Amberat Middens and the Palaeoenvironmental Record of the Inland Pilbara, Western Australia

By

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Declaration

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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ABBREVIATIONS

aDNA:	Ancient DNA
AMS:	Accelerator Mass Spectrometer
ANSTO:	Australian Nuclear Science and Technology Organisation
BHPBIO:	BHP Billiton Iron ore
BIF:	Banded Iron Formation
ENSO:	El Niño-Southern Oscillation
FUAL:	Flinders University Archaeology Laboratory
IPWP:	Indo-Pacific Warm Pool
ITCZ:	Inter-tropical Convergence Zone
LGM:	Last glacial Maximum
OHS:	Occupational Health and Safety
WA:	Western Australia

ABSTRACT

Archaeologists have long recognised the value of interpreting the archaeological record within a palaeoenvironmental context. Human behaviour can be driven by a number of factors including climatic change and resource availability. In recent times, there has been an increase in archaeological studies that use palaeoenvironmental information to shed light on the nature of human-environmental relationships. Unfortunately for many of the arid and semi-arid regions of Australia, this information is either lacking or completely absent. The Pilbara region of Western Australia has high biological and archaeological significance; however, very little is known about the environmental history of the area, and how humans might have adapted and responded to long-term climatic change.

Potential archives of palaeoenvironmental information exist in caves and rockshelters in the Packsaddle area of the inland Pilbara. These are amberat middens, hard and crystallised deposits formed by animal activity which are known to preserve botanical and faunal remains. These can be used to infer past vegetation and climatic change. This project sets out to assess how a multi-proxy analysis of the middens could be used to infer past climatic change and therefore help to characterise the nature of past human-environmental relationships.

This project identified some of the oldest known amberat middens in Australia. The findings showed that long-term changes in vegetation were evident mostly in the pollen and macrofossil records. Vegetation throughout the late Pleistocene was dominated by an open woodland. A shift occurs after 6000 BP to a more heterogenous pattern of vegetation with the increasing dominance of grassland communities. There were also several hiatuses in midden accumulation which might indicate that the Packsaddle area was effected by prolonged drought in the past, particularly during the Last Glacial Maximum. This might explain why patterns of occupation during this period have appeared so sparse in the archaeological record.

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INTRODUCTION

Archaeologists have long recognised the need to place the archaeological record into an environmental context and it is now generally accepted that changes in human behaviours can be driven by a number of factors which include climate and resource availability (e.g. Smith 2013; Veth 1995; Veth et al. 2000:60; Williams et al. 2010). The exploration of human-environmental relationships is archaeology's contribution to current discussions about ongoing climatic change, and this has led to the growing need for palaeoenvironmental information for which to compare with the archaeological record (Brown 1987:13; Denham and Mooney 2008:365; Fagan 1996:551; Naudinot and Kelly 2017:1–2 Williams 2015a:91).

In some well-watered regions of Australia, such as Arnhem Land and Tasmania, archaeologists are increasingly detecting positive correlations between human behaviours and climatic change (e.g. Asmussen and McInnes 2013; Bourke et al. 2007; Porch and Allen 1995). Unfortunately for the arid and semi-arid regions, such as the inland Pilbara region of Western Australia (WA), records of changing climate are either lacking or completely absent. This is due to the lack of traditional sampling locales (lakes, dunes, and fluvial deposits) and the unsuitable environmental conditions for the preservation of organic proxy data, such as pollen and macrofossils (cf. Wallis 2001).

The Australian continent spans a vast array of climatic zones and the response of these zones to the major circulation systems can vary and are sometimes contradictory. The broad-scale palaeoenvironmental research in Australia is heavily based on geomorphic sources of evidence for changing climate, such as lakes, rivers and desert dunes (e.g. Fitzsimmons et al. 2013; Reeves et al. 2013a). The interpretation of these sources can be problematic due to: spatial discontinuity; large errors in thermoluminescence dating, and the complexity of environmental variables that can influence them (Bowler 2001:75; Hesse 2004:91; Reeves et al. 2013b:106). The broad-scale evidence from geomorphic sources contributes little to the understanding of how climatic change shaped biotic distributions

(Pearson and Betancourt 2002:500; Veth et al. 2000:60). The ambiguity associated with the interpretation of geomorphic sources has increased the need for stratified deposits of organic proxies, such as pollen, macrofossils and phytoliths. While uncommon, they can be used to reveal the way that biotic populations have adapted and shifted in response to changing environmental conditions at the regional and local levels (Field et al. 2017; Murray et al. 2012:136). This type of information is more precise and less ambiguous than geomorphic sources; however, it is severely limited by poor preservation and availability (Fitzsimmons 2013:81–82).

This project was funded by BHP Billiton Iron Ore (BHPBIO), who requested that samples of 'stick-nest rat middens' [1] in the Packsaddle Range and surrounds (an area of the inland Pilbara) be analysed to determine whether they would similarly prove to be palaeoenvironmental archives as they had been in other semi-arid regions. Middens are thought to be the product of rodent nest building and collecting behaviour; however, they can contain contributions from a range of reptile, mammal and bird species (Pearson et al. 2001). Middens are formed by successive generations of animal occupation which can form a hardened and stratified deposit of crystallised urine. This material, also known as amberat, can provide ideal conditions for the preservation of floral and faunal remains which can be used as proxies for biotic change. This information can then be used to infer past climatic conditions (Allen et al. 2000; Berry 1991; Green et al. 1983; McCarthy 1999; McCarthy and Head 2001; McCarthy et al. 1996; Nelson et al. 1990; Pearson and Dodson 1993; Pearson et al. 1999, 2001).

In North America (where midden research was first established), studies of packrat middens have made dramatic contributions to the understanding of environmental change over the last 50,000 years (Pearson and Betancourt 2002:499). Researchers in Australia were hopeful that they could achieve similar dramatic results by using the same methods and techniques for analysing Australian middens;

[1] The idea that the middens were built by stick-nest rats was based on their physical similarities to middens described in studies from interstate and the known presence of stick-nest rats in the region (cf. Copley 1999), coupled with discussions with Dr Stuart Pearson. While this is a high possibility, there is still currently no evidence available to confirm what species was responsible for creating the Packsaddle Range middens.

however, the mid- to late Holocene age of most middens in Australia has limited the value of middens for detecting long-term environmental trends, especially over periods such as the Last Glacial Maximum (LGM). A midden was recently collected at Mt. Brockman in the inland Pilbara and this returned an age of 30,490 ± 380 cal. BP; this is by far the oldest midden ever found in Australia (MacPhail 2011). This example aside, there have been no other investigations into inland Pilbara middens despite this their known presence in many caves and rockshelters and their potential to contribute to our understandings of long-term environmental change.

Over the past two decades, archaeological consulting work in the inland Pilbara has generated large numbers of site recordings but comparatively little published research (Morse 2009:1). In the limited circumstances where findings have been published, there is very little understanding of the relationships that existed between humans and their local environment, despite discussions being centred around human behavioural responses to climatic variability during the LGM and the mid- to late Holocene. Brown's (1987:11–13) seminal publication, which investigated rockshelters of the Packsaddle Range, was the first to recognise that patterns of change in the archaeological record could be related to environmental change, but noted the sparseness of data needed to explore this relationship further. Subsequent studies have been shaped by, and continued to build on Brown's work, but the lack of palaeoenvironmental information has remained a persistent issue.

Due to a preoccupation with finding the earliest occupation dates and with investigating the impact of the LGM, the late Pleistocene period has been a primary research focus in inland Pilbara archaeology (Frankel 1995:651–652; Ryan and Morse 2009:6). The deep archaeological deposits found in some rockshelters have produced a record of human presence in the landscape since around 35,000 BP (Dias and Rapley 2014; Law et al. 2010). While this early occupation is well established, there are varying perspectives surrounding the nature of this occupation, particularly during the LGM. The LGM period in broader northwest Australia was thought to have commenced at around 35,000 BP after which the climate became progressively drier due to decreased summer and annual rainfall (van der Kaars et al.

2006:884). These conditions did not fully ameliorate until around 14,000 BP when summer rainfall increased significantly (Wyrwoll and Miller 2001).

In Veth (1989, 1993, 1995) and Smith's (1987) well-known models for human colonisation, the inland Pilbara is thought to have functioned as a refuge during the period of increased aridity associated with the LGM. According to Veth (1989:81), refuges were seen to comprise of, 'the extensive systems of piedmont/montane uplands and riverine/gorge systems of Australia which provided reliable networks of water during the climatic oscillations of the last 40,000 years.' These models, along with other models applicable to northwest Australia, are based on biogeography, demography, and ecology and broad-scale environmental approaches have been used to build them (e.g. O'Connor et al. 1993; O'Connor and Veth 1996; Veth et al. 2008; Veth et al. 2016). These models are explicit and testable, and can be approached at different scales; however, there has been a lack of local environmental data available to test them in a fine-grained fashion. This issue is reflected in some inland Pilbara rockshelters that show evidence of local abandonment and reduction in occupation intensity throughout the LGM (e.g. Brown 1987; Hughes et al. 2011; Law et al. 2010:70; Marwick 2002a; Slack et al. 2009).

Williams et al. (2013:4621–4622) has questioned how the refugium model can be applied to the Pilbara when the region is located within the major monsoon belt which was severely affected during the LGM. Williams et al. (2013:4621–4622) speculated that local environmental and resource factors were responsible. Slack et al. (2009:38) similarly suggested that local weather patterns could be used to explain why occupation continued during the LGM in some of the less watered areas. If these environmentally based considerations are to progress, additional local palaeoenvironmental evidence is needed to measure the timing, severity and impact of the LGM. If not the result of climatic stress, other explanations for patterns of abandonment in the archaeological record could be further pursued, such as the role of preservation bias and poor chronological resolution (e.g. Marwick 2009). There is also a possibility that rockshelters skew archaeological interpretation to a view that the landscape was only visited intermittedly, when the patterns actually reflect that rockshelters were not the focus of human

occupation (Ryan and Morse 2009). With an improved understanding of the local palaeoenvironment this could be explored further.

Archaeological patterns suggesting the intermittent and brief occupation of rockshelters during the LGM continue until the mid- to late Holocene, when they begin to change (Brown 1987; Edwards and Murphy 2003; Marwick 2009; Veitch and Hook 2009). Very little research attention has been devoted to this period, which is surprising as around 80% of all recorded sites in the inland Pilbara date to this time (Morse 2009:2). There are very few interpretations of mid- to late Holocene archaeological patterns, and most of these are from Brown's (1987) research on rockshelters in the Newman area and the Packsaddle Range. Other studies show comparable patterns such as: increased artefact accumulation rates and radiocarbon dates; the appearance of new technologies such as backed artefacts; tula adzes and seed grinding implements; the presence of symbolic behaviour, such as the production of painted rock art; and the introduction of new site types such as stone arrangements and walled structures (Edwards and Murphy 2003:45; Marwick 2002a; Marwick 2009; McDonald and Veth 2013; Wallis and Matthews 2016). Unpublished reports documenting test excavations in the Packsaddle Range show similar patterns, such as increased stone artefact numbers and the appearance of backed artefacts and seed grinding implements in the upper layers of deposits (e.g. Brown and Mulvaney 1983; Comtesse and Harris 2008; Huonbrook Environment and heritage 2013).

In the broader Australian context, these changes in the diversity and the density of the archaeological record have traditionally been interpreted as reflecting major demographic changes due to sociocultural factors or 'intensification' (e.g. Lourandos 1993; Lourandos and Ross 1994). As with the LGM period, recent studies in the more tropical and temperate zones have increasingly explored the role of the environment in influencing these human behaviours; the general agreement is that climatic variability played an important role in the unprecedented changes that occurred to human demography and in the way that the landscape and its resources were utilised (e.g. Asmussen and McInnes; Attenbrow et al. 2009; Bourke et al. 2007; Brockwell et al. 2013; Holdaway et al. 2010; Hughes et al. 2017; McGowan et

al. 2012; Smith et al. 2008; Smith and Ross 2008; Stevenson et al. 2015; Ulm 2013; Williams et al. 2010, 2013, 2015a, 2015b). These changes are typically indicated by: increased artefact discard rates; the appearance of new stone artefact technologies; the increased use of marginal landscapes; the establishment of long distance exchange networks; and the intensive use of different resources such as seeds and marine species (Asmussen and McInnes 2013; Attenbrow et al. 2009; Brockwell et al. 2013; Smith and Ross 2008; Smith et al. 2008). Positive correlations between these indicators of behavioural change and periods of climatic change have been found increasingly in regions of Australia where there is greater access to palaeoenvironmental information (e.g. Asmussen and McInnes 2013; Attenbrow et al. 2009; Bourke et al. 2007; Porch and Allen 1995; Smith et al. 2008; Williams et al. 2010, 2013, 2015a, 2015b). Due to the lack of traditional sampling locales and the poor preservation of organic material, very little palaeoenvironmental research has ever been conducted in the Pilbara region; therefore, there is currently very thin evidence to suggest if similar changes in the inland Pilbara were also related to climatic variability (Marwick 2002a:225; Ulm 2013; Williams et al. 2010:831).

The archaeological research presented above demonstrates how the dominant discussions of occupation during the LGM and the mid- to late Holocene have been surrounded with ambiguity and uncertainty due to a lack of palaeoenvironmental and sometimes archaeological research. In other regions of Australia, the increasing availability of more detailed paleoenvironmental data has increasingly allowed archaeologists to characterise the relationship between humans and their environments (Denham and Mooney 2008:365). This is also the case internationally, which is evident in the rapid growth of palaeoenvironmental-focused and often multidisciplinary studies in archaeology (e.g. Beresford-Jones et al. 2009; Douglass and Zinke 2015; Ivanova et al. 2016; Kindermann et al. 2006; Mancini et al. 2013). If archaeologists working in the inland Pilbara are to engage with these current discussions, they will need improved access to local palaeoenvironmental records to inform their research (Naudinot and Kelly 2017:1–2).

1.1 Research Question and Aims

This thesis sets out to assess how the analysis of middens can be used to infer past climatic change and therefore help to characterise the nature of past human-environmental relationships in the inland Pilbara region.

This question is answered by addressing the following three aims:

1. Determine the chronology and temporal resolution of the middens and confirm what animal/s created them;
2. Evaluate the botanical contents of the middens to inform our understanding of vegetation change through time in the study region;
3. Assess the palaeoenvironmental implications of the middens and consider their potential to contribute to an understanding of past human responses to climatic change.

1.2 Significance of the Study

The presence of middens in caves and rockshelters in the inland Pilbara has mostly been overlooked by archaeologists. When excavations have been conducted in sites containing abundant, obvious middens, the ensuing reports have failed to mention the presence of these palaeoenvironmental archives (e.g. Dias et al. 2005; Huonbrook Environment and Heritage 2013). As noted above, this is despite the increasing need for more palaeoenvironmental records at the local-level in the absence of traditional sampling locales (Ulm 2013:189; Williams et al. 2015a:106; Wallis 2000, 2001). The inland Pilbara is an archaeologically significant region with a human history that extends back over 35,000 years — developing a detailed understanding of its palaeoenvironmental context is essential if archaeologists are to understand more comprehensively the nature of this occupation through time. The presence of possible palaeoenvironmental archives in the form of middens has the potential to address this gap in knowledge.

1.3 Limitations

In any study of middens, several taphonomic issues exist (Pearson and Betancourt 2002). The animal's foraging and nest building behaviours may influence the fossil contents of the middens used to infer climate (Head et al. 1998:162). However, given the assumption that the animal's behaviour is consistent, the variations in abundance should be the result of other drivers of change such as climate (Webeck and Pearson 2005:467). Identifying the animal species which contributed to the middens will go some way in beginning to understand the taphonomic processes that were also involved (Pearson 1997:41).

Loosely constructed middens can be open systems for long periods of time and are susceptible to re-working of material and to contributions from multiple species; this can make their stratigraphy extremely complex (Head et al. 1998:162; Pearson et al. 2001:439). If the midden is located in a dry setting, such as a rockshelter, and is cemented together by a matrix of crystallised urine (indurated), it should be impenetrable with very little, if any, re-working of organic material (Webeck and Pearson 2005:466). Middens are considered to be more reliable than loose cave sediments for preserving organic material (Pearson et al. 2001:439). For this reason, samples will only be collected from intact indurated middens that show minimal disturbances. They will then be interpreted using established techniques and methods which acknowledge the different physical characteristics that can occur (e.g. McCarthy 1999; Spaulding et al. 1990; Van Devender 1990; Webeck and Pearson 2005).

Middens are susceptible to a variety of conditions which can lead to the degradation of the material, such as might be caused by water and insects; this places some limits on sample size (McCarthy and Head 2001:683). Macrofossils have been the primary source of evidence for climate change in North American studies of pack rat (*Neotoma*) middens, but in Australia the preservation of plant macrofossils has not been ideal and they often cannot be identified to species or sometimes even genus level (Pearson and Betancourt 2002:504). To address issues of preservation bias, this project uses a multiproxy approach combining pollen, macrobotanics and aDNA analyses to help override the

weaknesses of each individual proxy. As mentioned above, only middens which a cemented together with crystallised urine and show minimal damage will be sampled.

Another limitation of this project has been the lack of access to commercial-in-confidence reports that detail the findings of archaeological excavations at some of the rockshelters where herbivore middens were sampled. The first of these issues does not detract in any way from the analysis or interpretation, and the latter issue can be dealt with in the future as reports and subsequent publications are forthcoming.

1.4 The Study Area

The study area, shown in Figure 1.1, is located within the boundaries of BHPBIO mining tenements which include Packsaddle Range, South Flank and Governor Range. These ranges are a part of the Hamersley Plateau, a mountainous area that transverses the Pilbara from roughly east to west (Thackway and Cresswell 1995:69). The hills and gorges of the Hamersley Plateau contain many caves, rockshelters and overhangs that are favoured habitats of small mammals (Baynes and McDowell 2010:285), and that also provided opportunities for people to shelter during inclement weather (Brown 1987:17; Clark 1982:24).

The wider Pilbara region is one of the oldest land surfaces on Earth and is geologically distinct from surrounding regions such as the sandy deserts to the north and east (Pepper 2013:1226; Pillans 2007:439). The geology is linked to a high diversity of regional habitats with different landforms and soil types supporting a range of vegetation compositions from open woodlands to hummock grasslands (Brown 1987:6–7; Pepper et al. 2013:1228). In the Biogeographic Regionalisation of Australia, the vegetation of the Hamersley Plateau has been described generally as, 'Mulga low woodland over bunch grasses on fine textured soils and snappy gum over spinifex grassland on skeletal sandy soils of the ranges' (Thackway and Cresswell 1995:69; see also Beard 1975).

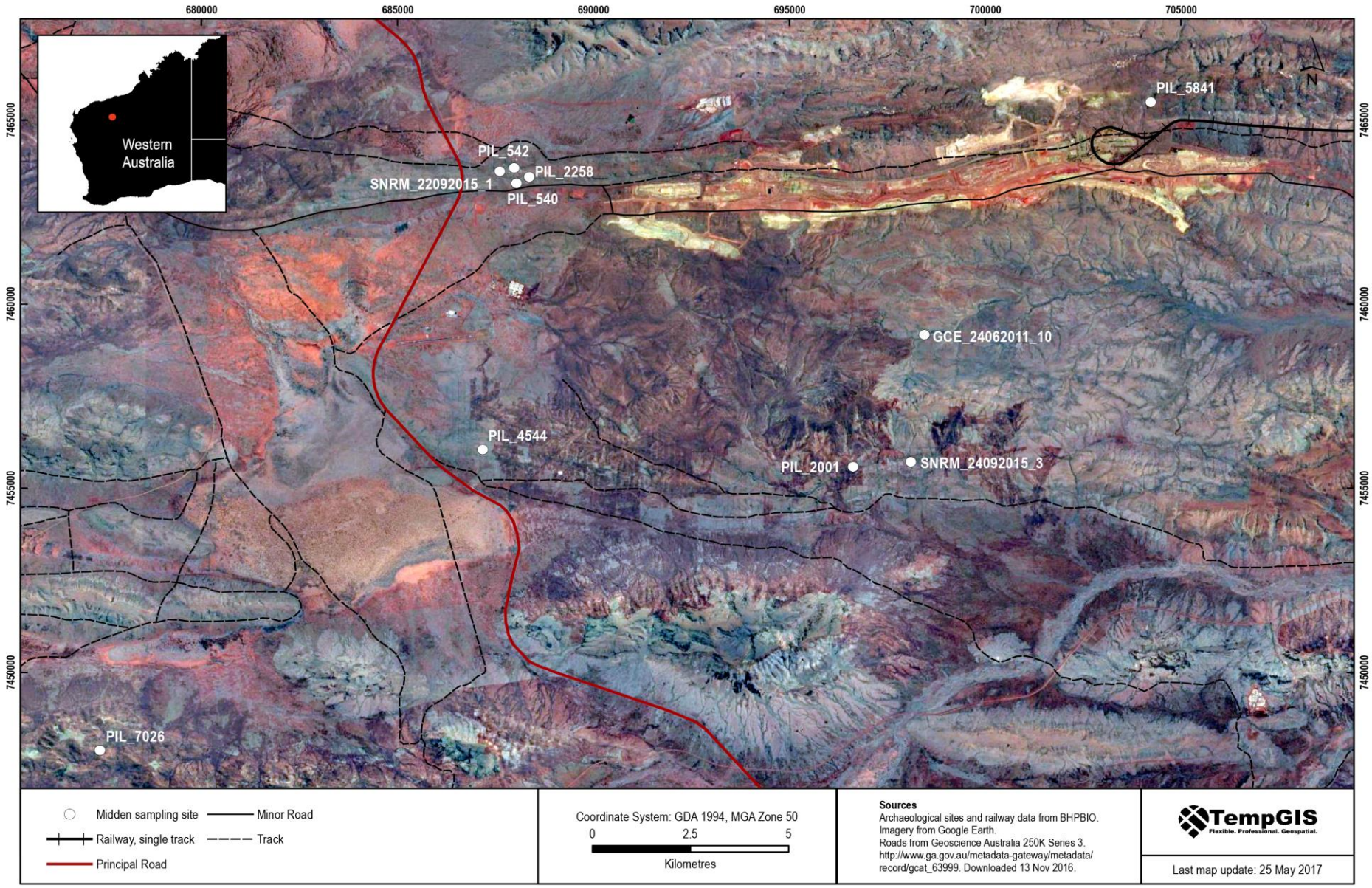

Figure 1.1 Location map for the Packsaddle Range area including the midden sites sampled during this project (map provided by TempGIS).

1.4.1 Climate

In the modern climate of northwest Australia, the Inter-tropical Convergence Zone (ITCZ) and the Indo-Pacific Warm Pool (IPWP) strongly influence the strength of the summer monsoon (Reeves et al. 2013b:98–99). The IPWP is sensitive to changes in the global El Niño-Southern Oscillation (ENSO) circulation system which involves interaction between the Pacific Ocean and its overlying atmosphere (Gagan et al. 2004:127). El Niño or La Niña events are caused by temperatures in the Pacific Ocean becoming warmer or cooler than usual; this brings increased variability in rainfall and temperature (Bureau of Meteorology 2012:2). The onset of ENSO brought a major shift in climate patterns across the Pacific, increasing aridity throughout the arid regions of Australia; this system is still active today (Turney et al. 2007:421).

The Pilbara region today is semi-arid and receives most of its rainfall from December through to the end of March when the summer monsoon is at its strongest. The Packsaddle study area receives an annual rainfall of about 300mm which is lower than the more elevated areas of the Hamersley Plateau which receive an annual rainfall of 500mm (Bureau of Meteorology 2017). While rainfall in the Pilbara can be highly variable, the frequent occurrence of summer thunderstorms and tropical cyclones means that long periods of drought are rare (Bureau of Meteorology 2017). Due to the high topography, the Hamersley Plateau has a higher annual rainfall than the adjacent lower plains areas and is close to the boundary of the intermediate area which receives both summer and winter rainfall (van Der Kaars and De Deckker 2003:115). Rainfall records for the Hamersley are only available for around the last 100 years show predominantly summer rainfall which can be highly variable (Bureau of Meteorology 2017). It is uncertain how far the recent variability in rainfall extends back through time (Fitzsimmons et al. 2013:80).

1.5 Thesis Outline

This chapter commenced with a background on inland Pilbara archaeology and then introduced the potential palaeoenvironmental archives known as middens. After providing this context, it introduced the research question, aims, significance, limitations and some important details about the study area.

Chapter Two reviews broad-scale palaeoenvironmental evidence applicable to northern Australia. It looks at some current issues in Australian archaeology which are being addressed through studies of human-environmental relationships and considers how the archaeological record of the inland Pilbara could be similarly approached. The chapter finishes by exploring the contribution that the study of middens has made to the understanding of arid and semi-arid climates to demonstrate how this might facilitate another avenue of inquiry for archaeologists working in the inland Pilbara.

Chapter Three summarises the methods used during the fieldwork and laboratory stages of the project. It details the preparation of samples and macrofossil analysis in the Flinders University Archaeology Lab (FUAL). Preparation and analysis of samples for pollen, micro-charcoal, hair and ancient DNA (aDNA), stages which were undertaken by specialists other than the author, are also outlined in this section.

In Chapter Four, the results from radiocarbon, pollen, micro-charcoal, macrofossil and aDNA analysis are presented using a series of graphs, tables and descriptions to describe results on a site-by-site basis. Following is a summary that integrates the results from all sites and analyses to provide an overview of vegetation change through time.

Chapter Five addresses the aims by discussing the chronology and the temporal resolution of middens and providing an overview of vegetation change through time in the Packsaddle Range

and surrounds; this overview is supported by comparisons with other broad-scale and regional paleoenvironmental evidence. It then discusses possible relationships between these findings and the local archaeological record and concludes with an assessment of the archaeological and palaeoenvironmental implications of the middens.

Chapter Six concludes the thesis by summarising the findings and re-addressing the research question and aims. It also makes recommendations for future research opportunities.

LITERATURE REVIEW

2.1 Introduction

This chapter starts with a review of the currently available broad and regional palaeoenvironmental evidence that is relevant to the inland Pilbara region. Secondly, it will explore the current developments in environmental archaeology in Australia, and will identify studies which have also used aspects of palaeoenvironmental research to understand more about the nature of human-environmental relationships. It concludes with a discussion about the development of midden research in Australia and where this situation stands today in order to provide the context for this project.

2.1.1 Palaeoenvironment

2.1.1.1 Continental

Palaeoenvironmental research in Australia has developed considerably during the last two decades, with numerous studies emerging mostly in the southeastern regions where there is greater access to traditional sampling locales (e.g. Fitzsimmons and Barrow 2010; Kemp et al. 2012; Reeves et al. 2013a:23, 99). This increasing number of regional and local studies has led to the development of the continent-wide syntheses which propose broad-scale patterns of climatic change; however, most of WA, especially the Pilbara, has largely been left out of these discussions (e.g. Fitzsimmons et al. 2013; Reeves et al. 2013a, 2013b; Turney et al. 2006, 2007). Continent-wide syntheses tend to focus on the history of the large-scale ocean-atmospheric drivers of climate change such as the Inter-tropical Convergence Zone and the Indo-Pacific Warm Pool (Reeves et al. 2013a:23). There is extremely limited information available for how these large-scale ocean-atmospheric systems interacted with the regional and local climate of the Pilbara, and very little is known about the response of the landscape and biota to such long-term climatic

change. Table 1.1 presents an overview of the broad-scale literature for palaeoclimatic change over the last 35,000 years alongside the evidence which is more specific to northwest Australia (this period was chosen as it coincides with the known period for human occupation in the inland Pilbara). At the very general level, it is agreed upon that from 35,000 BP, a warming and drying trend commenced which progressed into widespread aridity across the continent known as the LGM. Following the LGM, at around 14,000 BP, conditions became much warmer and wetter; this trend continued until the mid- Holocene when the onset of ENSO brought increased rainfall variability and drier conditions (e.g. Gagan et al. 2004:139; Hesse et al. 2004:98–99; Reeves et al. 2013a:27, 29). This information provides the backdrop for understanding the regional and local palaeoclimate.

2.1.1.2 Regional

The last 35,000 years of climatic change in northwest Australia has mostly been reconstructed from the palynological analysis of offshore sediment cores in the Indian Ocean (e.g. van der Kaars and De Deckker 2002; van der Kaars et al. 2006). The sediment cores provide the longest continuous record of palaeoclimate available for northwest Australia and they focus heavily on the varying strength of the summer monsoon as the main driver of climatic change (van der Kaars and De Deckker 2002, van der Kaars et al. 2006). The general pattern that has emerged from these studies is that from around 32,000 to 14,000 BP, there is a reduction in the effectiveness of the summer monsoon accompanied by drier conditions. After 14,000 BP, the summer monsoon reactivated and conditions were wetter. After 3000 BP, conditions were thought to be very similar to today with increased variability and winter/summer rainfall (van der Kaars and De Deckker 2002, van der Kaars et al. 2006). The pollen catchment of sediment cores is extremely large as demonstrated by the presence of Indonesian pollen spores in offshore WA cores that were transported by ocean currents (van der Kaars and De Deckker

	EARLY GLACIAL 35,000 BP - 30,000 BP	LAST GLACIAL MAXIMUM 30,000 BP - 18,000 BP	DEGLACIAL 18,000 BP - 12,000 BP	EARLY HOLOCENE 12,000 BP - 8,000 BP	MID HOLOCENE 8,000 BP - 5,000 BP	LATE HOLOCENE 5,000 BP - PRESENT
AUSTRALIA WIDE	Warming and drying trend commences (Reeves et al. 2013a:27).	Widespread aridity across the continent (Hesse et al. 2004:99). Cooler, drier and windier. Low carbon dioxide levels and reduced vegetation (Reeves et al. 2013a:30).	Increased spatial variability to landscapes (Fitzsimmons et al. 2013:91). Widespread climatic amelioration and increased water availability across the continent (Hesse et al. 2004:98).	Warmer and wetter than today (Reeves et al. 2013a:30).	The onset of ENSO begins to increase rainfall variability (Gagan et al. 2004:139).	Increased rainfall variability and drier conditions indicative of ENSO (Reeves et al. 2013a:29).
NORTHWEST AUSTRALIA	Relatively cool and wet but with increasing variability (Reeves et al. 2013b:108).	Reduced effect of the summer monsoon (Fitzsimmons et al. 2013:91).	Summer monsoon is active again at around 14,000 BP (Wyrwoll and Miller 2001). Wetter than today (van der Kaars and De Deckker 2002:37). Denser vegetation (Hesse et al. 2004:98).	Summer monsoon is at its peak (Reeves et al. 2013b:109).	Summer monsoon begins to weaken, drier conditions (Reeves et al. 2013b:108). The onset of ENSO begins to increase rainfall variability (Gagan et al. 2004:139).	Increased rainfall variability and drier conditions indicative of ENSO (Gagan et al. 2004:139; Shulmeister and Lees 1995:12).

Table 2.1 Palaeoenvironmental change since the Early Glacial period in Australia and northwest Australia.

2002). Offshore sediment cores are also more likely to reflect the regional coastal vegetation rather than inland vegetation as pollen concentrations decrease rapidly as the distance from the shore increases (van der Kaars and De Deckker 2002:24). Nevertheless, these records provide a useful backdrop for comparison with the inland Pilbara midden record, and offer valuable suggestions for the relationships that exist between a range of different vegetation species and the annual average rainfall.

Additional evidence for climatic change in northwest Australia comes from changes recorded in ancient foreshore dunes in the Gregory Lakes System and Fitzroy Basin WA (Bowler et al. 2001; Wyrwoll and Miller 2001; Veth et al. 2009). Bowler et al. (2001) provided climatic information based on the last 300,000 years of dune activity; however, the temporal resolution was very coarse and information for the last 60,000 years was missing due to sampling limitations (Bowler et al. 2001:77). Veth et al. (2009) investigated stratified units contained within a creek bed showing a record of lake phases between 20,000 and 50,000 BP, but encountered difficulties which are typical of geomorphic sources, such as the complexity of correlations between landforms and uncertainties surrounding thermoluminescence dating (Veth et al. 2009:9). Wyrwoll and Miller (2001) used evidence from Lake Gregory and the Fitzroy Basin to infer the reactivation of the summer monsoon at 14,000 BP following the LGM. While this does correlate well with van der Kaars and De Deckker's (2002:38) suggestion of a more effective summer monsoon and wetter conditions after 14,000 BP, there is currently no evidence for how this would have manifested at the local level in the Packsaddle area.

Very little is known about the local climate of the Pilbara region over the last 35,000 years. Macphail and Stone (2004) did analyse fossil pollen and spores preserved in organic rich-claystone in the Yandi iron ore deposits in the inland Pilbara; however, this record extends from the late Eocene to the early Miocene so has little relevance for archaeological research.

The broad-scale and regional palaeoclimatic evidence has shown similar trends of increasing aridity, amelioration and increased rainfall variability over the last 35,000 years; however, there is currently no direct evidence for how these fluctuations have manifested at the local or regional level in the Pilbara and the Packsaddle area specifically.

2.2 Human-environmental relationships

Spatially and temporally variable factors of the physical environment which are crucial for human survival, such as water availability, are known to be important drivers behind human behavioural change (Brown 1987:13; Fagan 1996:551; Ulm 2013; Williams et al. 2010:832). Environmental change affects the archaeological record indirectly by influencing human behaviours and decisions which then determine the nature and amount of physical evidence which is left behind (Attenbrow 2004:203). This field of investigation is commonly known as environmental archaeology, defined by the application of the Earth and biological sciences to study the relationships between humans and their environments (Reitz et al. 2008:3). Advances in palaeoenvironmental science have enabled archaeologists to examine the nature of human-environmental interaction in much more detail than ever before. Case studies that use the theoretical and practical approaches of environmental archaeology to integrate archaeological and palaeoenvironmental records have become increasingly available, but these are restricted to a limited number of regions (e.g. Branch 2005; Reitz et al. 2008; Crombé and Robinson 2017; Kelly et al. 2013). In Australia, archaeologists have tended to favour social and cultural drivers of behavioural change, but this is changing as the dynamic relationships that exist between humans and their environments become increasingly evident (Turney and Hobbs 2006:144; Vannieuwenhuyse 2017:172).

Regional studies in archaeology that use palaeoclimatic data exist mostly in the temperate and tropical zones. Asmussen and McInnes (2013) showed a close correlation between high levels of toxic *Macrozamia* seed use and the onset of ENSO-driven climatic conditions. Other studies such

as Bourke et al. (2007) and Holdaway et al. (2010) explore the relationship between past human behaviours and climate change by considering the archaeological record in the context of what is known of significant phases of climate change. These studies support the hypothesis that climatic change may have been a significant factor influencing human behaviour mainly through its role in changing the availability and predictability of important resources such as water (Bourke et al. 2007:98).

While these studies have proven that positive correlations exist, the climatic records used were sometimes extremely distant from the locations being studied; this was due to the lack of suitable proxies nearby. Bourke et al. (2007:91) used broad-scale information from the Indo-Pacific region, 'in the absence of regional or location specific palaeoclimatic data.' Asmussen and McInnes (2012:474) used climatic data from sources in the Galapagos Islands, Peru and the southern Ecuadorian Andes around 13,000 km away. Holdaway et al. (2010) investigated heat retainer hearths in western New South Wales but used palaeoclimatic evidence from New Zealand and a deep-sea sediment core in Southeast Asia. Holdaway et al. (2010:193) noted that this was not the ideal situation, but they clarified that their choice was due to the lack of appropriate palaeoenvironmental records in their study region. This highlights a widespread problem for studies investigating regional and local human responses to climate change: the absence of climatic records in many parts of Australia causing archaeologists to extrapolate, and the subsequent use of records that do not always acknowledge the possibility that local and regional variations may occur independently of broad-scale climatic systems (Haberle and David 2004:169).

Studies that have utilised local sources of palaeoclimatic data are few and far between in Australia, but those that do exist demonstrate that comparing records can reveal the complexity of human responses to local environmental contexts. Work conducted in the Kimberley region of northwest Australia is an excellent example of the use of local palaeoenvironmental records to help understand patterns and diversity in the archaeological record. McGowan et al. (2012) used

climate information from a mound spring sediment core to positively correlate the onset of ENSO with local changes in rock art styles. While Field et al. (2017) do not explicitly compare their data from peat springs against the archaeological record, they recognise the importance of their research for providing a context for the archaeological record as 'essential.' Veth et al. (2009:9) also identified the enormous potential in the use of the Lake Gregory system in the Kimberley for studying human-environmental relationships, but as mentioned earlier, the use of geomorphic sources of data has been a challenge because of the complexity of the landscape and difficulties in luminescence dating. Wallis (2001) examined phytoliths from the Carpenter's Gap 1 rockshelter to reconstruct local vegetation patterns and climatic conditions. Vannieuwenhuyse et al. (2017) used micromorphological analysis at the Carpenter's Gap 1 and 3 shelters to develop a comprehensive reconstruction of human-environmental relationships over the past 50,000 years. The introduction of palaeoenvironmental archives in the form of herbivore middens in cave and rockshelter contexts might enable similar types of studies to be conducted in the inland Pilbara.

Unfortunately for the rest of northwest Australia there are relatively few sites that preserve palaeoenvironmental data in such close association to archaeological deposits (Field et al. 2017). It would be ideal if the climatic records from the Kimberley region mentioned above could be transferrable to the Pilbara; however, the Kimberley has a much higher rainfall with a stronger seasonal climate (Marwick 2002b:21; Veth 1995:733). In the Pilbara, archaeologists have often extrapolated records from other locations in northern Australia to try and describe the palaeoclimatic context of their research (Bulloch 2011:6–9). Bulloch (2011:7) referred to the work of van der Kaars and De Deckker (2002) but acknowledged that, 'there may have been very different environmental conditions in the inland Pilbara,' yet the information from that core was the, 'best available' at the time (this situation is unchanged). The use of extrapolation can be highly problematic given the growing recognition that current regional climates can be highly variable, and regions separated by hundreds of kilometres may have experienced very different climatic conditions over time (Reeves et al. 2013; Williams 2015a:91). Van der Kaars and De

Deckker (2002) analysed pollen from off-shore marine sediment cores in the Indian Ocean to demonstrate changing vegetation through time; however, these records reflected only regional coastal vegetation (van Der Kaars and De Deckker 2002; van Der Kaars et al. 2006). The pollen catchments were also extremely large, with ocean currents transporting pollen from regions as far away as Indonesia and New Guinea (van Der Kaars 1991).

Marwick (2002b:23) gave a comprehensive overview of the past climate of the arid interior including the Kimberley, but in the absence of published local environmental data, he assumed that the conditions in the inland Pilbara were similar to the interior. Other studies from the Hamersley Plateau mention little about the role of climate despite discussing such ideas as the nature of occupation during the LGM (e.g. Hook 2009; Hughes et al. 2011). Slack et al. (2009:38) proposed that increasing rainfall influenced residential mobility after the LGM; however, they do not specify what climatic records support this. According to Weiming Jia (2011:80), palaeoenvironmental research applied to archaeological contexts should be, 'strongly detail-focused and firmly grounded in specific time, space, and cultural contexts.' While there are broad-scale climatic records available, there is currently no evidence of such a detailed and specific nature available for which to compare to the archaeological record.

The recent introduction of the continent-wide syntheses in palaeoenvironmental science has provided a context for archaeologists to also consider broad-scale trends (e.g. Fitzsimmons et al. 2013; Reeves et al. 2013a, 2013b). Studies by Williams et al. (2010, 2015a, 2015b) have proposed a new continental narrative for human settlement by adding a human component to the newly available continental syntheses for palaeoclimates (e.g. Fitzsimmons et al. 2013; Reeves et al. 2013a, 2013b). They used time-series analysis of radiocarbon dates to reconstruct population histories and compared these to mostly broad-scale climatic histories for a wide range of time periods and environments (Williams 2015b:105). The general assumption is that frequencies of radiocarbon dates can be used as proxies for changes in population on the basis that the dates represent occupational events (Williams et al. 2010, 2015a, 2015b). A clear gap in coverage of

these models is the Pilbara region, where they have been unsuccessful at revealing any new information, especially about its role as a refugium (Williams et al. 2015b:4623).

The continental narratives of Williams et al. (2010, 2015a, 2015b) have not been without criticism. Hiscock and Attenbrow (2016) have raised serious concerns about the use of radiocarbon dates as evidence for population size. They state that there are serious analytical, conceptual and methodological flaws in their broad-scale narratives and argue against the, 'overly simplistic nature' of inferences. Furthermore, Smith et al. (2008:399) consider the use of broad-scale climatic histories to inform the archaeological record to be a less favourable alternative to fine-grained regional palaeoenvironmental records. Ulm (2013) agrees that more regional studies are needed to recognise the complex differences in human behaviours between regions, and to avoid treating humans as a one-dimensional group (Denham and Mooney 2008:369). Weiming Jia (2011:80) describes broad-scale models as having their use as simple and accessible overviews, but recommend that research should focus on individual sites within small areas and with narrow time periods. Williams et al. (2010, 2015a, 2015b) appeared to agree with these sentiments, and concluded that there is still a need for more detailed archaeological investigations which are targeted at the local and regional scales (e.g. Williams et al. 2013:4623; Williams et al. 2015b:91). For this to be possible, there needs to be more local and regional palaeoclimatic studies that are spatially constrained, such as Wallis (2001:103) suggested for the northwest region. The locally and regionally constrained nature of amberat middens may fulfil this need.

2.3 Amberat Middens

Amberat middens are found in many parts of the world and are produced by the following: pack rats (Neotoma) and porcupines (Erethizon) in North America; viscacha (Lagidium), leaf-eared mice (Phyllotis), chinchilla rats (Abrocoma), and mountain degu (Octodontomys) in South America; rock hyrax (Procavia capensis) and dassie rat (Petromus) in Africa and the Middle East; and mountain voles (Alticola) and pikas (Ochotona) in Central Asia (Elias 2013:674). The presence of a bitumen-

like, indurated material in Gnalta rockshelter in western New South Wales was first noticed and analysed for palaeoenvironmental purposes in 1979. It was in this study that the material was first attributed to the stick-nest rat based on the faecal pellets that were present (Green et al. 1983:32, 34). It did not take long for this material to be compared with that of pack rats in North America, for which there was already an extensive amount of literature available (Green et al. 1983:32). According to Green et al. (1983:34), the similarities between the midden from Gnalta and pack rat middens were 'striking.' In the beginning, there were high hopes that Australian middens would provide information about past vegetation dynamics to the same degree (Green et al. 1983:32). Pack rat middens have made a huge contribution to the understanding of late Quaternary climates and ecological change in North American arid and semi-arid environments. The methods and approaches used in packrat midden research have been applied to Australian middens with the hope of achieving the same magnitude of success (Pearson and Betancourt 2002:499–500). This optimism is illustrated best in the comment by Pearson and Dodson (1993:347) that Australian middens may be, 'one of the keys to unlocking the late Quaternary environmental record of the Australian arid zone' (Pearson and Dodson 1993:347).

Soon after their initial analysis, Berry (1991) and Nelson et al. (1990) looked at the macrofossil contents of middens from central Australia, and were the first to apply analytical methods standardised for use in pack rat midden research (e.g. Betancourt and Davis 1984; Betancourt et al. 1986; Spaulding et al. 1990; Van Devender 1990; Webb 1986; Wells 1976). From about 1993 to 2001, there were numerous studies of Australian middens which applied methods of pollen and macrofossil analysis with a very strong focus on taphonomic issues. These studies have mostly relied on pollen evidence, which gives both a regional and localised picture of vegetation. The use of plant macrofossils, often considered as secondary evidence, can give extra local site-specific reconstructions of vegetation based on the animal's collecting proclivity (e.g. Allen et al. 2000; Berry 1991; Green et al. 1983; McCarthy 1999; McCarthy and Head 2001; McCarthy et al. 1996; Nelson et al. 1990; Pearson 1999; Pearson and Dodson 1993; Pearson et al. 1999). This was due

to the often fragmentary nature of macrofossils and the perceived greater diversity and abundancy of pollen. The main conclusion reached by all is that only very subtle changes in vegetation could be detected using pollen analysis, and that these records could be interpreted as temporal 'snap-shots' rather than continuous records. It is important to note that most of these middens date within the last 4,000 years (Allen et al. 2000; Pearson 1999:43; Webeck and Pearson 2005:468). Pearson and Betancourt (2002:504) did not think that these previous analyses had provided a definitive view of Holocene vegetation, and that it may have been beyond what is identifiable with current macrofossil and pollen analysis techniques alone.

The application of aDNA techniques in the study of herbivore middens is relatively recent and has shown to be a promising step forward that is complementary to the traditional methods of pollen and macrofossil analysis (JØRgensen et al. 2012:1996; Murray et al. 2012). Ancient DNA analysis has proven its ability to detect plant species identified in the pollen and macrofossil analysis of middens, while also identifying some species which could not be detected by those traditional techniques (Murray et al. 2022). Ancient DNA sequencing can also identify midden contributors to a much more detailed taxonomy (Pearson and Dodson 1993:34). Despite further research that is needed, Murray et al.'s (2012) study shows that middens are a valuable source of material for aDNA analysis and there is much potential for applying this methodology to Australian middens where palaeoenvironmental data is lacking.

The study of packrat middens in North America has made dramatic contributions to the understanding of long-term environmental change. The evidence from Australian middens was considered by Pearson and Betancourt (2002) to be much less dramatic in comparison. Pearson et al. (1999:306) suggested that due to the late Holocene age of most middens and the possible stability of Australian ecosystems during this time, it would probably be unlikely that major environmental change would be encountered in the record. Despite not providing the dramatic results expected by earlier studies, middens have still enriched the knowledge about biotic change in central parts of Australia by providing a localised record of flora and fauna (Murray et al.

2012:136; Webeck and Pearson 2005:466). It would be reasonable to assume that this knowledge could also be extended to the inland Pilbara, especially if middens of greater antiquity can be discovered.

Pearson and Betancourt (2002:503) made a point that Australian researchers have tended to be preoccupied with taphonomic issues, namely stratigraphic problems, and that perhaps the resources could have been, 'put to better use dating more deposits and increasing the chance of extending the chronology into the Last Glacial.' Pearson and Betancourt (2002:506–507) suggested that for the future direction of Australian based research, 'the search for middens of great antiquity needs to be restarted' and that, 'the sampling needs to use a more synoptic perspective to select prospective sites.' It is especially encouraging that a midden recorded at Mount Brockman in the inland Pilbara has returned the oldest radiocarbon date in Australia (30,490 ±380 BP; this date remains unpublished) (MacPhail 2011). This is an extremely significant find given that majority of middens studied so far have only been dated to within the last 2500 years (Pearson et al. 1999:301). There is a critical need for further synoptic dating of the inland Pilbara middens in order to determine the range of dates available, and to assess their potential for more targeted research.

2.4 Conclusion

When amberat middens in Australia were first studied, there were great hopes that applying the same techniques and approaches from pack rat midden research would achieve the same results. While most studies have only found subtle changes in Holocene vegetation, this may represent stability and resilience. Pearson and Betancourt (2002:503) suggested that the focus needed to shift from detailed stratigraphic work to dating of middens to find pre-glacial or glacial middens. The inland Pilbara middens have not been previously investigated, but the 30,490 ±380 BP age of the Mount Brockman midden previously recorded from the inland Pilbara is very promising (Macphail 2011). If the middens in the Packsaddle area prove to be of a similar age range and can

provide a long-term record of local climatic change, researchers would be less inclined to utilise only broad-scale models which disregard regional variation (Ulm 2013:185). Furthermore, middens have the potential to provide the missing link between climatic change and patterns of change in the archaeological record. Middens may be considered a novel approach, but the absence of any other sources of regional or local paleoenvironmental data makes them a valuable alternative to unreliable and broad-scale extrapolations from geomorphic sources and distant offshore sediment cores.

METHODOLOGY

3.1 Introduction

This chapter outlines the field and laboratory methods used to extract and analyse proxy data from the amberat midden samples in order to develop a preliminary overview of vegetation change and determine the palaeoenvironmental implications of the middens.

Amongst others, Pearsall (1989:455) and Chase et al. (2012:114) emphasised the importance of using multiple sources of evidence for reconstructing vegetation change because it permits the building of reliable, precise and unbiased models of vegetation dynamics. Pollen and macrofossil analyses have traditionally been used together in palaeoenvironmental studies because the latter tend to represent local vegetation communities while the former represent regional vegetation communities (Birks and Birks 2000:31). Pollen and macrofossil data therefore complement each other and, in addition to aDNA (which has been shown to identify species that are not evident in pollen and macrofossil analyses), the three sources of evidence work together effectively (JØRgensen et al. 2012:1996; Murray et al. 2012:141).

For this project, pollen, micro-charcoal, macrofossil and aDNA data were interpreted within a chronological framework to develop a preliminary overview of vegetation change in the Packsaddle Range area.

3.2 Field Methods

3.2.1 Survey

Field survey was carried out in September 2015 to locate and collect potential herbivore middens in the Hamersley Plateau region of the inland Pilbara. Rather than a random sampling strategy, a targeted strategy was adopted to ensure that adequate material would be recovered to allow the project to be undertaken. Samples were collected from sites that were known to contain midden deposits based on information from previous archaeological surveys, and local knowledge of Banjima and BHPBIO representatives. Additional sites were located using systematic surveys to target ridgelines where deep rockshelters and overhangs of the morphology suited to the accumulation of such deposits were most likely to occur. These types of geological features provide the protection needed to facilitate the preservation of midden deposits, which are extremely sensitive to dissolution in water (McCarthy and Head 2001:683). A total of 51 samples were collected from 34 middens at 11 sites in the Packsaddle Range, South Flank and Governors Range within the boundaries of BHPBIO tenements.

3.2.2 Midden Sampling

A standard recording form was developed to systematically collect information about each site and the middens that were sampled (Appendix 1); this information was later entered into an Excel spreadsheet. The approximate dimensions of each midden were measured and sketched, and the condition of the nest was evaluated. Where available, a pre-existing site plan was used to plot the location of each midden within the site. If no site plan was available, a sketch plan was made of the site and the locations of each midden recorded. In addition to the information gathered in recording forms, photographs were taken to capture the general location and the scale of each midden (cf. McCarthy and Head 2001:683) (Figure 3.1).

The selection of middens for sampling was based on the availability and accessibility of the deposits. In nearly all cases one sample was taken from each discrete deposit. However, some of the middens encountered were too high for a person to reach from ground level and, as we were working within a mining tenement, would have required a 'Working at Heights' permit and scaffolding to sample. As this was not logistically feasible, in such instances the locations of these middens were noted on the site plan in the anticipation that they might be sampled in the future. Samples were carefully removed from the underlying banded ironstone formation substrate using a hammer and chisel, and were bagged and labelled individually with a site name and unique identification code. Where possible, one sample was taken from each midden deposit; multiple samples were taken from the larger deposits to identify any possible stratigraphy. Where samples were very small, the entire deposit was taken. A bulk sampling method was chosen to identify late Pleistocene aged middens with potential for further stratigraphic sampling, as these can be used to address questions about long-term vegetation change (Pearson 1999:305).

