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Regime change: An anthracological assessment of fuel selection and management at Madjedbebe (Malakunanja II), Mirarr country, Australia

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Abstract

Australian anthracology is an informative yet under-developed field despite the fact that it can reveal valuable information about fuel wood selection, anthropogenic woodland management, and the palaeoenvironment. Fuel wood selection and management is assessed through the application of anthracology (wood charcoal analysis) at the rock shelter site of Madjedbebe, Mirarr country, Northern Territory, Australia. Madjedbebe provides a sequence of fourteen hearths unrivalled in Australian anthracology for their number and temporal span (240-7 years cal BP – c.55,000). These hearth charcoals are identified using a bespoke collection of reference woods constructed for this study. Each of the hearths is sampled to 200 fragments of charcoal or 100% of the available charcoal fragments. The Madjedbebe hearths are used to assess hypothesised fuel wood selection strategies including 1) the principle of least effort, 2) localised preferential selection, and 3) non-local selection. This investigation finds fuel wood selection remained locally focused over the past 20,000 years. The inhabitants of Madjedbebe consistently targeted two vegetation communities, open Eucalypt woodland and monsoon vine forest for their fuel wood, with minor contributions from a third – *Grevillea/Banksia* shrubland. There is a clear diachronic change in the taxonomic composition of the hearths from *Acacia* sp. dominance to increased taxon richness. This shift does not align with any major shifts in climate or woodland composition and is probably due to a change in anthropogenic selection preferences.

In addition to assessing fuel wood selection strategies the Madjedbebe charcoal assemblage also allows for the provenance of ‘matrix charcoal’ (charcoal found in the sedimentary matrix of the site, outside of a defined context) to be determined to some degree. The provenance and therefore interpretative value of matrix charcoal has until now remained uncertain. Occurring outside of a defined archaeological context, this class of charcoal may have been the dispersed remains of a hearth, the detritus of a bushfire, or both. Determining the provenance of matrix charcoal is critical to determining its analytic value. Understanding the charcoal bearing context and how the context formed is essential for anthracological interpretation and palaeoenvironmental reconstruction (Asouti and Austin 2005; Chabal 1992; Chabal et al. 1999). This study finds through a chi-squared comparison of the taxonomic composition of hearth (C3/4A), matrix (C3/4), and environmental charcoal that matrix charcoal is likely anthropogenic in origin. This result demonstrates matrix charcoal are

the remains of multiple fuel wood selections and can be used like ‘dispersed charcoal’ to reconstruct the palaeoenvironment (Asouti et al. 2015; Figueiral and Mosbrugger 2000).

Finally, this thesis contributes the first conceptual model for fuel wood selection in Australian anthracology. This model considers the place of fuel wood, an essential daily resource, in anthropogenic fire regimes. While the antiquity of anthropogenic fire regimes remains undefined, it is undeniable that these ethno-historically observed landscape practices have an immense impact on the prevalence of resources in a landscape. However, the fuel which is consumed in the landscape fire is the same fuel which is collected for the hearth. If fire burns an area indiscriminately, whether natural or anthropogenic in origin, the local supply of this valuable resource will be decimated. This model considers anthropogenic fire regimes as a niche modifying practice that represents instances in the history of a landscape. It is postulated that fuel wood could be easily included as part of mosaic burning practices. Areas for fuel wood collection would be protected from both anthropogenic and natural bushfires to maintain a consistent local supply of this essential daily resource. The ‘burn on departure’ model is presented as a heuristic tool for understanding the place of fuel wood within an anthropogenic fire regime. This model proposes that humans would burn a fuel wood collection area only as they departed as part of their seasonal or annual rounds.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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Publications during candidature

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Dotte-Sarout, E., **X. Carah**, C. Byrne (2015) Not just carbon: assessment and prospects for the application of anthracology in Oceania. *Archaeology in Oceania* 50:1-22.

Clarkson, C., M. Smith, B. Marwick, R. Fullagar, L. Wallis, P. Faulkner, T. Manne, Z. Jacob, R. Roberts, **X. Carah**, K. Lowe, E. Hayes, J. Matthews. (2015) The Archaeology, Chronology and Stratigraphy of Madjedbebe (Malakunanja II): A site in northern Australia with early occupation. *Journal of Human Evolution* 83:46-64.

