

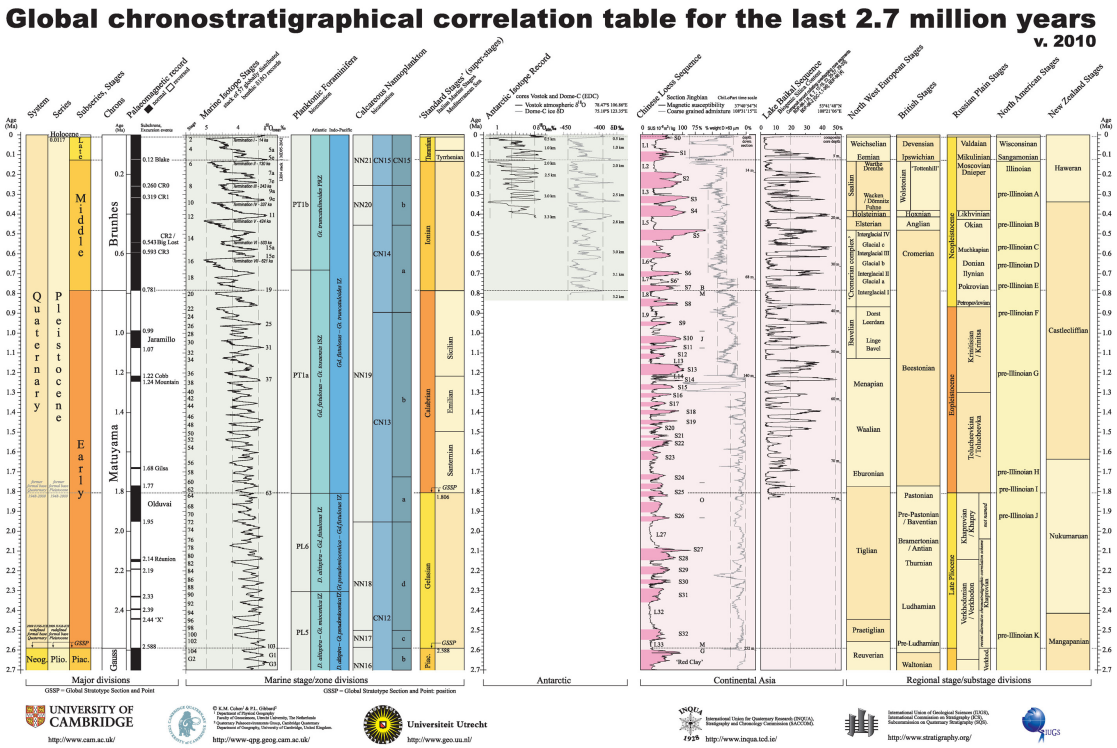


Figure 2.2 The International Commission on Stratigraphy's International Stratigraphic Chart for the Quaternary Period. (www.stratigraphy.org/upload/QuaternaryChart1.JPG)

Paleoecological Approaches and Data

Palaeoecological reconstructions draw on a variety of datasets that, because of their sensitivity to climate or environment, can be used as evidence of past environmental conditions. Such proxy data can be temporally discontinuous information, as in the case of plant remains preserved in packrat middens or fossil vertebrates, providing a 'snapshot' of conditions and biota during a particular period. Ideally, they are continuous or nearly-continuous time series, such as tree-ring records or lake-sediment profiles, in order to examine ecological change on fine temporal scales. Some stratigraphic proxy span hundreds of thousands to millions of years, as in the case of trace atmospheric gas records entombed in Antarctic ice cores or foraminiferal data from long marine cores, whereas other time series offer seasonal to annual resolution for the last few centuries, such as tree-ring data.

Palaeoecological studies that describe vegetation history generally span centuries to millennia and utilize fossil pollen, plant macrofossils and other plant remains. Chronologies for such records come from incremental age models, such as counting annually laminated lake sediments, or from radiometric dating methods, primarily radiocarbon (^{14}C) dating of terrestrial organic remains and lead-210 (^{210}Pb) dating of recent sediments. Radiocarbon dating is by far the most widely used technique for developing late-Quaternary chronologies, and age determinations are made on small fragments of terrestrial plants, charcoal particles, and sometimes on organic lake sediments. Calibrated radiocarbon years incorporate the effect of variations in radiocarbon production in the atmosphere, the impact of climate cycles, storage in

different carbon reservoirs, and the effects of human activity. Age models are mathematical constructs that use a sequence of individual dates from a sedimentary record to develop an interpolated chronology for the entire time series. The veracity of radiometric dates and the age model can sometimes be determined by comparison with independent time-stratigraphic markers, such as a volcanic tephra of known age, the presence of pollen from an non-native plant species with a known invasion history, variations in palaeomagnetic field strength that have been dated elsewhere, or other historic events with a detectable signature.

Historical sciences, like palaeoecology, often answer questions through an iterative process of testing multiple working hypotheses. Plausible hypotheses (explanations) are formulated at the outset of the study, and the data are used to evaluate the merits of each hypothesis and reject those that do not hold up to scrutiny. Some hypotheses are rejected outright, others are modified in light of new discoveries, and new hypotheses emerge during the course of an investigation. In the case of vegetation history, research and testable hypotheses have focused on reconstructing ancient ecosystems (including the individuals, populations, and communities therein) and their response to past changes in climate, disturbances, and human activity. The motivation is that understanding past ecological interactions will provide insight into those occurring at present and likely in the future. Broad-scale investigations are often concerned with understanding the hierarchy of climatic and nonclimatic drivers that have shaped ecosystems at a variety of spatial and temporal scales.

Sediment cores from natural lakes and wetlands are the best source of information on the history of terrestrial environments. Fossils, geochemistry and other proxy preserved in the layers of sediment provide a record of conditions in the watershed through time. Such records begin when the lake was first formed, and they end with the uppermost layer deposited in the current year. Most natural lakes and wetlands were created by ice recessional processes following the LGM, but lakes can also formed following volcanic eruptions or as a result of fluvial processes, landslides, and coastal aggradation. Boreal wetlands are features of deglaciation but wetlands can also be formed by coastal, fluvial and other geomorphic processes that damn waterways or impound natural springs. Selection of a lake or wetland site for study is based on decisions about whether the vegetation, geological substrate, and climate of the location are representative of a particular region. A good research question in palaeoecology has importance beyond the boundaries of the study or site (i.e., it is one that addresses a timely scientific question or that proposes to look at old findings with a new, possibly transformative approach). In addition, such a research question can be answered by thoughtful selection of study sites, critical examination of multiple palaeoecological proxy, and a plan for using site results to gain broader inference.

Types of Proxy Data in Paleoecological Studies

In this section, we discuss different sources and types of palaeoecological proxy data and provide examples of studies that have employed them. Of particular importance are the temporal and spatial scales that each type of proxy data addresses (Figure 2.1).

Temporal scales include annual, decadal, centennial and millennial. Spatial scales range from meters to many hundreds of kilometers.

Proxy Data of Terrestrial Ecological Change

Tree-Ring Data Most temperate tree species (i.e., those growing between 25–65° latitude) produce annual growth rings. Tree rings can be sampled using a simple coring device that extracts a pencil-width core of wood from the bark to the pith of a tree. Cores are prepared for analysis by simple sanding and polishing procedures. Rings are sequentially counted to provide the age of a tree. The varying width of rings over time provides information about the environmental and climate history of a locale. By analysing the pattern of ring widths, insight can be gained into the conditions under which the tree was subjected over the course of its life. The ring patterns are analogous to bar codes that can be matched to nearby trees. It is by matching or 'crossdating' the distinct pattern of ring widths between living and dead trees that a tree-ring chronology can be constructed. Dating by tree rings is called 'dendrochronology'. Crossdating is a straightforward concept but complicated by differences in growth rates among individual trees, local factors and the occasional problem of missing rings because of poor growing conditions. It is important to sample many trees in an area to overcome these issues.

Dendrochronological data cover a timespan of centuries to millennia at annual-to-interannual resolution. Tree-ring studies have been conducted on six continents. Tree-ring data is utilized to make ecological and climatological inferences about the past. These data have also been used to study the history of fire – this will be discussed later in the chapter.

Dendroecology is the application of tree-ring analysis to ecological questions. One major area of research in this subdiscipline is forest disturbance dynamics. This research area seeks to reconstruct and understand forest dynamics as driven by external disturbances both biotic (e.g., insect outbreaks) and abiotic (e.g., fire, flood, windthrow). Investigations often focus on identifying the timing and spatial extent of tree-growth releases or suppressions and cohort establishment events.

Dendroclimatology is the study of past climate using tree-ring data. Climate records are developed by comparing ring-width patterns with modern climate data to build a calibration function. The instrument-based calibration is then used to convert the tree-ring record from the earlier, pre-observational period and estimate variations of the climate variable back in time. A major strength of tree-ring climate proxy data is that reconstructions can be replicated across large spatial networks. The North American Drought Atlas contains a 2005-year-long record of yearly drought estimated from 835 tree-ring chronologies (Cook et al., 2004; http://iridl.ldeo.columbia.edu/SOURCES/.LDEO/.TRL/.NADA2004/pdsiatlashtml/pdsiviewmaps.html). These data show that long-lived severe droughts have been a feature of North American climate for centuries and had negative consequences for some pre-industrial societies (e.g., Munoz et al., 2014; Stahle et al., 1998).

Pollen Data The assemblages of pollen grains in lake, wetland and bog sediments preserve the record of past vegetation and data derived from pollen studies can be used to provide an indication of the response of vegetation to climate and environmental changes as well as to human impacts over thousands of years. Pollen is produced by angiosperms

(flowering plants) and gymnosperms (seed-producing plants), and not surprisingly, wind-pollinated species that produce a lot of pollen each year are more abundant in the sediments than insect-pollinated species. Pollen falls on the surface of a body of water and becomes incorporated in the sediment and cores can be extracted from the sediment accumulated at the bottom of a lake, wetland or bog. The temporal scale of a pollen record depends on how fast sediment accumulates in a lake or wetland basin. Typically records of vegetation change derived from pollen analysis have centennial-scale resolution. However, greater temporal resolution can often be achieved if the research questions require it. The spatial resolution of pollen records varies from site to site and is often not well resolved. The size of sample lakes and wetlands strongly influences pollen source area and smaller (< 0.5 ha) sites are preferred to provide vegetation histories at the watershed scale (Ritchie, 1987).

In order to perform pollen analysis, sediment samples are taken at regular intervals in the lake/wetland/bog sediment core, and these samples are treated with a variety of chemicals to remove all the constituents except the pollen grains (see Chapter 21). The residue of pollen is mounted on glass slides and examined under the microscope at magnifications of 400–1000x. Pollen grains (generally between 25-100 microns in size) are identified by comparison with modern reference material and published atlases. Typically, 300–400 pollen grains are tallied for a given sample in the core, and it can take a trained analyst two or three hours or more to ‘count’ a sample. The ability to assign a pollen grain to a particular plant taxon is variable and the taxonomic resolution limits interpretation in some cases. For example, grass pollen cannot be identified below the

taxonomic level of family (Poaceae), so it is not possible to determine whether the grass pollen comes from alpine, steppe or riparian species. Most pollen grains are securely identified to the level of genus or family but species identifications are often inferred by phytogeography. The presence of seeds, needles and other plant remains in the core also provides species identifications in cases where pollen cannot. A typical pollen record from temperate latitudes will include about 50 different pollen types from trees, shrubs and aquatic plants.

Pollen counts at each level in the sediment core are converted to percentages and accumulation rates, and changes in the proportion of different taxa through time are the basis for interpreting past vegetation. Because pollen does not have 1:1 relationship with the plants that produce it, modern studies are used to interpret past pollen assemblages. Modern pollen information comes from the surface sediments of lakes or pollen traps set out by researchers. The number and quality of surface pollen studies varies from place to place. In North America and Europe hundreds of surface samples have been collected and provide excellent calibration for the interpretation of pollen data through time (www.neotomadb.org).

As an example of the application of pollen data to understand past vegetation and climate, Williams et al. (2004) produced a synthesis of the late-Quaternary vegetation history in northern and eastern North America, examining changes across different levels of ecological organization from individual taxa to biomes. Broad-scale features of vegetation history emerged by comparing the records from multiple sites, and these could be compared with site-specific features that described local responses at individual sites.

Different aspects of past vegetation dynamics were revealed by individual pollen time series, pollen maps, dissimilarity measures and estimates of temporal rates of vegetation change. The synthesis suggested that distribution and composition of vegetation were relatively stable during the LGM and during the mid- to late Holocene (last 6000 years). This stability was in contrast to the rapid changes that occurred during the late-glacial period to early Holocene transition (14,000–6000 years ago) and in the last 500 years. The history of particular pollen types suggested that the dominant tree species behaved independent of each other in their response to past climate change, and shifts in range were attributed to changes in regional moisture patterns, causing west-to-east responses and changes in temperature evidenced by south-to-north shifts. Some of the common plant communities today developed in the early Holocene, but there are also vegetation types common to the late-glacial period (e.g., *Picea*–Cyperaceae–*Fraxinus*–*Ostrya*/*Carpinus*) that no longer exist. The study is an excellent example of how vegetation changes across multiple spatial and temporal scales and the use of pollen data to reconstruct the distribution, composition and structure of plant communities over time.

Plant Macrofossils Macroscopic remains of plants, including seeds, leaves, needles and fruits, can be found in most deposits suitable for pollen analysis (Birks, 2013). The best sites for these types of records are wetland sites or the littoral margins of lakes within steep catchments, where the opportunity for slopewash or stream input to deliver organic detritus is increased. Species identifications provided by these remains complement pollen-based interpretations by providing greater taxonomic resolution and also confirming the local presence of particular plants (unlike their pollen which can be

transported long distances). In wetland deposits, the identification of bryophytes has offered useful information on temperature and hydrologic conditions (Mauquoy and van Geel, 2013). While the majority of plant remains in lake sediments are from aquatic taxa, the less common occurrence of terrestrial plant macrofossils has helped resolve important points in vegetation history (Jackson and Weng, 1994).

Packrat Middens In semiarid regions, packrat midden data provide important vegetation information from semi-arid regions where lake-sediment pollen records are rare (Betancourt et al., 1990). The middens of packrats (21 different species of *Neotoma*) and other nest-building mammals are composed of plant material cemented into caves and rock crevices by urine. In dry settings, these nests are preserved for thousands of years, entombing plant remains of past vegetation as a series of cemented layers. The preservation of plants in midden deposits is excellent, and the remains have been used to reconstruct the local plant communities and population dynamics as well as make broader inferences about climate through the analysis of isotopic signatures and stomata density. Vegetation reconstructions depend on understanding the foraging area and dietary preferences of packrats, as well as the factors that may have led to differential preservation of the remains also pose challenges for interpretation (Elias, 2013; Finley, 1990).

In the American Southwest, plant assemblages in packrat middens that date to the LGM indicate large downslope shifts in the biogeographic range of subalpine conifers, such as *Pinus longaeva* and *Pinus flexilis*, as a result of cool humid conditions. Midden studies have also been used to trace the migration history of conifer species during the

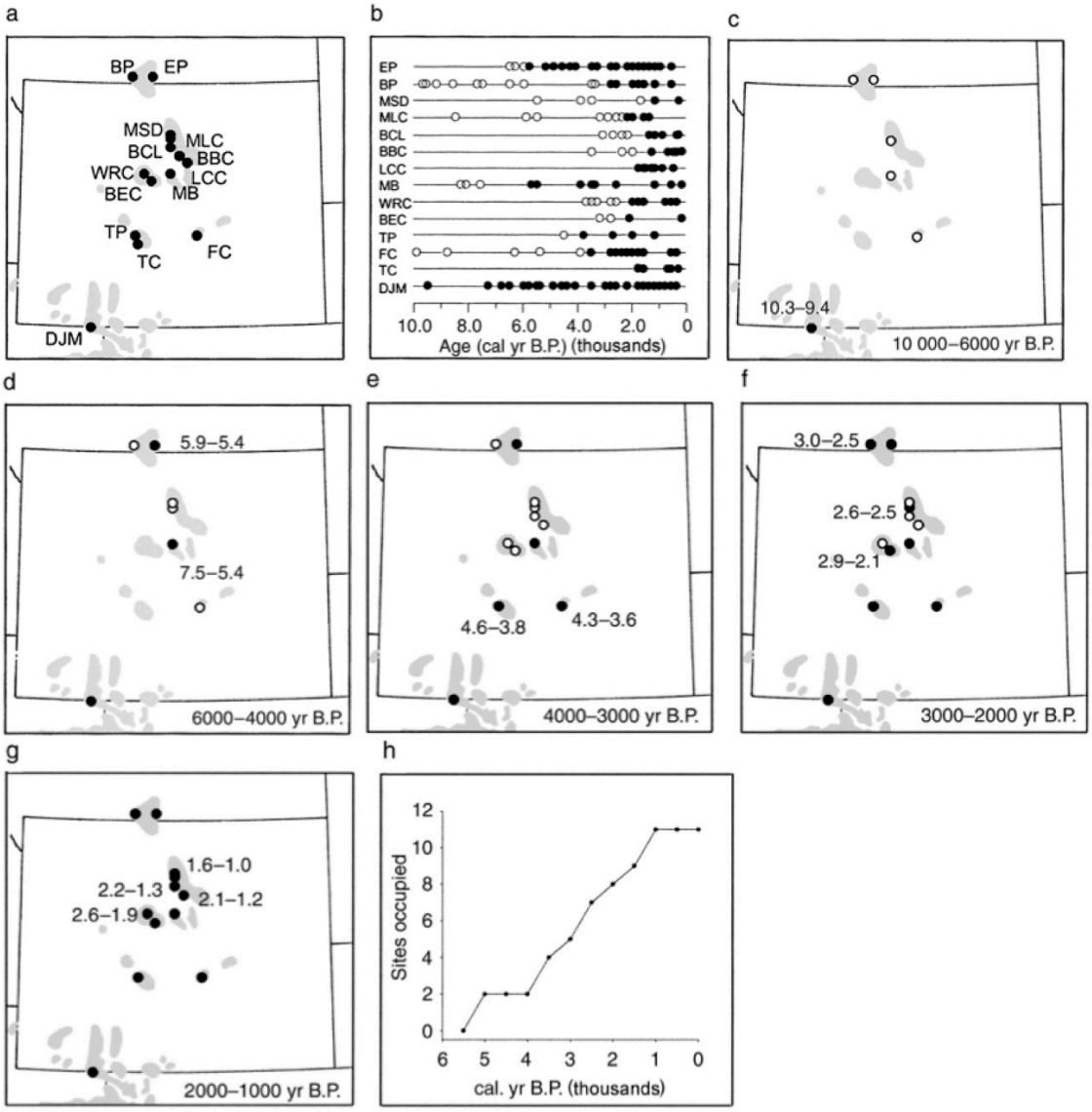


Figure 2.3 The location of woodrat-midden records of Utah juniper invasion in Wyoming and adjacent regions. Calibrated dates given in thousands of years before present (ka). (a) Locations of woodrat-midden study sites (black circles) and modern distribution of Utah juniper (grey circles) in Wyoming and adjacent states. (b) Holocene records of presence (filled circles) and absence (open circles) of Utah juniper macrofossils from woodrat middens at 14 sites. (c) Map of presence (filled circles) and absence (open circles) of Utah juniper macrofossils in woodrat middens dating between 10 and 6 ka. (d) Presence and absence of Utah juniper macrofossils between 6 and 4 ka (e) Presence and absence of Utah juniper between 4 and 3 ka. (f) Presence and absence of Utah juniper between 3 and 2 ka. (g) Presence and absence of Utah juniper between 2 and 1 ka. (h) Number of study sites occupied by Utah juniper as a function of time in the mid-to-late Holocene. Source: Lyford et al., 2003: 576/7. © 2003 by the Ecological Society of America.

Holocene. A recent study of remains of Utah juniper (*Juniperus osteosperma*) in packrat middens document its spread into Wyoming and Montana during the Holocene (Lyford et al., 2003). Utah juniper became established first in northeast Utah in the early Holocene about 9000 years ago (Figure 2.3 a–h). In mid-Holocene the species had advanced into central Wyoming and southern Montana.

Because of the wide distribution of packrat middens in the region, it was possible to study the dispersal, landscape structure, and climate variability that governed the spatial and temporal patterns of the juniper establishment (Lyford et al., 2003).

Fire Two forms of primary proxy data have been used to study the history of fire on the landscape: tree-ring data and charcoal particles from lake, bog, small hollow and wetland sediments. Tree-ring data are widely used to reconstruct the timing and occasionally the extent of past fires. Fires that are not severe enough to kill trees often leave distinctive scars that can be used to determine the exact calendar year a fire occurred. These ‘fire scars’ are preserved within tree-ring sequences. Fire-scar chronologies have been compiled at local-to-regional scales in many regions including western North America and southern South America (Swetnam, 2002; Veblen et al., 2003; Falk et al., 2011). The fire-scar network for western North America includes over 800 fire chronologies spanning centuries. This network shows a close correlation between drought years and years with extensive fire activity (Swetnam, 2002). Fire-scar networks can be created and analysed at a range of spatial scales, from trees and stands to subcontinents, revealing different patterns and processes at different scales (Falk et al., 2011). In forests where few fire scars are present, stand-age analysis has been used to

reconstruct the dates of past fires. This method requires the dating of a large number of trees in an area in order to determine when even-aged cohorts of trees became established. Pulses of tree regeneration occur after fire and other disturbances such as insect outbreaks, thus determining the age of tree cohorts in a forest allows researchers to determine the timing of forest disturbances.

The fire-scar network in western North America shows that large-scale climate teleconnections strongly influence fire activity on a sub-continental scale. A study by Kitzberger et al. (2007) employed both dendroclimatological methods and a large network of fire-scarred trees in the western United States in order to examine the links between large-scale climate teleconnections and fire activity. Three climate indices – El Nino Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multidecadal Oscillation (AMO) – were reconstructed using tree-ring chronologies from the U.S. and Mexico in the case of ENSO and PDO, and Finland, France, Italy, Jordan, Norway, Russia, Turkey, and the U.S. in the case of AMO (Kitzberger et al., 2007). The fire-activity record was composed of individual fire chronologies from 238 sample sites. Synchronous fire activity across the sample sites was compared to the climate indices. The study found the warm phase of AMO has synchronized fire activity over multidecadal timescales in the western U.S. for the last 500 years (Figure 2.4; Kitzberger et al., 2007).

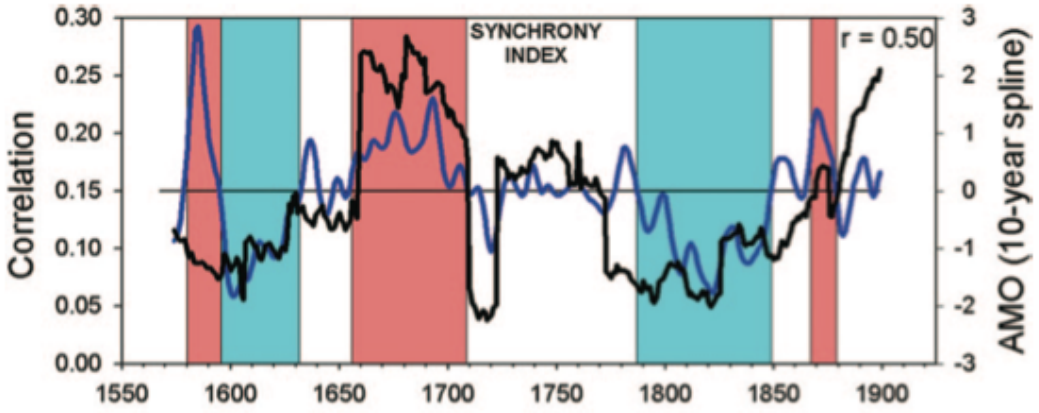


Figure 2.4 Comparison of Fire Synchrony Index and the Atlantic Multidecadal Oscillation (AMO). The indices of fire synchrony reconstructed from tree-ring data (50-year moving correlations between selected regions, black line) compared with a 10-year spline of reconstructed AMO (blue line). Light blue and light red shaded areas indicate periods of low and high AMO, respectively. The association of AMO and continental-scale synchrony of fire across western North America is consistent with the role of AMO in determining patterns of drought across the western U.S. Fire was strongly synchronous across western North America during 1650–1770 (except 1710–1725) and after 1880 and weakly synchronous during 1550–1649 and 1750–1849. The highest degree of fire synchrony occurred from 1660–1710, coincident with the longest and warmest phase of the AMO during the past five centuries. Conversely, the lowest degree of fire synchrony occurred from 1787–1849, coincident with the coldest phase of the AMO. Source: Kitzberger et al., 2007: 546. © (2006) National Academy of Sciences, U.S.A.

The second palaeofire proxy are the charred pieces of wood, leaves and grass deposited and preserved in anaerobic environments such as bogs, lakes and wetlands (Brown and Power, 2013). The charcoal from sediment cores from these depositional environments are used to reconstruct fire activity over thousands of years. This method of fire-history research is based on extracting the charcoal from contiguous intervals of sediment cores and examining them under the microscope. Generally two different size classes of particles are analysed: microscopic and macroscopic charcoal. Microscopic particles are counted from pollen slides at a magnification of 400x, while macroscopic pieces greater than 125 microns (μm) are isolated from the sediment and analysed at 40x

magnification. Microscopic charcoal can travel long distances before settling in a lake, and it is not typically analysed at continuous intervals. Macroscopic charcoal comes fires within a radius of < 20 km of the lake (Higuera et al., 2009). It is analysed in every sample throughout a core and used to reconstruct local-scale fire episodes (Whitlock and Larson, 2001). Macroscopic charcoal data are converted to charcoal accumulation rates (number of particles cm^{-2} yr^{-1}). As with pollen and tree-ring data, modern studies are used to calibrate and inform the interpretation of charcoal abundance in the pre-observational period.

Analysis of charcoal is undertaken in order to determine and describe the fire regime of a particular area of study. A fire regime describes the characteristics of fire (frequency, size and severity) and its role in a particular ecosystem. A suite of climate, fuel, and landscape variables are required for fire to occur and spread, but their relative importance changes across spatial and temporal scales. Recent advances in statistical methods of charcoal analysis have added to our understanding of past fire regime characteristics (e.g., Higuera et al., 2009; Kelly et al., 2011). Figure 2.5 summarizes the most commonly reconstructed fire regime metrics, including charcoal accumulation rates, background charcoal and mean fire return intervals.

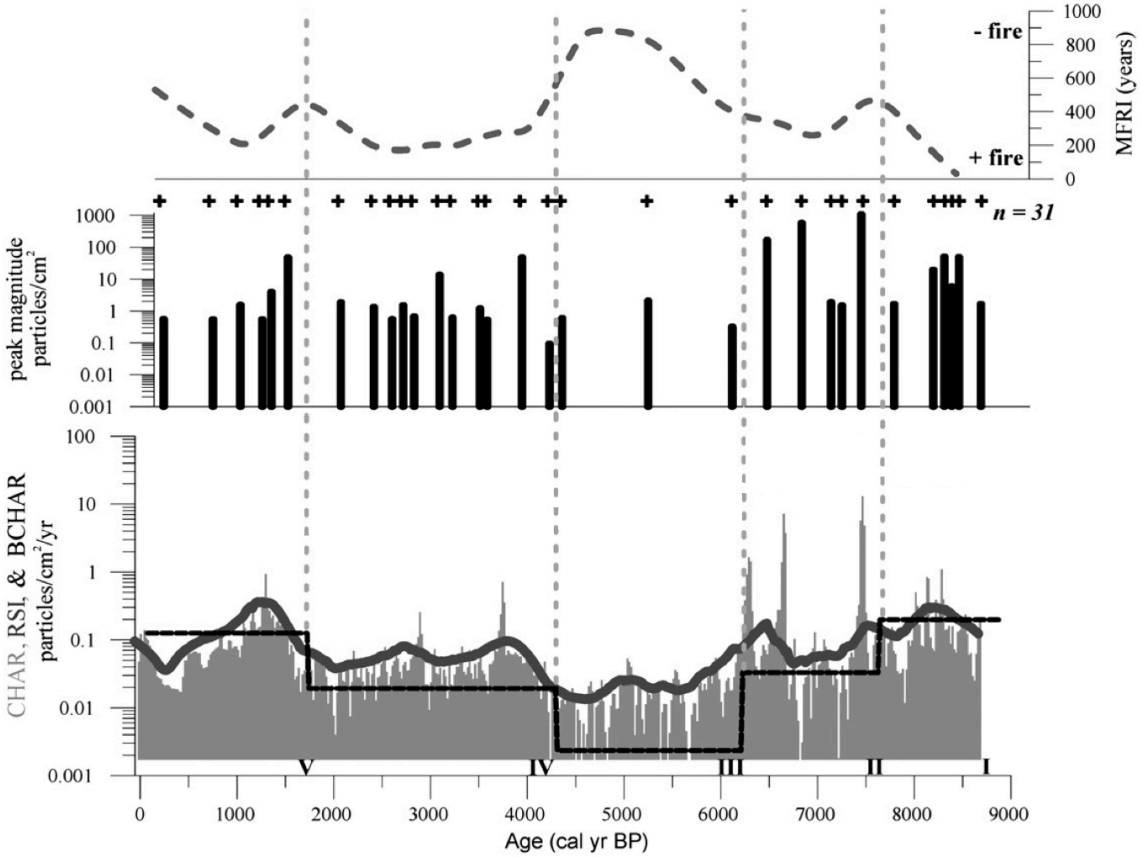


Figure 2.5 Charcoal data from Morris Pond, Utah, USA over the past 9,000 years. This figure summarizes the typical metrics of a fire regime that charcoal data has been used to reconstruct. The top panel shows the Mean Fire Return Interval (MFRI). This metric reflects the frequency of fire through time at the site. The second panel shows statistically significant peaks in fire activity and the associated magnitude of the peaks. These peaks are interpreted as local (within 1–3 km) fire episodes. Peak magnitude is a measure of the total charcoal deposition for a fire episode and often reflects the type and amount of vegetation that was burned. The bottom panel shows Charcoal Accumulation Rate (CHAR), Background Charcoal (BCHAR), and the regime shift index algorithm (RSI). CHAR is the measure of the number of charcoal particles per cm^2 per year. Background charcoal (BCHAR) is the slowly varying trend in CHAR and changes in this metric often represent variability in the abundance of fuel or biomass at the site (for example, forests produce more charcoal than grasslands or tundra). The RSI was used to identify statistically significant changes in BCHAR and delineate fire regime zones. The dashed vertical lines indicate fire regime zones derived RSI. Source: Morris et al., 2013: 30. © 2012 University of Washington. Published by Elsevier Inc.

In a regional-scale study from the South Island, New Zealand, McWethy et al. (2009) explored changes in fire activity after Polynesians arrived on the island ca. 1280

CE. Prior to this time, New Zealand was uninhabited by humans and fire was infrequent and ecologically insignificant. The approach of this study was to investigate regional trends in biomass burning by reconstructing local-scale fire activity at many watersheds across a climatic gradient from high to low precipitation. The study also examined climate to determine if temperature anomalies may have contributed to flammability in the decades after human arrival. In order to reconstruct watershed-scale fire activity, high-resolution macroscopic charcoal was analysed in continuous samples through the sediment core. Individual records showed very low levels of fire prior to human arrival, a period of high fire activity, represent one to a few fires, followed by low fire activity until the time of European arrival. Comparison of several charcoal records across the South Island revealed the regional patterns of fire activity over the last 1000 years (Figure 2.6). A period of high fire activity lasting a few decades was evident in all but the wettest and highest elevation sites, although the dates of this period varied. This Initial Burning Period marked the arrival of Māori to the island and the rate of deforestation at this time suggests deliberate and targeted use of fires (Perry et al., 2012). Following the Initial Burning Period, Māori maintained low level fires to sustain vital resources. The study found that fires were not associated with anomalous summer temperatures, and thus the influence of climate on the fire activity was negligible. This study is a good example of using charcoal analysis to test hypotheses of the drivers (human vs. climatic) of fire activity.

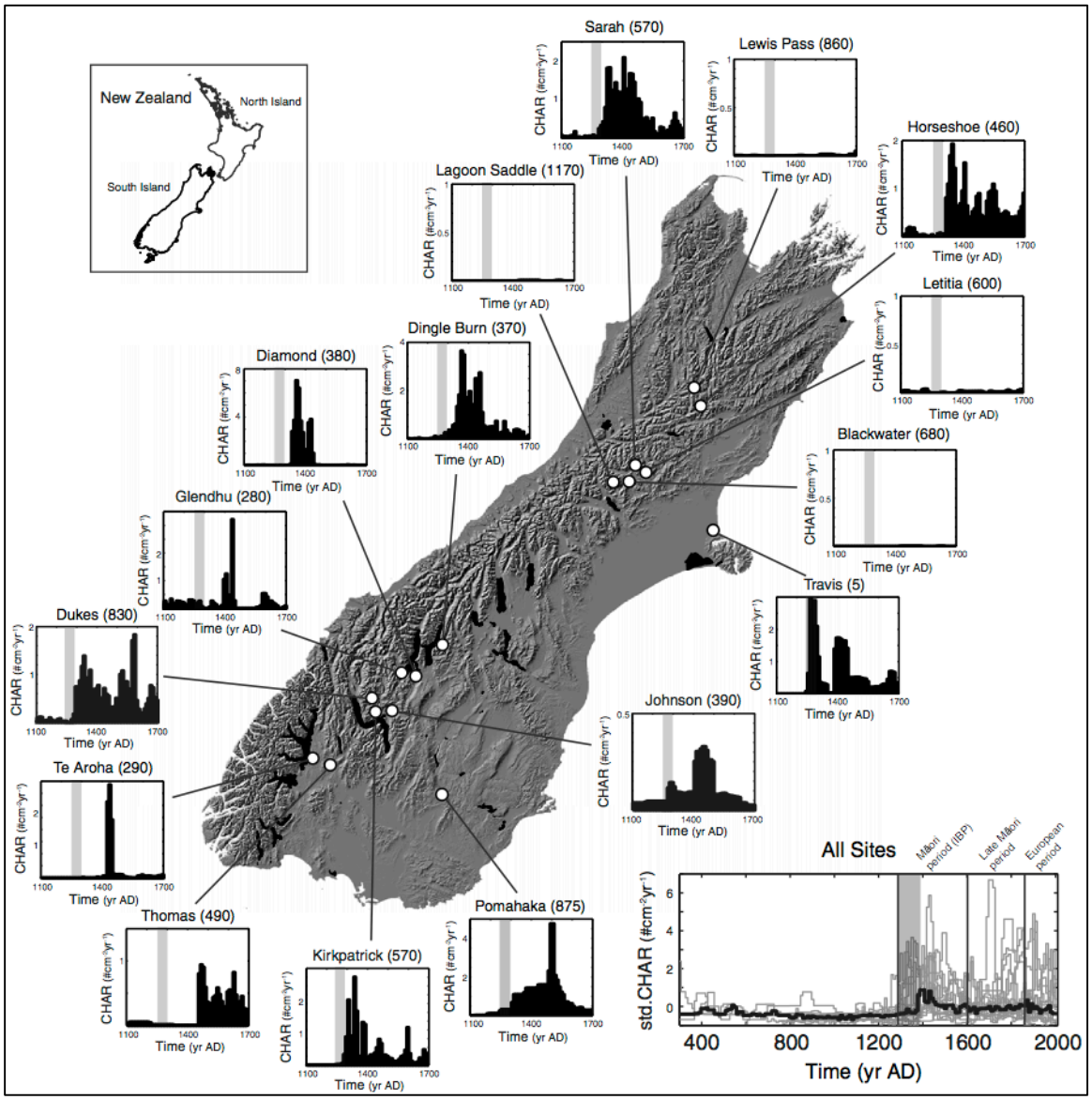


Figure 2.6 Local-scale charcoal records from 16 sites on New Zealand's South Island. Most records have a clear peak in fire activity within 200 years of human arrival implicating anthropogenic burning as the ignition source of these fire events. Source: McWethy et al. 2010: 21344. © The National Academy of Sciences of the USA.

Dung Fungal Spores Dung fungal spores in lake, bog and wetland sediments are a proxy data source that has rapidly gained use in the last decade (Gill et al., 2013). These fungi are a type of coprophilous fungi that grow on animal dung. They require herbivore digestion to complete its life cycle, producing spores on the dung of mammals.

Palaeoenvironmental reconstructions that incorporate dung spore analysis hold promise as a proxy for the presence and perhaps abundance of large herbivores. These animals can have strong effects on ecosystems by maintaining vegetation openness and patchiness, removing material that would otherwise fuel landscape fire, dispersing seeds, and physically disturbing soil and recycling nutrients (Rule et al., 2012).

The dung fungal spores of the genera *Sporormiella*, *Sordaria* and *Podospora* are the three most reliable indicators of large herbivore activity (Baker et al., 2013). The spores are transported to lakes and other depositional environments by slopewash. The relationship between the amount of dung spores in sediments is influenced by both the abundance of dung in the watershed as well as its distance from the lakeshore. The methodology for quantifying dung spore source area and large herbivore population size is still developing. Reconstruction of herbivore densities has been performed using accumulation rates (number of spores/cm^2/year), and percentage in relation to the pollen sum. The use of accumulation rates is thought to be a superior approach as relative percentage does not provide a proxy for herbivory (plant consumption) that is independent from vegetation changes (Baker et al., 2013).

A number of recent palaeoecological studies have used *Sporormiella* spores to investigate the question of the timing and impacts of megafaunal decline (e.g., Robinson et al., 2005; Davis and Shafer, 2006; Gill et al., 2009; Rule et al., 2012). A study from northeast Australia examined the population collapse of megafauna that occurred around 40 thousand years ago shortly after people first arrived on the continent. This study reconstructed vegetation, fire and *Sporormiella* between 3,000 and 130,000

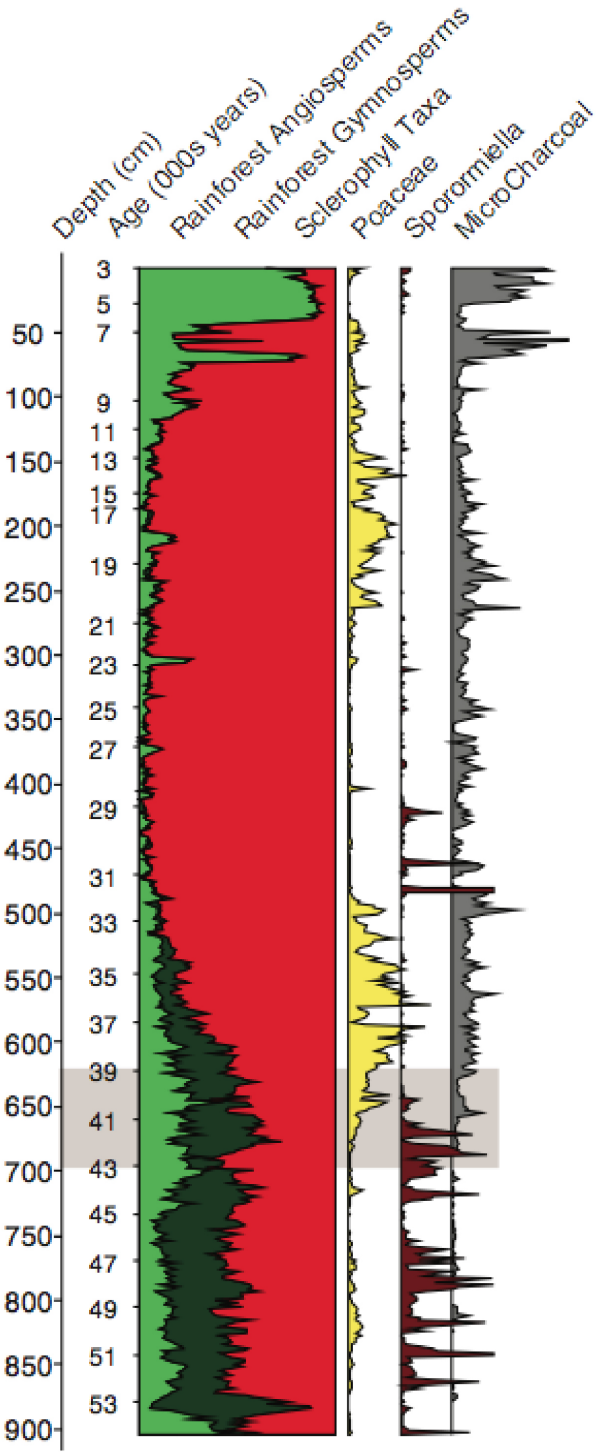


Figure 2.7 Pollen, charcoal and *Sporormiella* diagrams for Lynch's Crater, northeast Australia. The interval during which *Sporormiella* declined and charcoal first increased is shaded grey. A large shift in vegetation from a rainforest to sclerophyll assemblage is evident in the millennia following *Sporormiella* decline and charcoal increase. Source: Rule et al., 2012: 1484. © Science.

years ago with a special emphasis on the period between 39,000–43,000 (Rule et al., 2012). *Sporormiella* declined markedly between 40–41,000. This decrease was followed by an increase in charcoal and the pollen of grass and sclerophyll shrubs that tolerate frequent fires (Figure 2.7). This transition in vegetation in the absence of major climate perturbations thus it appears the mass extinction of megafaunal triggered major changes to vegetation and ecosystem functioning.

Supporting Limnologic Proxy Data

Diatoms Diatoms are algae in the division Bacillariophyta that occur in almost all aquatic environments (Jones, 2013). The siliceous skeleton or frustule of these microscopic unicellular organisms is identifiable to the species level and provides information on aquatic conditions that can be tied to changes in nutrients, water temperature, pH, and light penetration. Quaternary diatom remains have proven useful as indicators of local limnologic conditions and used to reconstruct past lake-level changes, water chemistry variations, and human disturbances of lake ecosystems. They are found in a wide range of aqueous or subaqueous environments as benthic (bottom dwelling), epiphytic (attached to plants), or planktonic (free-floating) and thus occupy a wide variety of niches. A key issue in diatom analysis is the accuracy with which diatom assemblages in sediments reflect the composition of the source communities and habitats from which they are collected. To this end, most analyses rely on comparison of the

composition of assemblages, as well as the physical limitations of indicator taxa (Korhola, 2013).

Diatom analysis has provided perhaps the strongest case for acid rain effects from industrialization. In a classic study, Battarbee et al. (1984) showed that changes in the assemblages of diatoms preserved in lake sediments provided evidence of 19th and 20th lake acidification in northwestern Europe and North America. The strong relationship between diatom occurrence and water pH allows reconstruction of past pH levels with remarkable precision. Although long-term acidification is a natural process for lakes in areas of resistant base-poor bedrock, diatom analyses of sediments spanning the last 150 years indicated rapid and unprecedented acidification.

In studies where diatom records have been developed at several sites, the limnologic reconstructions often show considerable variability that reflect local site-specific variability superimposed on climate change (Fritz and Anderson, 2013). In some cases, the variability is a result of the changes in vegetation, particularly the early colonization of plants following deglaciation and their impact on catchment nitrogen cycling (Fritz et al., 2004). In other locations, the differences reflect the influence of different substrates and the mineralogy of the parent rock on lake nutrients, pH, and water clarity (Bigler et al., 2002).

Chironomids Diptera: Chironomidae (non-biting midges) are a large taxonomic group of insects that live in most aquatic or semiaquatic habitats during their larval stages (Walker, 2013). The exoskeletal remains that are sloughed during larval molting accumulate in the sediments of lakes, and the well-preserved chitinous head capsules are

identifiable to species by comparisons with specimens of extant species. As with diatoms, information on the modern biology and habitat of individual taxa is the basis for environmental reconstructions. Paleoecological studies have focused on the development of quantitative calibration models (e.g., transfer functions) for the reconstruction of past environmental parameters based on the composition of the chironomid assemblage (Walker 2013). This calibration is then applied to time-series of chironomid remains to interpret past conditions. Some of the issues that vex specialists include misinterpreting past assemblages because modern samples are generally taken in summer (whereas the sedimentary record preserves the year-round assemblage); concerns about taphonomy and redeposition of fossil remains from different locations in the lake, thus misinterpreting the assemblage; differences in taxa abundance related not to the environment but to differences in the duration of larval life cycle and number of generation and larval stages; and differential preservation of more robust head capsules thus distorting the record (Brooks et al. 2012, Velle and Heiri , 2013).

Chironomid records have been studied in a variety of locations to reconstruct climate change, land-use and other human activities. For example, they have been used to examine the ecological consequences of eutrophication of temperate lakes; monitor water pollution related to industrial inputs and airborne pollutants; record acidification trends in lake sediments; and assess changes in water salinity through time. Because air temperature influences processes of emergence, swarming, and settling, statistical correlation between chironomid assemblages and July air temperature is often stronger than that of surface water temperature (Massoferro et al. 2009). Available records

indicate that chironomids can be successfully used to reconstruct temperature changes, especially if chironomid analysis is embedded in multiproxy, or multisite, studies.

Lithology, Geochemistry and Mineralogy Examination of the sediments, independent of their biotic constituents, provides information on the history of the watershed and the lake as an important context for palaeoecological reconstructions. A variety of non-destructive tools, including colour reflectance, digital imaging, radiography and X-ray imaging and CT scanning, are used in initial descriptions (Hodder and Gilbert, 2013; Kemp et al., 2001). Further analysis of the inorganic fraction of sediment, through mineralogical and geochemical analysis, has been used to identify changes in inorganic inputs to the basin that may relate to changes in erosion, windiness, pollution inputs and nutrients (Last, 2001). Variations in the authigenic (locally formed) carbonate content of the sediments can be a good measure of chemistry and pH changes related to water temperature. The organic component of the sediments is produced by different types of biota in from the lake and watershed (Meyers and Ishiwatari, 1993). Organic matter in lake sediments comes from the detritus of terrestrial plants to aquatic algae and bacteria, each with different chemical signatures. The original composition of organic matter may be further altered by biotic and abiotic processes, and the degree of alteration also contains important palaeoenvironmental information (e.g., the degree of water-column mixing).

The isotope compositions of authigenic and biogenic carbonates and diatom silica are commonly examined to better understand changes in temperature, precipitation patterns, evaporation and the carbon cycle. Fluctuations in the isotope composition of

authigenic or biogenic minerals are mainly a function of long-term changes in the balance between precipitation and evaporation as well as relative contributions between surface water and groundwater. Interpretation of isotope data from the various components within a lake sediment core requires a detailed knowledge and modern calibration of the processes that control and modify the signal; this must be determined for an individual lake system to establish the relationship between the measured signal, the isotopic composition of the host waters, and climate.

Multi-Proxy Records and Global Syntheses

Comparing multiple proxy data from a single site provides opportunities to reconstruct past environmental change within the whole watershed. A good example of this type of approach comes from Yellowstone National Park where a 9400-year-old core from Crevice Lake was analysed for pollen, charcoal, geochemistry, mineralogy, diatoms and stable isotopes to develop a nuanced understanding of Holocene environmental history (Figure 2.8; Whitlock et al., 2012). The pollen data indicated that the watershed supported a closed *Pinus*-dominated forest and low fire frequency prior to 8200 (calibrated) calendar years before present (cal yr BP; where present = CE 1950), followed by open parkland until 2600 cal yr BP, and open mixed-conifer forest thereafter. Charcoal data suggested that fire activity shifted from infrequent stand-replacing fires initially to frequent surface fires in the middle Holocene and stand-replacing events in recent centuries. Low values of $\delta^{18}O$ were evidence of high winter precipitation in the early Holocene, followed by steadily drier conditions after 8500 cal yr BP. Carbonate-

rich sediments before 5000 cal yr BP implied warmer summer conditions than after 5000 cal yr BP. High values of molybdenum (Mo), uranium (U), and sulphur (S) indicated anoxic bottom-waters before 8000 cal yr BP, between 4400 and 3900 cal yr BP, and after 2400 cal yr BP. Diatom assemblages suggested well-developed spring conditions and water-column mixing through much of the Holocene, but also revealed a period between 2200 and 800 cal yr BP with strong summer stratification, phosphate limitation, and

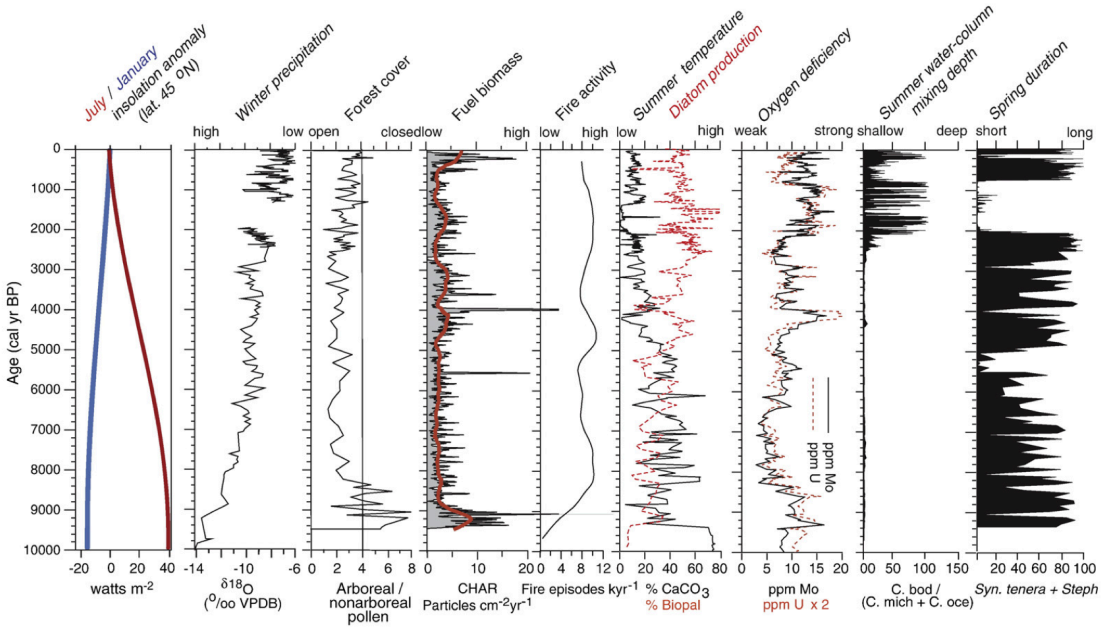


Figure 2.8 The summary of the environmental proxy at Crevice Lake over the last 9400 years. Shown plotted with July and January insolation anomalies. Source: Whitlock et al., 2012: 99. © 2012 Elsevier B.V.

oxygen-deficient bottom waters. Together, the proxy data implied wet winters, protracted springs, and warm, effectively wet summers in the early Holocene and less snowpack, cool springs, and warm dry summers in the middle Holocene. In the late Holocene, the region experienced extreme changes in winter, spring, and summer conditions, with

particularly short springs and dry summers and winters during the Roman Warm Period (~ 2000 cal yr BP) and Medieval Climate Anomaly (1200–800 cal yr BP). Long springs and mild summers occurred during the Little Ice Age (500–100 cal yr BP) and these conditions persist to the present. Although the proxy data indicate effectively wet summer conditions in the early Holocene and drier conditions in the middle and late Holocene, summer conditions were governed by multi-seasonal controls on effective moisture that operated over different time scales.

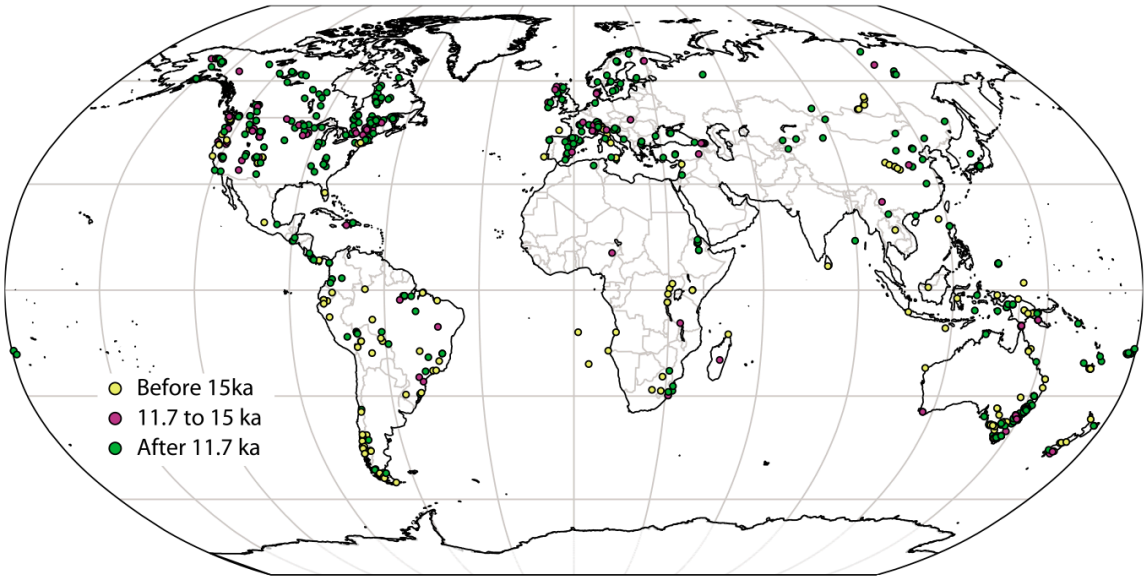


Figure 2.9 Map showing the location of charcoal records in the Global Charcoal Database version 2 (GCD v2). The database is maintained by the Global Palaeofire Working Group (www.gpwg.org/gpwgdb.html). Source: Daniau et al., 2012: 4. © 2012. American Geophysical Union.

Whereas multi-proxy comparison allows for in-depth analysis of a single site or a group of nearby sites, combining the records from a single proxy such as charcoal or pollen data affords the opportunity to reconstruct palaeoenvironmental history over a very large spatial scale. Continental- to global-scale syntheses of late glacial and Holocene fire

activity and vegetation distribution have been compiled and are the subject of ongoing research. Global-scale syntheses of fire activity have been compiled and analysed by the Global Palaeofire Working Group (www.gpwg.org; Daniau et al., 2013). The Global Charcoal Database (GCD v2) contains almost 700 sedimentary charcoal records from six continents (Figure 2.9). The general global pattern of biomass burning over the last 21,000 years shows a widespread increase associated with the transition from cold glacial to warm Holocene climates (Figure 2.10; Power et al., 2008; Daniau et al., 2012; Marlon et al., 2013). The influence of temperature on fire activity at this large scale is pervasive. The Palaeovegetation Mapping Project (known as BIOME 6000: Prentice and Webb, 1998) was developed to create fully-documented pollen and plant macrofossil data sets for 6750 and 21,000 cal yr BP, and to construct global maps of biomes for these time periods based on plant functional types and biomes. The BIOME 6000 database is publically available and updated with new datasets (www.bridge.bris.ac.uk/resources/Databases/BIOMES_data). The most recent version of the BIOME 6000 database (v4.2) has records for 11,166 modern sites, 1794 sites at 6750 cal yr BP, and 318 sites at 21,000 cal yr BP (Figure 2.11). Palaeovegetation datasets have been utilized to train and test palaeovegetation models (Figure 2.12; Kaplan et al., 2003; Prentice et al., 2011; Levavasseur et al., 2012) and to model past climate (Figure 2.13; Cheddadi et al., 1996; Ferrera et al., 1999; Bartlein et al., 2011).

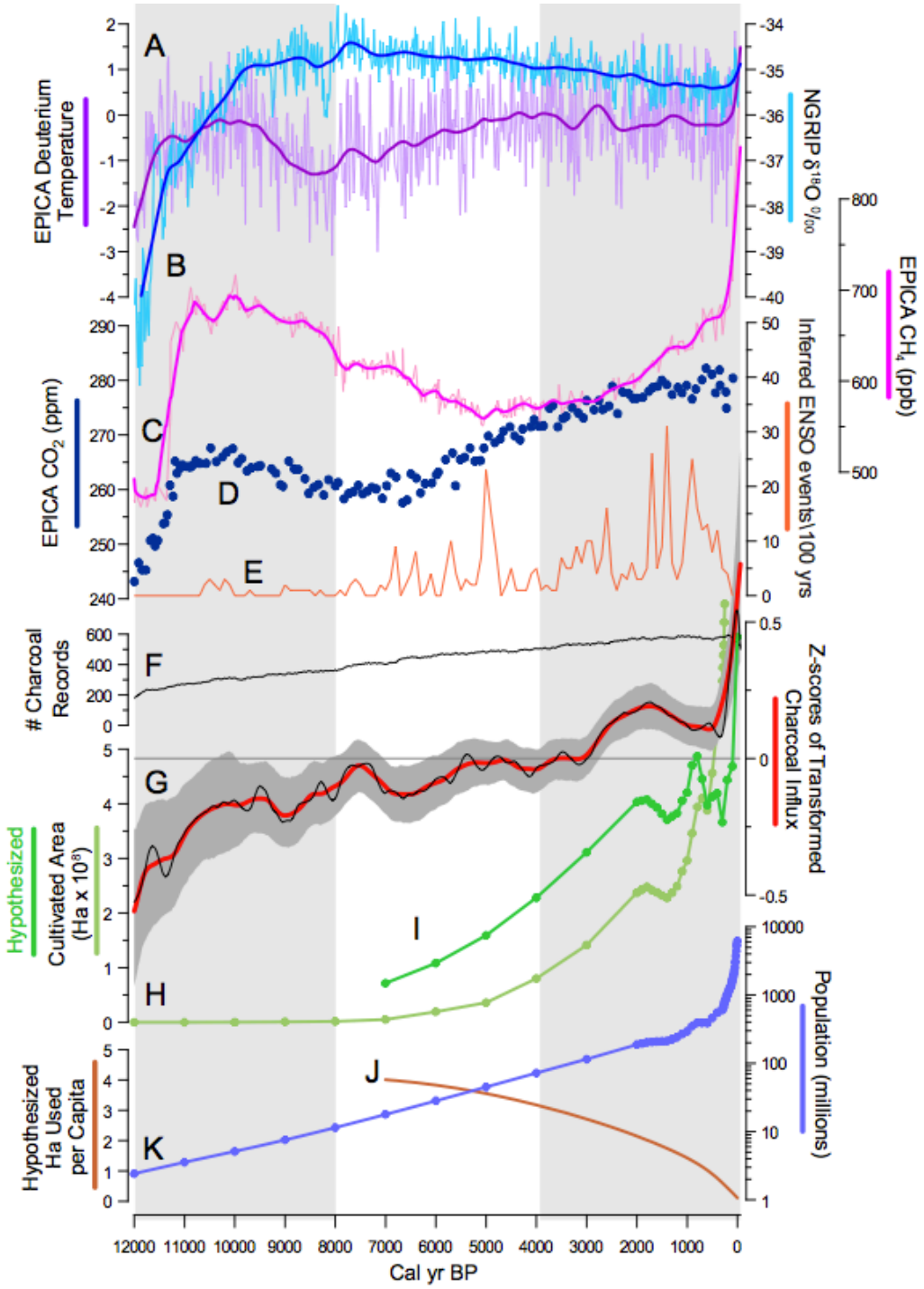


Figure 2.10 Comparison of 12,000 years of reconstructed global biomass burning and paleoclimate records and anthropogenic indicators. Globally fire was low at the beginning of the Holocene and increased during the Holocene (panel G). This trajectory is consistent with the global increase in temperature through the glacial-interglacial transition (panels A and B). Source: Marlon et al., 2013: 18. © 2013 Elsevier Ltd.