Figure 3.1 Midden PIL_542 SNR 7 in situ inside a crevice (10 cm scale).

To assist with pollen and macrofossil identifications the surrounding plant species from around each site to a range of around 150 m were qualitatively described; this distance represents the observed foraging range of the greater stick-nest rat in trial reintroductions to arid Australia (Moseby and Bice 2004:119). Plant species identifications were made by reference to a vegetation list for the local area, and the knowledge of Wallis and BHPBIO representative Peter Sweeny. Owing to restrictions on the removal of plants from the BHPBIO mining tenement, no samples of the modern vegetation could be removed for use as reference material.

3.3 Laboratory Methods

The 51 field samples were sub-sampled for radiocarbon, pollen, aDNA and macrofossil analyses (see Figure 3.2 for overview). Sub-samples were removed carefully ensuring that a portion of each sample was left unprocessed for future research. Twenty-nine of the samples were subject to radiocarbon dating. All samples underwent pollen analysis and processing to extract macrofossils. Macrofossil analysis was only conducted on the 29 dated samples as, without a temporal context, it was not possible to reconstruct vegetation changes over time. Six sub-samples were sent for a pilot study to assess the feasibility of using them for aDNA analysis. Individual hairs were selected from processed samples and sent to Dr Jeff Foulkes to potentially identify the midden contributor(s); however, due to logistical issues, the results could not be finalised for inclusion in this project.

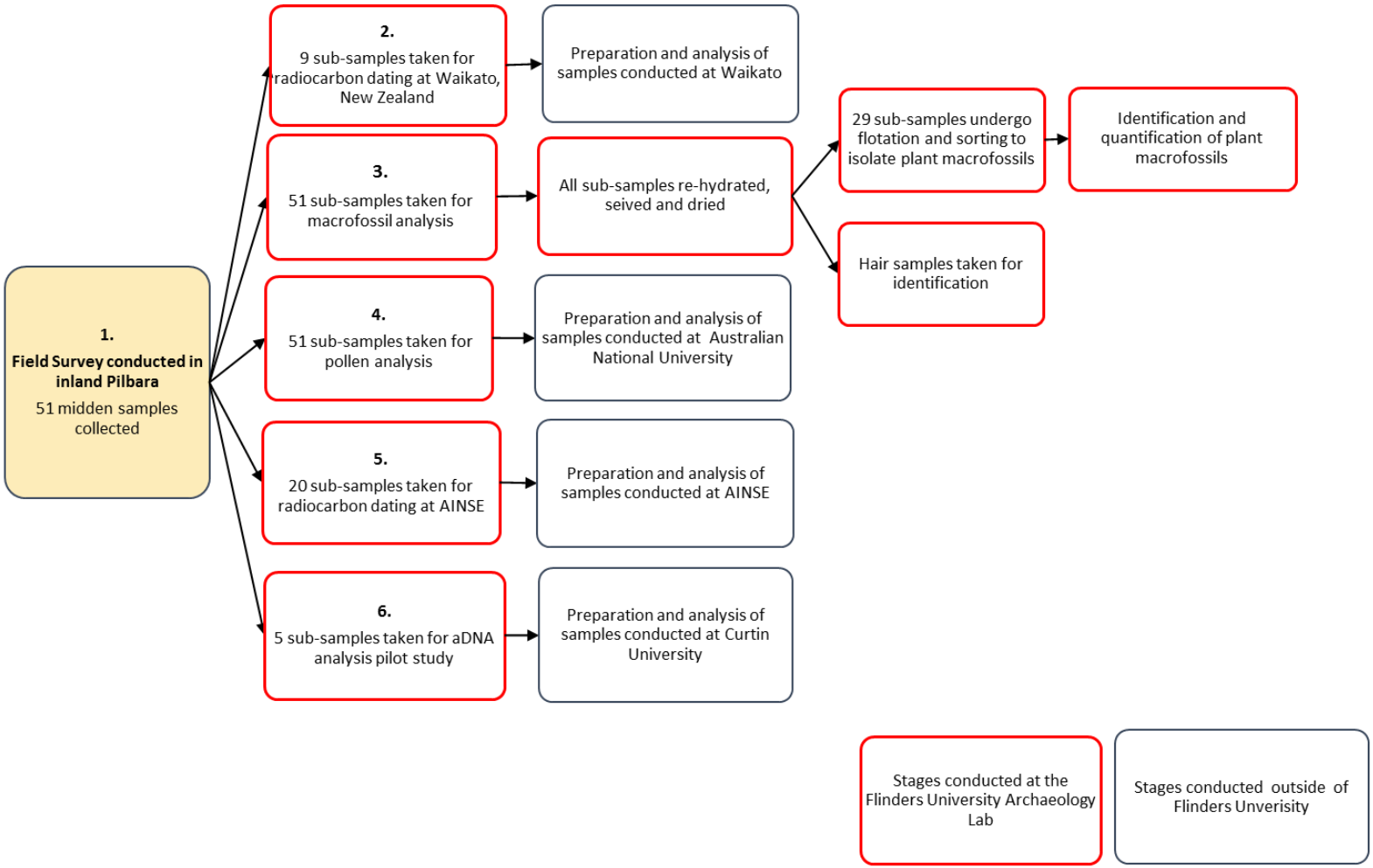

Figure 3.2 Flow chart summary of methodology.

3.3.1 Radiocarbon Analysis

The main purpose of radiocarbon analysis is to provide a chronological context for the recovered pollen, macrofossil and aDNA. In other studies of stick-nest rat middens, this has been achieved using standard radiocarbon dating, or accelerator mass spectrometer (AMS) dating of amberat, scats, plant fragments and wood (e.g. Allen et al. 2000:335; McCarthy et al. 1996:209; Pearson 1997:70). For this project, BHPBIO provided funding for nine sub-samples to be radiocarbon dated at the Waikato Laboratory, New Zealand. A subsequent successful application to the Australian Nuclear Science and Technology Organisation (ANSTO) for facility access and funding, led to the submission of a further 20 sub-samples for dating. Owing to the limited funding available for dating, and so as to maximise outcomes from the macrofossil analysis, the decision was made to focus the dating attempts on the middens that yielded the highest amounts of vegetative material.

The nine sub-samples for dating at Waikato were selected in the early stages of the project before re-hydration to extract macrofossils was undertaken. The selection of these sub-samples was based on a visual examination to identify areas which contained a visible amount of plant material and/or scats suitable for dating. Studies in Australia have found that the dating of scats provides the most accurate estimate of midden age, as the age of the scat is most closely associated with the age of occupation and construction of the midden (Pearson 1997:70; Pearson et al. 2001:437; Webeck and Pearson 2005:467). Scats are also rich in plant materials which directly reflect the atmospheric C14 content, making them ideal for radiocarbon dating (cf. Turney et al. 2006:753). At Waikato, unprocessed samples were homogenised and then chemically pre-treated for standard radiocarbon and AMS dating. Samples were washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

The 20 samples that were chosen for dating at ANSTO were selected after re-hydration. These samples were shown to have high weights of yield per sample (meaning they contained more potential material for macrofossil analysis with potentially high levels of plant material) and so sub-samples of the

corresponding unprocessed midden were sent for dating. The samples represented a range of sites across the entire study area affording good spatial coverage. They also contained suitable material for radiocarbon dating such as abundant visible organics and intact animal scats. Areas with visible plant material and scats were targeted in close proximity to where pollen sub-samples had been removed from, as this material can be assumed to be contemporaneous (Pearson et al. 1999:304). Where possible, the samples were taken from the interior portions of the midden to minimise the risks of external contamination. Treatment and preparation of samples for AMS dating was conducted at ANSTO. Samples were treated with a standard treatment acid to remove soluble contaminants. After drying, the extracted macrofossils underwent combustion to extract the carbon as carbon dioxide. This was then converted into graphite, so that the carbon could be analysed in the accelerator.

The radiocarbon dates from Waikato and ANSTO were calibrated in OxCal version 4.3 using the SHCal13 Southern Hemisphere calibration curve (Bronk Ramsey 2009; Hogg et al. 2013).

3.3.2 Pollen and micro-charcoal

Australian studies of stick-nest rat middens have shown that the number of preserved pollen within middens is sufficient for reconstructing vegetation change (e.g. Allen et al 2000; McCarthy and Head 2001). Pollen can be deposited into middens in a variety of ways: wind-dispersed, animal dispersed (on plants used for nest building, attached to fur and in scats), slope wash and insect dispersed (Haberle and Hopf 2016; Pearson 1999:39) (Figure 3.3).

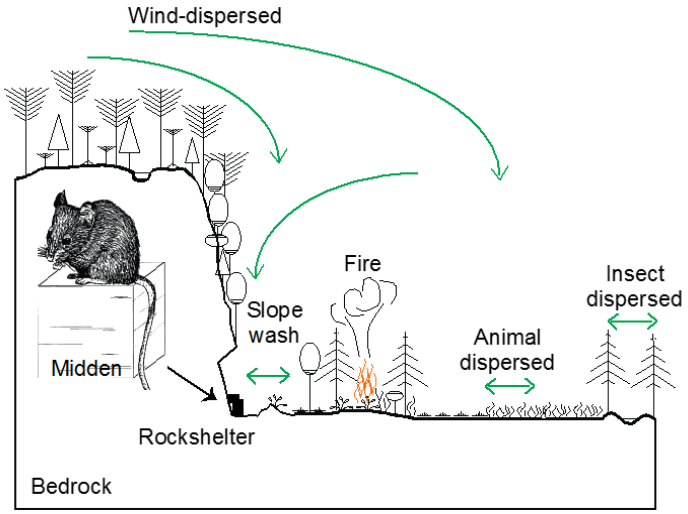

Figure 3.3 Model of potential pollen dispersal mechanisms from the source plant to the point of deposition (herbivore midden) (Model by Haberle and Hopf 2016).

Sub-samples were taken from all 51 samples and sent for processing at the Australian National University (ANU) by Professor Simon Haberle and Ms. Feli Hopf (Appendix 3). The sub-samples were removed from areas of the midden containing abundant plant material close to the locations where sub-samples were also removed for radiocarbon dating and assumed to be contemporaneous (Pearson et al. 1999:304). This ensured a close association between the pollen results and the time period that they represent.

The methods used for pollen analysis were adapted from previous studies (Webeck and Pearson 2005; Pearson and Betancourt 2002; Allen et al. 2000; McCarthy et al. 1996). These are described by Haberle and Hopf (2016:2) as follows:

> Samples were weighed and sample volume estimated by water displacement in a graduated cylinder, ranging from 1.5-3.5cm^3 and 1.36-4.46g, respectively. Pollen processing included dissolving the sample in water, followed by standard HCl, KOH and acetolysis methods (Faegri and Iversen 1989), including addition of *Lycopodium* marker grains to calculate concentrations of pollen, spores and microscopic charcoal (Stockmarr 1971) and sieving through 125 µm mesh to remove macroscopic material. Lithium polytungstate was used at a specific gravity of 2.0 to further concentrate pollen in the samples (Caffrey and Horn 2013). Pollen, spores and microscopic charcoal (> 10µm) were counted at 400 x magnification using a Zeiss Axiophot microscope and identifications made using the reference collection held at the Department of Archaeology & Natural History, Australian National University (ANU) and the Australian Pollen and Spore Atlas (APSA Members 2007). Pollen

percentages were calculated using the total pollen sum (minimum of 200 pollen grains counted). Pollen diagrams were produced using Tilia v. 2.0.33 (Grimm 2013).

Fine fragments of charcoal and burnt grass phytoliths preserved alongside pollen remains in herbivore middens can be used to infer fire occurrence through time in the landscape. Haberle and Hopf (2016:3) quantified micro-charcoal (considered to be the fraction between 10 to approximately 125) on pollen slides to measure peaks in charcoal abundance (Whitlock and Larsen 2001). These were interpreted to represent possible fire episodes in the past that may have contributed to changes in the vegetation recorded in the pollen record. Micro-charcoal is dispersed in a similar fashion to pollen, though larger and heavier fragments are less likely to be transported long distances by wind or insect dispersal (Haberle and Hopf 2016:3) (Whitlock and Larsen, 2001) (Figure 3.3).

3.3.3 Macrofossils

Recovery

The midden samples were heavily indurated and required processing to extract the macrofossils. This method of extraction is well established by studies in North America and Australia (e.g. McCarthy 1999; Spaulding et al. 1990; Van Devender 1990; Webeck and Pearson 2005), and followed techniques described in Berry (1991:306), McCarthy (1999:62), and McCarthy and Head (2001:683).

Prior to soaking, middens were sub-sampled using a hammer and chisel to remove sections ready for processing that had the least amount of visible contamination (e.g. plant material loosely attached to the outer surface). Each sample was cleaned using a stiff brush to remove any loose surface contaminants and weighed. Information including the initial weight, soaking/drying time and dates, and the final processed weight of sample were recorded on a standardised recording form (Appendix 2) (Figure 3.3).

Figure 3.4 Indurated middens prior to soaking. Left: PIL_5841 SNR 3, Right: PIL_5841 SNR 1.

Samples were placed into large, clean plastic containers and completely submerged in de-mineralised water, with a lid placed on to prevent any airborne contaminants (Figure 3.4). They were given 5–10 days to completely disaggregate depending on size. During the soaking period, samples were checked regularly and agitated to speed up the disaggregation process. Once disaggregation was complete, the re-hydrated residue was wet sieved through a 500 µm stainless-steel sieve to capture macrofossils. The sieving process required repeated washing of residue with de-mineralised water to remove all traces of crystallised urine and very fine sediments (Figure 3.5). The residue was spread onto a metal tray lined with absorbent paper towel and placed into the drying oven for approximately 12 hours at 40°C or until dry. Once completely dry, the sample was bagged, weighed and labelled prior to sorting.

Figure 3.5 Soaking process at FUAD.

Figure 3.6 Sieving a sample at FUAD.

Sorting and Flotation

Of the 51 samples that were collected during the field survey and rehydrated, 29 were analysed in detail to identify plant macrofossils. These were the same samples which had been radiocarbon dated, as this provided a framework for the macrofossil analysis. Without a known date associated with the midden, the nature of vegetation change over time cannot be determined. The remaining undated but processed samples have been retained for possible future research.

Manual sorting of entire samples was found to be time consuming and difficult due to the mixture of very fine sediments and plant materials and the large size of some samples. Previous published studies of herbivore middens noted that sorting was done under magnified lamp, but given their much larger scopes, the time taken to sort the samples seemed to be less of a concern (Allen et al. 2000:334; McCarthy 1999:62; McCarthy et al. 1996:209). After attempting to sort the first sample it became apparent that some modifications of the conventional methods were needed to meet the project timelines while still achieving a high level of sorting accuracy.

As an alternative to manually hand sorting samples, flotation was chosen to isolate macrofossils from inorganic material. Flotation is a popular method used in archaeology to recover all sizes of macrobotanics from sediments (cf. Pearsall 1989:19). Testing the technique using a dummy sample of similar physical make up as the midden samples showed that it would be an effective technique to reduce sorting times despite requiring some minor hand sorting after.

Again, owing to the large size of many of the samples and the time constraints on the project, samples were again sub-sampled. Pearsall (1989:120) recommended sorting only 25–50% of a sample to obtain representative plant assemblages. Prior to flotation, 14 g, 7 g or 3.5 g sub-samples were taken from each sample, and placed into a petri-dish. Fourteen grams represented 50% of the average total weight of yield of the 29 re-hydrated samples. However, some of the samples fell under this weight so smaller samples were taken to leave a sufficient amount of sample for future analysis while keeping within the 25–50% range. The 25–50% sample sizes were manageable for the scale of laboratory equipment, and sufficient to achieve the aims of the project within the available time.

Using precision scales, samples were placed into labelled petri dishes and the exact weight was recorded. Samples were viewed under magnified lamp to remove coarse gravels and pebbles so that they did not contribute to the weight of the representative sample.

Each sample was added to a bucket containing 1.5 L of de-mineralised water. The water and sample were stirred to create a whirlpool effect which suspended the plant material (light fraction), leaving behind the heavy fraction (rocks, sediment) in the base of the bucket. The light suspended fraction was carefully decanted into a 500 μm sieve. The heavy fraction was removed separately and dried alongside the light fraction in a drying oven at 40°C for around three hours or until dry (Figure 3.6). Both fractions then underwent detailed sorting to isolate the identifiable components of the plant material.

Figure 3.7 Flotation of sample and finished result showing separated heavy (left) and light fractions (right).

Both fractions were sorted under a magnified lamp to isolate the plant material, which was then weighed collectively prior to further identification of individual types. In conventional studies of stick-nest rat middens, samples are sorted into other categories such as insect remains, faecal pellets and bones and teeth (e.g. McCarthy 1999:62). However, there was very little bone/tooth material recovered from the Packsaddle samples. Due to insufficient quantities of such faunal material, plant macrofossils were the only category with sufficient materials to warrant analysis at this stage. The remaining samples will be maintained for future research.

Identification

A stereo zoom microscope (model no. ASZ400) was used at 10x magnification to scan plant material for potentially identifiable plant macrofossils with diagnostic features and plant parts that could be matched with reference materials. Photographs of distinct macrofossils were taken using a Dino-Eye C-Mount camera (model no. AM-7023CT) at magnifications ranging from 10x to 45x depending on the size of the macrofossil(s). Macrofossils were identified using FloraBase (www.florabase.dpaw.wa.gov.au) and Seeds of South Australia (www.saseedbank.com.au), in addition to reference books by Bonney (1994), Erickson et al. (2016) and Sweedman and Merritt (2006). Identifications were also made with the assistance of Dan Duval at the South Australian Seed Conservation Centre and Helen Vonow at the State Herbarium

of South Australia. It was difficult to always identify to the species level due to variable preservation, but in many cases, a genus level identification could be made. In some instances, the types identified could not be matched with known reference material. In such instances, the type was assigned as 'Unidentified type A', 'Unidentified type B' etc., and a description of the characteristic features noted. It is possible that future research may allow these types to be identified to at least the genus level.

Numerical counts of identified plant macrofossils were volumetrically adjusted and expressed as relative counts. This method accounts for the differences in representative sample size. For each sample, the weight of the representative sample was divided by the weight of the heaviest sample (14.094). This volumetrically adjusted weight was then multiplied by the numerical counts to determine the relative counts. The raw numerical counts are presented in Appendix 5. The relative counts were used to determine which plant species were present in the middens at different moments in time and this was used to express possible changes in vegetation assemblages over time. These results were then compared to the results from the radiocarbon dating, pollen and aDNA analyses.

In order to assess the potential of the Pilbara herbivore middens to provide palaeoenvironmental information, it was important to determine the source of the middens. Knowing the source of the middens would potentially impact on how the radiocarbon, pollen, macrofossil and aDNA information could be interpreted as it could influence our understanding of the likely accumulation processes and introduce contamination risks (Pearson 1997:41). While the morphology of the middens and common understandings suggested the stick-nest rat was the likely midden contributor, there was also a possibility that another animal, or combination of animals, contributed to the middens. Both Berry (1991:308) and Pearson (1997:234) found that midden contributors may have included brushtail possums, rock wallabies, and burrowing bettongs as evidenced by scats (faeces), bones and hair. In a more recent study by Murray et al. (2012), herbivore middens similar to those in the current study (including one from Brockman Ridge in the Pilbara), were shown to contain DNA from a range of Australian rodent species not just stick-nest rats. Initial visual examination of the middens after collection

showed that there was a large amount of hair embedded within the indurated samples. Animal hair is a durable substance that can survive long periods of time in a range of contexts (Bonnichsen et al. 2001:775). Numerous characteristics of the hair can be examined to identify the animal from which it derives (Huffman and Wallace 2012:129). The species of animal(s) represented in the Pilbara middens were identified using a combination of visual hair analysis, and aDNA analysis. For the visual hair analysis, hairs recovered from samples after the re-hydration process were selected and sent to Dr Jeff Foulkes of the Nature Conservation Society of South Australia. It was intended that Foulkes would examine cross-sections of the hair shaft; however, the results of this analysis are still forthcoming.

Ancient DNA analysis is useful in the absence of, or in addition to, faunal macrofossils for identifying midden contributors. Ancient DNA analysis can successfully identify not only plants present in the middens, but also animals to a much higher taxonomic level than can be achieved through bones, hair and faecal pellets alone (Kuch et al. 2002:913; Murray et al. 2012). It was intended for aDNA analysis to identify the animal contributors of the inland Pilbara middens; however, the animal aDNA results were not prepared in time for inclusion in this project.

3.3.4 Ancient DNA

Middens were sub-sampled at FUAL and then sent for aDNA analysis to Mr. Daniel Werndly at Curtin University, WA. Sub-samples from the initial six radiocarbon dated middens were sent to Werndly for a pilot study to assess the preservation of DNA of the samples. Both un-processed and processed samples were treated at Curtin University to assess the level of potential contamination introduced during the midden processing.

RESULTS

4.1 Introduction

This chapter presents the results from the radiocarbon, pollen, plant macrofossil and aDNA analysis of the midden samples on a site-by-site basis and then in a summary of the different analytical techniques. Twenty-nine of the samples in this project were selected for comprehensive radiocarbon dating and plant macrofossil analysis. All of the samples were subjected to pollen analysis, while five of the samples (from amongst the original 29 subject to plant macrofossil analysis) were assessed to determine the preservation of aDNA.

4.2 Radiocarbon Dating

The calibrated ages for the 29 sub-samples that were radiocarbon dated are presented in Table 4.1 (other samples were not dated owing to financial constraints). Full radiocarbon results are included in Appendices 6 and 7. The samples range in age from 800 to 31,760 cal. BP. Eight middens were dated to the late Pleistocene, five to the early Holocene, and 16 to the mid- to late Holocene. At PIL_542, nearly all of the 7 dated middens were late Pleistocene in age, and the most recent two were early Holocene. PIL_5841 was the only other site which contained both Holocene and Late Pleistocene middens, and the only other site to produce a late Pleistocene age was SNRM_24092015_3. PIL_540 contained three mid- to late Holocene aged middens; PIL_4544 and PIL_2001 contained all Holocene aged middens.

Figure 4.1 shows a distribution plot of the calibrated ages. It shows that herbivore middens have been present in rockshelters and caves relatively consistently throughout the past 19,000 years cal. BP; however, across all sites, there is a major gap in the age distribution of middens at 19,860–31,100 cal. BP, and two minor gaps at 6000–4000 cal. BP, and 10,000–8000 cal. BP. Most of the dates are also concentrated in the mid-to late Holocene.

Midden Code	Lab Code	AMS/ Radiometric	Calibrated Age (yrs BP) 95.4 % Probability
SNRM_22092015_1	OZU482	AMS	5050–5440
SNRM_24092015_3 SNR 2	OZU483	AMS	15,710–16,090
PIL_2258 SNR 2	OZU473	AMS	5310–5580
PIL_540 SNR 1	Wk-42960	AMS	2100–2130
PIL_540 SNR 2	OZU464	AMS	3400–3590
PIL_540 SNR 3	OZU465	AMS	3070–3350
PIL_542 SNR 4B	OZU467	AMS	12,080–12,560
PIL_542 SNR 4C	OZU468	AMS	31,100–31,760
PIL_542 SNR 5	Wk-42961	AMS	12,050–12,430
PIL_542 SNR 6B	OZU469	AMS	13,420–13,710
PIL_542 SNR 7	OZU470	AMS	9540–9890
PIL_542 SNR 8	OZU471	AMS	10,240–10,510
PIL_542 SNR 9	OZU466	AMS	19,400–19,860
PIL_5841 SNR 1 (Right)	Wk-42962	AMS	16,620–17,120
PIL_5841 SNR 2B	OZU481	AMS	10,590–11,080
PIL_5841 SNR 3	OZU480	AMS	6750–7160
PIL_5841 SNR 4	Wk-42963	AMS	2350–2700
PIL_4544 SNR 2	OZU474	AMS	2000–2160
PIL_4544 SNR 3A	Wk-42966	AMS	2750–2870
PIL_4544 SNR 3B	Wk-42965	AMS	800–930
PIL_4544 SNR 3C	OZU476	AMS	12,420–12,650
PIL_4544 SNR 4A	Wk-42967	Radiometric	6650–6890
PIL_4544 SNR 5A	OZU478	AMS	1590–1730

Midden Code	Lab Code	AMS/ Radiometric	Calibrated Age (yrs BP) 95.4 % Probability
PIL_4544 SNR 5B	OZU479	AMS	6900–7170
PIL_4544 SNR 5C	Wk-42968	Radiometric	10,250–10,560
PIL_2001 SNR 1A	OZU472	AMS	6740–6950
PIL_2001 SNR 1B	Wk-42964	Radiometric	2750–2930
PIL_2001 SNR 3A	OZU475	AMS	9550–9890
PIL_2001 SNR 3B	OZU477	AMS	2850–3070

Table 4.1 Radiocarbon results for 29 midden samples. All samples comprised individual faecal pellets that could be extracted as such from the midden, or bulk faecal material extracted from the midden.

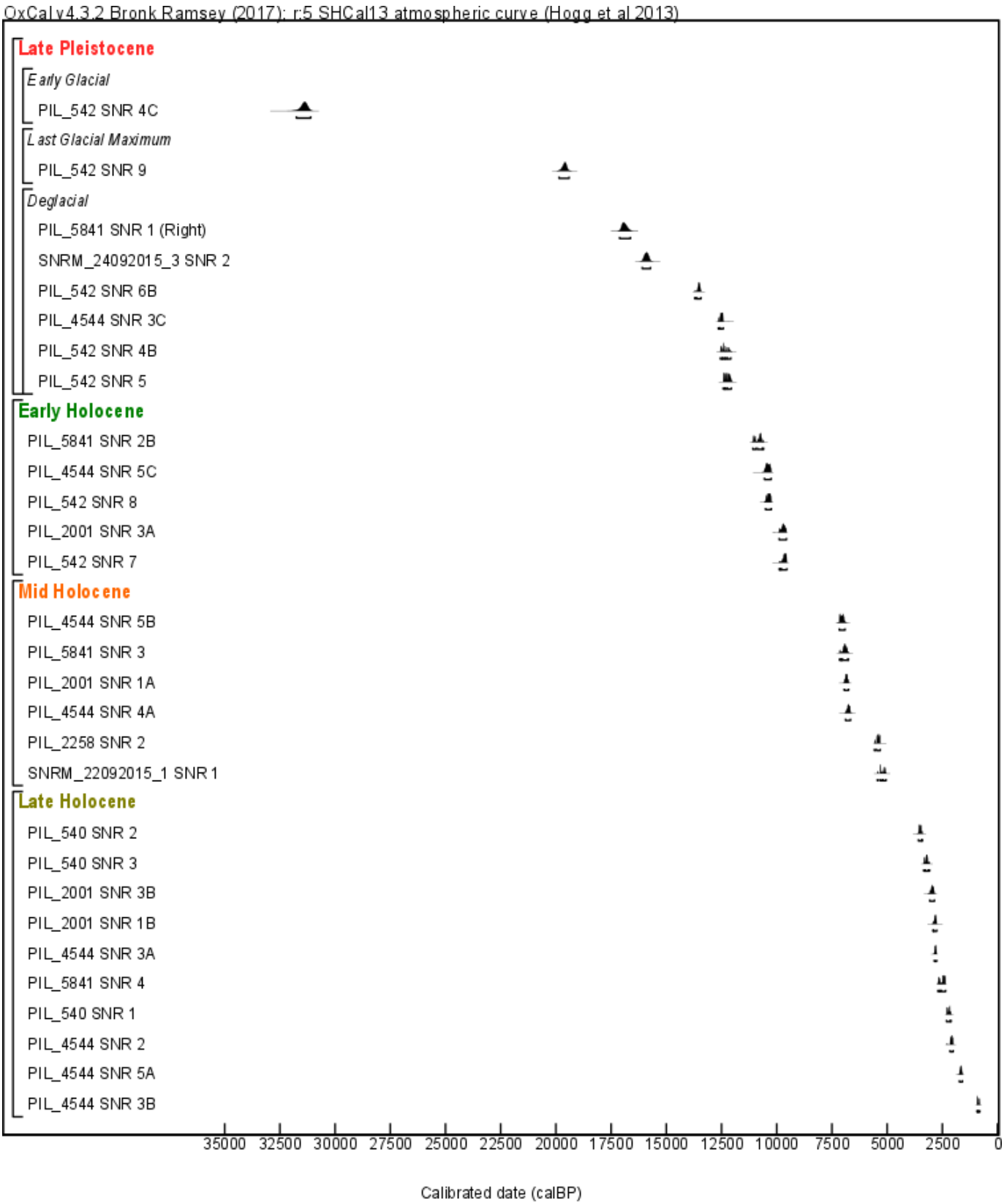

Figure 4.1 Plot of calibrated age distributions for 29 radiocarbon dated midden samples.

4.3 Results by Site

4.3.1 SNRM_22092015_1

SNRM_22092015_1 is a crevice in Banded Iron Formation (BIF) located on the east side of a narrow gully at South Flank about 5 m above an ephemeral watercourse. The surrounding vegetation is summarised in Appendix 8. The small but very dark crevice is approximately 1 m in height, 2 m deep and 1 m wide and contained one small midden (SNR 1) in the rear of the crevice at ground level (Figure 4.2).

Figure 4.2 (left) Sample SNR 1 from SNRM_22092015_1 in situ (10 cm scale); (right) the entrance to SNRM_22092015_1 (Paul Taylor in view) (photographs by Lynley Wallis).

The entire midden was sampled and the dimensions were 26 x 25 x 10 cm. AMS dating of SNR 1 returned an age range of 5050–5440 cal. BP (OZU482). The pollen and macrofossil assemblages of SNR 1 were dominated by trees, such as Myrtaceae and *Callitris* sp., but also contained a range of grasses and a high representation of Cyperaceae. There were also a high number of unidentified leaf fragments and Unknown Type G. Further detailed results from plant macrofossil and pollen analysis of SNR 1 are summarised in Tables 4.2 and 4.3.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unknown Types	Relative Counts
SNR 1	5050–5440	HERBS:		Leaf fragments	804
		Asteraceae	4	Plant fibres	800
		Cyperaceae	52	Twigs	24
				Unknown Type G	462
		GRASSES:			
		Poaceae	4		
		Triodia sp.	32		
		Dicanthium sericeum	16		
		Themeda triandra	12		
		TREES AND SHRUBS:			
		Callitris sp.	137		
		Solanum sp.	40		

Table 4.2 Summary of plant macrofossil analysis results from SNRM_22092015_1.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	5050–5440	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Myrtaceae Type 2 (*Corymbia* sp.) with Myrtaceae trees and shrubs making up almost 100% of the total pollen sum. Other taxa (~1–2%) include *Gyrostemon* and ferns.	Not analysed

Table 4.3 Summary of pollen and aDNA analysis results from SNRM_22092015_1.

4.3.2 SNRM_24092015_3

SNRM_24092015_3 is a small rockshelter located on the western side of a narrow gorge at South Flank about 12 m above an ephemeral watercourse. The rockshelter contained two small and very dusty middens, one of which was on a ledge and the other found inside a cavity (Figure 4.3). This rockshelter also contained a walled structure; however, despite detailed surveys having been conducted in the vicinity by consultant archaeologists in the past, this site had not been previously recorded (Jade Pervan pers. comm.). The surrounding vegetation is summarised in Appendix 8.

Figure 4.3 (left) Sample SNR 1 from SNRM_24092015_3 in situ; (right) Sample SNR 2 from SNRM_24092015_3 (10 cm scales) (photographs by Lynley Wallis).

4.3.2.1 SNR 1

Sample SNR 1 was located inside of a crevice elevated 2 m above ground level. The dimensions were 14 x 8 x 4 cm and the entire midden was sampled. SNR 1 was not dated and the results of pollen analysis show that the record was dominated by trees and shrubs.

4.3.2.2 SNR 2

Sample SNR 2 was located on a ledge elevated 2 m above ground level and was very dusty. The dimensions were 23 x 12 x 7 cm and a portion of the midden was sampled. AMS dating of SNR 2 returned an age range 15,710–16,090 cal. BP (OZU483). The minimal macrofossil assemblage in SNR 2 was dominated by grasses and unknown plant fibres. Myrtaceae trees dominated the pollen record, with a range of trees and shrubs present.

The detailed results from plant macrofossil and pollen analysis of SNR 1 and 2 are summarised in Tables 4.4 and 4.5.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unknown Types	Relative Counts
SNR 1	Undated	Not analysed			
SNR 2	15,710–16,090	GRASSES		Plant fibres	1208
		Poaceae	20	Twigs	16
		Triodia sp.	4	Unknown Type G	4
		Dicanthium sericeum	12		
		TREES AND SHRUBS			
		Callitris sp.	4		
		Solanum sp.	8		

Table 4.4 Summary of plant macrofossil analysis results from SNRM_24092015_3.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae trees and shrubs making up about 85% of the total pollen sum. Other trees and shrubs (~5%) include *Acacia, Casuarina, Dodonaea,* Malvaceae*,* Rhamnaceae *and Solanum* type. Herbaceous taxa (~10%) are dominated by grasses (Poaceae) with Chenopods making up a minor part of the group.	Not analysed
SNR 2	15,710–16,090	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae trees and shrubs making up about 80% of the total pollen sum. Other trees and shrubs (~8%) include *Acacia, Casuarina, Dodonaea,* Loranthaceae, Malvaceae*, Rubiaceae* cf. *Timonius* and *Triumfetta.* Herbaceous taxa (~12%) are dominated by grasses (Poaceae).	Not analysed

Table 4.5 Summary of pollen and aDNA analysis results from SNRM_24092015_3.

4.3.3 PIL_4544

PIL_4544 is a large deep rockshelter located in South Flank on the eastern side of a north-east trending gully around 30 m above the gully floor. Eleven samples were collected from five discrete middens in the darkest regions of the rockshelter, which were along the northern wall (Figure 4.4). Eight of the samples were radiocarbon dated and returned ages from 800 to 12,650 cal. BP. The archaeology of this site is currently being investigated on behalf of BHPBIO by Scarp Archaeology (Jade Pervan pers. comm.) but results were not made available to the author for consideration in this study. The vegetation surrounding PIL_4544 is summarised in Appendix 8.

Figure 4.4 Samples from PIL_4544 in situ. Upper left: SNR 1; upper right: SNR 2; middle left: SNR 3A; middle right: SNR 3B, 3C and 3D; Lower left: SNR 4; and lower right: SNR 5 (10 cm scales) (photographs by Lynley Wallis).

4.3.3.1 SNR 1

Sample SNR 1 was located along a ledge elevated approximately 1.5 m above ground level. The dimensions were 61 x 18 x 15 cm and a section of the nest was removed. SNR 1 was not dated, but its pollen assemblage was dominated by grasses.

4.3.3.2 SNR 2

Sample SNR 2 was located along a ledge elevated approximately 1.6 m above ground level. The dimensions were 34 x 13 x 10 cm and a section of the sample was removed. AMS dating of SNR 2 returned an age range of 2000–2160 cal. BP (OZU474). The few identifiable macrofossils in this sample were mostly from grasses and herbs such as Cyperaceae and *Boerhavia coccinea* (Figure 4.5). Also present were prickles (Unknown Type B) and seed pods (Unknown Type I) from unknown species (Figure 4.5). Myrtaceae dominated the pollen assemblage.

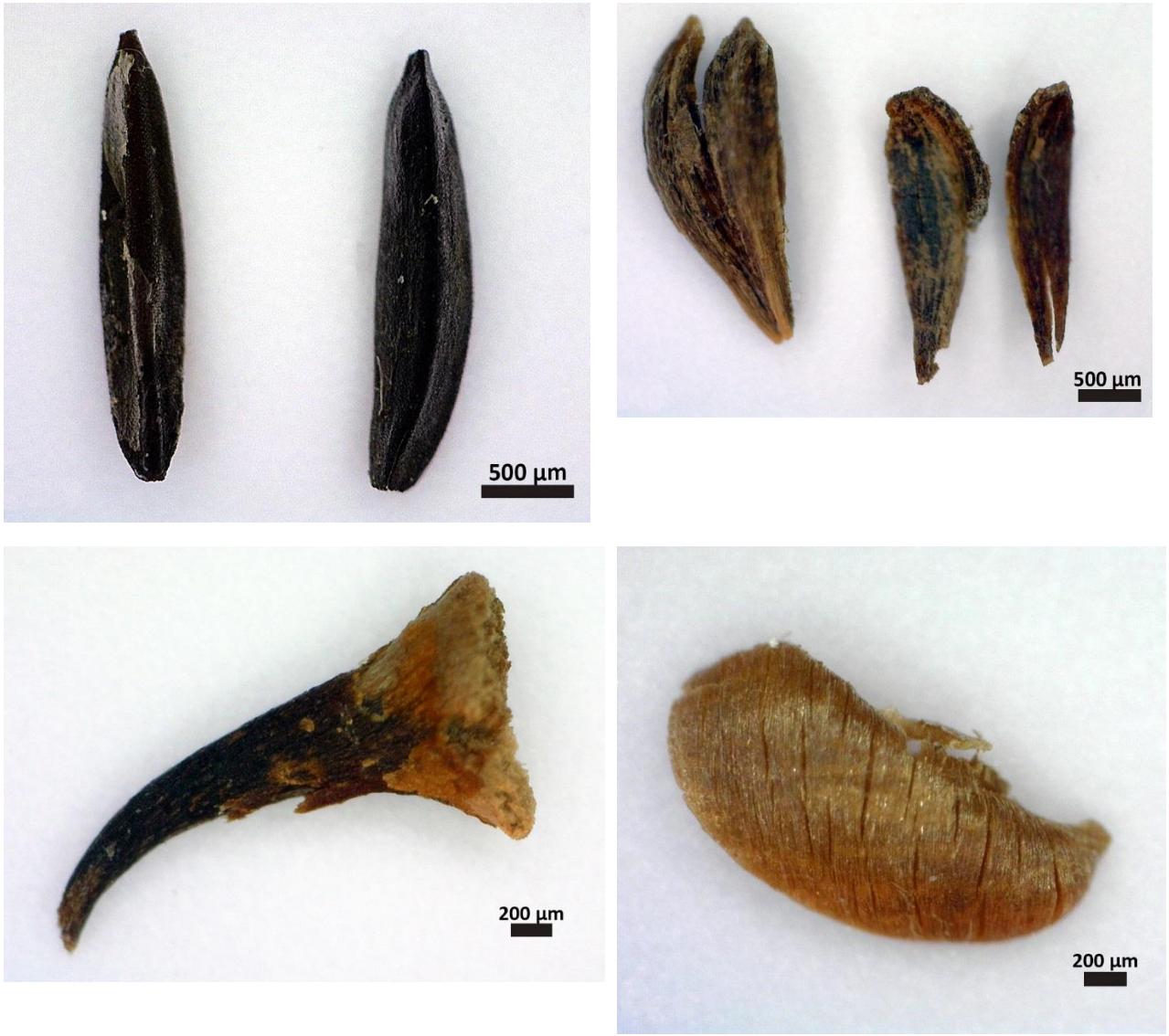

Figure 4.5 Plant macrofossils from PIL_4544 SNR 2: (upper left) Cyperaceae seeds; (upper right) fragmentary *Boerhavia coccinea* seed pod; (lower left) Unknown Type B (prickle); and (lower right) Unknown Type I.

4.3.3.3 SNR 3

Sample SNR 3 was a long midden located along a large rock slab elevated approximately 2.75 m above ground level; a portion of the midden had clearly detached from the main section and had fallen to the ground. SNR 3A was the detached portion of the midden, the dimensions of which were 30 x 20 x 17 cm, all of which was processed. AMS dating of SNR 3A returned an age range of 2750–2870 cal. BP (Wk-42966). Grasses, such as *Dicanthium sericeum*, were dominant in the macrofossil record of SNR 3A, while the pollen record was dominated by Myrtaceae (Figure 4.6). The remaining SNR 3 samples (SNR 3B, SNR 3B2, SNR 3C and SNR 3D) were collected from the main section of the midden along the rock slab. The overall dimensions of this midden were 261 x 85 x 20 cm. AMS dating of SNR 3B returned an age range of 800–930 cal. BP (Wk-42965), making it the most recent in the project. SNR 3B contained mostly grasses, such as *Aristida* sp. and possibly *Enneapogen* sp., chewed twigs and the only occurrence of *Portulaca oleracea* (Figures 4.6 and 4.7). The SNR 3B pollen record was dominated by both Poaceae grasses and Myrtaceae trees as was the case for SNR 3B 2, which was found in close proximity but was not dated. SNR 3C returned an age range of 12,420–12,650 cal. BP (OZU476), and contained only grass macrofossils, though its pollen assemblage was dominated by both grasses and Myrtaceae. The pollen record of SNR 3D was also dominated by Poaceae but its age is unknown.

Figure 4.6 Unidentified grass seed (possibly *Enneapogen*) from PIL_4544 SNR 3B.

Figure 4.7 (Upper left) *Dicanthium sericeum* seeds from PIL_4544 SNR 3A; (upper right) *Aristida* sp. floret from PIL_4544 SNR 3B; (lower left) chewed twig of unknown species from PIL_4544 SNR 3B; and (lower right) *Portulaca oleracea* seed pods from PIL_4544 SNR 3B.

4.3.3.4 SNR 4

Sample SNR 4 was located inside of a small alcove elevated approximately 1.5 m above ground level. The dimensions were 50 x 150 x 17 cm and one section of the very dusty midden was removed. Radiometric dating of SNR 4 returned an age range of 6650–6890 cal. BP (Wk-42967). SNR 4 was barren of both macrofossils and pollen; however, aDNA identified a range of herbs, trees and grasses.

4.3.3.5 SNR 5

Sample SNR 5 was located on top of a large slab of roof fall which was elevated approximately 1.1 m above ground level. The dimensions were 218 x 120 x 8 cm and three sections (SNR 5A, SNR 5B and SNR 5C) were removed for analysis. The results from plant macrofossil, pollen and aDNA analysis of SNR 1–5 are summarised in Tables 4.6 and 4.7. AMS dating of SNR 5A returned an age range of 1590–1730 cal.

BP (OZU478) and its pollen and macrofossil assemblage was dominated by grasses and Myrtaceae, with a diverse range of species represented. SNR 5B returned an age range of 6900–7170 cal. BP (OZU479) and showed a relatively balanced representation of Myrtaceae, Poaceae and other herbaceous taxa in the pollen record. *Triodia* sp. dominated the macrofossil record. SNR 5C returned an age estimate of 10,250–10,560 cal. BP (Wk-42968). The pollen assemblage of SNR 5C was dominated by Myrtaceae, with Unknown Type G and Poaceae being prevalent in the macrofossil record. SNR 5C also contained a possible seed pod of an unidentified type that was not present in any other sample (Figure 4.8).

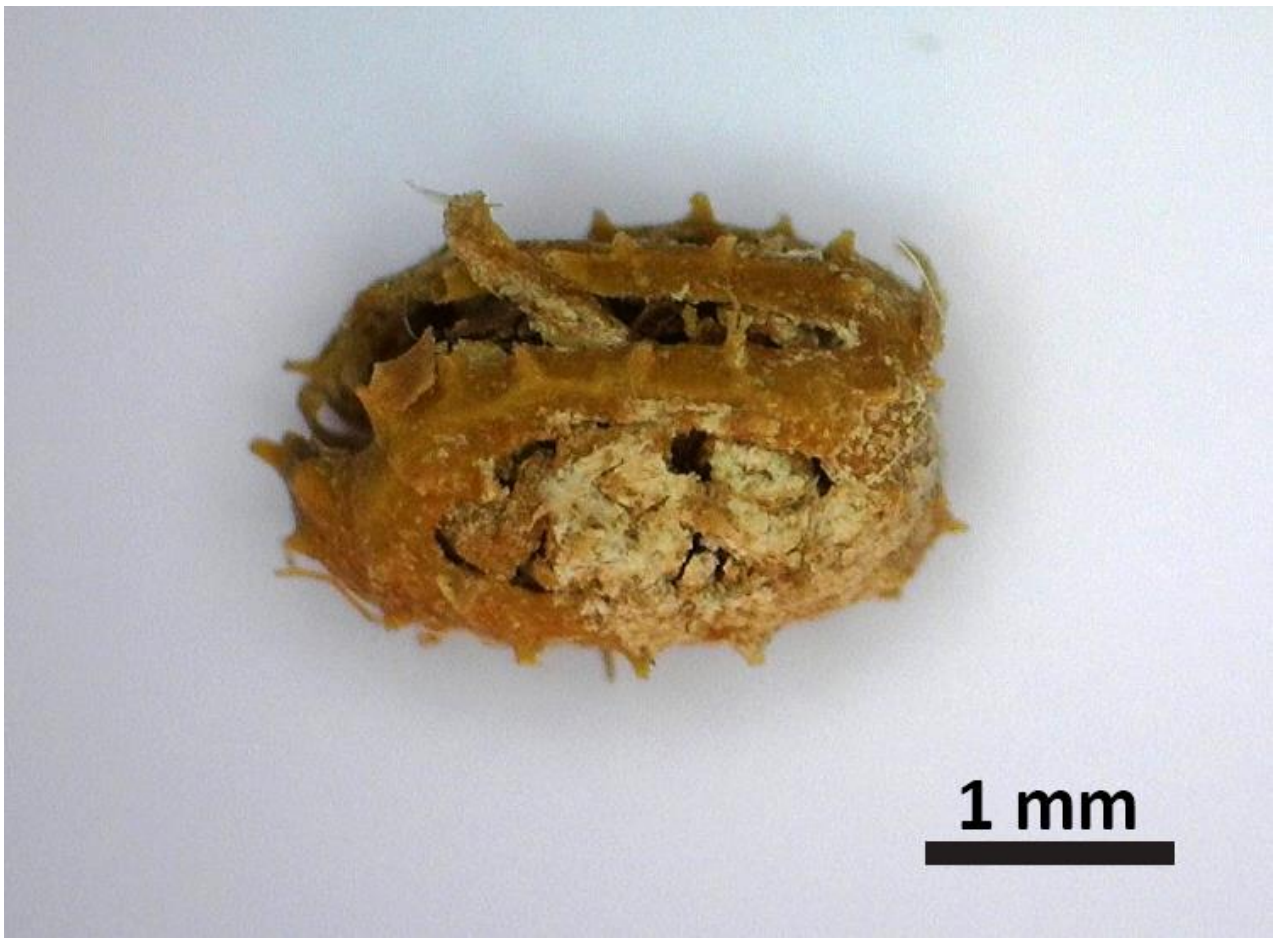

Figure 4.8 Unknown Type A seed pod from PIL_4544 SNR 5C.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unknown Types	Relative Counts
SNR 1	Undated	Not analysed			
SNR 2	2000–2160	HERBS		Plant fibres	1986
		Cyperaceae	4	Twigs	12
		Boerhavia coccinea	8	Unknown Type B	2
				Unknown Type G	12
		GRASSES		Unknown Type H	2
		Poaceae	10	Unknown Type I	4
		Triodia sp.	8		
		Dicanthium sericeum	2		
		SHRUBS			
		Sida sp.	2		
		Solanum sp.	2		
SNR 3A	2750–2870	HERBS		Plant fibres	2001
		Cyperaceae	4	Twigs	6
				Unknown Type B	2
		GRASSES		Unknown Type G	2
		Poaceae	8	Unknown Type H	2
		Triodia sp.	12		
		Dicanthium sericeum	40		
		Themeda triandra	14		
SNR 3B	800–930	HERBS		Leaf fragments	3
		Cyperaceae	1	Plant fibres	2511
		Boerhavia coccinea	3	Twigs	1
		Portulaca oleracea	2	Unknown Type B	4
				Unknown Type G	15
		GRASSES			
		Poaceae	15		
		Dicanthium sericeum	5		
		Themeda triandra	12		
		SHRUBS			
		Solanum sp.	11		
SNR 3B2	Undated	Not analysed			
SNR 3C	12,420–12,650	GRASSES		Plant fibres	6442
		Poaceae	16	Twigs	16
		Dicanthium sericeum	4		
		Themeda triandra	4		
SNR 3D	Undated	Not analysed			
SNR 4A	6650–6890	None		Plant fibres	20
SNR 5A	1590–1730	HERBS		Plant fibres	2006
		Boerhavia coccinea	2	Twigs	4
				Unknown Type B	2
		GRASSES		Unknown Type G	2
		Poaceae	18		
		Triodia sp.	26		
		Dicanthium sericeum	2		
		SHRUBS			
		Sida sp.	4		
		Solanum sp.	2		

SNR 5B	6900–7170	GRASSES		Plant fibres	4830
		Poaceae	4	Twigs	16
		Triodia sp.	44	Unknown Type B	8
		Dicanthium sericeum	4		
		Themeda triandra	4		
		SHRUBS			
		Solanum sp.	16		
SNR 5C	10,250–10,560	HERBS		Plant fibres	7039
		Amaranthus mitchelli	1	Unknown Type A	1
				Unknown Type B	1
		GRASSES		Unknown Type G	18
		Poaceae	42		
		Aristida sp.	1		
		Themeda triandra	2		
		SHRUBS			
		Sida sp.	2		
		Solanum sp.	28		

Table 4.6 Summary of plant macrofossil analysis results from PIL_4544.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	Undated	Assemblage dominated by Poaceae which makes up about 75% of the total pollen sum. Other herbaceous taxa (~5%) include chenopods and Asteraceae. Tree and shrub taxa (~20%) are dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae Type 2 and 3, *Casuarina* and *Dodonaea* making up a minor part of the group.	Not analysed
SNR 2	2000–2160	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 70% of the total pollen sum. Other trees and shrubs (~2%) include *Acacia, Dodonaea*, Malvaceae and Rhamnaceae. Herbaceous taxa (~28%) are dominated by Poaceae, with chenopods, Asteraceae and *Trichodesma* making up a minor part of the group.	Not analysed
SNR 3A	2750–2870	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 70% of the total pollen sum. Other trees and shrubs (~1%) include *Dodonaea*. Herbaceous taxa (~25%) are dominated by grasses (Poaceae) with Chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 3B	800–930	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) (~50%) and Poaceae (~30%). Other trees and shrubs (~10%) include Myrtaceae Type 2 and 3, *Dodonaea, Grevillea/Hakea*, Malvaceae, Rhamnaceae, Rubiaceae cf. *Timonius* and *Triumfetta*. Other herbaceous taxa (~10%) include chenopods and Asteraceae.	Not analysed
SNR 3B2	Undated	Assemblage dominated by Poaceae which make up about 50% of the total pollen sum. Other herbaceous taxa (~5%) include chenopods, Asteraceae and *Trichodesma*. Tree and shrub taxa (~45%) are dominated by Myrtaceae Type 2 (*Corymbia* sp.) with Myrtaceae Type 1 and 3, *Acacia, Dodonaea*, Malvaceae and *Solanum* sp. making up a minor part of the group.	Not analysed

SNR 3C	12420–12650	Assemblage dominated by Poaceae, which makes up about 70% of the total pollen sum. Other herbaceous taxa (~10%) include chenopods and Asteraceae. Tree and shrub taxa (~20%) are dominated by Myrtaceae Type 2 (*Corymbia* sp.) with Myrtaceae Type 1 and 3, *Dodonaea*, Malvaceae and *Solanum* sp. making up a minor part of the group.	Not analysed
SNR 3D	Undated	Assemblage dominated by Poaceae, which makes up about 45% of the total pollen sum. Other herbaceous taxa (~15%) include chenopods and Asteraceae. Tree and shrub taxa (~40%) are dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae Type 2 and 3, *Acacia, Casuarina, Grevillea/Hakea, Gyrostemon, Dodonaea*, Malvaceae, Rhamnaceae and *Triumfetta* making up a minor part of the group.	Not analysed
SNR 4A	6650–6890	Nil	Taxa present: (In processed sample) Grasses: *Avena* Trees and shrubs: *Pinus, Musa* Taxa present: (In unprocessed sample) Herbs: Apioideae, Micrandreae (can also be trees or shrubs), Brassicaceae, *Allium,* Pedaliaceae. Grasses: Loliinae, *Phalaris, PACMAD Clade.* Trees and shrubs: Theaceae, Solanaceae, *Acacia, Citrus*, Maleae.
SNR 5A	1590–1730	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) (~40%) and Poaceae (~50%). Other trees and shrubs (~5%) include Myrtaceae Type 2 and 3, and *Dodonaea*. Other herbaceous taxa (~5%) include chenopods and Cyperaceae.	Not analysed
SNR 5B	6900–7170	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) (~30%) and Poaceae (~30%). Other trees and shrubs (~20%) include Myrtaceae Type 2 and 3, *Gyrostemon*, *Dodonaea*, Malvaceae and Rhamnaceae. Other herbaceous taxa (~20%) include chenopods, Asteraceae, Convolvulaceae, Haloragaceae, *Trichodesma* and Pteridaceae cf. *cheilanthes* (ferns).	Not analysed
SNR 5C	10250–10560	Assemblage dominated by Myrtaceae Type 1 and 2 (*Eucalyptus* type and *Corymbia* sp.) with Myrtaceae trees and shrubs making up about 80% of the total pollen sum. Other trees and shrubs (~5%) include *Dodonaea* and Malvaceae. Herbaceous taxa (~15%) are dominated by Poaceae, with chenopods, Asteraceae, Haloragaceae and Pteridaceae cf. *Cheilanthes* (ferns) making up a minor part of the group.	Taxa present: (In processed sample) Herbs: *Theobroma* (Malvaceae) Grasses: PACMAD Clade Trees and shrubs: Solanaceae*, Solanum,* Myrtaceae. Taxa present: (In unprocessed sample) Herbs: *Allium.* Grasses: Poeae. Trees and shrubs: *Musa.*

Table 4.7 Summary of pollen and aDNA analysis results from PIL_4544.