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Dr J. Tyler Faith provided assistance with the statistical approaches used in this thesis.

Assoc. Prof. Patrick Moss produced the palynological sequence for Madjedbebe presented in Appendix C.

Statement of parts of the thesis submitted to qualify for the award of another degree

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Keywords

anthracology, fire regime, wood charcoal, arnhem land, kakadu, archaeobotany, niche construction theory, historical ecology, fire ecology, hunter-gatherer

Australian and New Zealand Standard Research Classifications (ANZSRC)

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Fields of Research (FoR) Classification

FoR 2101 Archaeology 100%

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List of Abbreviations used in the thesis

BP – Before Present

CA – Correspondence analysis

Cal BP – Calibrated (date) Before Present

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DNPRSR – Department of National Parks, Recreation, Sport and Racing

ENS – Ecologically Noble Savage

ENSO – El Nino-Southern Oscillation

EP – effective precipitation

GAC – Gundjeihmi Aboriginal Corporation

GBDBG – The George Brown Darwin Botanic Gardens

HISPID - Herbarium Information Standards and Protocols for Interchange of Data

IAWA – International Association of Wood Anatomists

IPWP – Indo-Pacific warm pool

ITCZ – inter-tropical convergence zone

ITF – Indonesian-through-flow

LGM – Last Glacial Maximum

MJB – Madjedbebe

MKII – Malakunanja II

NCT – Niche construction theory

NISP – number of identifiable specimens

NTAXA – number of taxa

PLE – Principle of Least Effort

PNG – Papua New Guinea

RLS – radial longitudinal section

SEM – Scanning electron microscope

SSS – sea surface salinity

SST – sea surface temperatures

TLS – tangential longitudinal section

TS – transverse section

UQARC – University of Queensland Archaeological Reference Collection

UQM – University of Queensland Macrofossil

USDA – United States Department of Agriculture

Chapter One - Introduction

1.1 Introduction

Anthracology, the study of wood charcoal, allows researchers to explore the relationship humans have with wood (Asouti and Austin 2005; Picornell-Gelabert and Servera-Vives 2017). Through the taxonomic identification and dendrological description of wood charcoal, anthracologists can define fuel selection practices, signs of deforestation and management, and reconstruct palaeoenvironments (Asouti and Austin 2005). This technique has a long history of use in Europe and the Near East, but has so far been applied sparingly in Australia (Dotte-Sarout et al. 2015). The current study and others also in progress are demonstrating the great potential of anthracology in Australia (see Whitau et al. *in press*).

Until recently Australia anthracology has developed independently of the international literature. For this reason and because of factors intrinsic to Australian archaeology key methodological and theoretical issues remain to be resolved. The resolution of these issues will strengthen the application of the technique in Australia and will vastly improve our understanding of the relationship humans have shared with wood in the past. Through the anthracological analysis of wood charcoal from fourteen hearths at the site of Madjedbebe (formerly known as Malakunanja II) this thesis will investigate early fire use in Australia and diachronic shifts in fuel wood selection strategies. It will also define the provenance and analytic value of matrix charcoal – a class of charcoal that has been relied upon for palaeoenvironmental reconstructions in Australian anthracology but whose source remains undefined. This is of critical importance as, "…no sound evaluation of the composition of a charcoal assemblage is feasible, unless the type and duration of the human activities associated with fuel consumption and the presence of charcoal debris in the archaeological sediments are adequately understood" (Asouti and Austin 2005:3; see also Chabal 1992; Chabal et al. 1999). Finally, this thesis will develop a heuristic model through which fuel management in Australia can be conceptualised as part of a fire regime. Anthropogenic fire regimes are known ethno-historically as key features in Indigenous landscape management practices. It is therefore essential that models be developed to interrogate how the inhabitants of a landscape managed fuel wood availability and predictability of supply.

1.2 Research aims and rationale

This research is focused on the anthropogenic use of fire at Madjedbebe, both in a domestic setting and in the landscape, and how these activities affect fuel wood selection and supply diachronically. The hearth is the central focus of the domestic space and needs to be constantly supplied with fuel. Therefore, the management of fuel in the landscape is a critical aspect of anthropogenic resource management. The Madjedbebe archaeological record provides a sequence of hearths through which to examine fuel wood selection and management in the landscape.