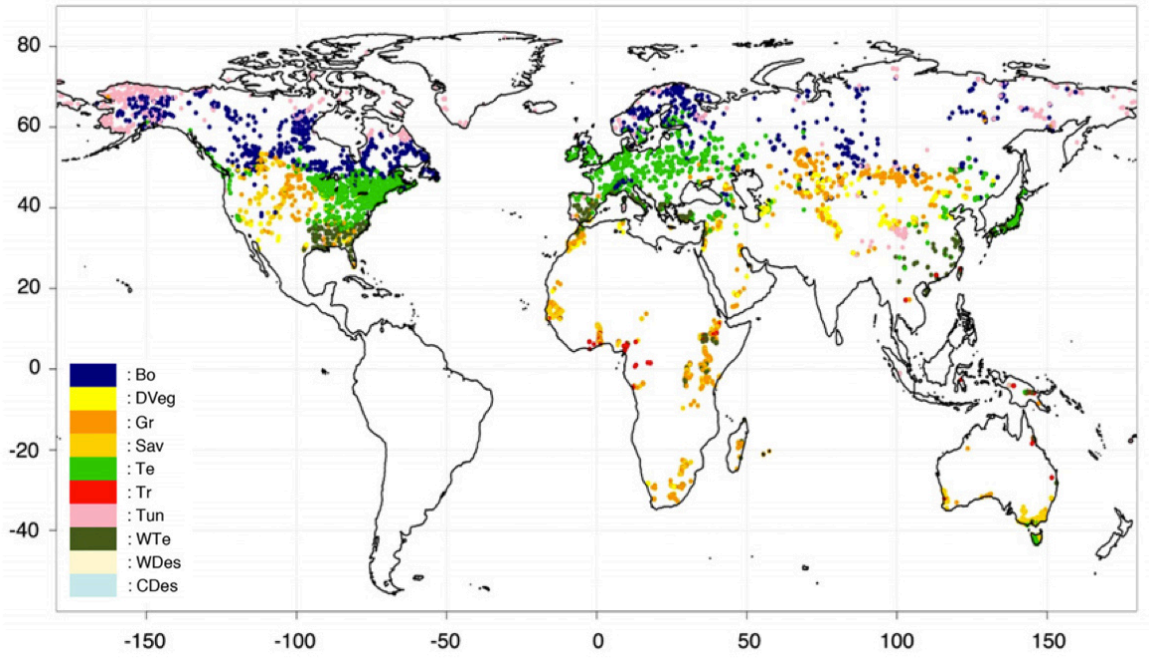


Figure 2.11 Pollen data collected in the BIOME 6000 database for the modern period (0 cal yr BP). In the legend, 'Bo' stands for boreal forests, 'DVeg' for desert vegetation, 'Gr' for grasslands and dry shrublands, 'Sav' for savannas and dry woodlands, 'Te' for temperate forests, 'Tr' for tropical forests, 'Tun' for tundra, 'WTe' for warm-temperate forests, 'WDes' for warm deserts and 'CDes' for cold deserts. Data from Prentice et al. (2000), Harrison et al. (2001), Bigelow et al. (2003) and Pickett et al. (2004), available online at www.bridge.bris.ac.uk/resources/Databases/BIOMES_data.

Important conclusions have been drawn from these synthetic efforts. They demonstrate that at a global scale fire is controlled largely by temperature (Marlon et al., 2013). Thus, while prehistoric humans likely influenced fire activity in certain locales, globally climate is the primary control. These syntheses are also important for data-model comparisons. Many vegetation and climate models operate at large spatial scales (for example at 0.5-1.0° grid cells) and in order to make meaningful comparisons, palaeoenvironmental reconstructions need also to be compiled at a large spatial scale. One critique of these global-scale syntheses is that there is an uneven distribution of data with a more dense concentration of sites in North America and Europe than in the other continents, which

may skew interpretation. Thus, it is important to support continued palaeoecological studies in Asia, Australia, South America and Africa and incorporate them into global databases.

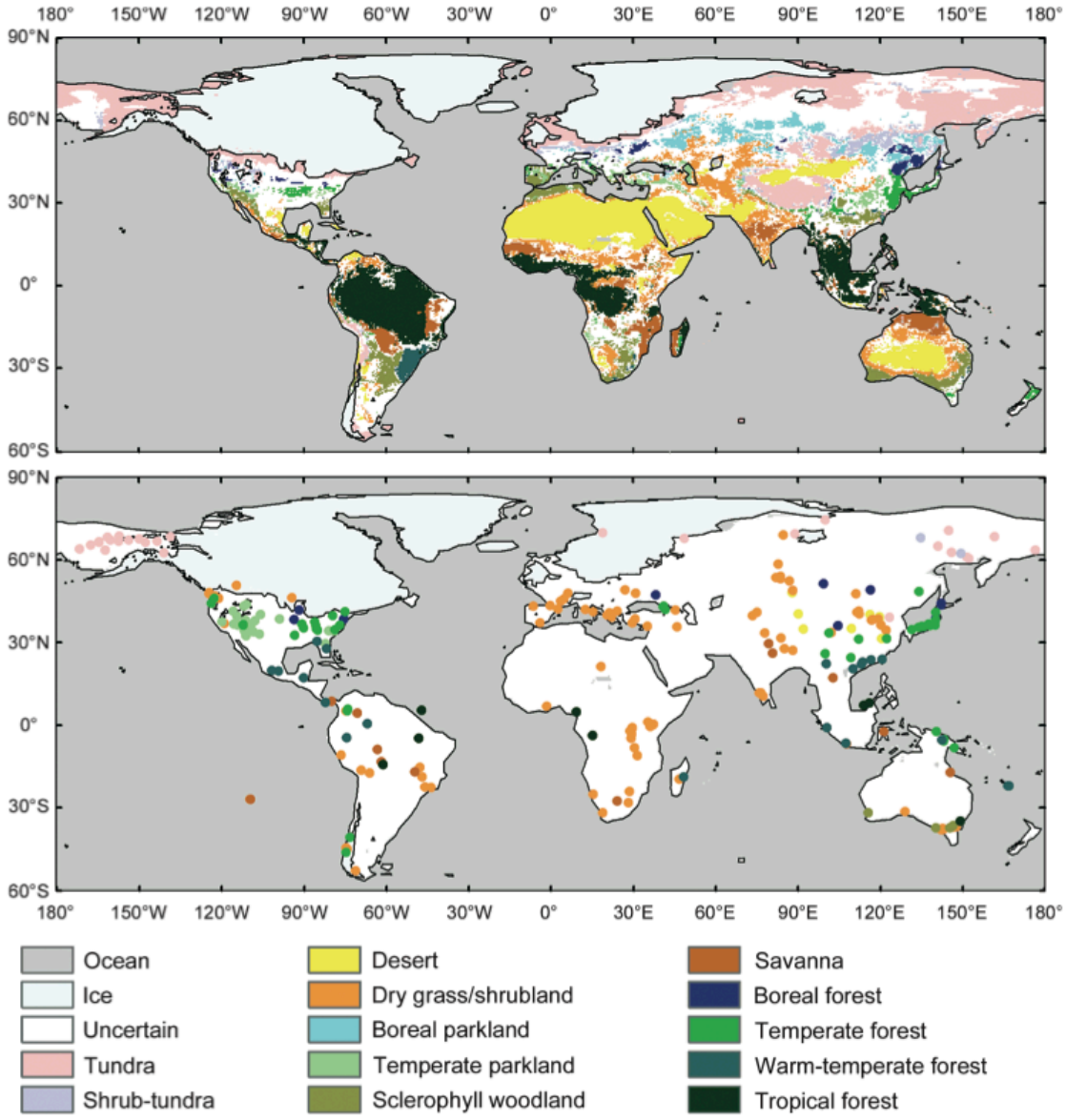


Figure 2.12 Data-model comparison of reconstructed vegetation at the Last Glacial Maximum. A comparison of simulated biome distribution at the last glacial maximum (LGM, 21,000 years ago) by the Land Processes and eXchanges (LPX) model (top panel) with LGM biomes inferred from pollen and plant macrofossil records compiled by the BIOME 6000 project (bottom panel). Source: Prentice et al. 2011: 993 . © 2011 New Phytologist Trust.

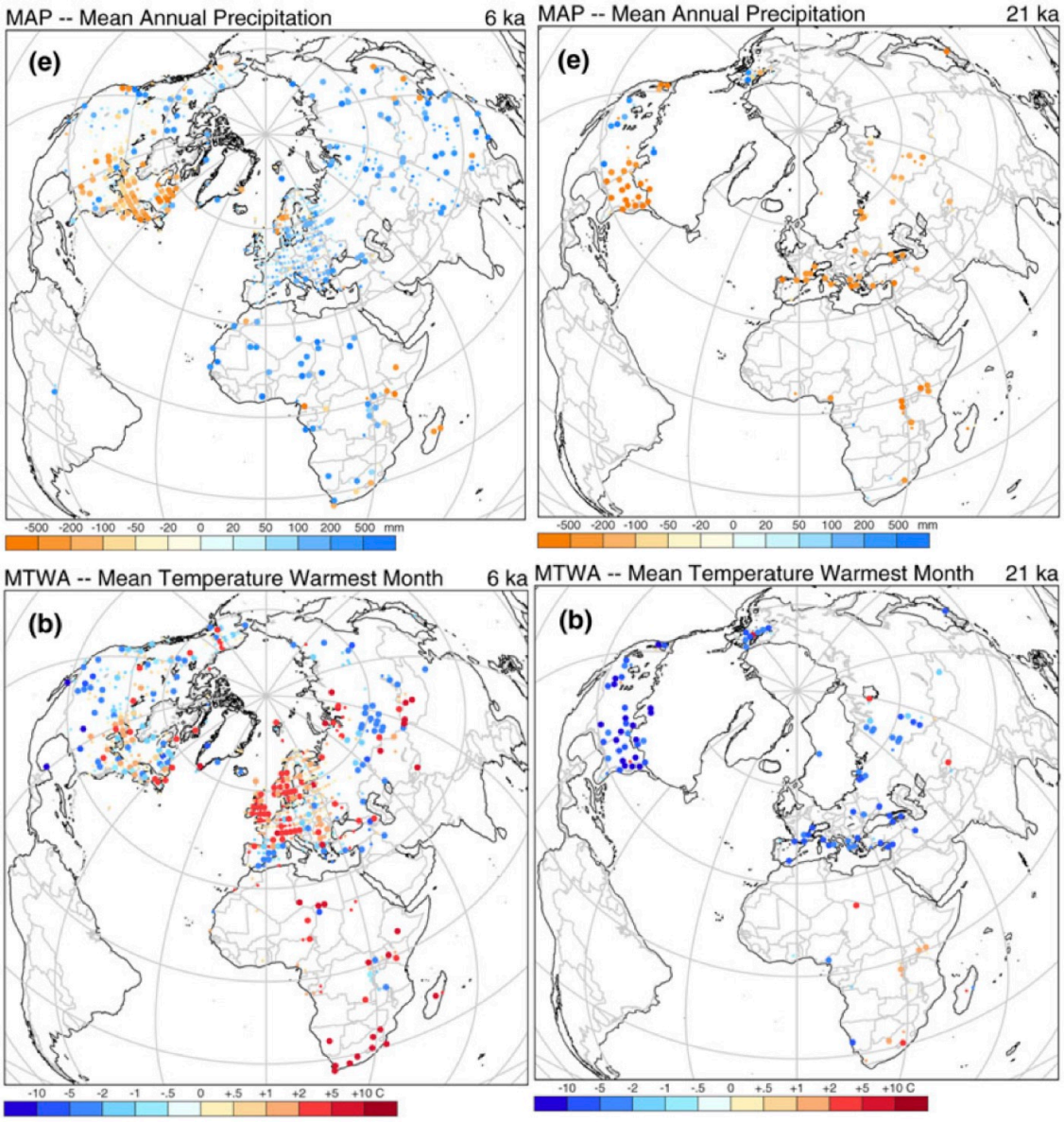


Figure 2.13 Mean annual precipitation and mean temperature of the warmest month at 6000 and 21,000 cal yr BP reconstructed from fossil pollen data. Source: Bartlein et al. 2011: 792-793. © The Author(s) 2010.

Conclusion

The study of terrestrial palaeoecology has seen stimulating developments during recent years and it has become one of the most dynamic areas of biogeographical research. Geographical insights can be achieved by employing the appropriate types of data to answer specific, well-formed research questions. The application of independent dating, multivariate analyses, the establishment of databases, and increasing quantitative precision of proxy reconstructions have broadened the scope of the discipline and help extend our understanding of ecosystem dynamics beyond modern observations. Studies range from understanding the selective pressure and genetic make-up of individuals, to reconstructing populations, communities and ecosystems across the entire globe. Many of the proxy data sets allow simultaneous examination at multiple spatial and temporal scales; combinations of data-data, data-model and inter-model comparisons allow better understanding of the hierarchy of biophysical drivers of past ecosystem change.

Proxy data operate at different spatial and temporal scales (Figure 2.1), and while their interpretation is firmly grounded in uniformitarianism, the strongest proxies are those that are well grounded in modern empirical and observational research so that the constraints on present distribution are well understood. This information is essential to calibrate and refine interpretation of the past. With proxy data, there is also the opportunity to explore past conditions that may have no analogue in the present. The examples of novel ecosystems in the past offer some of the most intriguing areas of research as we explore ecosystems responses in the future under projected climate change.

Most areas of palaeoecology are moving from an inductive data-gathering stage to more deductive approaches that generate and explore testable hypotheses about past environments. Individual records lie at the heart of any interpretation, but data composites and mapped summaries are capturing the dynamics of ecosystem change at broad temporal and spatial scales. Geography, with its interest in pattern and process at different scale has the capacity to contribute greatly to palaeoecology. Collaborative research and exchange among biogeographers and palaeoecologists, climate and ecosystem modellers, molecular geneticists, archaeologists and historians and conservation biologists and land-use managers will continue opening new doors of inquiry and relevance.

Summary

- We examine some of the approaches and data used to reconstruct terrestrial ecosystem change. Research employing these methods comes under the auspice of ecological biogeography, which is concerned with the factors that have lead to the current distribution of plants on the landscape.

- Palaeoecological research usually concerns ecosystem dynamics during the Quaternary period (the last 2.58 million years), and in particular over the last 21,000 years, which includes the last glacial maximum (LGM) and the Holocene (the current interglacial period that began 11,700 years ago).

- We outline the approaches taken to reconstruct terrestrial ecosystem change including tree rings, pollen, plant macrofossils, packrat middens, charcoal and dung fungal spores, as well as supporting palaeolimnological information from diatoms, chironomids and lake-sediment lithology, geochemistry and mineralogy.

- Proxy records can be used alone, but fuller understanding is achieved by combining and comparing multiple proxy data from single or groups of sites. Alternatively, developing geographic networks of records from a single proxy type, such as charcoal or pollen data, provides insights about patterns of environmental change over broad spatial scales.

Key Readings

- Elias, S.A. and C.J. Mock (2013) *Encyclopedia of Quaternary Science*

This encyclopedia is the most comprehensive and up-to-date overview of Quaternary science available. It contains 357 broad-ranging articles authored by well-respected researchers from around the world.

- Last et al. (2001) *Tracking Environmental Change Using Lake Sediments: Volume 2: Physical and Geochemical Methods*.

- Smol et al. (2010). *Tracking Environmental Change Using Lake Sediments: Volume 3: Terrestrial, Algal, and Siliceous Indicators*.

These reference books detail the most important indicators used by paleoecologists and paleolimnologists, including pollen analysis, plant macrofossils, charcoal, diatoms, stable isotopes, geochemistry, lithostratigraphy, and mineralogy.

- Birks, H.J.B. and Birks, H.H. (2004) *Quaternary Palaeoecology*.

- Delcourt, H.R. and Delcourt, P. (1991) *Quaternary Ecology: A Paleoecological Perspective*.

These volumes discuss the approaches by which Quaternary terrestrial environments can be reconstructed from fossils and sediments. They provide in-depth explanation of the methods and assumptions for working with a variety of proxy data.

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CHAPTER THREE

A 17,000-YEAR-LONG RECORD OF VEGETATION AND FIRE FROM CRADLE MOUNTAIN NATIONAL PARK, TASMANIA

Contribution of Authors and Co-Authors

Manuscript in Chapter 3

Author: Laura N. Stahle

Contributions: Defined the experimental design, participated in fieldwork, described the sediment cores, measured magnetic susceptibility, loss-on-ignition and other lithological properties of the cores, counted charcoal and pollen samples from Wombat Pool, analyzed the data, and wrote the manuscript.

Co-Author: Cathy Whitlock

Contributions: Supported this research under National Science Foundation grant OISE-09664472, helped define the experimental design, participated in fieldwork, discussed the results and implications, and edited the manuscript.

Co-Author: Simon G. Haberle

Contributions: Supported this research under Australian Research Council grant DP0664898, helped define the experimental design, participated in fieldwork, and discussed the results.

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Abstract

On centennial to millennial timescales fire regimes are driven by climate changes, vegetation composition and human activities. We reconstructed the postglacial vegetation and fire history based on pollen and charcoal data from a small lake in Cradle Mountain National Park and investigated the influence that climate, people, and vegetation had on past fire regimes. In the late-glacial period, a slowly warming climate led to a shift in vegetation from coniferous alpine shrubland to *Phyllocladus* woodland. During this period, fire activity was very low. The initial increase in fires occurred between 12,500–11,000 cal yr BP and led to a decline in forest taxa, a resurgence of grasses and a rise in the pyrophytic buttongrass *Gymnoschoenus*. The highest fire activity in the record occurred between 10,900–9400 cal yr BP, the warmest interval of the postglacial period based on independent proxy records. Subalpine trees had depressed levels of pollen during this time. After 9000 cal yr BP, fire activity declined substantially, and fire-sensitive rainforest reached its maximum extent ca. 8500–6500 cal yr BP. A major fire perturbation occurred ca. 3,600 cal yr BP, and thereafter rainforest shifted to open *Eucalyptus* woodland. The comparison of reconstructed fire and vegetation history at Wombat Pool to climate records and archeological data indicated that climate was the primary driver of the observed changes. In the late glacial and early Holocene, climate warming and individual species dispersal traits likely drove changes in vegetation composition that in turn impacted the fire regime. A relatively wet mid-Holocene climate favored rainforest trees whereas the drier and more variable climate of the late Holocene contributed to a decline in rainforest and a shift toward mixed forest as

wet sclerophyll elements increased. Archeological evidence suggests humans reoccupied the region ca. 4000 cal yr BP. This may have added an ignition source that was absent in the previous ca. 7000 years and may have contributed to the large fire event ca. 3600 cal yr BP. Although pre-European populations may have been a source of ignition locally, the reconstructed fire history trends from Cradle Mountain National Park match well with large-scale changes in climate patterns.

Introduction

Fire is an important element of the Australian ecosystem that affects vegetation composition and landscape structure (Jackson, 1968; Jackson, 1999; Bowman, 2000; Wood and Bowman, 2012). Changes in fire frequency have long been recognized as an important driver of ecological change (Jackson, 1968), governing the relative abundance of rainforest, shrubland, and dry *Eucalyptus* forest. Variations in fire occurrence through time have been attributed to past changes in climate as well as to deliberate burning by humans who have inhabited the island for at least the last 40,000 years (Cosgrove, 1999). Detailed knowledge of fire history in Tasmania, however, is limited, with only four high-resolution charcoal-based studies (Fletcher et al., 2014a, b; Fletcher et al., 2015; Rees et al., 2015; McWethy et al., *in review*) for the entire island.

The ecological history of northwestern Tasmania, in particular, is poorly known, with the exception of notable studies by Colhoun and van de Geer (1986), Colhoun et al. (1999), and Anker et al. (2001). This mountainous region supports significant tracts of intact subalpine communities, which contain endemic old-growth temperate rainforest

trees and coniferous shrubs. In recent decades, subalpine communities have become increasingly fragmented as a result of fire, which is a concern for conservation and forest management (Brown et al., 1983; Kirkpatrick, 1984b; Kirkpatrick and Dickinson, 1984; Kirkpatrick and Balmer, 1991; Johnson and Marsden-Smedley, 2002; Kirkpatrick and Bridle 2013). Fire is an essential part of these communities (Holz et al., 2015), but little information exists about the long-term relationships between fire, vegetation, and climate. In this study, we describe a high-resolution charcoal and pollen record from a small lake to reconstruct fire activity and vegetation changes over the last 17,000 years in the subalpine region. Wombat Pool (41.65°S, 145.95°E, 998 m elevation) is a small (0.4 ha), high-elevation lake in the northern section of the Cradle Mountain-Lake St Clair National Park, part of the Tasmanian Wilderness World Heritage Area (Fig. 1). We compare this lake sediment reconstruction with independent paleoclimatic and archeological data to discern the relative influence of climate and people in shaping the vegetation and fire history.

Study Area

Climate

Climate information for the northern part of Cradle Mountain-Lake St Clair National Park comes from the Waldheim station at Cradle Valley (903 m; Australian Bureau of Meteorology, http://www.bom.gov.au/climate/averages/tables/cw_096005.shtml). From 1917-2009, average winter (JJA) minimum temperature was -0.3° C and average summer (DJF)

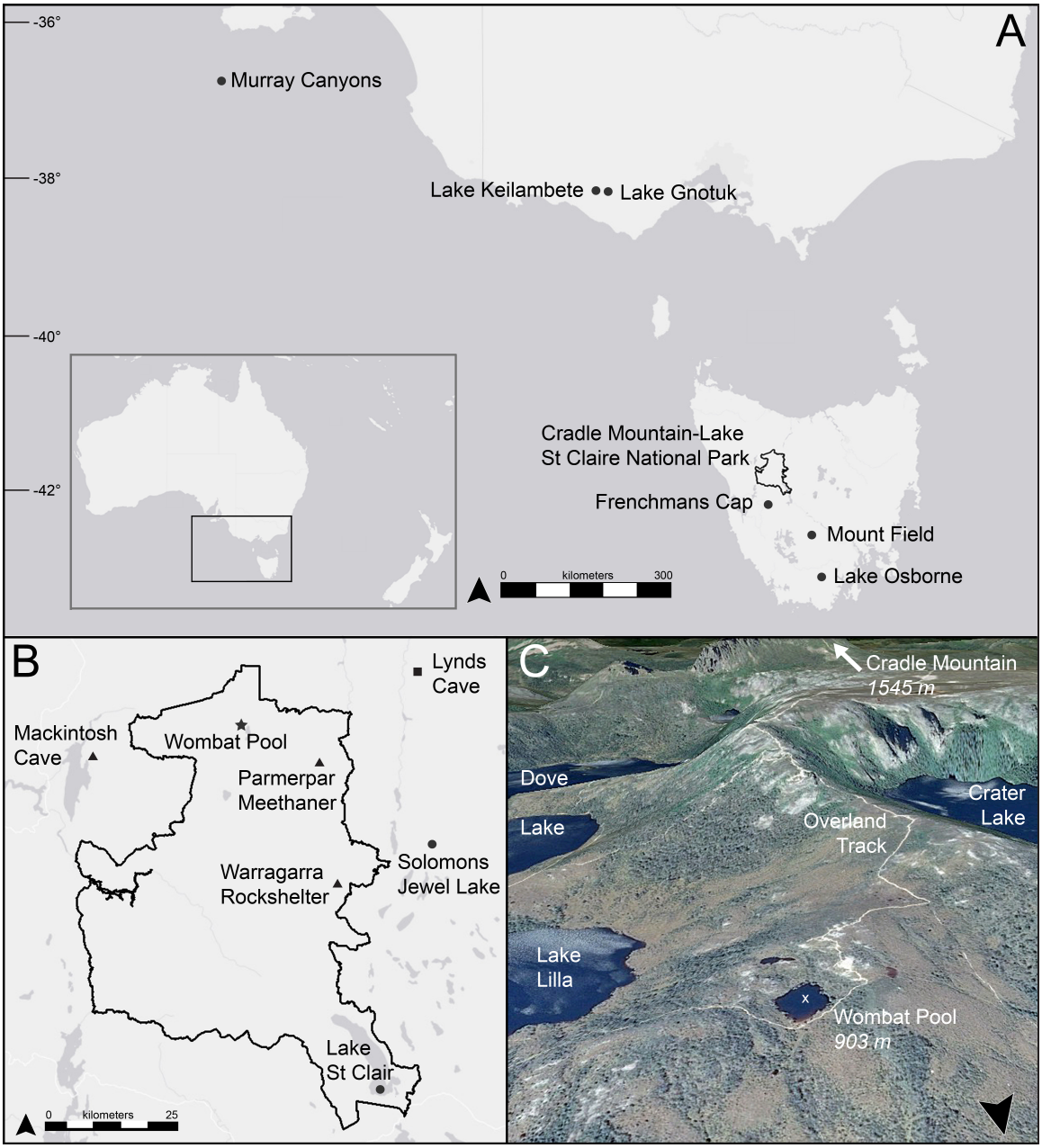


Figure 3.1 Map showing the location of Wombat Pool and other sites mentioned in the text (circle = lake or marine sediment record, triangle = archeological site, square = speleothem record, star = Wombat Pool, white x = coring location).

maximum temperature was 16.3° C. Precipitation is associated with the strength and latitudinal position of the Southern Hemisphere Westerly Winds (SWW), which influence the position of the storm tracks. A strong west-to-east precipitation gradient

exists on the island and the presence of western mountains results in an orographic rainfall effect at Cradle Mountain. Average annual precipitation in the national park is 2651 mm, and almost twice as much precipitation is delivered in winter (297 mm in JJA) as in summer (151 mm in DJF). Modern studies have shown a correlative relationship between precipitation anomalies and both El Niño/Southern Oscillation (ENSO) and Southern Annular Mode (SAM; Hendon et al., 2007; Hill et al., 2009; Risbey et al., 2009). In northern Tasmania, ENSO explains between 10-40% of rainfall variability and the relationship is strongest in winter (Risbey et al., 2009). The positive SAM phase is associated with reductions in winter rainfall in Tasmania, while the negative SAM is associated with increases in rainfall in spring and summer (Hendon et al., 2007).

A strong relationship exists in Tasmania between annual area burned and October-May (i.e. spring, summer and fall) rainfall (Nicholls and Lucas, 2007). Large fire events in recent decades have been associated with abnormally low humidity and high temperatures, and strong gusty winds in the summer months. Typically, this occurs when northwesterly winds come from the heart of the Australian continent and pass over Tasmania (Nicholls and Lucas, 2007).

Vegetation

Cradle Mountain-Lake St Clair National Park is located in the transition zone between the drier, more fertile east and the wet, infertile region to the west. A mix of dolerite and quartzite substrates with areas of granite comprises the majority of the Park. The vegetation is diverse and composed of a mosaic of pyrophytic and pyrophobic assemblages. One-third of Tasmania's vascular flora are present (Kirkpatrick and

Balmer, 1991), including the culturally and ecologically important, endemic conifer trees *Athrotaxis selaginoides* and *A. cupressoides*. Cradle Mountain is also one of the few areas in Tasmania where the island's alpine shrub species co-occur (*Podocarpus lawrencii*, *Microcachrys tetragona*, *Diselma archeri*, *Microstrobus niphophilus*, *Nothofagus gunnii* and the two *Athrotaxis* species; Kirkpatrick and Bridle, 2013). In Tasmania, climatic treeline occurs where the mean temperature of the warmest month is 10°C, which is at approximately 1100 m elevation (Kirkpatrick, 1984a). Downslope of the alpine community are extensive tracks of rainforest, wet sclerophyll forests and patches of waterlogged moorland. Many different rainforest types persist in the area and all are classified as "extremely fire sensitive," meaning there is a very high potential ecological impact of a single fire in these vegetation types (Pyrke and Marsden-Smedley, 2005). Where growth rates are highest, *Nothofagus cunninghammii* forms near-monospecific stands; where growth rates slow, *Athrotaxis* spp. become dominant. Where growth rates are very slow, *N. gunnii* dominates (Kirkpatrick and Balmer, 1991). Two species of *Eucalyptus* are important components of the flora in this region. Woodlands of *E. subcrenulata* interspersed with open scrub, and forest woodlands of *E. coccifera* form a mosaic with rainforest and moorland dominated by the perennial sedge *Gymnoschoenus sphaerocephalus* (Kirkpatrick 1984a). Other abundant genera include *Leptospermum, Richea, Dicksonia, Melaleuca, Banksia, Pomaderris, Orites,* and *Astelia*. A number of Asteraceae, Poaceae, Restionaceae and Ericaceae are also present.

Wombat Pool is surrounded by a mosaic of wet sclerophyll forest and shrub communities, areas of buttongrass (*Gymnoschoenus* species), mixed forest containing

rainforest and *Eucalyptus* species, and alpine shrubland. *Athrotaxis cupressoides* of different age classes grow directly on the edge of this small lake. Within 100 m of the lake, a woodland community with *Eucalyptus coccifera* overstory and shrub understory was present. Shrubland with plants from the Proteaceae, Myrtaceae, Ericaceae and other families, as well as buttongrass tussocks occur within 100 m of the lake. Within 500 m of the site lie patches of mixed forest, containing rainforest species (*N. cunninghammii*, *Phyllocladus* and *A. selaginoides*), and areas of alpine vegetation with the woody shrubs *P. hookeriana* and *D. archeri*.

Material and Methods

Field

A 331-cm-long sediment core was obtained from Wombat Pool in 2011 using a modified Livingstone piston sampler. The mud-water interface and top 25 cm of sediment was captured with a plastic piston corer. Coring was performed from an anchored platform in the deepest part of the lake (2 m). Cores were extruded in the field and shipped to the National Lacustrine Core Facility (LacCore) at the University of Minnesota.

Lithology

Initial core descriptions were performed at LacCore. Cores were split lengthwise with one half reserved as an archival half and the other used as the working half. The working half was described, imaged and analyzed. The archival halves of the cores are housed at the Paleoecology Laboratory at Montana State University. Density (g cm^{-3})

was measured at 0.5-cm continuous intervals on the split surface of the cores and used as an indicator of changes in porosity and lithology. Magnetic susceptibility (MS) was also measured at 0.5-cm continuous intervals. MS measures changes in inorganic allochthonous sediment input from erosional processes (Gedye et al., 2000).

Chronology

Bulk sediment samples were submitted to Woods Hole NOSAMS AMS facility for radiocarbon dating. Radiocarbon ages were calibrated using the Southern Hemisphere radiocarbon calibration dataset SHCal13 (Hogg et al., 2013). Chronologies were developed by modeling sediment age as a function of sediment depth. Two-sigma calibrated ages and probability distributions were determined for each radiocarbon date using Clam v2.2 (Blaauw, 2010). The age-depth modeling was performed using a smoothing spline (error-weighted with smoothness set at 0.4) and a repeated sampling of point estimates approach (1000 iterations) that allows each date to influence the age model through the probability density function of the calibrated age. Although Bayesian (i.e. Bacon; Blaauw and Christen, 2011) methods were also considered for age-depth modeling, Clam software was used in this study because it employs smoothing functions that result in a smooth curve for the median sample ages.

Charcoal Analysis

In order to reconstruct local fire history (i.e., within a few kilometers of the site), charcoal analysis was performed on 2-cm^3 volume samples taken at continuous 0.5-cm intervals following the method described by Whitlock and Larsen (2001). Samples were

wet-screened through a 125-μm mesh sieve and charcoal particles were counted under a stereomicroscope at 40x magnification. This size fraction was chosen because modern studies have shown particles of this size class do not travel far from their source and can be employed to reconstruct watershed-scale fires (Clark 1988; Whitlock and Larson, 2001). Charcoal concentrations and deposition times were calculated and converted to charcoal accumulation rates (CHAR; particles cm^{-2} yr^{-1}). To account for temporal variations in sampling intervals resulting from variable sedimentation rates, the CHAR time series was interpolated to 30 years, the median resolution of the record (Higuera et al., 2010). CHAR was then decomposed into background (BCHAR) and peak components (Higuera et al., 2009; http://CharAnalysis.googlepages.com) with a 1250-yr lowess smoother robust to outliers. A mixed Gaussian model was used to decompose the high frequency component of the time series into "noise" and "peaks", the peak component being the 95th percentile of the noise population (Higuera et al., 2009). Peaks were tested for statistical significance by comparing the original charcoal counts with the values of the previous five samples (150 yr). Where the peak count had at least a 0.5% chance of coming from the same Poisson-distributed population as the smallest number of charcoal particles counted in the preceding 150 years then the peak was considered insignificant (Higuera et al., 2009). Charcoal peaks are assumed to represent one or more fires during the time span of the peak (30 yr). The suitability of the records for fire-episode identification was assessed with the signal-to-noise index (SNI); only periods where SNI >3 were considered appropriate for charcoal peak interpretation (Kelly et al., 2011). A 1000-yr bandwidth was used to calculate the SNI. Fire size and/or intensity

were inferred from the magnitude of individual charcoal particle count peaks (Higuera et al., 2009). The fire history was divided into fire regime zones (Fire Intervals, FI) applying a regime shift index (RSI) algorithm described by Rodionov (2004) to the CHAR time series. It incorporated a sequential Student's *t*-test (Huber's WF=5, P>0.01, cut-off=70 yr) and determined where significant changes in the mean values of two adjacent regimes occur. These transitions were used to delineate fire regime intervals. Plots were made in R version 3.2.2 (R Core Team, 2015).

Pollen Analysis

Sediment samples of 0.25-1.0 cm^3 in volume were taken at <300-yr intervals (median sample resolution = 196 yr) for pollen analysis. Samples were prepared according to the standard KOH, HF, HCl and acetolysis method described by Bennett and Willis (2001). A *Lycopodium* tracer was added to each sample in order to calculate the pollen concentration (grains cm^{-3}) and accumulation rate (PAR; grains cm^{-2} yr^{-1}). Identification was performed at 400x and 1000x magnification. Analysis was partially conducted at Australian National University using reference collections for Australian taxa housed by the Australasian Pollen and Spore Atlas (apsa.anu.edu.au; APSA-Members, 2007) and the Newcastle Pollen Collection (Hopf et al., 2005). Pollen counts exceeded 350 terrestrial grains per sample (median = 389) and pollen percentages were based on the terrestrial sum. Interpretation of the pollen data was based on a comparison with modern pollen data from lake-sediment samples in the Cradle Mountain region and with the extensive dataset published by Fletcher and Thomas (2007). Plots were made

using the program Tilia v2.0 (Grimm, 1990). The pollen-percentage record was divided into zones using constrained cluster analysis (CONISS; Grimm, 1988).

Results

Lithology

The core lithology consisted of two units. Unit 1 (331–273 cm depth; older than 16,540 cal yr BP; Fig. 2) was inorganic glacial silt and clay. This unit had high magnetic susceptibility (-0.9 – 2.0 SI units; mean = 0.624) and density (1.165–1.949 g cm^{-3}; mean = 1.667), indicating substantial mineral clastic input during this period. Unit 2 (272.5–0 cm depth; 16,540– -61 cal yr BP) was composed of fine-detritus gyttja and featured low readings of magnetic susceptibility (-2.2 – 0.3 SI units; mean = -1.478) and density (0.847–1.237 g cm^{-3}; mean = 0.944).

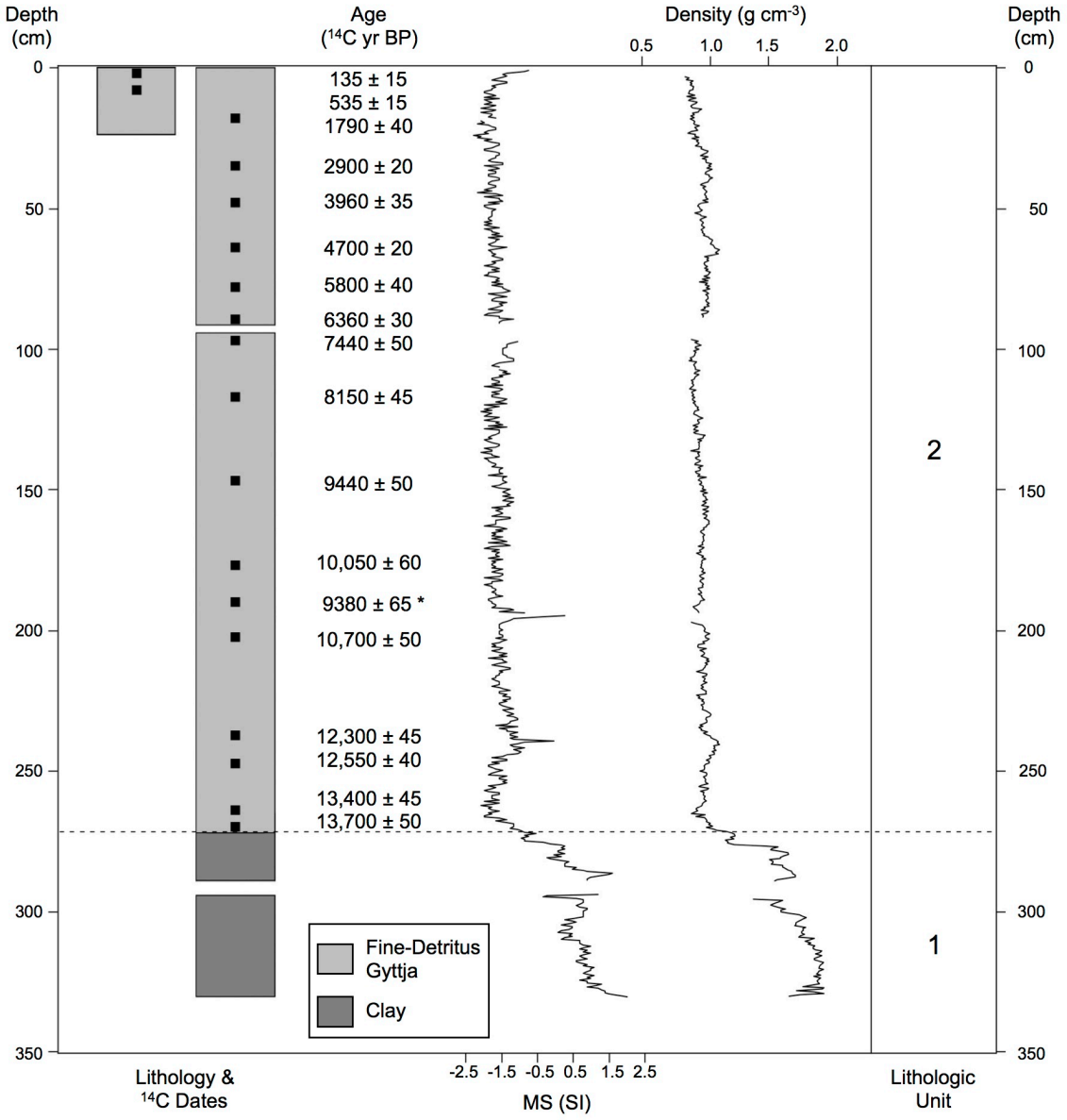


Figure 3.2 Lithology, radiocarbon dates, magnetic susceptibility, and density data for the Wombat Pool cores. The asterisk indicates the date that was not used in the chronology.

Chronology

Eighteen bulk sediment samples from Wombat Pool were submitted for AMS radiocarbon dating analysis (Table 1). One sample was excluded from construction of the

Table 3.1 Radiocarbon dating results from Wombat Pool. Calibrations (cal yr BP) are based on the Southern Hemisphere calibration curve SHCal13.14C (Hobbs *et al*. 2013).

Core	Core Depth (Top; cm)	Cumu-lative Depth (Top; cm)	Lab Number (NOSA MS)	Material Dated	Radio-carbon Age (^{14}C yr BP)	Error (^{14}C yr BP	d13C	Age (cal yr BP) & Probability *
12C	2.5	2.0	OS-122004	Bulk sediment	135	15	-27.54	64-119; 30.1 186-231; 19.2 11-37; 17.7 243-271; 16.2 124-149; 11.5 175; 0.1
12C	9.0	8.0	OS-122005	Bulk sediment	535	15	-27.17	520-553; 90.7 611-619; 4.3
12A-1	18.0	18.0	OS-105361	Bulk sediment	1,790	40	-27.11	1562-1746; 94.2 1774-1781; 0.8
12A-1	35.0	35.0	OS-113893	Bulk sediment	2,900	20	-27.28	2916-3063; 82.5 2879-2913; 12.4
12A-1	48.0	48.0	OS-105362	Bulk sediment	3,960	35	-27.03	4236-4443; 91.6 4483-4512; 3.4
12A-1	64.0	64.0	OS-113894	Bulk sediment	4,700	20	-27.02	5343-5467; 81.6 5314-5337; 13.4
12A-1	78.0	78.0	OS-105363	Bulk sediment	5,800	40	-27.19	6448-6659; 95
12A-1	89.5	89.5	OS-108112	Bulk sediment	6,360	30	-26.89	7167-7314; 95
12A-2	2.5	97.0	OS-108115	Bulk sediment	7,440	50	-27.11	8152-8349; 85.5 8049-8097; 6.5 8103-8121; 1.9 8131-8141; 1.1
12A-2	22.5	117.0	OS-105366	Bulk sediment	8,150	45	-27.2	8975-9149; 82.2 9161-9255; 8.4 8792-8828; 2.6 8867-8883; 1.1 8899-8912; 0.7
12A-2	52.5	147.0	OS-105365	Bulk sediment	9,440	50	-27.32	10,496-10,757; 94.6 10,444-10,449; 0.3
12A-2	82.5	177.0	OS-105364	Bulk sediment	10,050	60	-27.08	11,268-11,751; 95
12A-2	95.5	190.0	OS-108113	Bulk sediment	9,380	65	-26.7	10,371-10,716; 90.6 10,298-10,332; 2.9 10,337-10,356; 1.4

12A-3	8.0	202.5	OS-105367	Bulk sediment	10,700	50	-26.74	12,552-12,710; 93.8 12,454-12,462; 1.1
12A-3	43.0	237.5	OS-105540	Bulk sediment	12,300	45	-27.07	14,369-15,073; 95
12A-3	53.0	247.5	OS-113895	Bulk sediment	12,550	40	-26.27	13,996-14,429; 95
12A-3	69.5	264.0	OS-113973	Bulk sediment	13,400	45	-24.92	15,877-16,252; 95
12A-3	78.0	272.5	OS-105541	Bulk sediment	13,700	50	-22.39	16,242-16,712; 95

* Calibrated ages derived from Clam v2.2 and represented the 2-sigma error ranges.

age-depth model, because it was judged to be anomalously young. A preliminary model was developed by independently modeling age as a function of depth in each core. The final age-depth model was developed by Monte Carlo fitting smoothing splines through the probability distribution of all calibrated ages (Fig. 3). We developed two alternative chronologies based on AMS radiocarbon dates by applying different degrees of smoothing. The preferred chronology allowed for changes in sedimentation rates across different lithologies (Fig. 2). The extrapolated age of the core is 20,150 cal yr BP. This age estimate is likely too old, inasmuch as sedimentation rates during deglaciation were probably higher than the extrapolation would imply.

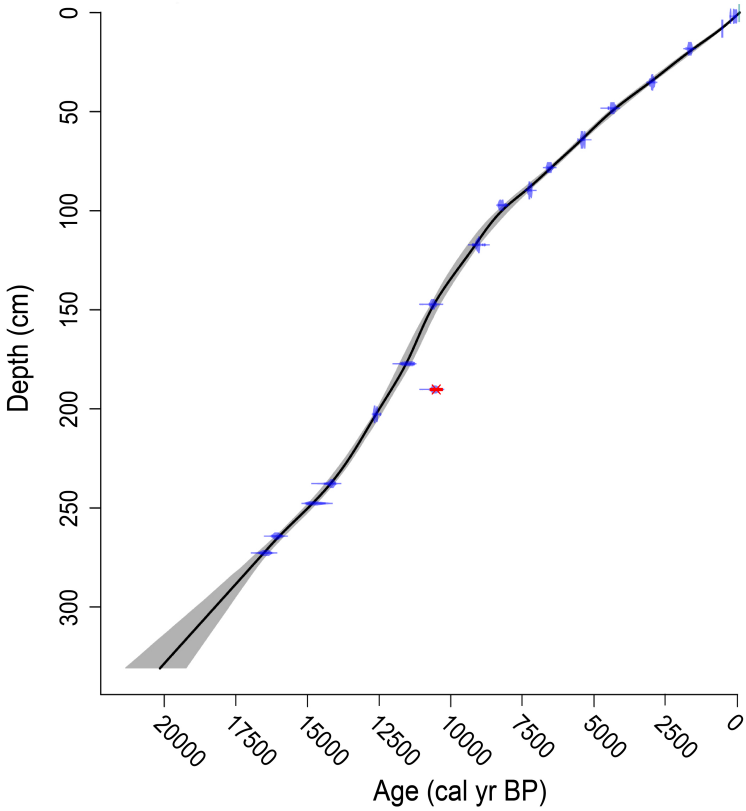


Figure 3.3 Age-Depth Model for Wombat Pool. The age-depth model (black line) and 95% confidence intervals (gray shading) are shown. The distributions of the calibrated radiocarbon ages that were used to develop the model are shown in black, and the date that was not included in the model is indicated in gray.

Pollen

Pollen Zone 1 (281.0–262.5 cm depth; 17,055–15,865 cal yr BP) featured high percentages of Poaceae (14-30%) and Asteraceae (12-21%; Fig. 4). Chenopodiaceae percentages were 3-6% and *Allocasuarina* values fluctuated between 3-8%. Subalpine shrubs were moderately represented, including *Microcachrys tetragona* (2-5%), Ericaceae (3-5% after 272.5 cm; ca. 16,500 cal yr BP), *Athrotaxis-Diselma* (1-5%), and other subalpine taxa (*P. hookeriana*, *P. lawrencii*, and *Tasmannia lanceolata*; up to 2%). Below 265.5 cm depth (16,000 cal yr BP), *Gymnoschoenus* percentages range between 4-

5%, which is significant as buttongrass is a very poor pollen disperser; values as low as 1% have been recorded where the plant is locally abundant (Fletcher and Thomas, 2007). Cyperaceae percentages reached 8% in Zone 1, which were the highest of the record. Comparisons with modern pollen data suggest that the vegetation corresponding to Zone 1 consisted of a coniferous alpine shrubland and buttongrass moorland in the local vicinity of Wombat Pool, and open, grass and herb vegetation was likely present in the extralocal area (Harris and Kitchener, 2005; Fletcher and Thomas, 2007).

Pollen Zone 2 (262.5–244.5 cm depth; 15,865–14,600 cal yr BP) had declining values of Poaceae (12-23%), Asteraceae (7-14%), *Microcachrys tetragona* (0.5-3%), other subalpine shrubs (up to 2%), *Allocasuarina* (2-4%), and Chenopodiaceae (4-5%), and increasing percentages of *Phyllocladus* (7-19%) and *Pomaderris* (7-12%). *Astelia alpina*, a poor pollen-disperser, reached the highest percentages of the record (up to 3%). Cyperaceae percentages oscillated up to 5% during this period. This pollen assemblage suggests that the vegetation of this period resembled a modern coniferous subalpine shrub community with a significant sedgeland component (Harris and Kitchener, 2005). Pollen Zone 3 (244.5–183.5 cm depth; 14,600–11,800 cal yr BP) featured *Phyllocladus* as the dominant pollen taxa (14-29%), and values were highest between 244.5–232.5 cm depth (ca. 14,500–14,000 cal yr BP). *Pomaderris* pollen was initially fairly abundant (9-13%) but percentages declined above 212.5 cm depth (ca. 13,000 cal yr BP). Asteraceae percentages were lower than in the previous two pollen zones, and values of 7-11% were reached below 218.5 cm depth (ca. 13,200 cal yr BP) but declined

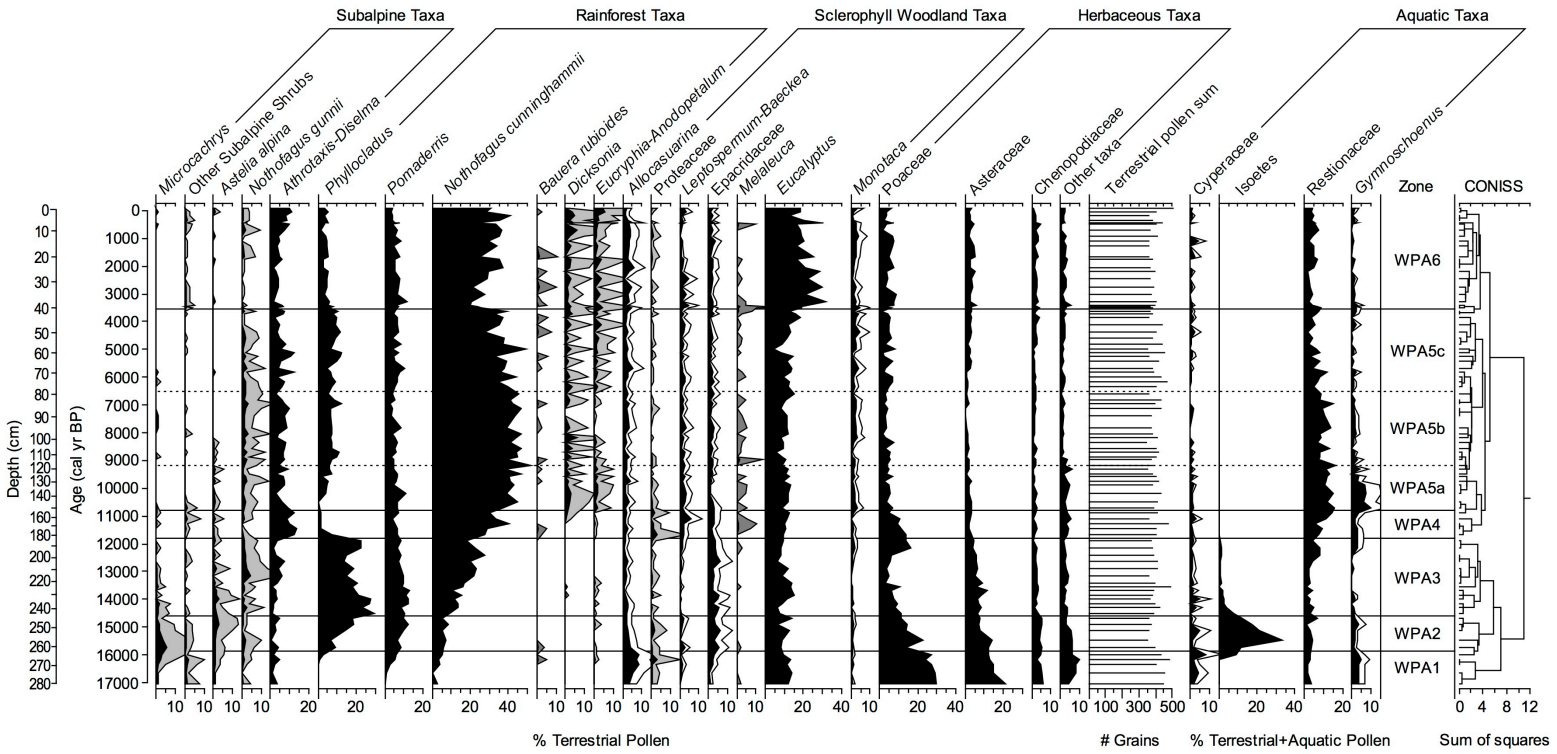


Figure 3.4 Pollen Diagram for Wombat Pool. Pollen diagram for percentage of selected taxa from Wombat Pool. Note differing scales on x-axes. Dark gray shading indicates 10x exaggeration, light gray shading indicates 5x exaggeration, and white shading indication 2x exaggeration. Isoetes values were divided by 50 to aid readability.

to 5% above that depth. *N. gunnii*, a short-distance pollen-disperser, reached values of up to 5% between 218.5–195.0 cm depth (ca. 13,000–12,000 cal yr BP). Poaceae percentages were low (4-7%) but increased dramatically at 195.0 cm depth (ca. 12,200 cal yr BP) to 17%. *Astelia* and Cyperaceae declined in abundance from the beginning of this period until 229.5 cm depth (ca. 13,800 cal yr BP) and were present only in trace amounts after. Pollen Zone 3 suggests a period of mixed rainforest with cold-tolerant taxa near the lake and widespread coverage of the pioneer rainforest species *Phyllocladus* (Harris and Kitchener, 2005).

Pollen Zone 4 (183.5–153.0 cm depth; 11,800–10,800 cal yr BP) featured a steep decline in the percentages of *Phyllocladus* pollen to a low of 1%, high levels of *Athrotaxis-Diselma* (9-14%), increased Poaceae (up to 14%), and the appearance of short-distance pollen-dispersing woody shrubs *Leptospermum-Baeckea*, *Melaleuca* and Proteaceae (*Banksia marginata*, *Orites-Bellendena*, *Persoonia*, *Telopea*; 4-7%). *Gymnoschoenus* pollen percentages increased at 195.5 cm depth (12,300 cal yr BP) and reached values of 3.4%.

Pollen Zone 5 (153.0–40.5 cm depth; 10,800–3565 cal yr BP) includes three sub-zones. Subzone 5a (153.0–119.5 cm depth; 10,800–9200 cal yr BP) featured the highest percentages of *Gymnoschoenus* pollen (up to 10%) and a steady presence of pollen of *Leptospermum-Baeckea*, *Pomaderris*, and *Monotoca* (2-3%, 5-11% and 1-3%, respectively). Temperate rainforest taxa including *Eucryphia-Anodopetalum* and the tree fern *Dicksonia antarctica* appeared in higher than trace amounts during this pollen zone. *N. cunninghammii* pollen also increased and by 135.0 cm depth (10,000 cal yr BP)

reached >40% indicating a local presence (Fletcher and Thomas, 2007). This pollen assemblage suggests that the vegetation resembled modern buttongrass moorland with woody shrub components and rainforest elements (Harris and Kitchener, 2005). Sustained high levels of *N. cunninghammii* (39-52% and mostly >40%) dominated Subzone 5b (119.5–78.0 cm depth; 9200–6500 cal yr BP). *Pomaderris* was lower (3-5%) and *Gymnoschoenus* fell to values of 0-2%. Percentages of the subalpine tree *N. gunnii* were primarily between 2-4% and *Athrotaxis-Diselma* fluctuated between 3-10%. This pollen assemblage suggests development modern temperate rainforest (Harris and Kitchener, 2005).

At the beginning of Subzone 5c (78.0–40.5 cm depth; 6500–3565 cal yr BP), *N. cunninghammii* dropped below 40% and percentages became more variable suggesting the population may have moved farther from the lake at this time and/or become more sparse. Throughout this zone, *N. cunninghammii* fluctuated between 28-49% (mean = 37%). *Pomaderris* reached up to 10% of the terrestrial sum in Subzone 5c (78.0–40.5 cm depth; 6500–3565 cal yr BP), while levels of *Athrotaxis-Diselma* oscillated dramatically—as low as 2.5% and as high as 12.3%. *N. gunnii* percent fell below 2%. Pollen Zone 6 (40.5–0 cm depth; 3565–-61 cal yr BP) marks the dominance of *Eucalyptus* pollen, especially between 40.5–22.5 cm depth (2000-3500 cal yr BP) when it reached levels of 19-31%. *N. cunninghammii* dropped to 19-29%, but this taxon is strongly over-represented in the regional pollen rain, and these percentages do not indicate a local presence (Fletcher and Thomas, 2007). The pollen assemblage between 40.5-22.5 cm (2000-3500 cal yr BP) suggests the establishment of a modern wet

sclerophyll forest dominated by *Eucalyptus* spp. (Harris and Kitchener, 2005). After 22.5 cm depth (2000 cal yr BP), *Eucalyptus* and *N. cunninghammii* percentages were more variable; however, *N. cunninghammii* persisted at low values and only reached >40% once at 5.5 cm depth (ca. 200 cal yr BP). In the last ca. 800 years (10.5-0 cm depth), *Athrotaxis-Diselma* pollen was higher than it was in the previous 4000 years, reaching percentages of up to 11%. *Dicksonia* also reached the highest values of the record (4-6%). In uppermost 2.5 cm of the core (last 100 years) *Eucryphia-Anodopetalum* pollen reached values of 5-6%, which was its best representation of the record. The data suggest the presence of a mixed forest with wet sclerophyll elements as well as subalpine and temperate rainforest (Harris and Kitchener, 2005) during the last 2000 years.

Charcoal

Throughout the record, there is a close correspondence between the timing of shifts between fire intervals (FI) and pollen zones, however, the shifts do not occur at exactly the same time (Fig. 5). This section describes the results of charcoal analysis. Fire interval (FI) 1 (281.0–246.0 cm depth, 17,055–14,720) had a mean CHAR value of 0.06 particles cm^{-2} yr^{-1}. Fires were very infrequent and four small fire events were identified in this period (mean = 9.11 particles cm^{-2} $peak^{-1}$). FI 2 (246.0–188.0 cm depth; 14,720–11,990 cal yr BP; mean CHAR = 0.43 particles cm^{-2} yr^{-1}) was characterized by low levels of biomass burning with more (3.5-5/1000 yr) local fires than before. Twelve fire episodes were identified (11 with SNI > 3.0; mean = 7.50 particles cm^{-2} $peak^{-1}$). FI 3 (188.0–155.5 cm depth; 11,990–10,880 cal yr BP) had much higher rates of charcoal

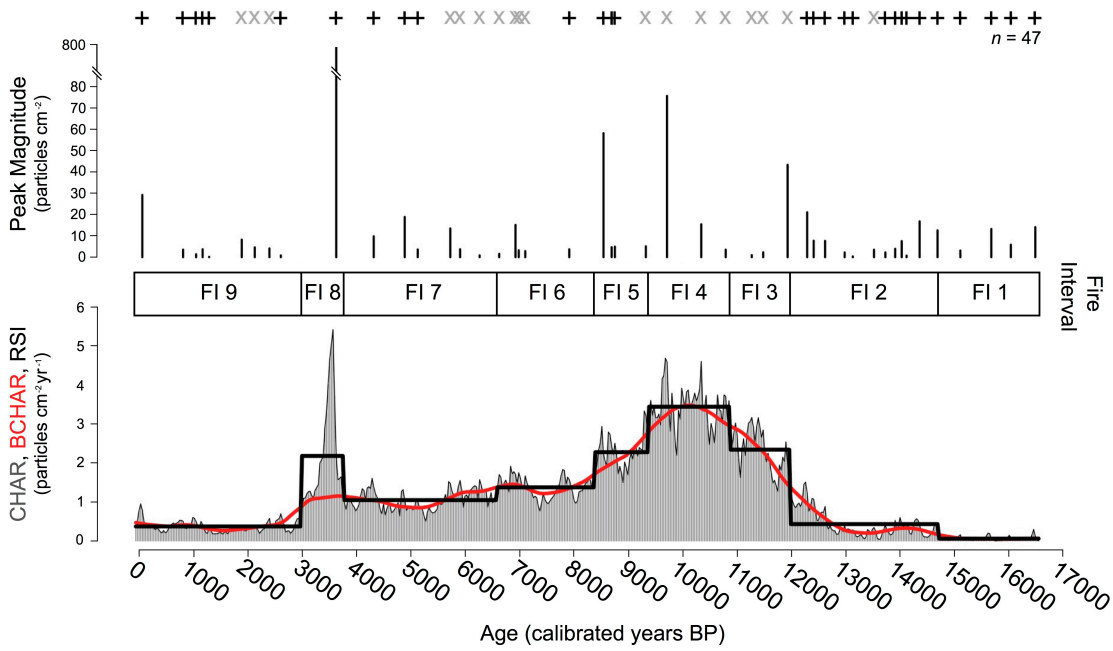


Figure 3.5 Charcoal Summary for Wombat Pool. Charcoal data for Wombat Pool. Charcoal accumulation rate (CHAR; gray histogram), background CHAR (red line), charcoal peaks (signal-to-noise ratio >3.0 = +, signal-to-noise ratio <3.0 = ×), peak magnitude, and signal-to-noise ratio were determined using CharAnalysis (Higuera et al., 2009). Solid black line on bottom figure indicates Fire Intervals derived from regime shift index algorithm (RSI; Rodionov, 2004). Fire Intervals (FI 1-9) and Pollen Zones (WPA1-6) are displayed.

accumulation than the previous two intervals (CHAR mean = 2.465 particles cm^{-2} yr^{-1}). The shift from FI 2 to 3 was marked by a large steplike increase in charcoal levels. Three fire episodes were recorded in FI 3, but the low SNI suggests that it is difficult to determine whether these were local fire events (Kelly et al., 2011).

FI 4 (155.5–122.0 cm depth; 10,880–9380 cal yr BP; mean CHAR = 3.44 particles cm^{-2} yr^{-1}), had the highest levels of biomass burning of the record. None of the three fire episodes identified in this period had >3.0 SNI. FI 5 (122.0–102.5 cm depth; 9380–8390 cal yr BP; mean CHAR = 2.275 particles cm^{-2} yr^{-1}) had high biomass burning and two of the largest magnitude peaks of the record (8690 ± 15 cal yr BP with 40.695

particles cm^{-2} $peak^{-1}$ and 8540 ± 15 cal yr BP with 58.236 particles cm^{-2} $peak^{-1}$). Biomass burning was substantially reduced in FI 6 (102.5–79.5 cm depth; 8390–6590 cal yr BP; mean CHAR = 1.375). FI 7 (79.5–53.0 cm depth; 6590–3770 cal yr BP; mean CHAR = 1.048 particles cm^{-2} yr^{-1}) featured low biomass burning. Three of the fire episodes identified in this period had SNI values that exceed 3.0 (mean = 10.80 particles cm^{-2} $peak^{-1}$).