4.3.4 PIL_2001

PIL_2001 is a large deep rockshelter located in South Flank on the eastern side of a north-east trending gully around 30 m above the gully floor. This site is gender restricted and was only entered and sampled by the male members of the field team. Eleven samples were collected from five discrete middens in the darkest regions of the rockshelter, which were along the northern wall (Figure 4.9). Eight of the samples were radiocarbon dated and returned ages ranging from 800 to 12,650 cal. BP. The archaeology of this site is currently being investigated on behalf of BHPBIO by Scarp Archaeology (Jade Pervan pers. comm.) but results were not made available to the author for consideration in this study. The vegetation surrounding PIL_4544 is summarised in Appendix 8.

Figure 4.9 In situ midden samples from PIL_2001; (upper left) SNR 1; (upper right) SNR 2; (lower left) SNR 3A; and (lower right) SNR 3B (10 cm scales) (photographs by Lynley Wallis).

4.3.4.1 SNR 1

Sample SNR 1 was located inside of a crevice elevated approximately 2 m above ground level. The dimensions were 100 x 50 x 35 cm and the midden was removed in two sections (SNR 1A and SNR 1B). AMS dating of SNR 1A returned an age range of 6740–6950 cal. BP (OZU472) while radiometric dating of SNR 1B returned an age range of 2750–2930 cal. BP (Wk-42964). SNR 1A and SNR 1B both contained a large amount of unknown plant fibres along with a high number of grasses. The pollen record shows that SNR 1A was dominated by trees and SNR 1B was dominated by grasses. Figure 4.10 shows the diverse range of grass and herbaceous seeds found in SNR 1B.

Figure 4.10 Macrofossils recovered from PIL_2001: SNR 1B (upper right) *Triodia* sp. florets; (upper right) unidentified Cyperaceae seed; (lower left) *Polycarpaea* sp. seed heads; and (lower right) Unknown Type G.

4.3.4.2 SNR 2

Sample SNR 2 was located along a ledge elevated approximately 3 m above ground level. The midden appeared to be very weathered and dusty; the midden dimensions were 120 x 80 x 10 cm and three sections (SNR 2A, SNR 2B and SNR 2C) of the midden were removed, none of which were dated. SNR 2A and SNR 2B were both dominated by Myrtaceae, while SNR 2C was dominated by Poaceae, with trees and shrubs also making up a large part of the assemblage.

4.3.4.3 SNR 3

Sample SNR 3 was located along a ledge elevated approximately 2.2 m above ground level and was sampled in two parts (SNR 3A and SNR 3B). The overall dimensions were 150 x 80 x 20 cm. AMS dating of SNR 3A returned an age range of 9550–9890 cal. BP (OZU472) The pollen record of SNR 3A was dominated by Myrtaceae, with a high number of kangaroo grass (*Themeda triandra*) seeds found in the macrofossil assemblage. SNR 3B returned an age range of 2850–3070 cal. BP (OZU477). The pollen record of SNR 3B is dominated by both Poaceae and Myrtaceae; the macrofossil record also shows a high number of grasses. A summary of the results from macrofossil and pollen analysis of SNR 1–3 are presented in Tables 4.8 and 4.9.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unknown Types	Relative Counts
SNR 1A	6740–6950	GRASSES		Bark fragments	4
		Poaceae	20	Leaf fragments	2
		Aristida sp.	2	Plant fibres	10054
		Dicanthium sericeum	6	Twigs	4
		Themeda triandra	6	Unknown Type F	4
				Unknown Type G	38
		SHRUBS			
		Solanum sp.	6		
SNR 1B	2750–2930	HERBS		Plant fibres	5015
		Cyperaceae	3	Twigs	10
		Polycarpaea sp.	6	Unknown Type B	6
				Unknown Type F	1
		GRASSES		Unknown Type G	64
		Poaceae	11		
		Aristida sp.	3		
		Triodia sp.	21		
		Dicanthium sericeum	4		
		Themeda triandra	14		
		SHRUBS			
		Solanum sp.	3		
		Boerhavia coccinea	1		

SNR 2A	Undated	Not analysed			
SNR 2B	Undated	Not analysed			
SNR 2C	Undated	Not analysed			
SNR 3A	9550–9890	HERBS		Plant fibres	1808
		Polycarpaea sp.	4	Unknown Type B	1
				Unknown Type G	20
		GRASSES			
		Poaceae	14		
		Aristida sp.	2		
		Triodia sp.	9		
		Themeda triandra	17		
		SHRUBS			
		Solanum sp.	3		
SNR 3B	2850–3070	HERBS		Leaf fragments	8
		Cyperaceae	4	Plant fibres	3220
		Boerhavia coccinea	4		
		GRASSES			
		Poaceae	28		
		Triodia sp.	52		
		Themeda triandra	4		
		SHRUBS			
		Solanum sp.	8		

Table 4.8 Summary of plant macrofossil analysis results from PIL_2001.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1A	6740–6950	Assemblage dominated by Myrtaceae (*Eucalyptus* type and *Corymbia* sp.) with Myrtaceae making up about 85% of the total pollen sum. Other trees and shrubs (~1%) include *Dodonaea* and Malvaceae. Herbaceous taxa (~14%) are dominated by Poaceae, with Asteraceae and Pteridaceae cf. *Cheilanthes* (ferns) making up a minor part of the group.	Not analysed
SNR 1B	2750–2930	Assemblage dominated by Poaceae, which make up about 60% of the total pollen sum. Other herbaceous taxa (~3%) include chenopods and Asteraceae. Tree and shrub taxa (~40%) are dominated by Myrtaceae (*Corymbia* sp.) with *Dodonaea, Gyrostemon*, Loranthaceae and Malvaceae making up a minor part of the group.	Not analysed
SNR 2A	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 80% of the total pollen sum. Other trees and shrubs (~1%) include Araliaceae cf. *Astrotricha*, *Dodonaea*, Malvaceae and Rubiaceae cf. *Timonius*. Herbaceous taxa (~20%) are dominated by Poaceae, with Asteraceae, chenopods, Convolvulaceae and Pteridaceae cf. *Cheilanthes* (ferns) making up a minor part of the group.	Not analysed
SNR 2B	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 85% of the total pollen sum. Other trees and shrubs (~2%) include *Acacia*, Araliaceae cf. *Astrotricha, Dodonaea*, Loranthaceae, Malvaceae, *Solanum* type and Rubiaceae cf. *Timonius*.	Not analysed

		Herbaceous taxa (~13%) are dominated by Poaceae with Asteraceae, chenopods and Cyperaceae making up a minor part of the group.	
SNR 2C	Undated	Assemblage dominated by Poaceae, which make up about 40% of the total pollen sum. Other herbaceous taxa (~5%) include chenopods, Asteraceae, Monolete spore and Pteridaceae cf. *Cheilanthes* (ferns). Tree and shrub taxa (~55%) are dominated by Myrtaceae Type 1 and 2 (*Eucalyptus* type and *Corymbia* sp.) with Myrtaceae Type 3, *Callitris*, *Casuarina, Dodonaea* and *Solanum* type making up a minor part of the group.	Not analysed
SNR 3A	9550–9890	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 85% of the total pollen sum. Other trees and shrubs (~1%) include Malvaceae and Rubiaceae cf. *Timonius*. Herbaceous taxa (~15%) are dominated by Poaceae, with Asteraceae and Pteridaceae cf. *Cheilanthes* (ferns) making up a minor part of the group.	Not analysed
SNR 3B	2850–3070	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) (~45%) and Poaceae (~45%). Other trees and shrubs (~8%) include Myrtaceae Type 2 and 3, *Dodonaea* and *Casuarina*. Other herbaceous taxa (~2%) include chenopods and Asteraceae.	Not analysed

Table 4.9 Summary of pollen and aDNA analysis results from PIL_2001.

4.3.5 GCE_24062011_10

GCE_24062011_10 is a crevice in BIF located in a large deep gully at South Flank close to an ephemeral watercourse and a waterhole. The painted rock art surrounding this site was subjected to detailed recording by Wallis et al. (2015). The crevice contained one small midden (SNR 1) on top of a ledge which was elevated around 3 m above ground level in a relatively open position (Figure 4.11). The entire midden was sampled and the dimensions were 30 x 11 x 10 cm. The sample was not radiocarbon dated. Its pollen record was dominated by trees with herbaceous taxa making up a minor part of the record.

The surrounding vegetation the site is summarised in Appendix 8 and the results from the pollen analysis of SNR 1 are presented in Table 4.10.


Figure 4.11 (left) The ledge that sample SNR 1 was sitting on in 4.3.5 GCE_24062011_10 and (right) sample SNR 1 in situ (10 cm scale) (photographs by Lynley Wallis).

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 80% of the total pollen sum. Other trees and shrubs (~1%) include *Callitris, Dodonaea, Ficus*, Rhamnaceae and Rubiaceae cf. *Timonius*. Herbaceous taxa (~20%) are dominated by Poaceae with Asteraceae and chenopods making up a minor part of the group.	Not analysed

Table 4.10 Summary of pollen and aDNA analysis results from GCE_24062011_10.

4.3.6 PIL_2258

PIL_2258 is a relatively large rockshelter located on the southern side of the main ridge of Packsaddle Range. The rockshelter contained four small middens that were all heavily indurated and dusty and located within proximity to a walled structure (Figure 4.7). The surrounding vegetation is summarised in Appendix 8.

Figure 4.12 **In situ samples from PIL_2258: (upper left) SNR 1; (upper right) SNR 2; (lower left) SNR 3; and (lower right) SNR 4 (10 cm scales) (photographs by Lynley Wallis).**

4.3.6.1 SNR 1

Sample SNR 1 was located on a ledge elevated 2 m above ground level. The dimensions were 35 x 20 x 5 cm and the entire midden was sampled. SNR 1 was not dated. Its pollen assemblage was dominated by Myrtaceae.

4.3.6.2 SNR 2

Sample SNR 2 was located on a ledge elevated 1.5 m above ground level. The dimensions were 34 x 15 x 6 cm and the entire midden was sampled. AMS dating of SNR 2 returned an age range 5310–5580 cal. BP (OZU473). The pollen record of SNR 2 shows dominant trees and shrubs, and very little macrofossil material was present.

4.3.6.3 SNR 3

Sample SNR 3 was located on a ledge elevated 80 cm above ground level. The dimensions were 18 x 6 x 8 cm and the top section of the midden was sampled. SNR 3 was not dated. Its pollen record was dominated by Myrtaceae.

4.3.6.4 SNR 4

Sample SNR 4 was located on a ledge elevated 2 m above ground level. The dimensions were 17 x 5 x 6 cm and the entire midden was sampled. SNR 4 was not dated. Its pollen record shows that both Myrtaceae and Poaceae dominated.

The results from plant macrofossil and pollen analysis of SNR 1–4 are presented in Tables 4.11 and 4.12.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unidentified Types	Relative Counts
SNR 1	Undated	Not analysed			
SNR 2	5310–5580	GRASSES Poaceae *Triodia* sp.	 20 4	Plant fibres	48
SNR 3	Undated	Not analysed			
SNR 4	Undated	Not analysed			

Table 4.11 Summary of plant macrofossil analysis results from PIL_2258.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 72% of the total pollen sum. Other trees and shrubs (3%) include *Acacia, Dodonaea, Solanum* type, Rhamnaceae, *Rubiaceae* cf. *Timonius* and *Triumfetta.* Herbaceous taxa (~25%) are dominated by Poaceae, with chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 2	5310–5580	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 65% of the total pollen sum. Other trees and shrubs (~5%) include Araliaceae*, Dodonaea,* Malvaceae*, Rubiaceae* cf. *Timonius* and *Triumfetta*. Herbaceous taxa (~30%) are dominated by Poaceae, with chenopods, Asteraceae and *Trichodesma* making up a minor part of the group.	Not analysed
SNR 3	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 65% of the total pollen sum. Other trees and shrubs (~5%) include *Acacia, Dodonaea*, *Grevillea/ Hakea*, *Gyrostemon*, Malvaceae *Solanum* type and *Rubiaceae* cf. *Timonius.*	Not analysed

		Herbaceous taxa (~30%) are dominated by Poaceae, with chenopods, Asteraceae and *Trichodesma* making up a minor part of the group.	
SNR 4	Undated	Assemblage dominated by grasses (Poaceae) (~35%) and Myrtaceae Type 2 (*Corymbia* sp.) (~35%). Other trees and shrubs (~10%) include Myrtaceae Type 3 (*Corymbia* sp. ornate), Araliaceae, *Dodonaea*, Euphorbiaceae, *Gyrostemon*, Malvaceae, *Solanum* type and *Rubiaceae* cf. *Timonius*. Other herbaceous taxa include (~20%) chenopods and Asteraceae with *Trichodesma* and Cyperaceae making up a minor part of the group.	Not analysed

Table 4.12 Summary of pollen and aDNA analysis results from PIL_2258.

4.3.7 PIL_540

PIL_540 is located on the southern side of Packsaddle Range at the top of a hill slope approximately 500 m from an ephemeral watercourse. It is a large open rockshelter facing east which measures 16.5 m across the dripline, 18 m deep from the dripline to the rear and 5.75 m high (Huonbrook Environment and Heritage 2013:64). The surrounding vegetation is summarised in Appendix 8. Three samples were collected from the southern half of the rockshelter in crevices and on ledges where light exposure was minimal (Figure 4.14). All of the collected samples were dated and range in age from 2100–3590 cal. BP. The archaeology of this site was previously recorded by Dias et al. (2005:73–77) and Huonbrook Environment and Heritage (2013). Dias et al. (2005) recorded surface stone artefacts and well preserved wooden artefacts. A subsequent 1 x 1 m excavation by Huonbrook Environment and Heritage (2013:73) revealed that the site had been occupied since around 15,000 cal. BP and possibly later. The stone artefact distribution suggested that occupation was sparse until the late Holocene.

Figure 4.13 In situ samples from PIL_540: (left) SNR 1, (centre) SNR 2 and (right) SNR 3 (10 cm scales) (photographs by Lynley Wallis).

4.3.7.1 SNR 1

Sample SNR 1 was located in a crevice elevated 3 m above ground level. The dimensions were 36 x 18 x 8 cm and the entire midden was sampled. AMS dating of SNR 1 returned an age range of 2100–2130 cal. BP (Wk-42960). The macrofossil assemblage comprised a large number of leaf and bark fragments (especially when compared to samples from other sites). Herbs and grasses were minimal in the macrofossil record and the pollen record was dominated by Myrtaceae.

4.3.7.2 SNR 2

Sample SNR 2 was located on a ledge elevated 3.5 m above ground level and was heavily weathered. Its dimensions were 30 x 35 x 20 cm though only a portion of the midden was sampled. AMS dating of SNR 2 returned an age range of 3400–3590 cal. BP (OZU464). The macrofossil assemblage contained abundant kangaroo grass (*Themeda triandra*) seeds but very few other identified macrofossils (Figure 4.15). Myrtaceae dominated the pollen record but herbaceous taxa were also well represented.

Figure 4.14 *Themeda triandra* (kangaroo grass) seeds from PIL_540 SNR 2.

4.3.7.3 SNR 3

Sample SNR 3 was located inside a deep crevice elevated approximately 4 m above ground level. The dimensions were 58 x 28 x 10 cm and the entire midden was sampled. AMS dating of SNR 3 returned an age range of 3070–3350 cal. BP (OZU465). This sample contained a diverse range of macrofossils, mostly grass seeds and other herbaceous taxa (Figure 4.16). The pollen record was dominated by Myrtaceae, with other herbaceous taxa also well represented in the assemblage.

The results from plant macrofossil, pollen and aDNA analysis of SNR 1–3 are presented in Tables 4.13 and 4.14.

Figure 4.15 Macrofossils recovered from PIL_540 SNR 3: (upper left) *Sida* sp. seed pods; (upper right) *Goodenia* sp. seed; and (bottom) *Calotis* sp. (daisy family) seed.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unknown Types	Relative Counts
SNR 1	2100–2130	HERBS		Bark fragments	4
		Boerhavia coccinea	2	Leaf fragments	120
		Calotis sp.	4	Plant fibres	402
				Twigs	46
		GRASSES		Unknown Type G	2
		Poaceae	6		
		Triodia sp.	4		
		Themeda triandra	2		
SNR 2	3400–3590	HERBS		Leaf fragments	1
		Boerhavia coccinea	1	Plant fibres	521
				Twigs	1
		GRASSES			
		Poaceae	4		
		Triodia sp.	4		
		Themeda triandra	18		
SNR 3	3070–3350	HERBS		Plant fibres	798
		Calotis sp.	2	Unknown Type D	2
		Goodenia sp.	2		
		GRASSES			
		Poaceae	12		
		Triodia sp.	30		
		Themeda triandra	60		
		SHRUBS			
		Sida sp.	2		
		Solanum sp.	4		

Table 4.13 Summary of plant macrofossil analysis results from PIL_540.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	2100–2130	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 80% of the total pollen sum. Other trees and shrubs (~1%) include *Acacia, Dodonaea* and *Rubiaceae* cf. *Timonius*. Herbaceous taxa (~20%) are dominated by Poaceae, with chenopods and Asteraceae making up a minor part of the group.	Taxa present: (In processed sample) Herbs: Gnaphalieae, *Plantago,* Ingeae, *Chorchorus,* Malvoideae. Trees and shrubs: *Acacia, Citrus,* Sapindaceae. Taxa present: (In unprocessed sample) Grasses: Poeae, *PACMAD Clade.* Trees and shrubs: Sapindaceae.
SNR 2	3400–3590	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 65% of the total pollen sum. Other trees and shrubs (~3%) include *Acacia, Gyrostemon*, Malvaceae and *Rubiaceae* cf. *Timonius*. Herbaceous taxa (~30%) are dominated by Poaceae, with chenopods and Asteraceae making up a minor part of the group.	Not analysed

SNR 3	3070–3350	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 60% of the total pollen sum. Other trees and shrubs (~3%) include *Acacia* and *Dodonaea*. Herbaceous taxa (~35%) are dominated by Poaceae and chenopods, with Asteraceae making up a minor part of the group.	Not analysed

Table 4.14 Summary of pollen and aDNA analysis results from PIL_540.

4.3.8 PIL_542

PIL_542 is located in the Packsaddle Range. It is a large rockshelter near the crest of a ridgeline, adjacent to a steep, seasonal and rocky watercourse approximately 50 m away. It sits around 10 m below the ridgeline and 30 m above a gully and measures 9.5 m across the dripline, 30 m deep to the rear and 4.5 m high (Huonbrook Environment and Heritage 2013:45). Twelve samples were collected from nine discrete middens in the areas of the rockshelter where light exposure was minimal (Figures 4.17 and 4.18). Dated samples range from 9540 to 31,760 cal. BP. Many of the middens were high up on ledges and were not easily accessible without scaffolding; as such, only samples that were accessible from ground level could be collected for analysis.

PIL_542 was initially recorded by Dias et al. (2005:67–72) and was subsequently excavated by Huonbrook Environment and Heritage (2013:45–63). The site was considered to have high research potential with high numbers of artefacts and organic materials. Radiocarbon dating and artefact numbers suggested that first occupation of the site occurred sometime after 40,000 cal. BP and continued until the LGM at a low intensity. The most intensive and frequent use of the site occurred during the late Holocene (Huonbrook Environment and Heritage 2013:63). An overview of vegetation surrounding the site is given in Appendix 8.

Figure 4.16 In situ samples from PIL_542: (upper left) SNR 1; (upper centre) SNR 2; (upper right) SNR 3; (lower left) SNR 4; (lower centre) SNR 5; and (lower right) SNR 6 (10 cm scales) (photographs by Lynley Wallis).

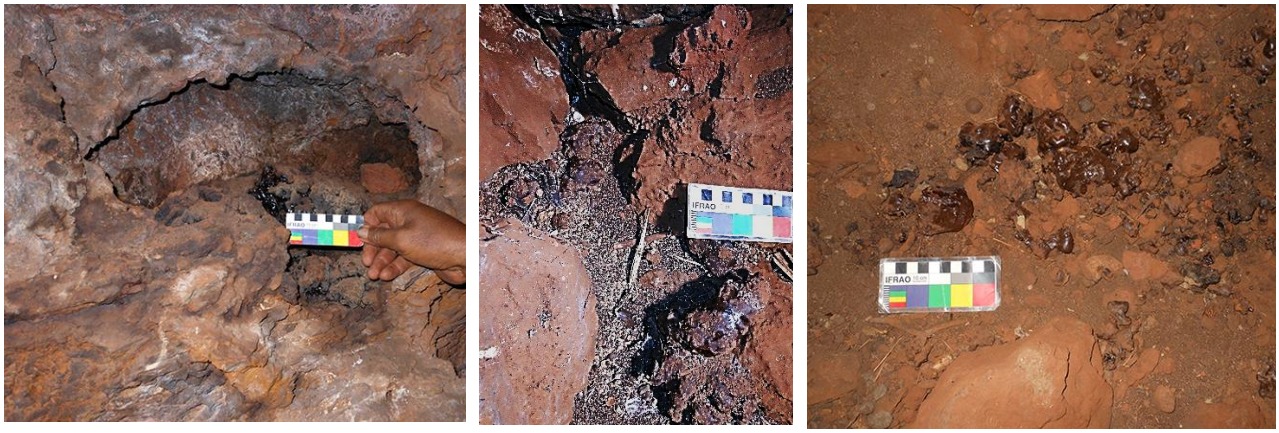

Figure 4.17 In situ samples from PIL_542: (left) SNR 7, (centre) SNR 8 and (right) SNR 9 (10 cm scales) (photographs by Lynley Wallis).

4.3.8.1 SNR 1

Sample SNR 1 was located along the north wall where it was elevated 1.3 m above ground level. The dimensions were 55 x 28 x 15 cm and a section of the midden was sampled. SNR1 was not dated and neither was it subject to detailed macrofossil analysis. Its pollen record was dominated by Myrtaceae.

4.3.8.2 SNR 2

Sample SNR 2 was located along the north wall where it was elevated 2.2 m above ground level. The dimensions were 30 x 34 x 25 cm and a section of the midden was sampled. SNR 2 was not dated and neither was it subject to detailed macrofossil analysis. Its pollen record was heavily dominated by Myrtaceae.

4.3.8.3 SNR 3

Sample SNR 3 was located at the very rear of the rockshelter and was positioned at ground level as it had fallen from above. The dimensions were 40 x 70 x 30 cm and two sections of the middens were sampled (3A and 3B). SNR 3A was removed from the top portion of the midden and SNR 3B from the lower portion; neither has been dated and neither were they subject to detailed macrofossil analysis. The pollen record of both were dominated by Myrtaceae.

4.3.8.4 SNR 4

Sample SNR 4 was located at the very rear of the rockshelter and was elevated approximately 2.2 m above ground level. The dimensions were 35 x 50 x 30 cm and three sections of the midden were sampled. SNR 4A was not dated. AMS dating of SNR 4B returned an age range of 12,080–12,560 cal. BP (OZU467) and the sample had a diverse range of species represented in the macrofossil record (Figure 4.19). The pollen record of SNR 4B was dominated by *Acacia* and Myrtaceae. SNR 4C returned an age range of 31,100–31,760 cal. BP (OZU468), making it the oldest dated sample of the project. The pollen assemblage of this sample was dominated by Myrtaceae, with comparatively few grasses or herbs in the macrofossil record. Myrtaceae was also represented in the aDNA record.

Figure 4.18 Macrofossils recovered from PIL_542 SNR 4B: (upper left) *Daucus glochidiatus* (native carrot) seed pod; (upper right) unidentified plant fibres; (lower left) *Solanum* sp. (bush tomato) seed; and (lower right) Unidentified Type B (prickle).

4.3.8.5 SNR 5

Sample SNR 5 was located at the rear of PIL_542 and was partially embedded into the ground. The dimensions were 65 x 28 x 18 cm and a section of the midden was sampled. AMS dating of SNR 5 returned an age range of 12,050–12,430 cal. BP (Wk-42961). There were a high number of *Callitri*s sp. leaf segments and other unknown leaf, bark and twig fragments in the macrofossil record (Figure 4.20). The pollen record was dominated by Myrtaceae, as were all other samples collected from PIL_542.

Figure 4.19 *Callitris* sp. jointed leaves from PIL_542 SNR 5.

4.3.8.6 SNR 6

Sample SNR 6 was in two separate parts and was located on the floor of the rockshelter amongst roof fall. The dimensions of SNR 6A were 10 x 14 x 13 cm and those of SNR 6B were 15 x 12 x 13 cm. SNR 6A was not dated but contained a pollen record dominated by *Acacia* and Myrtaceae. AMS dating of SNR 6B returned an age range of 13,420–13,710 cal. BP (OZU469) and contained a large number of *Callitris* sp. leaf segments and other unknown fragments of leaves, twigs and bark. Its pollen record was dominated by Myrtaceae.

4.3.8.7 SNR 7

Sample SNR 7 was located inside of a small crevice elevated approximately 2.5 m above ground level. The midden dimensions were 20 x 8 x 22 cm and a section of the midden was sampled. AMS dating of SNR 7 returned an age range of 9540–9890 cal. BP (OZU470). In the macrofossil record, there was a very high number of unknown leaf, twig and bark fragments (Figure 4.21). Unknown Type G and *Solanum* sp. were also dominant. The pollen record was dominated by a range of trees and shrubs but mostly Myrtaceae.

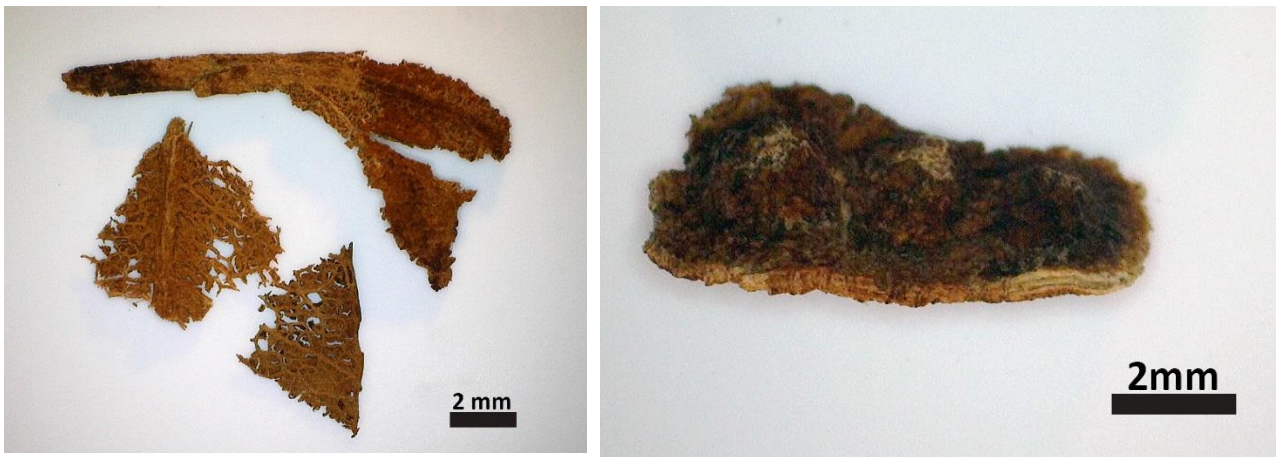

Figure 4.20 Macrofossils recovered from PIL_542 SNR 7: (left) Unidentified leaf fragments and (right) Unknown Type C.

4.3.8.8 SNR 8

Sample SNR 8 was located on the floor near the centre of PIL_542. The midden dimensions were 12 x 10 x 5 cm and the entire midden was sampled. AMS dating of SNR 8 returned an age range of 10,240–10,510 cal. BP (OZU471). As with other middens collected from PIL_542, there was a high number of unknown leaf fragments and twigs (Figure 4.22); however, there was very little identifiable material when compared to other PIL_542 middens. The only seed that could be identified was from an unknown species of Asteraceae (daisy) (Figure 4.22). The pollen record was dominated by a range of trees and shrubs.

Figure 4.21 Macrofossils recovered from PIL_542 SNR 8: (left) unidentified Asteraceae seed and (right) a twig from an unknown species.

4.3.8.9 SNR 9

Sample SNR 9 was located on the floor near the centre of PIL_542, though it had not clearly fallen from above. The dimensions were 9 x 8 x 4 cm and the entire midden was sampled. AMS dating of SNR 9 returned an age range of 19,400–19,860 cal. BP (OZU466). SNR 9 contained a large amount of fragmentary leaves and twigs, which is typical of other PIL_542 samples, but contained no identifiable material. The pollen record was dominated by heavily by Myrtaceae.

The results from plant macrofossil, pollen and aDNA analysis of SNR 1–9 are presented in Tables 4.15 and 4.16.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unknown Types	Relative Counts
SNR 1	Undated	Not analysed			
SNR 2	Undated	Not analysed			
SNR 3A	Undated	Not analysed			
SNR 3B	Undated	Not analysed			
SNR 4A	Undated	Not analysed			
SNR 4B	12,080–12,560	HERBS		Plant fibres	200
		Daucus glochidiatus	1	Unknown Type B	3
				Unknown Type G	4
		GRASSES		Unknown Type I	2
		Poaceae	3		
		Aristida sp.	1		
		Themeda triandra	1		
		TREES AND SHRUBS			
		Callitris sp.	2		
		Solanum sp.	13		
SNR 4C	31,100–31,760	GRASSES		Plant fibres	1192
		Poaceae	6		
		Aristida sp.	4		
		Triodia sp.	6		
		TREES AND SHRUBS			
		Callitris sp.	6		
		Solanum sp.	14		
SNR 5	12,050–12,430	GRASSES		Bark fragments	3
		Poaceae	6	Leaf fragments	30
		Themeda triandra	3	Plant fibres	801
				Twigs	26
				Unknown Type B	2
		TREES AND SHRUBS			
		Callitris sp.	2		
		Solanum sp.	9		
SNR 6A	Undated	Not analysed			

SNR 6B	13,420–13,710	GRASSES		Bark fragments	20
		Poaceae	3	Leaf fragments	801
		Triodia sp.	1	Plant fibres	150
		Themeda triandra	2	Twigs	36
				Unknown Type B	1
				Unknown Type G	1
		TREES AND SHRUBS			
		Callitris sp.	20		
		Solanum sp.	6		
SNR 7	9540–9890	HERBS		Leaf fragments	1207
		Portulaca oleracea	12	Plant fibres	483
				Twigs	64
		GRASSES		Unknown Type C	4
		Poaceae	4	Unknown Type G	32
				Unknown Type J	4
		SHRUBS			
		Solanum sp.	28		
SNR 8	10,240–10,510	HERBS		Leaf fragments	20
		Asteraceae	2	Plant fibres	199
				Twigs	10
SNR 9	19,400–19,860	-	-	Leaf fragments	402
				Plant fibres	201
				Twigs	72

Table 4.15 Summary of plant macrofossil analysis results from PIL_542.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 80% of the total pollen sum. Other trees and shrubs (~5%) include *Acacia*, *Araliaceae* cf. *Astrotricha*, *Dodonaea* and *Rubiaceae* cf. *Timonius*. Herbaceous taxa (~15%) are dominated by Poaceae,with chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 2	Undated	Assemblage dominated by Myrtaceae Type 1 and 2 (*Eucalyptus* type and *Corymbia* sp.) with Myrtaceae making up about 90% of the total pollen sum. Other trees and shrubs (~1%) include *Dodonaea*. Herbaceous taxa (~10%) are dominated by Poaceae, with chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 3A	Undated	Assemblage dominated by Myrtaceae Type 2 (Corymbia sp.) with Myrtaceae making up about 90% of the total pollen sum. Other trees and shrubs (~1%) include *Acacia*, *Dodonaea*, *Euphorbiaceae* and *Loranthaceae*. Herbaceous taxa (~10%) are dominated by Poaceae, with chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 3B	Undated	Assemblage dominated by Myrtaceae Type 2 (*Corymbia* sp.) with Myrtaceae making up about 85% of the total pollen sum. Other trees and shrubs (~1%) include *Acacia* and Euphorbiaceae. Herbaceous taxa (~15%) are dominated by Poaceae, with chenopods and Asteraceae making up a minor part of the group.	Not analysed

SNR 4A	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 80% of the total pollen sum. Other trees and shrubs (~2%) include *Acacia*, *Callitris* and Loranthaceae. Herbaceous taxa (~20%) are dominated by Poaceae, with chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 4B	12,080–12,560	Assemblage dominated by Myrtaceae Type 1 and 2 (~50%), and *Acacia* (~20%). Other trees and shrubs (~3%) include Myrtaceae Type 3 (*Corymbia* sp. ornate), *Dodonaea*, Euphorbiaceae and *Rubiaceae* cf. *Timonius*. Herbaceous taxa (~30%) are dominated by Poaceae and *Pteridaceae* cf. *Cheilanthes* (ferns), with chenopods, Asteraceae and Haloragaceae making up a minor part of the group.	Not analysed
SNR 4C	31,100–31,760	Assemblage dominated by Myrtaceae Type 2 (*Corymbia* sp.) with Myrtaceae making up about 80% of the total pollen sum. Other trees and shrubs (~5%) include *Acacia*, *Dodonaea*, Loranthaceae, *Gyrostemon*, and *Rubiaceae* cf. *Timonius*. Herbaceous taxa (~15%) are dominated by Poaceae, with chenopods, Asteraceae and *Pteridaceae* cf. *Cheilanthes* (ferns) making up a minor part of the group.	Not analysed
SNR 5	12,050–12,430	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 60% of the total pollen sum. Other trees and shrubs (~20%) include *Acacia Dodonaea, Gyrostemon*, Euphorbiaceae, Loranthaceae, Rhamnaceae, *Solanum* type and *Rubiaceae* cf. *Timonius*. Herbaceous taxa (~20%) are dominated by Poaceae, with chenopods, Asteraceae and *Pteridaceae* cf. *Cheilanthes* (ferns) making up a minor part of the group.	Taxa present: (In processed sample) Herbs: *Mentha*. Grasses: *Avena,* Micrairoideae. Trees and shrubs: *Pinus, Morus*, *Musa*. Taxa present: (In unprocessed sample) Herbs: *Nepeto,* Pedaliaceae, Anacardium. Cannabis. Grasses: PACMAD Clade. Trees and shrubs: *Pinus, Prunus,* Myrtaceae.
SNR 6A	Undated	Assemblage dominated by Myrtaceae Type 1 and 2 (*Eucalyptus* type and *Corymbia* sp.) (~45%) and *Acacia* (~30%). Other trees and shrubs (~5%) include *Dodonaea*, Euphorbiaceae, *Gyrostemon*, Malvaceae, Rhamnaceae, *Solanum* type, *Callitris* and *Triumfetta*. Herbaceous taxa (~20%) are dominated by Poaceae, with chenopods, Asteraceae and Monolete spore making up a minor part of the group.	Not analysed
SNR 6B	13,420–13,710	Assemblage dominated by Myrtaceae Type 2 (*Corymbia* sp.) with Myrtaceae trees and shrubs making up about 80% of the total pollen sum. Other trees and shrubs (~10%) include *Acacia* and *Callitris* with Euphorbiaceae and Loranthaceae making up a minor part of the group. Herbaceous taxa (~10%) are dominated by Poaceae, with chenopods, Asteraceae and Cyperaceae making up a minor part of the group.	Not analysed

SNR 7	9540–9890	Assemblage dominated by Myrtaceae Type 1 and 2 with Myrtaceae making up about 50% of the total pollen sum. Other trees and shrubs (~15%) include *Acacia, Dodonaea*, Euphorbiaceae, *Grevillea/Hakea* and *Rubiaceae* cf. *Timonius.* Herbaceous taxa (~35%) are dominated by Poaceae, with chenopods, Asteraceae, Convolvulaceae and *Pteridaceae* cf. *Cheilanthes* (ferns) making up a minor part of the group.	Not analysed
SNR 8	10,240–10,510	Assemblage dominated by Myrtaceae Type 2 (*Corymbia* sp.) with Myrtaceae making up about 40% of the total pollen sum. Other trees and shrubs (~25%) include *Dodonaea, Gyrostemon*, Euphorbiaceae, Loranthaceae, Polygalaceae, and Rhamnaceae. Herbaceous taxa (~35%) are dominated by Poaceae, with chenopods, Asteraceae, Convolvulaceae and *Pteridaceae* cf. *Cheilanthes* (ferns) making up a minor part of the group.	Not analysed
SNR 9	19,400–19,860	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 85% of the total pollen sum. Other trees and shrubs (~5%) include *Acacia*, *Dodonaea*, Euphorbiaceae, *Gyrostemon*, Rhamnaceae and *Rubiaceae* cf. *Timonius*. Herbaceous taxa (~10%) are dominated by Poaceae, with Chenopods and Asteraceae making up a minor part of the group.	Not analysed

Table 4.16 Summary of pollen and aDNA analysis results from PIL_542.

4.3.9 PIL_5841

PIL_5841 is located on the eastern side of Packsaddle Range adjacent to an ephemeral gully creek. It is a very large cavernous rockshelter that sits at the base of a large BIF cliff along a northwest-southeast trending gully. The rockshelter measures 3.2 m wide, 22 m deep and 1.5 m high, and consists of three distinct chambers (Czerwinski 2013:26). Eight samples were collected from five discrete middens in the darkest regions of the cave (Figure 4.23). Four of the samples were radiocarbon dated and returned ages from 2350 to 17,120 cal. BP.

The archaeology of this site was investigated by Wallis (2015) as a part of a study into walled rockshelters of the Pilbara. Through excavation, Wallis (2015:75) found that initial use of the site appeared to have occurred around 17,000 cal. BP. From this moment onwards, use of the rockshelter was sporadic until around 4300 cal. BP as demonstrated by the increased presence of charcoal and stone artefacts. A walled feature across the northern opening of the rockshelter appears to have been constructed in the last millennium (Wallis 2015:75). The vegetation surrounding PIL_5841 is summarised in Appendix 8.

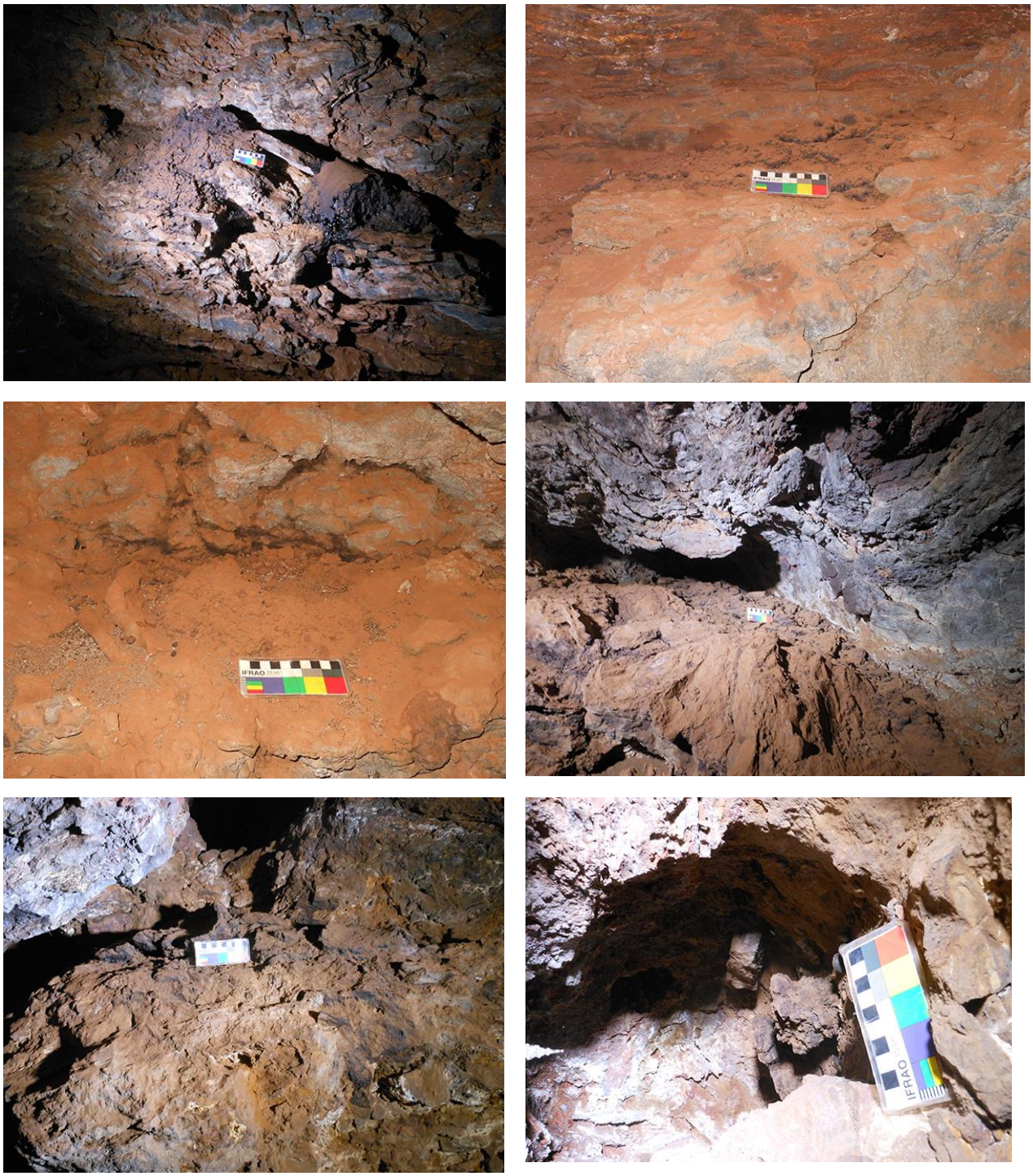

Figure 4.22 In situ samples from PIL_5841: (upper left) SNR 1; (upper right) SNR 2A; (middle left) SNR 2B; (middle right) SNR 3; (lower left) SNR 4; and (lower right) SNR 5 (10 cm scales) (photographs by Lynley Wallis).

4.3.9.1 SNR 1

Sample SNR 1 was a large midden located on a ledge in the outer chamber and was elevated 1.4 m above ground level. This midden was initially sampled by Wallis (2015) but was resampled during this project

using more effective methods. The dimensions were 161 x 45 x 17 cm and the midden was sampled in three sections to capture its entire length (right, centre and left). AMS dating of SNR 1 (right) returned an age estimate of 16,620–17,120 cal. BP (Wk-42962); the other sections were not dated. SNR 1 (right) contained a wide range of species in the macrofossil record but was heavily dominated by Myrtaceae pollen. Myrtaceae was also present in the aDNA record along with *Callitris* sp. and a range of other herbs. The other sections of the midden that were not dated also contained a pollen record dominated by Myrtaceae.

4.3.9.2 SNR 2

Sample SNR 2 was located on a ledge in the outer chamber and was elevated 1.6 m above ground level. The midden was sampled in two sections (2A and 2B) which were both heavily covered in dust with a crumbling appearance. The dimensions of SNR 2A were 40 x 43 x 4 cm and, given the small size of the midden, it was sampled in its entirety. The pollen record of SNR 2A was dominated by Myrtaceae and Cyperaceae. The dimensions of SNR 2B were 20 x 17 x 6 cm, and this midden was also sampled in its entirety. AMS dating of SNR 2B returned an age estimate of 10,590–11,080 cal. BP (OZU481). The pollen record of SNR 2B was dominated by Myrtaceae; the macrofossil record was diverse and had a moderate number of grasses (Figure 4.24).

Figure 4.23 Macrofossils recovered from PIL_5841 SNR 2B: (left) *Triumfetta* sp. seed pod and (right) Unknown Type I.

4.3.9.3 SNR 3

Sample SNR 3 was located on a ledge in the middle chamber, elevated approximately 1.35 m above ground level. The dimensions were 130 x 50 x 8 cm and one section of the midden was sampled. Similar to SNR 2, SNR 3, it was heavily covered in dust and appeared to be breaking apart in places. The broken parts of the midden were avoided and the shiny indurated section was targeted to reduce the risk of contamination. AMS dating of SNR 3 returned an age range of 6750–7160 cal. BP (OZU480). The macrofossil record is represented by a diverse range of identifiable species with grasses and *Solanum* sp. being the most dominant; the pollen record is unknown at this stage (Figure 4.25, Figure 4.26 and Figure 4.27).

Figure 4.24 Macrofossils recovered from PIL_5841 SNR 3: (left) unidentified plant fibres and (right) and unidentified grass seeds.

Figure 4.25 Macrofossils recovered from PIL_5841 SNR 3: (upper left) *Amaranthus mitchelli* seed; (upper right), Unidentified Asteraceae floret; (lower left) *Cleome viscosa* seed pod; and (lower right) unidentified *Triodia* sp. seed.

Figure 4.26 *Solanum* sp. (bush tomato) seeds (from PIL_5841 SNR 3.

4.3.9.4 SNR 4

Sample SNR 4 was located inside a crevice elevated approximately 1.4 m above ground level. The midden dimensions were 70 x 25 x 10 cm and most of the sample was removed. AMS dating of SNR 4 returned an age range of 2350–2700 cal. BP (Wk-42963). Poaceae dominated the pollen record of SNR 4 and there was also a high occurrence of Cyperaceae, which was also represented in the macrofossil record. There were also a few unknown macrofossils such as Unknown Type F, a seed pod (Figure 4.28).

Figure 4.27 Unknown Type F, seed pod from PIL_5841 SNR 4.

4.3.9.5 SNR 5

Sample SNR 5 was located inside of the same crevice as SNR 4 and was elevated approximately 1.65 m above ground level. The midden dimensions were 20 x 12 x 9 cm and a loose section of the midden was sampled. SNR 5 was not dated. Its pollen record was dominated by Poaceae.

The results from plant macrofossil, pollen and aDNA analysis of SNR 1–5 are presented in Tables 4.17 and 4.18.

Sample Code	Calibrated Age (yrs BP)	Identified Types	Relative Counts	Unknown Types	Relative Counts
SNR 1 (Right)	16620–17120	HERBS		Bark fragments	2
		Cyperaceae	4	Leaf fragments	24
		Boerhavia coccinea	4	Plant fibres	1993
				Twigs	10
		GRASSES			
		Poaceae	4		
		Dicanthium sericeum	12		
		SHRUBS			
		Sida sp.	2		
		Solanum sp.	8		
SNR 1 (Centre)	Undated	Not analysed			
SNR 1 (Left)	Undated	Not analysed			
SNR 2A	Undated	Not analysed			
SNR 2B	10590–11080	GRASSES		Plant fibres	503
		Poaceae	27	Unknown Type G	13
		Triodia sp.	5	Unknown Type I	1
		Dicanthium sericeum	3	Unknown Type J	1
		SHRUBS			
		Solanum sp.	7		
		Triumfetta sp.	1		
SNR 3	6750–7160	HERBS		Plant fibres	3214
		Asteraceae	2	Unknown Type G	10
		Amaranthus mitchelli			
		Boerhavia coccinea			
		Cleome Viscosa			
		GRASSES			
		Poaceae	15		
		Triodia sp.	12		
		Dicanthium sericeum	7		
		Themeda triandra	3		
		SHRUBS			
		Solanum sp.	40		
SNR 4	2350–2700	HERBS		Plant fibres	1204
		Cyperaceae	1	Twigs	1
				Unknown Type F	2
		GRASSES		Unknown Type G	5
		Poaceae	9	Unknown Type I	2
		Dicanthium sericeum	2		
		SHRUBS			
		Solanum sp.	13		
SNR 5	Undated	Not analysed			

Table 4.17 Summary of plant macrofossil analysis results from PIL_5841.