The aims of this research are 1) to explore the use of domestic hearths over a 55,000 year period at Australia’s oldest known archaeological site, including the earliest confirmed use of fire by humans in the continent. 2) To examine fuel wood selection strategies diachronically and explore how shifts in other subsistence practices may affect collection strategies. 3) To establish the provenance of matrix charcoal and therefore its usefulness as a palaeoenvironment record which is tied in space and time with the archaeological record. And 4) to propose a conceptual model for understanding fuel wood management as part of landscape management practices, in particular, anthropogenic fire regimes.

Madjedbebe is a sandstone rock shelter on the western face of the Djuwamba massif in Kakadu National Park, Northern Territory, Australia (Fig. 1.1) (Clarkson et al. 2015). It is located between the eroding western edge of the Arnhem Land plateau and the Magela Creek wetlands. This landscape is bounded by the South Alligator River to the west of the site and the East Alligator River to its east. This region will subsequently be referred to as the Alligator Rivers region.

Madjedbebe is located in a dynamic landscape rich in cultural and ecological heritage. The range of archaeological sites, the richness of their deposits, and the ancient rock art galleries, places the Alligator Rivers region on par with the great cultural landscapes of the world (Jones and Negerevich 1985:1). The site of Madjedbebe provides an archaeological sequence unrivalled in the region, not just for its antiquity but its substance. Unlike many of the sites in this region, this site was extensively excavated. An initial excavation in 1972 by Kamminga demonstrated the site contained a rich cultural deposit (Kamminga and Allen 1973). This archaeological potential led Roberts et al. (1990a) to re-excavate the site in 1989. They found in the sand sheet below the midden a diverse lithic assemblage and artefacts lying in sands dating between 52 ± 11 and 61 ± 13 ka BP. This chronology made Madjedbebe the oldest