A fire regime shift to higher biomass burning occurred at 53.0 cm depth (3770 cal yr BP). FI 8 (53.0–34.5 cm depth; 3770–2990 cal yr BP; mean CHAR = 2.18 particles cm^{-2} yr^{-1}) indicates a period of fires, punctuated by the largest charcoal peak of the entire record at 41.0 cm (3620 ± 15 cal yr BP; 764.671 particles cm^{-2} $peak^{-1}$). In the 800 years after this large fire event, pollen of *Gymnoschoenus*, Poaceae, Asteraceae and *Pomaderris* increased in abundance and *Melaleuca* and *Monotoca* pollen had the highest values of the record. An interval of low biomass burning and low fire frequency characterized the fire regime of the last ca. 3000 years (FI 9: 34.5–0 cm depth; 2990– -61 cal yr BP; mean CHAR = 0.374 particles cm^{-2} $peak^{-1}$).

Discussion

Late-Glacial Period (ca. 17,000–14,500 cal yr BP)

The Last Glacial Maximum (LGM) in Tasmania was relatively short-lived and ice cover was geographically confined. Ice caps were present in the Central Plateau and West Coast Ranges, and systems of valley and cirque glaciers formed on surrounding mountains, including at Cradle Mountain (Barrows et al., 2002; O'Donnell, 2010). Rapid

contraction of glaciers occurred between ca. 18,000–16,000 cal yr BP with most locales becoming ice-free by 16,000 cal yr BP (Mackintosh et al., 2006). At Wombat Pool, the catchment was unstable and had poorly developed soils prior to ca. 16,000 cal yr BP as evidenced by the inorganic composition of the sediments (silt and clay) and elevated values for density and magnetic susceptibility. The low level of biomass burning was partly a result of sparse discontinuous fuels. After ca. 16,000 cal yr BP, the catchment likely became stabilized as evidenced by the change in lithology to organic gyttja and the decrease in MS and density values.

The pollen data suggest that shrubs and herbs dominated the local vegetation. Moderate values for *Astelia alpina*, *Microcachrys tetragona*, *Gymnoschoenus* and Ericaceae suggest both alpine and moorland communities surrounded the lake, whereas high values for grasses and Asteraceae taxa and moderate amounts of Chenopodiaceae indicate the extralocal vegetation contained considerable areas of herbaceous cover (Macphail, 1975). Pollen from *N. cunninghammii* and *Eucalyptus* was present in small amounts, and based on glacial refugia estimates (Kirkpatrick and Fowler, 1998) and modern pollen-vegetation relationships (Fletcher and Thomas, 2007), were likely transported moderate to long distances before being deposited at Wombat Pool. About 15,000 cal yr BP, *Phyllocladus aspleniifolius*, the early-colonizing rainforest species started to increase and by 14,500 cal yr BP was an important part of the local vegetation. Evidence for cool conditions at this time comes from marine, ice and pollen data from the region (Fig. 6). Sea-surface temperatures (SSTs) inferred from alkenones and faunal assemblages in marine cores obtained south of Tasmania (44-45° S) and in the

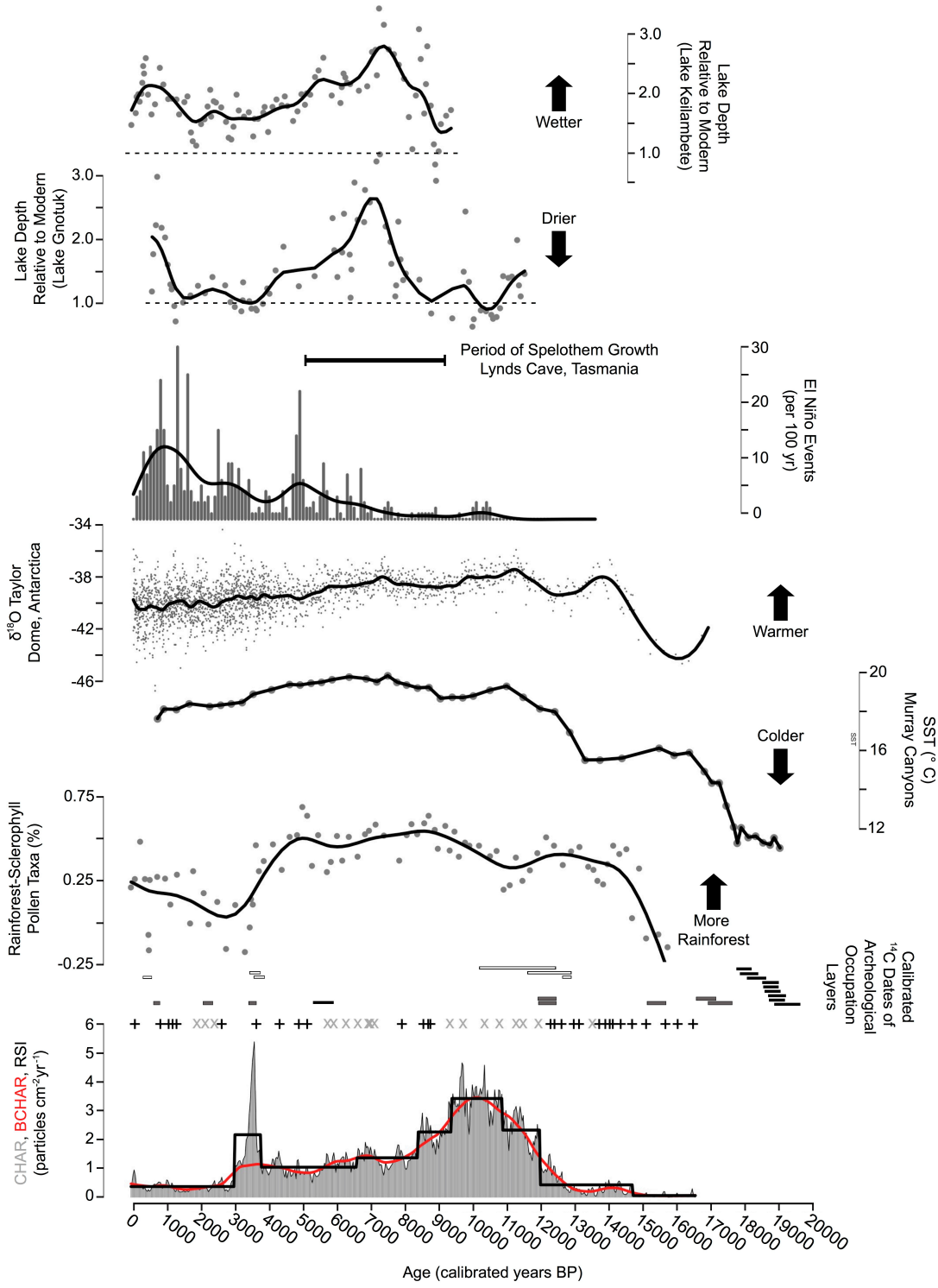


Figure 3.6 Climate, Fire, Vegetation, and Human Occupation Summary for Wombat Pool. A and B) Modeled reconstructions of lake depths relative to modern (modern depth = dashed line) for Lake Keilambete and Lake Gnotuk in southern Victoria, Australia

(Wilkins et al., 2013). C) The stalagmite growth record Lynds Cave, Tasmania. This record spans 5,000-9,200 cal yr BP (Xia et al., 2001). D) The number of El Niño events per 100 years (Moy et al., 2002) with smoothing spline (spar = 0.6). E) Oxygen isotope ratios from Taylor Dome, Antarctica (Grootes et al., 1999) with smoothing spline (spar = 0.6). F) Alkenone-derived sea surface temperature reconstruction from marine core MD03-2611 at Murray Canyons off the coast of South Australia (Calvo et al., 2007). G) The ratio of forest pollen taxa to non-forest pollen taxa in the terrestrial pollen record from Wombat Pool, Tasmania with smoothing spline (spar = 0.6). H) The 1σ calibrated age range of ^{14}C dates on occupation layers at three archeological sites within 25 km of Wombat Pool (Mackintosh Cave = black bars, Warragarra rockshelter = white bars, Parmerpar Meethaner rockshelter = gray bars). I) Charcoal accumulation rate (gray histogram), background CHAR (red line), regime shift index (black line), charcoal peaks (signal-to-noise ratio >3.0 = +, signal-to-noise ratio <3.0 = ×) from Wombat Pool, Tasmania.

Murray Basin region northwest of Tasmania (36° S) were higher than the glacial period but lower than later Holocene levels (Calvo et al., 2007, Sikes et al., 2009). Likewise, Antarctic air temperature, based on $\delta^{18}O$ data, remained low (Grootes et al., 2001; EPICA Members, 2004). High levels of Poaceae and Asteraceae and low levels of tree taxa characterized many of the pollen records from Tasmania and the southeastern Australian mainland during this period (Colhoun and van der Geer, 1986; D'Costa et al., 1989; Colhoun et al., 1999; Hopf et al., 2000; Colhoun and Shimeld, 2012).

Although an abundance of ethnographic evidence from 16-18th centuries indicates Aboriginal Tasmanians frequently and adeptly used fire to shape the Tasmanian landscape (Gammage, 2008, 2011), little is known about how and where fire may have been used in earlier time periods. We consider human presence in the Cradle Mountain region as evidence of a potential anthropogenic fire ignition source. The first evidence of people in Tasmania is dated to ca. ca. 39,000 cal yr BP (Allen, 1996). Three archeological sites within 25 km of Wombat Pool have been excavated and radiocarbon

dated (Fig. 1 and Fig. 6). Two of these, Parmerpar Meethaner and Warragarra, were first occupied about 35,000 years ago (Cosgrove, 1999; Cosgrove et al., 2010), and the third, Mackintosh Cave ca. 20,500 cal yr BP (Stern and Marshall, 1993). The three sites are located at lower elevations than Wombat Pool (250, 300 and 600 m elevation, respectively, compared with 998 m elevation). Warragarra rockshelter has evidence of sporadic, light occupation in the early and late Holocene. Parmerpar Meethaner experienced intense use between ca. 22,000–17,000 cal yr BP (Cosgrove, 1995). Intensive occupation occurred at Mackintosh Cave ca. 20,500-18,000–cal yr BP and was followed by apparent abandonment of the site until the late Holocene (Stern and Marshall, 1993). The period of use and occupation of Parmerpar Meethaner rockshelter and Mackintosh Cave mostly predates the beginning of the Wombat Pool record, and the interval of overlap prior to 14,500 cal yr BP (17,000-14,500 cal yr BP) was the time of lowest biomass burning at Wombat Pool (FI 1 and 2). The fire regime during this period is consistent with what would be expected given the climate (Whitlock et al. 2010; McWethy et al. 2013), therefore, if people were using fire in the region at this time it did not result in alternations to fire regime that deviated from the expectations given climate.

Late-Glacial to Early-Holocene Transition (ca. 14,500–11,500 cal yr BP)

Alpine and moorland communities were replaced by forests at the end of the late-glacial period. *Phyllocladus* was dominant between 14,500–11,900 cal yr BP. This early successional species is one of the few bird-dispersed plants in the Cradle Mountain region (Kirkpatrick, 1977). *Phyllocladus* also expanded in other parts of western Tasmania during the late-glacial period, including at Mt. Field and Lake Vera (Macphail,

1979; Markgraf et al., 1986). Modern analysis has shown that *Phyllocladus* pollen is over-represented in the regional pollen rain, typically comprising 4-12% of the total terrestrial pollen in open moorland and alpine communities (Fletcher and Thomas, 2007). The initial rise at Wombat Pool could be from extralocal or distant populations; however, by 14,500 cal yr BP, values were high enough to indicate local presence (Fletcher and Thomas, 2007). The wide environmental tolerance of *Phyllocladus* combined with its bird-dispersed seeds (Barker and Kirkpatrick, 1994; Barker, 1995) help explain the early preponderance of *Phyllocladus* in a variety of montane and alpine settings.

Warming during this period is inferred from marine cores from the Australian region and Antarctic air-temperature records (Fig. 6; Grootes et al., 2001; EPICA Members, 2004). In addition, sea-surface temperature reconstructions in the Murray Basin northwest of Tasmania increased substantially after 13,000 cal yr BP (Calvo et al., 2007), and suggest an increase in adjacent land temperatures (Cook et al., 2000). Biomass burning increased considerably at ca. 12,000 cal yr BP (i.e. FI 3) and coincided with a brief resurgence in Poaceae pollen. Climate conditions would have favored both fires and grass expansion. Human use and occupation in the Cradle Mountain region is documented at Warragarra rockshelter at ca. 13,000–11,000 cal yr BP (Lourandos, 1983; Allen and Porch, 1996), and at Parmerpar Meethaner rockshelter at ca. 17,000–12,000 cal yr BP (Cosgrove, 1995). People may have provided an ignition source during this period that contributed to the observed increase in charcoal influx. Increases in temperatures during this period best explain the increase and dominance of *Phyllocladus* and would have also promoted fire activity.

Early Holocene (ca. 11,500–9000 cal yr BP)

At the beginning of the Holocene, warming coupled with increased aridity favored increased fires and a brief resurgence of grass. The interval of highest fire activity between 10,900 and 9400 cal yr BP was also the period with highest pollen percentages of *Gymnoschoenus*, *Leptospermum-Baeckea*, and *Banksia*. Buttongrass is highly flammable (i.e. burns in a wide variety of conditions; Pyrke and Marsden-Smedley, 2005), and it vegetatively reproduces allowing it to regenerate vigorously after fire (Burrows, 2002). The arrival of *Banksia* and *Leptospermum-Baeckea* in this period likely provided a local woody fuel source that increased the amount of biomass burned compared with previous periods when herbaceous taxa were dominant. A positive feedback with woody shrubs and fires may have operated during this period. The high flammability of the shrub component created conditions for its persistence and only after the climate shifted towards effectively moister conditions at 9000 cal yr BP did this relationship breakdown (Jackson, 1968).

Regional rainforest development continued in the early Holocene (Fig. 6). An increase in fires at the same time as rainforest expansion is recorded at Wombat Pool as well as other Australian records (i.e. Haberle, 2005; Fletcher et al., *in preparation*). The appearance of the woody, sclerophyllous vegetation community at this time provided a local fuel source while rainforest taxa expanded regionally (Macphail 1979; Hopf 2000; Anker 2001) and locally. Fires may have occurred along the rainforest-sclerophyll woodland margin and microclimate conditions prevented spread into the rainforest (i.e. Haberle 2005). Increased fire activity and increased rainforest taxa were both likely

responding to warming climate but were occurring in spatially disparate areas of the regional landscape. After 11,900 cal yr BP, pollen of *Phyllocladus* declined and those of *Athrotaxis-Diselma* rose and remained abundant until 10,700 cal yr BP, and increased around the lake edge and on nearby south-facing slopes. During the early Holocene, steadily increasing amounts of *N. cunninghammii* pollen suggest its increasing abundance in the Cradle Mountain region. Its late arrival at Wombat Pool compared with *Phyllocladus* or *Athrotaxis* may have been limited by its slow rates of establishment in relatively cool conditions.

Early-Holocene aridity in western Tasmania has been explained by weakened Southern Hemisphere Southwesterly Wind (SWW) flow (Fletcher and Moreno, 2012; Rees et al., 2015). During years when the SWW are positioned south of the island and/or are weak, less precipitation falls in the Cradle Mountain region (Gillet et al., 2006; Gupta and England, 2006). The weakening during the early Holocene is inferred from chironomid records from western Tasmania (Rees et al., 2015) and low lake levels in southwestern Victoria (Fig. 6; Wilkins et al., 2013). The effects of higher-than-present winter and annual insolation (Berger and Loutre, 1991) may have also contributed to aridity in this period by promoting drier summers, milder winters and longer effective spring across the Southern Hemisphere mid-latitudes (Whitlock et al., 2007). Increased biomass burning during the early Holocene has been recorded at other cool-temperate western Tasmanian sites (Fletcher et al., 2015; Rees et al., 2015) and observed in many Patagonian records (Whitlock et al., 2007; Iglesias and Whitlock, 2014), suggesting the importance of large-scale climatic controls on fire activity. Evidence of a human

influence on Tasmanian fire regimes is less compelling. After ca. 11,000 cal yr BP, two of the three archeological sites near Wombat Pool contain no evidence of human occupation at this time (Stern and Marshall, 1993; Allen and Porch, 1996). The third site, Parmerpar Meethaner rockshelter, showed low intensity human occupation in the early Holocene (Cosgrove, 1995).

Middle Holocene (ca. 9000–4500 cal yr BP)

Montane rainforest in the Cradle Mountain region reached its greatest Holocene extent during the middle Holocene (Fig. 6). The highest levels of pollen percentages of *N. cunninghammii* indicate its presence at Wombat Pool between ca. 9000 and 6000 cal yr BP. In addition, *N. gunnii* and *Athrotaxis* were intermittently important during middle Holocene. Large stepwise declines in biomass burning occurred at ca. 9400 and ca. 8400 cal yr BP, and a smaller decline was recorded ca. 6600 cal yr BP. High-resolution charcoal records from Frenchmans Cap (Fletcher et al., 2015; Fletcher et al., *in prep*) and Mount Field (Rees et al., 2015) also indicate a Holocene minimum in fires during this period. Increased effective moisture from ca. 9000-6500 cal yr BP likely favored the expansion of rainforest taxa and reduced landscape flammability. After ca. 6500 cal yr BP, increased variability among the montane rainforest taxa occurred, suggesting canopy opening and/or fluctuating abundances of rainforest tree species possibly as a result of intermittent wet and dry intervals.

Regional climate records provide evidence for relatively wet and warm conditions during the middle Holocene (Fig. 6). See surface temperature (SST) in the Murray Basin reached a Holocene maximum at ca. 8000-5000 cal yr BP with values 2.1° C higher than

present between 6000 and 5500 cal yr BP (Calvo et al., 2007). After ca. 5500 cal yr BP, SSTs steadily decline to the present day (Calvo et al., 2007). The chironomid record of summer temperatures from two sites on Mount Field shows a mixed signal, with one site recording the warmest period at ca. 6700 cal yr BP and a second site showing delayed warming at ca. 4600 cal yr BP (Rees and Cwynar, 2010). Evidence from speleothems from Lynds Cave, 25 km west-northwest of Wombat Pond, suggests a Holocene thermal maximum between ca. 7400-8000 cal yr BP (Xia et al., 2001).

The evidence for relatively high effective moisture during the middle Holocene comes from multiple sources. Between 9200 and 5000 cal yr BP, increased speleothem growth at Lynds Cave, (Xia et al., 2001) is interpreted as evidence of wetter conditions (Zhao et al., 2001). Higher precipitation has also been inferred in western Tasmania between 7000 and 4500 cal yr BP from the relative abundance of *Phyllocladus* compared with *N. cunninghammii* and *Atherosperma moschatum* (i.e. the Lake Vera paleovegetation index) in a pollen record from the Frenchmans Cap region (Fletcher and Moreno, 2011). Lake levels in southeastern mainland Australia also record a Holocene high-stand at ca. 7200 cal yr BP (Fig. 6; Wilkins et al., 2013). High effective moisture during the middle Holocene has been attributed to the increased intensity of moisture-delivering SWW in latitudes north of 50° S (Fletcher and Moreno, 2011, 2012). Aside from a brief period of occupation at Parmerpar Meethaner at ca. 5000 cal yr BP, humans either abandoned the region or were not occupying rockshelters (Cosgrove, 1995). The proxy evidence point to the cool wet conditions of the middle Holocene as the primary

cause for reduced fire activity although the apparent absence of people may have resulted in the removal of an important ignition source and contributed to lower biomass burning.

Late Holocene (ca. 4500 cal yr BP –present)

A substantial change in vegetation in the Cradle Mountain region occurred during the late Holocene. Areas of wet, closed montane rainforest became more restricted, while open *Eucalyptus* woodland communities expanded, after ca. 3600 cal yr BP. The lowest amounts of *N. cunninghammii*, *Athrotaxis*, and *N. gunnii* and highest values of *Eucalyptus* and *Monotoca* pollen were recorded between ca. 3600-2000 cal yr BP. High amounts of Poaceae and Asteraceae after 3600 cal yr BP provides additional evidence of a shift to more-open canopy structured forests.

A major fire episode occurred at ca. 3620 ± 15 cal yr BP, and the magnitude of the charcoal peak (764.67 particles cm^{-2} yr^{-1}) was more than ten times greater than any other in the record, suggesting the occurrence of one or more large or severe fires (i.e. Whitlock et al., 2006; Higuera et al., 2009; Dunnette et al., 2014). After this fire episode, the rainforest taxa in the pollen record dropped to their lowest level of the Holocene and *Eucalyptus* became dominant (Fig. 6). A similar rapid replacement of rainforest by *Eucalyptus* woodland in the late Holocene is noted at Lake St Clair (Hopf et al., 2000), Mount Field (Macphail, 1979), and Lake Osborne in the Hartz Mountains of south-central Tasmania (Fletcher et al., 2014a). Rainforest elements including *N. cunninghammii* and *Athrotaxis* declined substantially at all these sites and were replaced by sclerophyll elements, especially *Eucalyptus* and Proteaceae. Fire played a substantial role in this transition at Lake Osborne; however, whether or not fire drove this shift at

Mount Field or Lake St Clair is currently unknown, as macroscopic charcoal has not been analyzed at these sites.

A significant difference between the records at Lake Osborne (the most detailed and high-resolution of these records) and Wombat Pool, however, is the late Holocene history of *Athrotaxis*. At Lake Osborne, *Athrotaxis* collapsed over the last ca. 3000 years. At Cradle Mountain, *Athrotaxis* declined after the fire episode ca. 3600 years ago, but has rebounded in the last 1000 years. Although large tracts of *Athrotaxis* forest have been lost from bushfires at the hands of Europeans (Marsden-Smedley, 1998), the pollen record from Wombat Pool indicates that *Athrotaxis* has become more abundant in the last ca. 1000 years than during the period between ca. 3600-1000 cal yr BP. This increase is also observed at Solomons Jewel Lake ~30 km southeast of Wombat Pool on the Central Plateau (Dodson, 2001). Dodson (2001) postulated that the expansion of *Athrotaxis* in the last 800-900 years was primarily along the stream channels and lakeshores where it grows today, which is the likely habitat of expansion near Wombat Pool as well. At Cradle Mountain, as elsewhere in western Tasmania, *Athrotaxis* and other montane and subalpine rainforest species are often confined to "topographic refugia" in geographically sheltered, south-facing settings where microclimate conditions are favorable for growth and fires occur infrequently (Wood et al., 2011; Yospin et al., 2015).

Fire activity decreased at Wombat Pool following the extreme fire episode at ca. 3600 cal yr BP. The shift in vegetation composition from montane rainforest to *Eucalyptus* woodland may have contributed to the decline in charcoal influx. The charcoal record from Lake Osborne shows a similar decrease in macroscopic charcoal

(>125 μm) after a vegetation shift from rainforest to *Eucalyptus* woodland ca. 3000 cal yr BP. The explanation at both sites is likely related to reduced fuel biomass and cooler conditions. Despite being more flammable than rainforest communities (Pyrke and Marsden-Smedley, 2005), *Eucalyptus*-dominated woodlands have a more open canopy structure, more widely spaced trees, and less overall fuel than the temperate rainforest communities that defined the mid-Holocene vegetation of Wombat Pool (Jackson, 1968; Jackson, 1999).

A generally cooler and drier climate and enhanced climate variability were features of the late Holocene in western Tasmania (Fig. 6). The cessation of speleothem growth at Lynds Cave at ca. 5000 cal yr BP indicates that effective moisture decreased to the point of precluding of stalagmite growth. A study of Australian dust deposition in New Zealand found that conditions in eastern mainland Australia were generally drier after 4800 BP and also more variable as a result of oscillating dry/wet El Niño/La Niña conditions (Marx et al., 2009). A number of studies from the tropical Pacific indicate changes in ENSO strength and variability in the late Holocene. Records from the western tropical Pacific suggests the onset or strengthening of ENSO ca. 5000 years ago (Shulmeister and Lees, 1995; Wanner et al., 2008), whereas evidence from the eastern tropical Pacific region shows strengthening and/or increased variability occurred at 3000-4000 cal yr BP (Moy et al., 2002; Conroy et al., 2008; Koutavas and Joanidea, 2012; Carré et al., 2014). A number of paleoecological records from Tasmania exhibit fluctuations in fire, vegetation or both in the late Holocene (i.e. Macphail, 1979; Fletcher et al., 2014a; Fletcher et al., 2015), and this variability has been attributed to ENSO

influences (Donders et al., 2007; Fletcher et al., 2014a; Fletcher et al., 2015; Rees et al., 2015; McWethy et al., *in review*). Given Wombat Pool's location in the region of northern Tasmania that is influenced by ENSO today (Hill et al., 2009), heightened ENSO variability could explain some of the oscillating vegetation patterns as well as the fuel conditions, including the large fire episode. However, the charcoal and pollen records from Wombat Pool are not of sufficient temporal resolution to show definitive phasing with El Niño and La Niña events.

Archeological evidence from two sites (Warragarra and Parmerpar Meethaner rockshelters) near Wombat Pool documents a resumption of human use ca. 4000 years ago that lasts to the European period (Lourandos, 1983; Cosgrove, 1995; Allen and Porch, 1996). People either repopulated a region that they had abandoned or shifted subsistence strategies back towards the use of rockshelter/cave sites (Cosgrove, 1999; Pike-Tay et al., 2008). In either case, they may have become a significant ignition source that was lacking during the previous ca. 7000 years.

The cause of the large fire episode at 3600 cal yr BP is impossible to determine from the paleoecological record, but the event was likely responsible for triggering a change in vegetation at Wombat Pool from a mixed forest with rainforest elements to a *Eucalyptus* woodland. The mosaic nature of the vegetation at Cradle Mountain today may be, in part, a legacy of this fire episode. This event appears to have provided an opening for *Eucalyptus* and other wet sclerophyll forest plants. Cool dry conditions in the late Holocene limited the ability of subalpine and temperate rainforest species, including *Athrotaxis*, to be maintained as the dominant and thus the shift to more

sclerophyll species. The occurrence of a large fire perturbation may have created a threshold that pushed the rainforest vegetation to a more sclerophyll-dominated assemblage.

Conclusions

The Wombat Lake record suggests that variations in climate have been the primary driver of changes in vegetation and fire over the last 17,000 cal years in the Cradle Mountain area. The importance of large-scale changes in the climate system is evident from comparing the pollen and charcoal data at Wombat Pool with paleoclimate proxy data from the region and Southern Hemisphere. In contrast, human occupation intensity near the site declined after 17,000 cal yr BP and was nearly absent by 11,000 cal yr BP. Past changes in vegetation and climate at Wombat Pool show little relationship to times of human activity in the local area.

Deglacial landscapes near Wombat Pool were initially covered by grass and herbs, and woody subalpine shrubs colonized the area at ca. 16,000 cal yr BP. Rainforest trees and shrubs were present at 14,000 cal yr BP when conditions were warmer than before but fires were infrequent. Fire activity increased between 12,500–11,000 cal yr BP and the highest fire activity occurred between ca. 10,900 and 9400 cal yr BP. Pollen data indicate a mosaic of wet and dry vegetation types, which suggests that fires primarily burned the fire-prone parts of the landscape covered by wet sclerophyll shrub and buttongrass moorland, while rainforest survived in protected humid settings. High fire activity in the early Holocene is attributed to the effects of high winter and annual

insolation during this period, which resulted in higher-than-present winter and annual temperatures that in turn lengthened the growing season and increased levels of fuel biomass. The early Holocene is also a time of high fire activity in southern South America, and warm dry conditions in temperate southern latitudes have been attributed to weaker and more southerly position of the Southern Hemisphere Westerlies than at present.

During the middle Holocene, ca. 8500–6500 cal yr BP, the montane rainforest was well developed near Wombat Pool and at other sites across western Tasmania. A decline in fire activity after ca. 8500 cal yr BP is attributed to high effective moisture and enhanced Southern Westerly flow. The hemispheric temperature record, regional lake levels, and local speleothem growth rates suggest that conditions became drier after ca. 6000 and cooler after ca. 5000 cal yr BP and these trends likely explain the decline in rainforest and subalpine taxa after ca. 6000 cal yr BP at Wombat Pool and across western Tasmania.

In the late Holocene, a large fire event occurred at ca. 3600 cal yr BP and was associated with a major shift in the vegetation from rainforest and subalpine taxa to open sclerophyll taxa. This event has also been noted at other sites in the region, suggesting that severe fires were supported by regionally dry conditions. The open sclerophyll woodland persisted until ca. 2000 cal yr BP when rainforest and subalpine taxa began to increase resulting in a mosaic of wet sclerophyll and rainforest communities. In the last 1000 years, *Athrotaxis-Diselma* has increased in abundance near Wombat Lake, in the absence of local fires, in contrast to its decline throughout much of western Tasmania. Its

local recovery may be cause for some optimism: if old-growth forests can be protected from fire, *Athrotaxis* may have some capacity to regenerate naturally in the Cradle Mountain region.

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CHAPTER FOUR

THE POSTGLACIAL AND HOLOCENE RECORD OF FIRE AND VEGETATION FROM CRADLE MOUNTAIN NATIONAL PARK, TASMANIA, AUSTRALIA

Contribution of Authors and Co-Authors

Manuscript Chapter 4

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Contributions: Defined the experimental design, participated in fieldwork, described the sediment cores, measured magnetic susceptibility, loss-on-ignition and other lithological properties of the cores, counted charcoal and pollen samples from Wombat Pool, analyzed the data, and wrote the manuscript.

Co-Author: Cathy Whitlock

Contributions: Supported this research under National Science Foundation grant OISE-09664472, helped define the experimental design, participated in fieldwork, discussed the results and implications, and edited the manuscript.

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Abstract

Fire activity was reconstructed at five sites and vegetation history at three sites in northwest Tasmania, Australia in order to examine the climate and human drivers of environmental change in the region. Watershed-scale reconstructions of fire were compared to regional vegetation history. Fire activity was very low until ca. 12,000 cal yr BP. An early-Holocene fire maximum, ca. 11,800-9800 cal yr BP, occurred during the warmest interval of the Holocene as recorded by regional paleoclimate proxy records. This period of elevated burning was also coincident with an increase in sclerophyll plant taxa. A regional maximum in rainforest taxa occurred at ca. 8500-5800 cal yr BP concurrent with sharply diminished biomass burning compared with the early Holocene. The increase in rainforest taxa is attributed to elevated effective moisture during this period. Conditions were more arid and variable in the late Holocene as compared with earlier periods, and an increase in fire activity occurred at ca. 4800-3200 cal yr BP. An abrupt increase in sclerophyll taxa, and decline of rainforest and subalpine taxa accompanied this increase in biomass burning. Elevated palynological richness during the Holocene co-occurred with high levels of charcoal suggesting that fires promoted high floristic diversity. At Cradle Mountain, there is no clear evidence that fire regimes or vegetation were extensively modified by humans prior to European settlement. Climate was the primary driver of fire activity over millennial timescales as explained by the close relationship between charcoal and climate proxy data.

Keywords: fire history, vegetation history, pyrogeography, Tasmania, fire ecology, vegetation heterogeneity, disturbance, biodiversity

Introduction

Understanding the long-term roles of climate and people on fire and vegetation in Tasmania has been an active area of investigation for decades. Work by Macphail and Colhoun among others was instrumental in establishing the sequence of postglacial vegetation development in western Tasmania (e.g. Macphail 1979; Colhoun and van de Geer, 1986; Colhoun et al., 1999). More recent paleoecological studies have been published from the Central Plateau (Dodson, 2001), Lake St Clair (Hopf et al., 2000), southwest Tasmania (Fletcher and Thomas, 2007a), the Hartz Mountains (Fletcher et al., 2014a), eastern Tasmania (Mackenzie and Moss, 2014), Flinders Island (McWethy et al., 2017), and western Tasmania (Anker et al., 2001; Fletcher and Thomas, 2010b). Fire history information in Tasmania is limited to five high-resolution charcoal-based studies that cover the entire Holocene (Fletcher et al., 2015; Rees et al., 2015; McWethy et al., 2016; Stahle et al., 2016; Beck et al., 2017), and two that span the mid-Holocene to present (Fletcher et al., 2014a; b).

Aboriginal peoples entered Tasmania at least 40,000 years ago (Cosgrove, 1999) and are believed to have used fire to enhance hunting success and facilitate travel (Cosgrove et al., 1990; Bowman, 1998; Gott, 2005; Gammage, 2008; 2011). As such, a longstanding issue in Tasmanian ecology concerns whether or not deliberate burning by Aboriginal people substantially influenced the natural fire regimes and vegetation. In this paper, we describe the postglacial fire and vegetation in the northern sector of Cradle Mountain-Lake St Clair National Park based on pollen and charcoal records from small lakes in close proximity. The objectives of this chapter are to: 1) reconstruct the

vegetation and fire history of the Cradle Mountain based on new paleoecological records; 2) interpret the environmental history of the region in light of past changes in climate and human activity; and 3) examine the influence of Holocene vegetation change on human land-use strategies as a way of exploring past human-fire interactions.

Study Area

Cradle Mountain-Lake St Clair National Park (CM-LSCNP) is located in northwest Tasmania, Australia and is part of the Tasmanian Wilderness World Heritage Area, a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Area. Hereafter, we refer to our study area as Cradle Mountain. The study lakes, Lake Hanson (41.663°S 145.973°E; 1007 m), Lake Lilla (41.652°S; 145.955°E; 933 m), Lake Wilks (41.673°S 145.955°E; 1060 m), Suttons Tarn (41.683°S 145.934°E; 1099 m), and Wombat Pool (41.650°S 145.950°E; 998 m), are located in the northern sector of the national park (Fig. 1; Table 1). The lakes are located within 0.6 and 5.0 km of each other in a topographically complex landscape scoured by late Pleistocene glaciation (Colhoun 1980; Thrush 2008). Dolerite, quartzite, and basalt underlie the study area. Soils are nutrient poor on dolerite and quartzite substrates while basalt-derived soils are more nutrient-rich and fertile.

The national park is located in the transition zone between eastern Tasmania, which has a drier climate and more fertile soils, and the western half of the state, which receives more precipitation and generally has infertile soils. Precipitation in Cradle Mountain is associated with the strength and latitudinal position of the Southern

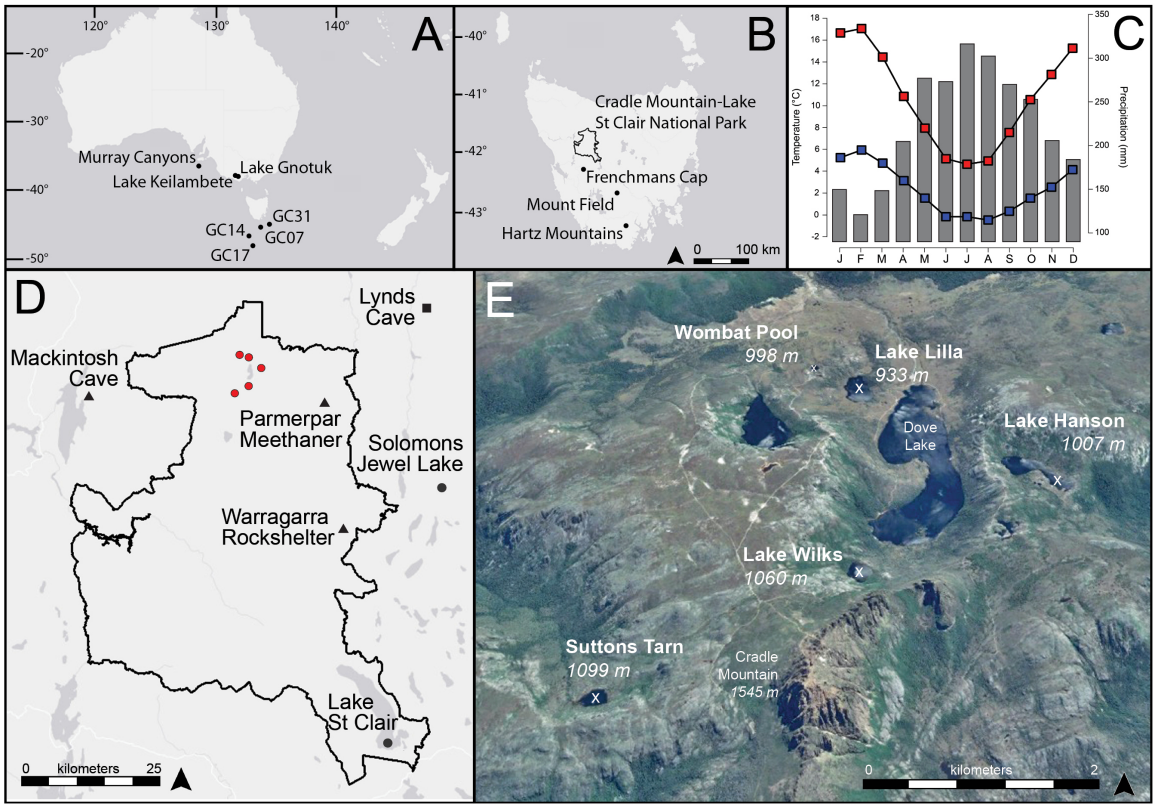


Figure 4.1 Map and modern climate of study area. (A) Map of Australia with location of regional climate data (black circles = marine and lake sediment records) discussed in the paper identified. (B) Map of Tasmania with Cradle Mountain-Lake St Clair National Park (black line) and other paleoecological sites discussed in the text (black circles) identified. (C) Monthly climate data for Cradle Mountain-Waldheim Station (#096995; 41.64° S, 145.94° E, 903 m elev.). Mean maximum temperature (red) and mean minimum temperature (blue; °C) 1926-1977, and mean precipitation (gray bars; mm) 1917-2009. (D) Map of Cradle Mountain-Lake St Clair National Park with location of study lakes (red circles), archeological sites (triangles), speleothem record (black square), and other lake records discussed in the text (black circles) identified. (E) Satellite image of study area with study lakes (white Xs), Dove Lake, and Cradle Mountain identified.

Hemisphere Westerly Winds (SWW), which influences the position of storm tracks. As a result of north-to-south mountain ranges, a strong west-to-east precipitation gradient exists on the island and the western mountains receive substantial orographic rainfall. At Cradle Mountain, the annual precipitation is 2650 mm with one-third falling in winter (JJA; Waldheim station at Cradle Valley, 903 m; Bureau of Meteorology;

http://www.bom.gov.au/climate/averages/tables/cw_096005.shtml; Fig. 1C). From 1917-2009, average winter (JJA) minimum temperature was -0.3° C and average summer (DJF) maximum temperature was 16.3° C. Precipitation anomalies are associated with the Southern Annular Mode (SAM) and El Niño/Southern Oscillation (ENSO). In western Tasmania, a positive SAM phase is associated with reductions in winter rainfall, whereas a negative SAM is associated with increases in rainfall in spring and summer (Hendon et al., 2007). In northern Tasmania, ENSO explains between 10-40% of rainfall variability and the relationship is strongest in winter (Risbey et al., 2009). During El Niño years, conditions are anomalously dry in Cradle Mountain while during La Niña years rainfall is above average (Hill et al., 2009). A strong relationship exists in Tasmania between annual area burned and October-May (i.e. spring, summer and fall) rainfall (Nicholls and Lucas, 2007; Williamson et al., 2016).

Table 4.1 Site & Core Information from Cradle Mountain.

Site	Position	Elevation (m a.s.l.)	Surface Area (ha)	Record Length (cm)	Water Depth (m)	Publication
Lake Hanson	41.663°S 145.973°E	1007	8.4	135.0	6.5	This manuscript
Lake Lilla	41.652°S; 145.955°E	933	7.2	81.5	13.2	This manuscript
Lake Wilks	41.673°S 145.955°E	1060	2.7	277.0		This manuscript
Suttons Tarn	41.683°S 145.934°E	1099	2.0	115.0	10.5	This manuscript
Wombat Pool	41.650°S 145.950°E	998	0.4	331.0	2.0	Stahle et al., 2016

Present-day vegetation in Cradle Mountain is composed of a diverse mosaic of vegetation types including temperate rainforest, wet sclerophyll woodland and shrub communities, mixed forest containing rainforest and *Eucalyptus* species, areas of moorland dominated by buttongrass (*Gymnoschoenus sphaerocephalus*), small grassland patches, and alpine shrublands and herblands. Many endemic plants occur in the area, including *Athrotaxis selaginoides* and *A. cupressoides*. These culturally and ecologically important conifer trees grow in temperate rainforest and subalpine forest stands. Key rainforest trees include the two *Athrotaxis* species, *Nothofagus gunnii* (synonym = *Fuscospora gunnii*), *N. cunninghammii* (synonym = *Lophozonia cunninghammii*), and *Phyllocladus aspleniifolius*. For consistency with fossil records, *Nothofagus* will be used in place of the newer genus names (Hill et al., 2015). Many types of cool temperate rainforest persist in Cradle Mountain including *Athrotaxis*-*N. gunnii* short rainforest, *A. cupressoides* open woodland, *N. gunnii* rainforest and scrub, *A. selaginoides* rainforest, *A. cupressoides* rainforest, *A. selaginoides* subalpine scrub, and *Nothofagus*-*Atherosperma* rainforest (Harris and Kitchener, 2005).

The vegetation consists of both pyrophobic and pyrophytic plant communities. All temperate rainforests are classified as "extremely fire sensitive" indicating the ecological impact from a single fire is potentially high (Pyrke and Marsden-Smedley, 2005). Alpine shrub species include *Podocarpus lawrencii*, *Microcachrys tetragona*, *Diselma archeri*, and *Microstrobus niphophilus* (Kirkpatrick and Bridle, 2013) all of which are extremely fire sensitive (Pyrke and Marsden-Smedley, 2005). Subalpine *Eucalypts* are also an important component of the vegetation mosaic in Cradle Mountain.

Eucalyptus subcrenulata and *E. coccifera* co-occur in subalpine, sclerophyll woodland and open scrub communities (Wells and Hickey 2005). These communities are classified as having "high fire sensitivity" which indicates they are fire-adapted communities that require at least 30 years between fires to maintain the defining species, while fire intervals greater than 80 years are required to reach mature stand structure (Pyrke and Marsden-Smedley, 2005). Shrubland and swamp forest plants from the Proteaceae, Myrtaceae, Ericaceae and other families are found in wet sclerophyll forest and scrub, mixed forest and moorland locales. These communities, except buttongrass moorlands, are classified as moderately fire sensitive indicating they are fire-adapted communities requiring at least 15 years between fires to maintain the defining species (Pyrke and Marsden-Smedley, 2005). Buttongrass moorland with and without emergent shrubs are considered to have low fire sensitivity indicating these communities are highly fire-adapted and that fire generally does not affect biodiversity (Pyrke and Marsden-Smedley, 2005).

The study lakes are presently occupied by a mosaic of the different vegetation communities that exist in Cradle Mountain. Lake Hanson is surrounded by a mature cool, temperate rainforest, areas of mixed forest, and *N. gunnii* stands. Lake Lilla is surrounded by wet sclerophyll forest and shrub, buttongrass moorland, and mixed forest containing rainforest trees (*N. cunninghammii*, *A. selaginoides*, *Phyllocladus aspleniifolius*) and *Eucalyptus* species. The Lake Wilks basin is occupied by *Athrotaxis* rainforest, substantial patches of *N. gunnii*, *Eucalyptus* woodland, and coniferous alpine heathland. Suttons Tarn contains a mix of *N. gunnii*-dominate cool, temperate rainforest and

coniferous alpine heath. Finally, Wombat Pool is surrounded by a mosaic of wet sclerophyll forest and shrub communities, areas of buttongrass, mixed forest, and alpine shrubland. *A. cupressoides* of different age classes grow directly on the edge of all study lakes.

Material and Methods

Field

Sediment cores were obtained from five small lakes in 2012 and 2013 from an anchored platform in the deepest water (Table 1). Cores from Lake Hanson, Lake Wilks, and Wombat Pool were obtained with a modified Livingstone piston sampler. A 6-cm-diameter polycarbonate tube attached to a universal gravity corer was used to collect cores from Lake Lilla and Suttons Tarn. The mud-water interface was captured with a plastic piston corer at Lake Hanson, Lake Wilks, and Wombat Pool. Cores from Lake Hanson, Lake Wilks, and Wombat Pool were extruded in the field and wrapped in cellophane and aluminum foil, while the entire cores were kept intact from Lake Lilla, and Suttons Tarn. The Lake Wilks samples were transported to the Australian National University, and the core from the other five sites were shipped to the National Lacustrine Core Facility (LacCore) at the University of Minnesota for initial lithological analysis.

Chronology and Lithology

Bulk sediment samples were submitted for radiocarbon dating from each lake. Radiocarbon ages were calibrated using the Southern Hemisphere radiocarbon calibration dataset SHCal13 (Hogg et al., 2013). Chronologies were developed by modeling

sediment age as a function of sediment depth using Clam v2.2 (Blaauw, 2010). The published chronology for Wombat Pool (Stahle et al., 2016) was used.

Core description, imaging, and magnetic susceptibility measurements for L. Hanson, L. Lilla, and Suttons Tarn were performed at LacCore. Cores were split lengthwise and one half was reserved as the archival half and the other working half was later destructively sampled. The archival halves of the cores from these three sites are stored at the Paleoecology Laboratory at Montana State University. For L. Hanson, L. Lilla, and Suttons Tarn, magnetic susceptibility (MS), which measures changes in inorganic allochthonous sediment input from erosional processes (Gedye et al., 2000), was measured at 0.5-cm continuous intervals.

Pollen Analysis

Pollen analysis was undertaken on the Lake Hanson and Suttons Tarn cores. Samples of 0.25-1.0 cm^3 volume were taken at 0.25 to 10.0 cm core-depth intervals and prepared using methods described in Bennett and Willis (2001). Pollen grains were identified at 400x and 1000x magnification to the lowest taxonomic level possible, and terrestrial pollen counts exceeded 300 grains per sample. Identifications were based on the Australasian Pollen and Spore Atlas (apsa.anu.edu.au; APSA-Members, 2007), the pollen reference collection at the Australian National University, and the online Newcastle Pollen Collection (Hopf et al., 2005). Pollen percentages were based on the terrestrial sum (trees, shrubs, herbs, and terrestrial pteridophytes). The pollen diagrams were grouped according to modern affinities: ‘Rainforest and Subalpine taxa’,

'Sclerophyll Woodland taxa', 'Grassland and Herbland taxa', and 'Wetland taxa'. A *Lycopodium* tracer was added to the pollen samples.

Interpretation of the pollen percentage data was based on a comparison with modern pollen data from Cradle Mountain lake-sediment samples and with the extensive dataset published by Fletcher and Thomas (2007b). The pollen-percentage record was divided into zones by visual inspection and constrained cluster analysis (CONISS; Grimm, 1988). Pollen diagram plots and CONISS analysis were made using the program Tilia v2.0 (Grimm, 1990).

Charcoal Analysis

Charcoal analysis was performed on 2-cm^3 volume samples taken at continuous 0.5-cm intervals at four sites and 1.0-cm intervals at Lake Wilks following the method described by Whitlock and Larsen (2001). Samples were washed through a 125-µm mesh sieve, and charcoal particles from the residues were counted under a stereomicroscope at 40x magnification. Charcoal particles in this size fraction (i.e. macroscopic charcoal) are deposited relatively close to their source area and widely used as a proxy of local fire activity (Clark 1988; Whitlock and Larsen, 2001). Charcoal concentrations and deposition times were calculated and converted to charcoal accumulation rates (CHAR; particles cm^{-2} yr^{-1}).

To account for temporal variations in sampling intervals resulting from variable sedimentation rates, the CHAR time series was interpolated to the median resolution of each record (Higuera et al., 2010). CHAR was then decomposed into background (BCHAR) and peak components (Higuera et al., 2009;

http://CharAnalysis.googlepages.com) with a 1250-yr lowess smoother robust to outliers. A mixed Gaussian model was used to decompose the high frequency component of the time series into "noise" and "peaks," the peak component being the 95th percentile of the noise population (Higuera et al., 2009). Charcoal peaks are assumed to represent one or more fires during the time span of the peak (referred to as "fire episodes"). Peaks were tested for statistical significance by comparing the original charcoal counts with the values of the previous five samples. Where the peak count had at least a 0.5% chance of coming from the same Poisson-distributed population as the smallest number of charcoal particles counted in the preceding five samples, the peak was considered insignificant (Higuera et al., 2009). The suitability of the records for fire-episode identification was assessed with a signal-to-noise index (SNI; Kelly et al., 2011) and only periods where SNI > 3.0 were considered appropriate for charcoal peak interpretation. A 1000-yr bandwidth was used to calculate the SNI. Fire size and/or intensity were inferred from the magnitude of charcoal particle counts for individual peaks (Higuera et al., 2009).

The fire history was divided into fire regime zones (Fire Intervals, FI) applying the regime shift index (RSI) algorithm described by Rodionov (2004) to the CHAR time series. It incorporated a sequential Student's *t*-test (Huber's WF = 5, $P > 0.01$, cut-off = 20 samples) and determined where significant changes in the mean values of two adjacent regimes occur. These transitions were used to delineate fire regime intervals. Plots were made in R v3.2.2 (R Core Team, 2015).

Statistical Methods

Generalized Additive Models (GAMs) were used to construct composite records of charcoal, vegetation (i.e. rainforest taxa, sclerophyll taxa, subalpine taxa, wetland taxa, grassland taxa), and palynological richness following the method described by Iglesias and Whitlock (2014). We estimated temporal trends in palynological richness in order to explore changes in biodiversity through time. Palynological richness is defined as the number of terrestrial pollen and spore types present in a pollen assemblage using a constant pollen sum value (Birks and Line, 1992). Palynological richness was calculated using Psimpoll version 4.27 (Bennett 2009) for Lake Hanson, Suttons Tarn and Wombat Pool using rarefaction to 317, 313, and 340 grains, respectively, as these were the minimum pollen counts for any sample in the three sequences. We also examined palynological evenness, or equitability of pollen types in each sample, in order to assess whether palynological richness was unduly influenced by the changes in taxonomic variability. Evenness was calculated as the inverse slope of the rank-order abundance of taxa exceeding 0.3 % in each sample following Giesecke et al. (2014) using the Vegan package (Oksanen et al. 2011) in the R programming language v3.2.2 (R Core Team, 2015) using the script developed by Giesecke et al. (2014). Finally, square chord distance (SCD) was used to assess the differences between the pollen taxa assemblages (Gavin et al., 2003) and calculated using the R package analogue v0.16-3 (Simpson, 2007; Simpson and Oksanen, 2015). For L. Hanson, Suttons Tarn, and Wombat Pool, the pollen sample with the highest ratio of rainforest and subalpine taxa (65.0 cm, 57.5 cm, and 42.0 cm, respectively) to sclerophyll taxa was used as the baseline for comparison in

order to identify how different the pollen assemblage in each sample was to a temperate rainforest assemblage (Macphail, 1975; Fletcher and Thomas, 2007b). A regime shift index (RSI) algorithm (Rodionov, 2004) was then applied to the SCD time series (Huber's WF = 5, $P > 0.1$, cut-off = 10 samples) in order to identify regime shifts in vegetation assemblages.

Results

Chronology and Lithology

A total of 32 radiocarbon samples from four cores (L. Hanson = 8, L. Lilla = 8, L. Wilks = 10, Suttons Tarn = 6) were submitted to Woods Hole NOSAMS AMS facility for radiocarbon dating analysis (Table 2). Preliminary models for the four sites were developed by independently modeling age as a function of depth in each core. The final age-depth models were developed by Monte Carlo fitting smoothing splines through the probability distribution of all calibrated ages in Clam v2.2 (Blaauw 2010; Fig. 2). The same degree of smoothing (0.4) was used in the construction of all four chronologies. The published age-depth model for Wombat Pool was used (Stahle et al., 2016).

The core lithology for L. Hanson, L. Lilla, and Suttons Tarn is displayed in Figure 3. Each record contained two units. These units were determined by visual analysis and magnetic susceptibility.

Table 4.2 Radiocarbon dating results from Lake Hanson, Lake Lilla, Lake Wilks, and Suttons Tarn. Calibrations (cal yr BP) are based on the Southern Hemisphere calibration curve SHCal13.14C (Hobbs *et al*. 2013).

Core	Depth (Top; cm)	Lab Number *	Material Dated	Radiocarbon Age (^{14}C yr BP)	Error (^{14}C yr BP	Age (cal yr BP) & Probability **
Lake Hanson 12A	10.0	OS-108059	Bulk sediment	1510	25	1306-1381; 89.7 1390-1403; 5.3
Lake Hanson 12A	22.0	OS-108109	Bulk sediment	2450	30	2347-2511; 75.5 2528-2537; 0.8 2590-2615; 4.5 2634-2697; 14.2
Lake Hanson 12A	40.0	OS-108110	Bulk sediment	4900	25	5486-5513; 10.8 5523-5526; 0.6 5580-5654; 83.5
Lake Hanson 12A	56.0	OS-108111	Bulk sediment	6190	25	6954-7159; 95.0
Lake Hanson 12C	71.5	OS- 104112	Bulk sediment	8050	35	8723-9009; 95.0
Lake Hanson 12A	72.0	OS-105542	Bulk sediment	7760	55	8419-8583; 95.0
Lake Hanson 12C	99.5	OS- 104113	Bulk sediment	9740	40	10812-10840; 1.9 10867-10952; 16.2 11070-11226; 76.8
Lake Hanson 12C	127.5	OS- 104114	Bulk sediment	10,600	40	12431-12572; 66.5 12581-12646; 28.5
Lake Lilla 12F	19.0	OS-105818	Bulk sediment	3660	50	3730-3745; 1.2 3768-3790; 1.8 3825-4089; 91.9

Lake Lilla 12F	27.0	OS-105819	Bulk sediment	4810	35	5330-5376; 11.7 5453-5591; 83.2
Lake Lilla 12F	35.0	OS-105820	Bulk sediment	6300	35	7022-7118; 17.4 7152-7267; 77.5
Lake Lilla 12F	43.0	OS-105821	Bulk sediment	8400	55	9143-9173; 2.5 9208-9217; 0.6 9239-9497; 91.9
Lake Lilla 12F	51.0	OS-106149	Bulk sediment	9070	40	9950-9987; 3.0 10,042-10,056; 0.9 10,149-10,256; 91.0
Lake Lilla 12F	59.0	OS-106054	Bulk sediment	9680	40	10,784-11,033; 56.5 11,060-11,185; 38.4
Lake Lilla 12F	67.0	OS-106055	Bulk sediment	10,400	35	12,023-12,317; 73.2 12,322-12,403; 21.8
Lake Lilla 12F	75.0	OS-100719	Bulk sediment	12,200	55	13,820-14,196; 95.0
Lake Wilks	23.0	105878	Bulk sediment	660	25	552-577; 23.6 583-649; 71.3
Lake Wilks	35.0	101997	Bulk sediment	1730	25	1523-1630; 83.3 1653-1691; 11.7
Lake Wilks	45.0	105879	Bulk sediment	2260	35	2128-2331; 95
Lake Wilks	58.0	101998	Bulk sediment	3590	25	3705-3897; 95
Lake Wilks	99.0	101668	Bulk sediment	3820	30	3989-4046; 14.6 4066-4240; 80.4
Lake Wilks	46.0	105874	Bulk sediment	1770	40	1531-1714; 95

Lake Wilks	119.0	105875	Bulk sediment	3570	45	3642-3664; 2.7 3683-3913; 92 3918-3920; 0.2 3955-3955; 0.1
Lake Wilks	163.0	105876	Bulk sediment	5620	75	6206-6503; 94.8 6524-6526; 0.1
Lake Wilks	228.0	105877	Bulk sediment	8150	120	8636-9316; 92.8 9358-9399; 2.1
Lake Wilks	273.0	101669	Bulk sediment	10,055	45	11,267-11,653; 89.3 11,661-11,708; 5.7
Suttons Tarn 13A	10.0	OS-118680	Bulk sediment	2570	20	2714-2752; 95.0
Suttons Tarn 13A	30.0	OS-118297	Bulk sediment	6080	20	6891-6997; 95.0
Suttons Tarn 13A	50.0	OS-118298	Bulk sediment	8750	25	9615-9616; 0.3 9623-9888; 94.6
Suttons Tarn 13A	70.0	OS-118299	Bulk sediment	10,550	30	12,421-12,509; 39.4 12,511-12,617; 55.5
Suttons Tarn 13A	90.0	OS-118300	Bulk sediment	12,100	35	13,809-14,103; 95.0
Suttons Tarn 13A	108.0	OS-118301	Bulk sediment	13,300	40	15,811-16,170; 95.0

* Lab numbers that begin with OS are from NOSAMS; lab numbers with no letters are from ANSTO
** Calibrated ages derived from Clam v2.2 and represented the 2-sigma error ranges

L. Hanson Unit 1 (135.0−129.5 cm depth; 13,030−12,715 cal yr BP) consisted primarily of inorganic glacial silt and clay. Magnetic susceptibility was high in this period (−1.3 to −0.1 SI units; mean = −1.355) indicating substantial mineral clastic input (Gedye et al., 2000). L. Hanson Unit 2 (129.0−12.5 cm depth; 12,715−1586 cal yr BP) was composed of fine-detritus gyttja. Magnetic susceptibility was generally lower in this period (−2.1 to 1.4 SI units; mean = −0.607) suggesting more organic sediment than Unit 1. Unit 2 included an increase in MS between 35.0−33.0 cm depth (4705−4429 cal yr BP), which was associated with a change in lithology toward clay-rich sediments and contemporaneous with a fire event. This interval is the only depth where fire and MS had concurrent increases.

L. Lilla Unit 1 (83.0−68.5 cm depth; 15,175−12,735 cal yr BP) contained inorganic clay and silt with high MS values (0.4 to -0.8 SI units; mean = -0.272). Unit 2 (68.5−12.5 cm depth; 12,735−2550 cal yr BP) was composed of fine-detritus gyttja and had lower MS values (-0.4 to -1.6 SI units; mean = -1.094).

Suttons Tarn Unit 1 (116.0−109.0 cm depth; 16,600−16,000 cal yr BP), like the earlier units in the other cores, was mostly inorganic clay and silt with elevated MS values (1.8 to 1.3 SI units; mean = 1.653). Unit 2 (109.0−0.0 cm depth; 16,000− -62 cal yr BP) was primarily composed of fine-detritus gyttja with low MS values (2.6 to -1.2 SI units; mean = 0.087).