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1 (Right)	16,620–17,120	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 80% of the total pollen sum. Other trees and shrubs (~1%) include *Dodonaea*, Rhamnaceae and *Solanum* type. Herbaceous taxa (~20%) are dominated by Poaceae and Cyperaceae, with chenopods, Asteraceae and Pteridaceae cf. *Cheilanthes* (ferns) making up a minor part of the group.	Taxa present: (In processed sample) Herbs: Apioideae Asteroideae, Boraginaceae (can also be a tree or shrub), *Teucrium, Lamiales, Indigofera, Euphorbia* (can also be a tree or shrub), Brassicaceae, *Gossypium.* Grasses: Triticeae, Andropogoneae, PACMAD Clade. Trees and shrubs: *Callitris, Acacia, Prunus,* Myrtaceae, Proteaceae. (In unprocessed sample) Grasses: Poa. Trees and shrubs: Myrtaceae.
SNR 1 (Centre)	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 70% of the total pollen sum. Other trees and shrubs (~2%) include *Solanum* type and *Dodonaea*. Herbaceous taxa (~30%) are dominated by Cyperaceae with Poaceae, chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 1 (Left)	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 73% of the total pollen sum. Other trees and shrubs (~2%) include *Dodonaea*. Herbaceous taxa (~25%) are dominated by Cyperaceae with Poaceae, *Pimelea* and *Trichodesma* making up a minor part of the group.	Not analysed
SNR 2A	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 90% of the total pollen sum. Other trees and shrubs (~2%) include *Dodonaea*, Malvaceae, *Solanum* type and *Triumfetta*. Herbaceous taxa (~8%) are dominated by Poaceae), with *Trichodesma*, chenopods and Asteraceae making up a minor part of the group.	Not analysed
SNR 2B	10,590–11,080	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 85% of the total pollen sum. Other trees and shrubs (~2%) include *Solanum* type. Herbaceous taxa (~15%) are dominated by Poaceae, with Cyperaceae making up a minor part of the group.	Not analysed
SNR 3	6750–7160	No results provided	Not analysed
SNR 4	2350–2700	Assemblage dominated by Poaceae which make up about 70% of the total pollen sum. Other herbaceous taxa (~5%) include *Pimelea* and Cyperaceae.	Not analysed

		Tree and shrub taxa (~25%) are dominated by Myrtaceae (*Eucalyptus* type and *Corymbia* sp.), with *Dodonaea* and Euphorbiaceae making up a minor part of the group.	
SNR 5	Undated	Assemblage dominated by Poaceae, which make up about 80% of the total pollen sum. No other herbaceous taxa were present. Tree and shrub taxa (~20%) are dominated by Myrtaceae; no other taxa were present.	Not analysed

Table 4.18 Summary of pollen and aDNA analysis results from PIL_5841.

4.3.10 PIL_7026

PIL_7026 is a small rockshelter at Governor Range close to an ephemeral watercourse and a waterhole. The crevice contained one small midden (SNR 1) inside of a crevice which was elevated around 3 m above ground level. The midden was in a relatively open and well-lit position and appeared to have a very weathered condition (Figure 4.12). The thickest area of the midden was sampled and the dimensions were 47 x 22 x 2 cm. The sample was not dated and neither was it subject to detailed macrofossil analysis. The PIL_7026 pollen record was dominated by Myrtaceae and other trees and shrubs. The painted rock art at this site was subjected to detailed recording by Wallis et al. (2015) and other surface artefacts such as grindstones, hammerstones and manuports were observed nearby the rockshelter.

The surrounding vegetation is summarised in Appendix 8 and the results from the pollen analysis of SNR 1 are presented in Table 4.19.

Figure 4.28 (left) The crevice at PIL_7026 containing the midden sample and (right) more detailed view of sample SNR 1 in situ (10 cm scale) (photographs by Lynley Wallis).

Sample Code	Calibrated Age (yrs BP)	Pollen	aDNA
SNR 1	Undated	Assemblage dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Myrtaceae making up about 60% of the total pollen sum. Other trees and shrubs (~20%) include *Dodonaea, Grevillea/ Hakea, Gyrostemon*, Malvaceae, *Solanum* type and Rubiaceae cf. *Timonius*. Herbaceous taxa (~20%) are dominated by chenopods, with Asteraceae, Haloragaceae and Pteridaceae cf. *Cheilanthes* (ferns) making up a minor part of the group.	Not analysed

Table 4.19 Summary of pollen and aDNA analysis results from PIL_7026.

In the next chapter, these results will be used to develop a reconstruction of vegetation change over time for each site. The overall trends of vegetation change are discussed and an explained in terms of the regional and broad-scale palaeoenvironmental evidence and other midden based studies.

DISCUSSION

5.1 Introduction

The purpose of this project was to assess how the analysis of middens from the inland Pilbara could be used to infer past climate change and therefore help to characterise the nature of human-environmental relationships. This chapter discusses the results from the multi-proxy analysis of middens and develops a series of reconstructions of vegetation change through time against a backdrop of previous midden studies and the regional palaeoenvironmental literature. Based on these reconstructions, the palaeoenvironmental implications of the middens will be assessed and some interpretations are made to demonstrate the contribution that this information could make towards archaeological understandings of human-environmental relationships.

5.2 Chronology and Temporal Resolution of Middens

Radiocarbon analysis of middens from the Packsaddle Range and surrounds has enabled a reconstruction of vegetation change through the late Quaternary — a time period for which very little palaeoenvironmental information currently exists in the region. Most dated middens in Australia are only late Holocene in age (MacPhail 2011; Pearson and Betancourt 2002:51). Accordingly, it was thought by Pearson et al. (1999:306) that late Pleistocene middens in Australia were either non-existent or exceptionally rare and for this reason, major shifts in plant taxa pre- and post- the last glacial maximum period could not be identified with any certainty. At the commencement of this project, the oldest known Australian midden was recorded in the Brockman Range, also in the inland Pilbara (30,490 ± 380 cal. BP), and while aDNA had been successfully recovered from it (Murray et al. 2012), attempts to recover plant macro- or

microfossils from it were singularly unsuccessful (MacPhail 2011). As such, the amberat middens of the inland Pilbara had garnered no further interest. However, the identification of several late Pleistocene-aged middens during this project, from which macro- and microfossils have been successfully recovered and analysed have demonstrated the strong potential for this kind of research to be undertaken in the inland Pilbara.

Radiocarbon results indicate that middens have been accumulating in caves and rockshelters in the Packsaddle Range and surrounds relatively consistently throughout the past 19,000 years; however, there is a major gap in the midden record from 31,000–19,860 cal. BP and two minor gaps at 6000–4000 cal. BP, and 10,000–8000 cal. BP. These gaps could be a result of the bulk sampling strategy used during this project, or they could be indicative of a genuine decline in midden accumulation during these periods, perhaps associated with a restriction in the range of the accumulator species. Given the limited scope of the current project and relatively small number of samples available to date, it is not possible to be certain at this stage which of these possibilities is more likely.

The botanical and charcoal contents of middens have provided a preliminary overview of environmental change using a series of vegetation snapshots (e.g. Webeck and Pearson 2005:468). Owing to the discontinuous nature of this record, the temporal resolution was variable. Majority of the middens were dated to the mid- to late Holocene so the resolution for this period was much finer. Late Pleistocene-aged middens were less common, so the resolution for this period was much coarser. Achieving a very fine temporal resolution was not feasible using the bulk sampling method used during this project but, as suggested earlier in response to gaps in the midden record, a higher resolution of data could be achieved in the future if individual middens could be stratigraphically sampled and dated.

Site PIL_542 contained the oldest dated midden of those sampled and thus represents the longest record of late Pleistocene vegetation in the project. Interestingly, there were no mid- to late

Holocene aged middens collected from this particular site; this sets it apart from the other sites sampled during this project and from most other midden sites across Australia (Pearson et al. 1999:298–301). The evidence reveals that after around 20,000 years of midden building during the late Pleistocene in site PIL_542, after 9540 cal. BP, middens no longer appear to have been constructed within this rockshelter. It is possible that this apparent cessation of midden building might merely be a sampling effect. As noted earlier, there were extremely large middens in this site that extended to the rockshelter ceiling but, owing to OHS constraints, only middens that could sampled from ground level were sampled. If the middens have accumulated vertically, this would mean that the youngest, most recent layers should be those that are higher up. If so, the sampling adopted during this project only captured the lower layers, which were invariably older. To test this theory, further sampling is needed to determine if height is a factor in the age of the midden, and if there are younger middens closer to the ceiling. If no mid- to late Holocene aged middens can be found this would show that factors other than sampling were responsible for the disappearance of the contributor species during this time. For example, climatically induced vegetation change affecting the viability of the animal's immediate habitat or anthropogenic burning (cf. Pearson et al. 1999:305).

Comparing an LGM aged midden with one from the late Holocene across different sites can be problematic because it does not always account for the spatial variations in vegetation that might occur between the sites to begin with. At PIL_5841, it was possible to compare vegetation between a midden from the end of the LGM with one from the late Holocene, demonstrating that a major shift from vegetation dominated by woodland to a more heterogenous structure of vegetation that included dominant grasses. This shift seems to have occurred sometime after 6750 cal. BP. Assuming that the taphonomic processes inside the rockshelter remained relatively consistent over the time period of concern, other factors that might be responsible for the dramatic change in vegetation, such as fire or climate, have been considered alongside short-term seasonal and spatial variations. To help strengthen this evidence there needs to be a more

detailed survey of the modern vegetation surrounding sites, combined with the collection and monitoring of modern pollen, to determine the magnitude of spatial differences. This information can then be factored into the interpretation of the fossil midden record (Haberle and Hopf 2016:7).

It became apparent during the course of the study that middens that were in 'open' positions within the rockshelter or were close to ground-level, tended to contain less botanical material than those that were elevated and in more closed-in positions. Many of the former middens were sampled; however, they were not dated because visually they appeared to be dominated by amberat with limited macrobotanical material apparent. The decision to focus the dating attempts on the middens that yielded the highest amounts of vegetative material may have led to a bias towards the better-preserved younger samples, which created the impression that midden activity was at its height during the mid- to late Holocene. Further dating of middens regardless of vegetative contents is needed to avoid this sampling bias. If shown to not be the result of sampling bias, a concentration in mid- to late Holocene aged middens could be interpreted as an actual increase in midden activity possibly due to changing climate and increased vegetation productivity (Pearson et al. 1999:305).

Interestingly, midden accumulation appears to cease completely after 800 cal. BP, despite there having been considerable activity during the mid- to late Holocene. This may be a result of the older more indurated middens surviving for much longer as un-indurated middens are suggested to be very short-lived and difficult to sample (Pearson 1997:222). However, if not the result of sampling or preservation bias, the absence of middens in the last 800 years could reflect the actual disappearance of the contributor species from rockshelters and caves due to climatic change or human influence (Haberle and Hopf 2016:7; Pearson et al. 1999:305). Stick-nest rats were known to be a regular part of the diet of Indigenous people before they became extinct soon after European occupation (Copley 1999:527). Early European settlers and explorers recorded instances where Indigenous people accompanied by dingoes would set fire to free-standing stick-

nests, and as the inhabitants fled the nest, they were either hit with sticks or captured by dingoes (Copley 1999:527; Tindale 1974; Troughton 1924). Copley (1999:527) also reported that many stick-nest remains in caves showed signs of having been burnt, and this is consistent with the presence of charcoal in the samples from the Packsaddle area.

5.3 Identification of Midden Contributors

The presence of rodent incisors and possible rodent faecal pellets throughout some of the samples suggests that a rodent, such as the stick-nest rat (*Leporillus* sp.), might have been responsible for accumulation of the middens. The exact identity of the midden contributors was not able to be confirmed due to a combination of logistical issues and the absence/fragmentary nature of faunal remains in the samples. Other than several incisor fragments, other bone material was very minimal and extremely fragmentary so formal identifications could not be made. According to Pearson et al. (2001:436), middens containing only hair, insect cuticles, and some teeth describe a very well-digested level of mastication which could be contributed to middens via ejecta from foxes, cats, lizards or snakes, and this is usually the case with heavily indurated middens, such as the type found in the inland Pilbara. Some of the middens contained abundant amounts of hair and it was initially hoped that Dr Jeff Foulkes would be able to identify this material to the species-level; however, other commitments meant that he was unable to provide the results in time for inclusion into this project. Regardless, future research should pursue this avenue of investigation.

The weathered surface texture and heavy dustiness of many of the Packsaddle middens suggests that they had ceased accumulating. No live animals, apart from some bats, were found in the immediate vicinity of any of the nests. While the specific contributors are unknown at this stage. This would be consistent with the main contributor being a stick-nest rat as the species is thought to have been extinct in WA since the 1920s or 1930s (Copley 1999:530); however, without any definitive identifications this cannot be proposed with certainty.

5.4 Contents of the Middens

5.4.1 Macrofossils

Macrofossil analysis identified a diverse range of vegetation species as represented mostly by seeds, florets and seed casings from grasses and herbaceous taxa. The number and diversity of grasses (mostly *Triodia* sp., *Dichanthium sericeum* and *Themeda triandra)* increases slightly after around 6000 cal. BP (Figure 5.1. There are many different species of *Triodia sp.* present in the Pilbara region today (WA Herbarium 2017). It was recorded growing close to all sites in the Packsaddle area. There is very little morphological difference between some *Triodia* species (Burbidge 1953:122). This factor made it difficult to identify the species of apparent *Triodia* sp. florets without a more specific reference collection for which to compare to. *Triodia* sp. predominantly occurs in regions with variable summer rainfall; it is well-adapted to fire, and its leaf anatomy makes it well-adapted to drought (Burbidge 1953:123; Lazarides 1997:381–382). *Themeda triandra* is widespread across Australia owing to its ability to grow in areas over a wide rainfall range of 500 to 2000 mm per year (Scattini 2008a). The high number of *Themeda triandra* that occurs after around 5300 cal. BP could indicate that, in the past, the annual rainfall in the Packsaddle area has been higher than it is today. The Packsaddle area currently receives an annual rainfall of 300 to 350 mm and both *Themeda triandra* and *Dichanthium sericeum* currently prefer to grow in areas with an annual rainfall of 500mm or higher (Bureau of Meteorology 2017; Scattini 2008a, 2008b). Neither species were recorded during this study to be growing within close proximity to the sites which does suggest that conditions may have been wetter in the past, especially from around 5000 to 3000 BP.

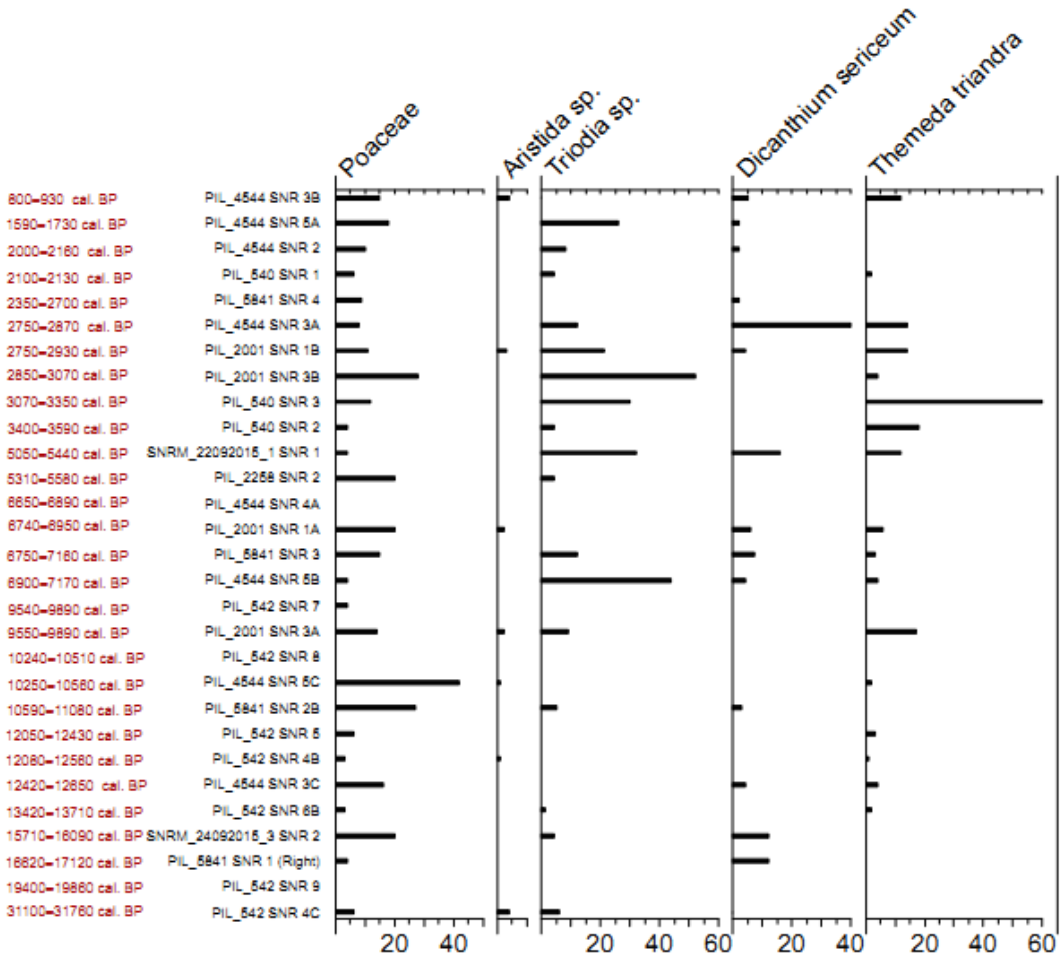

Figure 5.1 Summary diagram showing relative counts of grass macrofossils in order of calibrated sample age.

Herbs show a similar pattern to grasses (Figure 5.2). While there do not appear to be dramatic changes through time, there was a slight increase in most herbaceous species after about 5000 cal. BP, especially in the number of Cyperaceae and *Boerhavia coccinea* specimens. *Boerhavia coccinea* is considered to be a weed by pastoralists in Australia and it occurs in regions with an annual rainfall as low as 100 mm (Hashem and Amjad 2015). There is very little botanical information available for this species in Australia, but it is native to the Pilbara and it is recorded growing in the inland Pilbara today (WA Herbarium 2017). The increase in number of *Boerhavia coccinea* might indicate an expansion of the weed species into the Packsaddle area; however, at this stage it is not fully understood what the drivers for this expansion might have been.

Cyperaceae are known as sedges and are associated with wetlands and moist conditions (Field et al. 2017). So, the increased presence of sedges after around 3000 cal. BP could indicate wetter conditions in the Packsaddle area. Cyperaceae occurred mostly in middens from PIL_4544 and PIL_2001. These sites were both in gullies and close to ephemeral watercourses. A midden from SNRM_22092015_1 had the highest number of Cyperaceae compared to other sites and was located only 5 m above an ephemeral watercourse. Cyperaceae was not observed in the current vegetation surrounding sites; however, a more detailed survey would help to confirm this. If the species is no longer present in close proximity to these sites, this would indicate that the localities have been wetter throughout the past 5000 years.

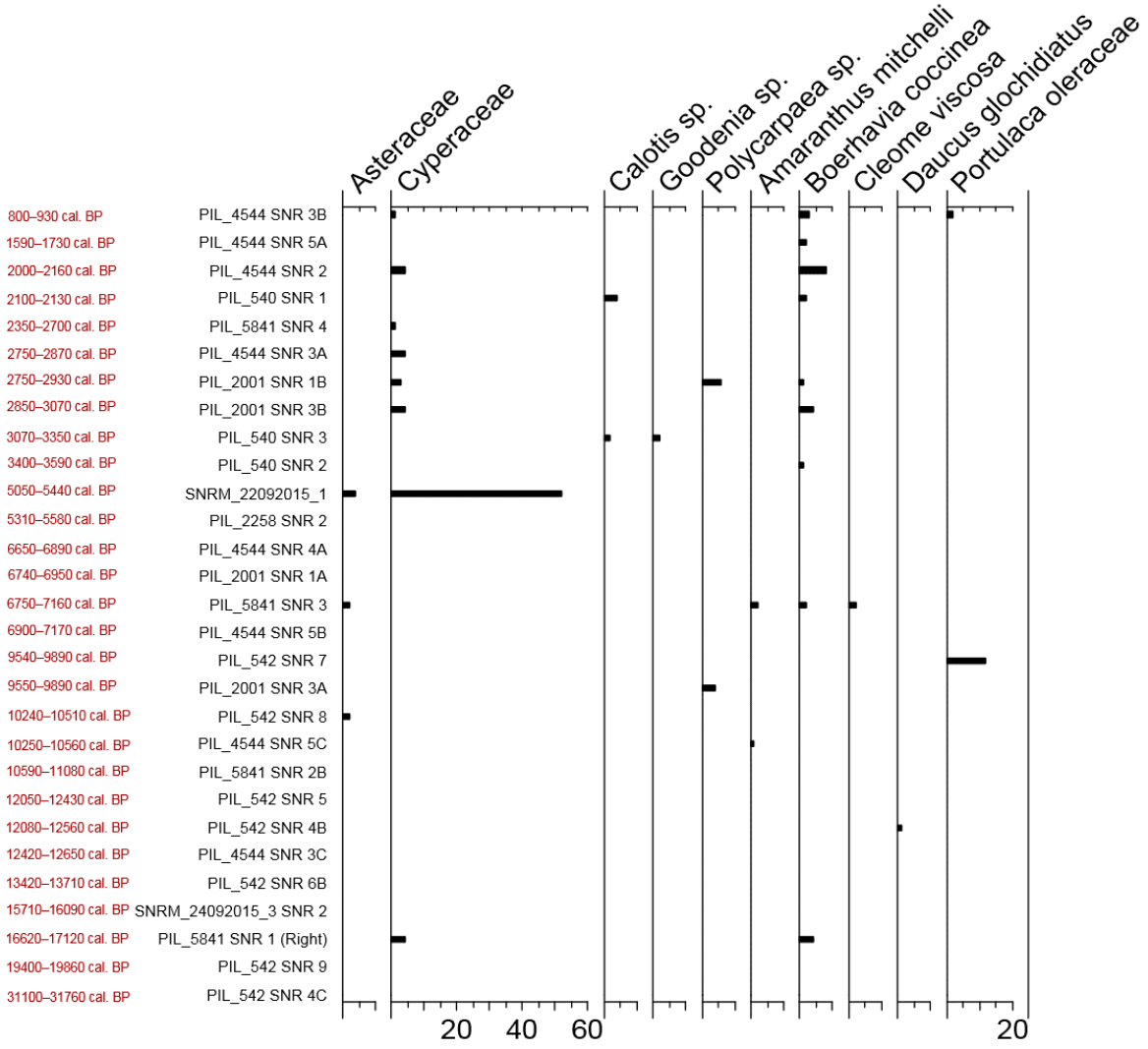

Figure 5.2 Summary diagram showing relative counts of herbaceous macrofossils in order of calibrated sample age.

Trees and shrubs are only represented by four different species in the macrofossil record: *Callitris* sp., *Sida* sp., *Solanum* sp. and *Triumfetta* sp. (Figure 5.3). There was, however, a large amount of unidentified bark, leave, and twig fragments in some samples, especially in those from PIL_542. *Callitris* sp. was only present in samples older than 12,000 cal. BP, despite one significant increase that occurred between 5050 and 5440 cal. BP.

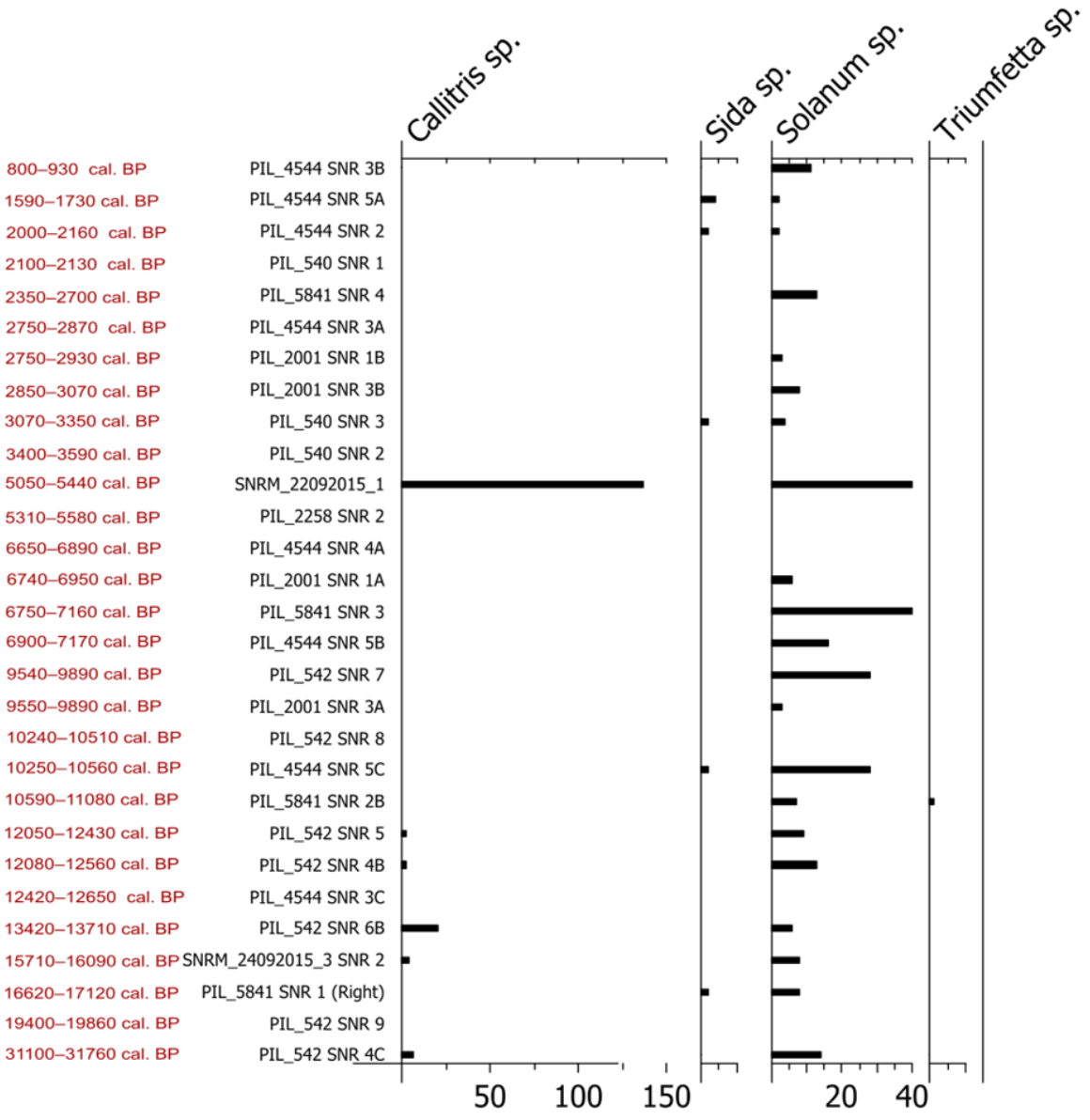

Figure 5.3 Summary diagram showing relative counts of tree and shrub macrofossils in order of calibrated sample age.

The overall identified macrofossil assemblage was dominated by grasses (mainly *Triodia* sp. and unidentified grass seeds) and *Solanum* sp. (bush tomato) with these species showing very little variation through time. The overall abundance of grasses and herbaceous taxa seems to have increased slightly from around 9500 cal. BP (grasses) and 5000 cal. BP (herbs), and this could be related to increased climatic variability. In addition to identified taxa, there were a number of unidentified seeds and plant parts that were assigned an Unknown Type classification. These Unknown types can be reclassified in the future if the correct identifications can be made. Any patterns shown in Figure 5.4 could then be used to infer environmental change.

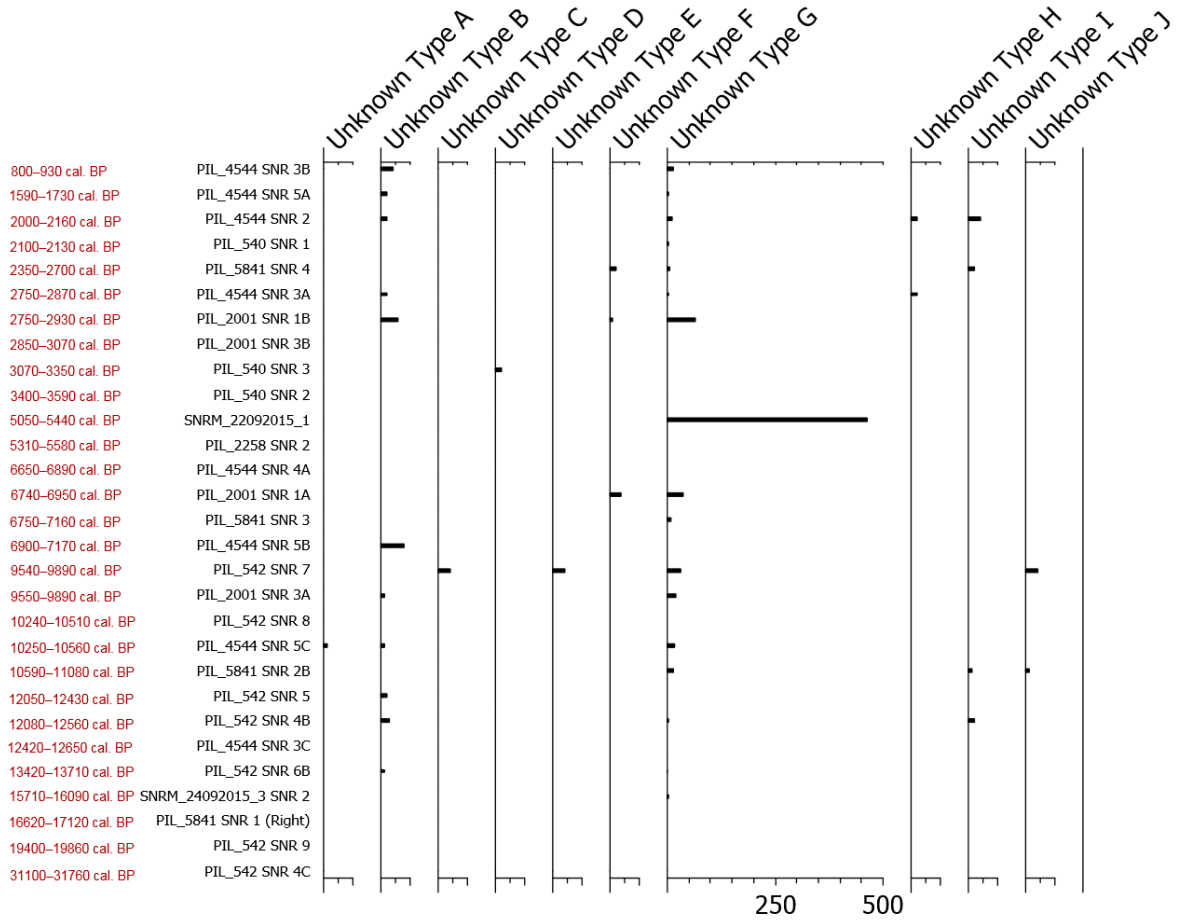

Figure 5.4 Summary diagram showing relative counts of Unknown Types in order of calibrated sample age.

In addition to seed macrofossils, most samples contained a large proportion of unidentified plant fibres that showed signs of mastication (Figure 5.1). These fibres generally lacked the distinctive morphological features required for microscopic identification using the available equipment or

were too fragmentary for comparison with reference collections, thereby precluding it being identified to species or even genus level. Similar material has also been recorded in middens in other studies and its dominance is thought to represent nesting material and the selection bias of midden contributors (Pearson and Dodson 1993:349; Webeck and Pearson 2005:468). The unidentified plant fibres generally formed a loose and tangled matrix of material that included animal hairs.

In comparison to the large amount of unidentified plant fibres, there were minimal twigs, bark or leaf fragments present in samples. Those that were present were often very fragmentary and did not exceed around 10 mm in length (Figure 5.5). Consequently, there are limitations to the extent of tree and shrub identifications that could be made from the macrofossil record, which has likely contributed to the dominance of grass and herbaceous taxa. As shown in Figure 5.5, the late Pleistocene/ early Holocene dated samples did show a slight increase in the occurrence of twigs, bark, and leaf fragments possibly from trees and shrubs. This is consistent with the pollen record, which showed that the local vegetation was dominated by woodlands at this time (Haberle and Hopf 2016:5).

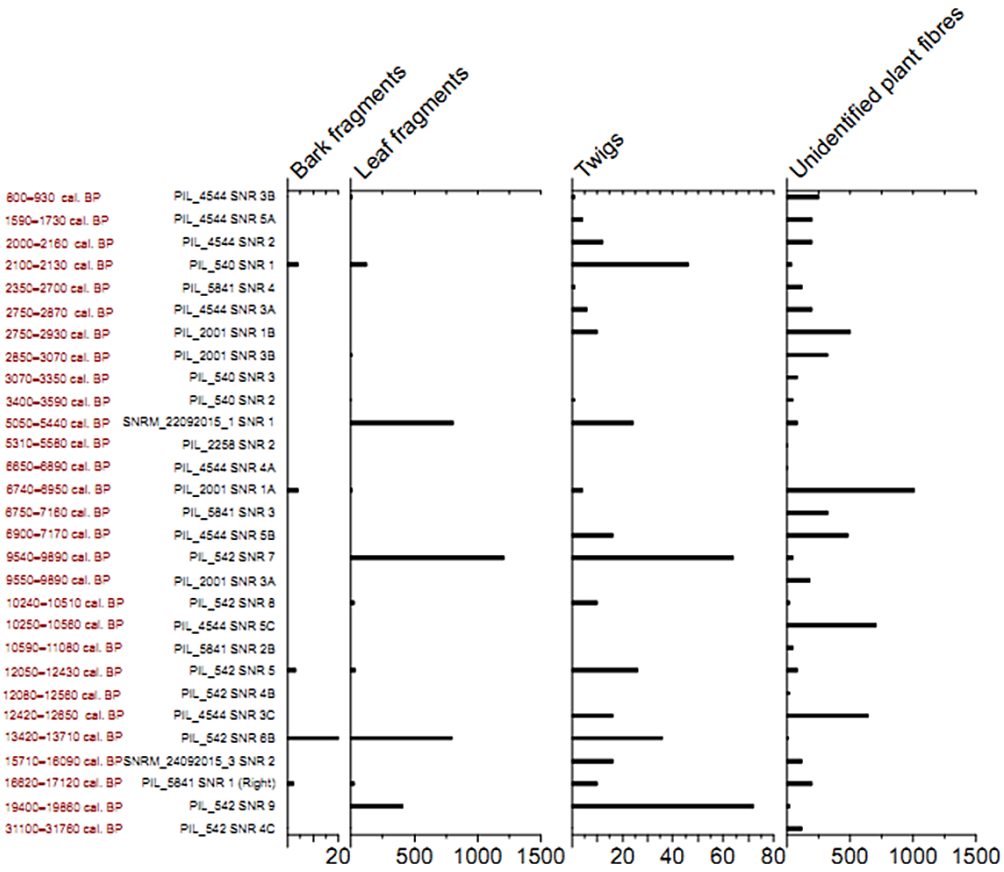

Figure 5.5 Summary diagram showing relative counts of unidentified macrofossil material in order of calibrated sample age.

5.4.2 Pollen and Charcoal

Pollen was abundant in most samples, with 114 pollen morphological taxa present, 55 of these were identified to Genera or Family level (Haberle and Hopf 2016). The pollen assemblage across all samples and sites was dominated by trees and shrubs, namely Myrtaceae (*Eucalyptus* type and *Corymbia* sp.). The other major dominant taxa were Poaceae, which only began to dominate the record after around 5000 cal. BP.

The overall trend in the pollen record showed that vegetation in middens dating pre-6000 cal. BP was mostly dominated by Myrtaceae and diverse trees and shrubs (Haberle and Hopf 2016:5). This trend continued throughout the early Holocene with little variation until the mid- Holocene when the pollen record displayed a shift towards more heterogeneous vegetation with open

woodlands, woodlands, and grasslands all dominating to varying degrees (Haberle and Hopf 2016:5).

During pollen analysis, microscopic fragments of charcoal and burnt grass phytoliths were found preserved alongside pollen. Figure 5.6 provides a summary of the microscopic charcoal contained in each sample. There were also some very fine fragments of macroscopic charcoal distributed throughout the macrofossil samples. The taphonomy of the microscopic charcoal at this stage is uncertain, but according to Clark (1988:75–76), microscopic charcoal can travel over regional and sub-continental distances by strong convection currents produced by wildfires. It is also dispersed in a similar way to pollen through wind and insect dispersal (Haberle and Hopf 2016:2). For this reason, the microscopic charcoal record provides an extra-regional record of fire and limited inferences can be made about local and site-specific fire regimes (Mooney et al. 2001:204). Macroscopic charcoal is deposited over shorter distances from the fire source; therefore, it can provide a localised record of fire (Clark 1988:75–76). The macroscopic charcoal might also be incorporated into the middens by animal collecting behaviour or, in rockshelters that were also used by humans, another possibility is that charcoal from human fires from within the shelter may have also found its way into the middens. Due to these complicating factors surrounding the taphonomy of microscopic and macroscopic charcoal, it was difficult to interpret the charcoal record in any meaningful way.

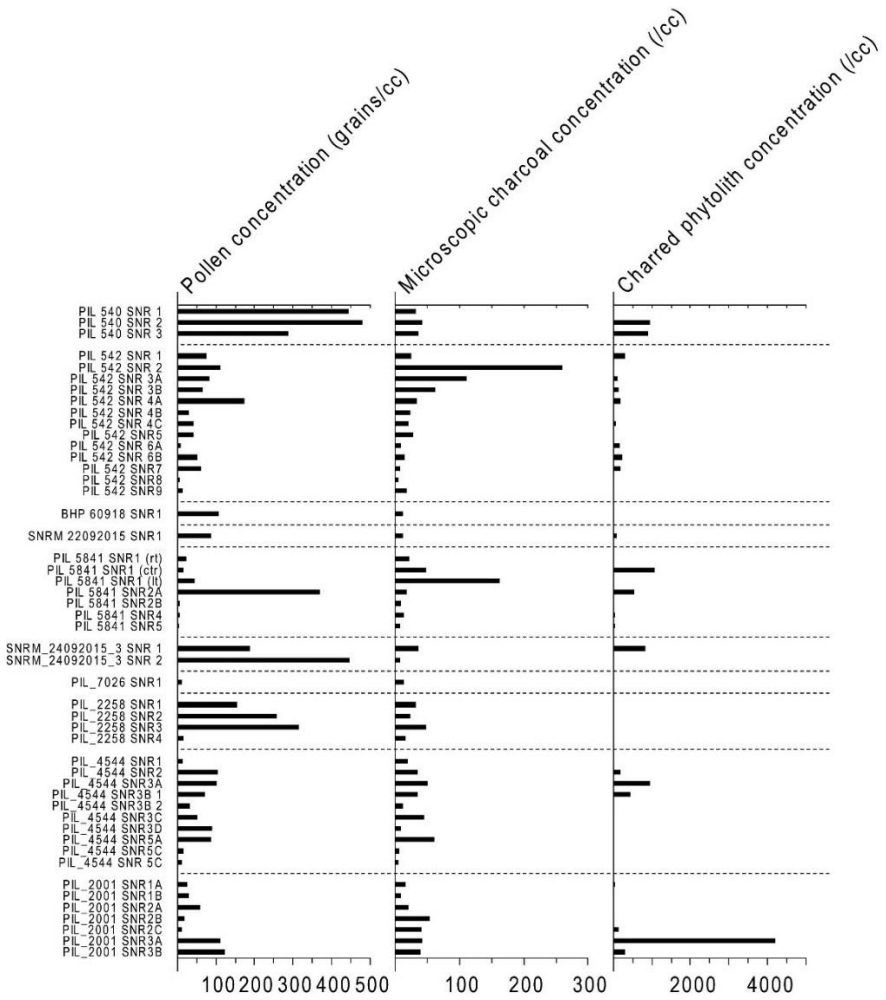

Figure 5.6 Summary diagram of pollen concentrations, microscopic charcoal concentrations and charred phytolith concentrations (from Haberle and Hopf 2016). Samples in order of midden code (dotted line zones) and sample number. Pollen percentage based on total pollen sum.

5.4.3 aDNA

The pilot study to test the preservation of aDNA in the midden samples was successful in identifying a range of vegetation species, predominantly herbaceous, but contamination was a major problem (Appendix 4 [raw data] and Figure 5.6). Many of the species detected were not found in either the pollen or the macrofossil records and, according to information held by FloraBase and the current vegetation surrounding the sites, do not occur at present in the inland

Pilbara. Three species (*Musa*, *Mentha* and *Poa)* have distributions currently restricted to southwest WA. This might indicate that the species once occurred much further north than the current distribution, but it is probably more likely to be a result of contamination as the aDNA lab is located in Perth, which is within the distribution range of these species. Some species detected were not native to Australia (e.g. *Avena* [wild oats], *Phalaris* [grass], Maleae [apples and pears], *Morus* [mulberry], *Anacardium* [cashew tree], *Cannabis, Prunus* [stone fruits]). This suggests multiple cases of contamination possibly due to the handling of samples and/ or from the processing of samples. Some of the processed samples (which had been handled multiple times and had come into contact with demineralised water) contained a greater diversity of species and a higher number of exotic and introduced species than unprocessed samples from the same midden. This finding was not consistent as two of the unprocessed samples contained a higher number and diversity of species than processed samples from the same midden. The level of contamination seen in these results is not overly surprising as the original sampling was not conducted with aDNA analysis in mind. Ancient DNA analysis was aimed at identifying the potential of such an approach and now that the preservation of aDNA has been confirmed, further work should undertake a more stringent approach to sampling to decrease the contamination levels.

Midden code	Midden Age (cal. BP)	Grass Taxa	Herbaceous Taxa	Tree and Shrub Taxa	
PIL_540 SNR 1	2100–2130		Gnaphalieae, Plantago, Ingeae, Chorchorus, Malvoideae	Acacia, Citrus, Sapindaceae	Processed Sample
		Poeae, PACMAD Clade		Sapindaceae	Unprocessed Sample
PIL_4544 SNR 4A	6650–6890	Avena		Pinus, Musa	Processed Sample
		Loliinae, Phalaris, PACMAD Clade	Apioideae, Micrandreae, Brassicaceae, Allium, Pedaliaceae	Theaceae, Solanaceae, Acacia, Citrus, Maleae	Unprocessed Sample
PIL_4544 SNR 5C	10,250–10,560	PACMAD Clade	Theobroma	Solanaceae, Solanum, Myrtaceae	Processed Sample
		Poeae	Allium	Musa	Unprocessed Sample
PIL_542 SNR 5	12,050–12,430	Avena, Micrairoideae	Mentha	Pinus, Morus, Musa	Processed Sample
		PACMAD Clade	Nepeta, Pedaliaceae, Anacardium, Cannabis	Pinus, Prunus, Myrtaceae	Unprocessed Sample
PIL_5841 SNR 1 (Right)	16,620–17,120	Triticeae, Andropogoneae, PACMAD Clade	Apioidezae, Asteroideae, Boraginaceae, Teucrium, Lamiales, Indigofera, Euphorbia, Brassicaceae, Gossypium	Callitris, Acacia, Prunus, Myrtaceae, Proteaceae	Processed Sample
		Poa		Myrtaceae	Unprocessed Sample

Table 5.1 Summary of results from aDNA pilot study in ascending order of calibrated age.

5.4.4 Summary

The botanical and micro-charcoal contents of most middens were exceptionally well preserved, even in those that were of a considerable age. The excellent preservation of the macrofossils alone shows that the rockshelters in which they are contained have never been subject to prolonged periods of wetness as this would have undoubtedly led to the degradation of the

material as it is highly sensitive to water, as the laboratory processing demonstrated. The pollen, micro-charcoal, macrofossil and aDNA records are complementary and could be used to reconstruct past vegetation. The aDNA record identified various species that were found in the pollen and macrofossil records but there are many exotic and introduced species.

This suggests that some of the samples were contaminated, particularly those that had been processed with demineralised water prior to analysis. The taxonomic resolution of pollen was good and the grains could be identified to the family or genus level. Pollen was abundant in most samples and analysis detected a diverse range of trees and shrubs that were not detected in the macrofossil record. The taxonomic resolution of the macrofossil record was excellent with some of the more complete seeds and seed pods being identified to the species level. Some of these species were not detected by pollen analysis.

5.5 Reconstructions of Vegetation Change Through Time

While it is understood that seasonal variations may have played a role in influencing vegetation changes seen in the midden samples, the following section presents reconstructions of vegetation at each site with a focus on the palaeoenvironmental implications of the results and the available archaeological record.

5.5.1 SNRM_22092015_1, SNRM_24092015_3 and PIL_2258

Only a single midden was dated from the following sites: SNRM_22092015_1, SNRM_24092015_3 and PIL_2258. As such, a reconstruction of vegetation change through time within these sites was not possible. However, in combination their records show that, at 5050–5440 cal. BP and 15,710–16,090 cal. BP, the local vegetation was dominated by woodland with a moderate occurrence of fire-sensitive species indicative of wet conditions and low burning. PIL_2258 SNR 2 showed a similar pattern of woodland vegetation at 5310–5580 cal. BP but with no fire-sensitive species and moderate burning.

5.5.2 PIL_4544

At the PIL_4544 site the vegetation record as preserved in the midden deposit commenced in the early Holocene at 12,420–12,650 cal. BP with an open woodland. At 10,250–10,560 cal. BP, the vegetation shifts to woodland with low levels of burning apparent, and then returns to an open woodland with a higher representation of grasses and herbaceous taxa at 6900–7170 cal. BP, this trend continues until the late Holocene and suggests stability in moisture since the early Holocene with perhaps some increasing variability after the mid- to late Holocene combined with moderate burning (Haberle and Hopf 2016:5).

5.5.3 PIL_2001

The PIL_2001 record commences in the early Holocene at 9550–9890 cal. BP with a woodland subject to moderate burning. This trend continues until around 2800 cal. BP, when two middens show that local vegetation shifts to grassland and open woodland with moderate burning.

5.5.4 PIL_540

The vegetation in the immediate vicinity of PIL_540 was dominated by woodlands with moderate burning and almost no fire sensitive species in the late Holocene. Archaeological excavation at the site revealed a pattern of stone artefact distribution which suggested infrequent occupation by humans before the late Holocene (Huonbrook Environment and Heritage 2013:64–75). The earliest artefacts were dated to 14,124–14,949 cal. BP; however initial occupation of the site was thought to be earlier. This means that middens would have been accumulating at around the same time that humans were occupying the rockshelter with highest intensity. This suggests that moisture conditions in the local area were reliable enough to support both people and the midden contributing animals. Perhaps the animals were attracted to the rockshelters by the increased organic debris that humans would have left behind.

5.5.5 PIL_542

PIL_542 is considered to be one of the most significant archaeological sites in the region. The upper layers of deposit in the rockshelter contained shell artefacts, wooden artefacts, large amounts of charcoal, stone artefacts and organic material (leaf litter, bone, scats, insect remains). Initial occupation of the site occurred around 40,000 BP and there was a small peak in artefact discard at this time. The rockshelter may have been occupied during the LGM; however low numbers of artefacts suggest occupation during this period was at its lowest. A peak in artefact discard from around 1200 cal. BP suggested that the most frequent and intensive use of the site occurred during this period (Huonbrook Environment and Heritage 2013:45–63). Further investigation into possible late Holocene middens in this rockshelter might would enable further correlations between the late Holocene intensification in occupation and potential impacts that this may have had on surrounding vegetation and midden accumulation.

The middens in this site represent a late Pleistocene/early Holocene record of local vegetation change. Between around 31,760 cal. BP and 9540 cal. BP, the vegetation changes very little. A highly diverse woodland vegetation dominated in the pre-Holocene period, which suggests good moisture availability (Haberle and Hopf 2016:5). The fire-sensitive species *Callitris* was present in the dated samples from around 31,000 cal. BP until around 12,000 cal. BP. *Callitris* is sensitive to both environmental conditions and fire so its absence from the record after 12,000 cal. BP could be used to infer specific climatic conditions or increased burning (Thompson and Eldridge 2005:557, 563). According to Thompson and Eldridge (2005:557), *Callitris* does not respond well to extended periods of low rainfall and drought, hence its presence in the macrofossil and pollen records might indicate an increasing level of moisture availiability following the LGM, which is supported by the dominance of Myrtaceae woodlands during this period (Haberle and Hopf 2016:5). *Callitris* is also sensitive to periods of above average rainfall and can be prone to waterlogging; however, this is uncommon (Thompson and Eldgride 2005:557). If LGM aged

middens can be identified at this site in the future, fluctuations in the presence of *Callitris* could be used to infer either periods of extended drought or above-average rainfall. The absence of the fire-sensitve species from around the site could also be indicative of increased burning, which could be a result of anthropogenic landscape management (cf. Carah 2010:52). The evidence is too superficial at this stage to suggest that similar management practices were carried out near PIL_542; however more detailed sampling of middens and the associated archeological record could enable future comparisons that show a connection to vegetation patterns.

5.5.6 PIL_5841

PIL_5841 represents a record of vegetation change from shortly after the LGM until the late Holocene. The range of pollen, macrofossils and micro-charcoal present in the post-LGM and early Holocene middens suggest that a woodland subject to moderate burning dominated, a situation that is indicative of increased moisture availability (Haberle and Hopf 2016:5). Initial human occupation of the site occurred at approximately 17,000 BP following the height of the LGM (Wallis 2015:67) which corresponds with the possible onset of midden construction. As suggested by the remains recovered from the middens, the late Holocene vegetation in the vicinity was dominated by a hummock grassland with low burning and low diversity of other species. This suggests that moisture availability was increasingly variable at this time (Haberle and Hopf 2016:5). PIL_5841 also contains a walled structure that partially prevents access to the rockshelter, built some time around 600 BP. It was hypothesised by Bindon and Lofgren (1982:123) that that function of walled structures in the Packsaddle Range was to, 'encourage habitation by small game and perhaps aid in making their capture more certain.' While it is difficult to confirm if the walled structure and the middens are connected, it is an interesting possibility to consider, but would need identification of younger middens as the middens dated during this project were constructed around 2500 years before the walled structure was built.

5.6 Synthesis and Human-Environmental Relationships

The major hiatus in midden building that occurred between 31,000 to 19,860 BP correlates with the broad-scale and regional climatic records that are in agreement that this period was characterised by widespread aridity across most of the continent (e.g. Fitzsimmons et al. 2013:91; Hesse et al. 2004:99; Reeves et al. 2013a:27). In northwest Australia, the summer monsoon was thought to have commenced reactivation at around 19,000 BP, but was most predominant from 14,000 to 13,000 BP (De Deckker et al. 2014; Field et al. 2017; van der Kaars et al. 2006:88; Wyrwoll and Miller 2001). This is supported by the midden evidence which showed that a diverse woodland dominated at this time which is indicative of increased moisture availability (Haberle and Hopf 2016:7). There was a significant shift in vegetation towards increasing heterogeneity that occurred from around 6000 BP as evidenced by the midden record (Haberle and Hopf 2016:7). This correlates with the onset of increased rainfall variability associated with ENSO; a pattern that is observed in both the broad-scale and regional records (e.g. Gagan et al. 2004:139; Shulmeister and Lees 1995:12).