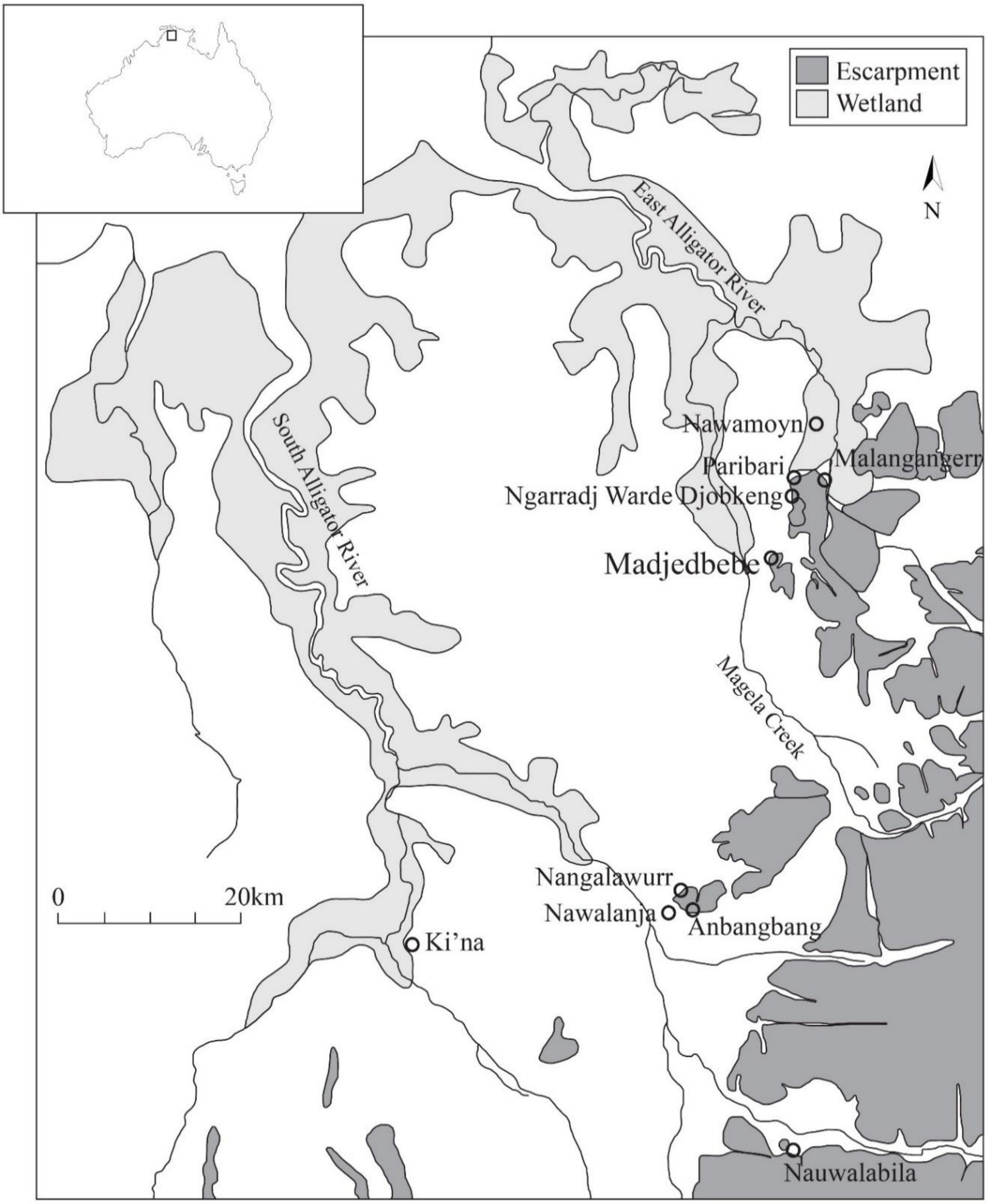
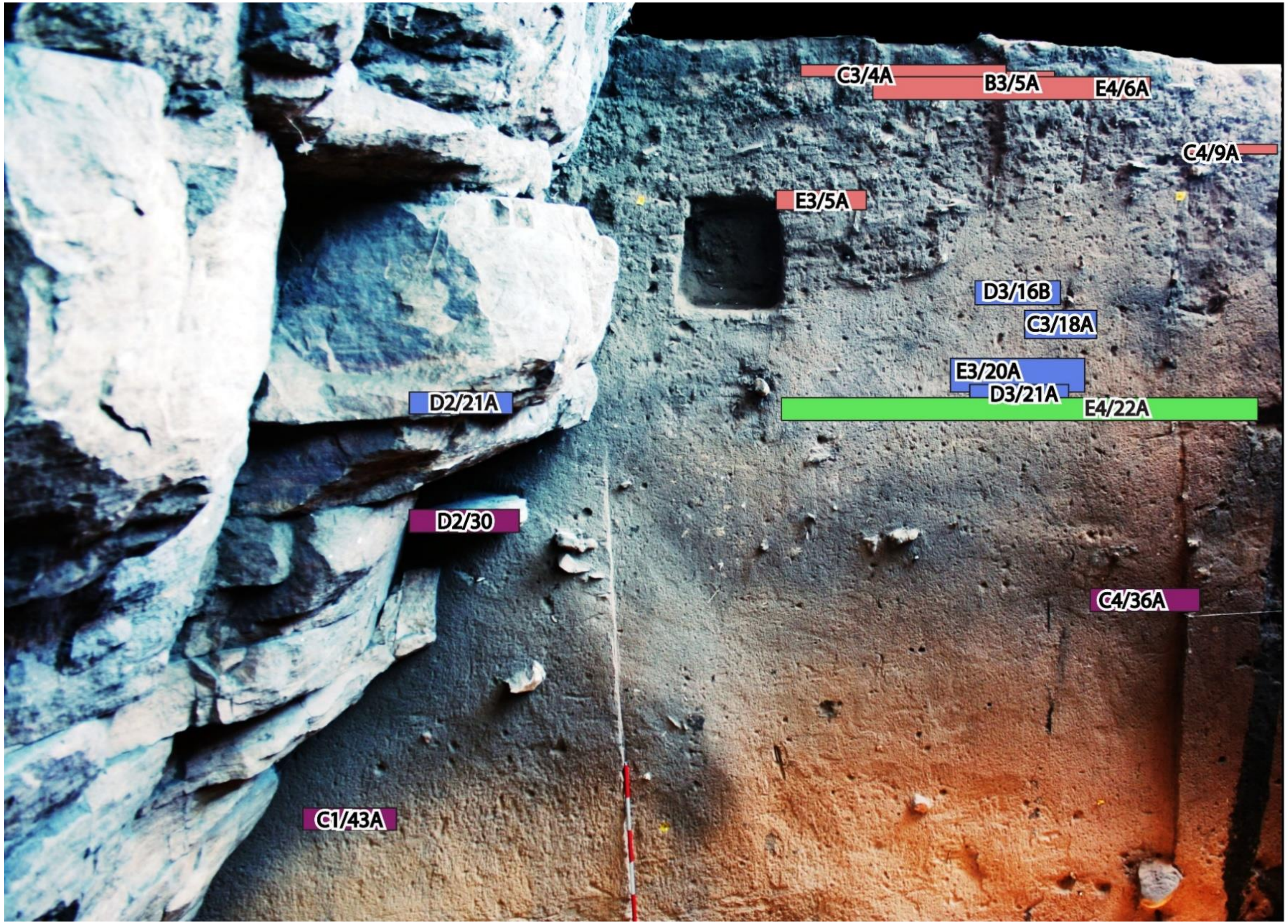