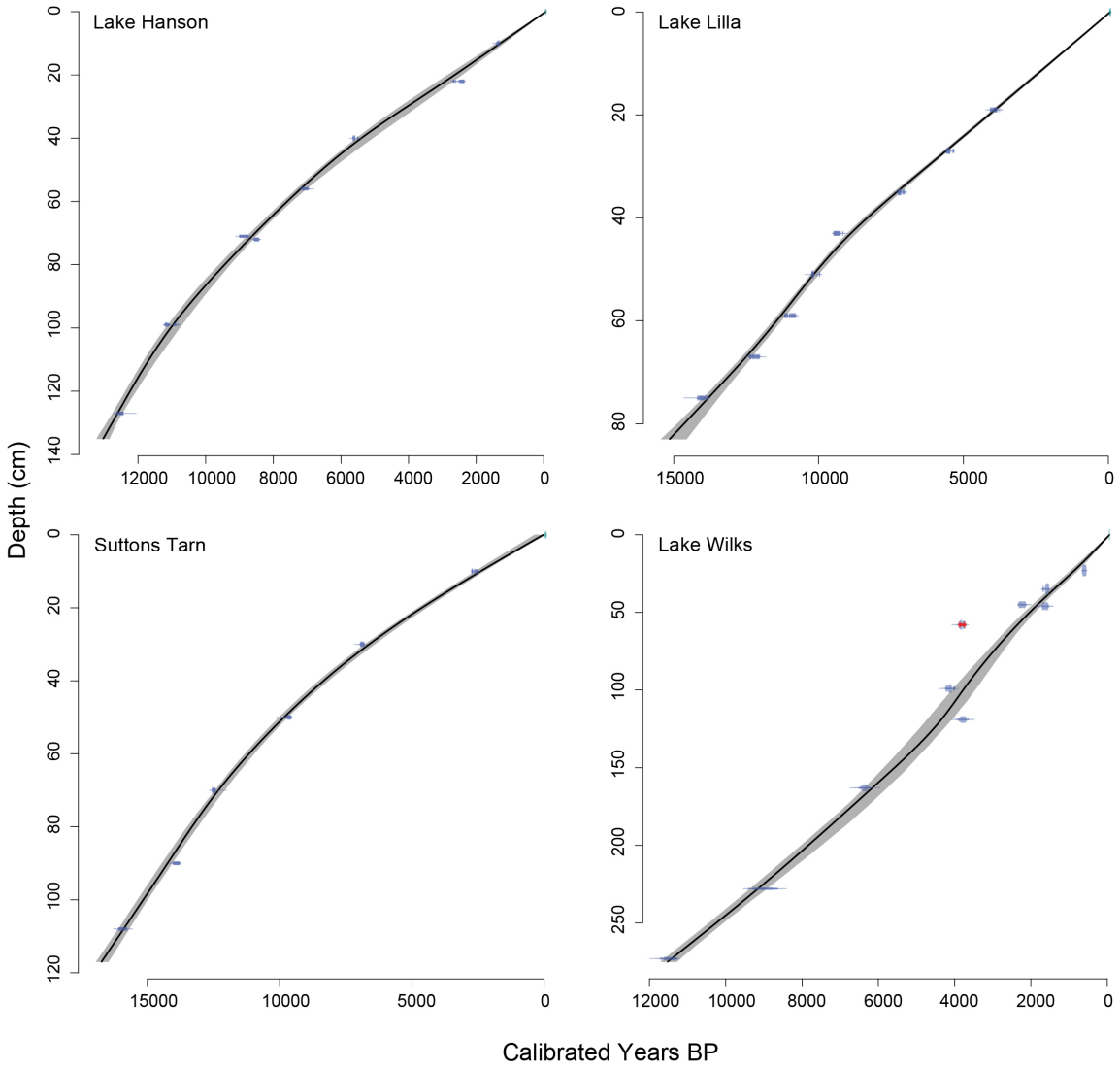


Figure 4.2 Age-depth models. Age depth models (black lines) for Lake Hanson, Lake Lilla, Suttons Tarn and Lake Wilks were made using Clam v2.2 (Blaauw, 2010). The 95% confidence intervals are shown as gray shading. The distributions of the calibrated radiocarbon ages that were used to develop the models are shown in blue, and the Lake Wilks date that was not included in its model is indicated in red.

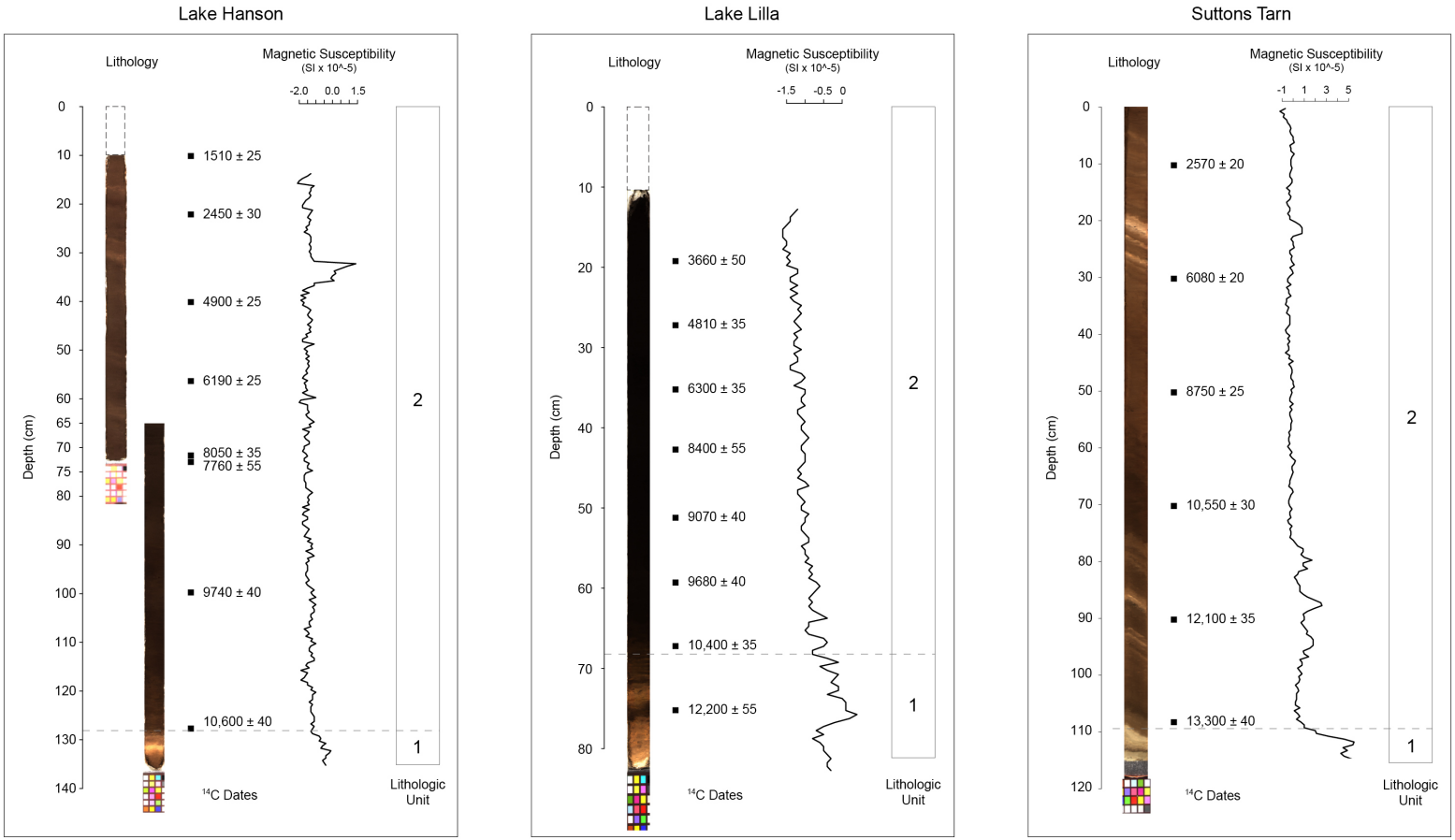


Figure 4.3 Lithology. Lithology (core photographs), uncalibrated radiocarbon dates and associated errors, and magnetic susceptibility from Lake Hanson, Lake Lilla, and Suttons Tarn. The top 10 cm of the Lake Hanson and Lake Lilla records (dashed line boxes) were subsampled in the field and thus not photographed.

Pollen

Lake Hanson (Fig. 4) Pollen Zone 1 (HAN-1; 133.0–105.5 cm depth; 13,000–11,500 cal yr BP) was dominated by *Phyllocladus* (11-27%) and featured moderate percentages of Asteraceae and Poaceae (9% and 10%). *Pomaderris* values were between 6-9%. *Eucalyptus*, a well-dispersed pollen type, fluctuated between 6-13%. Woody taxa, which are underrepresented in modern pollen rain studies (Fletcher and Thomas 2007b), included *Leptospermum-Baeckea*, Proteaceae, and Ericaceae in this zone (2%, 2% and 5%). After 114.5 cm depth, *N. gunnii* increased to 12%. This pollen assemblage suggests moderately open vegetation structure with herbaceous taxa and some shrubs and trees, perhaps growing near the lake. *Eucalyptus* and the pioneer rainforest species *Phyllocladus* were present in the region, but not likely growing locally for most of this period (Harris and Kitchener, 2005; Fletcher and Thomas 2007b).

Pollen Zone 2 (HAN-2; 105.5–83.0 cm depth; 11,500–9700 cal yr BP) featured high amounts of *N. gunnii* (11-18%) and sharply reduced amounts of *Phyllocladus* (2-4%). Rainforest trees increased in abundance and included *Athrotaxis* (4-5%), *Anodopetalum-Eucryphia* (4-5%), and *N. cunninghammii* (32-38%), the latter of which has excellent dispersal capacity and is strongly over-represented in the regional pollen rain (Fletcher and Thomas 2007b). *Pomaderris* and *Eucalyptus* remained at moderate values in this period (7-10% and 8-12%) and *Leptospermum-Baeckea* and Ericaceae were present in small amounts (2-4%). Poaceae and Asteraceae declined (2-5% and 1-3%). This pollen assemblage suggests that the vegetation resembled a modern *N. gunnii* rainforest with substantial scrub rainforest elements (Harris and Kitchener, 2005).

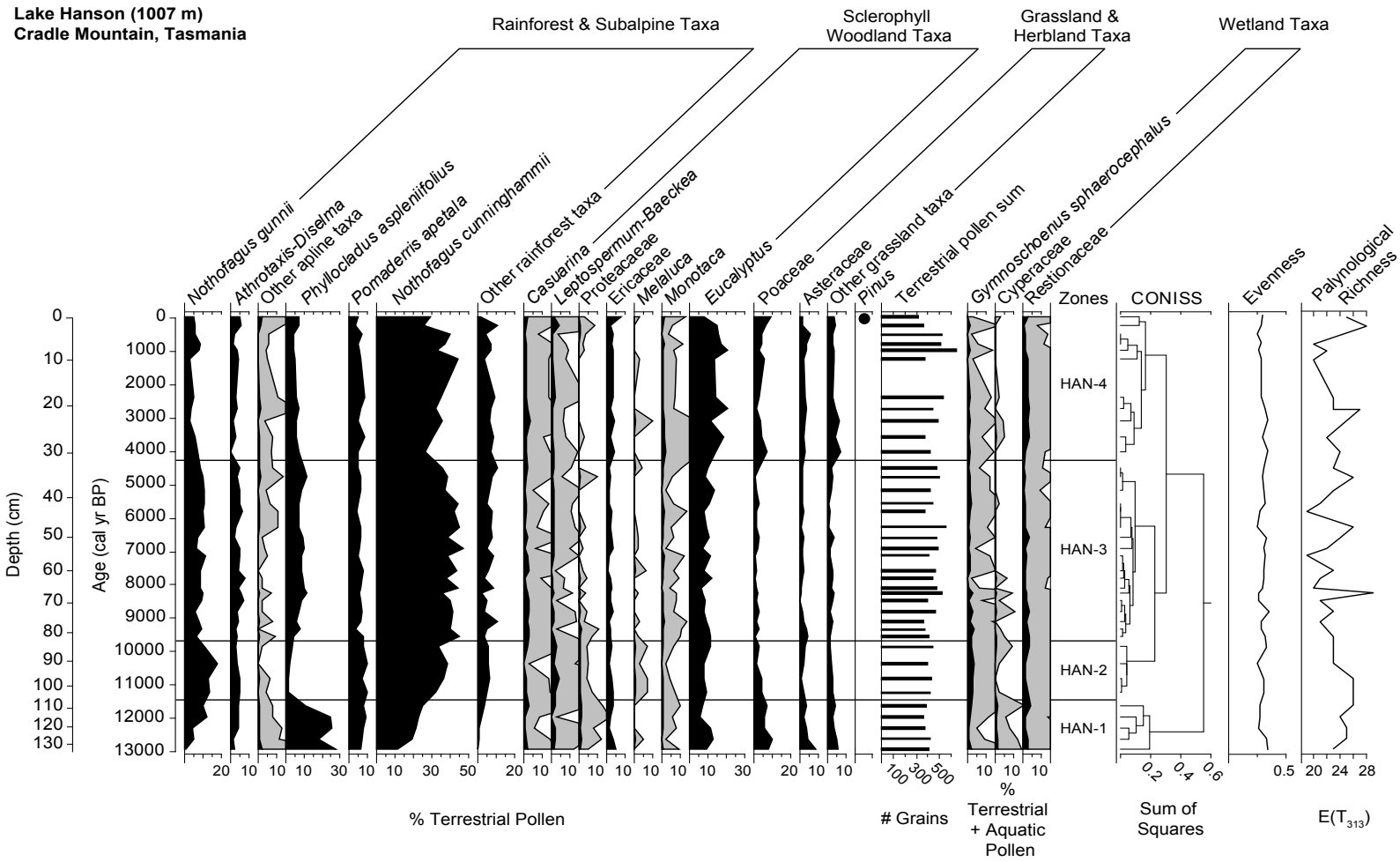


Figure 4.4 Pollen diagram of selected taxa from Lake Hanson. The gray shading indicates 10x exaggeration. The uppermost sample in the record contains *Pinus* indicated by a dot. Palynological richness, and evenness data are shown at right. Palynological richness was calculated by rarefaction analysis to 317 terrestrial pollen grains as described by Birks and Line (1992) in the program psimpoll (Bennett, 1994). Evenness was calculated using the method described in Giesecke et al. (2014). Note differing scales on the x axes.

Pollen Zone 3 (HAN-3; 83.0–31.0 cm depth; 9700–4250 cal yr BP) featured the highest amounts of *N. cunninghammii* in the record. At 81.0 cm depth (ca. 9550 cal yr BP), values reached >40% indicating a local presence (Fletcher and Thomas, 2007b). During this zone, *N. cunninghammii* fluctuated between 35-47% (mean = 41%) and peaked at 53.0 cm depth (ca. 6900 cal yr BP). *Athrotaxis-Diselma* type also achieved its highest values of the record in this zone (8%) at 62.0 cm depth (ca. 7800 cal yr BP) while oscillating between 3-9% (mean = 5%). *N. gunnii* values were lower than Zone 2 but retained moderate amounts in Zone 3 (6-12%, mean = 9%). Other rainforest taxa, including *Anodopetalum-Eucryphia* (2-8%), *Phyllocladus* (7-12%), *Pomaderris* (4-8%), and *Dicksonia antarctica* (up to 4%) had moderate values in this period, especially after 69.0 cm depth (ca. 8500 cal yr BP). The zone indicates that the vegetation was similar to a modern temperate rainforest dominated by *N. cunninghammii* (Harris and Kitchener, 2005).

Pollen Zone 4 (HAN-4; 31.0–0.0 cm depth; 4250– -61 cal yr BP) featured an increase in wet sclerophyll woodland taxa and a reduction in rainforest and subalpine taxa, including *N. cunninghammii*. *Eucalyptus* reached the highest values of the record (21%) and maintained amounts between 14-21% (mean = 16%) from 29.0-2.0 cm depth (ca. 4000-200 cal yr BP). Ericaceae maintained moderate amounts (2-8%, mean = 4%) during this zone and also achieved its maximum in this period (8%). Other wet sclerophyll woodland taxa equaled or exceeded their highest amounts for the record, including *Leptospermum-Baeckea* (4%), *Monotoca* (2%), and *Allocasuarina* (3%). The

uppermost sample of the core (0.0 cm depth, -61 cal yr BP) contained 4% *Pinus*, a non-native taxon.

Suttons Tarn (Fig. 5) Pollen Zone 1 (SUT-1; 110.5–97.5 cm depth; 16,100–15,000 cal yr BP) was dominated by grasses and forbs as evidenced by high abundances of Poaceae (up to 15%) and Asteraceae (up to 21%). *Allocasuarina*, Chenopodiaceae, and combined aquatic taxa had their highest values of the record in this period (9%, 5%, and 7%). This pollen assemblage indicates an open landscape of alpine herbs and forbs (Harris and Kitchener, 2005).

Pollen Zone 2 (SUT-2; 97.5–72.0 cm depth; 15,000–12,500 cal yr BP) was distinguished by high values for *Phyllocladus* (19-29%). Poaceae and Asteraceae declined from Zone 1 but remained in moderate amounts (7-9% and 8-12%). *Dichosciadium-Xanthosia* type (Apiaceae family), *Astelia alpina*, *Pomaderris*, and Proteaceae reached their highest values of the record during this period (7%, 4%, 9% and 3%). This pollen assemblage suggests a grassland-forest mosaic with a mix of herbaceous and woody subalpine elements near the lake and regional coverage of the pioneer rainforest species *Phyllocladus* (Harris and Kitchener, 2005).

Pollen Zone 3 (SUT-3; 72.0–59.0 cm depth; 12,500–11,100 cal yr BP) was marked by increased subalpine taxa. *Athrotaxis-Diselma* was as high as 15%, while poor pollen dispersers *Podocarpus lawrencei* and *Tasmannia lanceolata* reached 4% and 3%, respectively. *N. gunnii* increased to 9% and *Phyllocladus* declined to 8% above 67.0 cm depth (ca. 12,000 cal yr BP). Asteraceae and Poaceae continued to decline (<5%). Ericaceae increased to 4-5%. The pollen assemblage in this zone suggests the presence

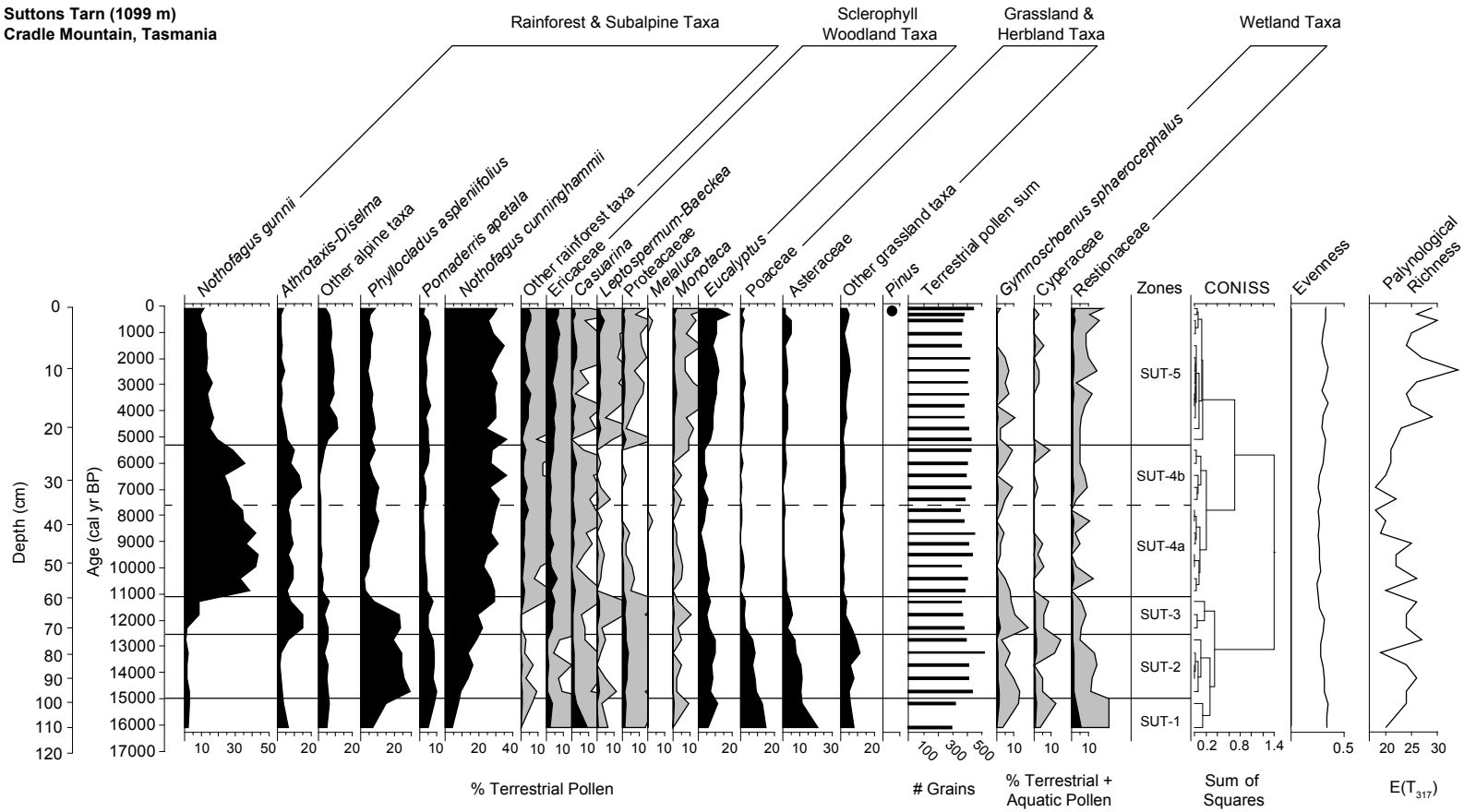


Figure 4.5 Pollen diagram of selected taxa from Suttons Tarn. The gray shading indicates 10x exaggeration. The uppermost sample in the record contains *Pinus* indicated by a dot. Palynological richness, and evenness data are shown at right. Palynological richness was calculated by rarefaction analysis to 317 terrestrial pollen grains as described by Birks and Line (1992) in the program psimpoll (Bennett, 1994). Evenness was calculated using the method described in Giesecke et al. (2014). Note differing scales on the x axes.

of an *Athrotaxis-N. gunnii* short rainforest with substantial subalpine shrubs (Harris and Kitchener, 2005).

Pollen Zone 4 (59.0–21.0 cm depth; 11,100–5300 cal yr BP) includes two subzones. Subzone 4a (59.0–35.0 cm depth; 11,100–7600 cal yr BP) featured the highest percentages of *N. gunnii* pollen in the record (33-44%, mean = 38%). *Athrotaxis-Diselma* was recorded at moderate amounts (6-10%). Ericaceae fluctuated between 2-6%. *N. cunninghammii* was higher than in previous periods (23-30%), but probably too low to indicate local presence (Fletcher and Thomas 2007b). This assemblage suggests a modern *N. gunnii*-rainforest (Harris and Kitchener, 2005). Sustained high levels of *N. gunnii* (24-36%) continued in Subzone 4b (35.0–21.0 cm depth; 7600–5300 cal yr BP) as well as an increased amount of *Athrotaxis-Diselma* (8-15%, mean = 11%). *N. cunninghammii* was also slightly higher (up to 26-36%). The vegetation in this subzone likely resembled a modern *Athrotaxis-N. gunnii* short rainforest (Harris and Kitchener, 2005).

Pollen Zone 5 (SUT-5; 21.0–0.0 cm depth; 5300– -62 cal yr BP) featured an increase in wet sclerophyll woodland elements and herbaceous taxa and decline in rainforest taxa. *Eucalyptus* increased substantially during this period—up to 19% (mean = 11%). Wet sclerophyll woodland taxa with pollen that disperses only short distances also increased, including *Allocasuarina* (up to 3%), Proteaceae (up to 2%), *Leptospermum-Baeckea* (up to 4%), and Ericaceae (4-8%). Herbaceous taxa increased as well. Asteraceae (up to 5%), Poaceae (up to 3%) and Chenopodiaceae (up to 3%) reached their highest values since the postglacial period (i.e. Zone 2). *Athrotaxis-*

Diselma and *N. gunnii* declined to 2-6% (mean = 4%) and 10-20% (mean = 14%), respectively. Rainforest shrubs increased—*Anodopetalum-Eucryphia*, *Dicksonia antarctica* and *Pomaderris* up to 4%, 3% and 6%. An increase was also recorded in two subalpine shrubs, *Microcachrys tetragona* (1-4%) and *Podocarpus lawrencei* (1-7%). A trace amount of *Pinus* was identified in the uppermost sample (0.0 cm depth, -62 cal yr BP).

Composite Vegetation Records, Palynological Richness, & Square-Chord Distance Generalized Additive Models (GAM) were employed to construct composite records of vegetation groups, as well as to composite the palynological richness curves. The two individual pollen records described above and the Wombat Pool record (Stahle et al. 2016), which represented 163 individual pollen samples, were used to build the regional composite records and estimate regional trends in vegetation. The preferred models for rainforest taxa, sclerophyll taxa, subalpine taxa, grassland taxa, and wetland taxa explained 78, 70, 73, 92, and 64% of the deviance, respectively (Table 3). Palynological richness and evenness were calculated using the pollen records for L. Hanson, Suttons Tarn, and Wombat Pool (Figs. 4, 5, Supplementary Fig. 1). The values for palynological richness varied between 19 and 29 at Lake Hanson, between 18 and 34 at Suttons Tarn, and from 15 to 29 at Wombat Pool. Evenness values were highly complacent for all three records varying at most 0.09 between samples and 0.1 over the entirety of each record out of a possible range of 1.0 (Figs. 4, 5, Supplementary Fig. 1). The low variability in the evenness results for all three sites gave us confidence in the palynological richness results. Low variability in the evenness values means that the

relative proportion of pollen types in all samples is fairly stationary indicating the richness results are robust and not unduly influenced by rare taxa (Giesecke et al., 2014). The preferred GAM for palynological richness explained 27% of the deviance (Table 3). Square-chore distance analysis (SCD) was performed on the pollen records for Lake Hanson, Suttons Tarn, and Wombat Pool in order to understand the Holocene vegetation history of each record (Fig. 7). The SCD values for L. Hanson varied from 3.9-28.5, for Suttons Tarn from 6.1-69.9, and for Wombat Pool from 7.0-31.4. The lower the number for a given sample, the more similar the pollen composition of that sample is to a sample dominated by rainforest and subalpine taxa and therefore a cool temperate rainforest (Macphail, 1975; Fletcher and Thomas, 2007b). A regime-shift algorithm (Huber's WF = 5, $P > 0.1$, cut-off = 10 samples; Rodionov, 2004) was applied to the three SCD time series in order to identify vegetation regimes with statistically significant differences. Four regimes were identified in the L. Hanson record: 13,000–11,500 cal yr BP (mean SCD = 23.3), 11500–8150 cal yr BP (mean SCD = 11.7), 8150–4250 cal yr BP (mean = 4.6), 4250– -61 cal yr BP (mean SCD = 12.7). Three regimes were identified in the Suttons Tarn record: 14,000–11,100 cal yr BP (mean SCD = 57.6), 11,100–4900 cal yr BP (mean SCD = 8.8), 4900– -62 cal yr BP (mean SCD = 28.6). Finally, three regimes were identified in the Wombat Pool record: 12,400–9800 cal yr BP (mean SCD = 22.6), 9800–4500 cal yr BP (mean SCD = 12.7), 4500– -61 cal yr BP (mean SCD = 19.5). The mid-Holocene regime at each site had the lowest mean SCD values meaning pollen assemblages were dominated by taxa of rainforest and subalpine types indicating

Table 4.3 Models employed in the reconstruction of regional trends in vegetation, fire, and palynological richness in Cradle Mountain, and sea surface temperatures (SSTs) south of Tasmania.

Data Type	# Samples	# Sites	Smoothing (k) Parameter	Degrees of Freedom	AIC	Deviance Explained	Family	Model
Charcoal	1497	5	40	27.76	3911.99	42%	Gaussian	$f(time_s) + site + \varepsilon_{ts}$
Rainforest Pollen Taxa	163	3	15	15.87	1045.00	78%	Gaussian	$f(time_s) + site + \varepsilon_{ts}$
Sclerophyll Woodland Pollen Taxa	163	3	15	14.17	889.44	70%	Gaussian	$f(time_s) + site + \varepsilon_{ts}$
Subalpine Pollen Taxa	163	3	9	10.60	1045.86	73%	Gaussian	$f(time_s) + site + \varepsilon_{ts}$
Grassland Pollen Taxa	163	3	9	11.65	841.27	91.6%	Gaussian	$f(time_s) + site + \varepsilon_{ts}$
Wetland Pollen Taxa	163	3	10	12.23	832.77	64.4%	Gaussian	$f(time_s) + site + \varepsilon_{ts}$
Palynological Richness	163	3	10	10.27	780.28	27%	Gaussian	$f(time_s) + \varepsilon_{ts}$
Sea Surface Temperature	78	4	5	11.29	245.62	77%	Gaussian	$f(time_s) + site + \varepsilon_{ts}$

$\varepsilon \sim N(\mu,\sigma)$

the vegetation resembled a cool temperate rainforest community (Macphail, 1975; Fletcher and Thomas, 2007b).

Charcoal

Lake Hanson The Lake Hanson charcoal record (Fig. 6) begins at 13,040 cal yr BP and ends at -61 cal yr BP. The median sample resolution of the record was 47 yr. CharAnalysis (Higuera et al. 2009) identified 23 fire episodes. Regime-shift analysis (Rodionov 2004) resulted in the identification of six Fire Intervals (FI). FI 1 (134.5−131.0 cm depth, 13,020–12,850 cal yr BP) had a mean CHAR value of 0.008 particles cm^{-2} yr^{-1}. No fires were identified in this period. Fire activity was slightly elevated in FI 2 (131.0−117.0 cm depth; 12,850–12,100 cal yr BP; mean CHAR = 0.116 particles cm^{-2} yr^{-1}) and one fire was identified (2.31 particles cm^{-2} yr^{-1}). FI 3 (117.0−103.0 cm depth; 12,100–11,250 cal yr BP) was characterized by the highest biomass burning of the L. Hanson record with a mean CHAR value of 0.420 particles cm^{-2} yr^{-1}. Four fire episodes were identified (mean CHAR = 12.71 particles cm^{-2} yr^{-1}). Fire activity declined in FI 4 (103.0−77.5 cm depth; 11,250−9230 cal yr BP) but remained relatively high (mean CHAR = 0.296 particles cm^{-2} yr^{-1}). Four fire episodes were identified (two with SNI > 3.0; mean CHAR = 18.46 particles cm^{-2} yr^{-1}). Fire activity declined from FI 4 to FI 5 (77.5−64.5 cm depth; 9230−8050 cal yr BP). The mean CHAR value in FI 5 was 0.176 particles cm^{-2} yr^{-1}. Two fire episodes were recorded in this period, but the low SNI suggests that it is difficult to determine whether these were local or regional fire events (Kelly et al., 2011). The final fire interval of the record, FI 6, was very long (64.5−0.0 cm depth; 8050− -61 cal yr BP). Low CHAR characterized this

period (mean CHAR = 0.064 particles cm^{-2} yr^{-1}). Twelve fire events were identified (8 with SNI > 3.0; mean CHAR = 6.410 particles cm^{-2} yr^{-1}).

Lake Lilla The Lake Lilla charcoal record (Fig. 6) spans 15,000 to -61 cal yr BP. The median resolution of the record was 89 yr. Due to the low sample resolution of this record, we employed a global threshold for peak identification rather than the more standard local thresholds in CharAnalysis (Higuera et al. 2009). Local thresholds were used for all other records. Eight fire episodes were identified in the Lake Lilla record. Regime shift analysis (Rodionov 2004) resulted in the identification of four Fire Intervals (FI). FI 1 (82.0−63.0 cm depth, 15,000–11,920 cal yr BP) contained virtually no charcoal (mean CHAR = 0.002 particles cm^{-2} yr^{-1}) and recorded no fires. Fire activity was elevated in FI 2 (63.0−55.5 cm depth; 11,920–10,850 cal yr BP; mean CHAR = 0.082 particles cm^{-2} yr^{-1}) and two very small magnitude fires were identified (mean peak magnitude = 1.53 particles cm^{-2} yr^{-1}). FI 3 (55.5−43.0 cm depth; 10,850−8890 cal yr BP) contained the highest biomass burning of the record (mean CHAR = 0.178 particles cm^{-2} yr^{-1}) and the largest magnitude peak of the record (75.08 particles cm^{-2} yr^{-1} at 55.0 cm; 10,800 cal yr BP). Two fire events were recorded in this interval. FI 4 (43.0−0.0 cm depth; 8890− -61 cal yr BP; mean CHAR = 0.044 particles cm^{-2} yr^{-1}) was long lasting. Four fire episodes were recorded (mean peak magnitude = 7.854 particles cm^{-2} yr^{-1}), including the second largest peak of the record (28.05 particles cm^{-2} yr^{-1} at 20.5 cm; 4300 cal yr BP).

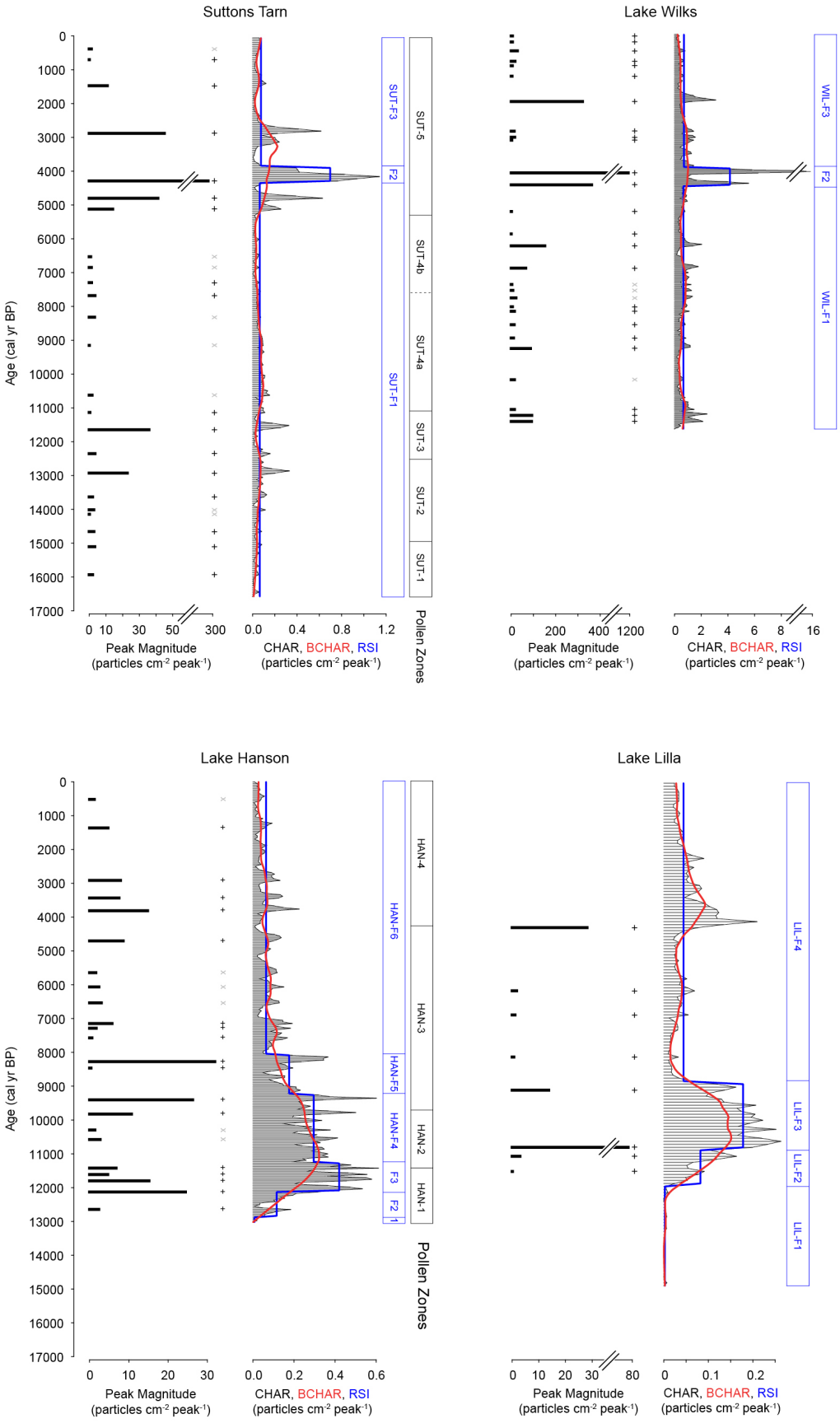

Suttons Tarn
Lake Wilks
Lake Hanson
Lake Lilla
Age (cal yr BP)
Peak Magnitude
(particles cm-2 peak-1)
CHAR, BCHAR, RSI
(particles cm-2 peak-1)
Pollen Zones
SUT-5
SUT-4b
SUT-4a
SUT-3
SUT-2
SUT-1
SUT-F3
F2
SUT-F1
WIL-F3
F2
WIL-F1
HAN-4
HAN-3
HAN-2
HAN-1
HAN-F6
HAN-F5
HAN-F4
F3
F2
F1
LIL-F4
LIL-F3
LIL-F2
LIL-F1

Figure 4.6 Charcoal data from Cradle Mountain sites. Charcoal accumulation rates (CHAR; gray histogram), background CHAR (red line), charcoal peaks (signal-to-noise ratio >3.0 = black +, signal-to-noise ratio <3.0 = gray ×), and peak magnitude (black bars) were determined using CharAnalysis (Higuera et al., 2009). Blue lines indicate shifts in CHAR as determined by regime-shift index algorithm (RSI; Rodionov, 2004). Fire Interval (FI) as determined by RSI shown in blue boxes above each site plot. Pollen zones for Lake Hanson and Suttons Tarn shown in black boxes (see Figs. 4 and 5).

Lake Wilks The Lake Wilks charcoal record (Fig. 6) begins at 11,640 cal yr BP and continues to -61 cal yr BP. The median sample resolution of the record was 44 yr. Twenty-eight fires were identified by CharAnalysis (Higuera et al. 2009) and three Fire Intervals were distinguished by regime- shift analysis (Rodionov 2004). FI 1 (277.0−121.0 cm depth; 11,640−4420 cal yr BP) had a mean CHAR value of 0.664 particles cm^{-2} yr^{-1}. Sixteen fire episodes were identified in this period (12 with SNI > 3.0; mean peak magnitude = 45.45 particles cm^{-2} yr^{-1}). FI 2 (121.0−104.0 cm depth; 4420−3900 cal yr BP) was a short interval that recorded the first and second highest magnitude fire events of the record: 361.36 particles cm^{-2} yr^{-1} (120.5 cm depth; 4400 cal yr BP) and 1203.0 particles cm^{-2} yr^{-1} (109.5 cm; 4050 cal yr BP). Mean CHAR in this period was very high (782.18 particles cm^{-2} yr^{-1}). FI 3 (104.0−0.0 cm depth; 3900− -61 cal yr BP) recorded a mean CHAR value of 0.7 particles cm^{-2} yr^{-1}. Ten fires in this period had a mean peak magnitude of 41.59 particles cm^{-2} yr^{-1}.

Suttons Tarn The Suttons Tarn charcoal record (Fig. 6) spans 16,575 to -62 cal yr BP. The median sample resolution was 64 yr. CharAnalysis (Higuera et al. 2009) identified 24 fire episodes. Regime shift analysis (Rodionov 2004) resulted in the identification of three Fire Intervals. FI 1 (115.0−18.5 cm depth; 16,575−4320 cal yr BP)

had a mean CHAR value of 0.065 particles cm^{-2} yr^{-1}, and 19 fire events. Twelve of the fires had SNI > 3.0 (mean peak magnitude = 11.096 particles cm^{-2} yr^{-1}). FI 2 was short-lived (18.5−16.5 cm depth; 4320−3870 cal yr BP) but had very high CHAR values (mean CHAR = 0.698 particles cm^{-2} yr^{-1}). The single fire identified in this period had the highest magnitude of any event in the record (272.64 particles cm^{-2} yr^{-1} at 18.5 cm depth; 4290 cal yr BP). FI 3 (16.5−0.0 cm depth; 3870− -62 cal yr BP) had a mean CHAR value of 0.075 particles cm^{-2} yr^{-1}, and four fires were identified (three with SNI > 3.0; mean peak magnitude = 18.61 particles cm^{-2} yr^{-1}).

Composite Charcoal Record A Generalized Additive Model (GAM) was employed to construct a composite record of fire activity in Cradle Mountain. The four individual records described above and the Wombat Pool record (Stahle et al., 2016) representing 1497 individual charcoal samples were used to build the composite charcoal record and estimate trends in fire activity. The preferred model explained 42% of the variance (Table 3).

Discussion

Fire & Vegetation History of Cradle Mountain

Late-glacial Period (ca. 17,000–14,500 cal yr BP) Following deglaciation, open vegetation was widespread in Cradle Mountain. Pollen data from Suttons Tarn and Wombat Pool indicate grasses and herbaceous plants especially in the Asteraceae family were dominant (Figs. 4, 5). Fire activity was extremely low during this period (Figs. 6,7).

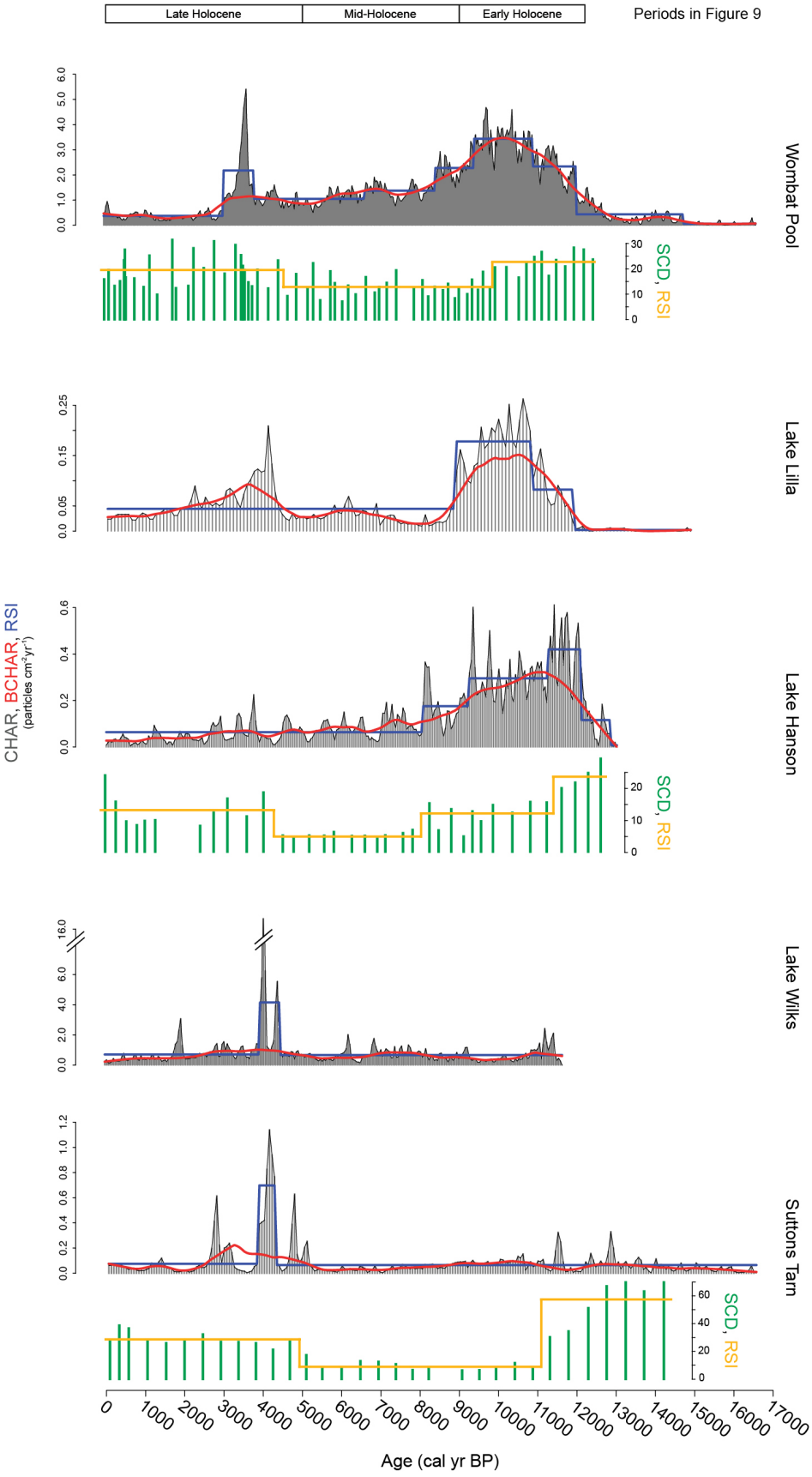

Late Holocene
Mid-Holocene
Early Holocene
Periods in Figure 9
Wombat Pool
Lake Lilla
Lake Hanson
Lake Wilks
Suttons Tarn
CHAR, BCHAR, RSI
(particles cm-2yr-1)
SCD, RSI
Age (cal yr BP)

Figure 4.7 Fire and vegetation summary for Cradle Mountain sites. Charcoal accumulation rate (CHAR; gray histograms), background CHAR (red lines), and regime shift index (RSI; blue lines) for the five charcoal records from Cradle Mountain. Square chord distance (SCD; green bars) and RSI (yellow lines) for each of the three pollen records from the Cradle Mountain region. For SCD, the lower the number the more similar the sample is to a temperate rainforest assemblage; the higher the number the more different the pollen sample is from a temperate rainforest assemblage.

Transition from Late Glacial to Early Holocene (ca. 14,500–11,500 cal yr BP)

Forest replaced the open vegetation of the late-glacial period beginning at ca. 14,500 cal yr BP. *Phyllocladus*, an early successional rainforest and mixed forest tree, became important at this time. This so-called *Phyllocladus* "bulge" is evident at other montane sites in western Tasmania (Macphail, 1979; Beck et al., 2017), and all three pollen records from Cradle Mountain register it. It occurred between ca. 13,000-12,000 cal yr BP at L. Hanson, ca. 15,000-12,000 cal yr BP at Suttons Tarn, and ca. 15,000-14,000 cal yr BP at Wombat Pool (Stahle et al. 2016). The L. Hanson sediment core extends only to 13,000 cal yr BP; thus, the oldest date for the *Phyllocladus*-dominated forest at that site may not reflect its establishment at the site. The early decline of the *Phyllocladus* forest at Wombat Pool may be due to that site's more open and exposed setting, which may have enabled woody shrub taxa, such as *Leptospermum-Baeckea*, *Melaleuca*, and Proteaceae, to colonize and compete with *Phyllocladus* earlier on.

Fire activity was low through most of this transitional period, and increased markedly at the beginning of the Holocene. Lake Hanson and Suttons Tarn record an initial uptick in fire at ca. 13,000 cal yr BP (Fig. 6). This increase was the beginning of a larger increase at Lake Hanson but it was short-lived at Suttons Tarn. At ca. 12,000 cal

yr BP, Lake Hanson, Lake Lilla, and Wombat Pool experienced sharp increases in biomass burning (Figs. 6, 7).

Early Holocene (ca. 11,500–9000 cal yr BP) The increase in fire activity at Lake Hanson, Lake Lilla, and Wombat Pool continued into the early-Holocene period until ca. 9500 cal yr BP. Prior to 11,000 cal yr BP, fire activity was slightly elevated at Suttons Tarn and Lake Wilks as well, but comparatively lower than the other three sites (Figs. 6, 7). These two sites are situated in smaller, topographically protected basins and at a higher elevation than the other three. Lake Wilks and Suttons Tarn have steep slopes around their basins, with rocky ridges and shallow soils (Fig. 1E). The protected settings and higher elevation of L. Wilks and Suttons Tarn compared with L. Hanson, L. Lilla, and Wombat Pool likely explains the relatively low CHAR levels during the early Holocene. Fires were smaller in these basins and fuel biomass was lower, but small increases were recorded in both.

At Wombat Pool and Lake Hanson (and presumably Lake Lilla given its close proximity to Wombat Pool), an increase in woody shrubs, such as *Leptospermum*-*Baeckea*, *Banksia*, *Tasmannia lanceolata*, Ericaceae, and *Podocarpus lawrencii*, likely contributed to the increase in biomass burning by providing a woody shrub layer that could carry fires and regenerate quickly following fire. In addition, *N. cunninghammii* pollen was present in values >40% at L. Hanson and Wombat Pool (Stahle et al. 2016), but not at L. Wilks (Chin and Haberle, 2013) or Suttons Tarn. The site differences suggest that *N. cunninghammii* was locally present but restricted to elevations below ca. 1000 m in Cradle Mountain at this time. The high CHAR suggests higher levels of

burning at low elevations, supported by a mosaic of pyrophytic sclerophyllous shrubs and rainforest. This may partially explain the higher CHAR in these lakes, inasmuch as fires would have started in low-elevation woody vegetation and burned to the edge temperate rainforest patches before being extinguished due to microclimate differences in these vegetation types (e.g. Tepley et al., 2016). The pollen record from Suttons Tarn indicates an increase in shrubs in the catchment (particularly Ericaceae) at this time as well, but locally the dominant taxon during this period, *N. gunnii*, suggests the presence of a shorter-statured subalpine rainforest with substantially less biomass than the taller rainforest patches at lower elevations. These differences in vegetation composition, along with topographic factors, likely explain the differences in the charcoal records from Wombat Pool, Lakes Hanson and Lilla and those from the higher-elevation Suttons Tarn and Lake Wilks.

Middle Holocene (ca. 9000–4500 cal yr BP) A multi-millennial phase of rainforest dominance was the primary feature of the mid-Holocene vegetation in Cradle Mountain. Herbaceous and sclerophyll woodland taxa declined to their lowest percentages of the Holocene and cool temperate rainforest taxa, especially *N. cunninghammii* and *N. gunnii*, reached their maximum. The rainforest maximum period has been noted in many pollen records from western Tasmania (e.g. Macphail 1979, Markgraf 1986, Colhoun 1996). Fire activity in Cradle Mountain during this period was greatly reduced from the early Holocene (Figs. 6, 7) and the magnitude of fire events was much lower than the early and late Holocene (Fig. 6; Stahle et al., 2016).

Late Holocene (ca. 4500 cal yr BP–present) The pollen data show a substantial change in vegetation type in the late Holocene. The closed rainforest that persisted for millennia in the mid-Holocene was replaced by open sclerophyll woodland across large swaths of Cradle Mountain as evidenced by a sharp increase in sclerophyll taxa, especially *Eucalyptus* at all three sites (Figs. 4, 5; Stahle et al., 2016). Rainforest and subalpine taxa, particularly *N. gunnii*, *Athrotaxis-Diselma*, and *N. cunninghammii*, declined in the pollen records of all three sites between ca. 5200-4000 cal yr BP (Figs. 4, 5; Stahle et al., 2016). Sclerophyll woodland shrubs, including *Monotoca*, *Ericaceae*, *Allocasuarina*, Proteaceae, and *Leptospermum-Baeckea*, as well as herbaceous taxa increased at this time. Small increases in shorter-lived rainforest taxa, such as *Pomaderris*, *Anodopetalum-Eucryphia* and *Dicksonia antarctica*, occurred as well. This shift indicates the development of mixed forests that contain woodland and rainforest species during the late Holocene. Finally, at Suttons Tarn, the highest elevation site, in addition to the increase in *Eucalyptus* and other sclerophyll taxa, subalpine shrubs also increased in abundance while *N. gunnii* declined substantially. Many other western Tasmanian sites record a shift away from rainforest and subalpine taxa toward sclerophyllous taxa in the late Holocene including at Lake St Clair (Hopf et al., 2000), Beatties Tarn, Eagle Tarn, Tarn Shelf (Mount Field; Macphail, 1979), Lake Osborne (Hartz Mountains; Fletcher et al., 2014a), and Paddy's Lake (Beck et al., 2017).

All five charcoal records from Cradle Mountain display a dramatic increase in fire occurrence between ca. 4800-3600 cal yr BP (Fig. 6, 7). At Lake Wilks, Suttons Tarn, and Wombat Pool, the largest fire event of these respective records occurred during this

interval and a fire regime shift was also recorded (Fig. 6; Stahle et al., 2016). Our records of catchment fires are of higher temporal resolution than our pollen records making it difficult to assess the role of fire in the establishment of open sclerophyll-dominated woodland. At Lake Osborne in the Hartz Mountains of southwest Tasmania, it has been suggested that the late-Holocene shift to sclerophyll-dominated vegetation was driven by recurrent fires between ca. 2900-2600 cal yr BP (Fletcher et al., 2014a). In Cradle Mountain it appears that the shift away from rainforest and subalpine communities toward sclerophyll woodland was more gradual and that the increase in *Eucalyptus* woodland preceded the increase late Holocene fire episodes (Supplemental Fig. 2).

Climate and Human Influences

The drivers of fire activity and vegetation change over time are both top-down and bottom-up. In this section, we assess the top-down impacts of climate on fire and vegetation in Cradle Mountain as well as possible bottom-up impacts from human activities. The potential impacts of people on fire and vegetation would be expected to be quite localized while the potential impacts of climate on fire and vegetation are expected to be large in spatial scale. For each time period, independent proxy evidence of large-scale changes in climate and archeological evidence of human activity are compared to our fire and vegetation reconstructions in order to determine the drivers of fire and vegetation history in Cradle Mountain.

Three well-studied archeological sites are situated within ca. 25 km of Cradle Mountain: Mackintosh Cave, Warragarra Rockshelter, and Parmerpar Meethaner Rockshelter (Fig. 1D). Analyses of these sites has characterized human occupation in

two ways: (1) radiocarbon dates on occupation layers—strata that contain human-made tools and animal bones with evidence of human butchery, and (2) discard rates—the number and kind of discarded bones and tools throughout the archeological deposits (Lourandos, 1983; Stern and Marshall, 1993; Cosgrove, 1995; Allen and Porch, 1996). Not every occupation layer has been radiocarbon dated so discard rates fill in the gaps between dates as well as provide more information about how and with what intensity sites were used over time (Jones, 1995; Cosgrove, 1999). While acknowledging the difficulty and limitations of comparing human fire ignitions, which occur at decadal to interannual temporal scales, to the centennial-scale paleoenvironmental reconstructions, we consider human presence in the Cradle Mountain region as evidence of a potential anthropogenic fire-ignition source. Little is known about how Aboriginal peoples may have used fire in the Pleistocene and Holocene; however, more recent evidence suggests fire was an important tool that was wielded with great skill. Anthropological research, the accounts of European colonizers, and landscape structure analysis suggest that Aboriginal peoples actively managed parts of the Tasmanian landscape through deliberate burning (Bowman, 1998; Marsden-Smedley and Kirkpatrick, 2000; Gott, 2005; Gammage, 2008, 2011; Onfray, 2012). In particular, fire was used to create patches of open land interspersed with woodlands. In the open patches, tender grasses and forbs grew after fire which attracted favored prey species, especially wallabies, while the woodland patches served as areas where hunters could move relatively undetected (Gammage, 2008, 2011). The goal of Aboriginal fire management is thought to have been to make hunting more predictable (Gammage, 2008, 2011). The available evidence

suggests the burning strategy of Aboriginal peoples consisted of low-intensity fires usually set in wetter seasons or after a rainfall event (Marsden-Smedley and Kirkpatrick, 2000).

The three archeological sites discussed here were first occupied in the Pleistocene and the most intense periods of use at both Parmerpar Meethaner and Mackintosh Cave pre-dates the paleoenvironmental record from Cradle Mountain. Parmerpar Meethaner Rockshelter is the second oldest archeological site yet discovered in Tasmania with a basal age of 38,111 ± 1207 cal yr BP (33,850 ± 450 ^{14}C BP; Cosgrove, 1995). Moderate to high levels of human use were recorded between ca. 23,000–12,000 cal yr BP with the highest levels between ca. 19,000–15,000 cal yr BP. Mackintosh Cave recorded a period of intense human occupation between ca. 21,000–17,500 cal yr BP (Stern and Marshall, 1993). The record from Warragarra Rockshelter begins ca. 12,000 cal yr BP.

Late-Glacial Period (ca. 17,000–14,500 cal yr BP) Deglaciation occurred between 18,000–16,000 cal yr BP in Tasmania (Barrows et al., 2002; Mackintosh et al., 2006). Of the five records, only Suttons Tarn and Wombat Pool predate 15,000 cal yr BP. Pollen samples from these two sites indicate an open landscape dominated by grasses and herbs with few if any fires in the late-glacial period. Climate proxy data indicates cool conditions during this period. Antarctic air temperatures, as recorded by δ^{18}O values, were low (Grootes et al., 2001; EPICA Members, 2004; Fig. 8H). Regional sea-surface temperatures (SSTs) were also relatively low compared with Last Glacial Maximum (LGM) values. Alkenones and faunal assemblages in marine cores from south (44-47° S)

and the northwest (36° S) of Tasmania indicate SSTs were higher than the LGM but lower than Holocene levels (Calvo et al., 2007; Sikes et al., 2009; Fig. 8F, G).

The archeological evidence indicates Warragarra and Parmerpar Meethaner Rockshelters experienced human use during this period. The evidence from Warragarra Rockshelter suggests a period with low levels of human use at ca. 12,000 cal yr BP (Lourandos, 1983; Allen and Porch, 1996; Fig. 8J). Parmerpar Meethaner contains evidence of high levels of human use during this period (Cosgrove, 1995; Fig. 8J). In the late-glacial period, very low levels of charcoal may have been a result of minimal human-set fires or the cool post-glacial conditions and limited of fuel biomass.

Transition from the Late-Glacial to Early Holocene (ca. 14,500–11,500 cal yr BP)

The replacement of herbaceous plants by *Phyllocladus*-dominated forest was likely aided by warming during this transitional period. Antarctic air temperature began warming at ca. 14,500 cal yr BP (Grootes et al. 2001; Fig. 8H) while regional SST began to rise rapidly ca. 13,500 cal yr BP (Calvo et al. 2007; Fig. 8F). At ca. 13,000, levels of biomass burning began a steady increase (Fig. 8J). Warming temperatures and enhanced fuel connectivity were likely joint drivers of increased fire activity in Cradle Mountain. However, human influences cannot be ruled out.