Conflicting evidence surrounding the nature of human occupation during the LGM in the inland Pilbara has been a focus of archaeological attention. Patterns in the archaeological record have led archaeologists to propose that rockshelters were either abandoned, visited intermittedly or occupied continuously throughout the LGM period (e.g. Brown 1987; Hughes et al. 2011; Law et al. 2010:70; Marwick 2002a; Slack et al. 2009). A major limitation preventing the resolution of this debate has been the lack of local palaeoenvironmental evidence to determine the role of climatic change. Pepper et al. (2013:1229) suggested that extreme aridity associated with the LGM may not have occurred in the Pilbara as the heterogeneous landscape, wetter climate (compared to surrounding regions) and isolation may have operated as a buffer against climatic variations. This is opposed to the regional palaeoclimatic evidence which showed that the LGM period in northwest Australia was characterised by a significant reduction in rainfall and colder

temperatures (e.g. van der Kaars et al. 2006:888). Unfortunately, no LGM-aged middens were identified during this project due to a major gap in the midden record from 31,000 to 19,860 cal. BP; therefore, the regional evidence for increased aridity could not be confirmed using the botanical evidence. The apparent absence of midden construction during the LGM period does suggest however that conditions were drier relative to the preceding period (cf. Pearson and Betancourt 2002:504). This supports the proposition that climatic stress may have affected human settlement patterns and mobility in the inland Pilbara; however, further research is needed to confirm if the absence of middens is a result of climate and not just the sampling method used. If the absence is climatically induced, this could be a reason why archaeological information for this period has been so sparse and ambiguous, particularly for the Packsaddle Range and surrounds. This would also support Brown's (1987:52) hypothesis that, due to harsh conditions, the Packsaddle Range would have been very rarely, if ever, exploited or inhabited during the late Pleistocene as it falls within the fringes of the Pilbara uplands.

Following the LGM in the period from 19,860 cal. BP to around 9000 cal. BP, vegetation was dominated by diverse trees and shrubs, which included *Callitris*, *Acacia* and Myrtaceae woodlands. Haberle and Hopf (2016:5) interpreted the dominance of woodlands as reflecting continued moisture availability during a time which was previously thought to be extremely arid. Wyrwoll and Miller (2001) presented clear evidence that the monsoon was reactivated as early as 14000 BP following the LGM although the exact timing remains contentious. The evidence from middens supports the presence of relatively moist conditions after around 19500 cal. BP, and Haberle and Hopf (2016:5) theorised that the area may have acted as a refugia for woody vegetation at that time. Even though the dates were somewhat contentious, it is interesting to note that two of the sites investigated during this study were initially occupied after 17,000 BP (Huonbrook Environment and Heritage 2013:45–63; Wallis 2015:67). An exception was PIL_542 which was first occupied at around 40,000 BP; however, low artefact numbers after this time suggested that occupation was extremely sparse until the late Holocene (Huonbrook Environment

and Heritage 2013:45–63). Increased moisture availability following the LGM may have made it possible for human populations to access the marginal Packsaddle area.

According to Brown (1987:46), rockshelters in the Packsaddle Range represent the move towards the increased use of marginal environments after 3000 BP as it is on the watershed of the major rivers and water can be scarce. This date roughly corresponds with the shift towards more heterogenous vegetation that occurred after around 6000 cal. BP in the midden record, but corresponds more closely with the increasing dominance of grasslands as detected in the pollen record after around 3000 cal. BP (Haberle and Hopf 2016:5). Haberle and Hopf (2016:5) suggested that the increased use of fire by human populations could have influenced such a change. Webeck and Pearson (2005:468) similarly proposed that the shift to a dominance of grass and herb vegetation in the midden record after 835 BP was a response to fire. The microscopic charcoal record from middens showed that fire events had been a part of the ecosystem in the Packsaddle Range and surrounds during the late Pleistocene and the Holocene, but no discernible patterns could be detected that might suggest that burning increased after the mid Holocene. Even if so, charcoal abundance does not always correspond with anthropogenic burning and can be a result of increased rainfall variability (Gagan et al. 2004:134). For this reason, it was not possible to form any final conclusions about the role of anthropogenic burning in the shift to more open vegetation during the late Holocene.

If not the result of anthropogenic burning, the shift in vegetation observed in the midden record during the late Holocene might be related to increased climatic variability as suggested by Haberle and Hopf (2016:5). Regional palaeoenvironmental evidence suggests that this trend commenced during the mid Holocene in northwest Australia as the summer monsoon began to weaken at the onset of ENSO conditions (e.g. Gagan et al. 2004:139; Shulmeister and Lees 1995:12). This appeared to coincide roughly with the increased use of rockshelters in the Packsaddle Range and surrounds during the late Holocene which could indicate a possible correlation. It was interesting that vegetation species which require moist conditions, such as Cyperaceae and *Themeda*

triandra, were found more often in middens in the last 5000 years. This does not correlate well with the regional records which suggested conditions were drier after this time for northwest Australia (e.g. Shulmeister and Lees 1995). ENSO is known to have influenced tropical cyclone systems and it is a possibility that such events may have occurred more often after the mid Holocene (Chan 2000). This would result in the flooding of ephemeral watercourses and increased moisture availability which would explain the presence of vegetation species such as Cyperaceae. It would also explain how humans were able to occupy the marginal Packsaddle area with greater intensity increasingly utilising rockshelters that were close to ephemeral watercourses.

This chapter has considered some of the possible correlations between environmental information derived from middens and the archaeological record; however, further high-resolution research of middens and the archaeological record is needed to confirm these potential correlations. The results have demonstrated that middens have important implications for the understanding of the local palaeoenvironment both through their well-preserved botanical contents, and the activities of animal contributors. Further sampling and dating is needed to confirm correlations between middens and climatic periods of interest along with the sampling and monitoring of the modern vegetation surrounding sites.

CONCLUSION

This chapter concludes the project by outlining the major findings and re-addressing the research aims. It also makes recommendations for future research opportunities while clarifying the limitations that were encountered and how these could be mitigated with future research.

6.1 Re-addressing the Research Aims

1. **Determine the chronology and temporal resolution of the middens and confirm what animal/s created them.**

The chronology of middens from the Packsaddle Range and surrounds has been shown to extend from the pre-Glacial period through to the late Holocene. This depth of chronology is not typical of middens found in other locations around Australia and has been a major limiting factor when it has come to addressing questions of long-term vegetation change (Pearson et al. 1999). This unique source of palaeoenvironmental information demonstrates spatial and temporal variations in the structure of vegetation at a resolution suitable for determining long-term environmental trends. The resolution could be refined with further dating of middens alongside investigations into the role that seasonal variation of rainfall plays in influencing long-term vegetation change.

Unfortunately, owing to time constraints and logistical issues, the animal contributors of middens could not be identified with certainty. The presence of rodent incisors and possible rodent scats throughout the sample does suggest that a species of rodent, such as a stick-nest rat, may have been a primary contributor in the past. Results from the aDNA analysis on animal identification and analysis of hairs recovered from the middens are still forthcoming, but were not available in time for inclusion into this project. The results from this analysis will no doubt give some further insight into the identity of the midden contributors and should be incorporated into any future research midden research.

2. **Analyse the botanical contents of the middens to inform our understanding of vegetation change through time in the study region;**

Elsewhere, long-term trends in vegetation change have not been identified sufficiently in Australian midden studies due to the mostly late Holocene age of middens (Pearson et al. 1999). The middens sampled during this project have yielded botanical remains of sufficient preservation and quantity to identify a long-term trend in vegetation change through time. The results of pollen and macrofossil analyses suggest a consistent pattern of vegetation change which is in general agreement with the regional palaeoenvironmental evidence. The midden record has shown that a diverse woodland dominated the Packsaddle study area during the late Pleistocene and the early Holocene. The mid- to late Holocene was characterised by a shift to more open and heterogenous vegetation after around 6000 cal. BP, and this is broadly consistent with regional records that show increasing variability in rainfall due to the onset of ENSO from around 5000 BP which resulted in conditions that were similar to that of today (e.g. Gagan et al. 2004:139; van der Kaars et al. 2006). Further sampling is needed to identify middens that represent the LGM period and so, as yet, it is unclear exactly how the changes associated with the last glacial period manifested in the Packsaddle study area. It is possible that the reduction in midden building at this time is indicative of a reduction in the range of the animal midden builders as a response to shifting water availability. At this stage, it is not clearly known to what extent seasonal and spatial variations have played in influencing these vegetation changes, but this could be a focus of future research.

3. **Assess the palaeoenvironmental implications of the middens and consider their potential to contribute to an understanding of past human responses to climatic change.**

This project has demonstrated that middens in the Packsaddle Range and surrounds have important implications for the understanding of vegetation change and potentially climatic change through time. This information provides a backdrop to understandings of past human responses to climatic change, especially during periods such as the LGM. The nature of human

occupation during the late Pleistocene has been a primary source of discussion in inland Pilbara archaeology (e.g. Brown 1987; Hughes et al. 2011; Law et al. 2010:70; Marwick 2002a; Slack et al. 2009). This project hoped to determine the climatic conditions that might have influenced patterns of abandonment or sparse occupation in the archaeological record during the LGM; however, the absence of middens from this period meant that no inferences could be made using vegetation change alone. The absence of middens during this period might be indicative of prolonged drier conditions that reduced the range or activity of midden building rodents, but further sampling is needed to determine if there is a real hiatus in midden accumulation at this time, or whether the apparent cessation is the result of sampling bias. If the absence of middens is result of altered climatic conditions, this would suggest increasingly hostile conditions that might support interpretations of local abandonment or reduction in occupation intensity in the Packsaddle Range and surrounds through the LGM.

6.2 Limitations and Future Research

The close association that exists between middens and archaeological deposits in rockshelters has the potential to provide further research opportunities, which would build on and strengthen the evidence produced during this project. The collection and sampling of middens was conducted with future research in mind. Middens were sub-sampled leaving generous sections of single middens unprocessed and relatively uncontaminated so that further work could be easily conducted on the already collected samples. The following section outlines some of the limitations that were encountered during this project and recommends the future research required to mitigate these limitations.

The bulk method of sampling and dating middens used during this project has shown that late Pleistocene middens can survive in an Australian semi-arid context over extended time periods and suggests that single middens can accumulate over thousands of years, potentially building a stratigraphic record of local vegetation change. Having established this, it is recommended that

future studies adopt more precise vertical stratigraphic sampling methods within large, discrete middens so as to allow for a higher resolution of data. Such an approach will enable the application of other analysis techniques such as charcoal and stable isotopes, however was beyond the scope of the pilot study reported herein (cf. Pearson and Betancourt 2002:505). Studies in Australia so far have concentrated heavily on the stratigraphic analysis of middens at the expense of identifying middens of suitable antiquity for identifying long-term vegetation change (e.g. Head 1993; Head et al. 1998; Pearson 1999). As suggested by Pearson and Betancourt (2002:503), in order to maximise the potential of midden studies to understanding late Quaternary vegetation patterns, greater attention should be had to identifying middens that are pre-glacial and glacial, and then targeting these middens for high resolution stratigraphic analysis. In line with this, it is suggested that rockshelter site PIL_542 should be a focus for future studies. This site contained the largest, oldest and highest number of middens than any other site in the project area. Furthermore, these middens occur alongside one of the most significant archaeological deposits in the region (Dias et al. 2005; Huonbrook Environment and Heritage 2013). Individual middens in PIL_542 should be systematically targeted for stratigraphic sampling to further refine the temporal resolution and to explore the possible absence of Holocene-aged middens at the site. Stratigraphic sampling of middens will also reveal more detailed information about the accumulation history of the middens and vegetation change at the site-specific level.

Some of the larger middens that had to be sampled in sections returned a range of dates which showed that, despite some possible hiatuses, inland Pilbara middens have been accumulating over many millennia. For example, the PIL_4544 SNR 3 midden samples suggested midden accumulation over at least a 12,000 year period: 800–930 cal. BP (Wk-42965); 2750–2870 cal. BP (Wk-42966); and 12,420–12,650 cal. BP (OZU476). These also support that stratigraphy might exist in the layering of the middens. Previous sampling of middens in Australia has shown that the stratigraphy can be very complex and that middens do not always contain horizontal layering; however, this understanding is based on middens that are only a few thousand years old (Pearson

1997:225). As the current project was a pilot study designed to assess in the first instance whether plant remains could successfully be recovered from the middens, it was outside of the current scope to undertake high resolution sampling within a single midden. Instead, the approach was to sample a large number of middens from different rockshelters in order to demonstrate 'proof of concept'. Now that we have shown this is indeed possible, the prospect of detailed stratigraphical sampling from within a single large midden is worth exploring further. Horizontal layers could be targeted to achieve a higher resolution of data and to overcome limitations associated with the bulk sampling method utilised in the current study and differences in vegetation between sites.

The method of dating just one sampled section from each midden does not take into account the full range of possible dates that might exist in the stratigraphic layers of middens that have been occupied over long periods. A way to test this would be to sample and systematically date entire middens to detect if a stratigraphy can be captured and if the same major and minor gaps exist. The presence of middens indicates the presence of animal contributors and sufficient biomass for midden construction; it is possible that midden-building activity correlates with climatic periods of interest (Pearson et al. 1999:305). For example, Pearson and Betancourt (2002:504) hypothesised that fewer middens would have been constructed during the LGM due to the climate effecting vegetation productivity. This is consistent with pollen evidence of van der Kaars et al. (2006:888), who suggested that extremely dry conditions were experienced in northwest Australia from 32,000–20,000 yrs BP due to virtually no summer rainfall. If sampling bias could be eliminated, gaps in the midden record would confirm that such extreme conditions also reached the Packsaddle Range and surrounds during this period.

There is a crucial need for further research which focuses more on the nature of the modern vegetation surrounding sites. Very little is known about the response of the local vegetation to extreme rainfall events brought on by tropical cyclones or thunderstorms. This type of information could then be compared to the fossil midden record to determine if these events

combined with seasonal variability in rainfall were responsible for the vegetation patterns observed. If the patterns are outside of the natural thresholds of seasonal variation, other factors such as long-term climatic change and anthropogenic impact can be considered with greater certainty.

A modern reference collection of vegetation specimens from around the sites combined with detailed surveying of the modern vegetation could also further strengthen the macrofossil evidence and would allow for additional macrofossil identifications. A modern pollen study at sites that contain extensive middens and archaeology (e.g. PIL_542) would also make an important contribution to future interpretations of the fossil pollen record by facilitating a greater understanding of the local pollen transport characteristics and pollen morphology (Pearson and Dodson 1993:353). Haberle and Hopf (2016:7) suggested a collection of pollen reference material from flowering plants in the region and a pollen rain monitoring program in midden sites in order to achieve this. Studies of the modern vegetation and pollen are also needed to develop a better understanding of the spatial variations that occur between sites. These understandings can then be factored into interpretations of the fossil vegetation record.

Future comparison of macrofossils with collections in the WA Herbarium or other relevant collections may aid in the identification of more species, especially those endemic to the Pilbara, as this was limited to reference books and the SA Herbarium and Seed Bank during this project. As expected, these collections contained mostly plant specimens found in SA. While there are some similarities in the semi-arid vegetation between the states, macrofossils that could have been identified against WA reference collections were not fully recognised. The Unknown types that were recorded and quantified during this project could be easily substituted with the correct identification in the future, adding further value to the macrofossil record.

The macrofossil analysis of middens identified the presence of charcoal fragments which could potentially be a subject for future research. Wood charcoals can be identified using a scanning

electron microscope and, if recovered from a stratified context, can be successfully used to develop palaeoenvironmental reconstructions based on fluctuations in woody taxa (e.g. Carah 2010; Whitau et al. 2016:1). The success of future charcoal investigations of fragments recovered from amberat middens will be dependent on establishing a more reliable stratigraphic chronology of middens. Charcoal studies could be used to explore anthropogenic land management practices and correlations with the archaeological record. For example, is there a correlation between the increased intensity of occupation of rockshelters and the increasing occurrence of charcoal in middens?

Other opportunities for future research include phytolith and isotopic analysis. Stable carbon and nitrogen isotope analysis was used recently to study rock hyrax middens in South Africa which are almost entirely composed of crystallised urine and have very similar characteristics to the inland Pilbara middens (e.g. Chase et al. 2010; Quick et al. 2011), suggesting such studies could also be of value in the Packsaddle Range area. Changes in the stable isotope record can reflect changes in moisture availability providing high-resolution evidence for long-term palaeoenvironmental change that has strong correlations with other climatic proxy records (Chase et al. 2013:202). Stable isotope analysis requires a detailed understanding of the accumulation rates of individual middens as well as good stratigraphic integrity. This type of analysis could be combined with detailed stratigraphic sampling of middens and could be compared to the existing pollen, macrofossil and charcoal records or used to complement future investigations into such records. The pollen analysis of middens identified the preservation of phytoliths (microscopic particles of silica produced by certain species of plants), which may also be used to reconstruct local vegetation patterns and palaeoclimatic reconstructions (e.g. Wallis 2001). Such an approach was not feasible in the current study owing to the lack of suitable laboratory equipment at Flinders University, but should be a focus of future midden studies.

As Murray et al.'s (2012) genetic study and this project has now shown, the level of preservation of aDNA found in hot and semi-arid environments, such as the inland Pilbara, can be sufficient to

represent a diverse range of vegetation species with some not detected by pollen and/ or macrofossil analyses. The large number of introduced and exotic plant species (contaminants) present in some of the samples caused a large degree of uncertainty surrounding the interpretation and the reliability of the aDNA data; however, as suggested by Murray et al. (2012:141) improvements in databases of reference material are needed for a higher level of taxonomic certainty. Further, the sampling techniques adopted in this study were not designed with aDNA analysis in mind. Rather, the aDNA assessments undertaken were ad hoc, and aimed to ascertain the potential for such an approach. Should such studies be planned in the future, the sampling strategy should be designed with aDNA at the forefront, which would almost certainly reduce the level of contamination encountered.

6.3 Summary

This project has demonstrated the value of amberat middens found in rockshelters of the inland Pilbara for understanding local vegetation and, by inference, palaeoenvironmental conditions and has outlined the research opportunities they present. These archives are currently one of the very few terrestrial sources of palaeoenvironmental information that exists in the inland Pilbara. Precise dating, stratigraphic sampling, and modern vegetation studies are now needed to enable the full palaeoenvironmental implications of the middens to be realised. Based on the evidence presented in this thesis, middens in rockshelters of the Packsaddle Ranges and surrounds are a promising avenue for addressing palaeoenvironmental and archaeological research questions.

REFERENCES

Allen, V., L. Head, G. Medlin and D. Witter 2000 Palaeoecology of the Gap and Coturaundee Ranges, western New South Wales, using stick-nest rat (*Leporillus* spp.) (Muridae) middens. *Austral Ecology* 25(4):333–343.

Asmussen, B. and P. McInnes 2013 Assessing the impact of mid- to late Holocene ENSO-driven climate change on toxic *Macrozamia* seed use: A 5000 year record from eastern Australia. *Journal of Archaeological Science* 40:471–480.

Atchison, J. and L. Head 1999 Preparing sub-fossil leaves from *Leporillus* spp. (Stick-nest rat) middens for measuring stomatal parameters. *Quaternary Australasia* 17(1):27–30.

Attenbrow, V. 2004 *What's Changing: Population Size or Land-use Patterns? The Archaeology of Upper Mangrove Creek, Sydney Basin.* Canberra: ANU E Press.

Attenbrow, V., G. Robertson and P. Hiscock 2009 The changing abundance of backed artefacts in south-eastern Australia: A response to Holocene climate change? *Journal of Archaeological Science* 36(12): 2765–2770.

Baynes, A. and M. McDowell 2010 The original mammal fauna of the Pilbara biogeographic region of north-western Australia. *Records of the Western Australian Museum* 78:285–298.

Beard, J.S. 1975 *Vegetation survey of Western Australia 1:1 000 000 vegetation series. Sheet 5, Pilbara*. Perth: University of Western Australia Press.

Beresford-Jones, D., H. Lewis and S. Boreham 2009 Linking cultural and environmental change in Peruvian prehistory: Geomorphological survey of the Samaca Basin, Lower Ica Valley, Peru. *Catena* 78(3):234–249.

Berry, S.L. 1991 The potential of fossil mammal middens as indicators of vegetation history in Central Australia. *Australian Journal of Botany* 39:305–313.

Betancourt, J.L. and O.K. Davis 1984 Packrat middens from Canyon de Chelly, northeastern Arizona: Palaeoecological and archaeological implications. *Quaternary Research* 21:56–64.

Betancourt, J.L., T.R. Van Devender and M. Rose 1986 Comparison of plant macrofossils in woodrat (*Neotoma* sp.) and porcupine (*Erethizon dorsatum*) middens from the western United States. *Journal of Mammalogy* 67:266–273.

Bindon, P. and M. Lofgren 1982 Walled rock shelters and a cached spear in the Pilbara region, Western Australia. *Records of the Western Australia Museum* 10:111–126.

Birks, H.H. and H.J. Birks 2000 Future uses of pollen analysis must include plant macrofossils. *Journal of Biogeography* 27(1):31–35.

Bureau of Meteorology 2017 *Climate Data Online*. Retrieved 15 June 2016 from <http://www.bom.gov.au/climate/data/index.shtml>.

Bonney, N. 1994 What seed is that? A field guide to the identification, collection and germination of native seed in South Australia. Adelaide: Neville Bonney.

Bonnichsen, R., L. Hodges, W. Ream, K.G. Field, D.L. Kirner, K. Selsor and R.E. Taylor 2001 Methods for the study of ancient hair: Radiocarbon dates and gene sequences from individual hairs. *Journal of Archaeological Science* 28(7):775–785.

Bourke, P., S. Brockwell, P. Faulkner and B. Meehan 2007 Climate variability in the mid- to late Holocene Arnhem Land region, north Australia: Archaeological archives of environmental and cultural change. *Archaeology in Oceania* 42(3):91–101.

Bowler, J.M., K.H. Wyrwoll and Y. Lu 2001 Variations of the northwest Australian summer monsoon over the last 300,000 years: The paleohydrological record of the Gregory (Mulan) Lakes System. *Quaternary International* 83–85:63–80.

Branch, N. 2005 *Environmental Archaeology: Theoretical and Practical Approaches*. London: Hodder Education.

Brockwell, S., B. Marwick, P. Bourke, P. Faulkner and R. Willan 2013 Late Holocene climate change and human behavioural variability in the coastal wet-dry tropics of northern Australia: Evidence from a pilot study of oxygen isotopes in marine bivalve shells from archaeological sites. *Australian Archaeology* 76:21–33.

Bronk Ramsey, C. 2009 Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1):337–360.

Brown, S. 1987 *Toward a Prehistory of the Hamersley Plateau, Northwest Australia*. Occasional Papers in Prehistory 6. Canberra: Research School of Pacific Studies, The Australian National University.

Bulloch, R. 2011 An Examination of Lithic Production and Formal Implements at Rockshelters in the Northflank Ranges, North-West Western Australia. Unpublished Honours thesis, University of Western Australia.

Burbidge, N.T. 1953 The genus Triodia R. Br. (Gramineae). *Australian Journal of Botany* 1(1):121–184.

Caffrey, M.A. and S.P. Horn 2013 The use of lithium heteropolytungstate in the heavy liquid separation of samples which are sparse in pollen. *Palynology* 37:143–150.

Carah, X. 2010 Corridors and Callitris: Examining the Changing Use of Environment, Through the Gledswood Shelter 1 Wood Charcoal Assemblage. Unpublished Honours thesis, School of Social Science, University of Queensland.

Chan, J. 2000 Tropical cyclone activity over the Western North Pacific associated with El Nino and La Nina events. *Journal of Climate* 13(16): 2960–2972.

Chase, B.M., A. Boom, A.S. Carr, M.E. Meadows and P.J. Reimer 2013 Holocene climate change in southernmost South Africa: Rock hyrax middens record shifts in the southern westerlies. *Quaternary Science Reviews* 82:199–205.

Chase, B.M., M.E. Meadows, A.S. Carr and P.J. Reimer 2010 Evidence for progressive Holocene aridification in southern Africa recorded in Namibian hyrax middens: Implications for African Monsoon dynamics and the ‘‘African Humid Period’’. *Quaternary Research* 74(1):36–45.

Chase, B.M., L. Scott, M.E. Meadows, G. Gil-Romera, A. Boom, A.S. Carr, P.J. Reimer, L. Truc, V. Valsecchi and L.J. Quick 2012 Rock hyrax middens: A palaeoenvironmental archive for southern African drylands. *Quaternary Science Reviews* 56:107–125.

Clark, C. 1982 Report on a Visit to the East Deepdale Mining Area, Pannawonica, 27–31 January 1982, Aboriginal Liaison. Unpublished report prepared for the Department of Aboriginal Sites, Western Australian Museum.

Clark, J. S. 1988 Particle motion and the theory of charcoal analysis: Source area, transport, deposition, and sampling. *Quaternary Research* 30:67–80.

Copley, P. 1999 Natural histories of Australia's stick-nest rats, genus *Leporillus* (Rodentia: Muridae). *Wildlife Research* 26(4):513–539.

Crombé, P. and E. Robinson 2017 Human resilience to Lateglacial climate and environmental change in the Scheldt basin (NW Belgium). Quaternary International 428:50–63.

Czerwinski, P. 2013 Part C of the Detailed Site Recording of Rockshelters in BHPBIO Packsaddle 4, Mining Area C, Pilbara, WA. Unpublished report prepared for BHPBIO by Land Access Solutions.

De Deckker, P., T.T. Barrows and J. Rogers 2014 Land–sea correlations in the Australian region: post-glacial onset of the monsoon in northwestern Western Australia. Quaternary Science Reviews 105:181–194.

Denham, T. and S. Mooney 2008 Human–environment interactions in Australia and New Guinea during the Holocene. *The Holocene* 18:365–371.

Dias, A. and S. Rapley 2014 New radiocarbon dates from the Chichester Range, Pilbara, Western Australia. *Journal of the Australian Association of Consulting Archaeologists* 2:9–14.

Dias, A., S. Rapley and M. Jimenez-Lozano 2005 The Report on the Aboriginal Archaeological Assessment of the Packsaddle Range and E deposit, South Areas, Mining Area C, Packsaddle. Unpublished report prepared for BHP Billiton Iron Ore.

Douglass, K. and J. Zinke 2015 Forging ahead by land and by sea: Archaeology and palaeoclimatic reconstruction in Madagascar. *African Archaeological Review* 32:267–299.

Edwards, K. and A. Murphy 2003 A preliminary report on archaeological investigations at Malea Rockshelter, Pilbara region, Western Australia. *Australian Archaeology* 56:44–46.

Elias, S.A. 2013 Rodent middens. In S.A. Elias (ed), *Encyclopedia of Quaternary Science*, pp.674–683. Amsterdam: Elsevier.

Erickson, T., R. Barrett, D, Merritt and K. Dixon 2016 *Pilbara Seed Atlas and Field Guide: Plant Restoration in Australia's Arid Northwest*. Melbourne: CSIRO Publishing.

Faegri, K. and J. Iverson 1989 *Textbook of Pollen Analysis.* New York: Wiley.

Fagan, B. 1996 *The Oxford Companion to Archaeology.* New York: Oxford University Press.

Field, E., H.A. McGowan, P.T. Moss and S.K. Marx 2017 A late Quaternary record of monsoon variability in the northwest Kimberley, Australia. *Quaternary International*:1–17.

Fitzsimmons, K.E. and T.T. Barrows 2010 Holocene hydrologic variability in temperate southeastern Australia: An example from Lake George, New South Wales. *The Holocene* 20 (4):585–597.

Fitzsimmons, K.E., T.J. Cohen, P.P Hesse, J. Jansen, G.C. Nanson, J. May, T.T Barrows, D. Haberlah, A. Hilgers, T. Kelly, J. Larsen, J. Lomax and P. Treble 2013 Late Quaternary palaeoenvironmental change in the Australian drylands. *Quaternary Science Reviews* 74:78–96.

Gagan, M.K., E.J. Hendy, S.G. Haberle and W.S. Hantoro 2004 Post-glacial evolution of the Indo-Pacific Warm Pool and El Niño-Southern oscillation. *Quaternary International* 118–119:127–143.

Green, N., J. Caldwell, J. Hope and J. Luly 1983 Pollen from an 1800 year old stick-nest rat (*Leporillus* sp.) midden from Gnalta, western New South Wales. *Quaternary Australasia* 1(1–2):31–41.

Grimm, E.C. 2013 *Tilia Version 2.0.33.* Springfield: Illinois State Museum.

Haberle, S. and B. David 2004 Climates of change: Human dimensions of Holocene environmental change in low latitudes of the PEPII transect. *Quaternary International* 118–119:165–179.

Haberle, S. and F. Hopf 2016 Palynological Analysis of Stick-nest Rat (*Leporillus* sp.) Middens in the Packsaddle Range and Surrounds, Pilbara, Western Australia. Unpublished report prepared for Wallis Heritage Consulting.

Hashem, A. and Amjad, M. 2015 Controlling Tar Vine (Boerhavia coccinea): An Emerging Summer Weed in the Western Australian Wheatbelt Retrieved 25 April 2017 from <file:///C:/Users/Emily/Downloads/Hashem%252c+Abul+et+al+-+Controlling+tar+vine+an+emerging+summer+weed%20(1).pdf>.

Head, L. 1993 Stick-nest rat (*Leporillus* spp.) nests as sources of arid and semi-arid zone palaeoclimatic data: Review and prospects. *Quaternary Australasia* 11(1):38–42.

Head, L., L. McCarthy, J. Quade, D. Witter, V. Allen and E. Lawson 1998 Classification and radiocarbon dating of *Leporillus* nests in semi-arid Australia and palaeoclimatic implications. *Palaeoclimates* 3(1–3):161–177.

Hesse, P.P., J.W. Magee and S. van der Kaars 2004 Late Quaternary climates of the Australian arid zone: a review. *Quaternary International* 118–119:87–102.

Hiscock, P. and V. Attenbrow 2016 Dates and demography? The need for caution in using radiometric dates as a robust proxy for prehistoric population change. *Archaeology in Oceania* 51(3):218–219.

Hogg, A.G., Q. Hua, P.G. Blackwell, M. Niu, C.E. Buck, T.P. Guilderson, T.J. Heaton, J.G. Palmer, P.J. Reimer, R.W. Reimer, C.S.M. Turney and S.R.H. Zimmerman 2013 SHCal13 southern hemisphere calibration, 0-50,000 years cal. BP. *Radiocarbon* 55(4):1889–1903.

Holdaway, S. J., P. C. Fanning, E. J. Rhodes, S. K. Marx, B. Floyd, and M. J. Douglass 2010 Human response to palaeoenvironmental change and the question of temporal scale. *Palaeogeography, Palaeoclimatology, Palaeoecology* 292(1–2):192–200.

Hook, F. 2009 A tale of two blades: macro-blade manufacture and discard in Paraburdoo, Western Australia. *Archaeology in Oceania* 44:23–31.

Hughes, P.J., G. Quartermaine and J. Harris 2011 Pleistocene rockshelters J23 and J24, Mesa J, Pilbara, Western Australia. *Australian Archaeology* 73:58–61.

Hughes, P.J., M.E. Sullivan and P. Hiscock 2017 Palaeoclimate and human occupation in southeastern arid Australia. *Quaternary Science Reviews* 163:72–83.

Huonbrook Environment and Heritage 2013 Test Excavations DIA Permit #453 P1 Deposit, Packsaddle Range, Mining Area C, the Pilbara. Unpublished report prepared for BHP Billiton Iron Ore.

Huffman, J. and J. Wallace 2012 *Wildlife Forensics: Methods and Applications*. Hoboken: Wiley-Blackwell.

Ivanova, S., M. Gurova, N. Spassov, L. Hristova, N. Tzankov, V. Popov, E. Marinova, J. Makedonska and V. Smith 2016 Magura Cave, Bulgaria: A multidisciplinary study of Late Pleistocene human palaeoenvironment in the Balkans. *Quaternary International* 415:86–108.

Jørgensen T., J. Haile, P. Moller, A.A. Andreev, S. Boessenkool, M. Rasmussen, F. Kienast, E. Coissac, P. Taberlet and C. Brochmann 2012 A comparative study of ancient sedimentary DNA, pollen and macrofossils from permafrost sediments of northern Siberia reveals long-term vegetational stability. *Molecular Ecology* 21:1989–2003.

Kelly, R.L., T. Surovell, B. Shuman and G. Smith 2013. A continuous climatic impact on Holocene human population in the Rocky Mountains. *Proceedings of the National Academy of Sciences* 110:443–447.

Kemp, J., L.C. Radke, J. Olley, S. Juggins and P. De Deckker 2012 Holocene lake salinity changes in the Wimmera, southeastern Australia, provide evidence for millennial-scale climate variability. *Quaternary Research* 77(1):65–76.

Kindermann, K., O. Bubenzer, S. Nussbaum, H. Riemer, F. Darius, N. Pöllath and U. Smettan 2006 Palaeoenvironment and Holocene land use of Djara, Western Desert of Egypt. *Quaternary Science Reviews* 25(13): 1619–1637.

Kuch, M., N. Rohland, J.L. Betancourt, C. Latorre, S. Steppan and H.N. Poinar 2002 Molecular analysis of a 11700-year-old rodent midden from the Atacama Desert, Chile. *Molecular Ecology* 11(5):913–924.

Law, W.B., D. Cropper and F. Petchey 2010 Djadjiling rockshelter: 35,000 ^{14}C years of Aboriginal occupation in the Pilbara, Western Australia. *Australian Archaeology* 70:68–71.

Lazarides M. 1997 A revision of Triodia including Plectrachne (Poaceae, Eragrostideae, Triodiinae). *Australian Systematic Botany* 10:381–489.

Lim, S., B.M. Chase, M. Chevalier and P.J. Reimer 2016 50,000 years of vegetation and climate change in the southern Namib Desert, Pella, South Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* 451:197–209.

Lourandos, H. 1993 Hunter-gatherer cultural dynamics: Long and short-term trends in Australian prehistory. *Journal of Archaeological Research* 1(1):67–88.

Lourandos, H. and A. Ross 1994 The great 'intensification debate': Its history and place in Australian archaeology. *Australian Archaeology* 39:54–63.

Macphail, M. 2011 Palynological analyses, 30 ka 'amberat' deposit, Brockman Ridge, Pilbara region, Western Australia. Unpublished report prepared for Scarp Archaeology.

Macphail, M. and M.S. Stone 2004 Age and palaeoenvironmental constraints on the genesis of the Yandi channel iron deposits, Marillana Formation, Pilbara, northwestern Australia. *Australian Journal of Earth Sciences* 51:497–520.

Mancini, M.V., N.V. Franco and G.A. Brook 2013 Palaeoenvironment and early human occupation of southernmost South America (South Patagonia, Argentina). *Quaternary International* 299:13–22.

Marwick, B. 2002a Inland Pilbara Archaeology: A Study of Variation in Aboriginal Occupation over Time and Space on the Hamersley Plateau. Unpublished Master of Arts thesis, University of Western Australia, Crawley.

Marwick, B. 2002b Milly's Cave: Evidence for Human Occupation of the Inland Pilbara during the Last Glacial Maximum. *Tempus* 7:21–33.

Marwick, B. 2009 Change or decay? An interpretation of late Holocene archaeological evidence from the Hamersley Plateau, Western Australia. *Archaeology in Oceania* 44:16–22.

McCarthy, L. 1999 A Holocene Vegetation History of the Flinders Ranges South Australia: Evidence from *Leporillus* spp. (Stick-Nest Rat) Middens. Unpublished PhD thesis, School of Geosciences, University of Wollongong, Wollongong.

McCarthy, L. and L. Head 2001 Holocene variability in semi-arid vegetation: new evidence from *Leporillus* middens from the Flinders Ranges, South Australia. *The Holocene* 11(6):681–689.

McCarthy, L., L. Head and J. Quade 1996 Holocene palaeoecology of the northern Flinders Ranges, South Australia, based on stick-nest rat (*Leporillus* spp.) middens: A preliminary overview. *Palaeogeography, Palaeoclimatology, Palaeoecology* 123:205–218.

McDonald, J. and P. Veth 2013 Rock art in arid landscapes: Pilbara and Western Desert petroglyphs. *Australian Archaeology* 77:66–81.

McGowan, H., S. Marx, P. Moss and A. Hammond 2012 Evidence of ENSO mega-drought triggered collapse of prehistory Aboriginal society in northwest Australia. *Geophysical Research Letters* 39(22):1–5.

Mooney, S.D., K.L. Radford and G. Hancock 2001 Clues to the 'burning question': Pre-European fire in the Sydney coastal region from sedimentary charcoal and palynology. *Ecological Management and Restoration* 2(3):203–212.

Morse, K. 2009 Emerging from the abyss archaeology - archaeology in the Pilbara region of WA. Archaeology in Oceania 44:1–5.

Moseby, K.E. and J.K. Bice 2004 A trial re-introduction of the Greater Stick-nest Rat (*Leporillus conditor*) in arid South Australia. *Ecological Management & Restoration* 5(2):118–124.

Murray, D.C., S.G. Pearson, R. Fullagar, B.M. Chase, J. Houston, J. Atchison, N.E. White, M.I. Bellgard, C. E., M. Macphail, M.T.P. Gilbert, J. Haile and M. Bunce 2012 High-throughput sequencing of ancient plant and mammal DNA preserved in herbivore middens. *Quaternary Science Reviews* 58:135–145.

Naudinot, N and R.L. Kelly 2017 Climate change and archaeology. *Quaternary International* 428:1–2.

Nelson, D.J., R.H. Webb and A. Long 1990 Analysis of stick nest rat (*Leporillus*: Muridae) middens from central Australia. In J.L. Betancourt, T.R. Van Devender and P. Martin (eds), *Packrat Middens: The Last 40,000 Years of Biotic Change*, pp.428–434. Tucson: University of Arizona Press.

O'Connor, S., P. Veth and N. Hubbard 1993 Changing interpretations of postglacial human subsistence and demography in Sahul. In M.A. Smith, M. Spriggs and B. Fankhauser (eds), *Sahul in Review: Pleistocene archaeology in Australia, New Guinea and island Melanesia*, pp.95–105. Canberra: The Australian National University Press.

O'Connor, S. and P. Veth 2006 Re-visiting the past: Changing interpretations of Pleistocene settlement subsistence and demography in northern Australia. In I. Lilley (ed), *Archaeology of Oceania: Australia and the Pacific Islands*, pp.31-47. Oxford: Blackwell Studies in Global Archaeology.

Pearsall, D. 1989 *Paleoethnobotany*. San Diego: Academic Press.

Pearson, S. 1997 Stick-nest Rat Middens as a Source Palaeo-environmental Data in Central Australia. Unpublished PhD thesis, Faculty of Science, School of Geography, University of New South Wales, Sydney.

Pearson, S. 1999 Late Holocene biological records from the middens of stick-nest rats in the central Australian arid zone. *Quaternary International* 59:39–46.

Pearson, S., A. Baynes and B. Triggs 2001 The record of fauna, and accumulating agents of hair and bone, found in middens of stick-nest rats (Genus *Leporillus)* (Rodentia: Muridae). *Wildlife Research* 28(4):435–444.

Pearson, S. and J.L. Betancourt 2002 Understanding arid environments using fossil rodent middens. *Journal of Arid Environments* 50:499–511.

Pearson, S. and J.R. Dodson 1993 Stick-nest rat middens as sources of palaeoecological data in Australian deserts. *Quaternary Research* 39:347–354.

Pearson, S., E. Lawson, L. Head, L. McCarthy and J. Dodson 1999 Spatial and temporal patterns of stick nest rat middens in Australia. *Radiocarbon* 41(3):295–308.

Pepper, M., P. Doughty and J.S. Keogh 2013 Geodiversity and endemism in the iconic Australian Pilbara region: A review of landscape evolution and biotic response in an ancient refugium. *Journal of Biogeography* 40:1225–1239.

Pillans, B. 2007 Pre-Quaternary landscape inheritance in Australia. *Journal of Quaternary Science* 22(5):439–447.

Porch, N. and J. Allen 1995 Tasmania: Archaeological and palaeo-ecological perspectives. *Antiquity* 69(265):714–732.

Reeves, J.M., T.T. Barrows, T.J. Cohen, A.S. Kiem, H.C. Bostock, K.E. Fitzsimmons, J.D. Jansen, J. Kemp, C. Krause, L. Petherick, S. J. Phipps and OZ-INTIMATE Members 2013a Climate variability over the last 35,000 years recorded in marine and terrestrial archives in the Australian region: an OZ-INTIMATE compilation. *Quaternary Science Reviews* 74:21–34.

Reeves, J. M., H.C. Bostock, L.K. Ayliffe, T.T. Barrows, P. De Deckker, L.S. Devriendt, G.B. Dunbar, R.N. Drysdale, K.E. Fitzsimmons, M.K. Gagan, M.L. Griffiths, S.G. Haberle, J.D. Jansen, C. Krause, S. Lewis, H.V. McGregor, S.D. Mooney, P. Moss, G.C. Nanson, A. Purcell and S. van

der Kaars 2013b Palaeoenvironmental change in tropical Australasia over the last 30,000 years – a synthesis by the OZ-INTIMATE group. *Quaternary Science Reviews* 74:97–114.

Reitz, E.J., L.A. Newsom, S.J. Scudder and C.M. Scarry 2008 Introduction to environmental archaeology. In E.J. Reitz, S.J. Scudder and C.M. Scarry (eds) *Case Studies in Environmental Archaeology*, pp.3–19. New York: Springer.

Ryan, I. and K. Morse 2009 Towards a late Holocene archaeology of the inland Pilbara. *Archaeology in Oceania* 44:6–15.

Scattini, W. 2008a *Kangaroo Grass*. Retrieved 14 March 2017 from <http://keys.lucidcentral.org/keys/v3/pastures/Html/Kangaroo_grass.htm>

Scattini, W. 2008b *Queensland Bluegrass*. Retrieved 14 March 2017 from <http://keys.lucidcentral.org/keys/v3/pastures/Html/Queensland_Bluegrass.htm>

Shulmeister, J. and B.G. Lees 1995 Pollen evidence from tropical Australia for the onset of an ENSO-dominated climate at c. 4000 BP. *The Holocene* 5(1):10–18.

Slack, M., M. Fillios and R. Fullagar 2009 Aboriginal settlement during the LGM at Brockman, Pilbara region, Western Australia. *Archaeology in Oceania* 44:32–39.

Smith, M. 1987 Pleistocene occupation in arid central Australia. *Nature* 328:710–711.

Smith, M. 2013 *The Archaeology of Australia's Deserts.* Cambridge: Cambridge University Press.

Smith, M., A.N. Williams, C.S. Turney and M.L. Cupper 2008 Human–environment interactions in Australian drylands: Exploratory time-series analysis of archaeological records. *The Holocene* 18(3):389–401.

Spaulding, W.G., J.L. Betancourt, L. Croft and K. Cole 1990 Packrat middens: Their composition and method of analysis. In J.L. Betancourt, T.R. Van Devender and P. Martin (eds), *Packrat Middens: The Last 40,000 Years of Biotic Change*, pp.104–133. Tucson: University of Arizona Press.

Stevenson, J., S. Brockwell, C. Rowe, U. Proske and J. Shiner 2015 The palaeo-environmental history of Big Willum Swamp, Weipa: An environmental context for the archaeological record. *Australian Archaeology* 80:17–31.

Stockmarr, J. 1971 Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13:615–621.

Sweedman, L. and D. Merritt 2006 *Australian Seeds*. Melbourne: CSIRO Publishing.

Thackway, R. and I.D. Cresswell (eds) 1995 *An Interim Biogeographic Regionalisation for Australia: A Framework for Establishing the National System of Reserves.* Canberra: Australian Nature Conservation Agency.

Thompson, W.A. and D.J. Eldridge 2005 White cypress pine (Callitris glaucophylla): A review of is role in landscape and ecological processes in eastern Australia. *Australian Journal of Botany* 53:555–570.

Tindale, N.B. 1974 *Aboriginal Tribes of Australia. Their Terrain, Environmental Controls, Distribution, Limits and Proper Names*. Canberra: Australian National University Press.

Troughton, E.L. 1924 The stick-nest building rats of Australia. *Australian Museum Magazine* 11:18–23.

Turney, C. and D. Hobbs 2006 ENSO influence on Holocene Aboriginal populations in Queensland, Australia. *Journal of Archaeological Science* 33:1744–1748.

Turney, C., S. Haberle, D. Fink, A.P. Kershaw, M. Barbetti, T.T. Barrows, M. Black, T.J. Cohen, T. Corrège, P.P. Hesse, Q. Hua, R. Johnston, V. Morgan, P. Moss, G. Nanson, T. van Ommen, S. Rule, N.J. Williams, J.X. Zhao, D. D'Costa, Y.X. Feng, M. Gagan, S. Mooney and Q. Xia 2006 Integration of ice-core, marine and terrestrial records for the Australian Last Glacial Maximum and Termination: a contribution from the OZ INTIMATE group. *Journal of Quaternary Science* 21(7):751–761.

Turney, C., J. Scourse, D. Rodbell and C. Caseldine 2007 Quaternary climatic, environmental and archaeological change in Australasia. *Journal of Quaternary Science* 22(5):421–422.

Ulm, S. 2013 'Complexity' and the Australian continental narrative: Themes in the archaeology of Holocene Australia. *Quaternary International* 285:182–192.

Van der Kaars, S. 1991 Palynology of eastern Indonesian marine piston-cores: A Late Quaternary vegetational and climatic record for Australasia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 85(3):239–302.

Van der Kaars, S. and P. De Deckker 2002 A late Quaternary pollen record from deep-sea core Fr10/95, GC17 offshore Cape Range Peninsula, northwestern Western Australia. *Review of Palaeobotany and Palynology* 120:17–39.

Van der Kaars, S. and P. De Deckker 2003 Pollen distribution in marine surface sediments offshore Western Australia. *Review of Palaeobotany and Palynology* 124:113–129.

Van der Kaars, S., P. De Deckker and F.X. Gingele 2006 A 100,000-year record of annual and seasonal rainfall and temperature for northwestern Australia based on a pollen record obtained offshore. *Journal of Quaternary Science* 21(8):879–889.

Van Devender, T.R. 1990 Late Quaternary vegetation and climate of the Chihuahuan Desert, United States and Mexico. In J.L. Betancourt, T.R. Van Devender and P. Martin (eds), *Packrat Middens: The Last 40,000 Years of Biotic Change*, pp.104–133. Tucson: University of Arizona Press.

Vannieuwenhuyse, D., S. O'Connor and J. Balme 2017 Settling in Sahul: Investigating environmental and human history interactions through morphological analyses in tropical semi-arid north-west Australia. *Journal of Archaeological Science* 77:172–193.

Veitch, B. and F. Hook 2005 A note on radiocarbon dates from the Paraburdoo, Mount Brockman and Yandicoogina areas of the Hamersley Plateau, Pilbara, Western Australia. *Australian Archaeology* 60:58–61.

Veth, P. 1989 Islands in the interior: A model for the colonization of Australia's arid zone. *Archaeology in Oceania* 24:81–92.

Veth, P. 1993 *Islands in the Interior: The Dynamics of Prehistoric Adaptations within the Arid Zone of Australia*. Ann Arbor, Michigan. *International Monographs in Prehistory 3.*

Veth, P. 1995 Aridity and settlement in northwest Australia. *Antiquity* 69(265):733–746.

Veth, P., J. McDonald and B. White 2008 Dating of Bush Turkey Rockshelter 3 in the Calvert Ranges established Early Holocene Occupation of the Little Sandy Desert, Western Australia. *Australian Archaeology* 66:33–44.

Veth, P., S. O'Connor and L.A. Wallis 2000 Perspectives on ecological approaches in Australian archaeology. Australian Archaeology 50:54–66.

Veth, P., M. Smith, J. Bowler, K. Fitzsimmons, A. Williams and P. Hiscock 2009 Excavations at Parnkupirti, Lake Gregory, Great Sandy Desert: OSL ages for occupation before the Last Glacial Maximum. *Australian Archaeology* 69:1–10.

Veth, P., I. Ward and K. Ditchfield 2017 Reconceptualising Last Glacial Maximum discontinuities: A case study from the maritime deserts of North Western Australia. *Journal of Anthropological Archaeology* 46:82–91.

WA Herbarium 2017 *Florabase* Retrieved 29 April 2016 from <https://florabase.dpaw.wa.gov.au/#>

Wallis, L.A. 2000 Phytoliths, Late Quaternary Environment and Archaeology in Tropical Semi-Arid Northwest Australia. Unpublished PhD thesis, Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, The Australian National University, Canberra.

Wallis, L.A. 2001 Environmental history of northwest Australia based on phytolith analysis at Carpenters Gap 1. *Quaternary International* 83–85:109–117.

Wallis, L.A. 2015 Findings from the Archaeological Investigation of Two Walled Rockshelters, Packsaddle Range, Pilbara. Unpublished report prepared for BHP Billiton Iron Ore.

Wallis, L.A., J. Huntley and J. Ralph 2015 Preliminary Advice on the Site Inspection and Study of Art Sites, Central Pilbara, June 2015. Unpublished report prepared for BHP Billiton Iron Ore.

Wallis, L.A. and J. Matthews 2016 Built structures in rockshelters of the Pilbara, Western Australia. *Records of the Western Australian Museum* 31:1–26.

Webb, R.J. 1986 Spatial and temporal distribution of radiocarbon ages on rodent middens from the southwestern United States. *Radiocarbon* 28:1–8.

Webeck, K. and S. Pearson 2005 Stick-nest rat middens and a late Holocene record of White Range, Central Australia. *The Holocene* 15(3):466–471.

Weiming Jia, P. 2011 Commentary: A critical review of environmental archaeology in Northeast China. *Asian Perspectives: The Journal of Archaeology for Asia and the Pacific* 50(1–2):17–89.

Wells, P.V. 1976 Macrofossil analysis of wood rat (*Neotoma*) middens as a key to the Quaternary vegetation history of arid America. *Quaternary Research* 6:223–248.

Whitlock, C. and C. Larsen 2001 Charcoal as a fire proxy. In J.P. Smol, H.J. Birks and W.M. Last (eds) *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators, Developments in Paleoenvironmental Research*, pp.75–97. Dordrecht: Kluwer Academic Publishers.

Williams, A., S. Ulm, A. Cook, M. Langley and M. Collard 2013 Human refugia in Australia during the Last Glacial Maximum and Terminal Pleistocene: A geospatial analysis of the 25–12 ka Australian archaeological record. *Journal of Archaeological Science* 40:4612–4625.

Williams, A., S. Ulm, I. Goodwin and M. Smith 2010 Hunter-gatherer response to late Holocene climatic variability in northern and central Australia. *Journal of Quaternary Science* 25(6):831–838.

Williams, A., P. Veth, W. Steffen, S. Ulm, C. Turney, J.M. Reeves, S.J. Phipps and M. Smith 2015a A continental narrative: human settlement patterns and Australian climate change over the last 35,000 years. Quaternary Science Reviews 123:91–112.

Williams, A., S. Ulm, C. Turney, D. Rohde and G. White 2015b Holocene demographic changes and the emergence of complex societies in prehistoric Australia. *PLoS One* 10(6):1–17.

Wyrwoll, K. and G.H. Miller 2001 Initiation of the Australian summer monsoon 14,000 years ago. *Quaternary International* 83–85:119–128.