Figure 1.1 Map of Alligator Rivers region showing Madjedbebe in relation to other archaeological sites in the area (redrawn from Clarkson et al. 2015).

known archaeological site in Australia and changed our understandings of human migration during the Pleistocene. Owing to its long chronology and potential for exploring the cultural expressions of the first Australians the site was re-excavated in 2012 and 2015 by Clarkson et al. (2015). A 4 x 3 m sounding was dug in 2012 and a further 2 x 2 m trench was added in 2015 – excavations of this size in Australia are rare. The current research project is exploring the subsistence strategies (macro- and micro-botanics, residues and usewear, fauna) and material culture and technology (lithics, bone points, shell tools/artefacts, rock art) of the inhabitants of Madjedbebe. Whilst these analyses span the entirety of the Madjedbebe archaeological sequence the lower deposits provide an insight into the earliest expressions of humanity in Australia.

Owing in no small part to the size of the excavation Madjedbebe has produced a sequence of domestic hearths ranging in age from 240-7 years cal BP to c. 55, 000 years old (Fig. 1.2. 1.3). The hearth sequence at Madjedbebe spans almost the entirety of human occupation in Australia. No other site in this region has a comparable sequence of hearth contexts. The oldest hearths in this sequence provide an opportunity to explore the earliest confirmed use of fire in Australia. Madjedbebe's archaeological record also provides an unrivalled opportunity through which to examine fuel wood selection and management. Owing to its long chronology its archaeological record spans multiple climatic and cultural changes which have affected the landscape and vegetation of the local area. These changes can be observed in palynological and geomorphological samples from multiple studies in the region. These data sets are, however, limited in their temporal scope and spatial catchment. Therefore, this research has limited its investigation of fuel wood selection strategies to focus on the last 20,000 years. During this period independent palaeoenvironmental data sets provide a sound regionally focused reconstruction of the local environment (Allen and Barton 1989; Clark and Guppy 1988; Hope et al. 1985; Moss [unpublished data]; van der Kaars 1991; van der Kaars et al. 2006; Woodroffe 1988; Woodroffe and Mulrennan 1993; Woodroffe et al. 1985). This independent palaeoenvironmental data provides a baseline off which inferences regarding human fuel wood selection strategies can be made.

Establishing palaeoenvironmental data sets which are spatially constrained and temporally aligned with the archaeological record is a key concern for archaeologists. The charcoal found in the sedimentary matrix of a site could potentially provide such a data set. However, the provenance of matrix charcoal has not yet been convincingly demonstrated. The Madjedbebe archaeological record provides an excellent opportunity to interrogate the



Late Holocene

E3/5A - 240-7 yr cal BP
C3/4A - 260-0 yr cal BP
E4/6A - 450-300 yr cal BP
B3/5A - 720-650 yr cal BP
C4/9A - 2860-2760 yr cal BP

Early Holocene

D3/16B - 8600-8460 yr cal BP
C3/18A - 9130-9000 yr cal BP
D2/21A - 9398-9034 yr cal BP
E3/20A - 12810-12710 yr cal BP
D3/21A - no date

Last Glacial Maximum

E4/22A - 18690-18410 yr cal BP

Oldest hearths

D2/30 - no date
C4/36A - 24970-24340 yr cal BP
C1/43A - no date

Figure 1.2 Madjedbebe south-west stratigraphic section with all fourteen hearths' locations and dates. Late Holocene hearths in red, terminal Pleistocene-early Holocene hearths in blue, the LGM hearth in green, and the oldest three hearths in purple.