The archeological evidence suggests sporadic, light occupation at Warragarra Rockshelter consistent with its use as a transient hunting base (Lourandos, 1983), and continued use of Parmerpar Meethaner Rockshelter but at a lower level than the proceeding ca. 4,000 years (Cosgrove, 1995). It is possible that as the climate warmed, hunting or other practices increased visits to and/or use of resources at higher elevations

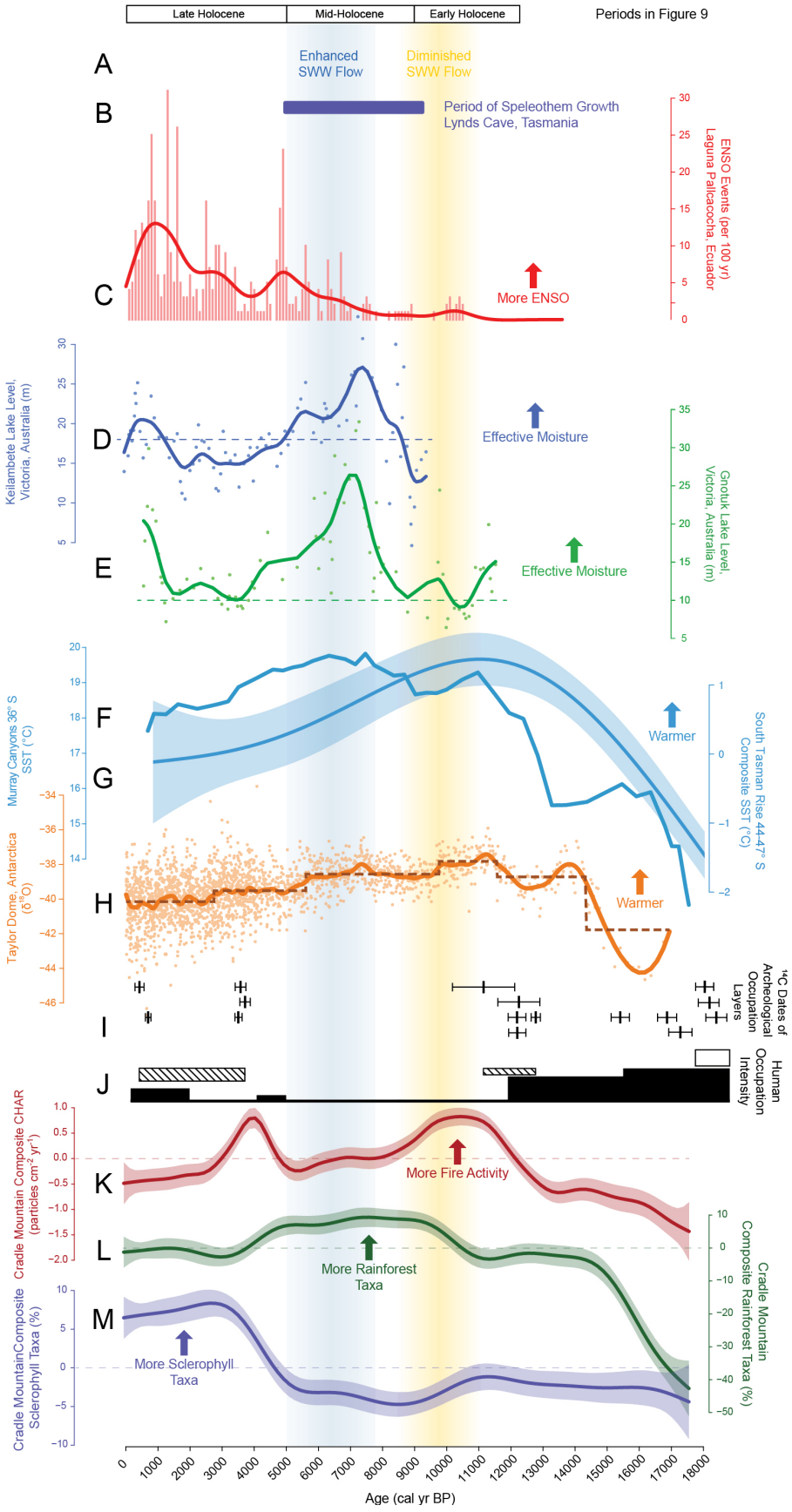

Late Holocene
Mid-Holocene
Early Holocene
Periods in Figure 9
A
Enhanced SWW Flow
Diminished SWW Flow
B
Period of Speleothem Growth Lynds Cave, Tasmania
ENSO Events (per 100 yr) Laguna Pallcacocha, Ecuador
C
More ENSO
Keilambete Lake Level, Victoria, Australia (m)
D
Effective Moisture
Gnotuk Lake Level, Victoria, Australia (m)
E
Effective Moisture
Murray Canyons 36° S SST (°C)
F
Warmer
South Tasman Rise 44-47° S Composite SST (°C)
G
Taylor Dome, Antarctica (δ18O)
H
Warmer
14C Dates of Archeological Occupation Layers
I
Human Occupation Intensity
J
Cradle Mountain Composite CHAR (particles cm-2 yr-1)
K
More Fire Activity
L
More Rainforest Taxa
Cradle MountainComposite Sclerophyll Taxa (%)
M
More Sclerophyll Taxa
Cradle Mountain Composite Rainforest Taxa (%)
Age (cal yr BP)

Figure 4.8 Comparison of climate and archeological data to Cradle Mountain fire and vegetation data. (A) Periods of enhanced and diminished Southern Hemisphere Southwesterly Winds (SWW) strength in the Tasmanian sector (summarized from Fletcher & Moreno 2012 and Rees et al. 2015). (B) Stalagmite growth record from Lynds Cave, Tasmania. This record spans 5000–9200 cal yr BP (Xia et al., 2001). (C) The number of El Niño events per 100 years (Moy et al., 2002) with smoothing spline (spar = 0.6). (D, E) Modeled reconstructions of lake depths relative to modern (dashed lines) for Lake Keilambete (blue) and Lake Gnotuk (green) in southern Victoria, Australia (Wilkins et al., 2013). (F) Alkenone-derived sea surface temperature (SST) reconstruction from marine core MD03-2611 at Murray Canyons off the coast of South Australia (Calvo et al., 2007). (G) Composite SST record from four sites (GC07, GC14, GC17, and GC31) south of Tasmania between 44-47° S latitude. Trends in SST were estimated by a GAM applied to alkenone-derived SST data and MAT-derived (modern analog technique) SST data (78 total samples from Sikes et al., 2009; standard errors are shown in light blue; see Table 4). (H) Oxygen isotope ratios from Taylor Dome, Antarctica (Grootes et al., 2001) with smoothing spline (orange; spar = 0.6) and regime shifts (dark orange dashed line; regime shift determined using algorithm from Rodionov, 2004). (I) The 1σ calibrated age range of ^{14}C dates on occupation layers at three archeological sites within ~25 km of Cradle Mountain (Warragarra Rockshelter, Parmerpar Meethaner Rockshelter, Mackintosh Cave). (J) Inferred occupation intensity from the three archeological sites within ~25 km of Cradle Mountain based on artefact discard rates and sediment accumulation rates (Warragarra rockshelter = white bars with diagonal lines (Allen & Porch, 1996), Parmerpar Meethaner rockshelter = black bars (Cosgrove, 1995), Mackintosh Cave = white bar (Stern & Marshall 1993)). (K) Composite fire history record from the Cradle Mountain region. Trends in fire activity were estimated by GAMs applied to the charcoal influx data (n = 1497; standard errors are shown in light shading). (L, M) Composite rainforest (green) and sclerophyll (purple) taxa from the Cradle Mountain region. Trends in pollen taxa were estimated by GAMs applied to the pollen percent data (n = 163; standard errors are shown in light shading).

in the Cradle Mountain area and that deliberate burning may have contributed to higher levels of biomass burning after ca. 13,000 cal yr BP. However, the marked increase in temperatures combined with increased fuel availability at this time would also be expected to promote higher fire activity than before (e.g. Whitlock et al., 2007), with or without human involvement.

Early Holocene (ca. 11,500–9000 cal yr BP) Sustained high fire activity relative to the rest of the record defines this period in Cradle Mountain. In particular, the period from ca. 11,200-9800 cal yr BP recorded high biomass burning, as evidenced by the CHAR records (Fig. 8J). Regional climate data indicate that the early Holocene was the warmest period of the postglacial period and was relatively dry as well. Antarctic temperature at Taylor Dome reached its height between ca. 11,500-9500 cal yr BP (Grootes et al., 2001; Fig. 8H). SSTs south of Tasmania exhibited steady increase throughout the postglacial period and reached a maximum at ca. 11,000 cal yr BP (Sikes et al. 2009; Fig. 8G), and SSTs northwest of Tasmania were also high at this time (Calvo et al., 2007; Fig. 8F). A lake-level reconstruction from Lake Gnotuk in southern Victoria, Australia, exhibits low water levels in the early Holocene that suggest low regional effective moisture (Wilkins et al., 2013; Fig. 8E). At the latitude of northern Tasmania, the strength of the Southern Hemisphere Westerly Winds (SWW) was also diminished (Fig. 8A). This conclusion is based on chironomid, geoelemental, and grain size analysis from southern Tasmania (Rees et al., 2015), as well as a synthesis of Southern Hemisphere mid-latitude lake levels and reconstructed precipitation (Fletcher and Moreno, 2012).

The archeological record from sites in the Cradle Mountain region includes two ^{14}C dates from Warragarra Rockshelter from this period. The dates were derived from bulk sediment prior to AMS radiocarbon dating and the 1-sigma error margins are huge (>1500 years; Fig. 8I). The conclusion from two archeological surveys was that the use of Warragarra was short-lived and centered on ca. 12,000 cal yr BP (Lourandos, 1983;

Allen and Porch, 1996). No occupation layers from have been radiocarbon dated from Mackintosh Cave or Parmerpar Meethaner Rockshelter during this period (Fig. 8I). The artifact discard record from Parmerpar Meethaner indicates a significant and abrupt decline in human use of the site ca. 12,000 cal yr BP (Cosgrove, 1995; Fig. 8J). Increased temperature and lower effective moisture coupled with increases in biomass, particularly woody shrubs, were the likely drivers of elevated biomass burning during this period.

Middle Holocene (ca. 9000–4500 cal yr BP) Paleoclimatic evidence suggests a relatively wet period that was as warm or slightly less warm than the early Holocene. At Lynds Cave, 25 km northwest of Cradle Mountain, a period of speleothem growth from 9200-5000 cal yr BP implies higher effective moisture at this time (Xia et al., 2001; Zhao et al., 2001; Fig. 8B). High lake levels at lakes Keilambete and Gnotuk in Victoria indicate that increased precipitation was a regional phenomenon. These records show a synchronous rise in the mid-Holocene with a Holocene high-stand at ca. 7200 cal yr BP (Wilkins et al., 2013; Fig. 8D, E). Furthermore, multiple lines of evidence indicate SWW flow was enhanced in the Tasmanian sector between ca. 8000-5000 cal yr BP (Fletcher and Moreno 2011, 2012; Rees et al., 2015; Fig. 8A). Storm tracks would have delivered more precipitation to western Tasmania, including Cradle Mountain, than in the early Holocene when the SWW flow was weak at this latitude. The evidence for a relatively warm mid-Holocene includes SSTs northwest of Tasmania where the Murray Canyons record indicate maximum Holocene SSTs at ca. 7500 cal yr BP and warm but declining SSTs after this (Calvo et al., 2007; Fig. 8F). The Taylor Dome $\delta^{18}O$ record indicates temperatures were slightly lower than the early-Holocene maximum but still elevated in

the mid-Holocene (Grootes et al., 2001; Fig. 8H). The evidence from chironomid-derived temperature reconstructions is mixed, as are SSTs from the region south of Tasmania. Summer temperatures at Mount Field were reconstructed from chironomids at two sites and disagree on the timing of the Holocene thermal maximum—ca. 6700 cal yr BP and ca. 4500 cal yr BP, respectively (Rees and Cwynar, 2010). The composite record of four SST records from 44-47° S indicates a steady decline occurred after a Holocene maximum at ca. 11,000 cal yr BP (Sikes et al. 2009; Fig. 8G). On balance, the paleoclimate evidence strongly indicates that the mid-Holocene in Tasmania was characterized by high effective moisture. High effective moisture in this period likely favored temperate rainforest expansion, which was recorded at a multitude of sites across western Tasmania (e.g. Macphail 1979, Markgraf 1986, Colhoun 1996; Hopf et al., 2000; Beck et al., 2017), and reduced fire activity, which was also recorded south of Cradle Mountain near Frenchmans Cap (Fletcher et al. *in review*) and north of Cradle Mountain at Paddy's Lake (Beck et al., 2017).

Between ca. 10,000 and 4000 cal yr BP, the absence of radiocarbon dated artifacts from the three archeological sites in the Cradle Mountain region (Fig. 8I), suggest an absence of people or very low-intensity use. Artifact discard rates indicate that Parmerpar Meethaner Rockshelter was visited and used during the mid-Holocene but at sharply reduced levels from the late-glacial period (Cosgrove, 1995; Fig. 8J). Across western Tasmania, archeological evidence suggests that many caves and rockshelters were abandoned at this time (Cosgrove, 1999). People may have been present in the area and employed different subsistence strategies that rarely or never included use of

rockshelters (Cosgrove, 1999; Pike-Tay et al., 2008), or they moved to other regions. If people were absent, the lack of anthropogenic ignitions may have contributed to the lower fire activity in the mid-Holocene. However, high effective moisture in western Tasmania would be expected to both promote temperate rainforest development and suppress fire activity in any case (Wood et al., 2011; Yospin et al., 2015). We consider climate as the primary driver of mid-Holocene vegetation and fire conditions.

Late Holocene (ca. 4500 cal yr BP–present) The replacement of long-lived rainforest trees by herbaceous plants, woodland shrubs, and shorter-lived rainforest trees and shrubs (i.e. *Pomaderris apetala*, *Dicksonia antarctica*, *Anodopetalum-Eucryphia*) in the late Holocene is consistent with evidence of a more variable climate after ca. 6000-5000 cal yr BP. Increased variability in the late Holocene was possibly a result of the onset and/or strengthening of ENSO. Paleoproxy data indicate ENSO strengthened at ca. 5000 cal yr BP (Shulmeister and Lees, 1995; Moy et al., 2002; Wanner et al., 2008; Fig. 8C) and may have led to increased variability in Tasmania due to oscillating La Niña (wet) and El Niño (dry) states (Marx et al., 2009). Fluctuations in vegetation composition and/or fire occurrence are observed at many sites in the late Holocene and attributed to increased climate variability (i.e. Haberle 2005; Donders et al., 2007; Fletcher et al., 2014a, 2015; Rees et al., 2015; McWethy et al., 2016; Beck et al., 2017). Overall, mean regional climate conditions were cooler and drier in the late Holocene. Speleothem growth ceased at 5000 cal yr BP at Lynds Cave, indicating lower effective moisture after this time (Xia et al., 2001; Fig. 8B). Lake levels in Victoria declined from the mid-Holocene high stand and were low between ca. 5000-1000 cal yr BP (Wilkins et

al., 2013; Fig. 8D, E). Regional SSTs declined from early/mid-Holocene maxima indicating cooling (Calvo et al., 2007; Sikes et al., 2009; Fig. 8F, G), and the Taylor Dome record exhibits slowly declining temperature after ca. 8000 cal yr BP and increased variability after ca. 5000 cal yr BP (Grootes et al., 2001; Fig. 8H).

Archeological evidence from Warragarra and Parmerpar Meethaner Rockshelters suggests a modest resumption in human occupation after ca. 3900 cal yr BP (Fig. 8I, J). The low number of artifacts indicates less intensive use at Parmerpar Meethaner than in the early postglacial period (Cosgrove, 1995), whereas light, sporadic use was apparently a feature of both the late-glacial/early-Holocene and late-Holocene occupation periods at Warragarra (Lourandos, 1983; Allen and Porch, 1996). The presence of people in the region could have provided an ignition source that was lacking in the mid-Holocene; however, it is impossible to directly link the resumption of use of these sites with an increase in anthropogenic ignitions. In addition, the large spatial area impacted by increased fire in the late Holocene is inconsistent with what is known about the targeted and strategic manner in which Aboriginal peoples employed fire (Marsden-Smedley and Kirkpatrick, 2000; Gott, 2005; Gammage, 2008, 2011).

Holocene Vegetation and Land-Use Strategies: Past Human-Fire Interactions

The pollen records from Wombat Pool, Lake Hanson, and Suttons Tarn exhibit a very similar pattern during the Holocene. All sites show a multi-millennial phase of rainforest dominance in the middle Holocene, while in the early and late Holocene periods, vegetation composition differed from the prototypical Tasmanian cool temperate

rainforest. This can be seen in the SCD graphs for each site (Fig. 7). The difference in the timing of vegetation shifts at each site closely corresponds to changes in local fire activity. Lake Hanson displays two stepwise shifts in the early Holocene at ca. 11,400 cal yr BP and ca. 8150 cal yr BP. Both shifts were associated with a decline in fire activity (Fig. 7). Likewise, the pollen data at Suttons Tarn suggests a shift toward rainforest after the charcoal record registers a decline in fire activity ca. 11,000 cal yr BP (Fig. 7). Wombat Pool also recorded a shift in the vegetation ca. 9800 cal yr BP (Fig. 7) although this predated a decline in fire activity at the site by a couple hundred years. All three sites record a prolonged period of rainforest dominance in the mid-Holocene, followed by a shift away from temperate rainforest and toward wet sclerophyll woodland in the late Holocene between 4900-4300 cal yr BP at all three sites (Fig. 7). The early and late Holocene assemblages were more similar to one another than they were to the middle Holocene assemblages (Fig. 7).

In addition to the relationship between vegetation composition (as measured by SCD) and fire, a close correspondence between fire activity (as measured by CHAR) and floristic diversity (as measured by palynological richness) is also evident in the data (Fig. 9). The early-Holocene fire maximum (ca. 11,800-9800 cal yr BP) coincided with an increase in sclerophyll and subalpine taxa and high palynological richness values. The mid-Holocene featured maximum temperate rainforest expansion at ca. 8500-5500 cal yr BP associated with declining palynological richness. The lowest palynological richness was recorded at the end of this phase, a period that also featured low fire activity. An

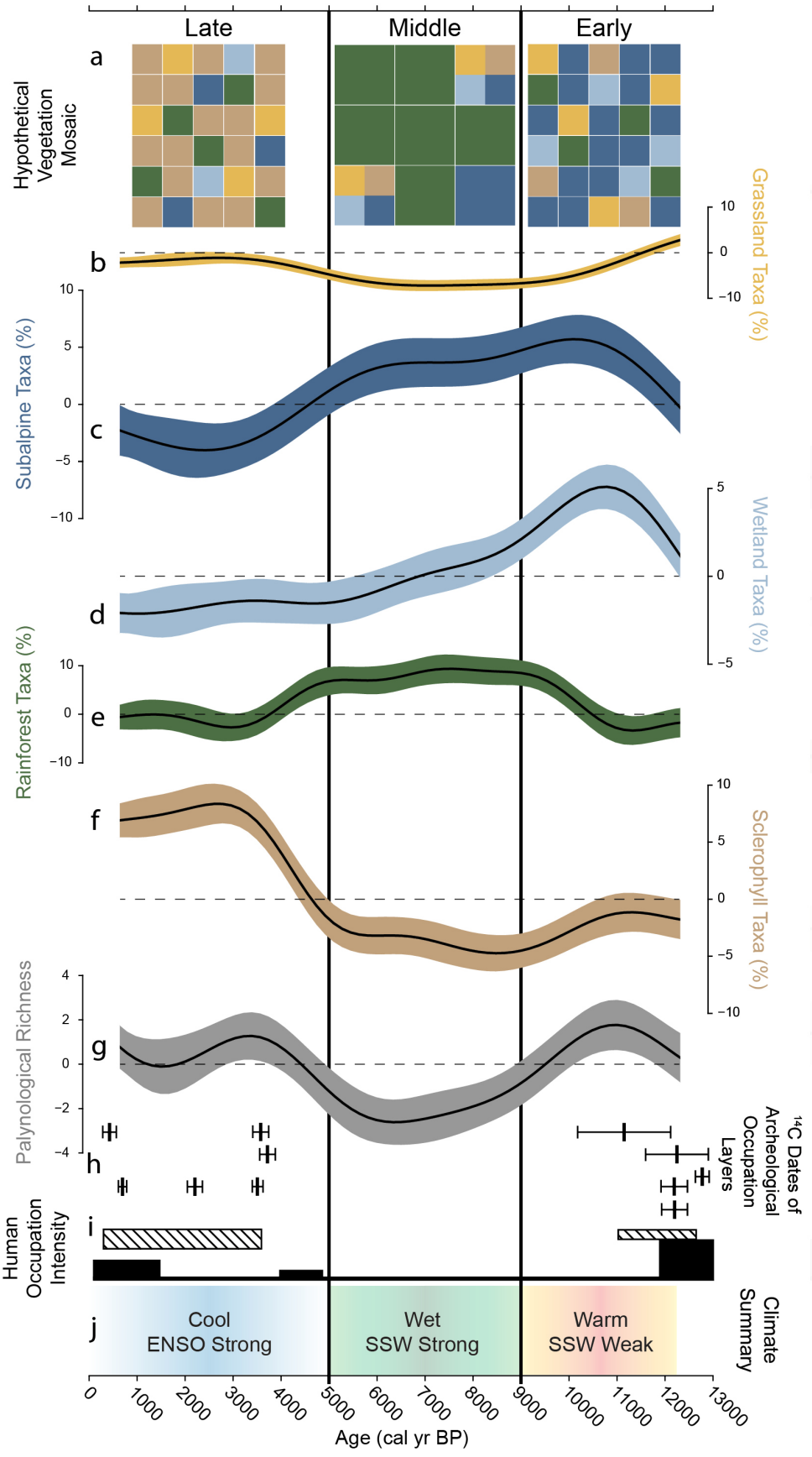

Late
Middle
Early
a
Hypothetical Vegetation Mosaic
b
Grassland Taxa (%)
c
Subalpine Taxa (%)
d
Wetland Taxa (%)
e
Rainforest Taxa (%)
f
Sclerophyll Taxa (%)
g
Palynological Richness
h
¹⁴C Dates of Archeological Occupation Layers
i
Human Occupation Intensity
j
Climate Summary
Cool ENSO Strong
Wet SSW Strong
Warm SSW Weak
Age (cal yr BP)

Figure 4.9 Summary pollen, charcoal, & archeological data. a) Hypothetical vegetation mosaic for early, middle and late Holocene periods. b) Composite grassland taxa. c) Composite subalpine taxa. d) Composite wetland taxa. e) Composite rainforest taxa. f) Composite sclerophyll taxa. g) Composite palynological richness. h) The 1σ calibrated age range of ^{14}C dates on occupation layers at two archeological sites within ~25 km of Wombat Pool. i) Occupation intensity at the two acheological sites (Warragarra rockshelter = white bars with diagonal lines, Parmerpar Meethaner rockshelter = black bars) as measured by artifact discard rates (Cosgrove, 1995; Allen & Porch, 1996). The height of the bar corresponds to inferred occupation intensity, i.e. the higher the bar, the higher the intensity. Note Parmerpar Meethaner had continuous occupation through the Holocene mostly at very low levels, and a prolonged hiatus in occupation was recorded at Warragarra. j) Climate summary with dominate parameter and driver indicated. The trends in pollen (b-f) were estimated by GAMs applied to the pollen percent data (n = 163; black lines = mean; shading = standard errors).

abrupt increase in fire at ca. 4800-3200 cal yr BP was accompanied by increases in the pollen of sclerophyll taxa, declines in rainforest taxa, and high palynological richness values. This relationship suggests that, during the Holocene, elevated levels of burning were associated with high floristic diversity in Cradle Mountain (Fig. 9). The early and late Holocene periods of elevated burning coincided with diminished rainforest taxa, whereas a multi-millennial decline in mid-Holocene fire activity was coincident with a prolonged period of rainforest dominance (Fig. 9). The increase in palynological richness in the early Holocene resulted from increases in both sclerophyllous and subalpine taxa and the late Holocene rise in palynological richness was primarily driven by an increase in sclerophyll taxa (Fig. 9).

The patterns evident in the SCD and palynological richness data suggest changes in spatial heterogeneity of vegetation during the early, middle and late Holocene. The pollen data indicates that, during the middle Holocene, Cradle Mountain was host to extensive rainforest which was homogeneous in composition. In contrast, present-day

vegetation in Cradle Mountain is a mosaic of rainforest, wet sclerophyll, mix forest, sedgeland, sclerophyll scrub, grassland, and subalpine forest and shrubland communities (Kirkpatrick and Balmer, 1991; Marsden-Smedley and Kirkpatrick, 2000). The pollen records suggest this habitat heterogeneity developed ca. 4,600 cal yr BP in association with increasing climate variability. Based on the pollen records and SCD analysis, the early Holocene vegetation was also heterogeneous with a mosaic of rainforest, mixed forest, open woodland, shrubland, sedgeland, and grassland (Fig. 9). The differences between the three Holocene periods are best-explained climatic differences between the periods. Warming in the early Holocene facilitated an expansion of forest and shrub communities, while the relatively aridity of this period likely restricted rainforest to isolated wetter microclimates. The wetter conditions of the middle Holocene, in contrast, favored expansion temperate rainforest and more homogeneous vegetation. The drier, more variable conditions of the late Holocene supported a return toward a more patchy vegetation structure. The mosaic nature of the Cradle Mountain vegetation today may be a legacy of the shift from a wetter mid-Holocene to a drier, more variable late Holocene. Today, temperate rainforest persists primarily on south-facing slopes and topographically sheltered locales (Wood et al., 2011; Yospin et al., 2015).

The questions of whether, how, and when Aboriginal Tasmanians may have altered the landscapes they inhabited though the use of fire is a long-discussed and long-investigated topic (e.g. Jones, 1969; Jackson, 1968, 1999; Ellis, 1985; Bowman, 1998; Hope, 1999; Gott, 2002, 2005; Gammage, 2008, 2011; McIntosh et al., 2009; Fletcher and Thomas, 2010a; Onfray, 2012; Bowman et al., 2013; Fletcher, et al., 2014; Holz et

al., 2015; McWethy et al. 2016; Romanin et al., 2016; Stahle et al., 2016). In this context of this study, however, these are perhaps the wrong set of questions or at least ones that cannot be answered with charcoal, pollen, and archeological data alone. Our data describe changes in the structure and composition of the vegetation, and the broad patterns suggest a climate control. This information, in turn, can be used to examine how climate, vegetation, and fire dynamics may have impacted Aboriginal subsistence strategies. Heterogeneous vegetation, for example, would have been more conducive to hunting strategies than more uniform closed forest (Fig. 9A). Cosgrove et al. (1990) put forth a model of human occupation based on access to favored prey species and grasslands (see also Cosgrove 1995; Pike-Tay et al., 2008). It postulates that discrete grassland patches occur on the fertile substrates that exist within a much larger complex of forests, shrublands and sedgelands. Marsupials would have been drawn to these grasslands, which created "ecologically tethered" animal resources (Cosgrove et al., 1990). Aboriginal peoples would have moved between discrete grassland patches that served as relatively predictable areas for hunting. The faunal assemblages from Warragarra Rockshelter and Mackintosh Cave include red-necked wallaby (*Macropus rufogriseus*) and wombat (*Vombatus ursinus*), and these two prey species also dominate the human-killed faunal remains found in most southwestern Tasmanian cave sites (Cosgrove 1999). Parmerpar Meethaner Rockshelter contained a small amount of wombat and many smaller prey species, such as ringtail possums (*Pseudocheirus peregrinus*), pademelons (*Thylogale billardierii*), and potoroo (*Potorous tridactylus*). The patch model of Cosgrove (1990) was developed to explain hunting of red-necked

wallaby, however, later refinement of the model (Cosgrove 1995) suggests a hunting strategy for wombats and other prey at Parmerpar Meethaner that would have focused on nearby patches of fertile grassland. In the Cradle Mountain region, the archeological occupation history, both timing and inferred intensity, is closely aligned with the paleoecological history of grassland and sclerophyll taxa. As grassland taxa declined in the late glacial period, occupation at Mackintosh Cave ceased (Stern and Marshall, 1993). In the early Holocene, human occupation ceased at Warragarra Rockshelter and drastically diminished Parmerpar Meethaner as grassland declined further (Fig. 9). In the late Holocene, sclerophyll and grassland taxa increased and human use of Warragarra Rockshelter resumed, while occupation intensity at Parmerpar Meethaner increased. As discussed earlier, late Holocene increases in grassland and sclerophyll woodland taxa were coincident with an increase in fire.

It has been suggested that increased climate variability and aridity in the late Holocene created drought conditions (Holz et al., 2015; Yospin, et al. 2015) which may have increased the vulnerability of rainforest to anthropogenic burning. However, it is also conceivable that Aboriginal fire management practices were a response to climate-driven vegetation change, and that burning was more effective under the late-Holocene climate conditions and in already heterogeneous vegetation. In this case, climate shaped the template of vegetation and fire and humans took advantage of the opportunities that were created. While it is not possible to say if humans played a role in the increase in fire activity ca. 4000 cal yr BP or facilitated the spread of open sclerophyll woodlands in Cradle Mountain, records from elsewhere in western Tasmania indicate sclerophyll

forests expended over a large area pointing to a large-scale driver like climate as the primary control, but locally human ignitions may have hastened this transition.

Conclusions

The pollen and charcoal evidence from Cradle Mountain suggests that during late-glacial period, the vegetation was largely open and fires were rare; forests were likely restricted to lower elevations. After ca. 14,000 cal yr BP, rainforest taxa and subalpine woody shrubs began to increase in abundance. Fire continued to be infrequent, with the exception of a short-lived increased at high elevation sites—Suttons Tarn and Lake Wilks.

In the early Holocene, a fire activity maximum occurred at the three lower elevation sites—Lake Hanson, Lake Lilla, and Wombat Pool—while biomass burning remained low at the higher sites. The elevational differences and basin characteristics likely resulted in climate-controlled differences in vegetation and fuel flammability. Lower sites supported larger areas of rainforest and sclerophyll vegetation communities while higher sites supported more subalpine vegetation. At the lower sites, fires in the sclerophyll communities may have burned frequently into the rainforest margin, producing the large amount of charcoal observed in these records during the early Holocene.

The mid-Holocene period featured a multi-millennial phase of cool, temperate rainforest dominance at all sites. Fire activity was sharply reduced during this period as well. The relatively wet conditions of the mid-Holocene, inferred from independent

paleoclimate proxy data, likely allowed the rainforest to reach its maximum extent. Many pollen records from across western Tasmania record higher amounts of rainforest taxa during this period. The late Holocene marks a regional shift toward open sclerophyll woodland associated with increased climate variability and decreased precipitation. The mosaic nature of the vegetation in Cradle Mountain evident in the modern landscape has been a feature of the last ca. 4600 years. All five Cradle Mountain sites recorded a large-scale fire event in the late Holocene. These fire events hastened the shift in compositional balance from vegetation dominated by rainforest to one with substantial open sclerophyll woodland.

The human-fire linkages in Cradle Mountain are tenuous and it is difficult to see their influence on fire regimes beyond those created by climate. Aboriginal peoples may have increased or facilitated burning in the early Holocene; however, increased fuel availability especially of sclerophyll taxa combined with warming led to more fires. Archeological evidence suggests the cave and rockshelter sites near Cradle Mountain were either abandoned or had significantly less use during the mid-Holocene when it was wetter and the vegetation was uniform, and human occupation was high in the early and late Holocene when the vegetation featured a mosaic of rainforest, mixed forest, sclerophyll woodlands, and grasslands. Such a patchwork of habitats may have benefited wildlife and facilitated hunting and foraging. In contrast, the homogenous rainforest-dominant landscape of the middle Holocene would have restricted wildlife diversity and hunting opportunities. People may have used fire to maintain and/or increase the mosaic arrangement, however, the widespread shift toward more open sclerophyll woodlands in

many areas of western Tasmania suggests that large-scale changes in climate were ultimately responsible for creation of a heterogeneous landscape. Climate variability, including an oscillation of wet and drought periods within an overall drier climate, created the vegetation and fire conditions which led to the large-scale vegetation shift observed in Cradle Mountain.

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CHAPTER FIVE

CONCLUSION

The Tasmanian Wilderness World Heritage Area is one of the most intact wilderness areas in the world. It protects nearly 1.6 million ha of wilderness containing prodigious ecological, geological, and cultural heritage (Tasmanian Parks and Wildlife Service; UNESCO World Heritage Centre). Cradle Mountain-Lake St Clair National Park is the northernmost piece of the wilderness area. The ecological diversity, evidenced by a high rate of endemism, is one of the most important characteristics of this area. This dissertation focuses on reconstructing the vegetation and fire history of Cradle Mountain since the last glaciation (ca. 17,000 cal yr BP). In particular, it utilizes fossil pollen and charcoal contained in lake-sediment cores to trace vegetation development and dynamics as well as fire activity through time. It includes the first peer-reviewed publications from the northern sector of Cradle Mountain-Lake St Clair National Park (termed Cradle Mountain) and as such significantly advances our understanding of the paleoenvironmental history of Cradle Mountain region. The study objectives were to (1) review the common approaches and data used to reconstruct terrestrial ecosystem change, (2) reconstruct the postglacial history of vegetation and fire activity at decadal to centennial scales; (3) evaluate the spatiotemporal patterns of climate-fire-vegetation linkages and identify the importance of regional and local controls on Holocene ecological history; (4) assess the role of Aboriginal Tasmanian land management in driving environmental change.

Methods and Data of Reconstructing Terrestrial Environmental Change

The study of terrestrial paleoecology has seen stimulating developments during recent years and it has become one of the most dynamic areas of biogeographical research. The application of independent dating, multivariate analyses, the establishment of databases, and increasing quantitative precision of proxy reconstructions have broadened the scope of the discipline and help extend our understanding of ecosystem dynamics beyond modern observations. The common terrestrial proxy data: tree-rings, pollen, plant macrofossils, packrat middens, charcoal, and dung fungal spores, as well as supporting paleolimnological information from diatoms, chironomids and lake-sediment lithology allow examination of environmental change at multiple spatial and temporal scales. The interpretation of proxy data is firmly grounded in uniformitarianism, the principle states that physical relationships and characteristics of biological entities in the past can be deduced from their present abundance and distribution. The best proxies are those that are well grounded in modern empirical and observational research so that present limitations are well understood. This information is essential to calibrate and refine interpretation of the past. With proxy data, there is also the opportunity to explore past conditions that may have no analog in the present. Proxy records can be used alone, but fuller understanding is achieved by combining and comparing multiple proxy data from single or groups of sites. Alternatively, developing geographic networks of records from a single proxy type, such as charcoal or pollen data, provides insights about patterns of environmental change over broad spatial scales.

Postglacial History of Vegetation and Fire Activity in Cradle Mountain

The Cradle Mountain vegetation history is based on three high-resolution pollen records from Lake Hanson, Suttons Tarn, and Wombat Pool, whereas the fire activity reconstruction is based on high-resolution charcoal records from these three sites as well as Lake Lilla and Lake Wilks. In the initial period of deglaciation (ca. 17,000-14,500 cal yr BP), open vegetation was widespread in Cradle Mountain. Pollen data indicate grasses and herbaceous plants were dominant. Grass, herbs, and coniferous shrubs dominated the local vegetation at individual lakes. Important taxa included *Poaceae*, Asteraceae, *Astelia alpina*, *Microcachrys tetragona*, *Gymnoschoenus sphaerocephalus*, and Ericaceae. Fire activity was extremely low during this period. During the transition from the late-glacial period to the early Holocene (ca. 14,500-11,500 cal yr BP), forest replaced much of the open vegetation. *Phyllocladus aspleniifolius*, an early successional tree found in rainforest and mixed forest settings, became important at this time. Fire activity was low through most of this transitional period, and increased markedly at the beginning of the Holocene. In the early Holocene (ca. 11,500-9,000 cal yr BP), a fire activity maximum occurred at the three lower elevation sites—Lake Hanson, Lake Lilla, and Wombat Pool—while biomass burning remained low at the higher sites. The increase in fire activity at Lake Hanson, Lake Lilla, and Wombat Pool continued into the early-Holocene period until ca. 9500 cal yr BP. Suttons Tarn and Lake Wilks are situated in smaller, topographically protected basins and at a higher elevation than the other three which along with more discontinuous fuels explains the relatively low levels of fire activity during the early Holocene. Low-elevation sites supported larger areas of rainforest and

sclerophyll communities while higher sites featured more subalpine vegetation. At the lower sites, fires in the sclerophyll communities may have burned frequently into the rainforest margin, producing the large amount of charcoal observed in these records during the early Holocene.

Rainforest dominated the vegetation of the mid-Holocene (ca. 9000-4500 cal yr BP). Herbaceous and sclerophyll woodland taxa, such as *Eucalyptus*, *Leptospermum-Baeckea*, *Monotaca*, Poaceae, Asteraceae, and Proteaceae, declined to their lowest percentages of the Holocene, and cool temperate rainforest taxa, especially *N. cunninghammii* and *N. gunnii*, reached their maximum. Fire activity in Cradle Mountain during this period was greatly reduced from the early Holocene and the magnitude of fire events was much lower than that of the early and late Holocene. The pollen data show a substantial change in vegetation in the late Holocene (4500 cal yr BP to present). The closed rainforest that persisted for millennia in the mid-Holocene was replaced by open sclerophyll woodland across large areas of Cradle Mountain, as evidenced by a sharp increase in sclerophyll taxa, especially *Eucalyptus*. Rainforest and subalpine taxa declined in the pollen records of all three sites between ca. 5200-4000 cal yr BP. Sclerophyll woodland shrub and herbaceous taxa increased at this time. Small increases in shorter-lived rainforest taxa, such as *Pomaderris*, *Anodopetalum-Eucryphia* and *Dicksonia antarctica*, occurred as well. This shift indicates the development of mixed forests that contain woodland and rainforest species during the late Holocene. All five charcoal records from Cradle Mountain display a dramatic increase in fire occurrence

between ca. 4800-3600 cal yr BP. At Lake Wilks, Suttons Tarn, and Wombat Pool, the largest fire event of these respective records occurred during this interval.

Climate-Fire-Vegetation Linkages and Regional and Local Controls on Holocene Paleoenvironmental History

Pollen and high-resolution charcoal records suggest that the postglacial history of Cradle Mountain is strongly influenced by large-scale changes in climate, particularly effective moisture and temperature. Deglaciation occurred between 18,000-16,000 cal yr BP in Tasmania (Barrows et al., 2002; Mackintosh et al., 2006). Climate proxy data indicates cool conditions during the late-glacial period (ca. 17,000-14,500 cal yr BP) when Cradle Mountain had open vegetation and very low fire activity. High levels of Poaceae and Asteraceae and low levels of tree taxa characterized many of the pollen records from Tasmania and southeastern Australian during this period (Colhoun and van der Geer, 1986; D'Costa et al., 1989; Colhoun et al., 1999; Hopf et al., 2000; Colhoun and Shimeld, 2012; Beck et al., 2017). Antarctic air temperatures, as recorded by $\delta^{18}O$ values, were low (Grootes et al., 2001; EPICA Members, 2004). Regional sea-surface temperatures (SSTs) were also relatively low compared with Last Glacial Maximum (LGM) values (Calvo et al., 2007; Sikes et al., 2009). Warming during the late-glacial to early-Holocene transition (ca. 14,500-11,500) is inferred from marine cores from the Australian region and Antarctic air-temperature records (Grootes et al., 2001; EPICA Members, 2004). Reconstructed SSTs in the Murray Basin northwest of Tasmania increased substantially after 13,000 cal yr BP (Calvo et al., 2007), suggesting an increase in adjacent land temperatures (Cook et al., 2000). Biomass burning increased

considerably at ca. 12,000 cal yr BP and coincided with a brief resurgence in Poaceae pollen.

Regional climate proxy data indicate the early Holocene (ca. 11,500-9000 cal yr BP) was warm with lower effective moisture than the earlier transition period and the later mid-Holocene. Weakened Southern Hemisphere Southwesterly Wind (SWW) flow during this period has been inferred from chironomid records from western Tasmania (Rees et al., 2015) and low lake levels in southwestern Victoria (Wilkins et al., 2013). The effects of higher-than-present winter and annual insolation (Berger and Loutre, 1991) may have also contributed to aridity in this period by promoting dry summers, mild winters and longer spring conditions across the Southern Hemisphere mid-latitudes (Whitlock et al., 2007). Warmer air temperature is suggested by Antarctic temperature at Taylor Dome, which reached its height between ca. 11,500-9500 cal yr BP (Grootes et al., 2001). Climate conditions during the early Holocene explain high fire activity at low-elevation sites and an increase in woody shrub communities at the low elevation lakes in Cradle Mountain. These communities included *Leptospermum-Baeckea*, *Banksia*, and Ericaceae as well as buttongrass and would have provided flammable fuels for fire spread. Furthermore, increased biomass burning during the early Holocene has been recorded at other cool-temperate western Tasmanian sites (Fletcher et al., 2015; Rees et al., 2015) and observed in many Patagonian records (Whitlock et al., 2007; Iglesias and Whitlock, 2014), suggesting the importance of large-scale climate controls on fire activity.

Paleoclimatic evidence suggests a relatively wet period that was as warm or slightly less warm than the early Holocene from ca. 9000-5000 cal yr BP. At Lynds Cave, 25 km northwest of Cradle Mountain, speleothem growth at the time implies higher effective moisture (Xia et al., 2001; Zhao et al., 2001). High lake levels at lakes Keilambete and Gnotuk in Victoria suggest that increased precipitation was a regional phenomenon. These records show a synchronous rise in the mid-Holocene with a Holocene high-stand at ca. 7200 cal yr BP (Wilkins et al., 2013). Furthermore, multiple lines of evidence indicate SWW flow was enhanced in the Tasmanian sector between ca. 8000-5000 cal yr BP (Fletcher & Moreno 2011, 2012; Rees et al., 2015). Storm tracks would have delivered more precipitation to western Tasmania, including Cradle Mountain, than in the early Holocene when the SWW flow was weak at this latitude. High effective moisture favored the observed expansion of cool, temperate rainforest at Cradle Mountain. The regional climate as well as microclimate conditions of the rainforests would have diminished the likelihood of fire spread. The reconstruction shows much less fire activity in the mid-Holocene than in the early Holocene.

Overall, mean regional climate conditions became cooler and drier than the mid-Holocene during the late Holocene. Speleothem growth ceased at 5000 cal yr BP at Lynds Cave (Xia et al., 2001), and lake levels in Victoria declined from the mid-Holocene high stand (Wilkins et al., 2013). Regional SSTs declined from early/mid-Holocene maxima indicating cooling (Calvo et al., 2007; Sikes et al., 2009), and the Taylor Dome record exhibits slowly declining temperature after ca. 8000 cal yr BP and increased variability after ca. 5000 cal yr BP (Grootes et al., 2001). Increased variability

attributed to enhanced El Niño-Southern Oscillation activity was also an important feature of late Holocene climate in Southern Australia. Conditions were more variable as a result of oscillating dry/wet El Niño/La Niña conditions (Marx et al., 2009; Fletcher et al., 2015; Rees et al., 2015).

The replacement of long-lived rainforest trees by herbaceous plants, woodland shrubs, and shorter-lived rainforest trees and shrubs (i.e. *Pomaderris apetala*, *Dicksonia antarctica*, *Anodopetalum-Eucryphia*) in Cradle Mountain is consistent with more frequent El Niño-induced drought within an overall drier mean climate after ca. 5000 cal yr BP. The increase in fire occurrence at all Cradle Mountain sites between ca. 4800-3600 cal yr BP may have been precipitated by the oscillating wet and dry conditions. Fluctuations in vegetation composition and/or fire occurrence are observed at many sites in the late Holocene and attributed to increased climate variability (i.e. Haberle 2005; Donders et al., 2007; Fletcher et al., 2014a, 2015; Rees et al., 2015; McWethy et al., 2016; Beck et al., 2017). Following extreme fire episodes in Cradle Mountain between ca. 4800-3600 cal yr BP, biomass burning declined and was quite low until present. The shift in vegetation from montane rainforest to *Eucalyptus* woodland may have contributed to the decline in charcoal influx.

The Role of Aboriginal Tasmanian Land-Management

Aboriginal peoples entered Tasmania at least 40,000 years ago (Cosgrove, 1999) and are believed to have used fire to enhance hunting success and facilitate travel (Cosgrove et al., 1990; Bowman, 1998; Gott, 2005; Gammage, 2008; 2011). As such, a

longstanding issue in Tasmanian ecology concerns whether or not deliberate burning by Aboriginal people substantially influenced the natural fire regimes and vegetation shaped by climate and physical environment. However, little is known about how Aboriginal peoples may have used fire in the Pleistocene and Holocene.

Recent evidence suggests fire was an important tool that was wielded with great skill. Anthropological research, the accounts of European colonizers, and landscape structure analysis suggest that Aboriginal peoples actively managed parts of the Tasmanian landscape through deliberate burning (Bowman, 1998; Marsden-Smedley and Kirkpatrick, 2000; Gott, 2005; Gammage, 2008, 2011; Onfray, 2012). In particular, fire was used to create patches of open land interspersed with woodlands. In the open patches, tender grasses and forbs established after fire which attracted favored prey species, especially wallabies, while the woodland patches served as areas where hunters could move relatively undetected (Gammage, 2008, 2011). Aboriginal fire management likely focused on make hunting more predictable (Gammage, 2008, 2011). The available evidence suggests the burning strategy of Aboriginal peoples consisted of low-intensity fires usually set in wetter seasons or after a rainfall event (Marsden-Smedley and Kirkpatrick, 2000).

In order to investigate the potential impact of deliberate human-set fires on the fire history in Cradle Mountain, we investigated the archeological record from three well-studied archeological sites situated within ca. 25 km of Cradle Mountain: Mackintosh Cave, Warragarra Rockshelter, and Parmerpar Meethaner Rockshelter. While acknowledging the difficulty and limitations of comparing human fire ignitions, which

occur at decadal to interannual temporal scales, to the centennial-scale paleoenvironmental reconstructions, we considered human presence in the Cradle Mountain region as evidence of a potential anthropogenic fire-ignition source. The three sites were first occupied in the Pleistocene and the most intense periods of use at both Parmerpar Meethaner and Mackintosh Cave—ca. 19,000-15,000 and ca. 21,000-17,500 cal yr BP, respectively—pre-date the paleoenvironmental record from Cradle Mountain (Cosgrove, 1995; Stern and Marshall, 1993). The record from Warragarra Rockshelter begins ca. 12,000 cal yr BP at which time there was evidence of sporadic, light occupation consistent with its use as a transient hunting base (Lourandos, 1983). This period may have spanned approximately 500-1000 years after which time there is no evidence of human use of the site until the late Holocene (Allen and Porch, 1996).

Around ca. 14,500 cal yr BP a small increase in biomass burning is evident in the two records that extend past 16,000 cal yr BP, Suttons Tarn and Wombat Pool. Discrete fire episodes were recorded in these watersheds between ca. 16,500-12,000 cal yr BP when there is evidence of Aboriginal Tasmanians in the area. After ca. 12,000 cal yr BP, there was a steep decline in the discard rates at Parmerpar Meethaner interpreted as a significant decline in human use of this rockshelter, but not complete abandonment (Cosgrove, 1995). For the next 7000 years, until ca. 5000 cal yr BP, human use of the site continued at very low levels. A small increase in discard rates was recorded between ca. 5000-4000 cal yr BP, after which time they were again depressed until ca. 2000 cal yr BP when artifact discard rates indicate use-intensity levels of about half those during the late-glacial period. Meanwhile, at about 3700 cal yr BP at Warragarra, evidence of human use

resumed. The archeological deposits indicate that Warragarra was never occupied as intensely as Parmerpar Meethaner and was instead probably used as a transient hunting base during the summer months (Lourandos, 1983; Allen and Porch, 1996).

Climate was the primary driver of fire activity in the Cradle Mountain records. However, it is possible that human ignitions also played a role in particular times. In the late-glacial period when the archeological record indicates human occupation was elevated, low levels of charcoal and rare fire events characterize the fire history. These fires may have been a result of human ignitions in a fuel-limited system. As discussed above, fire activity reached a maximum in the early Holocene, and biomass burning was especially high between ca. 11,200-9,800 cal yr BP. This period was a time very low or no human occupation in the region. Although, we have concluded that increased temperature and lower effective moisture coupled with increased woody shrubs were the likely drivers of high fire activity during this period, it is possible that human-set fires played a role. Likewise, we have concluded that the mid-Holocene rainforest maximum was driven by high effective moisture, and that regional climate conditions coupled with the microclimate conditions of the cool, temperate rainforest inhibited fire activity. Although the nearby archeological sites indicate infrequent and/or very low intensity human use, people may have been present in the area and employed different subsistence strategies that rarely or never included use of rockshelters (Cosgrove, 1999; Pike-Tay et al., 2008) although this hypothesis remains to be tested. If people were absent, the lack of anthropogenic ignitions may have contributed to the lower fire activity in the mid-Holocene.

This dissertation found that the long-term shift toward drier, cooler, more variable conditions in the late Holocene changed the vegetation in Cradle Mountain toward a more heterogeneous structure that included *Eucalyptus* woodlands, mixed forest, rainforest, buttongrass moorland, and sclerophyll shrub communities. The large-magnitude of the late-Holocene fire events at all five sites may have been the result, in part, of this mosaic arrangement which would have made small rainforest patches more vulnerable to fire due to their proximity to more flammable vegetation types. A modest resumption in human occupation was recorded in the late Holocene and the presence of people in the region could have provided an ignition source that was lacking in the mid-Holocene; however, it is impossible to directly link the resumption of use of these sites with an increase in anthropogenic ignitions. In addition, the large area impacted by increased fire in the late Holocene is inconsistent with what is known about the targeted and strategic manner in which Aboriginal peoples employed fire.

The patterns that emerge from our reconstructions strongly suggest a climate-mediated control on vegetation and fire but anthropogenic burning may have enhanced the effects of climate. Although we cannot definitively comment on human influence on fire activity, we can use the vegetation patterns suggested by our high-resolution datasets to examine how climate, vegetation, and fire dynamics may have impacted Aboriginal subsistence strategies. Heterogeneous vegetation, for example, would have been more conducive to hunting strategies than uniform closed forest. The present vegetation mosaic indicate that this heterogeneity developed about 4500-3500 cal yr BP. This interval is also the time when nearby rockshelter sites show increased use after thousands of years

of little activity. A widely-accepted model of Aboriginal land use suggests that people moved between discrete grassland patches within a much larger complex of forests, shrublands and sedgelands, and these patches served as relatively predictable areas for hunting. In the Cradle Mountain area, grassland patches occur on fertile basaltic substrates and attract marsupials to feed on tender grasses creating "ecologically tethered" animal resources (Cosgrove et al., 1990). I suggest that development of this late Holocene mosaic may have increased human exploitation and burning in the area. Thus, Aboriginal fire management practices may have been a response to climate-driven vegetation change, given that the onset of drier conditions predates the shift to heterogeneous vegetation. In this case, climate shaped the template of vegetation and fire and humans took advantage of the opportunities that were created.

Future Directions

Two conclusions drawn from this investigation motivate future research. One, that vegetation changed in substantial ways between the early and mid-Holocene and again between the mid- and the late Holocene. Compositionally, there were shifts to and away from temperate rainforest dominance. I have also hypothesized that structural shifts occurred between heterogeneous and homogeneous vegetation arrangements. Two, that fire activity and vegetation were primarily driven by climate over the ca. 17,000 years encompassed in the Cradle Mountain records.

A more thorough study of the long-term edaphic controls on vegetation in Cradle Mountain may help elucidate our finding that heterogeneity has varied over time as well

as our hypothesis that a more heterogeneous vegetation composition favored human hunting strategies during certain periods and may explain the archeological pattern of human occupation in the region. Certain plants in Cradle Mountain have specific edaphic preferences (Kirkpatrick, 1982; Harris and Kitchener, 2005). For example, *A. selaginoides* and *N. gunnii* do not regenerate in poorly drained soils even with an adjacent seed source (Kirkpatrick and Dickinson 1984). A positive feedback is developed between waterlogged soils and vegetation composition in that reduced transpiration rates due to the replacement of trees by wetland plants such as buttongrass results water-saturated soils which, in turn, limits tree seedling establishment and leads to the exclusion of trees (Fletcher et al., 2014b). This process or a similar one may have led to the establishment of present mosaic ca. 4000 years ago. It may be possible to investigate a fine-scale landscape changes due to edaphic processes and/or human activities by taking peat and soil cores within areas of buttongrass dominance with waterlogged soils. This may allow the antiquity of these patches to be established and then compared to fire activity.

An investigation of the relationship between lichens and bryophytes and rainforest health and resilience may also yield important information about possible feedbacks between smaller patch sizes of rainforest communities and deterioration in tree heath and/or habitat quality. Lichens and bryophytes play a critical role in nutrient cycling, nitrogen fixation, and water retention in western Tasmanian rainforests, many of which grow on nutrient poor substrates (Jarman et al., 1991). The epiphyllous lichen *Roccellinastrum flavescens* is found exclusively on the leaves of *A. cupressoides* (Kantvilas 1990). Large, old growth *N. cunninghammii* trees support a significantly

higher diversity of lichen species than younger, smaller trees, and forest fragmentation can have detrimental effects on lichen populations (Morley and Gipson, 2010). Impoverishment in lichen communities within Cradle Mountain's rainforest refugia communities may impact the resilience of those forests going forward, and may have contributed to the fragmentation and decline of rainforest communities in the mid- to late Holocene. It would be useful to know if and what role lichens and bryophytes play in the regeneration of cool, temperate rainforest trees by contributing to soil nutrients, water retention, or other factors.

Finally, a comparison between the reconstructions presented here and the results from a landscape-scale model of vegetation and fire specifically parameterized for Cradle Mountain-Lake St Clair National Park (FireBGCv2; Yospin et al., 2015) could assist in hypothesis testing. In particular, it would be useful to examine whether climate changes alone are sufficient to explain the simulated vegetation and fire patterns. If they were not, it may be due to the role of Aboriginal land-management practices played in shaping the vegetation and fire history of Cradle Mountain.

Final Remarks

The future of the Gondwanan temperate rainforest lineages is uncertain. Recent increases in temperatures, more frequent droughts, and longer fire seasons threaten many of Tasmania's endemic mesic taxa, and projected climate trends suggest that these conditions will continue in the future (Grotes et al., 2010, 2015; Jolly et al., 2015). The tolerance of and time to recover from fire differs greatly among vegetation communities,

and has been shown to take centuries in the case of *Nothofagus* and *Athrotaxis* in Tasmania (Kirkpatrick & Dickinson 1984; Pyrke, 2013; Fletcher et al., 2014a). Longer fire seasons will increase the likelihood of fire damage to the remaining stands of cool, temperate rainforest (Lucas et al., 2007; Holz et al., 2015; Yospin et al., 2015). Fortunately, the ecological, cultural, and intrinsic value of Tasmania's temperate rainforests are widely recognized. A major reason for the designation of the UNESCO Tasmanian Wilderness World Heritage Area in 1982 and its extensions in 1989 and 2013 was the unique temperate rainforests (The Wilderness Society). The National Park and World Heritage Area protections cannot ensure the continued persistence of rainforests in the face of changing climate conditions that include an increase in destructive fires driven by extreme fire weather. Scientists have recommended additional protection in the form of robust and timely government-funded suppression of future uncontrolled fires that threaten the Tasmanian Wilderness (Bowman, 2016; Kirkpatrick, 2016). It may be necessary to implement more drastic forms of protection for remaining rainforest patches in order to not only suppress fire but also to prevent it in these pyrophobic plant communities. In the coming years and decades, substantial efforts will likely be required to ensure further contraction of cool, temperate rainforests is avoided.