APPENDICES

8.1 LIST OF APPENDICES

Appendix 1: Midden Recording Form

Appendix 2: Lab Recording Form

Appendix 3: Haberle and Hopf (2016) Pollen Analysis Report

Appendix 4: aDNA Raw Data

Appendix 5: Raw Macrofossil Counts

Appendix 6: Radiocarbon Results from Waikato

Appendix 7: Radiocarbon Results from ANSTO

Appendix 8: Vegetation List

Appendix 9: Macrofossil Specimens and Unknown Types

8.2 Appendix 1: Midden Recording Form

Site ID | Date

Nest ID | General Area Name

GPS coordinates (GDA94) E / N

Aspect | Geological Unit

Description of topographic locality

Surrounding vegetation

Nest measurements

height _____cm length _____cm width _____cm

Areal extent _____m2

Nest Condition

Description of where in the RS the nest is positioned

Other features of the RS

Sample details

Photo numbers

Site plan sketch

Nest and sample sketch

8.3 Appendix 2: Lab Recording Form

Extraction of macro-fossils from stick-nest rat middens worksheet

Emily McBride, Masters Project Date commenced _____ Date completed _____

Sample #	Sample Weight (g)	Container #	Date/time soaking commenced	Date/time checked and filtered	Date/time into oven	Date/time removed from oven	Cooling complete?	Weight of extracted sample (g)	Weight of yield per sample (%)
		1							
		2							
		3							
		4							
		5							
		6							

8.4 Appendix 3: Haberle and Hopf (2016) Pollen Analysis Report

Palynological Analysis of Stick-nest Rat (*Leporillus* sp.) middens in the Packsaddle Range and Surrounds, Pilbara, Western Australia.

Report prepared for Wallis Heritage Consulting (ABN 24 436 468 794)

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1. Introduction

Despite the cultural and biological significance of the Pilbara region of northwestern Australia, little is known about the long-term environmental changes that occurred in the region since the arrival of people over 40,000 years ago. Regional-scale, marine-core pollen and charcoal data is available from locations off the west and north Australian coast (van de Kaars and DeDecker, 2002; Wang *et al*., 1999). These records suggest that the region was well vegetated (wet) during interglacials and sparsely vegetated (dry) during glacials. These offshore interpretations of late Quaternary wet/dry climatic and vegetation trends prove similar to reconstructions derived from inland Lake Gregory (Reeves *et al*., 2014; Hesse *et al*., 2004; Wyrwoll and Miller, 2001). Over the last 35,000 years, human occupants of the region would have encountered poorly vegetated environments for the first 20000 years. It is only after approximately 14,000 years ago that monsoon activity increases rapidly and greater moisture and vegetation cover is available (Reeves *et al*. 2014; Hesse *et al*., 2004). The analyses of rockshelter sediments by Wallis (2001; phytoliths) and McConnell and O'Connor (1997; plant-macro remains) provide local compositional insight and detail on plant-to-people interactions that broadly support these regional climatic reconstructions.

The potential of Stick-nest Rat middens (derived from the nests created by the now extinct mammal *Leporillus* sp.) to provide palaeoecological evidence from the Australian arid zone is now well established (Webeck and Pearson, 2005; Pearson and Betancourt, 2002; Allen *et al*., 2000; McCarthy *et al*., 1996). While these studies acknowledge that contamination, variability in pollen source and taphonomic uncertainties of pollen preserved in the middens can lead to interpretive difficulties there remains a need for further palaeoecological research on midden deposits in order to refine our capacity to reconstruct past environments of Australia's arid regions. The general principle for interpreting pollen derived from Stick-nest Rat middens is that the presence of a pollen taxa is evidence of its parent plants being present in the local (~10m) to extra-local (~100m) environment at the time the midden was constructed (Webeck and Pearson, 2005). This doesn't exclude the possibility that regional wind blown pollen may be incorporated into the pollen assemblage, however, this is likely to be a minor component compared to pollen produced from local plant sources. The relative abundance of material in the midden may reflect the rats' collecting proclivity; however, assuming consistent collecting behaviour, different abundances in middens will reflect vegetation change (Pearson and Betancourt, 2002). Relative changes within middens reflect vegetation snapshots at one point through time. These principles of interpretation will be applied to the Stick-nest Rat samples examined in this study and have the potential to reveal new insights into past human-vegetation-climate interactions in the study region.

The vegetation of the Packsaddle Range and surrounds region can be broadly described from historical systematic flora surveys of the Pilbara, which are limited to Burbidge (1959) and Beard (1975), and further refining of the original Beard mapping by Shepherd *et al*. (2002). The vegetation within the Packsaddle Range area is dominated by two vegetation associations: (i) *Eucalyptus* - *Corymbia* and *Triodia wiseana* (hard spinifex) open woodland to tree steppe on the ranges; and (ii) *Acacia aneura* (mulga) low woodland in the valleys. The density of trees and shrubs compared to hummock grassland is complex function of fire regime, climate and edaphic factors. A shift in any one of these factors is likely to result in changes in tree and shrub density that may be detectable in the pollen assemblage preserved within Stick-nest Rat middens.

2. Methodology: Pollen and Micro-Charcoal Analysis

The study of pollen and micro-charcoal preserved in a range of pollen preserving contexts (including Stick-nest Rat middens) is one of the main ways we can reconstruct past vegetation patterns and changes to the landscape through time. The techniques have been in use for nearly a century and have found applications in the study of climate change, archaeology and human impact on the environment through to industrial application in petroleum geology.

2.1 Pollen Analysis

Pollen grains are plant parts that play a role in fertilization during plant reproduction and are found in the flowers of angiosperms and gymnosperms. Pollen is dispersed from one plant to another in many ways, but the most common is either wind-dispersed (anemophilous) or insect-dispersed (entomophilous). Pollen grains can also be dispersed by slope wash and animal (including human) agency (see Figure 1). Pollen grains are usually spherical or elliptical and vary in size from 10µm (0.01mm) to 100µm (0.1mm) and their shape and surface texture can be used to identify them to a parent plant family, genera or sometimes even species. The tough structure of pollen grains means that they are readily preserved in anaerobic (low oxygen) environments, such as bogs and lakes. They are also known to be well preserved in the viscous urine deposits (or amberat) built by the now extinct Stick-nest Rat (*Leporillus* sp) into middens (Pearson and Betancourt, 2002).

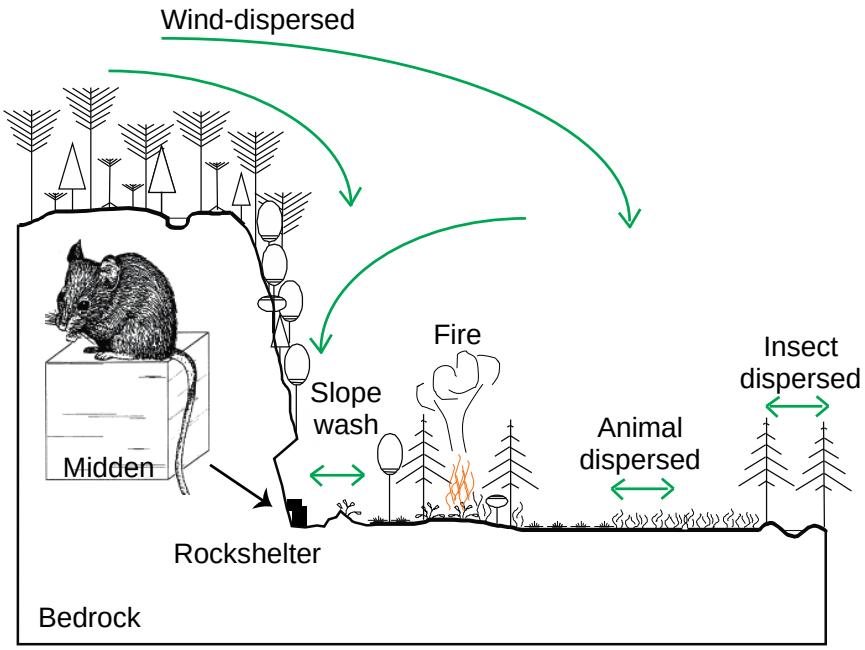

Figure 1. Model of potential pollen dispersal mechanisms from the source plant to the point of deposition (Stick-nest Rat midden). Micro-Charcoal is dispersed in a similar fashion, though larger and heavier fragments are less likely to be transported long distances by wind or insect dispersal (Whitlock and Larsen, 2001). Stick-nest Rat middens also includes pollen carried on the animals body from soil and plants.

The method used to prepare the samples for pollen analysis is adapted from previous studies (Webeck and Pearson, 2005; Pearson and Betancourt, 2002; Allen *et al*., 2000; McCarthy *et al*., 1996). Samples were weighed and sample volume estimated by water displacement in a graduated cylinder, ranging from 1.5-3.5cm^3 and 1.36-4.46g, respectively (see Table 1). Pollen processing included dissolving the sample in water, followed by standard HCl, KOH and acetolysis methods (Faegri and Iversen, 1989), including addition of *Lycopodium* marker grains to calculate concentrations of pollen, spores and microscopic charcoal (Stockmarr, 1971) and sieving through 125 µm mesh to remove macroscopic material. Lithium polytungstate was used at a specific gravity of 2.0 to further concentrate pollen in the samples (Caffrey and Horn, 2013). Pollen, spores and microscopic charcoal (> 10µm) were counted at 400 x magnification using a Zeiss Axiophot microscope and identifications made using the reference collection held at the Department of Archaeology & Natural History, Australian National University (ANU) and the Australian Pollen and Spore Atlas (APSA Members, 2007). Pollen percentages were calculated using the total pollen sum (minimum of 200 pollen grains counted). Pollen diagrams were produced using Tilia v. 2.0.33 (Grimm, 2013).

It is important to note that the interpretation of past vegetation in the context of Stick-nest Rat middens is limited by: (i) the absence of modern pollen rain studies of arid vegetation communities in the region; (ii) the absence of taphonomic studies examining the potential pollen dispersal vectors associated with pollen preserved in Stick-nest Rat middens; (iii) our limited understanding of pre-European vegetation and its representation in the most recent Stick-nest Rat middens; and (iv) the significant vegetation changes that have occurred during the post-European period, in particular due to the impact of feral animals. However, by comparing the proportion of each pollen type that is preserved in sediments of known age, we can produce a preliminary reconstruction of the potential vegetation surrounding the site. A time series of pollen spectra can be constructed by examining samples at intervals determined by radiocarbon analysis, both within sites and between sites. When multiple sites are analysed the pollen assemblages provide us with a window into past vegetation changes both spatially and temporally across the landscape, and at a particular point in the landscape. Examples of pollen types and micro-charcoal identified in this study are given in Figure 2.

		Weight (g)	Volume (cc)			Weight (g)	Volume (cc)
1	PIL_540 SNR 1	3.39	2.5	**27**	SNRM_24092015_3 SNR 1	2.14	2.0
2	PIL_540 SNR 2	4.06	3.0	**28**	SNRM_24092015_3 SNR 2	2.53	2.0
3	PIL_540 SNR 3	1.79	2.0	**29**	PIL_7026 SNR 1	1.55	1.5
4	PIL_542 SNR 1	2.16	2.0	**30**	PIL_2258 SNR 1	2.08	2.0
5	PIL_542 SNR 2	2.70	2.0	**31**	PIL_2258 SNR 2	3.69	3.0
6	PIL_542 SNR 3A	3.21	2.0	**32**	PIL_2258 SNR 3	3.15	3.0
7	PIL_542 SNR 3B	3.42	2.5	**33**	PIL_2258 SNR 4	2.68	2.5
8	PIL_542 SNR 4A	3.02	2.5	**34**	PIL_4544 SNR 1	3.66	3.0
9	PIL_542 SNR 4B	2.99	2.5	**35**	PIL_4544 SNR 2	1.53	1.5
10	PIL_542 SNR 4C	2.56	2.0	**36**	PIL_4544 SNR 3A	3.71	3.5
11	PIL_542 SNR 5	2.57	2.0	**37**	PIL_4544 SNR 3B 1	4.03	3.5
12	PIL_542 SNR 6A	2.44	2.0	**38**	PIL_4544 SNR 3B 2	2.53	2.5
13	PIL_542 SNR 6B	2.91	2.5	**39**	PIL_4544 SNR 3C	3.96	3.0
14	PIL_542 SNR 7	3.45	2.5	**40**	PIL_4544 SNR 3D	1.78	1.5
15	PIL_542 SNR 8	1.36	1.5	**41**	PIL_4544 SNR 4A	3.31	3.0
16	PIL_542 SNR	3.25	2.5	**42**	PIL_4544 SNR 5A	2.50	2.0
17	BHP60918 SNR 1	3.23	2.5	**43**	PIL_4544 SNR 5B	2.05	2.0
18	SNRM_22092015 SNR 1	2.72	2.5	**44**	PIL_4544 SNR 5C	2.55	2.0
19	PIL_5841 SNR 1 (Right)	2.49	2.0	**45**	PIL_2001 SNR 1A	2.26	2.0
20	PIL_5841 SNR 1 (Centre)	3.49	3.0	**46**	PIL_2001 SNR 1B	3.20	2.5
21	PIL_5841 SNR 1 (Left)	4.46	3.0	**47**	PIL_2001 SNR 2A	2.41	2.0
22	PIL_5841 SNR 2A	2.05	2.0	**48**	PIL_2001 SNR 2B	3.05	2.5
23	PIL_5841 SNR 2B	2.05	2.0	**49**	PIL_2001 SNR 2C	2.66	2.5
24	PIL_5841 SNR 3	1.58	1.5	**50**	PIL_2001 SNR 3A	2.24	2.0
25	PIL_5841 SNR 4	3.43	3.0	**51**	PIL_2001 SNR 3B	3.19	2.5
26	PIL_5841 SNR 5	3.52	3.0				

Table 1. Samples analysed for pollen and micro-charcoal with sample weight and volume listed next to site sample code.

2.2 Micro-Charcoal Analysis

Fine fragments of charcoal are preserved alongside pollen remains in Stick-nest Rat midden samples and can be used to infer fire occurrence through time in the landscape. Micro-charcoal is generally considered to be the fraction between 10µm to approximately 125µm and can be quantified on pollen slides (Whitlock and Larsen, 2001). Peaks in charcoal abundance are interpreted to represent fire episodes in the past that may have contributed to changes in vegetation recorded in the pollen record. Burnt grass phytoliths are also recorded and are most likely derived from local grassland fires.

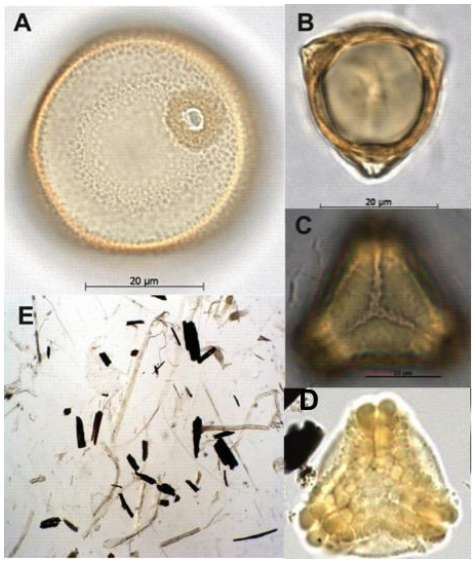

Figure 2. Pollen Grains (Reference Slides in the Online Australasian Pollen and Spore Atlas) and Micro-Charcoal from the Kimberley-Pilbara Region. A) Grass (*Spinifex longifolius* POACEAE), B) *Dodonaea lanceolata* SAPINDACEAE, C) *Eucalyptus dichromophloia* MYRTACEAE (TYPE 1), D) *Corymbia sp.* MYRTACEAE (TYPE 3), and E) Microscopic Charcoal Fragments on Pollen Slide (10-30 m long).

3 Results and Interpretation

3.1 Site and Sample Description

The fossil pollen and micro-charcoal assemblage found within each midden deposit is described below. Radiocarbon dates are also recorded in some sites depicted in Figure 3 and are based on AMS radiocarbon analysis of bulk organic samples (fecal pellets). The pollen and charcoal results are presented in detail in Figure 4 (a-f). The raw data is tabulated and presented in Appendix 1.

PIL 540 SNR 1-3

The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) with Mrytaceae trees and shrubs making up ~70-90% of the total pollen sum. Herbaceous taxa (10-30%) are dominated by grasses (Poaceae), with Chenopods and Asteraceae making up a minor part of this group. The diversity of pollen taxa distinguished is moderate (27 pollen morphological categories). Moderate levels of micro-charcoal are recorded in these samples. A high percentage of tree pollen is indicative of local woodland subject to moderate burning.

PIL 542 SNR 1-9

The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Mrytaceae Type 2 (*Corymbia* sp.). trees and shrubs, including *Acacia*, *Dodonaea* and *Callitris*, make up ~60-90% of the total pollen sum. Herbaceous taxa (5-30%) are dominated by grasses (Poaceae), with Chenopods, Asteraceae and ferns present. The diversity of pollen taxa distinguished is high (64 morphological categories). Moderate to high levels of micro-charcoal are recorded in these samples. The pollen assemblage reflects changes in the local vegetation between *Acacia* woodland associated with moderate burning and *Eucalyptus* woodland associated with higher burning.

BHP 60918 SNR 1

Only represented by one sample. The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) trees and shrubs making up ~80% of the total pollen sum. Herbaceous taxa (20%) are dominated by grasses (Poaceae), with minor presence of Chenopods and Asteraceae. The diversity of pollen taxa distinguished is moderate (16 pollen morphological categories). Low levels of micro-charcoal are recorded in this sample. A high percentage of tree pollen is indicative of local woodland subject to low burning.

SNRM 22092015 SNR 1

Only represented by one sample. The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Mrytaceae Type 2 (*Corymbia* sp.). Myrtaceae trees make up almost 100% of the total pollen sum. Other taxa (1-2%) include Gyrostemon and ferns. The diversity of pollen taxa distinguished is low (6 morphological categories). Low levels of micro-charcoal are recorded in this sample. A high percentage of tree pollen is indicative of local woodland subject to low burning

PIL 5841 SNR 1-5

The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Mrytaceae Type 2 (*Corymbia* sp.) for sample set 1-2 (70-90% of total pollen sum), with samples being 4-5 dominated by Poaceae (100% of total pollen sum). The total diversity of pollen taxa distinguished is moderate (34 morphological categories). Samples dominated by Myrtaceae trees also include the presence of *Dodonaea*, *Solanum*, and Cyperaceae, possibly indicative of wetter conditions. Moderate to high levels of micro-charcoal are recorded in these samples. The samples dominated by Poaceae have little other diversity in pollen and have low charcoal content. The pollen assemblage reflects changes in the local vegetation between woodland associated with moderate burning and a hummock grassland associated with low burning.

SNRM 24092015_3 SNR 1-2
The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Mrytaceae Type 2 (*Corymbia* sp.) with Myrtaceae trees and shrubs making up ~80-90% of the total pollen sum. Herbaceous taxa (10-20%) are dominated by grasses (Poaceae), with Chenopods making up a minor part of this group. The diversity of pollen taxa distinguished is moderate (20 morphological categories). Low levels of micro-charcoal are recorded in these samples. A high percentage of tree pollen is indicative of local woodland subject to low burning.

PIL 7026 SNR 1
Only represented by one sample. The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) with minor representation from *Dodonaea*, *Gyrostemon and Grevillia* which combined make up ~80% of the total pollen sum. Herbaceous taxa (20%) are dominated by Chenopods and Asteraceae. The diversity of pollen taxa distinguished is moderate (16 morphological categories). Low levels of micro-charcoal are recorded in this sample. A pollen assemblage is indicative of local woodland with a chenopod understorey subject to low burning.

PIL 2258 SNR 1-4
The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Mrytaceae Type 2 (*Corymbia* sp.) with Myrtaceae trees, Dodnaea, Malvaceae and Rubiaceae shrubs making up ~40-80% of the total pollen sum. Herbaceous taxa (20-50%) are dominated by grasses (Poaceae), with Chenopods and Asteraceae making up a minor part of this group. The diversity of pollen taxa distinguished is moderate (26 morphological categories). Moderate levels of micro-charcoal are recorded in these samples. A mixed percentage of tree and herbaceous taxa is indicative of local open woodland subject to moderate burning.

PIL 4544 SNR 1-5
The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Mrytaceae Type 2 (*Corymbia* sp.) with Mrytaceae trees and Dodonaea and Malvaceae shrubs making up ~20-80% of the total pollen sum. Herbaceous taxa (20-80%) are dominated by grasses (Poaceae), with Chenopods and Asteraceae making up a minor part of this group. The diversity of pollen taxa distinguished is moderate (39 morphological categories). Low to moderate levels of micro-charcoal are recorded in these samples. The variability between samples in dominance of trees and herbaceous taxa is indicative of changing local vegetation between, woodland, open woodland and grassland all subject to low to moderate burning.

PIL 2001 SNR 1-3
The pollen assemblage is dominated by Myrtaceae Type 1 (*Eucalyptus* type) and Mrytaceae Type 2 (*Corymbia* sp.) and Type 3 (*Corymbia* sp. ornate) with Mrytaceae trees and *Dodonaea* shrubs making up ~40-90% of the total pollen sum. Herbaceous taxa (10-60%) are dominated by grasses (Poaceae), with Chenopods and Asteraceae making up a minor part of this group. The diversity of pollen taxa distinguished is moderate (35 morphological categories). Low to moderate levels of micro-charcoal are recorded in these samples. The variability between samples in dominance of trees and herbaceous taxa is indicative of changing local vegetation between, woodland and open woodland all subject to low to moderate burning.

3.2 Sample Age and Changing Vegetation Through Time
A total of 9 samples were chosen for AMS radiocarbon analysis based on fragments of Stick-nest Rat middens (fecal pellets) being submitted to the Waikato Radiocarbon Laboratory in New Zealand. The results yielded ages ranging from ~900 to 17,000 cal BP. The sample age results and the associated pollen assemblage and vegetation interpretation are listed in Table 2. The AMS radiocarbon age results (cal BP) are also illustrated in Figure 3 alongside the dominant tree pollen spectra for all samples.

Three samples produced ages that occur in the late glacial period and into the early Holocene and represent the oldest known ages for Stick-nest Rat middens ever recorded in Australia (Pearson and Betancourt 2002). These samples give us an insight into the type of vegetation that was growing around the midden sites during the late glacial transition and suggest that vegetation was dominated by woodland. This contrasts with the other 5 samples ranging in age from ~3000-900 cal BP that show local site vegetation ranged from woodland, open woodland and grassland.

Vegetation represented by pollen and macrofossil records in previous palaeoecological studies of Stick-nest Rat middens has been interpreted as being controlled by climate (moisture) and fire during the Holocene. The earliest records so far in the published data are ~13,000 cal BP and are found in the northern Flinders Ranges, South Australia (McCarthy *et al.*, 1996). These samples are dominated by chenopods, which may be indicative of greater aridity during the late glacial transition in this region. Increases in shrubiness and tree density recorded in the mid-Holocene in the same region are also interpreted as being driven by increased moisture availability relative to the present (McCarthy *et al.*, 1996). A similar late Holocene study in the White Range (Northern Territory) records a dramatic increase in tree and shrub

vegetation at the expense of herbs between 3000-800 cal BP that is thought to be related to increasing moisture availability and changing fire regimes (Webeck and Pearson, 2005). In contrast, and further west in the Young Range (Western Australia), Pearson and Dodson (1993) record a shift towards less wooded vegetation between 900-300 yr BP. It is likely that greater use of fire due to increased population or changing climates would influence the density of woodland and abundance of grass understory, favoring fire adapted species over fire sensitive species of trees, shrubs and herbs.

In the Packsaddle Range area, Stick-nest Rat midden sites dating to the late glacial period show that rather than being dominated by chenopods indicative of extreme aridity (as recorded in the Flinders Ranges in South Australia, McCarthy *et al.*, 1996), the region maintained a diverse woodland vegetation where fire was a part of the ecosystem. This reflects continued moisture availability around the sites at a time generally considered to be relatively arid (Reeves *et al.*, 2014). The sites may have acted as a refugia for woody vegetation during this time. The shift towards more open vegetation at some sites during the late Holocene may be driven by changes in moisture availability or at least a greater interannual variability in moisture as a result of increased influence of ENSO (Pacific Ocean) and Indian Ocean Dipole related climate variability across Australia during the late Holocene and particularly after 2000 cal BP (Haberle *et al.*, 2012; Reeves *et al.*, 2014).

Sample code	**^{14}C age yr BP (Lab No.)**	**Cal BP (1 sigma)**	**Dominant Pollen (approx. %) $Taxa_{Div}$, Fire**	**Vegetation Interpretation**
PIL 4544 SNR 3B	1020 ± 20 (Wk-42965)	930-800	Myrtaceae (50%), Poaceae (50%) $Taxa_{Div}$=16, Fire=Moderate	Open Woodland
PIL 540 SNR 1	2220 ± 20 (Wk-42960)	2310-2140	Myrtaceae (80%), Poaceae (20%) $Taxa_{Div}$=13, Fire=Moderate	Woodland
PIL 5841 SNR 4	2470 ± 20 (Wk-42963)	2700-2630	Myrtaceae (20%), Poaceae (70%) $Taxa_{Div}$=9, Fire=Low	Grassland
PIL 4544 SNR 3A	2760 ± 20 (Wk-42966)	2870-2750	Myrtaceae (70%), Poaceae (20%) $Taxa_{Div}$=9, Fire=Moderate	Woodland
PIL 2001 SNR 1B	2770 ± 40 (Wk-42964)	2930-2750	Myrtaceae (20%), Poaceae (60%) $Taxa_{Div}$=16, Fire=Low	Grassland
PIL 4544 SNR 4A	5970 ± 40 (Wk-42967)	6890-6650	Barren	---
PIL 4544 SNR 5C	9280 ± 55 (Wk-42968)	10,560-10,250	Myrtaceae (70%), Poaceae (30%) $Taxa_{Div}$=11, Fire=Low	Woodland
PIL 542 SNR 5	10,443 ± 30 (Wk-42961)	12,430-12,250	Myrtaceae/Acacia (80%), Poaceae (20%) $Taxa_{Div}$=28, Fire=Moderate	Woodland
PIL 5841 SNR 1	13,980 ± 50 (Wk-42962)	17,120-16,620	Myrtaceae (80%), Poac./Cyperaceae (20%) $Taxa_{Div}$=14, Fire=Moderate	Woodland

Table 2. Radiocarbon dates and calibrated ages (cal BP) for selected Stick-nest Rat midden samples. Dominant pollen taxa, number of pollen morphological taxa identified ($Taxa_{Div}$) and relative abundance of charcoal (~fire events) are given for each sample alongside interpreted vegetation cover.

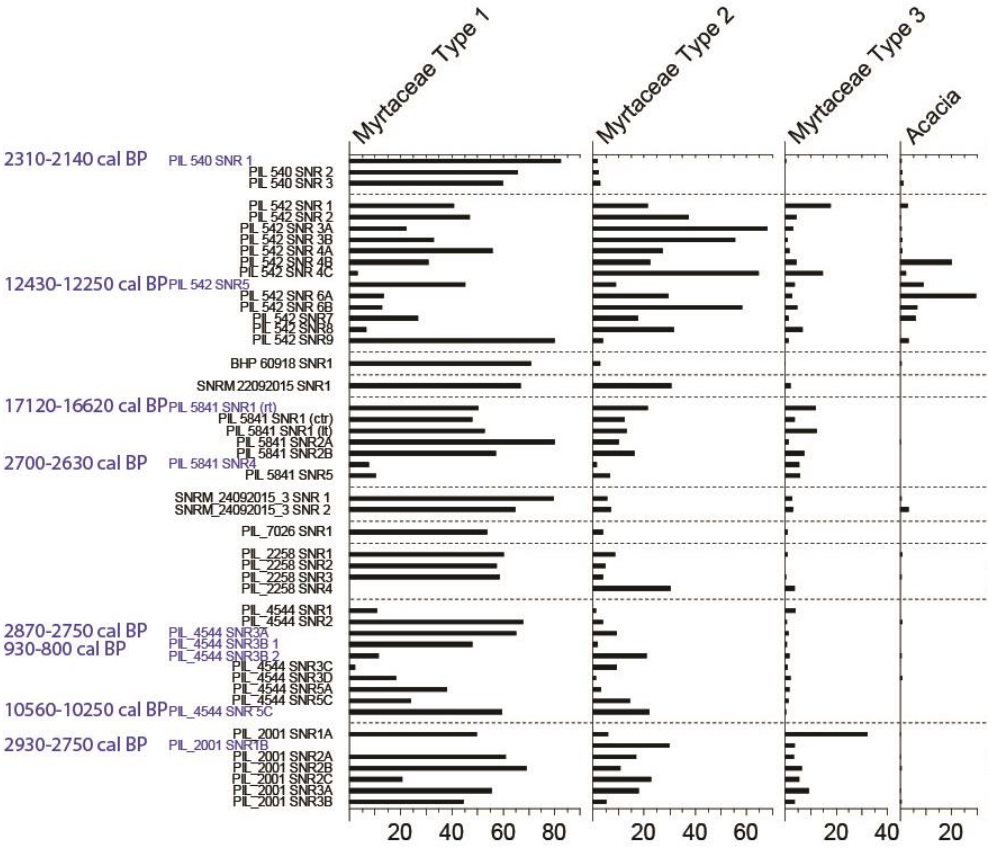

Figure 3. Pollen summary diagram for Stick-nest Rat midden samples in order of midden code (dotted line zones) and sample number. Calibrated radiocarbon dates derived from 9 selected samples are listed in blue text. PIL 4544 SNR 4A sample is dated to ~6750 cal BP is not included as it did not contain any pollen (see Table 2).

4 Conclusion

In summary, the pollen, charcoal and AMS radiocarbon analysis of 51 Stick-nest Rat midden samples from the Packsaddle Range region of the Pilbara, Western Australia, provides an insight into the nature of vegetation, burning and climate of the region over the last 17,000 cal BP. The results show the following:

(i) Stick-nest Rat midden samples preserve abundant pollen and charcoal (114 pollen morphological taxa with 55 taxa being identified to Genera or Family level).

(ii) Using information from previous studies and differences in relative abundance of pollen types and charcoal abundance in samples it is possible to infer past local vegetation cover around each site.

(iii) The study records the oldest Stick-nest Rat midden assemblage known in Australia (17,000 cal BP).

(iv) Samples dating to the late glacial transition (17-10ka) are dominated by diverse woodland and shrub taxa suggesting that the sites where these middens occur may have been refugia for woody plants during the drier last glacial period.

(v) Late Holocene samples show increasing vegetation heterogeneity which may be related to local factors, such as fire regime change, and regional climate change towards greater interannual variability. Human influence may also have played a role in creating regional differences in vegetation cover through fire management practices.

Future research should focus on providing a robust chronological framework for each sample to enable temporal as well as spatial comparisons across the region. There is also a need for a greater understanding of the modern pollen rain and pollen morphological identification. Collection of pollen reference material from flowering plants in the region and a pollen rain monitoring program in midden sites would provide much needed data to assist in better interpretations of fossil pollen records derived from Stick-nest Rat middens.

5 References

Allen, V., L. Head, G. Medlin, and D. Witter 2000. Palaeo-ecology of the Gap and Coturaundee Ranges, western New South Wales, using stick-nest rat (*Leporillus* spp.) (Muridae) middens. *Austral Ecology* 25:333–343.

APSA Members (2007) *The Australasian Pollen and Spore Atlas V1.0.* Canberra: Australian National University, http://apsa.anu.edu.au/

Beard, J. S. 1975. *Pilbara*. Explanatory Notes and Map Sheet 5, 1:1 000 000 series Vegetation Survey of Western Australia. University of Western Australia Press: Nedlands.

Burbidge, N.T. 1959. Div. Plant Ind. Tech Paper 12. Notes on plants and plant habitats observed in the Abydos-Woodstock area, Pilbara District, CSIRO, Western Australia.

Caffrey, M.A. and S. P. Horn 2013. The use of lithium heteropolytungstate in the heavy liquid separation of samples which are sparse in pollen. *Palynology* 37(1):143-150.

Faegri, K. and J. Iversen 1989. *Textbook of pollen analysis*. New York: Wiley.

Grimm, E.C. 2013. *Tilia Version 2.0.33*, Springfield: Illinois State Museum.

Haberle, S.G., S. Rule, P. Roberts, H. Heijnis, G. Jacobsen, C. Turney, R. Cosgrove, A. Ferrier, P. Moss, S. Mooney and P. Kershaw 2010. Paleofire in the wet tropics of northeast Queensland, Australia. *PAGES Newsletter* 18(2):78-80.

Hesse, P. P., J. W. Magee and S. van der Kaars 2004. Late Quaternary Climates of the Australian Arid Zone: a Review. *Quaternary International* 118-119: 87-102.

McCarthy, L., L. Head and J. Quade 1996. Holocene palaeoecology of the northern Flinders Ranges, South Australia, based on stick-nest rat **(***Leporillus* spp.) middens: a preliminary overview. *Palaeogeography, Palaeoclimatology, Palaeoecology* 123:205-218.

McConnell, K. and S. O'Connor 1997. 40,000 Year Record of Food Plants in the Southern Kimberley Ranges, Western Australia. *Australian Archaeology* (45): 20-31.

Pearson, S. and J.L. Betancourt 2002. Understanding arid environments using fossil rodent middens. *Journal of Arid Environments* 50:499–511.

Pearson, S. and J.R. Dodson 1993. Stick-Nest Rat Middens as Sources of Palaeoecological Data in Australian Deserts. *Quaternary Research* 39:347–354.

Reeves, J.M., H.C. Bostock, L.K. Ayliffe, T.T. Barrows. P. De Deckker, L.S. Devriendt, G.B. Dunbar, R.N. Drysdale, K.E. Fitzsimmons, M.K. Gagan, M.L. Griffiths, S.G. Haberle, J.D. Jansen, C. Krause, S. Lewis, H.V. McGregor, S.D. Mooneym, P. Moss, G.C. Nanson, A. Purcell, S. van der Kaars 2013. Palaeoenvironmental change in tropical Australasia over the last 30,000 years e a synthesis by the OZ-INTIMATE group. *Quaternary Science Reviews* 74:97-114.

Shepherd, D., G. Beeston, and A. Hopkins 2002. *Native Vegetation in Western Australia. Extent, Type and Status*. Resource Management Technical Report 249. Department of Agriculture, South Perth.

Stockmarr, J. 1971 .Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13:615-621.

van der Kaars, S. and P. De Deckker 2002. A Late Quaternary Pollen Record from Deep-Sea Core Fr10/95, Gc17 Offshore Cape Range Peninsula, Northwestern Western Australia. *Review of Palaeobotany and Palynology* 120(1-2):17-39.

Wallis, L. A. 2001. Environmental History of Northwest Australia Based on Phytolith Analysis at Carpenter's Gap 1. *Quaternary International,* 83-85: 103-117.

Wang, X., S. van der Kaars, P. Kershaw, M. Bird and F. Jansen 1999. A Record of Fire, Vegetation and Climate through the Last Three Glacial Cycles from Lombok Ridge Core G6-4, Eastern Indian Ocean, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 147(3-4):241-256.

Webeck, K. and S. Pearson 2005. Stick-nest rat middens and a late-Holocene record of White Range, central Australia. *The Holocene* 15(3):466-471.

Whitlock, C. and C. Larsen 2001. Charcoal as a Fire Proxy. *In:* Smol, J. P., Birks, H. J. B. & Last, W. M. (eds) *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators*, Developments in Paleoenvironmental Research, Dordrecht, Kluwer Academic Publishers: 75-97.

Wyrwoll, K. H. and G.H. Miller 2001. Initiation of the Australian Summer Monsoon 14,000 Years Ago. *Quaternary International* 83-85:119-128.

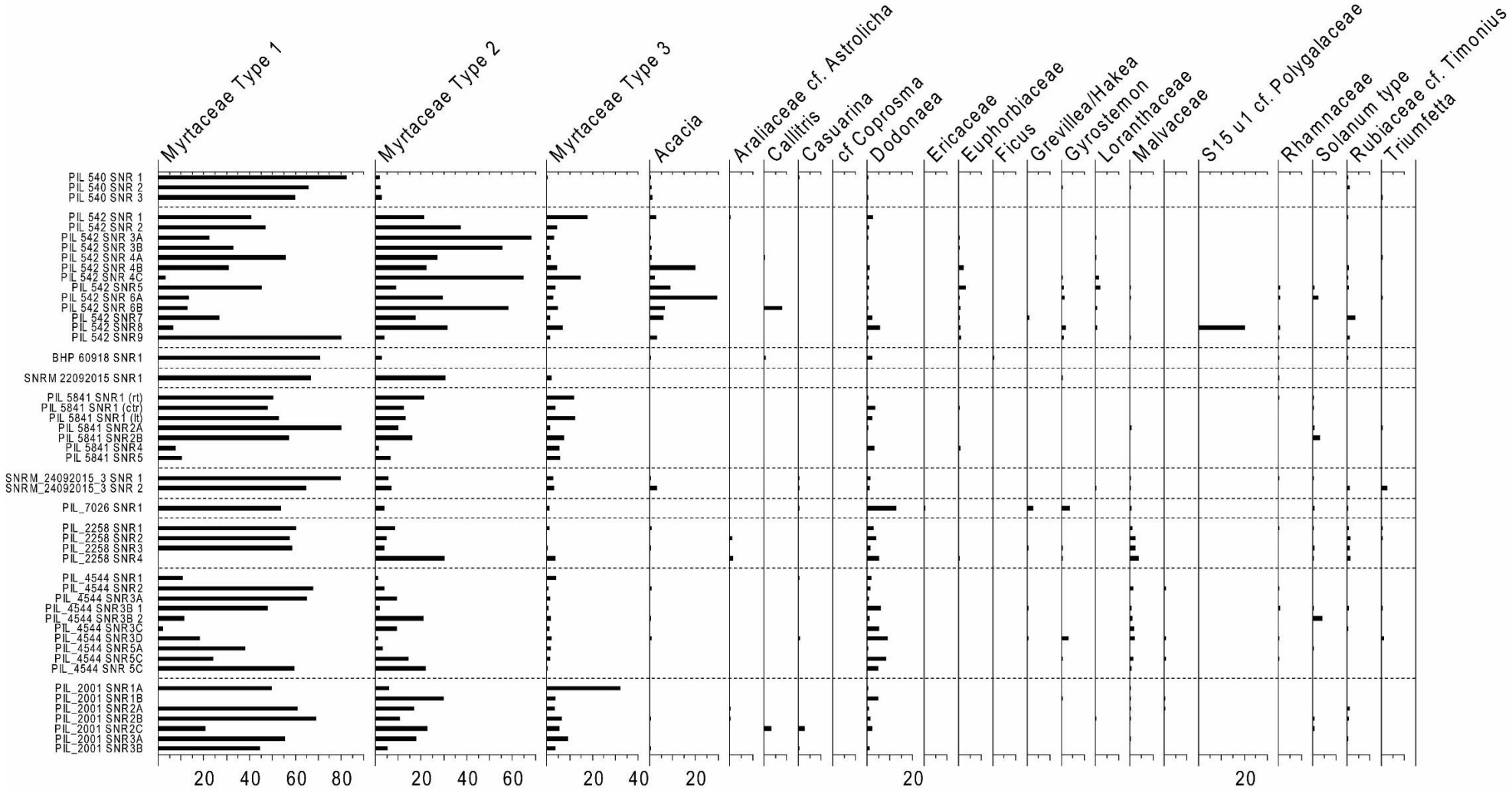

Figure 4a. Tree and shrub taxa pollen diagram for Stick-nest Rat midden samples in order of midden code (dotted line zones) and sample number. Pollen percentage based on total pollen sum.

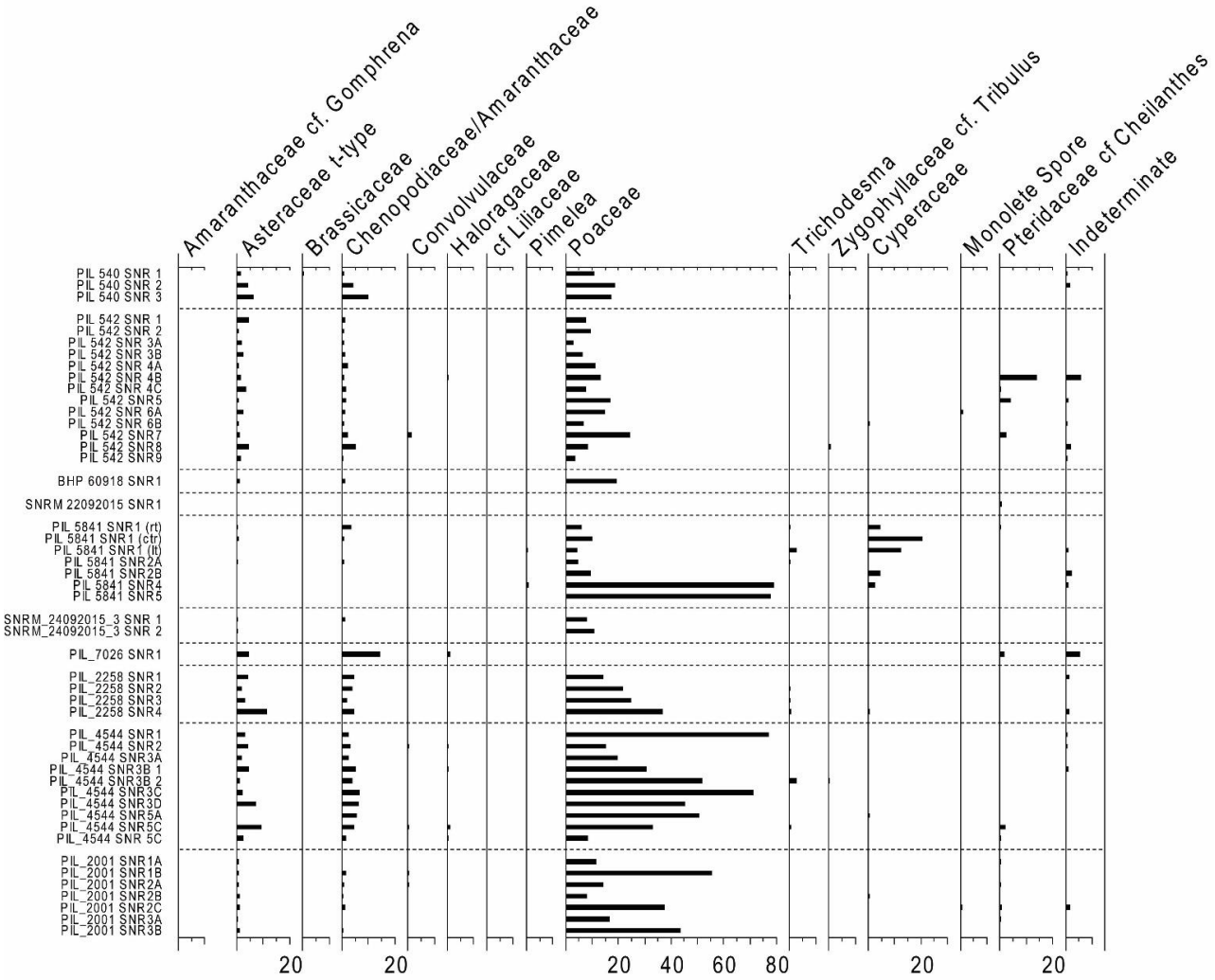

Figure 4b. Herbaceous taxa pollen diagram for Stick-nest Rat midden samples in order of midden code (dotted line zones) and sample number. Pollen percentage based on total pollen sum.

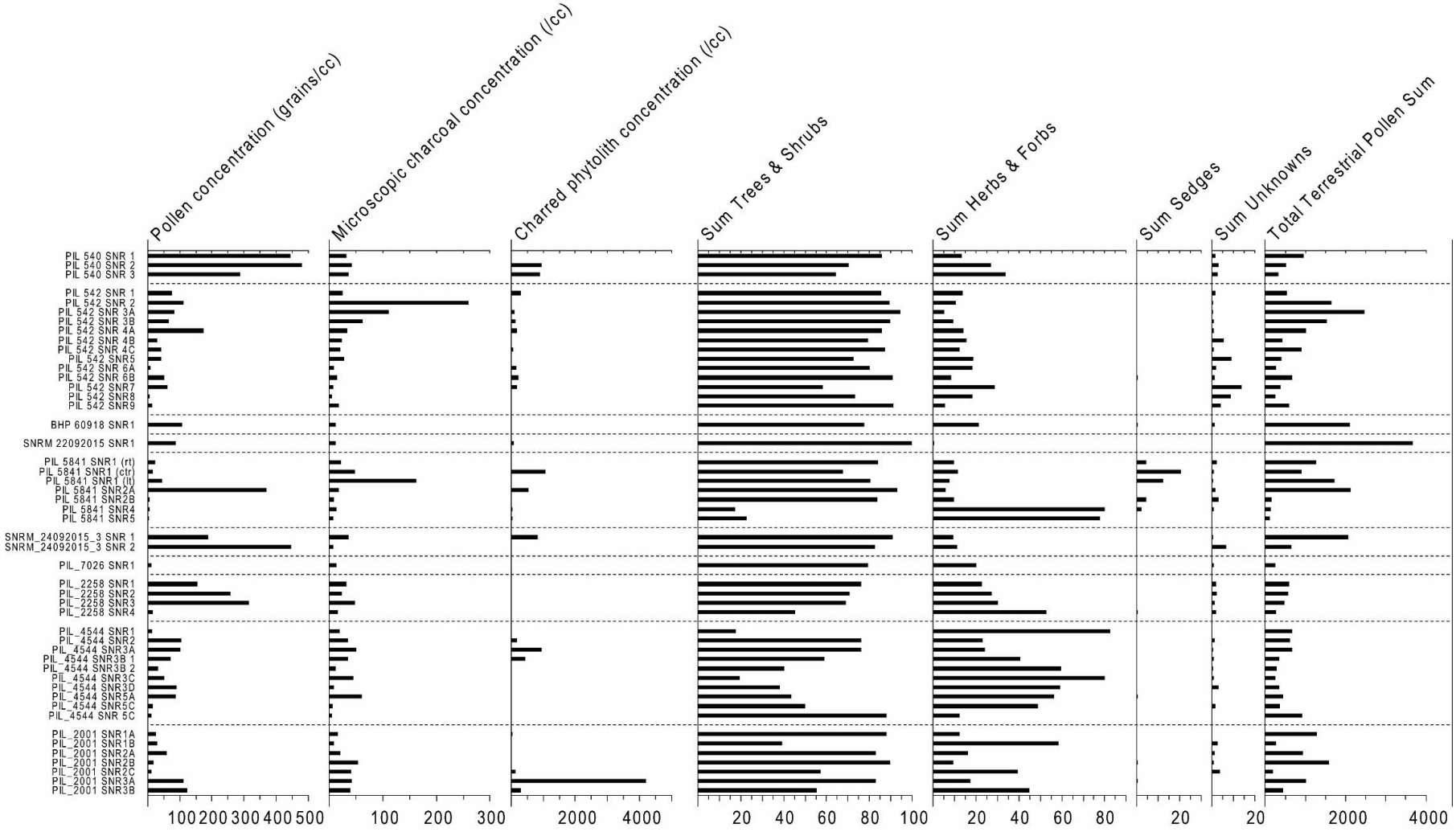

Figure 4c. Pollen, micro-charcoal and charred phytolith concentration diagram for Stick-nest Rat midden samples in order of midden code (dotted line zones) and sample number. Pollen sums for key taxa groupings are also illustrated. Pollen percentage based on total pollen sum.

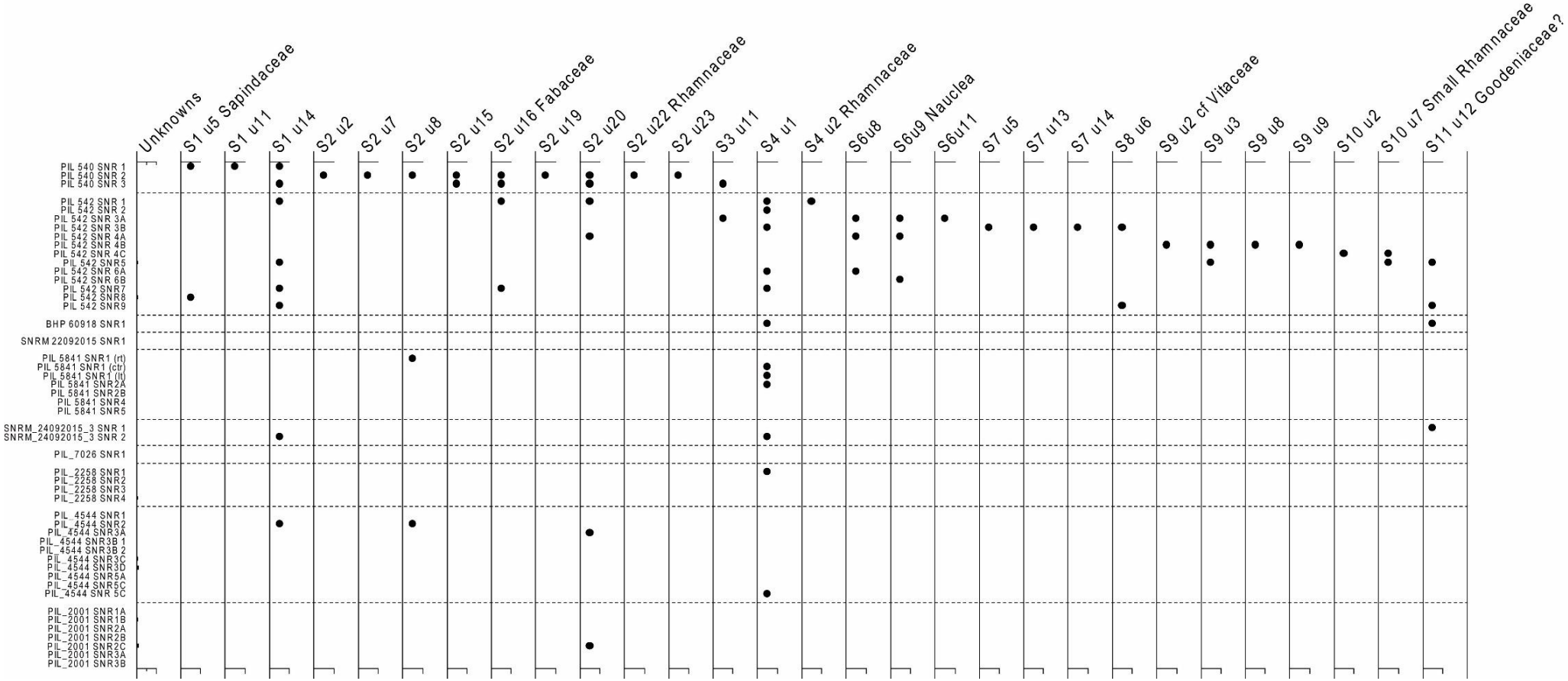

Figure 4d. Rare unidentified (morphological classification) pollen diagram for Stick-nest Rat midden samples in order of midden code (dotted line zones) and sample number. Presence of pollen taxa indicated by black dot.