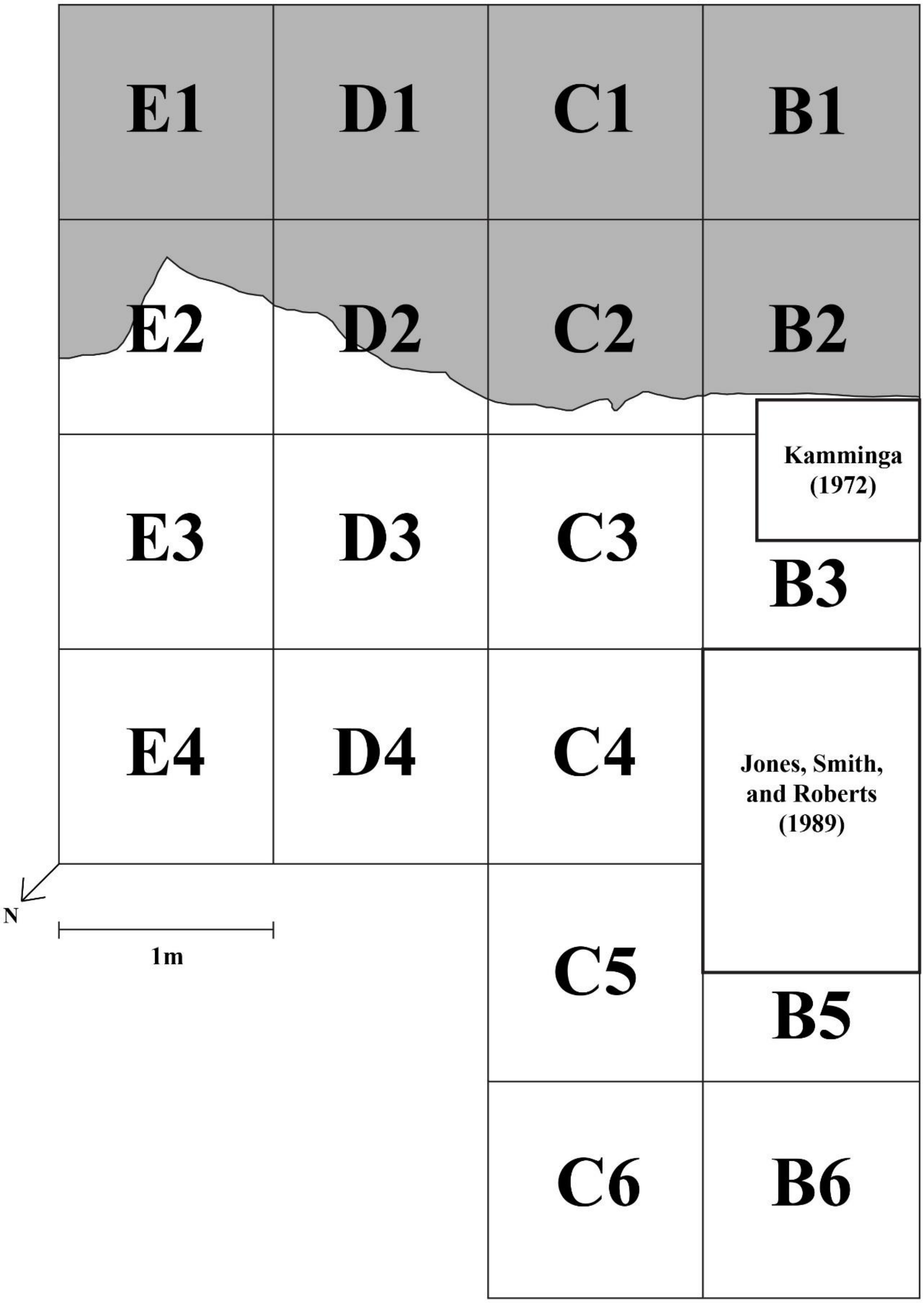


Figure 1.3 The Madjedbebe excavation grid. Note the squares in rows 1 and 2 were excavated as the rock shelter wall dipped away with depth. The location of Kamminga's 1972 excavation and Jones, Smith and Roberts 1989 excavation are shown. All other excavation squares (1x1m) were excavated by Clarkson et al – 2012, 2015.

provenance of matrix charcoal and potentially establish a palaeoenvironmental data set which is tied in space and time with the archaeological record. Such a palaeoenvironmental sequence would provide insights into environmental responses to changes in climate and the impact of anthropogenic activities in the landscape.