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APPENDICES

APPENDIX A

WOMBAT POOL CHRONOLOGY

Depth (cm)	Median Age (cal yr BP)	Minimum Age (95% CI) (cal yr BP)	Maximum Age (95% CI) (cal yr BP)
0.00	-109	-69	-85
0.25	-90	-50	-67
0.50	-70	-30	-48
0.75	-50	-9	-29
1.00	-31	12	-10
1.25	-11	33	9
1.50	8	53	28
1.75	27	73	47
2.00	47	93	66
2.25	66	113	85
2.50	85	133	104
2.75	104	154	124
3.00	124	175	143
3.25	143	196	162
3.50	163	218	181
3.75	182	239	201
4.00	202	260	220
4.25	222	281	240
4.50	242	303	259
4.75	261	325	279
5.00	281	347	299
5.25	301	369	319
5.50	321	391	339
5.75	341	413	359
6.00	361	436	379
6.25	381	458	400
6.50	401	480	420
6.75	421	502	441
7.00	441	525	462
7.25	461	548	483
7.50	481	571	505
7.75	502	593	526
8.00	523	616	548
8.25	543	639	570
8.50	564	662	592
8.75	584	685	614
9.00	605	708	637

9.25	626	731	659
9.50	647	754	682
9.75	667	777	705
10.00	688	799	728
10.25	709	822	752
10.50	730	845	775
10.75	751	869	799
11.00	772	893	822
11.25	793	918	846
11.50	815	942	870
11.75	836	967	894
12.00	857	991	918
12.25	879	1015	943
12.50	901	1040	967
12.75	923	1065	991
13.00	945	1090	1016
13.25	967	1114	1040
13.50	989	1138	1065
13.75	1011	1161	1089
14.00	1034	1185	1114
14.25	1056	1210	1139
14.50	1079	1235	1163
14.75	1102	1260	1188
15.00	1124	1284	1213
15.25	1147	1309	1237
15.50	1170	1332	1262
15.75	1193	1356	1287
16.00	1215	1379	1311
16.25	1238	1402	1336
16.50	1259	1427	1360
16.75	1282	1453	1385
17.00	1305	1478	1409
17.25	1327	1503	1434
17.50	1350	1528	1458
17.75	1372	1553	1482
18.00	1394	1578	1506
18.25	1417	1602	1530
18.50	1439	1625	1554
18.75	1462	1649	1578
19.00	1485	1673	1602
19.25	1508	1698	1625

19.50	1531	1723	1649
19.75	1554	1745	1672
20.00	1577	1767	1695
20.25	1600	1790	1719
20.50	1623	1815	1742
20.75	1646	1841	1765
21.00	1670	1866	1788
21.25	1692	1891	1811
21.50	1715	1913	1834
21.75	1738	1936	1856
22.00	1761	1959	1879
22.25	1784	1982	1902
22.50	1807	2007	1924
22.75	1829	2029	1947
23.00	1852	2053	1969
23.25	1875	2076	1991
23.50	1897	2100	2014
23.75	1920	2124	2036
24.00	1943	2147	2058
24.25	1965	2170	2080
24.50	1990	2195	2103
24.75	2014	2218	2125
25.00	2037	2240	2147
25.25	2060	2263	2169
25.50	2081	2285	2191
25.75	2103	2307	2213
26.00	2125	2329	2235
26.25	2148	2352	2257
26.50	2171	2374	2279
26.75	2193	2398	2300
27.00	2216	2421	2322
27.25	2240	2443	2344
27.50	2263	2464	2366
27.75	2286	2486	2388
28.00	2309	2507	2410
28.25	2332	2529	2431
28.50	2356	2551	2453
28.75	2379	2572	2475
29.00	2402	2595	2497
29.25	2426	2619	2519
29.50	2449	2643	2541

29.75	2472	2667	2562
30.00	2495	2690	2584
30.25	2518	2714	2606
30.50	2542	2738	2628
30.75	2565	2760	2650
31.00	2588	2784	2672
31.25	2611	2808	2694
31.50	2634	2832	2716
31.75	2657	2855	2738
32.00	2681	2876	2760
32.25	2705	2898	2782
32.50	2728	2920	2804
32.75	2751	2941	2827
33.00	2774	2962	2849
33.25	2798	2984	2871
33.50	2821	3007	2894
33.75	2845	3029	2916
34.00	2868	3052	2939
34.25	2891	3074	2961
34.50	2914	3097	2984
34.75	2936	3118	3006
35.00	2960	3140	3029
35.25	2981	3162	3052
35.50	3003	3186	3075
35.75	3026	3210	3098
36.00	3049	3234	3121
36.25	3070	3256	3144
36.50	3092	3279	3167
36.75	3113	3302	3190
37.00	3135	3325	3213
37.25	3157	3348	3237
37.50	3177	3371	3260
37.75	3198	3394	3283
38.00	3219	3417	3307
38.25	3241	3441	3330
38.50	3263	3464	3354
38.75	3285	3488	3377
39.00	3306	3511	3401
39.25	3327	3534	3424
39.50	3349	3557	3448
39.75	3371	3579	3471

40.00	3391	3601	3495
40.25	3413	3624	3518
40.50	3434	3647	3542
40.75	3456	3670	3565
41.00	3477	3692	3589
41.25	3499	3715	3612
41.50	3521	3738	3635
41.75	3543	3761	3659
42.00	3564	3783	3682
42.25	3586	3806	3706
42.50	3608	3829	3729
42.75	3629	3852	3752
43.00	3651	3874	3775
43.25	3673	3897	3798
43.50	3695	3919	3821
43.75	3716	3942	3844
44.00	3737	3963	3867
44.25	3758	3986	3890
44.50	3779	4008	3913
44.75	3800	4031	3936
45.00	3821	4052	3959
45.25	3843	4074	3981
45.50	3864	4096	4004
45.75	3885	4118	4026
46.00	3907	4140	4048
46.25	3928	4161	4070
46.50	3949	4183	4093
46.75	3971	4203	4115
47.00	3992	4225	4136
47.25	4013	4247	4158
47.50	4034	4268	4180
47.75	4055	4290	4201
48.00	4076	4311	4223
48.25	4096	4334	4244
48.50	4117	4355	4265
48.75	4137	4376	4286
49.00	4158	4397	4307
49.25	4179	4417	4327
49.50	4200	4437	4348
49.75	4221	4458	4368
50.00	4242	4476	4389

50.25	4263	4497	4409
50.50	4284	4517	4429
50.75	4305	4538	4449
51.00	4326	4558	4469
51.25	4347	4577	4489
51.50	4368	4597	4508
51.75	4389	4616	4528
52.00	4409	4634	4547
52.25	4429	4653	4567
52.50	4448	4672	4586
52.75	4468	4691	4605
53.00	4487	4711	4624
53.25	4507	4730	4643
53.50	4527	4749	4662
53.75	4548	4768	4681
54.00	4570	4786	4700
54.25	4592	4805	4719
54.50	4614	4823	4737
54.75	4635	4842	4756
55.00	4656	4861	4774
55.25	4676	4879	4793
55.50	4696	4897	4811
55.75	4717	4916	4829
56.00	4737	4936	4848
56.25	4757	4955	4866
56.50	4777	4973	4884
56.75	4798	4991	4902
57.00	4817	5010	4920
57.25	4838	5029	4938
57.50	4857	5047	4956
57.75	4875	5064	4974
58.00	4894	5084	4992
58.25	4914	5104	5010
58.50	4933	5123	5028
58.75	4953	5143	5046
59.00	4973	5161	5064
59.25	4992	5179	5082
59.50	5010	5196	5100
59.75	5030	5213	5118
60.00	5049	5230	5136
60.25	5067	5247	5153

60.50	5087	5264	5171
60.75	5106	5281	5189
61.00	5125	5298	5207
61.25	5146	5316	5225
61.50	5164	5335	5243
61.75	5184	5353	5261
62.00	5203	5371	5279
62.25	5222	5390	5296
62.50	5240	5408	5314
62.75	5259	5426	5332
63.00	5277	5445	5350
63.25	5295	5463	5368
63.50	5313	5481	5387
63.75	5331	5499	5405
64.00	5349	5517	5423
64.25	5367	5535	5441
64.50	5386	5554	5459
64.75	5404	5572	5478
65.00	5424	5590	5496
65.25	5443	5608	5514
65.50	5460	5626	5533
65.75	5478	5643	5551
66.00	5496	5660	5570
66.25	5515	5679	5588
66.50	5533	5697	5607
66.75	5552	5714	5625
67.00	5571	5731	5644
67.25	5591	5749	5663
67.50	5609	5768	5681
67.75	5627	5786	5700
68.00	5645	5803	5719
68.25	5662	5819	5738
68.50	5681	5837	5756
68.75	5699	5856	5775
69.00	5718	5874	5794
69.25	5736	5892	5813
69.50	5754	5912	5832
69.75	5773	5932	5851
70.00	5792	5951	5870
70.25	5810	5968	5889
70.50	5829	5985	5908

70.75	5847	6002	5927
71.00	5864	6019	5946
71.25	5882	6038	5965
71.50	5901	6056	5984
71.75	5920	6076	6003
72.00	5937	6093	6022
72.25	5955	6110	6041
72.50	5974	6127	6060
72.75	5991	6145	6079
73.00	6009	6164	6098
73.25	6027	6185	6117
73.50	6044	6205	6136
73.75	6063	6226	6155
74.00	6082	6246	6174
74.25	6102	6265	6193
74.50	6119	6284	6212
74.75	6138	6305	6231
75.00	6156	6325	6250
75.25	6175	6345	6269
75.50	6193	6364	6288
75.75	6211	6382	6307
76.00	6230	6401	6326
76.25	6249	6421	6345
76.50	6267	6439	6364
76.75	6286	6459	6382
77.00	6305	6478	6401
77.25	6324	6497	6420
77.50	6343	6517	6439
77.75	6362	6538	6458
78.00	6380	6558	6477
78.25	6399	6579	6495
78.50	6417	6600	6514
78.75	6436	6621	6533
79.00	6455	6639	6551
79.25	6474	6659	6570
79.50	6494	6680	6589
79.75	6513	6700	6607
80.00	6532	6719	6626
80.25	6551	6740	6644
80.50	6570	6761	6663
80.75	6589	6781	6682

81.00	6609	6801	6700
81.25	6628	6824	6719
81.50	6647	6846	6737
81.75	6667	6867	6756
82.00	6687	6887	6775
82.25	6705	6907	6793
82.50	6724	6928	6812
82.75	6743	6950	6831
83.00	6763	6972	6850
83.25	6783	6994	6868
83.50	6803	7016	6887
83.75	6823	7038	6906
84.00	6842	7060	6925
84.25	6861	7081	6944
84.50	6881	7104	6963
84.75	6900	7125	6982
85.00	6919	7147	7001
85.25	6938	7168	7020
85.50	6957	7189	7040
85.75	6976	7210	7059
86.00	6997	7230	7078
86.25	7015	7251	7098
86.50	7035	7271	7117
86.75	7055	7292	7137
87.00	7074	7312	7157
87.25	7091	7333	7176
87.50	7109	7355	7196
87.75	7127	7376	7216
88.00	7145	7396	7236
88.25	7163	7417	7257
88.50	7181	7439	7277
88.75	7197	7461	7297
89.00	7215	7482	7318
89.25	7232	7504	7338
89.50	7250	7525	7359
89.75	7267	7547	7380
90.00	7284	7569	7401
90.25	7300	7590	7422
90.50	7318	7611	7443
90.75	7337	7633	7464
91.00	7355	7654	7486

91.25	7372	7675	7507
91.50	7391	7697	7529
91.75	7409	7718	7550
92.00	7427	7739	7572
92.25	7445	7760	7593
92.50	7464	7780	7615
92.75	7483	7801	7636
93.00	7502	7821	7658
93.25	7519	7841	7679
93.50	7537	7861	7701
93.75	7555	7881	7722
94.00	7574	7901	7744
94.25	7591	7921	7765
94.50	7608	7941	7786
94.75	7626	7960	7807
95.00	7644	7980	7828
95.25	7662	8000	7849
95.50	7679	8018	7870
95.75	7697	8035	7891
96.00	7715	8055	7911
96.25	7732	8075	7932
96.50	7750	8095	7952
96.75	7767	8114	7972
97.00	7784	8134	7992
97.25	7801	8152	8011
97.50	7818	8169	8031
97.75	7835	8186	8050
98.00	7852	8204	8069
98.25	7869	8227	8088
98.50	7886	8246	8106
98.75	7904	8266	8124
99.00	7921	8284	8143
99.25	7938	8303	8161
99.50	7955	8321	8178
99.75	7972	8339	8196
100.00	7988	8355	8213
100.25	8005	8373	8230
100.50	8021	8391	8247
100.75	8036	8410	8264
101.00	8052	8428	8281
101.25	8068	8446	8297

101.50	8084	8463	8314
101.75	8099	8482	8330
102.00	8115	8499	8346
102.25	8132	8516	8362
102.50	8148	8532	8377
102.75	8164	8550	8393
103.00	8180	8567	8408
103.25	8196	8585	8424
103.50	8212	8603	8439
103.75	8228	8621	8454
104.00	8244	8638	8468
104.25	8259	8655	8483
104.50	8275	8672	8498
104.75	8290	8689	8512
105.00	8305	8705	8526
105.25	8321	8722	8541
105.50	8337	8738	8555
105.75	8352	8754	8569
106.00	8368	8770	8582
106.25	8383	8785	8596
106.50	8399	8801	8610
106.75	8414	8816	8623
107.00	8429	8831	8637
107.25	8444	8846	8650
107.50	8458	8862	8663
107.75	8474	8876	8677
108.00	8489	8890	8690
108.25	8504	8906	8703
108.50	8519	8920	8715
108.75	8535	8934	8728
109.00	8550	8949	8741
109.25	8565	8965	8754
109.50	8580	8980	8766
109.75	8595	8993	8779
110.00	8610	9008	8791
110.25	8625	9023	8804
110.50	8640	9038	8816
110.75	8654	9052	8828
111.00	8669	9066	8841
111.25	8683	9080	8853
111.50	8698	9093	8865

111.75	8713	9107	8877
112.00	8727	9120	8889
112.25	8742	9134	8902
112.50	8756	9147	8914
112.75	8771	9160	8926
113.00	8785	9172	8938
113.25	8800	9185	8950
113.50	8814	9198	8962
113.75	8828	9211	8973
114.00	8842	9225	8985
114.25	8857	9238	8997
114.50	8871	9251	9009
114.75	8885	9265	9021
115.00	8899	9277	9033
115.25	8913	9290	9045
115.50	8928	9303	9057
115.75	8942	9317	9069
116.00	8956	9330	9081
116.25	8970	9342	9093
116.50	8985	9354	9105
116.75	8999	9367	9117
117.00	9014	9379	9129
117.25	9028	9392	9141
117.50	9042	9406	9153
117.75	9056	9419	9165
118.00	9069	9432	9177
118.25	9083	9444	9190
118.50	9095	9457	9202
118.75	9106	9470	9214
119.00	9120	9482	9226
119.25	9132	9495	9239
119.50	9144	9507	9251
119.75	9155	9519	9264
120.00	9167	9531	9276
120.25	9180	9543	9288
120.50	9191	9556	9301
120.75	9202	9568	9313
121.00	9212	9581	9326
121.25	9224	9593	9338
121.50	9236	9605	9351
121.75	9247	9617	9363

122.00	9259	9629	9376
122.25	9271	9641	9388
122.50	9283	9653	9401
122.75	9296	9664	9414
123.00	9309	9676	9426
123.25	9321	9688	9439
123.50	9332	9699	9452
123.75	9344	9711	9464
124.00	9356	9724	9477
124.25	9367	9736	9490
124.50	9379	9748	9502
124.75	9391	9760	9515
125.00	9402	9772	9528
125.25	9412	9783	9540
125.50	9423	9795	9553
125.75	9435	9807	9566
126.00	9447	9819	9578
126.25	9461	9830	9591
126.50	9474	9842	9604
126.75	9484	9853	9617
127.00	9495	9865	9629
127.25	9507	9876	9642
127.50	9519	9887	9655
127.75	9531	9898	9668
128.00	9543	9909	9680
128.25	9554	9920	9693
128.50	9566	9931	9706
128.75	9579	9942	9718
129.00	9592	9954	9731
129.25	9604	9965	9744
129.50	9617	9976	9756
129.75	9629	9988	9769
130.00	9640	9999	9782
130.25	9652	10010	9795
130.50	9663	10022	9807
130.75	9675	10033	9820
131.00	9686	10044	9832
131.25	9698	10055	9845
131.50	9709	10066	9858
131.75	9721	10077	9870
132.00	9732	10088	9883

132.25	9744	10099	9895
132.50	9755	10110	9908
132.75	9767	10121	9920
133.00	9778	10131	9933
133.25	9790	10142	9945
133.50	9800	10153	9958
133.75	9811	10164	9970
134.00	9823	10174	9982
134.25	9835	10185	9995
134.50	9846	10195	10007
134.75	9857	10206	10020
135.00	9868	10217	10032
135.25	9879	10227	10044
135.50	9891	10238	10056
135.75	9903	10248	10069
136.00	9915	10257	10081
136.25	9926	10267	10093
136.50	9936	10276	10105
136.75	9946	10286	10117
137.00	9956	10296	10129
137.25	9967	10306	10141
137.50	9978	10316	10153
137.75	9989	10326	10165
138.00	10000	10336	10177
138.25	10011	10346	10189
138.50	10022	10355	10201
138.75	10033	10365	10212
139.00	10044	10375	10224
139.25	10054	10384	10236
139.50	10065	10394	10247
139.75	10076	10404	10259
140.00	10087	10413	10271
140.25	10097	10422	10282
140.50	10108	10431	10294
140.75	10119	10440	10305
141.00	10129	10450	10316
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166.50	11039	11406	11215
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182.50	11609	11955	11756
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184.50	11691	12021	11835
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186.50	11775	12091	11916
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187.50	11818	12125	11958
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189.50	11906	12195	12042
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190.25	11935	12221	12073
190.50	11946	12230	12084
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286.50	17103	17816	17381
286.75	17115	17834	17396
287.00	17127	17853	17412
287.25	17138	17872	17428
287.50	17150	17892	17443
287.75	17162	17912	17459
288.00	17175	17932	17474
288.25	17187	17952	17490
288.50	17200	17971	17505
288.75	17213	17991	17521
289.00	17225	18010	17536
289.25	17238	18030	17552
289.50	17250	18049	17568
289.75	17263	18068	17583
290.00	17275	18087	17599
290.25	17288	18106	17614
290.50	17300	18125	17630
290.75	17312	18144	17645
291.00	17324	18163	17661
291.25	17336	18182	17677
291.50	17348	18202	17692
291.75	17360	18221	17708
292.00	17372	18241	17723
292.25	17385	18262	17739
292.50	17397	18281	17754
292.75	17409	18300	17770
293.00	17421	18320	17785
293.25	17433	18339	17801
293.50	17445	18358	17817
293.75	17458	18377	17832
294.00	17470	18397	17848
294.25	17482	18416	17863
294.50	17494	18435	17879
294.75	17506	18454	17894
295.00	17518	18473	17910
295.25	17529	18492	17926
295.50	17541	18511	17941
295.75	17553	18531	17957
296.00	17565	18550	17972

296.25	17578	18570	17988
296.50	17590	18589	18003
296.75	17602	18609	18019
297.00	17614	18630	18034
297.25	17626	18650	18050
297.50	17637	18670	18066
297.75	17649	18691	18081
298.00	17661	18711	18097
298.25	17673	18732	18112
298.50	17684	18752	18128
298.75	17696	18772	18143
299.00	17708	18792	18159
299.25	17720	18812	18175
299.50	17732	18833	18190
299.75	17744	18853	18206
300.00	17756	18873	18221

APPENDIX B

LITHOLOGIC DATA FROM WOMBAT POOL

Depth (cm)	Age (cal yr BP)	Magnetic Susceptibility (SI units)
0.25	-67	no data
0.75	-29	no data
1.25	9	-0.7
1.75	47	-0.8
2.25	85	-1.3
2.75	124	-1.4
3.25	162	-1.3
3.75	201	-1.4
4.25	240	-1.6
4.75	279	-1.7
5.25	319	-1.3
5.75	359	-1.3
6.25	400	-1.5
6.75	441	-1.7
7.25	483	-1.6
7.75	526	-1.7
8.25	570	-1.7
8.75	614	-1.9
9.25	659	-1.9
9.75	705	-1.7
10.25	752	-1.6
10.75	799	-1.9
11.25	846	-1.5
11.75	894	-1.9
12.25	943	-1.8
12.75	991	-1.7
13.25	1040	-1.9
13.75	1089	-1.6
14.25	1139	-1.8
14.75	1188	-2.0
15.25	1237	-1.6
15.75	1287	-1.7
16.25	1336	-2.0
16.75	1385	-1.7
17.25	1434	-1.7
17.75	1482	-1.8
18.25	1530	-1.6
18.75	1578	no data

19.25	1625	-2.0
19.75	1672	-1.9
20.25	1719	-2.1
20.75	1765	-1.8
21.25	1811	-1.7
21.75	1856	-1.6
22.25	1902	-1.6
22.75	1947	-1.8
23.25	1991	-1.9
23.75	2036	-1.8
24.25	2080	-2.2
24.75	2125	-2.0
25.25	2169	-2.1
25.75	2213	-1.7
26.25	2257	-1.9
26.75	2300	-1.7
27.25	2344	-1.5
27.75	2388	-1.5
28.25	2431	-1.6
28.75	2475	-1.7
29.25	2519	-1.9
29.75	2562	-1.9
30.25	2606	-1.6
30.75	2650	-1.5
31.25	2694	-1.5
31.75	2738	-1.6
32.25	2782	-1.6
32.75	2827	-1.7
33.25	2871	-1.8
33.75	2916	-1.7
34.25	2961	-1.4
34.75	3006	-1.4
35.25	3052	-1.9
35.75	3098	-1.6
36.25	3144	-1.5
36.75	3190	-1.8
37.25	3237	-1.6
37.75	3283	-1.6
38.25	3330	-1.8
38.75	3377	-1.8
39.25	3424	-1.6

39.75	3471	-1.5
40.25	3518	-1.5
40.75	3565	-1.7
41.25	3612	-1.8
41.75	3659	-1.8
42.25	3706	-1.6
42.75	3752	-1.6
43.25	3798	-1.8
43.75	3844	-1.9
44.25	3890	-1.7
44.75	3936	-2.1
45.25	3981	-1.6
45.75	4026	-1.4
46.25	4070	-1.9
46.75	4115	-1.5
47.25	4158	-1.5
47.75	4201	-1.4
48.25	4244	-1.8
48.75	4286	-1.5
49.25	4327	-1.9
49.75	4368	-1.9
50.25	4409	-1.8
50.75	4449	-1.6
51.25	4489	-1.7
51.75	4528	-1.7
52.25	4567	-1.7
52.75	4605	-1.7
53.25	4643	-1.7
53.75	4681	-1.8
54.25	4719	-1.8
54.75	4756	-1.7
55.25	4793	-1.9
55.75	4829	-1.7
56.25	4866	-1.9
56.75	4902	-1.7
57.25	4938	-1.5
57.75	4974	-1.9
58.25	5010	-1.7
58.75	5046	-1.7
59.25	5082	-1.5
59.75	5118	-1.7

60.25	5153	-1.4
60.75	5189	-1.8
61.25	5225	-1.5
61.75	5261	-1.6
62.25	5296	-1.6
62.75	5332	-1.7
63.25	5368	-1.8
63.75	5405	-1.7
64.25	5441	-1.3
64.75	5478	-1.6
65.25	5514	-1.8
65.75	5551	-1.7
66.25	5588	-1.7
66.75	5625	-1.6
67.25	5663	-1.7
67.75	5700	-1.6
68.25	5738	-1.4
68.75	5775	-1.4
69.25	5813	-1.7
69.75	5851	-1.6
70.25	5889	-1.7
70.75	5927	-1.9
71.25	5965	-1.6
71.75	6003	-1.5
72.25	6041	-1.7
72.75	6079	-1.5
73.25	6117	-1.8
73.75	6155	-1.8
74.25	6193	-1.9
74.75	6231	-1.6
75.25	6269	-1.5
75.75	6307	-1.6
76.25	6345	-1.5
76.75	6382	-1.7
77.25	6420	-1.4
77.75	6458	-1.7
78.25	6495	-1.4
78.75	6533	-1.4
79.25	6570	-1.3
79.75	6607	-1.2
80.25	6644	-1.4

80.75	6682	-1.8
81.25	6719	-1.6
81.75	6756	-1.3
82.25	6793	-1.6
82.75	6831	-1.7
83.25	6868	-1.7
83.75	6906	-1.3
84.25	6944	-1.5
84.75	6982	-1.4
85.25	7020	-1.5
85.75	7059	-1.6
86.25	7098	-1.8
86.75	7137	-1.4
87.25	7176	-1.5
87.75	7216	-1.8
88.25	7257	-1.9
88.75	7297	-1.5
89.25	7338	-1.5
89.75	7380	-1.1
90.25	7422	-1.4
90.75	7464	-1.5
91.25	7507	-1.5
91.75	7550	no data
92.25	7593	no data
92.75	7636	no data
93.25	7679	no data
93.75	7722	no data
94.25	7765	no data
94.75	7807	no data
95.25	7849	no data
95.75	7891	no data
96.25	7932	no data
96.75	7972	no data
97.25	8011	no data
97.75	8050	-1.0
98.25	8088	-1.2
98.75	8124	-1.3
99.25	8161	-1.3
99.75	8196	-1.3
100.25	8230	-1.4
100.75	8264	-1.4

101.25	8297	-1.4
101.75	8330	-1.4
102.25	8362	-1.4
102.75	8393	-1.3
103.25	8424	-1.3
103.75	8454	-1.1
104.25	8483	-1.1
104.75	8512	-1.1
105.25	8541	-1.5
105.75	8569	-1.6
106.25	8596	-1.7
106.75	8623	-1.5
107.25	8650	no data
107.75	8677	-1.5
108.25	8703	-1.3
108.75	8728	-1.4
109.25	8754	-1.2
109.75	8779	-1.5
110.25	8804	-1.4
110.75	8828	-1.7
111.25	8853	-1.7
111.75	8877	-1.5
112.25	8902	-1.5
112.75	8926	-1.7
113.25	8950	-1.4
113.75	8973	-1.9
114.25	8997	-1.5
114.75	9021	-1.4
115.25	9045	-1.5
115.75	9069	-1.7
116.25	9093	-1.5
116.75	9117	-1.7
117.25	9141	-1.7
117.75	9165	-1.5
118.25	9190	-1.3
118.75	9214	-1.4
119.25	9239	-1.6
119.75	9264	-1.3
120.25	9288	-1.9
120.75	9313	-1.5
121.25	9338	-1.7

121.75	9363	-1.9
122.25	9388	-1.7
122.75	9414	-2.0
123.25	9439	-1.7
123.75	9464	-1.8
124.25	9490	-1.9
124.75	9515	-1.5
125.25	9540	-1.7
125.75	9566	-1.9
126.25	9591	-1.5
126.75	9617	-1.6
127.25	9642	-1.4
127.75	9668	-1.8
128.25	9693	-1.3
128.75	9718	-1.9
129.25	9744	-1.5
129.75	9769	-1.5
130.25	9795	-1.5
130.75	9820	-1.6
131.25	9845	-1.7
131.75	9870	-1.8
132.25	9895	-1.7
132.75	9920	-1.9
133.25	9945	-1.8
133.75	9970	-1.7
134.25	9995	-1.5
134.75	10020	-1.5
135.25	10044	-1.6
135.75	10069	-1.9
136.25	10093	-1.7
136.75	10117	-1.7
137.25	10141	-2.0
137.75	10165	-1.7
138.25	10189	-1.7
138.75	10212	-1.5
139.25	10236	-1.9
139.75	10259	-1.8
140.25	10282	-1.8
140.75	10305	-1.7
141.25	10328	-1.6
141.75	10350	-1.6

142.25	10373	-1.7
142.75	10395	-1.4
143.25	10417	-1.5
143.75	10438	-1.5
144.25	10460	-1.5
144.75	10481	-1.4
145.25	10502	-1.8
145.75	10523	-1.3
146.25	10543	-1.4
146.75	10563	-1.4
147.25	10583	-1.4
147.75	10603	-1.3
148.25	10622	-1.4
148.75	10641	-1.5
149.25	10660	-1.7
149.75	10679	-1.5
150.25	10697	-1.2
150.75	10715	-1.3
151.25	10733	-1.4
151.75	10751	-1.3
152.25	10768	-1.2
152.75	10785	-1.4
153.25	10803	-1.1
153.75	10820	-1.3
154.25	10836	-1.4
154.75	10853	-1.1
155.25	10869	-1.2
155.75	10886	-1.3
156.25	10902	-1.2
156.75	10918	-1.7
157.25	10934	-1.4
157.75	10949	-1.6
158.25	10965	-1.5
158.75	10980	-1.4
159.25	10996	-1.5
159.75	11011	-1.7
160.25	11027	-1.2
160.75	11042	-1.2
161.25	11057	-1.6
161.75	11072	-1.6
162.25	11087	-1.6

162.75	11102	-1.6
163.25	11117	-1.9
163.75	11132	-1.5
164.25	11147	-1.3
164.75	11162	-1.6
165.25	11177	-1.4
165.75	11192	-1.7
166.25	11207	-1.6
166.75	11222	-1.7
167.25	11237	-1.4
167.75	11252	-1.7
168.25	11268	-1.5
168.75	11283	-1.3
169.25	11298	-1.8
169.75	11314	-1.4
170.25	11329	-1.2
170.75	11345	-1.7
171.25	11360	-1.9
171.75	11376	-1.5
172.25	11392	-1.7
172.75	11408	-1.5
173.25	11424	-1.6
173.75	11441	-1.6
174.25	11457	-1.5
174.75	11474	-1.8
175.25	11491	-1.4
175.75	11508	-1.7
176.25	11525	-1.6
176.75	11542	-1.7
177.25	11560	-1.7
177.75	11578	-1.6
178.25	11595	-1.7
178.75	11614	-1.4
179.25	11632	-1.6
179.75	11651	-1.7
180.25	11669	-1.4
180.75	11688	-1.4
181.25	11707	-1.5
181.75	11727	-1.9
182.25	11746	-1.5
182.75	11766	-1.4

183.25	11785	-1.7
183.75	11805	-1.7
184.25	11825	-1.9
184.75	11845	-1.7
185.25	11865	-1.7
185.75	11886	-1.6
186.25	11906	-1.6
186.75	11927	-1.7
187.25	11947	-1.6
187.75	11968	-1.6
188.25	11989	-1.4
188.75	12010	-1.6
189.25	12031	-1.8
189.75	12052	-1.8
190.25	12073	-1.7
190.75	12095	-1.7
191.25	12116	-1.6
191.75	12137	-1.6
192.25	12159	-1.7
192.75	12180	-1.2
193.25	12201	-1.1
193.75	12223	-1.5
194.25	12244	-0.8
194.75	12266	no data
195.25	12288	0.3
195.75	12309	-0.6
196.25	12331	-1.1
196.75	12352	-1.2
197.25	12374	-1.3
197.75	12395	-1.4
198.25	12417	-1.5
198.75	12438	-1.5
199.25	12460	-1.5
199.75	12481	-1.5
200.25	12502	-1.4
200.75	12524	-1.5
201.25	12545	-1.5
201.75	12566	-1.5
202.25	12587	-1.4
202.75	12608	-1.4
203.25	12629	-1.6

203.75	12650	-1.3
204.25	12671	-1.4
204.75	12692	-1.5
205.25	12712	-1.7
205.75	12733	-1.6
206.25	12754	-1.7
206.75	12774	-1.4
207.25	12795	-1.5
207.75	12815	-1.7
208.25	12836	-1.5
208.75	12856	-1.3
209.25	12876	-1.5
209.75	12897	-1.3
210.25	12917	-1.8
210.75	12938	-1.4
211.25	12958	-1.4
211.75	12979	-1.3
212.25	12999	-1.5
212.75	13020	-1.7
213.25	13040	-1.5
213.75	13061	-1.2
214.25	13081	-1.2
214.75	13102	-1.5
215.25	13123	-1.4
215.75	13143	-1.5
216.25	13164	-1.5
216.75	13185	-1.6
217.25	13206	-1.6
217.75	13227	-1.7
218.25	13248	-1.6
218.75	13269	-1.5
219.25	13291	-1.5
219.75	13312	-1.5
220.25	13333	-1.7
220.75	13355	-1.5
221.25	13377	-1.4
221.75	13399	-1.2
222.25	13421	-1.5
222.75	13443	-1.5
223.25	13465	-1.3
223.75	13487	-1.4

224.25	13510	-1.2
224.75	13533	-1.2
225.25	13555	-1.4
225.75	13578	-1.3
226.25	13602	-1.5
226.75	13625	-1.5
227.25	13649	-1.4
227.75	13672	-1.3
228.25	13696	-1.1
228.75	13720	-1.4
229.25	13745	-1.3
229.75	13769	-1.2
230.25	13794	-1.1
230.75	13819	-1.3
231.25	13844	-1.1
231.75	13870	-1.0
232.25	13895	-1.0
232.75	13921	-1.2
233.25	13947	-1.2
233.75	13974	-1.3
234.25	14000	-1.6
234.75	14027	-1.0
235.25	14054	-1.5
235.75	14082	-1.3
236.25	14110	-1.3
236.75	14138	-1.0
237.25	14166	-1.2
237.75	14194	-1.2
238.25	14223	-1.0
238.75	14253	-1.2
239.25	14282	-1.1
239.75	14312	0.0
240.25	14342	-0.8
240.75	14372	-1.0
241.25	14403	-1.2
241.75	14434	-1.1
242.25	14465	-0.8
242.75	14496	-1.1
243.25	14528	-1.0
243.75	14560	-0.9
244.25	14592	-1.0

244.75	14625	-1.3
245.25	14657	-1.4
245.75	14690	-1.7
246.25	14724	-1.3
246.75	14757	-1.3
247.25	14791	-1.7
247.75	14825	-1.5
248.25	14859	-1.8
248.75	14893	-1.8
249.25	14928	-1.7
249.75	14963	-1.6
250.25	14998	-1.4
250.75	15033	-1.6
251.25	15068	-1.7
251.75	15103	-1.8
252.25	15139	-1.3
252.75	15174	-1.5
253.25	15210	-1.5
253.75	15245	-1.3
254.25	15281	-1.4
254.75	15317	-1.3
255.25	15353	-1.5
255.75	15389	-1.8
256.25	15424	-1.6
256.75	15460	-1.7
257.25	15496	-1.9
257.75	15531	-1.8
258.25	15567	-1.5
258.75	15603	-1.5
259.25	15638	-1.7
259.75	15673	-1.7
260.25	15708	-1.7
260.75	15743	-1.5
261.25	15778	-1.9
261.75	15813	-1.5
262.25	15847	-1.7
262.75	15882	-2.0
263.25	15916	-1.7
263.75	15949	-1.8
264.25	15983	-1.7
264.75	16016	-1.5

265.25	16049	-1.8
265.75	16082	-1.7
266.25	16115	-1.9
266.75	16147	-1.9
267.25	16179	-1.5
267.75	16211	-1.3
268.25	16243	-1.6
268.75	16275	-1.3
269.25	16306	-1.1
269.75	16338	-1.1
270.25	16369	-1.1
270.75	16400	-1.2
271.25	16431	-1.0
271.75	16463	-0.9
272.25	16494	-0.8
272.75	16525	-0.5
273.25	16556	-0.8
273.75	16587	-0.7
274.25	16618	-0.9
274.75	16649	-0.8
275.25	16681	-0.8
275.75	16712	-0.3
276.25	16743	-0.1
276.75	16774	0.2
277.25	16805	0.3
277.75	16836	0.2
278.25	16867	0.3
278.75	16898	0.1
279.25	16930	0.1
279.75	16961	0.3
280.25	16992	0.0
280.75	17023	0.2
281.25	17054	-0.2
281.75	17085	-0.1
282.25	17116	0.2
282.75	17147	0.4
283.25	17179	0.3
283.75	17210	0.3
284.25	17241	0.3
284.75	17272	0.6
285.25	17303	0.5

285.75	17334	0.8
286.25	17365	0.9
286.75	17396	1.6
287.25	17428	1.5
287.75	17459	1.2
288.25	17490	1.0
288.75	17521	0.9
289.25	17552	0.9

APPENDIX C

POLLEN COUNTS FROM WOMBAT POOL

Depth (cm)	Age (cal yr BP)	*Eucalyptus*	*Nothofagus cunninghammii*	*Phyllocladus aspleniifolius*	*Lagarostrobos franklinii*
0.25	-67	92	154	18	0
1.75	47	74	113	21	0
3.75	201	45	148	12	0
5.50	339	78	134	19	0
6.75	441	129	103	23	0
7.00	462	117	84	9	0
7.25	483	68	136	14	0
9.75	705	67	134	6	0
12.25	943	78	144	17	0
13.75	1089	72	106	17	0
15.75	1287	60	122	16	0
19.75	1672	93	91	20	0
20.75	1765	62	133	11	0
24.25	2080	76	137	11	0
25.75	2213	113	116	21	0
28.75	2475	82	105	17	0
31.75	2738	116	83	19	0
34.75	3006	80	103	14	0
37.75	3283	130	83	23	0
39.25	3424	89	78	22	0
39.75	3471	69	86	29	0
40.25	3518	74	99	22	0
41.25	3612	48	145	39	1
42.25	3706	60	122	30	0
43.75	3844	65	132	36	0
46.75	4115	53	156	39	0
49.75	4368	54	111	48	0
52.75	4605	43	145	35	0
55.75	4829	39	163	35	0
57.75	4974	16	173	23	0
59.75	5118	37	189	56	0
61.75	5261	53	117	41	0
64.25	5441	49	164	40	0
67.75	5700	52	144	17	0
69.25	5813	52	141	25	0
71.75	6003	42	190	31	0
73.75	6155	60	160	44	0
76.25	6345	49	160	28	0

79.75	6607	55	165	20	0
82.75	6831	46	177	36	0
84.25	6944	37	167	48	0
86.75	7137	37	202	30	0
89.75	7380	43	164	25	0
95.00	7828	42	146	26	0
97.75	8050	47	179	28	0
99.75	8196	33	181	28	0
102.25	8362	33	140	24	0
105.75	8569	39	190	29	0
108.25	8703	25	185	45	0
111.75	8877	36	181	40	0
114.25	8973	40	147	28	0
118.25	9190	33	198	22	0
120.75	9313	43	135	20	0
123.75	9464	41	180	27	0
126.25	9591	52	164	8	0
129.75	9769	41	173	23	0
132.25	9895	52	163	18	0
138.25	10189	51	167	18	0
145.25	10502	48	183	2	0
150.25	10697	35	145	3	0
156.25	10902	52	125	6	0
162.25	11087	41	120	5	0
168.25	11268	48	191	7	0
174.25	11457	43	116	7	0
180.75	11688	39	111	30	0
186.25	11906	36	68	84	0
192.25	12159	32	85	87	0
197.75	12395	33	108	57	0
203.75	12650	27	83	57	0
209.75	12897	49	95	76	0
215.75	13143	31	79	53	0
221.75	13399	56	67	82	0
225.25	13555	65	81	90	0
227.75	13672	55	39	76	0
231.25	13844	57	58	81	0
233.75	13974	41	42	101	0
236.75	14138	36	54	106	0
239.75	14312	27	57	98	0
243.25	14528	30	35	113	0

245.75	14690	49	19	64	0
248.75	14893	24	32	71	0
251.75	15103	46	19	52	0
256.75	15460	31	26	23	0
260.75	15743	38	28	44	0
264.25	15983	42	24	12	1
267.25	16179	54	14	3	0
270.00	16353	46	16	2	0
274.75	16649	62	1	0	0
281.25	17054	53	11	0	0

Anodopetalum-Eucryphia	*Dicksonia antarctica*	*Nothofagus gunnii*	*Athrotaxis-Diselma*	*Microcachrys tetragona*	*Orites-Bellendena*
23	2	3	49	0	0
24	15	3	45	1	0
7	17	3	28	0	0
10	8	3	32	0	0
1	19	1	14	0	0
10	3	2	24	0	0
7	2	2	40	1	0
4	23	7	26	0	0
5	8	1	16	0	0
2	1	0	18	0	0
6	10	3	13	0	0
2	0	5	17	0	0
14	12	1	23	0	0
5	9	1	7	0	0
1	0	1	11	0	0
15	10	0	15	0	0
2	3	1	17	0	0
13	7	1	10	0	0
3	3	0	6	0	0
12	8	2	23	0	0
14	11	1	25	0	0
16	8	0	12	0	0
4	9	5	28	0	1
6	12	1	24	0	0
1	0	1	9	0	0
16	12	1	21	0	0
1	0	6	14	0	0
9	6	7	18	0	0
6	0	5	36	0	0
5	10	3	19	0	0
10	5	2	56	0	0
0	0	6	38	0	0
7	8	3	23	0	0
0	0	9	17	0	0
7	5	2	48	1	0
5	10	4	14	0	0
1	0	8	35	2	0
7	15	7	25	0	0

0	1	8	11	0	0
3	10	7	25	0	0
3	7	14	28	0	0
0	0	9	43	0	0
1	0	5	27	1	0
0	9	4	31	1	0
0	0	12	17	0	0
2	24	5	15	0	0
4	0	6	27	0	0
0	15	4	30	0	0
3	0	10	28	0	0
1	11	3	28	2	0
5	0	9	28	0	0
3	7	6	16	0	0
7	1	2	32	0	0
1	8	3	11	0	0
8	0	7	26	0	0
3	7	12	31	0	0
8	3	5	28	0	0
7	13	4	12	0	0
2	10	7	24	0	0
7	7	5	37	1	0
0	5	4	51	2	1
1	2	4	31	0	0
2	0	0	47	2	0
1	0	1	55	0	0
1	0	3	51	0	0
0	0	6	14	0	0
0	0	5	6	2	0
0	0	7	11	0	0
0	0	8	30	0	0
0	0	11	16	2	0
0	0	16	21	1	2
3	0	3	15	2	2
1	1	7	5	5	1
2	0	4	10	0	0
1	1	1	12	2	2
0	0	5	14	0	0
2	0	3	7	6	0
0	0	10	7	4	0
1	0	2	5	5	1

0	0	2	17	2	1
3	0	2	9	7	4
0	0	1	11	7	5
0	0	7	2	12	1
1	0	6	20	26	4
1	0	4	7	13	2
2	0	4	19	8	10
0	0	2	9	4	2
0	0	0	5	1	2
0	0	4	17	1	1

Pherosphaera hookeriana	*Podocarpus lawrencei*	*Tasmannia lanceolata*	*Amperea xipholada*	*Banksia marginata*	*Bauera rubioides*
0	0	0	0	1	0
0	0	2	0	1	1
0	1	1	0	0	0
0	2	2	0	0	0
0	0	1	1	0	0
0	1	0	0	0	0
2	1	0	0	0	0
0	1	1	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	1	0	0	0
1	0	0	0	1	4
0	0	0	0	0	0
0	0	1	0	0	0
0	0	1	0	0	2
0	0	0	0	0	0
0	1	1	1	1	4
1	0	1	0	0	0
1	0	1	0	0	1
0	2	2	1	0	2
0	0	0	0	0	0
0	0	3	1	0	0
0	0	0	0	0	0
0	0	1	0	2	0
0	0	0	0	0	2
0	0	0	0	1	0
0	0	0	1	0	3
0	0	1	0	0	0
0	0	0	0	1	0
1	0	0	0	0	0
0	0	1	0	1	0
0	0	0	0	1	2
0	0	0	0	0	0
0	0	0	0	1	1
0	0	0	0	1	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	1	2
0	1	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	1
0	0	3	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	1	0	0	0	0
0	0	0	0	2	0
0	0	0	0	1	2
0	0	0	0	2	0
0	0	0	0	0	1
0	0	0	0	1	0
0	0	0	0	0	0
0	0	0	0	1	1
0	0	0	0	1	0
0	0	0	0	0	0
0	0	1	0	3	0
0	0	5	0	2	0
0	0	1	0	5	0
0	0	6	0	1	0
0	0	1	0	3	0
0	0	2	0	1	2
0	0	1	0	10	1
0	0	0	0	2	0
0	0	0	0	0	0
0	0	2	0	1	0
0	1	2	0	0	0
0	0	0	0	0	0
0	1	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	2	0	0	0	0
0	0	0	0	2	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	1	1	0	0	0

0	0	0	0	0	0
0	0	3	0	0	0
0	1	2	0	1	0
0	0	3	0	0	0
1	0	2	0	0	2
0	0	1	0	2	0
3	3	2	0	2	2
0	0	5	0	0	0
0	0	2	0	0	0
3	2	2	0	2	0

Pomaderris apetala	*Telopea truncata*	*Tetratheca pilosa*	*Allocasuarina*	*Boronia*	*Coprosma*
22	0	0	12	1	2
15	0	0	7	0	3
15	0	0	6	5	0
16	0	0	12	1	2
25	0	0	24	1	3
31	0	0	12	0	3
16	0	0	13	1	0
25	0	0	16	3	0
23	0	0	17	5	1
31	0	2	13	6	3
18	0	1	13	4	0
30	0	3	10	4	0
20	0	2	10	4	1
19	0	0	22	2	2
22	0	1	15	5	0
28	0	0	4	3	5
29	0	1	19	7	0
25	0	0	11	5	0
47	0	1	14	1	2
25	0	0	6	2	1
26	0	2	11	4	3
25	0	1	19	0	0
20	0	1	11	3	1
18	1	3	8	1	1
23	0	0	7	2	3
30	0	0	8	0	1
30	0	1	12	0	1
16	0	0	6	2	0
39	0	0	10	3	1
14	0	0	10	1	0
33	0	0	11	3	1
18	0	0	9	0	0
24	0	0	13	0	2
40	0	0	21	0	0
32	0	0	12	3	1
29	0	0	11	3	2
31	0	1	8	7	0
21	0	0	6	1	2

15	0	0	10	0	0
23	0	0	8	1	2
12	0	1	13	1	2
18	0	0	11	1	0
12	0	0	10	1	0
31	0	0	14	2	0
17	0	0	5	1	1
22	0	0	7	3	0
22	0	0	8	0	0
21	0	0	5	1	1
24	0	0	7	2	0
14	0	0	14	1	0
17	0	0	9	2	2
18	0	0	8	1	2
17	0	1	8	0	0
25	0	0	7	1	1
28	0	0	8	2	2
26	0	0	17	3	2
18	0	0	6	1	1
49	0	2	6	2	1
27	0	2	14	2	0
26	0	0	7	0	4
30	0	0	9	0	2
14	0	0	5	0	2
26	0	0	7	5	2
26	0	0	11	3	3
27	0	1	6	2	0
31	0	0	6	1	0
26	0	0	4	0	3
33	0	1	7	0	3
31	0	0	11	2	4
34	0	0	6	1	5
35	0	0	7	0	4
40	0	0	7	1	4
46	0	0	6	3	0
50	0	0	3	2	3
42	0	0	6	0	1
45	0	0	8	3	0
48	0	0	12	2	3
38	0	0	13	2	3
41	0	0	9	1	2

35	0	3	9	0	1
46	0	0	9	5	0
36	0	0	11	5	4
23	0	0	13	0	5
40	0	0	19	3	9
26	0	0	36	1	3
21	0	0	28	4	14
11	0	0	34	1	8
5	1	0	25	1	9
1	0	0	16	4	3

Dodonaea	*Leptospermum-Baeckea*	*Monotaca*	*Persoonia*	*Phebalium*	*Pimelea*
1	10	17	2	3	0
2	13	7	0	0	0
0	3	2	0	0	0
2	5	3	0	1	0
1	1	12	3	0	0
0	6	10	2	0	0
1	3	11	1	0	0
1	2	9	2	0	0
1	1	17	4	4	0
0	3	11	1	1	0
1	3	10	1	0	0
0	4	9	2	0	0
0	8	8	2	0	0
1	5	6	1	0	0
0	4	6	0	0	2
1	17	4	0	1	0
0	3	11	2	2	0
1	14	6	0	0	0
1	3	10	2	1	0
1	20	8	0	1	0
0	14	15	0	0	0
0	9	19	1	1	0
2	4	6	0	0	0
1	8	14	0	0	0
1	4	10	0	0	0
3	13	8	0	0	0
0	9	19	1	3	0
2	3	9	1	2	0
0	9	11	1	0	0
0	6	9	0	2	0
2	2	5	1	0	0
0	8	3	1	1	0
2	5	8	0	1	0
0	5	15	0	0	0
1	7	11	0	0	0
1	13	6	1	1	0
0	12	8	1	0	0
0	7	8	0	0	0

0	4	3	0	0	0
3	9	13	1	0	0
3	5	10	0	0	0
1	9	11	4	0	0
1	4	7	1	1	0
0	13	11	0	0	0
1	4	10	0	0	0
2	10	15	1	0	0
1	5	6	0	0	0
1	5	3	0	0	0
2	12	2	0	0	0
1	10	4	0	0	0
1	6	8	1	1	0
4	10	7	0	2	0
1	8	6	0	0	0
1	6	5	0	1	0
3	12	8	0	0	0
3	7	4	1	1	0
1	8	5	2	2	1
2	14	9	1	0	0
2	11	8	0	0	0
4	6	13	0	0	0
3	12	6	2	0	0
1	21	0	0	0	0
0	11	4	2	1	0
0	8	6	3	0	0
1	9	4	4	0	0
1	6	6	0	0	0
1	5	7	0	0	0
1	2	4	1	0	0
0	4	3	1	2	0
0	3	2	1	1	0
2	1	0	1	0	0
2	2	0	0	1	1
1	5	2	0	0	0
0	2	2	0	0	0
0	1	2	0	0	0
0	2	1	0	0	0
0	1	3	0	0	0
0	1	1	3	0	2
0	2	4	0	0	0

0	8	4	0	0	0
1	7	5	0	0	0
0	4	3	0	0	0
0	0	1	0	0	1
0	13	3	0	0	0
0	2	4	0	0	0
3	4	2	0	2	0
0	7	3	0	1	0
0	3	1	1	4	0
0	1	5	0	1	1

Epacridaceae	*Astelia alpina*	*Acacia*	*Plantago*	*Dichosciadium-Xanthosia* Type	*Euphrasia*
13	1	0	2	0	0
6	3	0	1	0	0
10	0	0	1	1	0
5	0	0	1	0	0
13	0	0	0	0	0
11	0	0	0	0	0
6	0	0	0	0	0
10	0	0	0	0	0
5	1	0	2	0	0
13	0	0	0	0	0
9	0	0	4	0	0
5	0	0	0	0	0
9	1	0	5	0	0
10	0	0	3	0	0
8	0	0	0	0	0
10	0	0	1	0	0
6	0	0	0	0	0
5	0	0	1	0	0
9	1	0	1	0	0
9	0	0	5	0	0
5	0	0	2	0	0
10	0	0	6	0	0
7	0	0	2	0	0
11	0	0	3	0	0
2	0	0	0	0	0
5	0	0	2	1	0
8	0	0	0	0	0
10	0	0	1	0	0
4	0	0	0	0	0
7	0	0	2	0	0
6	0	1	0	0	0
7	0	0	0	0	0
2	0	0	2	1	0
7	0	0	0	0	0
10	1	0	3	0	0
7	0	0	5	0	0
14	0	0	5	0	0
6	0	0	1	0	0

12	0	0	0	0	0
5	0	0	3	0	0
9	0	0	1	0	0
4	0	0	1	0	0
2	0	0	0	0	0
12	0	0	2	0	0
9	0	0	4	0	0
9	0	0	1	0	0
5	2	0	1	0	0
10	1	0	2	0	0
7	2	0	2	0	0
5	1	0	2	0	0
9	1	0	5	0	0
9	0	0	0	0	0
6	4	0	10	0	0
9	1	0	2	0	0
4	0	0	2	0	0
7	3	0	6	0	0
2	0	1	4	0	0
3	1	0	2	0	0
9	3	0	2	1	0
13	2	0	1	0	0
13	0	0	3	0	0
11	4	0	6	1	0
14	0	0	4	0	0
8	2	0	4	0	0
10	2	0	2	0	0
13	3	0	2	0	0
14	0	0	0	3	0
18	3	0	3	0	0
26	0	0	0	0	0
11	7	0	1	0	0
11	0	0	3	1	0
11	4	0	2	1	0
13	1	0	6	1	0
10	6	0	3	0	0
22	7	1	5	0	0
18	10	0	6	0	0
11	3	0	2	0	0
24	4	0	4	0	0
17	6	0	3	0	0

12	9	0	3	0	0
14	10	0	7	0	0
23	7	0	8	0	0
12	3	0	8	0	0
26	6	0	11	1	0
14	5	0	17	1	0
9	3	0	13	0	0
10	3	0	15	0	0
4	1	0	17	0	0
5	1	0	15	0	0

Epilobium	Apiaceae	Asteraceae (Tubuliflorae Type)	Asteraceae (Liguliflorae Type)	Caryophyllaceae
0	1	17	0	1
0	0	9	0	2
0	0	10	0	2
0	0	11	0	1
0	0	17	0	0
0	1	6	0	0
0	1	20	0	0
0	0	11	0	0
0	0	8	0	0
0	0	11	0	0
0	0	16	0	1
0	1	19	0	0
0	1	11	0	0
0	0	9	0	0
0	0	21	0	0
0	4	12	0	0
0	0	15	0	0
0	1	10	0	0
0	0	11	0	0
0	1	24	0	1
0	1	12	0	0
0	0	14	0	1
0	0	13	0	1
0	3	10	0	0
0	0	12	0	0
0	2	12	0	0
0	0	14	0	0
0	0	10	0	0
0	2	7	0	0
0	0	10	0	0
0	0	12	0	0
0	0	7	0	0
0	0	13	0	0
0	0	10	0	0
0	0	3	0	0
0	0	4	0	1
0	1	7	0	0
0	3	6	0	0

0	0	4	0	0
0	0	6	0	0
0	0	8	0	0
0	0	2	0	0
0	0	1	0	0
0	0	4	0	0
0	0	6	0	0
0	0	5	0	0
0	0	5	0	0
0	0	9	0	1
0	1	6	0	0
0	0	4	0	0
0	0	7	0	0
0	1	7	0	0
0	0	8	0	0
0	1	4	0	0
0	1	5	0	0
0	2	14	0	0
1	1	8	0	1
0	4	9	0	0
0	1	15	0	0
0	1	12	0	0
0	0	15	0	0
0	2	9	0	0
0	2	9	0	0
0	1	9	0	0
0	0	14	0	0
0	1	17	0	1
0	0	16	0	0
0	0	23	0	0
0	4	24	0	0
0	3	26	0	0
0	1	19	0	0
0	0	36	0	0
0	0	29	0	0
0	3	44	0	0
0	1	33	0	0
0	0	24	0	0
0	1	27	0	0
0	2	35	0	0
0	3	26	0	0

0	0	29	0	1
0	2	27	0	0
0	1	27	0	0
0	1	50	0	0
0	3	60	0	0
0	0	53	0	0
0	3	51	0	0
0	1	60	0	0
0	2	66	0	0
0	0	95	0	0

Chenopodiaceae	Fabaceae	Geraniaceae	Goodeniaceae	Liliaceae	Poaceae
5	1	0	1	0	30
7	0	1	0	0	14
8	1	0	1	0	13
8	0	0	0	0	10
10	0	0	0	2	27
10	0	0	1	1	28
18	0	0	0	0	14
7	0	0	0	0	7
13	0	0	0	0	27
12	0	0	0	0	28
5	0	0	0	3	25
12	0	0	0	0	19
7	1	0	0	0	21
6	1	0	0	0	27
9	0	0	0	0	15
10	0	0	0	0	17
11	0	0	0	0	11
7	0	0	0	0	34
14	0	0	0	0	30
7	0	0	0	0	31
10	2	0	0	0	8
15	1	0	0	0	23
9	0	0	0	0	4
5	0	0	0	0	17
14	0	0	0	0	20
10	1	0	0	0	22
9	0	0	0	0	21
11	0	0	0	3	23
12	0	0	0	0	14
3	0	0	0	2	29
7	0	0	0	0	9
4	0	0	0	1	9
6	0	0	0	0	30
6	0	0	0	0	11
6	0	0	0	0	9
8	0	0	0	0	29
8	2	0	0	1	32
8	0	0	1	0	20

8	1	0	0	0	11
8	0	0	0	0	15
5	0	0	0	0	10
8	0	0	0	0	18
5	0	0	0	1	12
5	1	0	0	0	13
5	0	0	0	0	8
3	0	0	0	2	13
2	0	0	0	1	25
12	0	0	0	0	12
9	0	0	0	2	24
4	0	0	0	0	19
9	0	0	0	1	22
8	0	0	0	0	13
3	3	0	0	3	18
4	0	0	0	0	15
7	0	0	0	0	28
6	0	0	0	1	10
4	0	0	0	0	18
12	2	0	0	0	23
5	0	0	0	1	15
11	0	0	0	2	27
10	0	0	0	0	20
4	0	0	0	1	40
11	0	0	0	1	46
12	0	0	0	0	46
6	0	0	0	1	56
4	1	0	0	0	51
10	0	0	0	0	63
8	0	0	0	1	24
10	0	0	0	0	24
12	0	0	0	0	16
10	0	0	0	4	19
10	0	0	0	2	13
17	0	0	0	0	53
13	1	0	0	2	23
10	2	0	0	0	26
8	0	0	0	1	27
10	1	0	0	0	37
7	0	0	0	1	34
14	0	0	0	1	44

19	0	0	0	1	41
20	1	0	0	0	55
16	1	0	0	4	51
15	1	0	0	3	80
26	2	0	0	0	67
21	4	0	0	1	118
12	0	0	0	2	95
20	0	0	0	1	110
24	2	0	0	0	132
28	0	0	0	0	135

Unknown Pollen	Indeterminate	Damaged/ Degraded/ Crumpled	*Spyridium*	Rutaceae (undiff.)	*Melaluca*
1	15	3	0	0	0
2	10	2	0	0	0
3	14	2	0	0	0
1	13	1	0	0	0
4	7	1	0	0	0
1	7	3	0	0	0
0	20	3	0	0	4
0	3	0	0	0	0
0	11	0	1	0	0
7	0	0	0	0	0
1	11	0	0	0	0
11	0	0	0	0	0
2	8	1	1	0	1
0	4	0	1	0	0
5	15	0	0	0	0
1	2	1	0	0	1
7	13	1	0	0	0
2	18	6	1	0	0
1	5	0	0	0	2
1	2	0	9	0	2
0	6	1	2	0	6
0	1	0	0	0	4
1	1	1	0	0	3
2	6	0	0	0	1
2	11	0	0	0	0
2	13	6	1	0	1
5	29	0	0	0	0
3	8	7	0	0	1
4	29	8	0	0	1
0	5	0	0	0	0
0	6	1	0	0	1
5	28	0	0	0	0
1	14	3	0	0	0
6	18	0	0	0	0
1	4	3	0	0	1
1	12	1	0	0	2
0	14	4	0	0	0
2	11	9	0	0	0

1	33	0	0	0	0
3	19	7	0	0	2
0	4	4	1	0	1
3	19	3	0	0	0
2	36	8	2	2	1
0	1	1	0	0	2
1	22	2	0	1	0
0	21	7	0	0	2
1	11	12	0	0	1
0	11	3	0	0	1
0	3	14	0	1	1
0	16	4	0	0	0
0	7	1	0	0	5
1	2	1	0	0	0
2	9	3	3	0	0
1	24	4	0	0	0
2	18	6	1	0	2
3	5	7	0	0	0
4	0	10	3	0	2
6	3	3	0	2	2
2	8	0	0	1	0
0	5	3	0	1	2
3	19	7	6	0	0
1	15	6	7	0	2
1	10	11	2	0	5
0	17	6	5	0	3
1	4	4	4	0	0
2	12	4	0	0	0
1	4	5	1	1	1
1	30	6	1	0	0
1	43	16	0	0	0
3	26	1	0	1	0
2	34	3	1	0	0
1	23	7	0	1	0
3	43	7	0	0	1
3	11	17	0	1	0
2	3	0	0	0	0
2	2	3	0	1	0
1	14	3	0	0	0
2	47	0	0	1	0
1	12	1	5	0	0

22	5	1	1	0	0
1	5	6	1	0	0
2	4	5	0	2	0
4	5	15	0	3	0
1	11	5	0	0	1
1	9	7	0	1	0
0	4	1	0	0	0
0	9	19	0	4	0
8	10	61	0	1	0
1	21	18	0	0	1

Rubiaceae	Scrophulariacae	Droseraceae	*Pinus*	*Gymnoschoenus sphaerocephalus*
0	0	0	2	9
0	0	0	0	5
0	0	0	0	1
0	0	0	0	6
0	0	0	0	4
0	0	0	0	5
0	0	0	0	1
0	0	0	0	0
0	0	0	0	1
0	0	0	0	2
0	0	0	0	1
0	0	0	0	0
0	0	0	0	3
0	0	0	0	1
0	0	0	0	0
0	0	0	0	5
0	0	1	0	2
0	0	0	0	3
0	0	0	0	2
0	0	0	0	12
0	0	0	0	4
0	0	0	0	9
0	0	0	0	8
0	0	0	0	7
0	0	0	0	0
0	0	0	0	11
0	0	0	0	0
0	0	0	0	1
0	0	0	0	0
0	0	0	0	3
0	0	0	0	5
0	0	0	0	0
0	0	0	0	2
0	0	0	0	0
0	0	0	0	9
0	0	0	0	1
0	0	0	0	5
0	0	0	0	4

0	0	0	0	0
0	0	0	0	4
0	0	0	0	2
0	0	0	0	4
0	0	0	0	7
0	0	0	0	7
0	0	0	0	8
0	0	0	0	4
0	0	0	0	4
0	0	0	0	0
0	0	0	0	6
0	0	0	0	3
0	0	0	0	12
0	0	0	0	2
0	0	0	0	15
0	0	0	0	0
0	0	0	0	15
0	0	0	0	11
0	0	0	0	27
0	0	0	0	33
0	0	0	0	26
0	0	0	0	38
0	0	0	0	14
0	0	0	0	7
0	0	0	0	7
0	0	0	0	11
0	0	0	0	13
0	0	0	0	11
0	0	0	0	11
0	0	0	0	1
0	0	0	0	0
0	0	0	0	2
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	5
0	0	0	0	5
0	0	0	0	0
0	0	0	0	2
0	0	0	0	3

0	0	0	0	7
0	0	0	0	14
0	0	0	0	5
0	1	0	0	5
0	1	0	0	5
0	0	0	0	15
0	0	0	0	18
1	1	0	0	14
0	0	0	0	15
0	0	0	0	15

Myriophyllum	Isoetes	Cyperaceae	Haloragaceae	Restionaceae
0	2	3	1	21
0	0	1	0	16
0	2	4	1	19
0	3	1	1	14
0	5	0	2	26
0	1	5	0	10
1	0	0	0	23
0	2	0	0	27
0	1	0	0	17
1	4	15	1	9
0	5	0	2	17
0	4	10	0	18
0	5	0	0	27
0	1	0	0	17
0	0	5	0	7
0	11	0	0	9
1	6	5	0	11
0	0	0	0	16
2	3	1	0	11
0	5	5	0	17
0	1	2	0	25
0	6	2	0	34
0	2	5	0	28
0	2	3	0	23
1	2	6	0	13
0	2	0	0	24
2	3	11	2	8
0	2	1	1	16
0	0	1	0	11
0	5	0	0	21
0	0	5	0	37
0	0	5	0	10
1	2	0	0	34
0	0	3	0	16
0	2	1	0	46
0	0	1	0	35
0	7	2	0	32
0	2	0	0	21

1	2	0	0	31
0	1	0	0	36
0	5	0	0	61
0	6	4	1	40
0	7	2	0	40
0	4	0	0	52
0	3	0	1	32
0	2	0	0	37
0	6	3	0	24
0	1	0	2	53
0	9	5	1	35
0	3	1	0	32
0	6	4	0	29
0	5	0	0	62
0	5	4	0	40
0	0	0	1	50
0	4	7	0	49
0	6	0	0	47
0	25	6	0	42
0	21	3	0	65
0	15	3	0	50
0	25	4	0	60
2	70	1	0	60
0	46	11	1	42
0	61	1	3	28
0	91	3	0	38
0	79	4	0	31
0	167	6	0	16
0	240	1	1	31
0	329	4	1	32
1	194	5	0	17
0	191	6	0	9
0	208	3	1	8
0	304	7	1	12
0	22	0	0	6
0	368	8	0	17
0	362	1	0	5
0	550	19	3	11
0	514	0	0	10
0	893	14	0	21
1	1515	0	0	12

1	2175	5	0	24
2	3254	2	0	5
0	3849	19	3	11
0	5858	5	1	16
0	2753	5	2	17
1	1919	36	1	12
4	29	8	0	12
0	19	10	0	8
0	2	21	1	9
1	4	9	0	16

Terrestrial Sum	Lycopodium tracer mean = 13911
505	60
404	11
360	20
381	21
443	68
383	36
405	24
365	17
410	19
359	15
357	20
363	12
380	15
366	10
394	22
366	14
388	10
377	2
407	9
397	26
365	12
385	24
370	22
385	32
357	8
440	7
400	12
382	1
440	13
350	7
458	15
359	13
421	8
380	12
390	10
433	5
466	12
403	3

362	12
432	9
397	5
435	19
375	14
372	12
383	37
411	6
342	18
406	6
418	22
403	4
374	29
381	3
354	26
384	5
404	23
420	8
382	34
430	24
409	31
387	33
412	33
363	31
475	37
401	43
405	39
372	33
382	19
389	21
414	11
409	12
362	25
399	24
493	16
387	14
381	8
364	25
393	9
428	24
386	4

358	37
377	25
359	37
349	58
397	26
433	68
480	40
405	117
451	95
448	253

APPENDIX D

CHARCOAL COUNTS FROM WOMBAT POOL

Depth (cm)	Age (cal yr BP)	Sample Volume (cm^3)	Charcoal Counts
0.25	-67	2	55
0.75	-29	2	87
1.25	9	0.5	38
1.75	47	0.5	30
2.25	85	1	37
2.75	124	1	28
3.25	162	1	25
3.75	201	1.5	43
4.25	240	1.5	48
4.75	279	2	44
5.25	319	2	56
5.75	359	2	46
6.25	400	2	32
6.75	441	2	45
7.25	483	2	34
7.75	526	2	53
8.25	570	2	71
8.75	614	2	83
9.25	659	2	78
9.75	705	2	89
10.25	752	2	101
10.75	799	2	95
11.25	846	2	58
11.75	894	2	74
12.25	943	2	84
12.75	991	2	121
13.25	1040	2	97
13.75	1089	1.5	49
14.25	1139	2	98
14.75	1188	2	61
15.25	1237	2	35
15.75	1287	2	70
16.25	1336	2	37
16.75	1385	2	36
17.25	1434	2	37
17.75	1482	2	43
18.25	1530	2	34
18.75	1578	2	48

19.25	1625	2	32
19.75	1672	1	34
20.25	1719	2	55
20.75	1765	2	69
21.25	1811	2	62
21.75	1856	2	68
22.25	1902	2	56
22.75	1947	2	46
23.25	1991	2	53
23.75	2036	2	67
24.25	2080	2	65
24.75	2125	2	68
25.25	2169	2	51
25.75	2213	1	17
26.25	2257	2	51
26.75	2300	2	56
27.25	2344	2	82
27.75	2388	2	102
28.25	2431	2	56
28.75	2475	2	61
29.25	2519	2	93
29.75	2562	2	98
30.25	2606	2	123
30.75	2650	2	76
31.25	2694	2	40
31.75	2738	1	24
32.25	2782	2	35
32.75	2827	2	48
33.25	2871	2	86
33.75	2916	2	108
34.25	2961	2	95
34.75	3006	2	197
35.25	3052	2	203
35.75	3098	2	233
36.25	3144	2	234
36.75	3190	2	200
37.25	3237	2	244
37.75	3283	1.5	204
38.25	3330	2	383
38.75	3377	2	407
39.25	3424	2	579