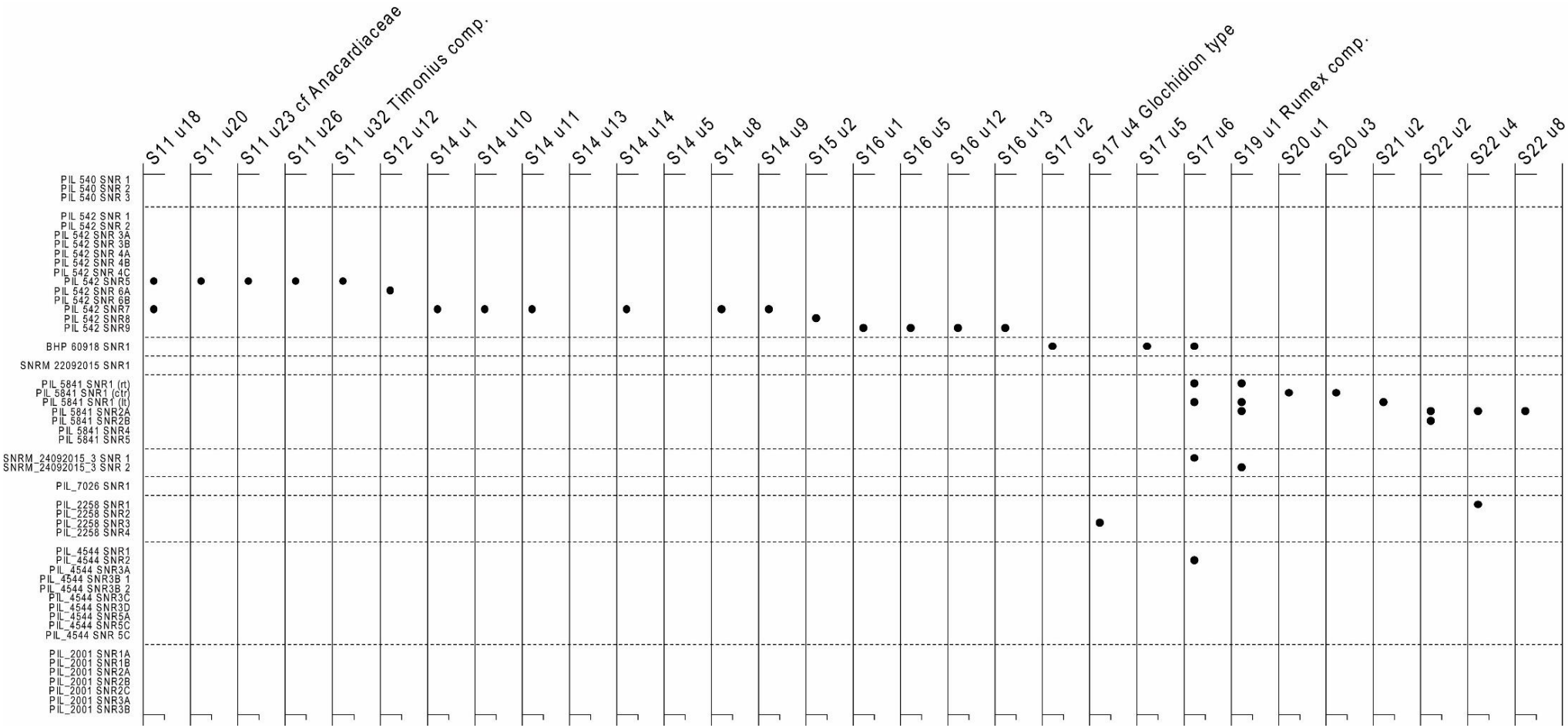

Figure 4e. Rare unidentified (morphological classification) pollen diagram for Stick-nest Rat midden samples in order of midden code (dotted line zones) and sample number. Presence of pollen taxa indicated by black dot.

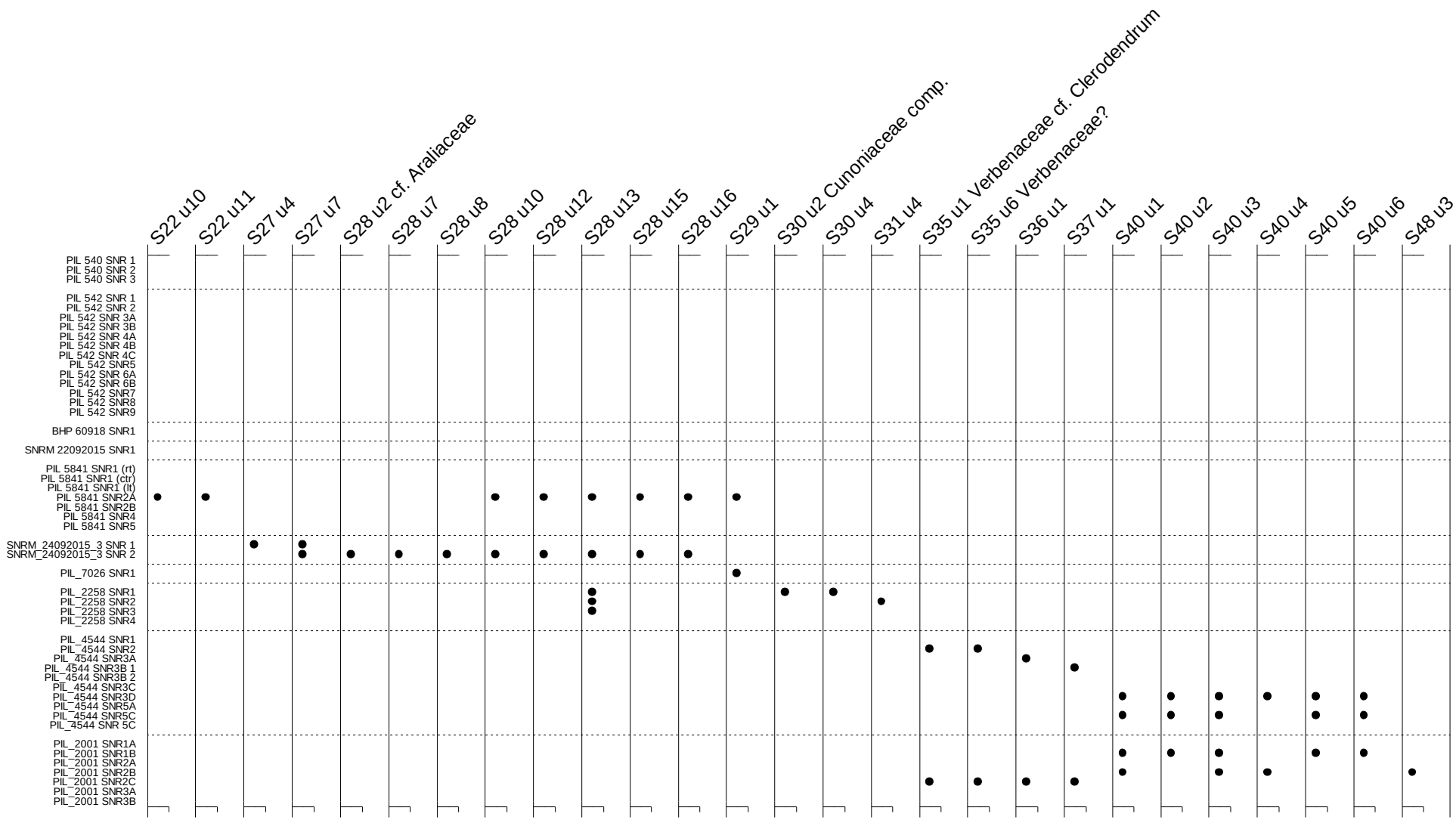

Figure 4f. Rare unidentified (morphological classification) pollen diagram for Stick-nest Rat midden samples in order of midden code (dotted line zones) and sample number. Presence of pollen taxa indicated by black dot.

Appendix 1: Raw Data Tables: Pollen and Charcoal Counts for Key Pollen Taxa and Rare Taxa.

	PIL 540 SNR 1	PIL 540 SNR 2	PIL 540 SNR 3	PIL 542 SNR 1	PIL 542 SNR 2	PIL 542 SNR 3A	PIL 542 SNR 3B	PIL 542 SNR 4A	PIL 542 SNR 4B
Microscopic charcoal concentration (/cc)	304495	418211	352425	239649	2593848	1098156	611105	321412	229499
Charred phytolith concentration (/cc)	0	940	881	282	0	102	128	171	0
Pollen concentration (grains/cc)	442646	479298	288107	75137	111407	82820	64291	172069	29815
Microscopic charcoal	644	446	400	1700	37904	32406	14306	1881	1750
Charred phytolith	0	1	1	2	0	3	3	1	0
Spike	12	5	8	50	103	208	132	33	43
Acacia	3	4	3	14	1	9	8	7	81
cf. Astrolicha	0	0	0	1	0	0	0	0	0
Callitris	0	0	0	0	0	0	0	1	0
Casuarina	2	0	0	0	0	3	0	1	0
cf. Coprosma	0	0	0	0	0	0	0	0	0
Myrtaceae Type 1	775	331	191	217	766	547	495	566	125
Myrtaceae Type 2	15	10	9	113	608	1664	842	273	91
Myrtaceae Type 3	1	0	0	95	72	74	12	15	18
Dodonaea	5	0	1	13	10	13	1	0	4
Ericaceae	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	0	0	0	3	7	6	2	9
Ficus	0	0	0	0	0	0	0	0	0
Grevillea/Hakea	0	1	0	0	0	0	0	0	0
Gyrostemon	1	2	0	0	0	0	1	1	1
Loranthaceae	0	0	0	0	0	4	0	2	0
Malvaceae	0	2	0	0	0	0	0	0	0
S15 u1 cf. Polygalaceae	0	0	0	0	0	0	0	0	0
Rhamnaceae	0	0	0	0	0	0	0	0	0
Solanum type	0	0	0	0	0	0	0	0	0
Rubiaceae cf. Timonius	2	4	0	1	0	0	0	0	3
Triumfetta	0	0	1	0	0	0	1	2	0
Amaranthaceae	7	21	31	5	11	17	13	21	3
cf. Gomphrena	0	0	0	0	1	0	0	0	0
Asteraceae t-type	12	21	20	24	8	39	33	5	6
Brassicaceae	2	0	0	0	0	1	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0	0
Haloragaceae	0	0	0	0	0	0	0	0	1
cf. Liliaceae	0	0	0	0	0	0	0	0	0
Pimelea	0	0	0	1	0	1	0	0	0
Poaceae	101	93	55	41	150	65	95	113	53
Trichodesma	1	0	1	0	0	0	0	0	0
cf. Tribulus	0	0	0	0	0	0	0	0	0
Cyperaceae	0	0	0	0	0	0	0	0	0
Monolete Spore	0	0	0	1	0	0	0	0	0
Pteridaceae cf. Cheilanthes	0	0	0	0	0	0	0	0	57
Indeterminate	4	7	0	1	2	7	4	0	23
Sum Trees & Shrubs	804	354	205	454	1457	2314	1360	868	323
Sum Herbs & Forbs	122	135	107	71	170	123	141	139	63
Sum Sedges	0	0	0	0	0	0	0	0	0
Sum Unknowns	14	15	8	8	5	13	14	7	22
Total Terrestrial Pollen Sum	940	504	320	533	1632	2450	1515	1014	408

	PIL 542 SNR 4C	PIL 542 SNR5	PIL 542 SNR 6A	PIL 542 SNR 6B	PIL 542 SNR7	PIL 542 SNR8	PIL 542 SNR9	BHP 60918 SNR1	SNRM 22092015 SNR1
Microscopic charcoal concentration (/cc)	196653	269958	76124	135895	66538	45580	165781	117287	110520
Charred phytolith concentration (/cc)	46	0	138	229	176	0	0	0	71
Pollen concentration (grains/cc)	41139	41151	7296	50521	59736	5306	13439	105274	86985
Microscopic charcoal	4269	2604	2761	1783	379	2027	7047	2330	4645
Charred phytolith	1	0	5	3	1	0	0	0	3
Spike	153	68	256	74	32	418	240	112	237
Acacia	18	36	78	43	22	0	19	5	0
cf. Astrolicha	0	0	0	0	0	0	0	0	0
Callitris	0	0	0	52	0	0	0	10	0
Casuarina	1	0	0	0	0	0	0	0	0
cf. Coprosma	0	0	0	0	0	0	0	0	0
Myrtaceae Type 1	29	180	35	83	100	15	473	1490	2441
Myrtaceae Type 2	581	35	78	385	66	73	22	56	1114
Myrtaceae Type 3	132	15	7	32	5	16	7	1	74
Dodonaea	7	3	1	3	8	13	3	42	1
Ericaceae	0	0	0	0	0	0	0	0	0
Euphorbiaceae	1	12	1	5	1	2	6	0	1
Ficus	0	0	0	0	0	0	0	9	0
Grevillea/Hakea	0	0	0	0	3	0	0	0	0
Gyrostemon	3	4	3	1	0	4	5	6	13
Loranthaceae	10	7	0	3	0	1	0	0	0
Malvaceae	0	1	1	0	0	0	1	0	0
S15 u1 cf. Polygalaceae	0	0	0	0	0	47	0	0	0
Rhamnaceae	0	2	1	0	0	1	2	2	1
Solanum type	0	2	6	0	0	0	0	0	0
Rubiaceae cf. Timonius	1	3	0	0	13	0	6	9	0
Triumfetta	0	0	1	0	0	0	0	0	1
Amaranthaceae	11	5	3	5	7	12	2	20	3
cf. Gomphrena	0	0	0	0	0	0	0	0	0
Asteraceae t-type	31	2	6	5	4	10	7	19	0
Brassicaceae	0	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	5	0	0	0	0
Haloragaceae	0	0	0	0	0	0	0	1	0
cf. Liliaceae	0	0	0	0	0	0	0	0	0
Pimelea	0	0	0	0	0	0	0	0	0
Poaceae	67	67	39	43	91	19	21	403	6
Trichodesma	0	0	0	0	0	0	0	0	0
cf. Tribulus	0	0	0	0	0	1	0	0	0
Cyperaceae	0	0	0	1	0	0	0	2	0
Monolete Spore	0	0	2	0	0	0	0	0	0
Pteridaceae cf. Cheilanthes	1	16	0	0	8	0	0	0	23
Indeterminate	3	3	0	4	0	4	2	1	1
Sum Trees & Shrubs	782	288	211	602	217	170	538	1630	3645
Sum Herbs & Forbs	109	74	48	53	107	42	30	443	9
Sum Sedges	0	0	0	1	0	0	0	2	0
Sum Unknowns	6	36	5	8	51	20	24	26	1
Total Terrestrial Pollen Sum	897	398	264	664	375	232	592	2101	3655

	PIL 5841 SNR1 (rt)	PIL 5841 SNR1 (ctr)	PIL 5841 SNR1 (lt)	PIL 5841 SNR2A	PIL 5841 SNR2B	PIL 5841 SNR4	PIL 5841 SNR5	SNRM_24092015_3 SNR 1	SNRM_24092015_3 SNR 2
Microscopic charcoal concentration (/cc)	209340	475539	1613167	162820	84582	120764	63906	348901	60617
Charred phytolith concentration (/cc)	0	1062	0	529	0	33	25	824	0
Pollen concentration (grains/cc)	23004	15933	43045	367755	6190	4466	2632	187746	444760
Microscopic charcoal	11375	26415	64203	924	1872	3624	2598	3812	86
Charred phytolith	0	59	0	3	0	1	1	9	0
Spike	383	261	187	40	156	141	191	77	10
Acacia	0	0	0	1	0	0	0	5	20
cf. Astrolicha	0	0	0	0	0	0	0	0	0
Callitris	0	0	0	0	0	0	0	0	0
Casuarina	0	0	0	0	0	0	0	4	1
cf. Coprosma	1	0	0	0	0	0	0	0	0
Myrtaceae Type 1	629	425	898	1688	79	10	11	1640	415
Myrtaceae Type 2	265	109	224	208	22	2	7	116	44
Myrtaceae Type 3	147	33	206	24	10	7	6	54	20
Dodonaea	3	31	38	8	0	4	0	30	7
Ericaceae	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	2	0	1	0	1	0	0	0
Ficus	0	0	0	0	0	0	0	0	0
Grevillea/Hakea	0	0	1	2	0	0	0	0	0
Gyrostemon	0	0	0	2	0	0	0	2	0
Loranthaceae	0	0	0	0	0	0	0	0	1
Malvaceae	0	0	0	9	0	0	0	2	1
S15 u1 cf. Polygalaceae	0	0	0	0	0	0	0	0	0
Rhamnaceae	2	0	0	0	0	0	0	2	0
Solanum type	1	2	0	10	4	0	0	3	0
Rubiaceae cf. Timonius	0	0	0	0	0	0	0	1	7
Triumfetta	0	0	0	3	0	0	0	1	15
Amaranthaceae	40	6	1	11	0	0	0	19	0
cf. Gomphrena	0	0	0	0	0	0	0	0	0
Asteraceae t-type	2	6	0	8	0	0	0	8	2
Brassicaceae	0	0	0	1	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0	0
Haloragaceae	0	0	0	0	0	0	0	0	0
cf. Liliaceae	1	0	0	0	0	0	0	0	0
Pimelea	0	0	4	0	0	1	0	0	0
Poaceae	75	90	72	98	13	106	83	162	68
Trichodesma	2	0	46	3	0	0	0	0	0
cf. Tribulus	0	0	0	0	0	0	0	0	0
Cyperaceae	54	183	206	1	6	3	0	0	0
Monolete Spore	0	0	0	0	0	0	0	0	0
Pteridaceae cf. Cheilanthes	1	0	0	0	0	0	0	0	0
Indeterminate	0	2	13	1	3	1	0	2	2
Sum Trees & Shrubs	1048	600	1367	1955	115	23	24	1860	531
Sum Herbs & Forbs	120	102	123	121	13	107	83	189	70
Sum Sedges	54	183	206	1	6	3	0	0	0
Sum Unknowns	27	6	7	30	4	1	0	6	43
Total Terrestrial Pollen Sum	1249	891	1703	2107	138	134	107	2055	644

	PIL_7026 SNR1	PIL_2258 SNR1	PIL_2258 SNR2	PIL_2258 SNR3	PIL_2258 SNR4	PIL_4544 SNR1	PIL_4544 SNR2	PIL_4544 SNR3A	PIL_4544 SNR3B 1
Microscopic charcoal concentration (/cc)	123584	312249	222263	462382	157886	176213	335509	492187	338328
Charred phytolith concentration (/cc)	0	0	0	0	0	0	174	929	424
Pollen concentration (grains/cc)	8872	152718	257035	313490	15297	12055	102682	101622	70803
Microscopic charcoal	3524	1196	473	689	2632	9762	1928	3177	1596
Charred phytolith	0	0	0	0	0	0	1	6	2
Spike	268	27	10	7	94	260	54	26	19
Acacia	0	4	0	2	0	0	5	0	0
cf. Astrolicha	0	0	5	0	3	0	0	0	0
Callitris	0	0	0	0	0	0	0	0	0
Casuarina	1	0	0	0	0	2	0	0	0
cf. Coprosma	0	0	0	0	0	0	0	0	0
Myrtaceae Type 1	130	354	320	276	0	70	405	427	160
Myrtaceae Type 2	9	51	27	18	77	7	22	60	6
Myrtaceae Type 3	2	5	0	1	9	26	4	8	2
Dodonaea	31	17	21	7	13	11	9	4	19
Ericaceae	1	0	0	0	0	0	0	0	0
Euphorbiaceae	0	0	1	0	1	0	0	0	0
Ficus	0	0	0	0	0	0	0	0	0
Grevillea/Hakea	6	1	0	2	0	0	0	1	1
Gyrostemon	9	0	0	2	1	0	0	0	0
Loranthaceae	0	0	0	0	0	0	0	0	0
Malvaceae	1	6	13	10	9	0	10	0	2
S15 u1 cf. Polygalaceae	0	0	0	0	0	0	0	0	0
Rhamnaceae	0	1	0	0	0	0	1	0	2
Solanum type	1	1	0	3	1	0	0	0	1
Rubiaceae cf. Timonius	1	3	7	4	3	0	0	0	2
Triumfetta	0	2	1	0	0	0	0	0	1
Amaranthaceae	35	25	21	8	11	15	18	16	17
cf. Gomphrena	0	1	0	0	0	0	0	0	0
Asteraceae t-type	11	24	9	15	29	20	24	11	15
Brassicaceae	0	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	1	0	0
Haloragaceae	2	0	0	0	0	0	1	0	1
cf. Liliaceae	0	0	0	0	0	0	0	0	0
Pimelea	0	0	0	0	0	0	0	0	0
Poaceae	0	82	121	117	94	513	90	129	102
Trichodesma	0	0	1	1	1	0	0	0	0
cf. Tribulus	0	0	0	0	0	0	0	0	0
Cyperaceae	0	0	0	0	1	0	0	0	0
Monolete Spore	0	0	0	0	0	0	0	0	0
Pteridaceae cf. Cheilanthes	4	0	0	0	0	0	0	0	0
Indeterminate	13	7	0	1	3	3	3	0	3
Sum Trees & Shrubs	192	445	394	325	116	116	453	500	196
Sum Herbs & Forbs	48	132	152	141	135	548	137	156	135
Sum Sedges	0	0	0	0	1	0	0	0	0
Sum Unknowns	2	10	12	6	5	1	7	2	3
Total Terrestrial Pollen Sum	242	587	558	472	257	665	597	658	334

	PIL_4544 SNR3B 2	PIL_4544 SNR3C	PIL_4544 SNR3D	PIL_4544 SNR5A	PIL_4544 SNR5C	PIL_4544 SNR 5C	PIL_2001 SNR1A	PIL_2001 SNR1B	PIL_2001 SNR2A
Microscopic charcoal concentration (/cc)	110690	437007	82702	593484	46802	41546	156477	83454	192847
Charred phytolith concentration (/cc)	0	0	0	0	0	0	19	0	0
Pollen concentration (grains/cc)	31511	50055	89684	85953	14421	11137	24240	29690	57012
Microscopic charcoal	1001	2139	317	1533	1155	1191	8192	725	3092
Charred phytolith	0	0	0	0	0	0	1	0	0
Spike	51	23	35	36	174	202	369	49	113
Acacia	1	0	2	0	0	0	2	0	1
cf. Astrolicha	0	0	0	0	0	0	0	0	1
Callitris	0	0	0	0	0	0	0	0	0
Casuarina	0	0	2	0	0	0	0	0	1
cf. Coprosma	0	0	0	0	0	0	0	0	0
Myrtaceae Type 1	32	5	62	167	87	545	628	0	565
Myrtaceae Type 2	60	23	4	14	52	202	74	78	154
Myrtaceae Type 3	5	2	7	7	4	3	406	10	31
Dodonaea	3	13	31	2	30	45	3	13	6
Ericaceae	0	0	0	0	0	0	0	0	0
Euphorbiaceae	0	0	0	0	0	0	0	0	1
Ficus	0	0	0	0	0	0	0	0	0
Grevillea/Hakea	0	0	1	0	0	1	0	0	0
Gyrostemon	0	0	10	0	2	2	0	1	0
Loranthaceae	0	0	0	0	0	0	0	0	0
Malvaceae	3	4	9	0	6	6	3	2	4
S15 u1 cf. Polygalaceae	0	0	0	0	0	0	0	0	0
Rhamnaceae	0	0	1	0	1	0	0	0	0
Solanum type	11	0	0	1	0	0	0	0	0
Rubiaceae cf. Timonius	0	1	0	0	0	0	0	0	8
Triumfetta	0	0	3	0	0	0	0	0	0
Amaranthaceae	11	16	21	24	16	12	1	3	6
cf. Gomphrena	0	0	0	0	0	0	0	0	0
Asteraceae t-type	3	5	24	0	33	21	9	2	6
Brassicaceae	0	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	1	0	0	1	3
Haloragaceae	0	0	0	0	3	2	0	0	0
cf. Liliaceae	0	0	0	0	0	0	0	0	0
Pimelea	0	0	0	0	0	0	0	0	0
Poaceae	148	176	154	222	119	77	144	146	131
Trichodesma	7	0	0	0	2	0	0	0	0
cf. Tribulus	1	0	0	0	0	0	0	0	0
Cyperaceae	0	0	0	1	0	0	0	0	0
Monolete Spore	0	0	0	0	0	0	1	0	0
Pteridaceae cf. Cheilanthes	0	0	0	0	7	1	2	0	1
Indeterminate	0	0	0	0	1	0	0	0	0
Sum Trees & Shrubs	115	48	130	191	180	804	1115	103	768
Sum Herbs & Forbs	170	197	201	246	176	112	155	153	149
Sum Sedges	0	0	0	1	0	0	0	0	0
Sum Unknowns	1	2	10	1	5	1	0	7	9
Total Terrestrial Pollen Sum	286	247	341	439	361	917	1270	263	926

	PIL_2001 SNR2B	PIL_2001 SNR2C	PIL_2001 SNR3A	PIL_2001 SNR3B
Microscopic charcoal concentration (/cc)	523281	399227	408108	384566
Charred phytolith concentration (/cc)	0	116	4185	282
Pollen concentration (grains/cc)	17450	10987	110243	121516
Microscopic charcoal	47050	6868	3706	1364
Charred phytolith	0	2	38	1
Spike	507	97	64	20
Acacia	7	0	1	1
cf. Astrolicha	3	0	0	0
Callitris	0	6	0	0
Casuarina	0	5	0	2
cf. Coprosma	0	0	0	0
Myrtaceae Type 1	1093	39	557	192
Myrtaceae Type 2	169	43	179	22
Myrtaceae Type 3	101	10	90	16
Dodonaea	21	4	0	5
Ericaceae	0	0	0	0
Euphorbiaceae	0	0	0	0
Ficus	0	0	0	0
Grevillea/Hakea	0	0	0	0
Gyrostemon	0	0	1	0
Loranthaceae	1	0	0	0
Malvaceae	3	0	3	0
S15 u1 cf. Polygalaceae	0	0	0	0
Rhamnaceae	0	0	0	0
Solanum type	9	1	0	0
Rubiaceae cf. Timonius	8	0	1	0
Triumfetta	0	0	0	0
Amaranthaceae	7	2	0	1
cf. Gomphrena	0	0	0	0
Asteraceae t-type	14	2	2	4
Brassicaceae	0	0	0	0
Convolvulaceae	0	0	0	0
Haloragaceae	1	0	0	0
cf. Liliaceae	0	0	0	0
Pimelea	0	0	0	0
Poaceae	123	71	167	188
Trichodesma	0	0	0	0
cf. Tribulus	0	0	0	0
Cyperaceae	4	0	1	0
Monolete Spore	0	1	0	0
Pteridaceae cf. Cheilanthes	0	1	2	0
Indeterminate	0	3	0	0
Sum Trees & Shrubs	1415	108	831	238
Sum Herbs & Forbs	145	75	170	193
Sum Sedges	4	0	1	0
Sum Unknowns	15	7	1	0
Total Terrestrial Pollen Sum	1579	190	1003	431

	PIL 540 SNR 1	PIL 540 SNR 2	PIL 540 SNR 3	PIL 542 SNR 1	PIL 542 SNR 2	PIL 542 SNR 3A	PIL 542 SNR 3B	PIL 542 SNR 4A	PIL 542 SNR 4B
Unknowns (other)	0	0	0	0	0	0	0	0	1
S1 u5 Sapindaceae	9	0	0	0	0	0	0	0	0
S1 u11	1	0	0	0	0	0	0	0	0
S1 u14	1	0	1	1	0	0	0	0	0
S2 u2	0	2	0	0	0	0	0	0	0
S2 u7	0	1	0	0	0	0	0	0	0
S2 u8	0	1	0	0	0	0	0	0	0
S2 u15	0	1	1	0	0	0	0	0	0
S2 u16 Fabaceae	0	1	4	1	0	0	0	0	0
S2 u19	0	1	0	0	0	0	0	0	0
S2 u20	0	1	1	2	0	0	0	2	0
S2 u22 Rhamnaceae	0	2	0	0	0	0	0	0	0
S2 u23	0	1	0	0	0	0	0	0	0
S3 u11	0	0	1	0	0	1	0	0	0
S4 u1	0	0	0	2	2	0	3	0	0
S4 u2 Rhamnaceae	0	0	0	1	0	0	0	0	0
S6u8	0	0	0	0	0	2	0	1	0
S6u9 Nauclea	0	0	0	0	0	1	0	2	0
S6u11	0	0	0	0	0	2	0	0	0
S7 u5	0	0	0	0	0	0	1	0	0
S7 u13	0	0	0	0	0	0	1	0	0
S7 u14	0	0	0	0	0	0	1	0	0
S8 u6	0	0	0	0	0	0	2	0	0
S9 u2 cf Vitaceae	0	0	0	0	0	0	0	0	2
S9 u3	0	0	0	0	0	0	0	0	4
S9 u8	0	0	0	0	0	0	0	0	1
S9 u9	0	0	0	0	0	0	0	0	2
S10 u2	0	0	0	0	0	0	0	0	0
S10 u7 Small Rhamnaceae	0	0	0	0	0	0	0	0	0
S11 u12 Goodeniaceae?	0	0	0	0	0	0	0	0	0
S11 u18	0	0	0	0	0	0	0	0	0
S11 u20	0	0	0	0	0	0	0	0	0
S11 u23 cf Anacardiaceae	0	0	0	0	0	0	0	0	0
S11 u26	0	0	0	0	0	0	0	0	0
S11 u32 Timonius comp.	0	0	0	0	0	0	0	0	0
S12 u12	0	0	0	0	0	0	0	0	0
S14 u1	0	0	0	0	0	0	0	0	0
S14 u10	0	0	0	0	0	0	0	0	0
S14 u11	0	0	0	0	0	0	0	0	0
S14 u13	0	0	0	0	0	0	0	0	0
S14 u14	0	0	0	0	0	0	0	0	0
S14 u5	0	0	0	0	0	0	0	0	0
S14 u8	0	0	0	0	0	0	0	0	0
S14 u9	0	0	0	0	0	0	0	0	0
S15 u2	0	0	0	0	0	0	0	0	0
S16 u1	0	0	0	0	0	0	0	0	0
S16 u5	0	0	0	0	0	0	0	0	0
S16 u12	0	0	0	0	0	0	0	0	0
S16 u13	0	0	0	0	0	0	0	0	0

	PIL 542 SNR 4C	PIL 542 SNR5	PIL 542 SNR 6A	PIL 542 SNR 6B	PIL 542 SNR7	PIL 542 SNR8	PIL 542 SNR9	BHP 60918 SNR1	SNRM 22092015 SNR1
Unknowns (other)	1	2	0	2	1	1	2	0	0
S1 u5 Sapindaceae	0	0	0	0	0	16	0	0	0
S1 u11	0	0	0	0	0	0	0	0	0
S1 u14	0	2	0	0	3	0	1	0	0
S2 u2	0	0	0	0	0	0	0	0	0
S2 u7	0	0	0	0	0	0	0	0	0
S2 u8	0	0	0	0	0	0	0	0	0
S2 u15	0	0	0	0	0	0	0	0	0
S2 u16 Fabaceae	0	0	0	0	7	0	0	0	0
S2 u19	0	0	0	0	0	0	0	0	0
S2 u20	0	0	0	0	0	0	0	0	0
S2 u22 Rhamnaceae	0	0	0	0	0	0	0	0	0
S2 u23	0	0	0	0	0	0	0	0	0
S3 u11	0	0	0	0	0	0	0	0	0
S4 u1	0	0	2	0	2	0	0	1	0
S4 u2 Rhamnaceae	0	0	0	0	0	0	0	0	0
S6u8	0	0	1	0	0	0	0	0	0
S6u9 Nauclea	0	0	0	1	0	0	0	0	0
S6u11	0	0	0	0	0	0	0	0	0
S7 u5	0	0	0	0	0	0	0	0	0
S7 u13	0	0	0	0	0	0	0	0	0
S7 u14	0	0	0	0	0	0	0	0	0
S8 u6	0	0	0	0	0	0	1	0	0
S9 u2 cf Vitaceae	0	0	0	0	0	0	0	0	0
S9 u3	0	2	0	0	0	0	0	0	0
S9 u8	0	0	0	0	0	0	0	0	0
S9 u9	0	0	0	0	0	0	0	0	0
S10 u2	2	0	0	0	0	0	0	0	0
S10 u7 Small Rhamnaceae	1	3	0	0	0	0	0	0	0
S11 u12 Goodeniaceae?	0	1	0	0	0	0	1	1	0
S11 u18	0	4	0	0	1	0	0	0	0
S11 u20	0	1	0	0	0	0	0	0	0
S11 u23 cf Anacardiaceae	0	1	0	0	0	0	0	0	0
S11 u26	0	1	0	0	0	0	0	0	0
S11 u32 Timonius comp.	0	4	0	0	0	0	0	0	0
S12 u12	0	0	1	0	0	0	0	0	0
S14 u1	0	0	0	0	2	0	0	0	0
S14 u10	0	0	0	0	7	0	0	0	0
S14 u11	0	0	0	0	3	0	0	0	0
S14 u13	0	0	0	0	0	0	0	0	0
S14 u14	0	0	0	0	3	0	0	0	0
S14 u5	0	0	0	0	0	0	0	0	0
S14 u8	0	0	0	0	3	0	0	0	0
S14 u9	0	0	0	0	5	0	0	0	0
S15 u2	0	0	0	0	0	1	0	0	0
S16 u1	0	0	0	0	0	0	3	0	0
S16 u5	0	0	0	0	0	0	1	0	0
S16 u12	0	0	0	0	0	0	2	0	0
S16 u13	0	0	0	0	0	0	1	0	0

	PIL 5841 SNR1 (rt)	PIL 5841 SNR1 (ctr)	PIL 5841 SNR1 (lt)	PIL 5841 SNR2A	PIL 5841 SNR2B	PIL 5841 SNR4	PIL 5841 SNR5	SNRM_24092015_3 SNR 1	SNRM_24092015_3 SNR 2
Unknowns (other)	0	0	1	1	0	0	0	0	0
S1 u5 Sapindaceae	0	0	0	0	0	0	0	0	0
S1 u11	0	0	0	0	0	0	0	0	0
S1 u14	0	0	0	0	0	0	0	0	1
S2 u2	0	0	0	0	0	0	0	0	0
S2 u7	0	0	0	0	0	0	0	0	0
S2 u8	4	0	0	0	0	0	0	0	0
S2 u15	0	0	0	0	0	0	0	0	0
S2 u16 Fabaceae	0	0	0	0	0	0	0	0	0
S2 u19	0	0	0	0	0	0	0	0	0
S2 u20	0	0	0	0	0	0	0	0	0
S2 u22 Rhamnaceae	0	0	0	0	0	0	0	0	0
S2 u23	0	0	0	0	0	0	0	0	0
S3 u11	0	0	0	0	0	0	0	0	0
S4 u1	0	1	1	1	0	0	0	0	3
S4 u2 Rhamnaceae	0	0	0	0	0	0	0	0	0
S6u8	0	0	0	0	0	0	0	0	0
S6u9 Nauclea	0	0	0	0	0	0	0	0	0
S6u11	0	0	0	0	0	0	0	0	0
S7 u5	0	0	0	0	0	0	0	0	0
S7 u13	0	0	0	0	0	0	0	0	0
S7 u14	0	0	0	0	0	0	0	0	0
S8 u6	0	0	0	0	0	0	0	0	0
S9 u2 cf Vitaceae	0	0	0	0	0	0	0	0	0
S9 u3	0	0	0	0	0	0	0	0	0
S9 u8	0	0	0	0	0	0	0	0	0
S9 u9	0	0	0	0	0	0	0	0	0
S10 u2	0	0	0	0	0	0	0	0	0
S10 u7 Small Rhamnaceae	0	0	0	0	0	0	0	0	0
S11 u12 Goodeniaceae?	0	0	0	0	0	0	0	2	0
S11 u18	0	0	0	0	0	0	0	0	0
S11 u20	0	0	0	0	0	0	0	0	0
S11 u23 cf Anacardiaceae	0	0	0	0	0	0	0	0	0
S11 u26	0	0	0	0	0	0	0	0	0
S11 u32 Timonius comp.	0	0	0	0	0	0	0	0	0
S12 u12	0	0	0	0	0	0	0	0	0
S14 u1	0	0	0	0	0	0	0	0	0
S14 u10	0	0	0	0	0	0	0	0	0
S14 u11	0	0	0	0	0	0	0	0	0
S14 u13	0	0	0	0	0	0	0	0	0
S14 u14	0	0	0	0	0	0	0	0	0
S14 u5	0	0	0	0	0	0	0	0	0
S14 u8	0	0	0	0	0	0	0	0	0
S14 u9	0	0	0	0	0	0	0	0	0
S15 u2	0	0	0	0	0	0	0	0	0
S16 u1	0	0	0	0	0	0	0	0	0
S16 u5	0	0	0	0	0	0	0	0	0
S16 u12	0	0	0	0	0	0	0	0	0
S16 u13	0	0	0	0	0	0	0	0	0

	PIL_7026 SNR1	PIL_2258 SNR1	PIL_2258 SNR2	PIL_2258 SNR3	PIL_2258 SNR4	PIL_4544 SNR1	PIL_4544 SNR2	PIL_4544 SNR3A	PIL_4544 SNR3B 1
Unknowns (other)	0	1	1	0	1	1	1	0	0
S1 u5 Sapindaceae	0	0	0	0	0	0	0	0	0
S1 u11	0	0	0	0	0	0	0	0	0
S1 u14	0	0	0	0	0	0	1	0	0
S2 u2	0	0	0	0	0	0	0	0	0
S2 u7	0	0	0	0	0	0	0	0	0
S2 u8	0	0	0	0	0	0	1	0	0
S2 u15	0	0	0	0	0	0	0	0	0
S2 u16 Fabaceae	0	0	0	0	0	0	0	0	0
S2 u19	0	0	0	0	0	0	0	0	0
S2 u20	0	0	0	0	0	0	0	1	0
S2 u22 Rhamnaceae	0	0	0	0	0	0	0	0	0
S2 u23	0	0	0	0	0	0	0	0	0
S3 u11	0	0	0	0	0	0	0	0	0
S4 u1	0	1	0	0	0	0	0	0	0
S4 u2 Rhamnaceae	0	0	0	0	0	0	0	0	0
S6u8	0	0	0	0	0	0	0	0	0
S6u9 Nauclea	0	0	0	0	0	0	0	0	0
S6u11	0	0	0	0	0	0	0	0	0
S7 u5	0	0	0	0	0	0	0	0	0
S7 u13	0	0	0	0	0	0	0	0	0
S7 u14	0	0	0	0	0	0	0	0	0
S8 u6	0	0	0	0	0	0	0	0	0
S9 u2 cf Vitaceae	0	0	0	0	0	0	0	0	0
S9 u3	0	0	0	0	0	0	0	0	0
S9 u8	0	0	0	0	0	0	0	0	0
S9 u9	0	0	0	0	0	0	0	0	0
S10 u2	0	0	0	0	0	0	0	0	0
S10 u7 Small Rhamnaceae	0	0	0	0	0	0	0	0	0
S11 u12 Goodeniaceae?	0	0	0	0	0	0	0	0	0
S11 u18	0	0	0	0	0	0	0	0	0
S11 u20	0	0	0	0	0	0	0	0	0
S11 u23 cf Anacardiaceae	0	0	0	0	0	0	0	0	0
S11 u26	0	0	0	0	0	0	0	0	0
S11 u32 Timonius comp.	0	0	0	0	0	0	0	0	0
S12 u12	0	0	0	0	0	0	0	0	0
S14 u1	0	0	0	0	0	0	0	0	0
S14 u10	0	0	0	0	0	0	0	0	0
S14 u11	0	0	0	0	0	0	0	0	0
S14 u13	0	0	0	0	0	0	0	0	0
S14 u14	0	0	0	0	0	0	0	0	0
S14 u5	0	0	0	0	0	0	0	0	0
S14 u8	0	0	0	0	0	0	0	0	0
S14 u9	0	0	0	0	0	0	0	0	0
S15 u2	0	0	0	0	0	0	0	0	0
S16 u1	0	0	0	0	0	0	0	0	0
S16 u5	0	0	0	0	0	0	0	0	0
S16 u12	0	0	0	0	0	0	0	0	0
S16 u13	0	0	0	0	0	0	0	0	0

	PIL_4544 SNR3B 2	PIL_4544 SNR3C	PIL_4544 SNR3D	PIL_4544 SNR5A	PIL_4544 SNR5C	PIL_4544 SNR 5C	PIL_2001 SNR1A	PIL_2001 SNR1B	PIL_2001 SNR2A
Unknowns (other)	1	1	3	1	0	0	0	2	0
S1 u5 Sapindaceae	0	0	0	0	0	0	0	0	0
S1 u11	0	0	0	0	0	0	0	0	0
S1 u14	0	0	0	0	0	0	0	0	0
S2 u2	0	0	0	0	0	0	0	0	0
S2 u7	0	0	0	0	0	0	0	0	0
S2 u8	0	0	0	0	0	0	0	0	0
S2 u15	0	0	0	0	0	0	0	0	0
S2 u16 Fabaceae	0	0	0	0	0	0	0	0	0
S2 u19	0	0	0	0	0	0	0	0	0
S2 u20	0	0	0	0	0	0	0	0	0
S2 u22 Rhamnaceae	0	0	0	0	0	0	0	0	0
S2 u23	0	0	0	0	0	0	0	0	0
S3 u11	0	0	0	0	0	0	0	0	0
S4 u1	0	0	0	0	0	1	0	0	0
S4 u2 Rhamnaceae	0	0	0	0	0	0	0	0	0
S6u8	0	0	0	0	0	0	0	0	0
S6u9 Nauclea	0	0	0	0	0	0	0	0	0
S6u11	0	0	0	0	0	0	0	0	0
S7 u5	0	0	0	0	0	0	0	0	0
S7 u13	0	0	0	0	0	0	0	0	0
S7 u14	0	0	0	0	0	0	0	0	0
S8 u6	0	0	0	0	0	0	0	0	0
S9 u2 cf Vitaceae	0	0	0	0	0	0	0	0	0
S9 u3	0	0	0	0	0	0	0	0	0
S9 u8	0	0	0	0	0	0	0	0	0
S9 u9	0	0	0	0	0	0	0	0	0
S10 u2	0	0	0	0	0	0	0	0	0
S10 u7 Small Rhamnaceae	0	0	0	0	0	0	0	0	0
S11 u12 Goodeniaceae?	0	0	0	0	0	0	0	0	0
S11 u18	0	0	0	0	0	0	0	0	0
S11 u20	0	0	0	0	0	0	0	0	0
S11 u23 cf Anacardiaceae	0	0	0	0	0	0	0	0	0
S11 u26	0	0	0	0	0	0	0	0	0
S11 u32 Timonius comp.	0	0	0	0	0	0	0	0	0
S12 u12	0	0	0	0	0	0	0	0	0
S14 u1	0	0	0	0	0	0	0	0	0
S14 u10	0	0	0	0	0	0	0	0	0
S14 u11	0	0	0	0	0	0	0	0	0
S14 u13	0	0	0	0	0	0	0	0	0
S14 u14	0	0	0	0	0	0	0	0	0
S14 u5	0	0	0	0	0	0	0	0	0
S14 u8	0	0	0	0	0	0	0	0	0
S14 u9	0	0	0	0	0	0	0	0	0
S15 u2	0	0	0	0	0	0	0	0	0
S16 u1	0	0	0	0	0	0	0	0	0
S16 u5	0	0	0	0	0	0	0	0	0
S16 u12	0	0	0	0	0	0	0	0	0
S16 u13	0	0	0	0	0	0	0	0	0

	PIL_2001 SNR2B	PIL_2001 SNR2C	PIL_2001 SNR3A	PIL_2001 SNR3B
Unknowns (other)	3	2	0	0
S1 u5 Sapindaceae	0	0	0	0
S1 u11	0	0	0	0
S1 u14	0	0	0	0
S2 u2	0	0	0	0
S2 u7	0	0	0	0
S2 u8	0	0	0	0
S2 u15	0	0	0	0
S2 u16 Fabaceae	0	0	0	0
S2 u19	0	0	0	0
S2 u20	0	1	0	0
S2 u22 Rhamnaceae	0	0	0	0
S2 u23	0	0	0	0
S3 u11	0	0	0	0
S4 u1	0	0	0	0
S4 u2 Rhamnaceae	0	0	0	0
S6u8	0	0	0	0
S6u9 Nauclea	0	0	0	0
S6u11	0	0	0	0
S7 u5	0	0	0	0
S7 u13	0	0	0	0
S7 u14	0	0	0	0
S8 u6	0	0	0	0
S9 u2 cf Vitaceae	0	0	0	0
S9 u3	0	0	0	0
S9 u8	0	0	0	0
S9 u9	0	0	0	0
S10 u2	0	0	0	0
S10 u7 Small Rhamnaceae	0	0	0	0
S11 u12 Goodeniaceae?	0	0	0	0
S11 u18	0	0	0	0
S11 u20	0	0	0	0
S11 u23 cf Anacardiaceae	0	0	0	0
S11 u26	0	0	0	0
S11 u32 Timonius comp.	0	0	0	0
S12 u12	0	0	0	0
S14 u1	0	0	0	0
S14 u10	0	0	0	0
S14 u11	0	0	0	0
S14 u13	0	0	0	0
S14 u14	0	0	0	0
S14 u5	0	0	0	0
S14 u8	0	0	0	0
S14 u9	0	0	0	0
S15 u2	0	0	0	0
S16 u1	0	0	0	0
S16 u5	0	0	0	0
S16 u12	0	0	0	0
S16 u13	0	0	0	0

	PIL 540 SNR 1	PIL 540 SNR 2	PIL 540 SNR 3	PIL 542 SNR 1	PIL 542 SNR 2	PIL 542 SNR 3A	PIL 542 SNR 3B	PIL 542 SNR 4A	PIL 542 SNR 4B
S17 u2	0	0	0	0	0	0	0	0	0
S17 u4 Glochidion type	0	0	0	0	0	0	0	0	0
S17 u5	0	0	0	0	0	0	0	0	0
S17 u6	0	0	0	0	0	0	0	0	0
S19 u1 Rumex comp.	0	0	0	0	0	0	0	0	0
S20 u1	0	0	0	0	0	0	0	0	0
S20 u3	0	0	0	0	0	0	0	0	0
S21 u2	0	0	0	0	0	0	0	0	0
S22 u2	0	0	0	0	0	0	0	0	0
S22 u4	0	0	0	0	0	0	0	0	0
S22 u8	0	0	0	0	0	0	0	0	0
S22 u10	0	0	0	0	0	0	0	0	0
S22 u11	0	0	0	0	0	0	0	0	0
S27 u4	0	0	0	0	0	0	0	0	0
S27 u7	0	0	0	0	0	0	0	0	0
S28 u2 cf. Araliaceae	0	0	0	0	0	0	0	0	0
S28 u7	0	0	0	0	0	0	0	0	0
S28 u8	0	0	0	0	0	0	0	0	0
S28 u10	0	0	0	0	0	0	0	0	0
S28 u12	0	0	0	0	0	0	0	0	0
S28 u13	0	0	0	0	0	0	0	0	0
S28 u15	0	0	0	0	0	0	0	0	0
S28 u16	0	0	0	0	0	0	0	0	0
S29 u1	0	0	0	0	0	0	0	0	0
S30 u2 Cunoniaceae comp.	0	0	0	0	0	0	0	0	0
S30 u4	0	0	0	0	0	0	0	0	0
S31 u4	0	0	0	0	0	0	0	0	0
S35 u1 Verbenaceae cf. Clerodendrum	0	0	0	0	0	0	0	0	0
S35 u6 Verbenaceae?	0	0	0	0	0	0	0	0	0
S36 u1	0	0	0	0	0	0	0	0	0
S37 u1	0	0	0	0	0	0	0	0	0
S40 u1	0	0	0	0	0	0	0	0	0
S40 u2	0	0	0	0	0	0	0	0	0
S40 u3	0	0	0	0	0	0	0	0	0
S40 u4	0	0	0	0	0	0	0	0	0
S40 u5	0	0	0	0	0	0	0	0	0
S40 u6	0	0	0	0	0	0	0	0	0
S48 u3	0	0	0	0	0	0	0	0	0

	PIL 542 SNR 4C	PIL 542 SNR5	PIL 542 SNR 6A	PIL 542 SNR 6B	PIL 542 SNR7	PIL 542 SNR8	PIL 542 SNR9	BHP 60918 SNR1	SNRM 22092015 SNR1
S17 u2	0	0	0	0	0	0	0	11	0
S17 u4 Glochidion type	0	0	0	0	0	0	0	0	0
S17 u5	0	0	0	0	0	0	0	3	0
S17 u6	0	0	0	0	0	0	0	1	0
S19 u1 Rumex comp.	0	0	0	0	0	0	0	0	0
S20 u1	0	0	0	0	0	0	0	0	0
S20 u3	0	0	0	0	0	0	0	0	0
S21 u2	0	0	0	0	0	0	0	0	0
S22 u2	0	0	0	0	0	0	0	0	0
S22 u4	0	0	0	0	0	0	0	0	0
S22 u8	0	0	0	0	0	0	0	0	0
S22 u10	0	0	0	0	0	0	0	0	0
S22 u11	0	0	0	0	0	0	0	0	0
S27 u4	0	0	0	0	0	0	0	0	0
S27 u7	0	0	0	0	0	0	0	0	0
S28 u2 cf. Araliaceae	0	0	0	0	0	0	0	0	0
S28 u7	0	0	0	0	0	0	0	0	0
S28 u8	0	0	0	0	0	0	0	0	0
S28 u10	0	0	0	0	0	0	0	0	0
S28 u12	0	0	0	0	0	0	0	0	0
S28 u13	0	0	0	0	0	0	0	0	0
S28 u15	0	0	0	0	0	0	0	0	0
S28 u16	0	0	0	0	0	0	0	0	0
S29 u1	0	0	0	0	0	0	0	0	0
S30 u2 Cunoniaceae comp.	0	0	0	0	0	0	0	0	0
S30 u4	0	0	0	0	0	0	0	0	0
S31 u4	0	0	0	0	0	0	0	0	0
S35 u1 Verbenaceae cf. Clerodendrum	0	0	0	0	0	0	0	0	0
S35 u6 Verbenaceae?	0	0	0	0	0	0	0	0	0
S36 u1	0	0	0	0	0	0	0	0	0
S37 u1	0	0	0	0	0	0	0	0	0
S40 u1	0	0	0	0	0	0	0	0	0
S40 u2	0	0	0	0	0	0	0	0	0
S40 u3	0	0	0	0	0	0	0	0	0
S40 u4	0	0	0	0	0	0	0	0	0
S40 u5	0	0	0	0	0	0	0	0	0
S40 u6	0	0	0	0	0	0	0	0	0
S48 u3	0	0	0	0	0	0	0	0	0