39.75	3471	2	753
40.25	3518	2	940
40.75	3565	2	1018
41.25	3612	2	401
41.75	3659	2	295
42.25	3706	2	309
42.75	3752	2	196
43.25	3798	2	149
43.75	3844	2	197
44.25	3890	2	189
44.75	3936	2	164
45.25	3981	2	139
45.75	4026	2	153
46.25	4070	2	211
46.75	4115	2	241
47.25	4158	2	185
47.75	4201	2	244
48.25	4244	2	226
48.75	4286	2	270
49.25	4327	2	204
49.75	4368	2	185
50.25	4409	2	159
50.75	4449	2	102
51.25	4489	2	149
51.75	4528	2	99
52.25	4567	2	146
52.75	4605	2	140
53.25	4643	2	110
53.75	4681	2	118
54.25	4719	2	129
54.75	4756	2	147
55.25	4793	2	95
55.75	4829	1.5	158
56.25	4866	2	177
56.75	4902	2	111
57.25	4938	2	122
57.75	4974	2	124
58.25	5010	2	127
58.75	5046	2	105
59.25	5082	2	150
59.75	5118	2	148

60.25	5153	2	119
60.75	5189	2	125
61.25	5225	2	106
61.75	5261	1.5	48
62.25	5296	2	105
62.75	5332	2	124
63.25	5368	2	110
63.75	5405	2	102
64.25	5441	2	108
64.75	5478	2	122
65.25	5514	2	159
65.75	5551	2	132
66.25	5588	2	148
66.75	5625	2	177
67.25	5663	2	150
67.75	5700	2	250
68.25	5738	2	195
68.75	5775	2	180
69.25	5813	2	181
69.75	5851	2	182
70.25	5889	2	246
70.75	5927	2	199
71.25	5965	2	129
71.75	6003	2	194
72.25	6041	2	160
72.75	6079	2	196
73.25	6117	2	203
73.75	6155	2	214
74.25	6193	2	217
74.75	6231	2	163
75.25	6269	2	254
75.75	6307	2	188
76.25	6345	2	192
76.75	6382	2	190
77.25	6420	2	117
77.75	6458	2	202
78.25	6495	2	144
78.75	6533	2	163
79.25	6570	2	152
79.75	6607	2	255
80.25	6644	2	245

80.75	6682	2	198
81.25	6719	2	224
81.75	6756	2	241
82.25	6793	2	175
82.75	6831	2	291
83.25	6868	2	249
83.75	6906	2	279
84.25	6944	2	222
84.75	6982	2	266
85.25	7020	2	246
85.75	7059	2	188
86.25	7098	2	260
86.75	7137	2	237
87.25	7176	2	208
87.75	7216	2	198
88.25	7257	2	181
88.75	7297	2	193
89.25	7338	2	147
89.75	7380	2	126
90.25	7422	2	206
90.75	7464	2	185
91.25	7507	2	162
91.75	7550	no data	no data
92.25	7593	no data	no data
92.75	7636	no data	no data
93.25	7679	no data	no data
93.75	7722	no data	no data
94.25	7765	no data	no data
94.75	7807	1	161
95.25	7849	1	122
95.75	7891	1.5	206
96.25	7932	2	238
96.75	7972	2	200
97.25	8011	1	75
97.75	8050	2	148
98.25	8088	2	186
98.75	8124	2	190
99.25	8161	2	180
99.75	8196	2	207
100.25	8230	2	200
100.75	8264	2	219

101.25	8297	2	205
101.75	8330	2	173
102.25	8362	2	214
102.75	8393	2	228
103.25	8424	2	241
103.75	8454	2	277
104.25	8483	2	302
104.75	8512	2	334
105.25	8541	2	256
105.75	8569	2	224
106.25	8596	2	199
106.75	8623	2	295
107.25	8650	2	308
107.75	8677	2	259
108.25	8703	2	247
108.75	8728	2	217
109.25	8754	2	261
109.75	8779	2	230
110.25	8804	2	162
110.75	8828	2	196
111.25	8853	2	178
111.75	8877	2	163
112.25	8902	2	145
112.75	8926	2	195
113.25	8950	2	192
113.75	8973	2	158
114.25	8997	2	161
114.75	9021	2	207
115.25	9045	2	220
115.75	9069	2	203
116.25	9093	2	199
116.75	9117	2	254
117.25	9141	2	228
117.75	9165	2	211
118.25	9190	2	212
118.75	9214	2	266
119.25	9239	2	211
119.75	9264	2	238
120.25	9288	2	339
120.75	9313	2	321
121.25	9338	2	325

121.75	9363	2	245
122.25	9388	2	373
122.75	9414	2	357
123.25	9439	2	330
123.75	9464	2	353
124.25	9490	2	328
124.75	9515	2	314
125.25	9540	2	326
125.75	9566	2	325
126.25	9591	2	301
126.75	9617	2	426
127.25	9642	2	392
127.75	9668	2	520
128.25	9693	2	435
128.75	9718	2	483
129.25	9744	2	315
129.75	9769	2	280
130.25	9795	2	378
130.75	9820	2	380
131.25	9845	2	273
131.75	9870	2	245
132.25	9895	2	210
132.75	9920	2	354
133.25	9945	2	277
133.75	9970	2	415
134.25	9995	2	340
134.75	10020	2	382
135.25	10044	2	317
135.75	10069	2	380
136.25	10093	2	389
136.75	10117	2	336
137.25	10141	2	333
137.75	10165	2	337
138.25	10189	2	349
138.75	10212	2	331
139.25	10236	2	379
139.75	10259	2	312
140.25	10282	2	353
140.75	10305	2	320
141.25	10328	2	409
141.75	10350	2	417

142.25	10373	2	274
142.75	10395	2	278
143.25	10417	2	328
143.75	10438	2	318
144.25	10460	2	246
144.75	10481	2	209
145.25	10502	2	206
145.75	10523	2	271
146.25	10543	2	215
146.75	10563	2	244
147.25	10583	2	178
147.75	10603	2	250
148.25	10622	2	214
148.75	10641	2	318
149.25	10660	2	256
149.75	10679	2	244
150.25	10697	2	237
150.75	10715	2	249
151.25	10733	2	198
151.75	10751	2	219
152.25	10768	2	300
152.75	10785	2	265
153.25	10803	2	226
153.75	10820	2	194
154.25	10836	2	243
154.75	10853	2	240
155.25	10869	2	191
155.75	10886	2	190
156.25	10902	2	174
156.75	10918	2	142
157.25	10934	2	183
157.75	10949	2	160
158.25	10965	2	211
158.75	10980	2	163
159.25	10996	2	188
159.75	11011	2	143
160.25	11027	2	144
160.75	11042	2	96
161.25	11057	2	97
161.75	11072	2	109
162.25	11087	2	158

162.75	11102	2	131
163.25	11117	2	170
163.75	11132	2	151
164.25	11147	2	119
164.75	11162	2	140
165.25	11177	2	152
165.75	11192	2	194
166.25	11207	2	183
166.75	11222	2	172
167.25	11237	2	184
167.75	11252	2	189
168.25	11268	2	217
168.75	11283	2	162
169.25	11298	2	187
169.75	11314	2	173
170.25	11329	2	142
170.75	11345	2	184
171.25	11360	2	191
171.75	11376	2	159
172.25	11392	2	220
172.75	11408	2	223
173.25	11424	2	178
173.75	11441	2	156
174.25	11457	2	182
174.75	11474	2	189
175.25	11491	2	199
175.75	11508	2	142
176.25	11525	2	154
176.75	11542	2	129
177.25	11560	2	190
177.75	11578	2	128
178.25	11595	2	145
178.75	11614	2	169
179.25	11632	2	111
179.75	11651	2	109
180.25	11669	2	117
180.75	11688	2	112
181.25	11707	2	135
181.75	11727	2	89
182.25	11746	2	98
182.75	11766	2	105

183.25	11785	2	177
183.75	11805	2	136
184.25	11825	2	163
184.75	11845	2	176
185.25	11865	2	166
185.75	11886	2	175
186.25	11906	2	219
186.75	11927	2	179
187.25	11947	2	119
187.75	11968	2	124
188.25	11989	2	101
188.75	12010	2	104
189.25	12031	2	66
189.75	12052	2	80
190.25	12073	2	70
190.75	12095	2	75
191.25	12116	2	84
191.75	12137	2	87
192.25	12159	2	65
192.75	12180	2	86
193.25	12201	2	84
193.75	12223	2	110
194.25	12244	0.5	38
194.75	12266	no data	no data
195.25	12288	2	112
195.75	12309	2	81
196.25	12331	2	50
196.75	12352	2	81
197.25	12374	2	97
197.75	12395	2	87
198.25	12417	2	94
198.75	12438	2	76
199.25	12460	2	47
199.75	12481	2	43
200.25	12502	2	47
200.75	12524	2	44
201.25	12545	2	86
201.75	12566	2	53
202.25	12587	2	56
202.75	12608	2	82
203.25	12629	2	68

203.75	12650	2	24
204.25	12671	2	32
204.75	12692	2	19
205.25	12712	2	38
205.75	12733	2	26
206.25	12754	2	23
206.75	12774	2	20
207.25	12795	2	26
207.75	12815	2	13
208.25	12836	2	15
208.75	12856	2	9
209.25	12876	2	25
209.75	12897	2	22
210.25	12917	2	27
210.75	12938	2	28
211.25	12958	2	13
211.75	12979	2	38
212.25	12999	2	25
212.75	13020	2	12
213.25	13040	2	27
213.75	13061	2	33
214.25	13081	2	15
214.75	13102	2	25
215.25	13123	2	22
215.75	13143	2	26
216.25	13164	2	20
216.75	13185	2	11
217.25	13206	2	6
217.75	13227	2	12
218.25	13248	2	10
218.75	13269	2	15
219.25	13291	2	14
219.75	13312	2	8
220.25	13333	2	6
220.75	13355	2	3
221.25	13377	2	11
221.75	13399	2	29
222.25	13421	2	20
222.75	13443	2	27
223.25	13465	2	11
223.75	13487	2	29

224.25	13510	2	23
224.75	13533	2	40
225.25	13555	2	17
225.75	13578	2	7
226.25	13602	2	4
226.75	13625	2	3
227.25	13649	2	7
227.75	13672	2	19
228.25	13696	2	21
228.75	13720	2	53
229.25	13745	2	25
229.75	13769	2	26
230.25	13794	2	20
230.75	13819	2	15
231.25	13844	2	20
231.75	13870	2	12
232.25	13895	2	41
232.75	13921	2	65
233.25	13947	2	15
233.75	13974	2	47
234.25	14000	2	67
234.75	14027	2	49
235.25	14054	2	39
235.75	14082	2	46
236.25	14110	2	46
236.75	14138	2	50
237.25	14166	2	33
237.75	14194	2	11
238.25	14223	2	28
238.75	14253	2	53
239.25	14282	2	67
239.75	14312	2	69
240.25	14342	2	61
240.75	14372	2	41
241.25	14403	2	25
241.75	14434	2	11
242.25	14465	2	15
242.75	14496	2	11
243.25	14528	2	13
243.75	14560	2	24
244.25	14592	2	22

244.75	14625	2	51
245.25	14657	2	58
245.75	14690	2	40
246.25	14724	2	8
246.75	14757	2	9
247.25	14791	2	13
247.75	14825	2	8
248.25	14859	2	7
248.75	14893	2	8
249.25	14928	2	8
249.75	14963	2	18
250.25	14998	2	11
250.75	15033	2	10
251.25	15068	2	15
251.75	15103	2	25
252.25	15139	2	5
252.75	15174	2	6
253.25	15210	2	4
253.75	15245	2	8
254.25	15281	2	3
254.75	15317	2	3
255.25	15353	2	2
255.75	15389	2	6
256.25	15424	2	3
256.75	15460	2	8
257.25	15496	2	6
257.75	15531	2	4
258.25	15567	2	10
258.75	15603	2	23
259.25	15638	1.5	26
259.75	15673	2	9
260.25	15708	2	3
260.75	15743	2	1
261.25	15778	2	0
261.75	15813	2	2
262.25	15847	2	1
262.75	15882	2	2
263.25	15916	2	3
263.75	15949	2	5
264.25	15983	1.5	9
264.75	16016	2	21

265.25	16049	2	8
265.75	16082	2	2
266.25	16115	2	4
266.75	16147	2	1
267.25	16179	2	5
267.75	16211	2	3
268.25	16243	2	7
268.75	16275	2	5
269.25	16306	1.5	3
269.75	16338	2	4
270.25	16369	2	4
270.75	16400	2	8
271.25	16431	2	21
271.75	16463	2	38
272.25	16494	1	6
272.75	16525	2	3
273.25	16556	2	3
273.75	16587	2	3
274.25	16618	1.5	0
274.75	16649	2	3
275.25	16681	2	8
275.75	16712	2	4
276.25	16743	2	5
276.75	16774	2	12
277.25	16805	2	6
277.75	16836	2	4
278.25	16867	2	4
278.75	16898	2	9
279.25	16930	2	3
279.75	16961	2	7
280.25	16992	2	7
280.75	17023	1.75	10
281.25	17054	2	3
281.75	17085	2	2
282.25	17116	2	6
282.75	17147	2	2
283.25	17179	2	3
283.75	17210	1.75	0
284.25	17241	2	1
284.75	17272	2	3
285.25	17303	2	1

285.75	17334	2	1
286.25	17365	2	1
286.75	17396	1.75	1
287.25	17428	1	0
287.75	17459	1.5	0
288.25	17490	2	1
288.75	17521	2	2
289.25	17552	1	1

APPENDIX E

LAKE HANSON CHRONOLOGY

Depth (cm)	Median Age (cal yr BP)	Minimum Age (95% CI) (cal yr BP)	Maximum Age (95% CI) (cal yr BP)
0.25	-26	-39	-7
0.75	41	25	59
1.25	109	89	128
1.75	176	152	197
2.25	243	215	267
2.75	310	278	339
3.25	378	342	409
3.75	445	403	480
4.25	512	466	553
4.75	579	529	625
5.25	647	592	697
5.75	714	654	769
6.25	781	717	841
6.75	848	779	914
7.25	915	842	986
7.75	982	904	1059
8.25	1049	967	1132
8.75	1117	1031	1204
9.25	1184	1094	1277
9.75	1251	1156	1349
10.25	1318	1219	1421
10.75	1385	1281	1494
11.25	1452	1343	1566
11.75	1519	1405	1638
12.25	1586	1466	1710
12.75	1653	1528	1783
13.25	1720	1591	1855
13.75	1787	1654	1928
14.25	1854	1716	2000
14.75	1921	1781	2072
15.25	1989	1844	2145
15.75	2056	1907	2217
16.25	2124	1967	2289
16.75	2191	2030	2362
17.25	2259	2089	2434
17.75	2327	2151	2507
18.25	2395	2213	2579

18.75	2464	2274	2651
19.25	2532	2336	2724
19.75	2601	2398	2796
20.25	2669	2463	2868
20.75	2738	2526	2940
21.25	2808	2592	3012
21.75	2877	2658	3083
22.25	2947	2724	3154
22.75	3017	2788	3226
23.25	3087	2853	3297
23.75	3157	2918	3368
24.25	3228	2983	3438
24.75	3298	3050	3509
25.25	3369	3117	3579
25.75	3440	3181	3650
26.25	3511	3247	3720
26.75	3582	3314	3790
27.25	3653	3381	3860
27.75	3724	3448	3930
28.25	3795	3513	4000
28.75	3866	3578	4069
29.25	3937	3643	4138
29.75	4008	3708	4207
30.25	4078	3773	4276
30.75	4149	3838	4343
31.25	4219	3903	4411
31.75	4290	3968	4478
32.25	4360	4035	4545
32.75	4429	4104	4612
33.25	4499	4170	4679
33.75	4568	4239	4744
34.25	4637	4308	4809
34.75	4705	4375	4875
35.25	4774	4441	4939
35.75	4841	4507	5002
36.25	4909	4575	5066
36.75	4976	4642	5129
37.25	5042	4709	5192
37.75	5108	4776	5254
38.25	5174	4843	5315
38.75	5239	4910	5376

39.25	5304	4976	5436
39.75	5368	5040	5498
40.25	5431	5104	5559
40.75	5494	5169	5619
41.25	5556	5234	5677
41.75	5618	5299	5736
42.25	5679	5364	5795
42.75	5739	5429	5852
43.25	5799	5492	5910
43.75	5859	5556	5967
44.25	5918	5620	6024
44.75	5976	5683	6082
45.25	6034	5745	6140
45.75	6092	5806	6195
46.25	6149	5868	6251
46.75	6205	5929	6307
47.25	6261	5991	6364
47.75	6317	6053	6419
48.25	6373	6113	6475
48.75	6428	6173	6529
49.25	6482	6233	6584
49.75	6536	6292	6639
50.25	6590	6350	6693
50.75	6644	6410	6747
51.25	6697	6469	6800
51.75	6750	6529	6854
52.25	6802	6588	6906
52.75	6855	6647	6959
53.25	6907	6707	7011
53.75	6958	6766	7063
54.25	7010	6825	7115
54.75	7061	6881	7167
55.25	7112	6938	7219
55.75	7163	6996	7270
56.25	7214	7053	7322
56.75	7264	7109	7373
57.25	7314	7164	7424
57.75	7364	7217	7475
58.25	7414	7272	7524
58.75	7464	7326	7574
59.25	7513	7379	7627

59.75	7562	7432	7677
60.25	7612	7483	7727
60.75	7660	7535	7776
61.25	7709	7587	7826
61.75	7758	7638	7876
62.25	7806	7689	7925
62.75	7855	7739	7974
63.25	7903	7791	8023
63.75	7951	7841	8072
64.25	7998	7891	8121
64.75	8046	7939	8170
65.25	8093	7988	8219
65.75	8141	8038	8267
66.25	8188	8087	8315
66.75	8235	8135	8363
67.25	8282	8181	8411
67.75	8329	8228	8458
68.25	8375	8274	8510
68.75	8422	8319	8555
69.25	8468	8366	8603
69.75	8515	8411	8652
70.25	8561	8457	8700
70.75	8607	8502	8746
71.25	8653	8547	8792
71.75	8699	8591	8839
72.25	8744	8634	8885
72.75	8790	8678	8931
73.25	8836	8721	8977
73.75	8881	8765	9025
74.25	8927	8809	9072
74.75	8972	8851	9120
75.25	9017	8892	9166
75.75	9062	8935	9213
76.25	9107	8976	9259
76.75	9152	9017	9305
77.25	9197	9059	9350
77.75	9241	9101	9396
78.25	9286	9143	9441
78.75	9330	9186	9486
79.25	9375	9228	9530
79.75	9419	9267	9574

80.25	9463	9306	9618
80.75	9507	9346	9663
81.25	9550	9386	9707
81.75	9594	9425	9751
82.25	9637	9464	9795
82.75	9680	9503	9838
83.25	9723	9542	9882
83.75	9766	9580	9926
84.25	9809	9620	9970
84.75	9852	9659	10014
85.25	9894	9698	10056
85.75	9936	9737	10098
86.25	9978	9776	10140
86.75	10020	9815	10181
87.25	10061	9854	10222
87.75	10102	9893	10262
88.25	10144	9931	10303
88.75	10184	9967	10343
89.25	10225	10005	10382
89.75	10265	10044	10422
90.25	10306	10081	10461
90.75	10346	10118	10499
91.25	10385	10155	10538
91.75	10425	10191	10576
92.25	10464	10228	10614
92.75	10503	10264	10651
93.25	10542	10300	10689
93.75	10580	10336	10727
94.25	10618	10372	10764
94.75	10656	10408	10801
95.25	10694	10443	10838
95.75	10731	10479	10875
96.25	10768	10514	10912
96.75	10805	10549	10950
97.25	10841	10584	10986
97.75	10877	10620	11021
98.25	10913	10656	11056
98.75	10949	10692	11091
99.25	10984	10728	11127
99.75	11019	10763	11162
100.25	11054	10797	11197

100.75	11088	10830	11231
101.25	11122	10864	11265
101.75	11156	10897	11299
102.25	11189	10931	11332
102.75	11222	10964	11366
103.25	11255	10997	11399
103.75	11288	11030	11431
104.25	11320	11063	11463
104.75	11352	11098	11494
105.25	11384	11133	11526
105.75	11416	11168	11557
106.25	11447	11202	11587
106.75	11478	11235	11618
107.25	11509	11268	11648
107.75	11540	11303	11679
108.25	11570	11337	11709
108.75	11600	11369	11739
109.25	11630	11403	11767
109.75	11660	11436	11796
110.25	11690	11468	11825
110.75	11719	11500	11854
111.25	11748	11531	11882
111.75	11778	11563	11910
112.25	11807	11594	11939
112.75	11835	11627	11967
113.25	11864	11660	11996
113.75	11892	11691	12024
114.25	11921	11722	12052
114.75	11949	11753	12080
115.25	11977	11784	12108
115.75	12005	11816	12135
116.25	12032	11846	12162
116.75	12060	11876	12191
117.25	12088	11906	12219
117.75	12115	11936	12246
118.25	12142	11966	12273
118.75	12169	11996	12300
119.25	12197	12026	12327
119.75	12224	12056	12354
120.25	12251	12085	12381
120.75	12277	12115	12408

121.25	12304	12144	12434
121.75	12331	12175	12462
122.25	12358	12205	12489
122.75	12384	12234	12516
123.25	12411	12263	12543
123.75	12437	12291	12576
124.25	12464	12321	12604
124.75	12490	12349	12630
125.25	12517	12378	12656
125.75	12543	12406	12682
126.25	12570	12436	12708
126.75	12596	12464	12735
127.25	12622	12492	12763
127.75	12649	12521	12793
128.25	12675	12547	12823
128.75	12702	12574	12854
129.25	12728	12599	12883
129.75	12754	12622	12911
130.25	12781	12646	12938
130.75	12807	12669	12969
131.25	12834	12691	12997
131.75	12860	12713	13028
132.25	12886	12735	13061
132.75	12913	12757	13091
133.25	12939	12779	13122
133.75	12965	12801	13151
134.25	12992	12823	13179
134.75	13018	12844	13207

APPENDIX F

LITHOLOGIC DATA FROM LAKE HANSON

Depth (cm)	Age (cal yr BP)	Magnetic Susceptibility (SI units)
0.25	-26	no data
0.75	41	no data
1.25	109	no data
1.75	176	no data
2.25	243	no data
2.75	310	no data
3.25	378	no data
3.75	445	no data
4.25	512	no data
4.75	579	no data
5.25	647	no data
5.75	714	no data
6.25	781	no data
6.75	848	no data
7.25	915	no data
7.75	982	no data
8.25	1049	no data
8.75	1117	no data
9.25	1184	no data
9.75	1251	no data
10.25	1318	no data
10.75	1385	no data
11.25	1452	no data
11.75	1519	no data
12.25	1586	no data
12.75	1653	no data
13.25	1720	no data
13.75	1787	no data
14.25	1854	-1.3
14.75	1921	-1.5
15.25	1989	-1.8
15.75	2056	-2.0
16.25	2124	-2.1
16.75	2191	-1.1
17.25	2259	-1.3
17.75	2327	-1.3
18.25	2395	-1.4
18.75	2464	-1.3

19.25	2532	-1.4
19.75	2601	-1.6
20.25	2669	-1.7
20.75	2738	-1.8
21.25	2808	-1.8
21.75	2877	-1.2
22.25	2947	-1.3
22.75	3017	-1.4
23.25	3087	-1.5
23.75	3157	-1.3
24.25	3228	-1.4
24.75	3298	-1.4
25.25	3369	-1.6
25.75	3440	-1.5
26.25	3511	-1.7
26.75	3582	-1.4
27.25	3653	-1.3
27.75	3724	-1.3
28.25	3795	-1.3
28.75	3866	-1.4
29.25	3937	-1.3
29.75	4008	-1.3
30.25	4078	-1.4
30.75	4149	-1.3
31.25	4219	-1.3
31.75	4290	-1.2
32.25	4360	-1.1
32.75	4429	1.4
33.25	4499	0.9
33.75	4568	0.5
34.25	4637	0.1
34.75	4705	0.2
35.25	4774	0.0
35.75	4841	-0.1
36.25	4909	0.1
36.75	4976	-1.1
37.25	5042	-1.1
37.75	5108	-1.5
38.25	5174	-1.8
38.75	5239	-1.4
39.25	5304	-1.9

39.75	5368	-1.6
40.25	5431	-1.9
40.75	5494	-1.7
41.25	5556	-1.8
41.75	5618	-1.5
42.25	5679	-1.3
42.75	5739	-1.4
43.25	5799	-1.5
43.75	5859	-1.4
44.25	5918	-1.2
44.75	5976	-1.3
45.25	6034	-1.5
45.75	6092	-1.3
46.25	6149	-1.4
46.75	6205	-1.3
47.25	6261	-1.6
47.75	6317	-1.5
48.25	6373	-1.8
48.75	6428	-1.8
49.25	6482	-1.1
49.75	6536	-1.5
50.25	6590	-1.7
50.75	6644	-1.5
51.25	6697	-1.6
51.75	6750	-1.4
52.25	6802	-1.6
52.75	6855	-1.4
53.25	6907	-1.5
53.75	6958	-1.4
54.25	7010	-1.5
54.75	7061	-1.6
55.25	7112	-1.5
55.75	7163	-1.7
56.25	7214	-1.8
56.75	7264	-1.5
57.25	7314	-1.7
57.75	7364	-1.6
58.25	7414	-1.6
58.75	7464	-1.5
59.25	7513	-1.8
59.75	7562	-1.5

60.25	7612	-1.0
60.75	7660	-1.9
61.25	7709	-2.0
61.75	7758	-1.5
62.25	7806	-1.5
62.75	7855	-1.5
63.25	7903	-1.4
63.75	7951	-1.6
64.25	7998	-1.5
64.75	8046	-1.3
65.25	8093	-1.1
65.75	8141	-1.4
66.25	8188	-1.3
66.75	8235	-1.8
67.25	8282	-1.4
67.75	8329	-1.5
68.25	8375	-1.7
68.75	8422	-1.6
69.25	8468	-1.4
69.75	8515	-1.4
70.25	8561	-1.7
70.75	8607	-1.7
71.25	8653	-1.8
71.75	8699	-1.6
72.25	8744	-1.5
72.75	8790	-1.7
73.25	8836	-1.7
73.75	8881	-1.4
74.25	8927	-1.5
74.75	8972	-1.5
75.25	9017	-1.2
75.75	9062	-1.6
76.25	9107	-1.7
76.75	9152	-1.7
77.25	9197	-1.7
77.75	9241	-1.6
78.25	9286	-1.6
78.75	9330	-1.6
79.25	9375	-1.4
79.75	9419	-1.2
80.25	9463	-1.4

80.75	9507	-1.5
81.25	9550	-1.4
81.75	9594	-1.5
82.25	9637	-1.4
82.75	9680	-1.8
83.25	9723	-1.4
83.75	9766	-1.7
84.25	9809	-1.8
84.75	9852	-1.5
85.25	9894	-1.5
85.75	9936	-1.8
86.25	9978	-1.8
86.75	10020	-1.6
87.25	10061	-1.4
87.75	10102	-1.5
88.25	10144	-1.6
88.75	10184	-1.7
89.25	10225	-1.3
89.75	10265	-1.5
90.25	10306	-1.2
90.75	10346	-1.3
91.25	10385	-1.2
91.75	10425	-1.6
92.25	10464	-1.3
92.75	10503	-1.1
93.25	10542	-1.5
93.75	10580	-1.4
94.25	10618	-1.6
94.75	10656	-1.5
95.25	10694	-1.5
95.75	10731	-1.5
96.25	10768	-1.6
96.75	10805	-1.6
97.25	10841	-1.5
97.75	10877	-1.4
98.25	10913	-1.6
98.75	10949	-1.5
99.25	10984	-1.3
99.75	11019	-1.1
100.25	11054	-1.3
100.75	11088	-1.2

101.25	11122	-1.0
101.75	11156	-1.4
102.25	11189	-1.2
102.75	11222	-1.0
103.25	11255	-1.2
103.75	11288	-1.1
104.25	11320	-1.1
104.75	11352	-1.3
105.25	11384	-1.3
105.75	11416	-1.2
106.25	11447	-1.4
106.75	11478	-1.4
107.25	11509	-1.3
107.75	11540	-1.7
108.25	11570	-1.5
108.75	11600	-1.4
109.25	11630	-1.6
109.75	11660	-1.2
110.25	11690	-1.3
110.75	11719	-1.0
111.25	11748	-1.3
111.75	11778	-1.4
112.25	11807	-1.4
112.75	11835	-1.2
113.25	11864	-1.3
113.75	11892	-1.1
114.25	11921	-1.1
114.75	11949	-1.5
115.25	11977	-1.6
115.75	12005	-1.4
116.25	12032	-1.9
116.75	12060	-1.5
117.25	12088	-1.6
117.75	12115	-1.7
118.25	12142	-1.9
118.75	12169	-1.5
119.25	12197	-1.5
119.75	12224	-1.2
120.25	12251	-1.3
120.75	12277	-1.0
121.25	12304	-1.2

121.75	12331	-1.2
122.25	12358	-1.2
122.75	12384	-1.4
123.25	12411	-1.2
123.75	12437	-1.3
124.25	12464	-1.3
124.75	12490	-1.3
125.25	12517	-1.2
125.75	12543	-1.1
126.25	12570	-1.1
126.75	12596	-1.1
127.25	12622	-1.3
127.75	12649	-1.1
128.25	12675	-1.2
128.75	12702	-1.3
129.25	12728	-1.2
129.75	12754	-0.8
130.25	12781	-0.7
130.75	12807	-0.8
131.25	12834	-0.4
131.75	12860	-0.6
132.25	12886	-0.7
132.75	12913	-0.1
133.25	12939	-0.2
133.75	12965	-0.4
134.25	12992	-0.4
134.75	13018	-0.6
135.25	13044	-0.5

APPENDIX G

POLLEN COUNTS FROM LAKE HANSON

Depth (cm)	Age (cal yr BP)	*Eucalyptus*	*Nothofagus cunninghammii*	*Phyllocladus aspleniifolius*	*Lagarostrobos franklinii*
0.0	-26	26	91	23	0
2.0	243	55	94	28	0
4.0	512	81	204	24	1
6.0	781	86	186	25	0
7.5	982	134	209	32	0
9.5	1251	52	166	20	0
18.0	2395	76	184	33	0
20.5	2738	92	141	32	0
23.0	3087	56	176	31	1
26.5	3582	69	115	23	0
29.5	4008	61	110	31	0
33.0	4499	48	169	48	0
35.0	4774	42	190	60	0
38.0	5174	57	154	37	0
41.0	5556	47	195	33	0
43.0	5799	30	154	27	0
47.0	6261	51	250	41	0
50.0	6590	50	180	44	0
53.0	6907	37	228	49	0
55.0	7112	47	156	36	0
59.5	7562	38	201	40	0
62.0	7806	55	167	42	0
65.0	8093	32	209	48	0
66.5	8235	37	187	61	0
69.0	8468	34	155	34	0
72.5	8790	38	190	34	0
76.0	9107	34	146	23	0
78.5	9330	39	146	30	0
81.0	9550	46	182	19	0
84.5	9852	52	146	16	0
90.5	10346	30	150	10	0
96.5	10805	35	157	9	0
102.5	11222	40	134	8	0
108.5	11600	28	95	42	0
114.5	11949	20	81	87	0
120.5	12277	43	79	95	0
126.5	12596	55	81	77	0
132.5	12913	40	47	113	0

Anodopetalum-Eucryphia	*Dicksonia antarctica*	*Nothofagus gunnii*	*Athrotaxis-Diselma*	*Microcachrys tetragona*	*Orites-Bellendena*
3	0	17	17	2	0
34	5	21	21	1	0
12	10	31	11	0	0
19	16	43	10	2	0
35	9	52	23	0	2
4	9	11	17	0	0
29	19	26	16	0	0
22	9	18	17	2	0
17	13	15	9	0	0
20	11	23	11	0	1
17	12	31	1	0	0
40	9	42	25	1	0
18	21	50	20	2	2
16	10	47	23	0	0
13	7	48	22	2	0
28	1	38	25	1	0
27	14	60	17	1	1
24	12	36	12	1	0
16	8	32	25	1	0
25	8	47	21	0	0
20	7	40	21	0	1
9	7	40	37	0	0
21	19	40	23	0	0
8	3	54	30	1	1
11	9	36	29	1	0
9	7	28	18	0	1
21	18	30	16	0	0
13	4	35	12	0	1
7	7	28	15	0	0
18	6	48	14	0	2
15	8	70	16	0	1
23	4	56	23	1	0
18	3	58	23	1	2
12	2	39	16	3	1
6	0	43	15	2	2
1	2	18	16	2	2
2	1	22	8	3	4
0	0	3	9	0	1

Pherosphaera hookeriana	*Podocarpus lawrencei*	*Tasmannia lanceolata*	*Amperea xipholada*	*Banksia marginata*	*Bauera rubioides*
0	0	5	0	0	0
0	2	1	0	0	0
0	0	1	0	0	0
0	0	0	0	1	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	2	0	0	0
0	0	1	0	0	0
0	1	1	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	2	0	0	0
0	0	4	0	1	0
0	0	1	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
1	0	0	0	1	0
0	0	0	0	0	0
0	0	0	0	1	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	1	0
0	0	1	0	0	0
0	0	1	0	0	1
0	0	0	0	0	0
0	0	1	0	0	0
0	0	1	0	1	0
0	0	0	0	2	0
0	0	2	0	3	0
0	0	1	0	0	0
0	0	0	0	1	0
0	0	0	0	1	0
0	0	1	0	0	0
0	0	0	0	3	0
0	0	0	0	2	0
0	1	1	0	1	0
0	1	1	0	1	0
0	4	5	0	1	0

Pomaderris apetala	*Telopea truncata*	*Tetratheca pilosa*	*Allocasuarina*	*Boronia*	*Coprosma*
14	0	0	7	1	1
13	0	1	6	4	1
35	0	0	4	1	0
24	0	0	8	5	0
37	0	0	10	1	0
22	0	0	5	3	0
42	0	0	7	2	2
27	0	0	9	3	0
22	0	0	16	2	5
32	0	0	4	1	2
20	0	0	6	3	1
24	0	0	10	1	1
29	1	0	8	1	0
25	0	0	2	2	3
20	0	0	6	1	3
15	0	0	4	0	0
34	0	1	4	3	0
29	0	0	10	2	0
27	0	0	3	0	1
18	0	0	8	1	0
36	0	0	12	5	2
29	0	0	4	0	1
29	0	0	7	1	0
28	0	0	12	2	3
24	0	0	12	2	0
30	0	0	13	1	2
21	0	0	7	1	0
13	0	0	10	2	0
29	0	0	12	1	0
34	0	0	10	0	1
39	0	0	1	1	0
29	1	0	6	1	0
42	0	0	6	1	1
29	1	0	11	0	1
32	0	0	3	0	1
28	0	0	2	1	0
29	0	0	6	1	0
26	0	0	7	0	0

Dodonaea	*Leptospermum-Baeckea*	*Monotaca*	*Persoonia*	*Phebalium*	*Pimelea*
1	5	4	1	2	0
0	15	2	3	3	0
2	2	2	2	5	0
0	4	6	0	3	0
2	6	4	0	2	0
0	3	3	0	1	0
3	10	4	0	3	0
1	3	3	0	0	0
2	3	9	0	1	1
0	3	6	0	0	0
3	6	9	0	2	0
2	5	5	0	0	0
2	3	3	1	0	0
1	7	1	0	2	0
3	5	3	0	1	0
0	4	5	0	1	0
4	7	3	0	0	0
4	8	3	0	0	0
3	5	1	0	0	0
2	6	5	0	0	0
1	1	3	0	2	0
3	3	4	1	0	0
1	3	2	0	2	0
6	6	4	1	0	0
4	1	3	0	1	0
7	6	3	1	0	0
0	5	5	0	0	0
0	1	4	1	0	0
4	5	4	0	0	0
6	11	3	0	0	0
1	5	1	0	0	0
2	19	2	0	0	0
2	9	3	1	0	1
1	8	4	0	0	0
0	1	2	2	0	0
1	9	3	0	0	0
0	9	1	0	0	0
0	5	4	0	1	0

Epacridaceae	*Astelia alpina*	*Acacia*	*Plantago*	*Dichosciadium-Xanthosia* Type	*Euphrasia*
26	0	0	4	0	0
7	1	0	1	2	0
20	2	0	0	0	0
16	1	0	0	0	0
23	3	0	0	0	0
14	2	0	0	0	0
20	4	0	0	0	0
10	6	0	0	0	0
22	0	0	4	0	0
9	2	0	3	0	0
19	1	0	0	1	0
8	1	0	0	0	0
12	1	0	1	0	0
5	1	0	1	0	0
7	1	0	0	0	0
10	2	0	0	0	0
12	4	0	2	0	0
14	0	0	3	0	0
19	1	0	0	0	0
6	2	0	1	0	0
5	0	0	0	0	0
8	0	0	3	0	0
14	0	0	2	0	0
10	2	0	6	0	0
8	0	0	0	0	0
15	0	0	1	0	0
6	2	0	0	0	0
7	0	0	2	0	0
8	2	0	3	0	0
11	0	0	2	0	0
6	0	1	2	0	0
11	2	0	0	0	0
16	0	0	2	0	0
14	0	0	1	0	0
8	1	0	2	0	0
6	1	0	2	0	0
14	0	0	5	0	0
20	2	0	5	0	0

Apiaceae	Asteraceae (Tubuliflorae Type)	Asteraceae (Liguliflorae Type)	Caryophyllaceae
0	6	0	0
0	7	0	0
0	30	0	1
0	19	0	0
0	23	0	1
0	8	0	0
1	17	0	1
2	17	0	0
0	16	1	0
3	9	0	0
0	14	0	0
0	8	0	0
0	7	0	1
0	8	0	0
0	6	0	0
0	10	0	0
0	6	0	0
0	11	0	1
0	8	0	0
0	7	0	0
1	11	0	0
0	6	1	0
0	6	0	0
0	7	0	0
0	1	0	1
1	9	0	0
0	8	0	0
0	13	0	0
0	18	0	0
0	15	0	0
0	9	0	0
1	5	0	2
0	10	0	0
1	15	0	0
0	9	0	1
0	15	0	0
1	19	0	0
1	36	0	0

Chenopodiaceae	Fabaceae	Geraniaceae	Goodeniaceae	Liliaceae	Poaceae
5	0	0	0	0	31
5	0	1	0	0	25
10	1	0	0	0	24
9	0	0	0	0	22
18	0	0	0	0	20
9	0	0	0	0	21
9	0	0	0	0	17
15	1	1	0	0	8
13	0	0	0	0	17
10	0	0	0	0	16
15	0	0	0	0	30
9	0	0	0	0	15
12	0	0	0	0	5
5	0	0	0	0	7
4	0	0	0	0	12
5	0	0	0	0	6
1	1	0	0	0	11
9	1	0	1	0	14
8	1	0	0	0	10
4	0	0	0	0	3
4	0	0	0	0	6
11	0	0	0	0	4
7	0	0	0	0	9
4	1	0	0	1	14
8	0	0	0	1	7
6	0	0	0	0	13
9	0	0	0	0	5
3	1	0	0	3	11
2	1	0	0	0	4
5	2	0	0	0	14
6	1	0	0	0	7
6	0	0	0	1	21
6	0	0	0	0	18
9	1	1	0	0	29
6	0	0	0	1	20
7	0	0	0	0	23
8	0	0	0	0	42
13	4	0	0	0	32

Unknown Pollen	Indeterminate	Damaged /Degraded/ Crumpled	*Spyridium*	Rutaceae (undiff.)
0	7	2	0	1
2	0	2	0	1
1	0	0	0	0
2	0	0	0	0
0	0	0	1	0
1	3	0	0	1
2	1	1	0	0
0	0	1	0	0
1	11	9	11	1
0	1	0	0	0
0	2	12	9	1
1	0	0	0	1
2	0	0	0	0
2	0	0	0	1
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	1
0	0	0	0	0
0	1	2	0	0
0	0	1	4	0
2	3	0	0	0
0	0	0	0	0
5	15	6	6	0
1	7	1	0	0
2	22	4	0	0
0	0	0	0	1
2	6	7	0	0
0	0	0	0	0
1	9	5	1	0
2	3	4	0	0
3	4	4	3	0
3	6	2	2	0
3	2	7	5	0
1	4	4	1	0
0	5	10	4	0
3	6	8	8	0
0	24	4	5	0

Melaluca	Rubiaceae	Scrophulariacae	Droseraceae	*Pinus*	*Gymnoschoenus sphaerocephalus*
1	0	0	0	14	1
0	0	0	0	0	6
0	0	0	0	0	1
0	0	0	0	0	3
0	0	0	0	0	9
1	0	0	0	0	1
0	0	0	0	0	7
0	0	0	0	0	4
5	0	0	0	0	8
0	0	0	0	0	3
0	0	0	0	0	6
2	0	0	0	0	3
0	0	0	0	0	6
0	0	0	0	0	5
0	0	0	0	0	9
0	0	0	0	0	6
1	0	0	0	0	6
1	0	0	0	0	7
1	0	0	0	0	2
0	0	0	0	0	5
3	0	0	0	0	7
0	0	0	0	0	1
0	0	0	0	0	3
1	0	0	0	0	16
0	0	0	0	0	3
0	0	0	0	0	13
1	0	0	0	0	5
0	0	0	0	0	12
1	0	0	0	0	10
3	0	0	0	0	10
1	0	0	0	0	13
3	0	0	0	0	11
3	0	0	0	0	11
0	0	0	0	0	8
0	0	0	0	0	4
0	0	0	0	0	2
2	0	0	0	0	4
0	0	0	0	0	10

Myriophyllum	Isoetes	Cyperaceae	Haloragaceae	Restionaceae
2	31	1	0	9
0	49	0	0	3
0	13	0	1	7
0	47	0	1	6
0	67	0	0	11
0	13	0	0	10
0	76	1	0	16
0	54	0	3	15
0	114	2	1	14
0	76	2	1	13
0	145	0	0	5
0	44	0	0	5
0	35	0	0	9
0	40	0	0	4
0	21	1	0	7
0	15	0	0	6
0	54	0	0	7
0	82	0	1	17
0	45	0	0	9
0	26	0	0	9
0	28	0	0	8
0	18	3	1	6
0	33	0	0	6
0	40	5	0	11
1	15	1	0	10
1	59	5	0	18
0	22	0	0	9
0	33	1	0	11
0	24	2	0	16
1	52	4	0	15
0	81	1	2	6
0	74	0	1	8
0	58	1	0	12
0	117	6	0	16
0	81	2	0	5
0	151	3	1	7
0	211	5	0	11
0	688	6	2	11

Terrestrial Sum	*Lycopodium* tracer mean = 13911
317	192
364	9
517	9
507	4
647	12
376	4
531	7
441	5
492	27
375	8
419	36
477	12
499	9
418	8
439	6
367	3
558	5
471	5
485	7
406	9
465	1
442	5
476	10
524	13
391	4
462	6
361	7
368	8
403	19
436	16
391	12
435	9
422	12
384	15
357	19
378	10
418	19
412	20

APPENDIX H

CHARCOAL COUNTS FROM LAKE HANSON

Depth (cm)	Age (cal yr BP)	Sample Volume (cm3)	Charcoal Counts
0.25	-26	2	2
0.75	41	2	8
1.25	109	2	5
1.75	176	2	10
2.25	243	2	7
2.75	310	2	8
3.25	378	2	15
3.75	445	2	11
4.25	512	2	10
4.75	579	2	1
5.25	647	2	4
5.75	714	2	5
6.25	781	2	2
6.75	848	2	7
7.25	915	2	6
7.75	982	2	2
8.25	1049	2	13
8.75	1117	2	8
9.25	1184	2	25
9.75	1251	2	19
10.25	1318	no data	no data
10.75	1385	no data	no data
11.25	1452	no data	no data
11.75	1519	2	3
12.25	1586	2	7
12.75	1653	2	2
13.25	1720	2	8
13.75	1787	2	12
14.25	1854	2	18
14.75	1921	2	10
15.25	1989	2	15
15.75	2056	2	16
16.25	2124	2	10
16.75	2191	2	8
17.25	2259	2	8
17.75	2327	2	7
18.25	2395	2	11
18.75	2464	2	3

19.25	2532	2	7
19.75	2601	2	14
20.25	2669	2	30
20.75	2738	2	25
21.25	2808	2	26
21.75	2877	2	37
22.25	2947	2	10
22.75	3017	2	8
23.25	3087	2	9
23.75	3157	2	11
24.25	3228	2	10
24.75	3298	2	38
25.25	3369	2	42
25.75	3440	2	18
26.25	3511	2	14
26.75	3582	2	13
27.25	3653	2	36
27.75	3724	2	64
28.25	3795	2	18
28.75	3866	2	6
29.25	3937	2	15
29.75	4008	2	12
30.25	4078	2	10
30.75	4149	2	10
31.25	4219	2	2
31.75	4290	2	4
32.25	4360	2	8
32.75	4429	2	14
33.25	4499	2	35
33.75	4568	2	38
34.25	4637	2	32
34.75	4705	2	18
35.25	4774	2	21
35.75	4841	2	18
36.25	4909	2	23
36.75	4976	2	18
37.25	5042	2	12
37.75	5108	2	4
38.25	5174	2	9
38.75	5239	2	11
39.25	5304	2	19

39.75	5368	2	16
40.25	5431	2	18
40.75	5494	2	28
41.25	5556	2	28
41.75	5618	2	29
42.25	5679	2	19
42.75	5739	2	16
43.25	5799	2	7
43.75	5859	2	20
44.25	5918	2	17
44.75	5976	2	25
45.25	6034	2	35
45.75	6092	2	19
46.25	6149	2	20
46.75	6205	2	14
47.25	6261	2	15
47.75	6317	2	18
48.25	6373	2	18
48.75	6428	2	22
49.25	6482	2	32
49.75	6536	2	21
50.25	6590	2	10
50.75	6644	2	10
51.25	6697	2	6
51.75	6750	2	9
52.25	6802	2	6
52.75	6855	2	6
53.25	6907	2	3
53.75	6958	2	10
54.25	7010	2	30
54.75	7061	2	28
55.25	7112	2	40
55.75	7163	2	20
56.25	7214	2	25
56.75	7264	2	38
57.25	7314	2	19
57.75	7364	2	16
58.25	7414	2	33
58.75	7464	2	21
59.25	7513	2	20
59.75	7562	2	44

60.25	7612	2	12
60.75	7660	2	18
61.25	7709	2	16
61.75	7758	2	20
62.25	7806	2	14
62.75	7855	2	16
63.25	7903	2	11
63.75	7951	2	10
64.25	7998	2	6
64.75	8046	2	24
65.25	8093	2	72
65.75	8141	2	63
66.25	8188	2	69
66.75	8235	2	51
67.25	8282	2	22
67.75	8329	2	29
68.25	8375	2	29
68.75	8422	2	38
69.25	8468	2	31
69.75	8515	2	19
70.25	8561	2	8
70.75	8607	2	10
71.25	8653	2	24
71.75	8699	1.5	27
72.25	8744	2	16
72.75	8790	1	6
73.25	8836	2	23
73.75	8881	2	20
74.25	8927	2	32
74.75	8972	2	23
75.25	9017	2	48
75.75	9062	2	32
76.25	9107	2	46
76.75	9152	2	33
77.25	9197	2	29
77.75	9241	2	63
78.25	9286	2	66
78.75	9330	2	111
79.25	9375	2	60
79.75	9419	2	39
80.25	9463	2	41

80.75	9507	2	39
81.25	9550	2	46
81.75	9594	2	55
82.25	9637	2	27
82.75	9680	2	47
83.25	9723	2	75
83.75	9766	2	92
84.25	9809	2	45
84.75	9852	2	31
85.25	9894	2	32
85.75	9936	2	44
86.25	9978	2	57
86.75	10020	2	53
87.25	10061	2	29
87.75	10102	2	19
88.25	10144	2	42
88.75	10184	2	48
89.25	10225	2	38
89.75	10265	2	67
90.25	10306	2	35
90.75	10346	1.5	25
91.25	10385	2	28
91.75	10425	2	61
92.25	10464	2	38
92.75	10503	2	66
93.25	10542	2	57
93.75	10580	2	55
94.25	10618	2	39
94.75	10656	2	54
95.25	10694	2	27
95.75	10731	2	34
96.25	10768	2	38
96.75	10805	2	58
97.25	10841	2	48
97.75	10877	2	42
98.25	10913	2	37
98.75	10949	2	57
99.25	10984	2	49
99.75	11019	2	45
100.25	11054	2	53
100.75	11088	2	47

101.25	11122	2	29
101.75	11156	2	33
102.25	11189	2	36
102.75	11222	1	10
103.25	11255	2	43
103.75	11288	1.5	58
104.25	11320	2	50
104.75	11352	2	38
105.25	11384	1.5	53
105.75	11416	2	82
106.25	11447	2	33
106.75	11478	2	28
107.25	11509	2	36
107.75	11540	2	60
108.25	11570	2	52
108.75	11600	2	75
109.25	11630	2	43
109.75	11660	2	41
110.25	11690	2	77
110.75	11719	2	56
111.25	11748	2	81
111.75	11778	2	58
112.25	11807	2	21
112.75	11835	2	29
113.25	11864	2	18
113.75	11892	2	30
114.25	11921	2	49
114.75	11949	1.5	22
115.25	11977	2	67
115.75	12005	2	84
116.25	12032	2	27
116.75	12060	2	46
117.25	12088	2	45
117.75	12115	2	30
118.25	12142	2	23
118.75	12169	2	23
119.25	12197	2	28
119.75	12224	2	10
120.25	12251	2	11
120.75	12277	1	12
121.25	12304	2	13

121.75	12331	2	12
122.25	12358	1.5	7
122.75	12384	2	16
123.25	12411	2	5
123.75	12437	2	2
124.25	12464	2	6
124.75	12490	1.5	2
125.25	12517	1.5	1
125.75	12543	1.5	0
126.25	12570	1.5	3
126.75	12596	1	3
127.25	12622	2	23
127.75	12649	1	9
128.25	12675	2	11
128.75	12702	2	14
129.25	12728	2	8
129.75	12754	2	6
130.25	12781	2	6
130.75	12807	2	9
131.25	12834	2	2
131.75	12860	2	1
132.25	12886	2	0
132.75	12913	1	0
133.25	12939	1.5	1
133.75	12965	1.5	2
134.25	12992	1	2

APPENDIX I

SUTTONS TARN CHRONOLOGY

Depth (cm)	Median Age (cal yr BP)	Minimum Age (95% CI) (cal yr BP)	Maximum Age (95% CI) (cal yr BP)
0.25	92	28	396
0.75	211	147	509
1.25	331	265	623
1.75	451	384	737
2.25	571	502	850
2.75	691	619	964
3.25	810	736	1078
3.75	930	853	1191
4.25	1049	970	1304
4.75	1168	1086	1418
5.25	1287	1202	1531
5.75	1405	1318	1644
6.25	1524	1434	1757
6.75	1642	1550	1870
7.25	1760	1665	1983
7.75	1878	1779	2095
8.25	1995	1893	2206
8.75	2112	2007	2314
9.25	2228	2121	2421
9.75	2345	2234	2528
10.25	2460	2347	2635
10.75	2576	2460	2745
11.25	2691	2572	2855
11.75	2805	2683	2966
12.25	2919	2793	3075
12.75	3033	2904	3185
13.25	3146	3014	3294
13.75	3259	3124	3405
14.25	3371	3233	3513
14.75	3483	3341	3626
15.25	3594	3449	3735
15.75	3705	3559	3842
16.25	3815	3666	3951
16.75	3925	3773	4058
17.25	4034	3880	4167
17.75	4143	3987	4276
18.25	4251	4093	4382

18.75	4358	4198	4489
19.25	4465	4302	4594
19.75	4572	4406	4701
20.25	4678	4510	4805
20.75	4783	4615	4909
21.25	4888	4716	5014
21.75	4992	4818	5117
22.25	5096	4919	5219
22.75	5199	5021	5321
23.25	5301	5123	5424
23.75	5403	5225	5527
24.25	5504	5325	5627
24.75	5604	5422	5730
25.25	5704	5518	5832
25.75	5803	5616	5931
26.25	5901	5713	6030
26.75	5999	5810	6129
27.25	6096	5906	6228
27.75	6193	6002	6326
28.25	6288	6097	6423
28.75	6383	6191	6520
29.25	6477	6284	6615
29.75	6571	6376	6711
30.25	6664	6468	6807
30.75	6756	6560	6902
31.25	6847	6652	6994
31.75	6938	6744	7086
32.25	7028	6835	7177
32.75	7117	6925	7268
33.25	7206	7015	7357
33.75	7293	7104	7447
34.25	7381	7192	7536
34.75	7467	7281	7622
35.25	7553	7368	7710
35.75	7638	7455	7798
36.25	7723	7542	7884
36.75	7807	7627	7970
37.25	7890	7712	8053
37.75	7973	7797	8137
38.25	8055	7882	8221
38.75	8137	7966	8303

39.25	8218	8048	8385
39.75	8298	8130	8466
40.25	8378	8212	8547
40.75	8457	8293	8628
41.25	8536	8374	8708
41.75	8614	8454	8787
42.25	8692	8534	8865
42.75	8769	8614	8943
43.25	8845	8693	9020
43.75	8921	8771	9096
44.25	8997	8850	9171
44.75	9072	8928	9247
45.25	9146	9005	9321
45.75	9221	9082	9395
46.25	9294	9158	9469
46.75	9367	9234	9543
47.25	9440	9309	9615
47.75	9512	9383	9687
48.25	9584	9459	9759
48.75	9656	9532	9831
49.25	9727	9602	9902
49.75	9797	9670	9972
50.25	9868	9738	10043
50.75	9937	9808	10114
51.25	10007	9874	10182
51.75	10076	9941	10250
52.25	10145	10010	10317
52.75	10213	10075	10384
53.25	10281	10138	10451
53.75	10348	10201	10517
54.25	10415	10268	10582
54.75	10482	10336	10647
55.25	10548	10398	10712
55.75	10614	10461	10776
56.25	10679	10523	10840
56.75	10744	10584	10903
57.25	10809	10645	10966
57.75	10873	10706	11029
58.25	10937	10768	11090
58.75	11000	10828	11152
59.25	11063	10886	11214

59.75	11126	10945	11274
60.25	11188	11003	11334
60.75	11250	11060	11396
61.25	11311	11118	11456
61.75	11372	11175	11517
62.25	11432	11233	11576
62.75	11492	11291	11633
63.25	11552	11349	11689
63.75	11611	11407	11745
64.25	11670	11464	11801
64.75	11728	11522	11856
65.25	11786	11578	11911
65.75	11843	11635	11965
66.25	11901	11691	12023
66.75	11957	11746	12075
67.25	12013	11800	12129
67.75	12069	11854	12183
68.25	12124	11908	12239
68.75	12179	11961	12294
69.25	12234	12014	12348
69.75	12288	12067	12403
70.25	12341	12119	12455
70.75	12394	12172	12511
71.25	12447	12225	12565
71.75	12500	12279	12622
72.25	12551	12333	12676
72.75	12603	12386	12731
73.25	12654	12437	12785
73.75	12705	12488	12838
74.25	12755	12539	12891
74.75	12806	12589	12944
75.25	12855	12639	12998
75.75	12905	12689	13051
76.25	12954	12738	13103
76.75	13003	12788	13153
77.25	13051	12839	13204
77.75	13100	12890	13256
78.25	13148	12940	13305
78.75	13196	12989	13356
79.25	13243	13037	13406
79.75	13291	13085	13455

80.25	13338	13133	13506
80.75	13385	13184	13556
81.25	13432	13234	13607
81.75	13479	13284	13656
82.25	13525	13333	13706
82.75	13572	13383	13755
83.25	13618	13432	13804
83.75	13664	13481	13851
84.25	13710	13530	13899
84.75	13756	13577	13946
85.25	13802	13624	13993
85.75	13848	13674	14040
86.25	13893	13723	14086
86.75	13939	13771	14133
87.25	13985	13817	14179
87.75	14030	13863	14226
88.25	14076	13911	14273
88.75	14121	13960	14320
89.25	14167	14004	14367
89.75	14213	14051	14414
90.25	14258	14100	14460
90.75	14304	14143	14509
91.25	14350	14188	14557
91.75	14396	14233	14602
92.25	14441	14279	14647
92.75	14487	14327	14693
93.25	14533	14375	14739
93.75	14579	14423	14785
94.25	14625	14473	14832
94.75	14671	14519	14879
95.25	14717	14567	14924
95.75	14763	14613	14971
96.25	14810	14658	15019
96.75	14856	14705	15063
97.25	14902	14751	15109
97.75	14948	14797	15155
98.25	14994	14844	15201
98.75	15041	14892	15247
99.25	15087	14936	15292
99.75	15133	14980	15338
100.25	15180	15026	15385

100.75	15226	15072	15431
101.25	15272	15115	15476
101.75	15319	15158	15521
102.25	15365	15202	15568
102.75	15411	15245	15614
103.25	15458	15288	15659
103.75	15504	15331	15704
104.25	15551	15374	15748
104.75	15597	15417	15792
105.25	15644	15460	15836
105.75	15690	15505	15881
106.25	15736	15548	15925
106.75	15783	15592	15969
107.25	15829	15637	16016
107.75	15876	15681	16063
108.25	15922	15723	16110
108.75	15969	15766	16158
109.25	16015	15809	16207
109.75	16062	15853	16254
110.25	16108	15896	16299
110.75	16155	15939	16345
111.25	16201	15982	16391
111.75	16248	16025	16437
112.25	16294	16069	16483
112.75	16341	16113	16528
113.25	16387	16156	16574
113.75	16433	16200	16621
114.25	16480	16244	16669
114.75	16526	16287	16716
115.25	16573	16331	16764
115.75	16619	16375	16811
116.25	16666	16419	16859
116.75	16712	16463	16907

APPENDIX J

LITHOLOGIC DATA FROM SUTTONS TARN

Depth (cm)	Age (cal yr BP)	Magnetic Susceptibility (SI units)
0.25	92	-0.7
0.75	211	-1.2
1.25	331	-0.8
1.75	451	-0.9
2.25	571	-0.6
2.75	691	-0.5
3.25	810	-0.3
3.75	930	-0.2
4.25	1049	-0.3
4.75	1168	-0.2
5.25	1287	0.0
5.75	1405	0.0
6.25	1524	0.1
6.75	1642	-0.3
7.25	1760	-0.2
7.75	1878	-0.2
8.25	1995	0.1
8.75	2112	-0.1
9.25	2228	-0.2
9.75	2345	-0.2
10.25	2460	-0.2
10.75	2576	-0.1
11.25	2691	-0.2
11.75	2805	-0.3
12.25	2919	-0.3
12.75	3033	-0.1
13.25	3146	-0.1
13.75	3259	-0.3
14.25	3371	-0.6
14.75	3483	-0.3
15.25	3594	-0.4
15.75	3705	-0.2
16.25	3815	-0.3
16.75	3925	-0.6
17.25	4034	-0.5
17.75	4143	-0.3
18.25	4251	-0.3
18.75	4358	-0.5

19.25	4465	-0.3
19.75	4572	-0.3
20.25	4678	0.2
20.75	4783	0.6
21.25	4888	0.8
21.75	4992	0.8
22.25	5096	0.8
22.75	5199	0.0
23.25	5301	-0.2
23.75	5403	0.0
24.25	5504	0.0
24.75	5604	0.1
25.25	5704	-0.3
25.75	5803	-0.3
26.25	5901	-0.1
26.75	5999	-0.2
27.25	6096	-0.1
27.75	6193	0.1
28.25	6288	-0.3
28.75	6383	-0.1
29.25	6477	0.0
29.75	6571	-0.3
30.25	6664	-0.5
30.75	6756	-0.5
31.25	6847	-0.2
31.75	6938	-0.6
32.25	7028	-0.4
32.75	7117	-0.4
33.25	7206	-0.2
33.75	7293	-0.6
34.25	7381	-0.6
34.75	7467	-0.7
35.25	7553	-0.4
35.75	7638	-0.5
36.25	7723	-0.6
36.75	7807	-0.3
37.25	7890	-0.3
37.75	7973	-0.3
38.25	8055	-0.3
38.75	8137	-0.5
39.25	8218	-0.7

39.75	8298	-0.6
40.25	8378	-0.3
40.75	8457	-0.5
41.25	8536	-0.3
41.75	8614	-0.5
42.25	8692	-0.4
42.75	8769	-0.4
43.25	8845	-0.7
43.75	8921	-0.3
44.25	8997	-0.4
44.75	9072	0.0
45.25	9146	-0.4
45.75	9221	-0.2
46.25	9294	-0.1
46.75	9367	-0.1
47.25	9440	-0.2
47.75	9512	-0.2
48.25	9584	0.0
48.75	9656	0.0
49.25	9727	0.1
49.75	9797	-0.2
50.25	9868	-0.1
50.75	9937	-0.2
51.25	10007	-0.3
51.75	10076	-0.3
52.25	10145	0.0
52.75	10213	-0.3
53.25	10281	-0.1
53.75	10348	-0.3
54.25	10415	-0.3
54.75	10482	-0.2
55.25	10548	-0.1
55.75	10614	-0.2
56.25	10679	-0.2
56.75	10744	-0.2
57.25	10809	-0.4
57.75	10873	-0.3
58.25	10937	-0.4
58.75	11000	-0.4
59.25	11063	-0.3
59.75	11126	-0.5

60.25	11188	-0.3
60.75	11250	-0.1
61.25	11311	-0.3
61.75	11372	-0.1
62.25	11432	0.2
62.75	11492	0.1
63.25	11552	-0.1
63.75	11611	-0.1
64.25	11670	0.0
64.75	11728	-0.1
65.25	11786	-0.2
65.75	11843	-0.3
66.25	11901	-0.3
66.75	11957	-0.4
67.25	12013	-0.1
67.75	12069	0.0
68.25	12124	-0.2
68.75	12179	-0.3
69.25	12234	-0.4
69.75	12288	-0.4
70.25	12341	-0.3
70.75	12394	-0.1
71.25	12447	-0.3
71.75	12500	-0.3
72.25	12551	-0.2
72.75	12603	-0.5
73.25	12654	-0.4
73.75	12705	-0.1
74.25	12755	-0.3
74.75	12806	-0.2
75.25	12855	-0.2
75.75	12905	-0.3
76.25	12954	0.0
76.75	13003	0.2
77.25	13051	0.4
77.75	13100	0.9
78.25	13148	0.9
78.75	13196	0.7
79.25	13243	1.0
79.75	13291	1.7
80.25	13338	0.9

80.75	13385	0.9
81.25	13432	1.3
81.75	13479	0.5
82.25	13525	0.4
82.75	13572	0.1
83.25	13618	0.3
83.75	13664	0.4
84.25	13710	0.6
84.75	13756	0.6
85.25	13802	0.6
85.75	13848	0.9
86.25	13893	1.3
86.75	13939	1.9
87.25	13985	2.5
87.75	14030	2.6
88.25	14076	1.9
88.75	14121	1.3
89.25	14167	0.9
89.75	14213	1.0
90.25	14258	1.0
90.75	14304	0.7
91.25	14350	0.9
91.75	14396	1.1
92.25	14441	1.3
92.75	14487	1.2
93.25	14533	1.6
93.75	14579	1.8
94.25	14625	1.8
94.75	14671	1.8
95.25	14717	1.5
95.75	14763	0.9
96.25	14810	1.0
96.75	14856	1.4
97.25	14902	0.6
97.75	14948	0.8
98.25	14994	0.8
98.75	15041	0.4
99.25	15087	0.6
99.75	15133	0.8
100.25	15180	0.5
100.75	15226	0.6

101.25	15272	0.5
101.75	15319	0.2
102.25	15365	0.4
102.75	15411	0.5
103.25	15458	0.3
103.75	15504	0.3
104.25	15551	0.3
104.75	15597	0.2
105.25	15644	0.2
105.75	15690	0.6
106.25	15736	0.1
106.75	15783	0.4
107.25	15829	0.6
107.75	15876	0.3
108.25	15922	0.7
108.75	15969	1.0
109.25	16015	1.0
109.75	16062	2.0
110.25	16108	2.1
110.75	16155	3.2
111.25	16201	4.6
111.75	16248	5.5
112.25	16294	5.4
112.75	16341	4.5
113.25	16387	4.9
113.75	16433	4.3
114.25	16480	4.6
114.75	16526	5.3
115.25	16573	2.5

APPENDIX K

POLLEN COUNTS FROM SUTTONS TARN

Depth (cm)	Age (cal yr BP)	*Eucalyptus*	*Nothofagus cunninghammii*	*Phyllocladus aspleniifolius*
0.25	92	50	135	37
1.25	331	70	106	20
2.25	571	39	94	18
4.25	1049	40	102	25
6.25	1524	31	124	19
8.25	1995	46	127	24
10.25	2460	49	110	17
12.25	2919	44	122	22
14.25	3371	44	119	27
16.25	3815	35	112	23
18.25	4251	32	113	28
20.25	4678	35	98	33
22.25	5096	30	154	26
24.25	5504	16	117	36
26.75	5999	15	109	20
29.00	6477	21	141	26
31.50	6938	12	110	45
34.00	7381	23	122	33
36.75	7807	17	105	28
39.25	8218	13	106	39
42.25	8692	8	121	36
44.75	9072	12	128	24
47.75	9512	20	106	21
50.75	9937	18	82	16
54.25	10415	25	106	7
57.75	10873	21	112	10
61.25	11311	25	105	26
65.25	11786	19	70	83
69.75	12288	25	82	87
74.25	12755	40	73	74
79.25	13243	51	68	123
84.25	13710	34	65	98
89.75	14213	37	55	104
95.25	14717	32	41	127
100.25	15180	36	24	47
110.25	16108	18	13	21

Lagarostrobos franklinii	*Anodopetalum-Eucryphia*	*Dicksonia antarctica*	*Nothofagus gunnii*	*Athrotaxis-Diselma*	*Microcachrys tetragona*
0	7	10	50	18	9
0	10	11	36	9	4
0	15	6	38	9	9
0	3	7	47	9	5
0	4	3	47	12	12
0	9	5	59	9	9
0	9	10	54	18	6
0	4	5	65	9	9
0	10	12	55	14	15
0	5	10	56	8	5
0	7	9	64	14	8
0	1	8	63	21	15
0	0	4	83	25	4
0	4	7	124	43	4
0	2	3	143	32	2
0	3	2	92	50	0
0	11	3	112	62	2
0	2	7	106	32	0
0	7	7	121	24	0
0	0	7	131	30	2
0	4	5	191	37	4
0	1	5	150	38	1
0	2	8	189	28	3
0	0	4	151	34	1
0	1	2	130	37	4
0	1	6	151	22	2
0	2	3	32	30	5
0	0	0	31	55	4
0	0	0	5	56	4
0	1	0	3	27	4
0	1	0	12	13	0
0	2	1	7	7	5
0	0	1	6	9	2
0	3	0	14	14	6
0	2	0	9	12	4
0	0	0	6	20	6

Orites-Bellendena	*Pherosphaera hookeriana*	*Podocarpus lawrencei*	*Tasmannia lanceolata*	*Amperea xipholada*	*Banksia marginata*
6	1	3	2	0	0
2	0	10	2	0	0
5	0	10	2	0	0
4	0	15	3	0	0
3	0	9	0	0	0
4	0	17	6	0	2
3	4	21	4	1	0
5	0	17	0	0	0
5	1	17	0	0	0
3	0	14	2	0	0
2	0	28	1	0	0
1	0	26	3	0	0
7	1	11	3	0	0
0	0	6	1	0	0
0	0	4	0	0	0
1	0	1	0	0	0
0	0	1	0	0	0
0	0	2	2	0	0
0	0	1	3	0	0
0	0	0	1	0	0
2	0	1	1	0	0
0	1	1	0	0	1
1	0	1	0	0	0
1	0	3	0	0	1
3	0	3	1	0	0
2	0	4	1	0	0
8	0	4	9	0	0
5	0	2	1	0	0
9	0	16	1	0	0
8	0	3	0	0	0
17	0	5	0	0	0
13	0	4	2	0	0
10	0	1	0	0	0
6	0	3	0	0	0
6	0	3	2	0	0
3	0	0	7	0	1

Bauera rubioides	*Pomaderris apetala*	*Telopea truncata*	*Tetratheca pilosa*	*Allocasuarina*	*Boronia*
0	12	0	0	5	4
0	8	1	0	9	2
0	18	0	2	3	3
0	22	0	0	6	1
0	18	1	1	11	0
0	13	0	0	12	1
1	17	0	0	2	4
0	12	0	0	4	1
0	18	0	0	1	0
0	24	0	0	7	2
0	12	0	0	4	0
0	21	0	0	6	2
0	19	1	0	0	0
0	23	0	0	3	0
0	18	0	0	11	2
0	7	0	0	5	1
0	15	0	0	7	4
0	14	0	0	4	1
0	7	0	0	5	0
0	8	0	0	8	1
0	11	0	0	4	0
0	10	0	0	5	1
0	11	0	0	3	0
0	12	0	0	1	0
0	16	0	0	4	1
0	16	0	0	7	0
0	27	0	0	6	2
0	18	0	0	2	0
0	18	0	0	3	0
0	30	1	0	3	2
0	41	0	0	8	0
0	33	0	0	6	2
0	32	1	0	7	4
1	41	0	0	5	0
0	27	0	0	10	3
0	14	0	0	27	0

Coprosma	*Dodonaea*	*Leptospermum-Baeckea*	*Monotaca*	*Persoonia*	*Phebalium*
0	1	7	9	0	2
3	0	7	4	0	0
1	1	16	5	1	1
1	1	5	3	0	0
2	0	5	6	0	0
0	1	5	3	0	1
2	1	8	3	0	1
1	2	5	5	0	0
1	0	8	8	0	0
1	1	5	7	0	1
2	1	2	3	0	0
3	2	9	5	0	0
0	2	4	4	0	0
1	1	0	4	0	0
1	0	1	0	0	0
1	1	0	2	0	0
1	0	1	0	0	0
2	1	3	2	0	0
1	1	0	1	0	0
1	2	1	0	0	0
0	0	0	1	0	0
1	1	1	1	0	0
0	1	2	2	0	0
0	1	1	2	0	0
1	3	1	2	0	0
0	1	0	0	0	0
1	2	6	1	0	0
6	3	6	4	0	0
1	0	1	1	0	0
3	1	2	2	0	0
5	0	1	0	0	0
1	0	0	2	0	0
2	0	2	1	0	0
7	0	5	1	0	0
3	1	1	3	0	0
4	1	2	0	0	0

Pimelea	Epacridaceae	*Astelia alpina*	*Acacia*	*Plantago*	*Dichosciadium-Xanthosia* Type
0	31	2	0	1	2
0	26	6	0	0	5
0	22	3	0	2	0
0	29	4	0	1	1
0	24	3	0	1	0
0	26	3	0	1	3
1	20	1	1	0	0
0	14	7	1	1	0
0	20	3	0	3	1
0	22	1	0	0	2
0	16	2	1	2	2
0	19	2	0	0	0
0	19	3	0	0	0
0	17	2	0	0	0
0	11	2	0	0	0
0	8	1	0	0	0
0	11	0	0	0	0
0	7	0	0	0	1
0	11	0	0	0	0
0	7	0	0	0	0
0	11	0	1	2	0
0	18	1	1	0	0
0	10	3	0	1	0
0	9	1	0	1	0
0	25	1	0	0	1
0	12	1	0	0	2
0	19	4	0	2	3
0	14	4	0	2	2
0	13	0	1	3	5
0	3	15	1	3	16
0	2	10	0	4	38
0	6	10	0	4	14
0	3	16	0	6	13
0	4	13	0	8	0
0	11	10	0	8	0
0	6	0	0	5	0

Euphrasia	*Epilobium*	Apiaceae	Asteraceae (Tubuliflorae Type)	Asteraceae (Liguliflorae Type)	Caryophyllaceae
0	0	1	9	0	0
0	0	0	6	0	0
0	0	0	20	0	0
0	0	0	19	0	0
0	0	3	5	0	0
0	0	1	11	0	0
1	1	1	12	0	0
0	0	0	13	0	0
0	1	0	6	0	0
0	0	0	12	0	0
0	0	1	10	1	0
0	0	0	12	0	0
0	0	0	8	0	0
0	0	0	7	0	0
0	0	1	11	0	0
0	0	0	8	0	0
0	0	0	2	0	0
0	0	1	4	0	0
0	0	0	6	0	0
0	0	2	4	0	0
0	0	0	5	0	0
0	0	0	3	0	0
0	0	2	5	0	0
0	0	1	5	0	0
0	0	1	10	0	0
0	0	0	9	0	0
0	0	0	16	0	0
0	0	0	21	0	0
0	0	3	13	0	1
0	0	2	30	0	0
0	0	0	43	0	0
0	0	1	46	0	0
0	0	1	49	0	0
0	0	1	47	0	0
0	0	3	36	0	0
0	0	2	61	0	0

Chenopodiaceae	Fabaceae	Geraniaceae	Goodeniaceae	Liliaceae	Poaceae
4	0	0	0	0	11
7	0	0	0	1	3
5	2	0	0	0	10
3	0	0	0	0	3
6	0	0	0	0	4
14	0	0	0	0	6
10	0	0	0	2	7
12	1	0	0	1	13
7	0	0	0	0	8
4	0	0	0	0	8
3	0	1	1	0	5
5	0	0	0	0	7
5	1	0	0	0	4
6	0	0	0	1	2
4	0	0	0	1	7
9	0	0	0	0	2
6	0	0	0	0	5
2	0	0	0	0	2
2	0	0	0	0	4
5	0	0	0	0	4
0	0	0	0	0	1
3	0	0	0	0	1
4	0	0	0	0	6
1	0	0	0	0	9
2	0	0	0	0	7
3	0	0	0	0	2
5	1	0	0	0	12
4	1	0	0	0	8
9	0	0	0	0	11
13	1	0	0	0	28
14	0	0	0	0	44
0	0	0	0	1	30
4	0	0	1	2	37
9	0	0	0	2	40
3	0	0	0	0	42
15	0	0	0	0	45

Unknown	Indeterminate	Damaged/ Degraded/ Crumpled	*Spyridium*	Rutaceae (undiff.)	*Melaluca*
3	1	0	0	1	0
0	1	0	0	2	0
3	0	0	1	0	1
0	1	0	0	0	0
1	0	0	0	0	0
0	0	0	0	0	0
0	0	2	0	0	0
0	0	0	0	0	0
1	0	0	0	0	0
0	2	0	0	0	0
0	0	0	0	1	0
0	12	0	0	0	0
1	1	0	0	0	0
2	0	0	0	0	0
0	0	0	0	0	0
0	5	0	0	0	0
1	9	3	0	0	0
0	6	1	0	0	0
0	0	1	0	0	0
1	0	0	0	0	1
1	0	0	0	0	0
0	0	0	1	0	0
0	0	1	0	0	0
0	0	0	0	0	0
0	0	0	0	1	0
0	0	1	0	0	0
0	1	0	0	0	0
0	0	0	0	0	0
0	0	1	0	1	0
0	0	0	0	0	0
2	0	7	0	0	0
0	9	3	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
5	2	0	0	0	0
0	16	0	0	0	0

Rubiaceae	Scrophulariacae	Droseraceae	*Pinus*	*Gymnoschoenus sphaerocephalus*	Myriophyllum
0	0	0	2	1	1
0	0	0	0	0	0
0	0	0	0	0	1
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	2	0
0	1	0	0	3	0
0	0	0	0	2	0
0	0	0	0	3	0
0	0	0	0	0	1
0	0	0	0	4	0
0	0	0	0	1	0
0	0	0	0	1	0
0	0	0	0	4	0
0	0	0	0	2	0
0	0	0	0	0	0
0	0	0	0	4	0
0	0	0	0	2	0
0	0	0	0	1	2
0	0	0	0	0	0
0	0	0	0	2	0
0	0	0	0	1	0
0	0	0	0	1	0
0	0	0	0	0	0
0	0	0	0	2	0
0	0	0	0	3	0
0	0	0	0	3	0
0	2	0	0	4	0
0	0	0	0	7	0
0	0	0	0	1	0
0	0	0	0	4	0
0	0	0	0	2	0
0	0	0	0	4	0
0	1	0	0	6	0
0	0	0	0	4	1
0	0	0	0	1	0

Isoetes	Cyperaceae	Haloragaceae	Restionaceae	Terrestrial Sum	*Lycopodium* tracer mean = 13911
151	0	1	8	436	12
136	1	0	4	371	28
266	0	1	6	365	21
186	0	0	3	360	25
181	2	0	3	355	20
168	0	0	4	418	17
226	1	0	6	405	22
141	1	0	1	395	22
145	0	0	5	405	16
182	0	1	3	372	22
193	0	0	2	376	13
159	0	1	2	409	26
205	0	0	2	420	24
223	4	0	2	427	26
153	0	0	2	400	14
123	0	1	3	387	20
160	1	0	4	423	20
138	0	0	1	380	23
143	0	0	0	352	16
112	0	0	4	374	18
96	0	1	1	447	25
76	2	0	2	410	20
75	1	1	0	430	17
37	2	0	1	355	24
79	0	0	5	395	25
75	0	0	0	386	21
121	3	0	2	357	31
87	2	0	3	367	18
95	2	0	2	370	18
142	6	0	2	389	25
163	6	1	7	509	29
107	0	0	6	406	37
91	2	0	5	407	42
23	2	1	5	432	26
6	4	1	9	313	31
3	1	2	16	293	95

APPENDIX L

CHARCOAL COUNTS FROM SUTTONS TARN

Depth (cm)	Age (cal yr BP)	Sample Volume (cm^3)	Charcoal Counts
0.25	92	2	29
0.75	211	2	35
1.25	331	2	36
1.75	451	2	24
2.25	571	2	14
2.75	691	2	19
3.25	810	2	9
3.75	930	2	10
4.25	1049	2	14
4.75	1168	2	38
5.25	1287	2	34
5.75	1405	2	57
6.25	1524	2	20
6.75	1642	2	17
7.25	1760	2	5
7.75	1878	2	5
8.25	1995	2	11
8.75	2112	2	4
9.25	2228	2	9
9.75	2345	2	29
10.25	2460	2	20
10.75	2576	2	27
11.25	2691	2	91
11.75	2805	2	280
12.25	2919	2	37
12.75	3033	2	94
13.25	3146	2	108
13.75	3259	2	22
14.25	3371	2	11
14.75	3483	2	8
15.25	3594	2	2
15.75	3705	2	8
16.25	3815	2	30
16.75	3925	2	175
17.25	4034	2	183
17.75	4143	2	497
18.25	4251	2	391
18.75	4358	2	38

19.25	4465	2	7
19.75	4572	2	13
20.25	4678	2	57
20.75	4783	2	264
21.25	4888	2	33
21.75	4992	2	49
22.25	5096	2	106
22.75	5199	2	26
23.25	5301	2	7
23.75	5403	2	12
24.25	5504	2	13
24.75	5604	2	7
25.25	5704	2	8
25.75	5803	2	5
26.25	5901	2	3
26.75	5999	2	22
27.25	6096	2	13
27.75	6193	2	14
28.25	6288	2	9
28.75	6383	2	8
29.25	6477	2	21
29.75	6571	2	15
30.25	6664	2	2
30.75	6756	2	9
31.25	6847	2	21
31.75	6938	2	5
32.25	7028	2	1
32.75	7117	2	6
33.25	7206	2	11
33.75	7293	2	21
34.25	7381	2	6
34.75	7467	2	15
35.25	7553	2	24
35.75	7638	2	19
36.25	7723	2	11
36.75	7807	2	14
37.25	7890	2	11
37.75	7973	2	14
38.25	8055	2	11
38.75	8137	2	22
39.25	8218	2	19

39.75	8298	2	24
40.25	8378	2	18
40.75	8457	2	11
41.25	8536	2	16
41.75	8614	2	10
42.25	8692	2	20
42.75	8769	2	19
43.25	8845	2	24
43.75	8921	2	26
44.25	8997	2	27
44.75	9072	2	27
45.25	9146	2	28
45.75	9221	2	13
46.25	9294	2	27
46.75	9367	2	31
47.25	9440	2	17
47.75	9512	2	19
48.25	9584	2	16
48.75	9656	2	23
49.25	9727	2	26
49.75	9797	2	18
50.25	9868	2	23
50.75	9937	2	20
51.25	10007	2	20
51.75	10076	2	37
52.25	10145	2	22
52.75	10213	2	24
53.25	10281	2	20
53.75	10348	2	31
54.25	10415	2	17
54.75	10482	2	38
55.25	10548	2	28
55.75	10614	2	47
56.25	10679	2	5
56.75	10744	2	13
57.25	10809	2	25
57.75	10873	2	13
58.25	10937	2	14
58.75	11000	2	25
59.25	11063	2	21
59.75	11126	2	32

60.25	11188	2	9
60.75	11250	2	9
61.25	11311	2	2
61.75	11372	2	8
62.25	11432	2	10
62.75	11492	2	82
63.25	11552	2	73
63.75	11611	2	49
64.25	11670	2	7
64.75	11728	2	1
65.25	11786	2	4
65.75	11843	2	11
66.25	11901	2	1
66.75	11957	2	4
67.25	12013	2	4
67.75	12069	2	2
68.25	12124	2	3
68.75	12179	2	11
69.25	12234	2	21
69.75	12288	2	11
70.25	12341	2	35
70.75	12394	2	30
71.25	12447	2	13
71.75	12500	2	9
72.25	12551	2	15
72.75	12603	2	21
73.25	12654	2	15
73.75	12705	2	12
74.25	12755	2	19
74.75	12806	2	34
75.25	12855	2	62
75.75	12905	2	74
76.25	12954	2	9
76.75	13003	2	12
77.25	13051	2	21
77.75	13100	2	6
78.25	13148	2	7
78.75	13196	2	17
79.25	13243	2	20
79.75	13291	2	10
80.25	13338	2	12

80.75	13385	2	6
81.25	13432	2	9
81.75	13479	2	18
82.25	13525	2	19
82.75	13572	2	24
83.25	13618	2	27
83.75	13664	2	6
84.25	13710	2	5
84.75	13756	2	10
85.25	13802	2	6
85.75	13848	2	1
86.25	13893	2	0
86.75	13939	2	4
87.25	13985	2	22
87.75	14030	2	20
88.25	14076	2	6
88.75	14121	2	14
89.25	14167	2	11
89.75	14213	2	10
90.25	14258	2	6
90.75	14304	2	5
91.25	14350	2	13
91.75	14396	2	4
92.25	14441	2	5
92.75	14487	2	1
93.25	14533	2	6
93.75	14579	2	6
94.25	14625	2	19
94.75	14671	2	12
95.25	14717	2	5
95.75	14763	2	4
96.25	14810	2	2
96.75	14856	2	5
97.25	14902	2	7
97.75	14948	2	5
98.25	14994	2	7
98.75	15041	2	17
99.25	15087	2	14
99.75	15133	2	9
100.25	15180	2	3
100.75	15226	2	6

101.25	15272	2	14
101.75	15319	2	6
102.25	15365	2	7
102.75	15411	2	4
103.25	15458	2	4
103.75	15504	2	2
104.25	15551	2	2
104.75	15597	2	4
105.25	15644	2	11
105.75	15690	2	9
106.25	15736	2	3
106.75	15783	2	6
107.25	15829	2	7
107.75	15876	2	9
108.25	15922	2	11
108.75	15969	2	6
109.25	16015	2	0
109.75	16062	2	2
110.25	16108	2	0
110.75	16155	2	2
111.25	16201	2	1
111.75	16248	2	1
112.25	16294	2	2
112.75	16341	2	4
113.25	16387	2	4
113.75	16433	2	14
114.25	16480	2	5
114.75	16526	2	5

APPENDIX M

LAKE LILLA CHRONOLOGY

Depth (cm)	Median Age (cal yr BP)	Minimum Age (95% CI) (cal yr BP)	Maximum Age (95% CI) (cal yr BP)
0	-62	-83	-46
0.25	-10	-31	7
0.75	95	73	113
1.25	199	178	218
1.75	304	281	323
2.25	408	384	430
2.75	513	488	537
3.25	617	591	643
3.75	722	694	749
4.25	826	796	856
4.75	931	899	963
5.25	1035	1003	1069
5.75	1140	1105	1176
6.25	1244	1208	1283
6.75	1349	1310	1389
7.25	1453	1413	1494
7.75	1558	1516	1600
8.25	1662	1619	1707
8.75	1767	1722	1814
9.25	1872	1824	1920
9.75	1976	1927	2026
10.25	2081	2030	2133
10.75	2186	2133	2239
11.25	2290	2235	2346
11.75	2395	2338	2452
12.25	2500	2441	2558
12.75	2605	2545	2664
13.25	2710	2648	2770
13.75	2814	2751	2876
14.25	2919	2856	2983
14.75	3024	2960	3087
15.25	3129	3064	3194
15.75	3234	3169	3299
16.25	3339	3274	3404
16.75	3444	3378	3510
17.25	3549	3482	3616
17.75	3654	3588	3721

18.25	3759	3694	3826
18.75	3864	3799	3934
19.25	3970	3904	4042
19.75	4075	4010	4146
20.25	4180	4117	4251
20.75	4286	4222	4355
21.25	4391	4327	4462
21.75	4496	4431	4569
22.25	4602	4538	4675
22.75	4708	4643	4780
23.25	4813	4750	4886
23.75	4919	4856	4992
24.25	5025	4964	5100
24.75	5131	5070	5207
25.25	5237	5177	5313
25.75	5343	5283	5420
26.25	5449	5390	5527
26.75	5556	5494	5634
27.25	5662	5602	5743
27.75	5769	5706	5852
28.25	5876	5811	5958
28.75	5983	5914	6065
29.25	6090	6017	6175
29.75	6196	6122	6283
30.25	6303	6226	6393
30.75	6410	6328	6503
31.25	6517	6430	6613
31.75	6623	6531	6725
32.25	6729	6633	6834
32.75	6836	6735	6943
33.25	6941	6834	7051
33.75	7047	6936	7158
34.25	7152	7035	7265
34.75	7258	7135	7371
35.25	7362	7235	7478
35.75	7467	7336	7581
36.25	7570	7436	7688
36.75	7674	7534	7793
37.25	7776	7633	7897
37.75	7879	7731	8001
38.25	7980	7828	8103

38.75	8080	7925	8204
39.25	8180	8020	8306
39.75	8279	8117	8407
40.25	8376	8210	8505
40.75	8473	8304	8603
41.25	8568	8397	8699
41.75	8662	8490	8794
42.25	8755	8581	8886
42.75	8847	8671	8978
43.25	8937	8760	9068
43.75	9026	8849	9155
44.25	9113	8939	9236
44.75	9199	9024	9320
45.25	9283	9108	9402
45.75	9367	9194	9483
46.25	9449	9279	9563
46.75	9530	9361	9641
47.25	9610	9441	9718
47.75	9689	9522	9795
48.25	9767	9604	9867
48.75	9844	9684	9942
49.25	9920	9764	10015
49.75	9995	9843	10087
50.25	10069	9922	10159
50.75	10143	9998	10229
51.25	10216	10074	10299
51.75	10288	10150	10371
52.25	10360	10220	10443
52.75	10431	10295	10513
53.25	10502	10371	10586
53.75	10572	10446	10661
54.25	10643	10515	10730
54.75	10713	10583	10803
55.25	10782	10651	10877
55.75	10852	10720	10950
56.25	10922	10789	11021
56.75	10991	10858	11090
57.25	11061	10927	11164
57.75	11131	10990	11236
58.25	11201	11059	11310
58.75	11271	11126	11382

59.25	11342	11196	11455
59.75	11413	11263	11529
60.25	11485	11331	11601
60.75	11557	11405	11676
61.25	11629	11472	11751
61.75	11702	11542	11827
62.25	11775	11616	11901
62.75	11849	11686	11979
63.25	11923	11756	12055
63.75	11998	11827	12131
64.25	12073	11902	12208
64.75	12149	11971	12286
65.25	12225	12041	12363
65.75	12302	12109	12443
66.25	12379	12179	12522
66.75	12457	12249	12601
67.25	12536	12318	12684
67.75	12615	12388	12765
68.25	12695	12458	12845
68.75	12775	12529	12926
69.25	12855	12606	13010
69.75	12936	12684	13092
70.25	13017	12757	13174
70.75	13099	12825	13257
71.25	13181	12892	13339
71.75	13263	12960	13422
72.25	13346	13029	13506
72.75	13429	13106	13590
73.25	13511	13178	13674
73.75	13594	13247	13759
74.25	13677	13316	13844
74.75	13760	13384	13930
75.25	13844	13454	14017
75.75	13927	13525	14104
76.25	14010	13596	14189
76.75	14093	13667	14277
77.25	14176	13739	14363
77.75	14259	13810	14453
78.25	14342	13881	14543
78.75	14425	13953	14635
79.25	14509	14024	14727

79.75	14592	14094	14818
80.25	14675	14163	14908
80.75	14758	14232	14999
81.25	14841	14301	15094
81.75	14924	14370	15186
82.25	15007	14439	15279
82.75	15091	14508	15370
83.25	15174	14577	15461

APPENDIX N

LITHOLOGIC DATA FROM LAKE LILLA

Depth (cm)	Age (cal yr BP)	Magnetic Susceptibility (SI units)
0.25	-10	no data
0.75	199	no data
1.25	408	no data
1.75	617	no data
2.25	826	no data
2.75	1035	no data
3.25	1244	no data
3.75	1453	no data
4.25	1662	no data
4.75	1872	no data
5.25	1036	no data
5.75	1140	no data
6.25	1245	no data
6.75	1349	no data
7.25	1454	no data
7.75	1558	no data
8.25	1663	no data
8.75	1768	no data
9.25	1872	no data
9.75	1977	no data
10.25	2081	no data
10.75	2186	no data
11.25	2290	no data
11.75	2395	no data
12.25	2500	no data
12.75	2605	-1.2
13.25	2710	-1.3
13.75	2814	-1.4
14.25	2919	-1.4
14.75	3024	-1.5
15.25	3129	-1.6
15.75	3234	-1.6
16.25	3339	-1.6
16.75	3444	-1.5
17.25	3549	-1.5
17.75	3654	-1.6
18.25	3759	-1.4
18.75	3864	-1.5
19.25	3970	-1.4
19.75	4075	-1.5

20.25	4180	-1.2
20.75	4286	-1.2
21.25	4391	-1.4
21.75	4496	-1.4
22.25	4602	-1.2
22.75	4708	-1.4
23.25	4813	-1.2
23.75	4919	-1.4
24.25	5025	-1.3
24.75	5131	-1.1
25.25	5237	-1.2
25.75	5343	-1.1
26.25	5449	-1.2
26.75	5556	-1.3
27.25	5662	-1.2
27.75	5769	-1.1
28.25	5876	-1.3
28.75	5983	-1.2
29.25	6090	-1.3
29.75	6196	-1.3
30.25	6303	-1.1
30.75	6410	-1.3
31.25	6517	-1.2
31.75	6623	-1.2
32.25	6729	-1.4
32.75	6836	-1.4
33.25	6941	-1.1
33.75	7047	-1.0
34.25	7152	-1.1
34.75	7258	-1.3
35.25	7362	-1.0
35.75	7467	-1.0
36.25	7570	-1.1
36.75	7674	-1.1
37.25	7776	-1.0
37.75	7879	-1.2
38.25	7980	-1.2
38.75	8080	-1.1
39.25	8180	-1.0
39.75	8279	-1.1
40.25	8376	-1.1
40.75	8473	-1.0
41.25	8568	-0.9
41.75	8662	-1.0

42.25	8755	-1.1
42.75	8847	-1.1
43.25	8937	-1.0
43.75	9026	-1.0
44.25	9113	-1.0
44.75	9199	-1.1
45.25	9283	-1.2
45.75	9367	-1.1
46.25	9449	-1.2
46.75	9530	-1.0
47.25	9610	-0.9
47.75	9689	-1.2
48.25	9767	-1.2
48.75	9844	-1.1
49.25	9920	-1.0
49.75	9995	-1.1
50.25	10069	-1.1
50.75	10143	-0.9
51.25	10216	-1.0
51.75	10288	-1.0
52.25	10360	-1.1
52.75	10431	-1.1
53.25	10502	-1.0
53.75	10572	-0.9
54.25	10643	-0.9
54.75	10713	-1.1
55.25	10782	-1.0
55.75	10852	-1.0
56.25	10922	-0.9
56.75	10991	-1.0
57.25	11061	-0.8
57.75	11131	-0.9
58.25	11201	-0.8
58.75	11271	-0.9
59.25	11342	-0.7
59.75	11413	-0.6
60.25	11485	-0.7
60.75	11557	-0.8
61.25	11629	-0.9
61.75	11702	-0.8
62.25	11775	-0.9
62.75	11849	-0.8
63.25	11923	-0.6
63.75	11998	-0.4

64.25	12073	-0.9
64.75	12149	-0.9
65.25	12225	-1.0
65.75	12302	-0.9
66.25	12379	-0.5
66.75	12457	-0.4
67.25	12536	-0.5
67.75	12615	-0.8
68.25	12695	-0.8
68.75	12775	-0.4
69.25	12855	-0.1
69.75	12936	-0.6
70.25	13017	-0.4
70.75	13099	-0.1
71.25	13181	-0.2
71.75	13263	-0.3
72.25	13346	-0.1
72.75	13429	-0.1
73.25	13511	-0.4
73.75	13594	0.0
74.25	13677	0.1
74.75	13760	0.1
75.25	13844	0.1
75.75	13927	0.4
76.25	14010	0.2
76.75	14093	-0.2
77.25	14176	-0.5
77.75	14259	-0.7
78.25	14342	-0.5
78.75	14425	-0.8
79.25	14509	-0.6
79.75	14592	-0.5
80.25	14675	-0.5
80.75	14758	-0.4
81.25	14841	-0.3
81.75	14924	-0.4
82.25	15007	-0.4
82.75	15091	-0.3

APPENDIX O

CHARCOAL COUNTS FROM LAKE LILLA

Depth (cm)	Age (cal yr BP)	Sample Volume (cm^3)	Charcoal Counts
0.25	-10	2	10
1.25	199	2	14
2.25	408	2	14
3.25	617	2	9
4.25	826	2	15
5.25	1035	2	10
6.25	1244	2	15
7.25	1453	2	19
8.25	1662	2	13
9.25	1872	2	20
10.25	2081	no data	no data
10.75	2186	0.5	10
11.25	2290	1	12
11.75	2395	1.5	14
12.25	2500	1.5	23
12.75	2605	1.5	14
13.25	2710	1.5	18
13.75	2814	2	21
14.25	2919	2	23
14.75	3024	1.5	26
15.25	3129	1.5	27
15.75	3234	2	30
16.25	3339	2	17
16.75	3444	1.75	27
17.25	3549	2	39
17.75	3654	2	44
18.25	3759	2	53
18.75	3864	2	51
19.25	3970	2	46
19.75	4075	2	88
20.25	4180	2	54
20.75	4286	2	24
21.25	4391	2	16
21.75	4496	2	11
22.25	4602	2	9
22.75	4708	2	15
23.25	4813	2	9
23.75	4919	2	14
24.25	5025	2	10
24.75	5131	2	11

25.25	5237	2	14
25.75	5343	2	11
26.25	5449	2	10
26.75	5556	2	13
27.25	5662	2	16
27.75	5769	2	22
28.25	5876	2	15
28.75	5983	2	15
29.25	6090	2	32
29.75	6196	2	22
30.25	6303	2	13
30.75	6410	2	14
31.25	6517	2	19
31.75	6623	2	14
32.25	6729	2	14
32.75	6836	2	23
33.25	6941	2	3
33.75	7047	2	12
34.25	7152	2	13
34.75	7258	2	14
35.25	7362	2	8
35.75	7467	2	6
36.25	7570	2	7
36.75	7674	2	5
37.25	7776	2	7
37.75	7879	2	5
38.25	7980	2	3
38.75	8080	2	13
39.25	8180	2	4
39.75	8279	2	5
40.25	8376	2	7
40.75	8473	2	7
41.25	8568	2	6
41.75	8662	2	9
42.25	8755	2	16
42.75	8847	2	30
43.25	8937	2	57
43.75	9026	2	57
44.25	9113	2	37
44.75	9199	2	32
45.25	9283	2	32
45.75	9367	2	49
46.25	9449	2	42
46.75	9530	2	72

47.25	9610	2	50
47.75	9689	2	52
48.25	9767	2	66
48.75	9844	2	55
49.25	9920	2	65
49.75	9995	2	67
50.25	10069	2	54
50.75	10143	2	44
51.25	10216	2	84
51.75	10288	2	45
52.25	10360	2	58
52.75	10431	2	42
53.25	10502	2	63
53.75	10572	2	75
54.25	10643	2	73
54.75	10713	2	57
55.25	10782	2	55
55.75	10852	2	28
56.25	10922	2	28
56.75	10991	2	53
57.25	11061	2	41
57.75	11131	2	32
58.25	11201	2	19
58.75	11271	2	16
59.25	11342	2	13
59.75	11413	2	17
60.25	11485	2	28
60.75	11557	2	26
61.25	11629	2	9
61.75	11702	2	22
62.25	11775	2	11
62.75	11849	2	6
63.25	11923	2	1
63.75	11998	2	1
64.25	12073	2	4
64.75	12149	2	1
65.25	12225	2	0
65.75	12302	2	0
66.25	12379	2	0
66.75	12457	2	1
67.25	12536	2	0
67.75	12615	2	1
68.25	12695	2	1
68.75	12775	2	3

69.25	12855	2	1
69.75	12936	2	2
70.25	13017	2	1
70.75	13099	2	2
71.25	13181	2	2
71.75	13263	2	0
72.25	13346	2	1
72.75	13429	2	0
73.25	13511	2	0
73.75	13594	2	0
74.25	13677	2	0
74.75	13760	2	0
75.25	13844	2	0
75.75	13927	2	0
76.25	14010	2	0
76.75	14093	2	0
77.25	14176	2	0
77.75	14259	2	0
78.25	14342	2	1
78.75	14425	2	1
79.25	14509	2	0
79.75	14592	2	0
80.25	14675	2	0
80.75	14758	2	3
81.25	14841	2	0

APPENDIX P

LAKE WILKS CHRONOLOGY

Depth (cm)	Median Age (cal yr BP)	Minimum Age (95% CI) (cal yr BP)	Maximum Age (95% CI) (cal yr BP)
0	-64	-79	-59
1	-26	-41	-15
2	13	-4	28
3	52	34	72
4	91	70	115
5	130	105	159
6	169	141	202
7	208	176	246
8	247	211	289
9	286	246	333
10	326	282	377
11	365	317	420
12	405	353	464
13	445	389	507
14	485	426	551
15	526	463	595
16	566	502	639
17	607	540	684
18	649	579	728
19	690	618	773
20	732	658	817
21	774	697	861
22	817	736	905
23	860	776	949
24	903	817	994
25	947	860	1040
26	990	902	1086
27	1035	945	1130
28	1079	987	1175
29	1123	1029	1221
30	1168	1072	1265
31	1213	1116	1311
32	1257	1160	1357
33	1302	1202	1402

34	1347	1245	1448
35	1391	1289	1494
36	1435	1333	1539
37	1480	1378	1585
38	1524	1422	1631
39	1567	1463	1677
40	1611	1504	1722
41	1654	1547	1766
42	1697	1586	1811
43	1740	1627	1855
44	1783	1669	1901
45	1825	1709	1944
46	1867	1748	1989
47	1909	1789	2034
48	1951	1831	2079
49	1992	1868	2122
50	2033	1910	2165
51	2074	1952	2208
52	2114	1991	2250
53	2155	2025	2294
54	2195	2059	2334
55	2234	2095	2374
56	2274	2130	2416
57	2313	2165	2459
58	2352	2199	2501
59	2391	2234	2537
60	2429	2270	2577
61	2467	2304	2616
62	2505	2338	2655
63	2543	2370	2694
64	2581	2402	2732
65	2618	2431	2769
66	2655	2465	2807
67	2692	2497	2846
68	2728	2528	2884
69	2765	2559	2919
70	2801	2588	2954
71	2837	2619	2993

72	2872	2650	3031
73	2908	2679	3071
74	2943	2709	3106
75	2978	2739	3142
76	3012	2769	3181
77	3047	2799	3219
78	3081	2827	3258
79	3115	2856	3294
80	3149	2889	3332
81	3182	2919	3370
82	3215	2948	3407
83	3249	2978	3442
84	3281	3007	3480
85	3314	3034	3518
86	3346	3062	3555
87	3379	3090	3591
88	3411	3123	3630
89	3442	3152	3662
90	3474	3180	3696
91	3505	3209	3733
92	3536	3237	3770
93	3567	3266	3806
94	3598	3294	3843
95	3628	3324	3880
96	3659	3353	3916
97	3689	3382	3951
98	3719	3412	3987
99	3748	3443	4022
100	3778	3473	4056
101	3807	3504	4092
102	3836	3534	4127
103	3865	3561	4161
104	3894	3592	4195
105	3923	3621	4229
106	3952	3653	4264
107	3981	3684	4300
108	4010	3716	4336
109	4039	3749	4371

110	4069	3784	4405
111	4099	3819	4439
112	4128	3853	4473
113	4159	3883	4507
114	4189	3917	4541
115	4220	3947	4575
116	4251	3977	4609
117	4283	4009	4643
118	4315	4045	4677
119	4348	4083	4711
120	4381	4120	4746
121	4415	4156	4780
122	4449	4193	4814
123	4484	4230	4849
124	4520	4262	4884
125	4556	4301	4918
126	4592	4339	4953
127	4629	4374	4989
128	4666	4415	5027
129	4704	4452	5065
130	4742	4491	5103
131	4780	4524	5138
132	4819	4559	5174
133	4859	4591	5209
134	4898	4626	5245
135	4938	4664	5281
136	4979	4702	5317
137	5020	4743	5354
138	5061	4782	5391
139	5102	4821	5428
140	5144	4862	5467
141	5186	4900	5504
142	5228	4940	5540
143	5271	4975	5577
144	5313	5010	5615
145	5356	5047	5653
146	5400	5086	5691
147	5443	5125	5729

148	5487	5165	5767
149	5530	5201	5806
150	5574	5238	5846
151	5619	5276	5883
152	5663	5313	5921
153	5707	5354	5959
154	5752	5393	5998
155	5797	5435	6036
156	5841	5481	6076
157	5886	5527	6115
158	5931	5572	6153
159	5976	5613	6193
160	6021	5654	6235
161	6066	5696	6276
162	6111	5737	6316
163	6156	5779	6356
164	6201	5822	6395
165	6246	5867	6436
166	6291	5911	6476
167	6336	5954	6516
168	6381	5999	6555
169	6426	6043	6596
170	6471	6086	6638
171	6516	6129	6678
172	6561	6173	6720
173	6606	6216	6763
174	6652	6260	6807
175	6697	6304	6853
176	6742	6351	6899
177	6787	6397	6942
178	6832	6442	6987
179	6877	6487	7033
180	6922	6533	7080
181	6968	6578	7125
182	7013	6624	7170
183	7058	6669	7215
184	7103	6715	7262
185	7149	6764	7309

186	7194	6811	7356
187	7239	6857	7405
188	7285	6906	7452
189	7330	6956	7499
190	7376	7007	7546
191	7421	7058	7591
192	7467	7109	7637
193	7513	7159	7685
194	7558	7207	7732
195	7604	7255	7779
196	7650	7304	7824
197	7696	7353	7870
198	7742	7404	7917
199	7788	7455	7964
200	7834	7505	8011
201	7880	7554	8059
202	7926	7605	8108
203	7972	7654	8156
204	8018	7704	8205
205	8065	7752	8249
206	8111	7804	8297
207	8158	7856	8346
208	8204	7908	8394
209	8251	7957	8443
210	8298	8010	8491
211	8345	8063	8539
212	8392	8116	8585
213	8439	8168	8631
214	8486	8217	8679
215	8533	8267	8727
216	8580	8316	8774
217	8628	8366	8822
218	8675	8416	8871
219	8723	8469	8919
220	8770	8521	8968
221	8818	8573	9014
222	8866	8626	9063
223	8914	8678	9110

224	8962	8729	9159
225	9010	8780	9206
226	9058	8831	9254
227	9107	8886	9303
228	9155	8934	9350
229	9204	8987	9398
230	9253	9038	9446
231	9302	9090	9494
232	9351	9144	9543
233	9400	9198	9592
234	9449	9253	9641
235	9498	9308	9691
236	9548	9360	9742
237	9597	9410	9791
238	9647	9461	9840
239	9696	9511	9889
240	9746	9561	9939
241	9796	9610	9988
242	9846	9662	10036
243	9896	9712	10085
244	9946	9765	10135
245	9996	9818	10185
246	10046	9871	10235
247	10097	9923	10284
248	10147	9973	10333
249	10197	10024	10383
250	10248	10073	10432
251	10299	10123	10482
252	10349	10175	10531
253	10400	10226	10580
254	10451	10274	10631
255	10501	10322	10682
256	10552	10370	10732
257	10603	10421	10782
258	10654	10469	10833
259	10705	10518	10884
260	10756	10566	10936
261	10807	10618	10986

262	10858	10669	11038
263	10909	10720	11089
264	10960	10769	11139
265	11011	10816	11189
266	11062	10862	11238
267	11113	10909	11291
268	11165	10956	11343
269	11216	11006	11395
270	11267	11057	11446
271	11318	11107	11498
272	11369	11152	11548
273	11421	11198	11600
274	11472	11243	11651
275	11523	11292	11701

APPENDIX Q

CHARCOAL COUNTS FROM LAKE WILKS

Depth (cm)	Age (cal yr BP)	Sample Volume (cm3)	Charcoal Counts
0	-64	2	18
1	-26	2	30
2	13	2	18
3	52	2	0
4	91	2	22
5	130	2	14
6	169	2	42
7	208	2	20
8	247	2	20
9	286	2	20
10	326	2	20
11	365	2	26
12	405	2	84
13	445	2	34
14	485	2	26
15	526	2	22
16	566	2	30
17	607	2	38
18	649	2	32
19	690	2	56
20	732	2	56
21	774	2	32
22	817	2	26
23	860	2	54
24	903	2	32
25	947	2	34
26	990	2	32
27	1035	2	44
28	1079	2	32
29	1123	2	54
30	1168	2	62
31	1213	2	32
32	1257	2	38
33	1302	2	52
34	1347	2	44

35	1391	2	20
36	1435	2	28
37	1480	2	30
38	1524	2	18
39	1567	2	40
40	1611	2	42
41	1654	2	50
42	1697	2	78
43	1740	2	120
44	1783	2	126
45	1825	2	184
46	1867	2	284
47	1909	2	126
48	1951	2	44
49	1992	2	30
50	2033	2	36
51	2074	2	32
52	2114	2	36
53	2155	2	40
54	2195	2	38
55	2234	2	38
56	2274	2	38
57	2313	2	54
58	2352	2	64
59	2391	2	46
60	2429	2	44
61	2467	2	74
62	2505	2	44
63	2543	2	40
64	2581	2	54
65	2618	2	66
66	2655	2	62
67	2692	2	70
68	2728	2	72
69	2765	2	100
70	2801	2	108
71	2837	2	42
72	2872	2	36

73	2908	2	46
74	2943	2	122
75	2978	2	108
76	3012	2	68
77	3047	2	64
78	3081	2	126
79	3115	2	62
80	3149	2	70
81	3182	2	42
82	3215	2	60
83	3249	2	22
84	3281	2	24
85	3314	2	38
86	3346	2	64
87	3379	2	58
88	3411	2	68
89	3442	2	90
90	3474	2	72
91	3505	2	46
92	3536	2	44
93	3567	2	20
94	3598	2	38
95	3628	2	24
96	3659	2	28
97	3689	2	70
98	3719	2	66
99	3748	2	48
100	3778	2	58
101	3807	2	92
102	3836	2	66
103	3865	2	76
104	3894	2	218
105	3923	2	206
106	3952	2	358
107	3981	2	642
108	4010	2	1326
109	4039	2	50
110	4069	2	92

111	4099	2	44
112	4128	2	74
113	4159	2	56
114	4189	2	56
115	4220	2	92
116	4251	2	70
117	4283	2	232
118	4315	2	286
119	4348	2	396
120	4381	2	186
121	4415	2	72
122	4449	2	58
123	4484	2	26
124	4520	2	62
125	4556	2	58
126	4592	2	46
127	4629	2	48
128	4666	2	36
129	4704	2	86
130	4742	2	60
131	4780	2	26
132	4819	2	68
133	4859	2	82
134	4898	2	50
135	4938	2	54
136	4979	2	68
137	5020	2	36
138	5061	2	48
139	5102	2	60
140	5144	2	62
141	5186	2	66
142	5228	2	42
143	5271	2	50
144	5313	2	32
145	5356	2	30
146	5400	2	22
147	5443	2	38
148	5487	2	18

149	5530	2	36
150	5574	2	26
151	5619	2	46
152	5663	2	30
153	5707	2	34
154	5752	2	24
155	5797	2	38
156	5841	2	62
157	5886	2	52
158	5931	2	34
159	5976	2	80
160	6021	2	66
161	6066	2	86
162	6111	2	106
163	6156	2	226
164	6201	2	60
165	6246	2	22
166	6291	2	40
167	6336	2	18
168	6381	2	20
169	6426	2	16
170	6471	2	10
171	6516	2	70
172	6561	2	50
173	6606	2	42
174	6652	2	60
175	6697	2	42
176	6742	2	102
177	6787	2	174
178	6832	2	120
179	6877	2	88
180	6922	2	66
181	6968	2	100
182	7013	2	48
183	7058	2	76
184	7103	2	100
185	7149	2	88
186	7194	2	82

187	7239	2	44
188	7285	2	44
189	7330	2	116
190	7376	2	40
191	7421	2	50
192	7467	2	108
193	7513	2	116
194	7558	2	44
195	7604	2	86
196	7650	2	54
197	7696	2	162
198	7742	2	68
199	7788	2	82
200	7834	2	54
201	7880	2	76
202	7926	2	80
203	7972	2	96
204	8018	2	48
205	8065	2	50
206	8111	2	110
207	8158	2	54
208	8204	2	30
209	8251	2	66
210	8298	2	50
211	8345	2	26
212	8392	2	36
213	8439	2	26
214	8486	2	92
215	8533	2	64
216	8580	2	34
217	8628	2	56
218	8675	2	8
219	8723	2	48
220	8770	2	46
221	8818	2	28
222	8866	2	54
223	8914	2	82
224	8962	2	34

225	9010	2	52
226	9058	2	74
227	9107	2	90
228	9155	2	138
229	9204	2	76
230	9253	2	38
231	9302	2	30
232	9351	2	38
233	9400	2	38
234	9449	2	14
235	9498	2	18
236	9548	2	38
237	9597	2	34
238	9647	2	20
239	9696	2	34
240	9746	2	38
241	9796	2	40
242	9846	2	16
243	9896	2	24
244	9946	2	46
245	9996	2	40
246	10046	2	48
247	10097	2	66
248	10147	2	68
249	10197	2	38
250	10248	2	40
251	10299	2	30
252	10349	2	16
253	10400	2	46
254	10451	2	26
255	10501	2	44
256	10552	2	36
257	10603	2	46
258	10654	2	92
259	10705	2	44
260	10756	2	52
261	10807	2	106
262	10858	2	98

263	10909	2	108
264	10960	2	88
265	11011	2	166
266	11062	2	40
267	11113	2	144
268	11165	2	276
269	11216	2	88
270	11267	2	114
271	11318	2	176
272	11369	2	220
273	11421	2	72
274	11472	2	22
275	11523	2	58
276	11574	2	56

APPENDIX R

SUPPORTING INFORMATION FOR CHAPTER 4

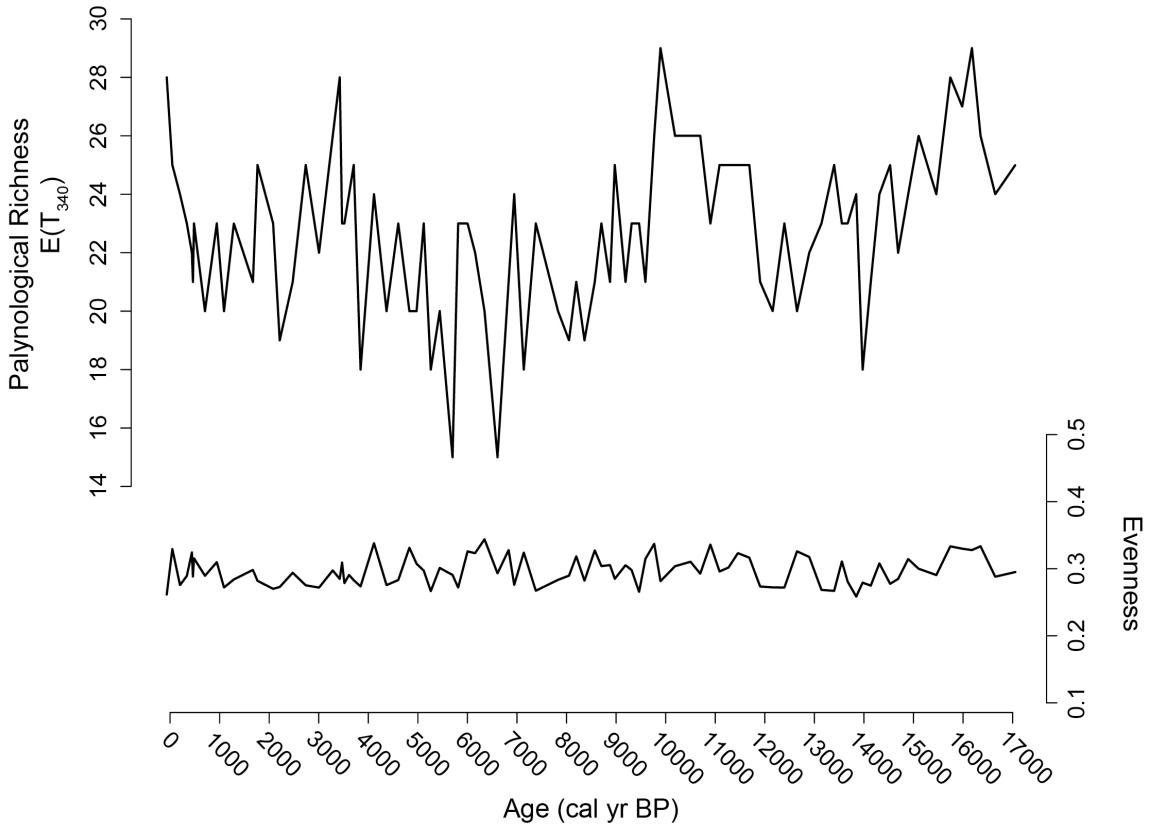


Figure A.1 Palynological richness and evenness for Wombat Pool. Palynological richness was calculated by rarefaction analysis to 340 terrestrial pollen grains as described by Birks and Line (1992) in the program psimpoll (Bennett, 1994). Evenness, the inverse slope of the rank-order abundance of taxa exceeding 0.3 % in the sample, was calculated using the method described in Giesecke et al. (2014).

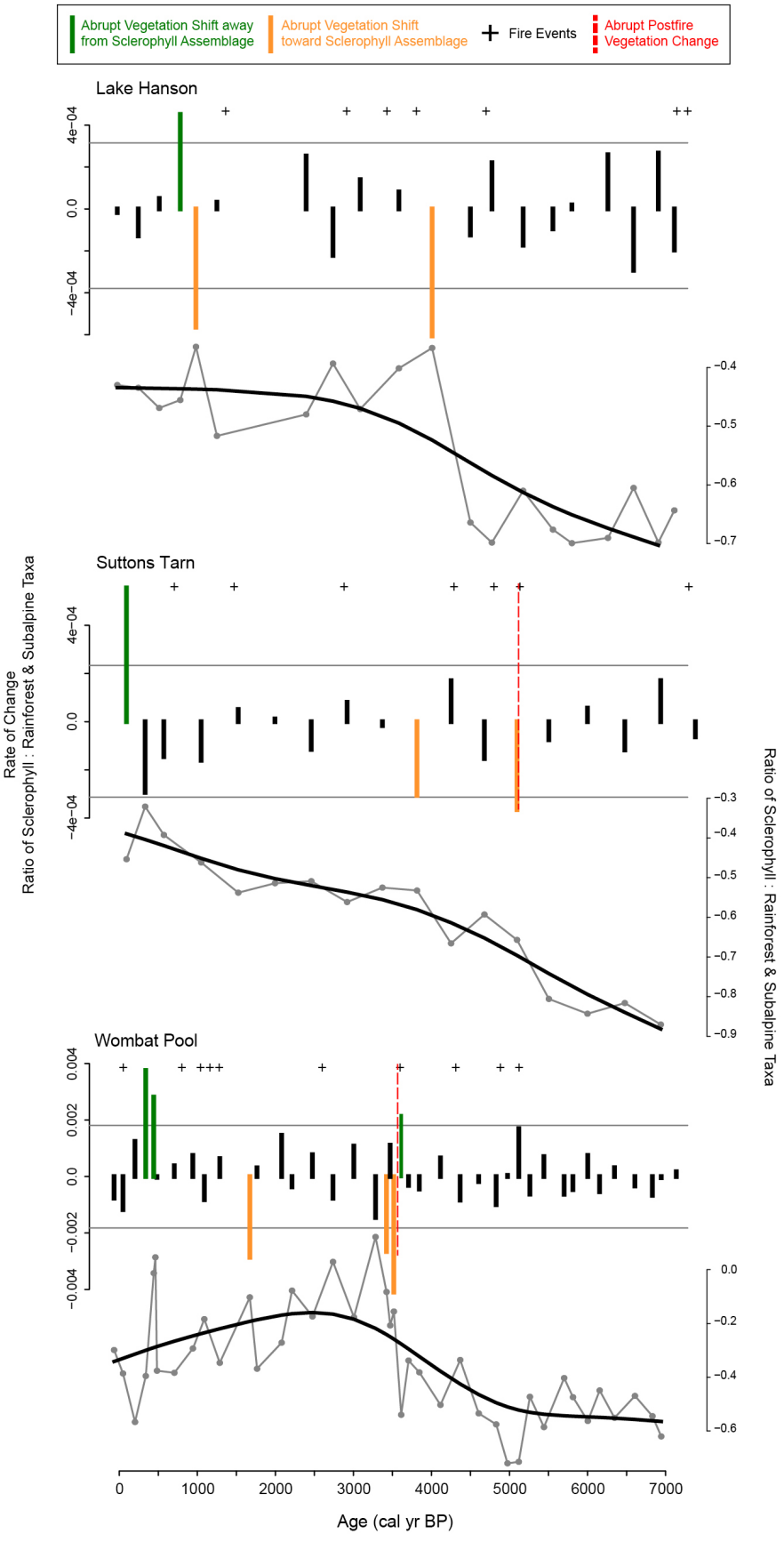

Abrupt Vegetation Shift away from Sclerophyll Assemblage
Abrupt Vegetation Shift toward Sclerophyll Assemblage
Fire Events
Abrupt Postfire Vegetation Change
Lake Hanson
Suttons Tarn
Wombat Pool
Rate of Change
Ratio of Sclerophyll : Rainforest & Subalpine Taxa
Ratio of Sclerophyll : Rainforest & Subalpine Taxa
Age (cal yr BP)
0
1000
2000
3000
4000
5000
6000
7000

Figure A.2 Sclerophyll vegetation and fire in the Late Holocene. The rate of change in the pollen percent ratio of sclerophyll taxa to subalpine plus rainforest taxa (bars) with 90% threshold (horizontal lines) for Lake Hanson, Suttons Tarn and Wombat Pool. Orange bars represent abrupt shifts toward a sclerophyllous assemblage and green bars represent abrupt shifts away from a sclerophyllous assemblage. Red dashed lines indicate instances when a shift toward sclerophyllous assemblage occurred following a fire event (black +) as identified by CharAnalysis (Higuera et al., 2009). The ratio of sclerophyll taxa to rainforest plus subalpine taxa is shown for each site (grey points and line) with smoothing spline (spar = 0.7).