	PIL 5841 SNR1 (rt)	PIL 5841 SNR1 (ctr)	PIL 5841 SNR1 (lt)	PIL 5841 SNR2A	PIL 5841 SNR2B	PIL 5841 SNR4	PIL 5841 SNR5	SNRM_24092015_3 SNR 1	SNRM_24092015_3 SNR 2
S17 u2	0	0	0	0	0	0	0	0	0
S17 u4 Glochidion type	0	0	0	0	0	0	0	0	0
S17 u5	0	0	0	0	0	0	0	0	0
S17 u6	2	0	1	0	0	0	0	1	0
S19 u1 Rumex comp.	21	0	1	1	0	0	0	0	2
S20 u1	0	1	0	0	0	0	0	0	0
S20 u3	0	2	0	0	0	0	0	0	0
S21 u2	0	0	3	0	0	0	0	0	0
S22 u2	0	0	0	10	4	0	0	0	0
S22 u4	0	0	0	1	0	0	0	0	0
S22 u8	0	0	0	5	0	0	0	0	0
S22 u10	0	0	0	2	0	0	0	0	0
S22 u11	0	0	0	1	0	0	0	0	0
S27 u4	0	0	0	0	0	0	0	1	0
S27 u7	0	0	0	0	0	0	0	1	4
S28 u2 cf. Araliaceae	0	0	0	0	0	0	0	0	10
S28 u7	0	0	0	0	0	0	0	0	6
S28 u8	0	0	0	0	0	0	0	0	1
S28 u10	0	0	0	2	0	0	0	0	2
S28 u12	0	0	0	1	0	0	0	0	3
S28 u13	0	0	0	1	0	0	0	0	2
S28 u15	0	0	0	1	0	0	0	0	1
S28 u16	0	0	0	1	0	0	0	0	1
S29 u1	0	0	0	1	0	0	0	0	0
S30 u2 Cunoniaceae comp.	0	0	0	0	0	0	0	0	0
S30 u4	0	0	0	0	0	0	0	0	0
S31 u4	0	0	0	0	0	0	0	0	0
S35 u1 Verbenaceae cf. Clerodendrum	0	0	0	0	0	0	0	0	0
S35 u6 Verbenaceae?	0	0	0	0	0	0	0	0	0
S36 u1	0	0	0	0	0	0	0	0	0
S37 u1	0	0	0	0	0	0	0	0	0
S40 u1	0	0	0	0	0	0	0	0	0
S40 u2	0	0	0	0	0	0	0	0	0
S40 u3	0	0	0	0	0	0	0	0	0
S40 u4	0	0	0	0	0	0	0	0	0
S40 u5	0	0	0	0	0	0	0	0	0
S40 u6	0	0	0	0	0	0	0	0	0
S48 u3	0	0	0	0	0	0	0	0	0

	PIL_7026 SNR1	PIL_2258 SNR1	PIL_2258 SNR2	PIL_2258 SNR3	PIL_2258 SNR4	PIL_4544 SNR1	PIL_4544 SNR2	PIL_4544 SNR3A	PIL_4544 SNR3B 1
S17 u2	0	0	0	0	0	0	0	0	0
S17 u4 Glochidion type	0	0	0	1	0	0	0	0	0
S17 u5	0	0	0	0	0	0	0	0	0
S17 u6	0	0	0	0	0	0	2	0	0
S19 u1 Rumex comp.	0	0	0	0	0	0	0	0	0
S20 u1	0	0	0	0	0	0	0	0	0
S20 u3	0	0	0	0	0	0	0	0	0
S21 u2	0	0	0	0	0	0	0	0	0
S22 u2	0	0	0	0	0	0	0	0	0
S22 u4	0	1	0	0	0	0	0	0	0
S22 u8	0	0	0	0	0	0	0	0	0
S22 u10	0	0	0	0	0	0	0	0	0
S22 u11	0	0	0	0	0	0	0	0	0
S27 u4	0	0	0	0	0	0	0	0	0
S27 u7	0	0	0	0	0	0	0	0	0
S28 u2 cf. Araliaceae	0	0	0	0	0	0	0	0	0
S28 u7	0	0	0	0	0	0	0	0	0
S28 u8	0	0	0	0	0	0	0	0	0
S28 u10	0	0	0	0	0	0	0	0	0
S28 u12	0	0	0	0	0	0	0	0	0
S28 u13	0	2	2	1	0	0	0	0	0
S28 u15	0	0	0	0	0	0	0	0	0
S28 u16	0	0	0	0	0	0	0	0	0
S29 u1	1	0	0	0	0	0	0	0	0
S30 u2 Cunoniaceae comp.	0	1	0	0	0	0	0	0	0
S30 u4	0	1	0	0	0	0	0	0	0
S31 u4	0	0	1	0	0	0	0	0	0
S35 u1 Verbenaceae cf. Clerodendrum	0	0	0	0	0	0	1	0	0
S35 u6 Verbenaceae?	0	0	0	0	0	0	1	0	0
S36 u1	0	0	0	0	0	0	0	1	0
S37 u1	0	0	0	0	0	0	0	0	1
S40 u1	0	0	0	0	0	0	0	0	0
S40 u2	0	0	0	0	0	0	0	0	0
S40 u3	0	0	0	0	0	0	0	0	0
S40 u4	0	0	0	0	0	0	0	0	0
S40 u5	0	0	0	0	0	0	0	0	0
S40 u6	0	0	0	0	0	0	0	0	0
S48 u3	0	0	0	0	0	0	0	0	0

	PIL_4544 SNR3B 2	PIL_4544 SNR3C	PIL_4544 SNR3D	PIL_4544 SNR5A	PIL_4544 SNR5C	PIL_4544 SNR 5C	PIL_2001 SNR1A	PIL_2001 SNR1B	PIL_2001 SNR2A
S17 u2	0	0	0	0	0	0	0	0	0
S17 u4 Glochidion type	0	0	0	0	0	0	0	0	0
S17 u5	0	0	0	0	0	0	0	0	0
S17 u6	0	0	0	0	0	0	0	0	0
S19 u1 Rumex comp.	0	0	0	0	0	0	0	0	0
S20 u1	0	0	0	0	0	0	0	0	0
S20 u3	0	0	0	0	0	0	0	0	0
S21 u2	0	0	0	0	0	0	0	0	0
S22 u2	0	0	0	0	0	0	0	0	0
S22 u4	0	0	0	0	0	0	0	0	0
S22 u8	0	0	0	0	0	0	0	0	0
S22 u10	0	0	0	0	0	0	0	0	0
S22 u11	0	0	0	0	0	0	0	0	0
S27 u4	0	0	0	0	0	0	0	0	0
S27 u7	0	0	0	0	0	0	0	0	0
S28 u2 cf. Araliaceae	0	0	0	0	0	0	0	0	0
S28 u7	0	0	0	0	0	0	0	0	0
S28 u8	0	0	0	0	0	0	0	0	0
S28 u10	0	0	0	0	0	0	0	0	0
S28 u12	0	0	0	0	0	0	0	0	0
S28 u13	0	0	0	0	0	0	0	0	0
S28 u15	0	0	0	0	0	0	0	0	0
S28 u16	0	0	0	0	0	0	0	0	0
S29 u1	0	0	0	0	0	0	0	0	0
S30 u2 Cunoniaceae comp.	0	0	0	0	0	0	0	0	0
S30 u4	0	0	0	0	0	0	0	0	0
S31 u4	0	0	0	0	0	0	0	0	0
S35 u1 Verbenaceae cf. Clerodendrum	0	0	0	0	0	0	0	0	0
S35 u6 Verbenaceae?	0	0	0	0	0	0	0	0	0
S36 u1	0	0	0	0	0	0	0	0	0
S37 u1	0	0	0	0	0	0	0	0	0
S40 u1	0	0	1	0	1	0	0	1	0
S40 u2	0	0	1	0	1	0	0	1	0
S40 u3	0	0	1	0	1	0	0	1	0
S40 u4	0	0	2	0	0	0	0	0	0
S40 u5	0	0	1	0	1	0	0	1	0
S40 u6	0	0	1	0	1	0	0	1	0
S48 u3	0	0	0	0	0	0	0	0	0

	PIL_2001 SNR2B	PIL_2001 SNR2C	PIL_2001 SNR3A	PIL_2001 SNR3B
S17 u2	0	0	0	0
S17 u4 Glochidion type	0	0	0	0
S17 u5	0	0	0	0
S17 u6	0	0	0	0
S19 u1 Rumex comp.	0	0	0	0
S20 u1	0	0	0	0
S20 u3	0	0	0	0
S21 u2	0	0	0	0
S22 u2	0	0	0	0
S22 u4	0	0	0	0
S22 u8	0	0	0	0
S22 u10	0	0	0	0
S22 u11	0	0	0	0
S27 u4	0	0	0	0
S27 u7	0	0	0	0
S28 u2 cf. Araliaceae	0	0	0	0
S28 u7	0	0	0	0
S28 u8	0	0	0	0
S28 u10	0	0	0	0
S28 u12	0	0	0	0
S28 u13	0	0	0	0
S28 u15	0	0	0	0
S28 u16	0	0	0	0
S29 u1	0	0	0	0
S30 u2 Cunoniaceae comp.	0	0	0	0
S30 u4	0	0	0	0
S31 u4	0	0	0	0
S35 u1 Verbenaceae cf. Clerodendrum	0	1	0	0
S35 u6 Verbenaceae?	0	1	0	0
S36 u1	0	1	0	0
S37 u1	0	1	0	0
S40 u1	1	0	0	0
S40 u2	0	0	0	0
S40 u3	1	0	0	0
S40 u4	1	0	0	0
S40 u5	0	0	0	0
S40 u6	0	0	0	0
S48 u3	1	0	0	0

8.5 Appendix 4: aDNA Raw Data

	Callitris	*Pinus*	Apioideae	Gnaphalieae	Asteroideae	Theaceae	Boraginaceae	*Mentha*	Nepetoideae	*Teucrium*	Lamiales	Pedaliaceae	*Plantago*	*Solanum*	*Solanaceae*
PIL 542 SNR5		1						1							
PIL 5841 SNR	1		1		1		1			1	1				
PIL 4544 SNR4A		1													
PIL 540 SNR1				1									1		
PIL 4544 SNR5C														1	1
PIL 5841 SNR1(RIGHT)															
PIL 5841 SNR1(RIGHT)															
PIL 542 SNR5									1			1			
PIL 542 SNR5		1													
PIL4544 SNR4A			1			1									1
PIL4544 SNR4A												1			1
PIL 540 SNR1															
PIL 540 SNR1															
PIL 4544 SNR5C															
PIL 4544 SNR5C															
	Processed														
	Unprocessed														

		Acacia	*Ingeae*	*Indigofera*	*Micrandreae*	*Euphorbia*	*Cannabis*	*Morus*	*Prunus*	*Maleae*	*Brassicaceae*	*Theobroma*	*Corchorus*	*Gossypium*	Malvoideae
PIL 542 SNR5								1							
PIL 5841 SNR1 (RIGHT)		1		1		1			1		1			1	
PIL 4544 SNR4A															
PIL 540 SNR1		1	1										1		1
PIL 4544 SNR5C												1			
PIL 5841 SNR1(RIGHT)															
PIL 5841 SNR1(RIGHT)															
PIL 542 SNR5															
PIL 542 SNR5							1		1						
PIL4544 SNR4A		1			1						1				
PIL4544 SNR4A										1					
PIL 540 SNR1															
PIL 540 SNR1															
PIL 4544 SNR5C															
PIL 4544 SNR5C															
	Processed														

		Myrtaceae	*Anacardium*	*Citrus*	Sapindaceae	Proteaceae	*Allium*	*Avena*	Loliinae	*Phalaris*	*Poa*	Poeae	Triticeae	Micrairoideae	Andropogone	PACMAD Clac	*Musa*
PIL 542 SNR5								1						1			1
PIL 5841 SNR1 (RIGHT)		1				1							1		1	1	
PIL 4544 SNR4A								1									1
PIL 540 SNR1				1	1												
PIL 4544 SNR5C		1														1	
PIL 5841 SNR1(RIGHT)																	
PIL 5841 SNR1(RIGHT)		1									1						
PIL 542 SNR5			1													1	
PIL 542 SNR5		1															
PIL4544 SNR4A				1			1		1								
PIL4544 SNR4A										1						1	
PIL 540 SNR1					1												
PIL 540 SNR1					1							1				1	
PIL 4544 SNR5C																	
PIL 4544 SNR5C							1					1					1
	Processed																
	Unprocessed																

8.6 Appendix 5: Raw Macrofossil Counts

SAMPLE NUMBER	ASTERACEAE	CYPERACEAE	POACEAE	TRIODIA	Aristida sp.	Themeda triandra	Dicanthium Sericeum	Callitris sp.	Calotis sp. 'Daisy'	Polycarpaea sp.	Goodenia sp.	Sida sp.	Solanum sp.	Triumfetta sp.	Amaranthus mitchelli 'Boggabri weed'	Boerhavia coccinea 'Tar vine'	Cleome Viscosa 'Tick weed'	Daucus glochidiatus 'Native carrot'	Portulaca Oleracea 'Pig weed'	Solanum diversiflorum 'Bush tomato'	BARK PIECES	TRIODIA SPINE	AWNS- TWISTED	LEAF FRAGMENTS	UNIDENTIFIED FIBRES	TWIGS	Unknown Type A	Unknown Type B	Unknown Type C	Unknown Type D	Unknown Type E	Unknown Type F	Unknown Type G	Unknown Type H	Unknown Type I	Unknown Type J
SNRM_22092015_1	1	13	1	8		3	4	34					3							7				200	200	6							115			
SNRM_24092015_3 SNR 2			5	1			12	1					2												300	4							1			
PIL_2258 SNR 2			5	1																					12											
PIL_540 SNR 1			3	2		1			2							1					2			60	200	23							1			
PIL_540 SNR 2			4	4		18	2									1								1	520	1										
PIL_540 SNR 3			6	15		30			1		1	1	2											0	400					1						
PIL_542 SNR 4B			3		1	1		2					2					1		11					200			3					4		2	
PIL_542 SNR 4C			3	3	2			3					1							6					600											
PIL_542 SNR 5			6			3		2					1							8	3			30	800	26		2								
PIL_542 SNR 6B			3	1		2		20												6	20			800	150	36		1					1			
PIL_542 SNR 7			1										2						3	5				300	120	16			1		1		8			1
PIL_542 SNR 8	1																			3				10	100	5										
PIL_542 SNR 9																								100	50	18										
PIL_5841 SNR 1 (Right)		2	2				6					1				2				4	1			12	1000	5										
PIL_5841 SNR 2B			27	5			3						7	1											500								13		1	1
PIL_5841 SNR 3	2		15	12		3	7						38		2	2	2			2		1	1		3200								10			
PIL_5841 SNR 4		1	9				2						13												1200	1						2	5		2	
PIL_4544 SNR 2		2	5	4			1					1				4				1					1000	6		1					6	1	2	
PIL_4544 SNR 3A		2	4	6		7	20																		1000	3		1					1	1		
PIL_4544 SNR 3B		1	15		4	12	5						7			3			2	4				3	2500	1		4					15			
PIL_4544 SNR 3C			4			1	1																		1600	4										
PIL_4544 SNR 4A																									10											
PIL_4544 SNR 5A			9	13			1					2	1			1									1000	2		1					1			
PIL_4544 SNR 5B			1	11		1	1						4										1		1200	4		2								
PIL_4544 SNR 5C			42		1	2						2	28		1										7000		1	1					18			
PIL_2001 SNR 1A			10		1	3	3													3	2			1	5000	2						2	19			
PIL_2001 SNR 1B		3	11	21	3	14	4			6			3			1							2		5000	10		6				1	64			
PIL_2001 SNR 3A			14	9	2	17				4			3												1800			1					20			
PIL_2001 SNR 3B		1	7	13		1							2			1								2	800										

8.7 Appendix 6: Radiocarbon Results from Waikato

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato
Radiocarbon Dating Laboratory

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Wednesday, 2 March 2016

Report on Radiocarbon Age Determination for Wk- 42960

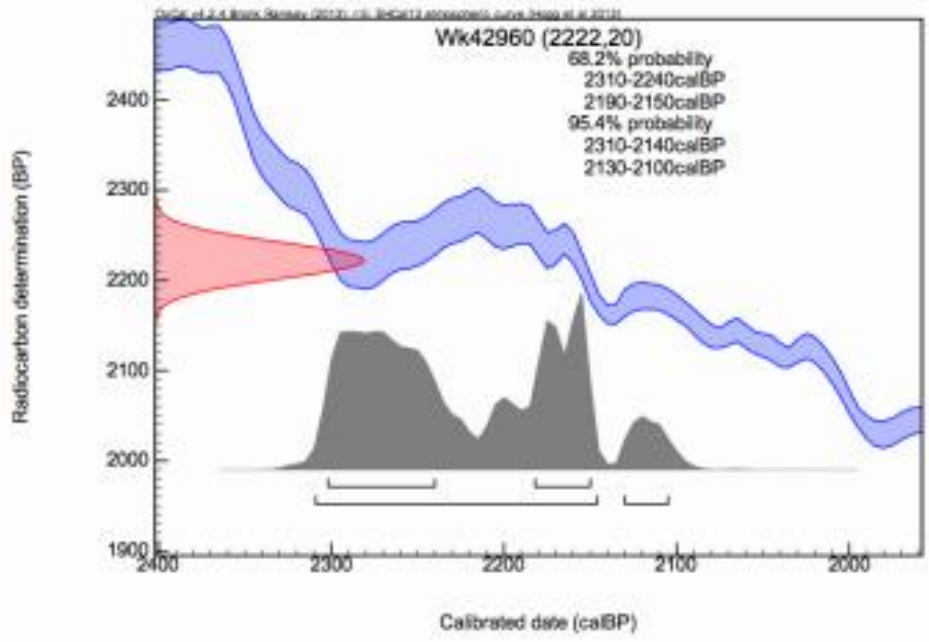
Submitter	LA Wallis
Submitter's Code	PIL_540 SNR1
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets
Physical Pretreatment	Sample homoginised.
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$D^{14}C$	-241.6 ±	1.9 ‰
$F^{14}C$%	75.8 ±	0.2 %
Result	**2222 ± 20 BP**	

(AMS measurement)

Comments

Please note: The Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has therefore been corrected for isotopic fractionation. However the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.



- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C$% is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42961

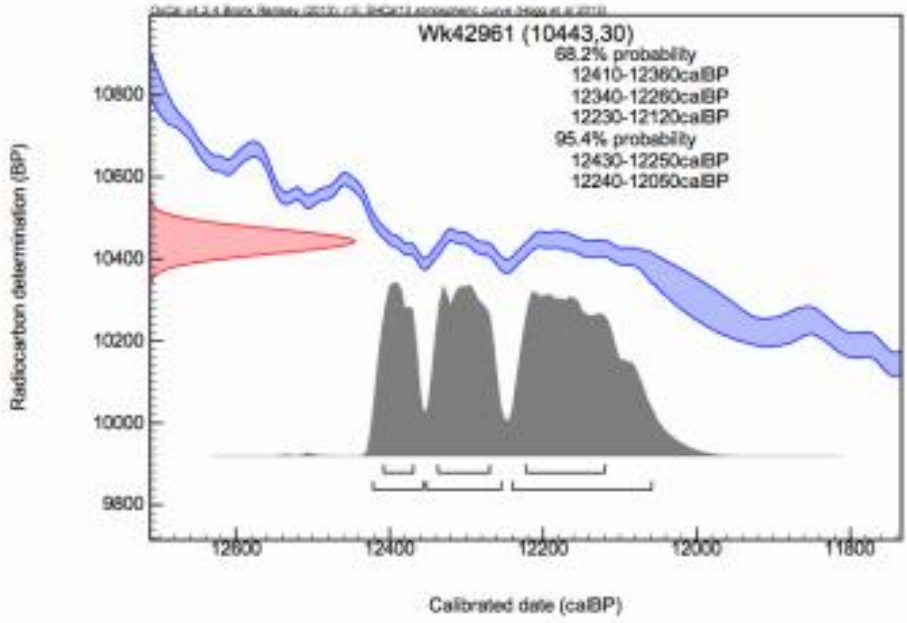
Submitter	LA Wallis
Submitter's Code	PIL_542 SNR5
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets
Physical Pretreatment	Sample homoginized.
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$D^{14}C$	-727.5 ±	1.0 ‰
$F^{14}C\%$	27.3 ±	0.1 %
Result	**10,443 ± 30 BP**	

(AMS measurement)

Comments

Please note: The Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has therefore been corrected for isotopic fractionation. However the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.



- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C\%$ is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42962

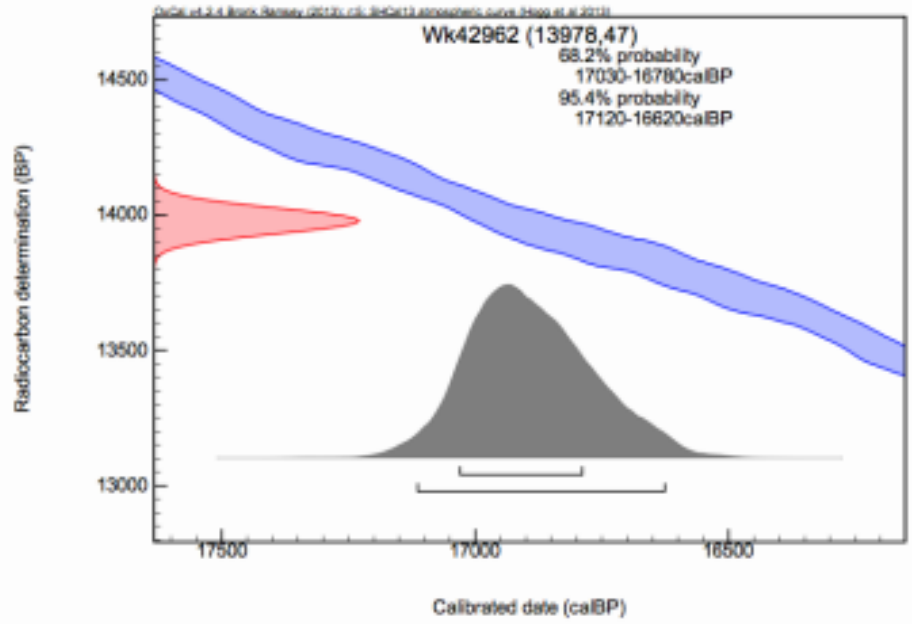
Submitter	LA Wallis
Submitter's Code	PIL_5841 SNR1(right)
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets etc
Physical Pretreatment	Sample homoginized
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$D^{14}C$	-824.5 ±	1.0 ‰
$F^{14}C$%	17.6 ±	0.1 %
Result	**13,978 ± 47 BP**	

(AMS measurement)

Comments

Please note: The Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has therefore been corrected for isotopic fractionation. However the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.



- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C$% is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42963

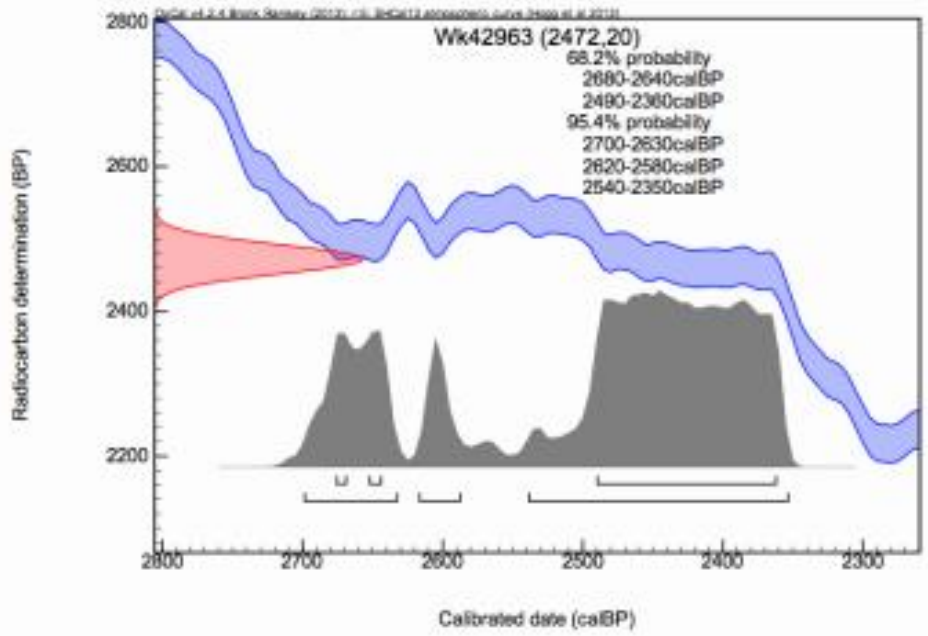
Submitter	LA Wallis
Submitter's Code	PIL_5841 SNR4
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets etc
Physical Pretreatment	Sample homoginized.
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$D^{14}C$	-264.9 ±	1.8 ‰
$F^{14}C$%	73.5 ±	0.2 %
Result	**2472 ± 20 BP**	

(AMS measurement)

Comments

Please note: The Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has therefore been corrected for isotopic fractionation. However the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.



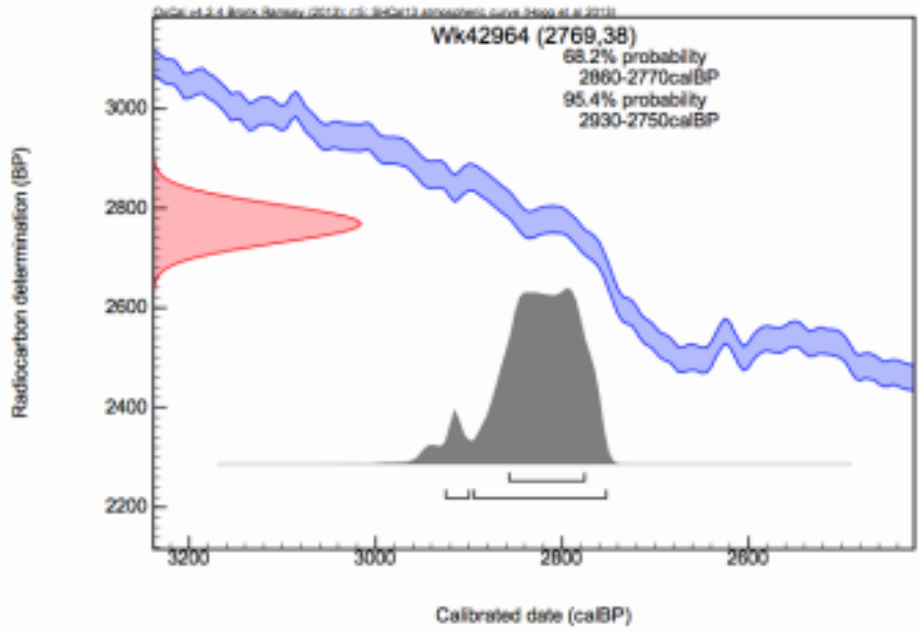
- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C$% is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42964

Submitter	LA Wallis
Submitter's Code	PIL_2001 SNR1B
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets etc
Physical Pretreatment	Visible contaminants removed.
Chemical Pretreatment	Washed in hot 10% HCl, rinsed and treated with hot 1% NaOH. The NaOH insoluble fraction was treated with hot 10% HCl, filtered, rinsed and dried.

$\delta^{13}C$	-17.9 ±	0.1 ‰
$D^{14}C$	-291.5 ±	3.3 ‰
$F^{14}C\%$	70.8 ±	0.3 %
Result	**2769 ± 38 BP**	

Comments



- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C\%$ is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42965

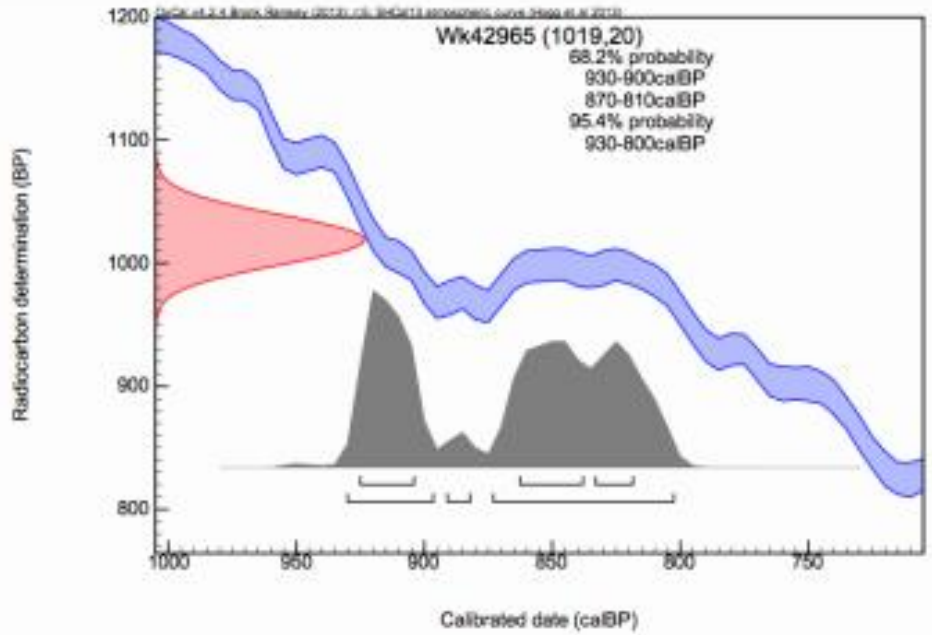
Submitter	LA Wallis
Submitter's Code	PIL_4544 SNR3B
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets etc
Physical Pretreatment	Sample homoginised.
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$D^{14}C$	-119.2 ±	2.1 ‰
$F^{14}C$%	88.1 ±	0.2 %
Result	**1019 ± 20 BP**	

(AMS measurement)

Comments

Please note: The Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has therefore been corrected for isotopic fractionation. However the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.



- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C$% is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42966

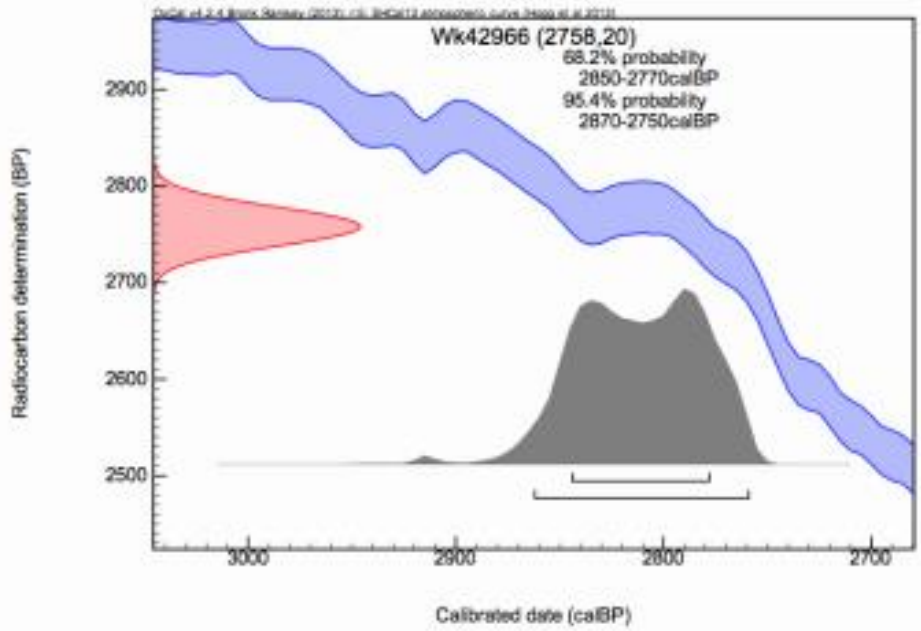
Submitter	LA Wallis
Submitter's Code	PIL_4544 SNR3A
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets etc
Physical Pretreatment	Sample homoginized.
Chemical Pretreatment	Sample washed in hot HCl, rinsed and treated with multiple hot NaOH washes. The NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried.

$D^{14}C$	-290.6 ±	1.8 ‰
$F^{14}C$%	70.9 ±	0.2 %
Result	**2758 ± 20 BP**	

(AMS measurement)

Comments

Please note: The Carbon-13 stable isotope value ($\delta^{13}C$) was measured on prepared graphite using the AMS spectrometer. The radiocarbon date has therefore been corrected for isotopic fractionation. However the AMS-measured $\delta^{13}C$ value can differ from the $\delta^{13}C$ of the original material and it is therefore not shown.



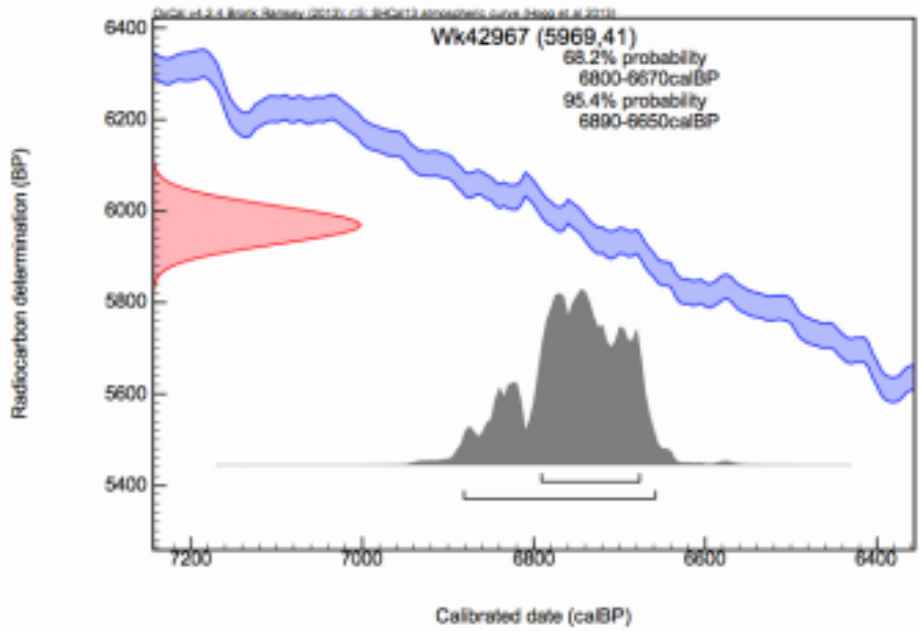
- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C$% is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42967

Submitter	LA Wallis
Submitter's Code	PIL_4544 SNR4A
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets etc
Physical Pretreatment	Visible contaminants removed.
Chemical Pretreatment	Washed in hot 10% HCl, rinsed and treated with hot 1% NaOH. The NaOH insoluble fraction was treated with hot 10% HCl, filtered, rinsed and dried.

$\delta^{13}C$	-19.6 ±	0.1 ‰
$D^{14}C$	-524.3 ±	2.4 ‰
$F^{14}C\%$	47.6 ±	0.2 %
Result	**5969 ± 41 BP**	

Comments



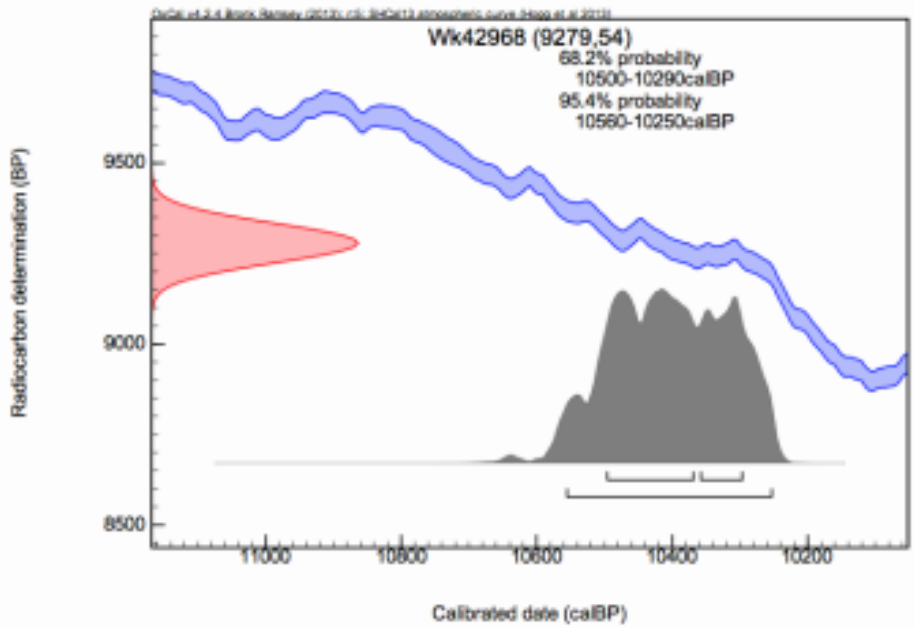
- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C\%$ is also known as *Percent Modern Carbon (pMC)*.

Report on Radiocarbon Age Determination for Wk- 42968

Submitter	LA Wallis
Submitter's Code	PIL_4544 SNR5C
Site & Location	Central Pilbara, Western Australia, Australia
Sample Material	Faecal pellets etc
Physical Pretreatment	Visible contaminants removed.
Chemical Pretreatment	Washed in hot 10% HCl, rinsed and treated with hot 1% NaOH. The NaOH insoluble fraction was treated with hot 10% HCl, filtered, rinsed and dried.

$\delta^{13}C$	-15.3 ±	0.1 ‰
$D^{14}C$	-685.0 ±	2.1 ‰
$F^{14}C\%$	31.5 ±	0.2 %
Result	**9279 ± 54 BP**	

Comments



- Explanation of the calibrated Oxcal plots can be found at the Oxford Radiocarbon Accelerator Unit's calibration web pages (http://c14.arch.ox.ac.uk/embed.php?File=explanation.php)
- Result is *Conventional Age or Percent Modern Carbon (pMC)* following Stuiver and Polach, 1977, Radiocarbon 19, 355-363. This is based on the Libby half-life of 5568 yr with correction for isotopic fractionation applied. This age is normally quoted in publications and must include the appropriate error term and Wk number.
- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.
- The isotopic fractionation, $\delta^{13}C$, is expressed as ‰ wrt PDB and is measured on sample CO_2.
- $F^{14}C\%$ is also known as *Percent Modern Carbon (pMC)*.

8.8 Appendix 7: Radiocarbon Results from ANSTO

Australian Government

Nuclear-based science benefiting all Australians

REPORT ON AMS ANALYSIS
(ANSTO Portal 10381; RUN 459) [Revised]

1 May 2017

Dr Alice Gorman
Flinders University
Bedford Park SA 5042

Email: alice.gorman@flinders.edu.au

RADIOCARBON RESULTS

	ANSTO code	Sample Type	Submitter ID	δ(^{13}C) per mil	percent Modern Carbon pMC	1σ error	Conventional Radiocarbon age yrs BP	1σ error
1	OZU464	Stick-nest	PIL_540 SNR #2	-21.6	66.20	0.23	3,315	30
2	OZU465	Stick-nest	PIL_540 SNR #3	-17.7	68.29	0.20	3,065	25
3	OZU466	Stick-nest	PIL_542 SNR #9	-20.6	13.18	0.08	16,280	60
4	OZU467	Stick-nest	PIL_542 SNR #4B	-21.7	27.06	0.12	10,500	40
5	OZU468	Stick-nest	PIL_542 SNR #4C	-20.0	3.19	0.07	27,670	180
6	OZU469	Stick-nest	PIL_542 SNR #6B	-20.0	23.16	0.12	11,750	45
7	OZU470	Stick-nest	PIL_542 SNR #7	-23.0	33.70	0.18	8,735	45
8	OZU471	Stick-nest	PIL_542 SNR #8	-15.4	31.62	0.16	9,250	45
9	OZU472	Stick-nest	PIL_2001 SNR #1A	-20.1	47.10	0.17	6,050	30
10	OZU473	Stick-nest	PIL_2258 SNR #2	-25.0*	55.60	0.21	4,715	30
11	OZU474	Stick-nest	PIL_4544 SNR #2	-20.2	76.55	0.22	2,145	25
12	OZU475	Stick-nest	PIL_2001 SNR #3A	-16.7	33.52	0.14	8,780	35
13	OZU476	Stick-nest	PIL_4544 SNR #3C	-19.4	26.81	0.12	10,575	40
14	OZU477	Stick-nest	PIL_2001 SNR# 3B	-15.7	69.76	0.25	2,890	30
15	OZU478	Stick-nest	PIL_4544 SNR #5A	-16.6	79.95	0.24	1,800	25
16	OZU479	Stick-nest	PIL_4544 SNR #5B	-13.9	46.31	0.22	6,185	40
17	OZU480	Stick-nest	PIL_5841 NSR #3	-15.3	46.76	0.27	6,105	50
18	OZU481	Stick-nest	PIL_5841 SNR #2B	-13.6	30.48	0.15	9,545	40
19	OZU482	Stick-nest	SNRM_22092015 SNR #1	-18.0	56.36	0.20	4,605	30
20	OZU483	Stick-nest	SNRM_24092015 SNR #2	-12.7	19.17	0.11	13,270	45

* = The value of δ(^{13}C) is assumed. A measured value is not available.

Note:

1. δ(^{13}C) values relate solely to the graphite derived from the fraction that was used for the radiocarbon measurement. It is sometimes the case that the δ(^{13}C) of this fraction is not the same as that of the bulk material. Measurements are determined using EA-IRMS (except for those, if present, marked with '$' which are accelerator based). Some δ(^{13}C) values may not have an associated uncertainty due to the limited number of determinations.

AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

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http://www.ansto.gov.au/ResearchHub/acceleratorsciencecentre/index.htm

2. The ages quoted are radiocarbon ages, not calendar ages.
3. The ages have been rounded according to M. Stuiver and A. Polach (1977). The definition of percent Modern Carbon and Conventional Radiocarbon age can also be found in this publication.
4. Please use the ANSTO Code number in publications. The AMS facility should be referenced as Fink *et al.* (2004).

References:

D. Fink, M. Hotchkis, Q. Hua, G. Jacobsen, A. M. Smith, U. Zoppi, D. Child, C. Mifsud, H. van der Gaast, A. Williams and M. Williams (2004) The ANTARES AMS facility at ANSTO, NIM B 223-224, 109-115.

M. Stuiver and A. Polach (1977) Reporting of ^{14}C data, *Radiocarbon* 19(3), 355-363. Available on-line at: https://journals.uair.arizona.edu/index.php/radiocarbon/article/view/493/498

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8.9 Appendix 8: Modern Vegetation Lists

PIL_542

Astrotricha hamptonii

Acacia hamersleyensis

Brachyscome ciliaris or Brachyscome ciliocarpa

Cymbopogen

Dodonaea

Dysphania rhadinostachya

Gossypium

Ptilotus obovatus

Sesbania

Stemodia

Streptoglossa

Themeda triandra

Triodia

Wild Banana

PIL_540

Brachyscome ciliaris or Brachyscome ciliocarpa

Acacia

Triodia

SNRM_22092015_1

Cymbopogen

Eucalyptus racemosa

Triodia

GCE_24_06_2011_1

Acacia tumida

Brachyscome ciliaris or Brachyscome ciliocarpa

Callitris

Cymbopogen

Ficus

Myrtaceae

Themeda triandra

Triodia

PIL_2258

Brachyscome ciliaris or Brachyscome ciliocarpa

Cymbopogen

Eriachne

Myrtaceae

Psydrax latifolia

Senna

Solanum

Triodia

PIL_4544

Acacia

Aristida

Brachyscome ciliaris or Brachyscome ciliocarpa

Cymbopogen

Eriachne

Eromophila latrobei

Grevillea

Hakea

Myrtaceae

Senna

SNRM_24092015_3

Acacia aneura

Capparis lasiantha

Corymbia ferriticola

Eriachne

Eucalyptus racemosa

Ficus

Pterocaulon sphacelatum

Ptilotus

Senna

Sida

Themeda triandra

Triodia

PIL_7026

Acacia aneura

Astrotricha hamptonii

Capparis lasiantha

Cymbopogen

Eriachne

Eromophila

Eucalyptus racemosa

Gossypium robinsonii

Ptilotus exaltus

Triodia

PIL_5841

Capparis lasiantha

Corymbia

Cymbopogen

Eucalyptus leucophloia

Eucalyptus racemosa

Hibiscus

Ptercaulon

Ptilotus calostachyus

Ptilotus obovatus

Senna

Sida

Solanum

Triodia

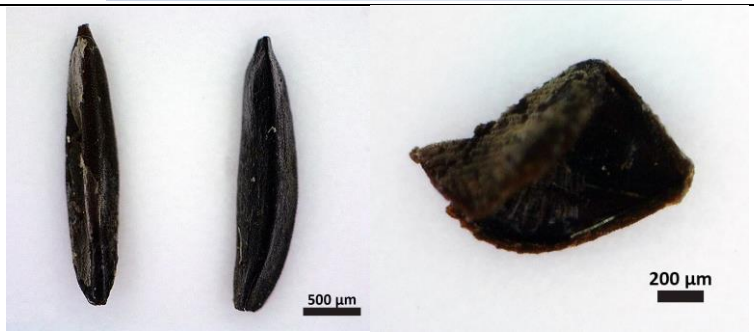
PIL_2001

Cymbopogen

Eucalyptus racemosa

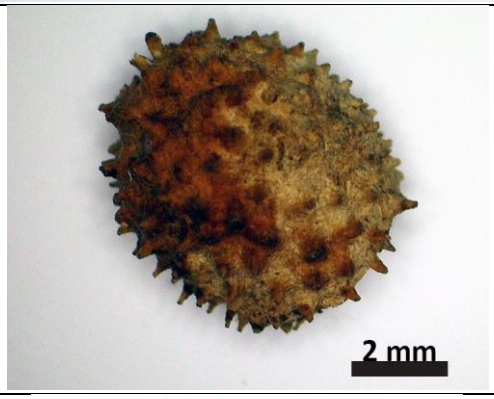
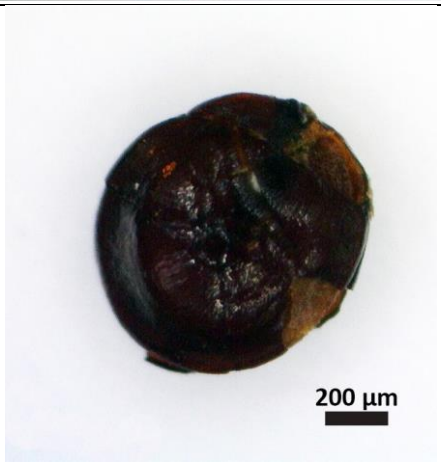
Triodia

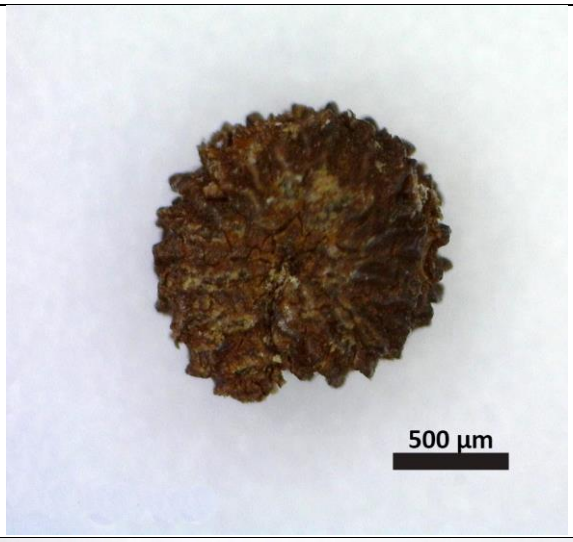
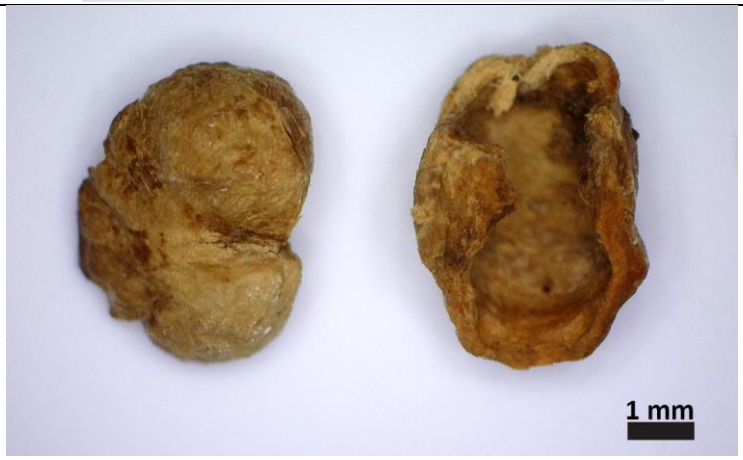
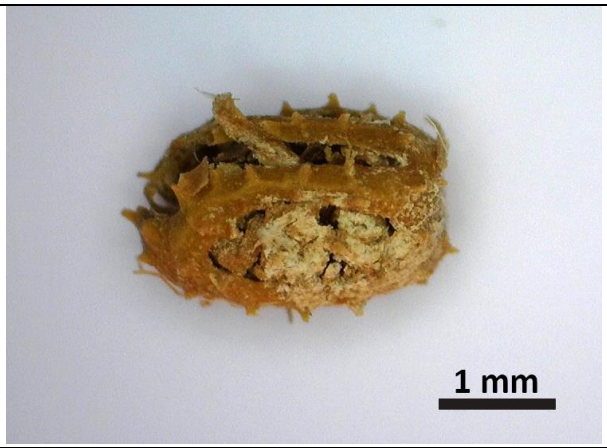
8.10 Appendix 9: Macrofossil Specimens and Unknown Types

Asteraceae 'Daisy Family'	
Cyperaceae 'Sedges'	
Poaceae 'Grasses'	
Poaceae ***Triodia* sp**. 'Spinifex'	

Poaceae ***Aristida* sp.**	
Poaceae ***Themeda triandra*** 'Kangaroo Grass'	
Poaceae ***Dichanthium sericeum***	
Cupressaceae ***Callitris* sp.** 'Cypress' Jointed leaves	

Asteraceae ***Calotis* sp.**	
Caryophyllaceae ***Polycarpaea*** sp.	
Goodeniaceae ***Goodenia* sp.**	
Malvaceae **Sida sp.**	

Solanaceae ***Solanum* sp.** 'Bush tomato'	
Malvaceae ***Triumfetta* sp.**	
Amaranthaceae ***Amaranthus mitchelli*** 'Boggabri weed'	
Nyctaginaceae ***Boerhavia coccinea*** 'Tar vine'	

Cleomaceae ***Cleome Viscosa*** 'Tick weed'	
Apiaceae ***Daucus glochidiatus*** 'Native carrot'	
Portulacaceae **Portulaca oleracea** 'Pig weed'	
Unknown Type A	

Unknown Type B	
Unknown Type C	
Unknown Type D	
Unknown Type E	

Unknown Type F	
Unknown Type G	
Unknown Type H	
Unknown Type I	

Unknown Type J