The effects of anthropogenic activities in the landscape and how these affect resource availability is a key research focus for archaeologists. The fourth aim of this thesis is to examine the place of fuel wood in the Indigenous Australian economy, which has seldom been considered in the past. A key landscape management practice which has been proposed for Australia is the ‘fire-stick farming’ hypothesis, originally proposed by Jones (1969, 1975, 1980a, 1980b) and subsequently explored by other researchers (Bird et al. 2005; Bliege Bird et al. 2008; Bowman 1998; Bowman et al. 2011; Gammage 2011; Horton 1982; Russell-Smith et al. 1997). This hypothesis, which is heavily based on ethnographic and historical observations, states Indigenous Australians used fire to shape their local environment to produce a managed and economically productive landscape. The absence, however, of fuel wood from these discussions of resource management is a glaring oversight. Globally, the absence of fuel from archaeological discussions and models has been raised by Picornell-Gelabert et al. (2017). The authors call for archaeologists, “…to locate fuel and energy [in] archaeological narratives as an arena of society and environment interactions and thus, a central and common topic for the entire archaeological community…” (Picornell-Gelabert et al. 2017:2). The proponents of the ‘fire-stick farming’ hypothesis need to consider that the fuel which is consumed in a landscape burn is the same fuel which is collected for the hearth. To hypothesise the use of landscape burning as a tool for resource management and omit fuel wood from those discussions is to leave an enormous hole in our understanding of human resource management practices. Fuel wood is an essential daily resource, if an area is burnt as part of a larger landscape management practice the fuel wood resource in that area will be decimated. Therefore fuel wood needs to be considered as an integral part of these practices. To fully explore and understand the fuel wood selection practices operating at Madjedbebe a new theoretical framework needs to be constructed. There needs to be a move away from unilinear understandings of fuel wood use based on a concept of supply and depletion to fuel wood management and its place in local ecology.

Shackleton and Prins (1992), in their often cited paper, discussed the application of the principle of least effort (PLE) in fuel wood studies. PLE is a ‘general law’ which does not accommodate local cultural and ecological nuance. The limitation of the principle of least effort for assessing fuel wood selection pressures in a non-permanent settlement was outlined by Shackleton and Prins (1992). They demonstrated that PLE would not apply in an area of abundant fuel wood and species diversity. Their interrogation of PLE demonstrates it does work in certain situations, when preferred fuel wood is locally depleted and people broaden their fuel wood selection to non-preferred fuel taxa or increasing their foraging range. However, if fuel wood is not being collected under these conditions, if it is being managed within particular ecological parameters, then a different framework needs to be developed. Shackleton and Prins (1992:633) stated that, “Additional factors such as annual burning of wood vegetation...may influence the process... [and] require further research.”

The omission of fuel wood from considerations of Indigenous economy and landscape management practices is an enormous gap in current theorising of past hunter-gatherer behaviour. This thesis will respond to the absence of fuel wood from these debates by proposing a new theoretical perspective. By taking the ‘fire-stick farming’ hypothesis as a hypothetical post-LGM land management practice, this thesis will explore the place of fuel wood in the Indigenous economy. It is proposed that the mosaic burning pattern observed ethnographically and historically should be seen as a form of niche construction (see Odling-Smee et al. 2003; Rowley-Conwy and Layton 2015). Through their landscape burning practice people are creating ecological niches for economic benefit, including the protection of fuel wood supply. The creation and maintenance of these niches over time produces an ‘ecological inheritance’, as defined by Odling-Smee et al. 2003, which is passed down one generation to the next, leaving an anthropogenic signature on the landscape.

The creation of landscapes as seen through the niche construction of mosaic burning will be interpreted through the framework of historical ecology. “Historical ecology traces the ongoing dialectical relations between human acts and acts of nature, made manifest in the *landscape*” (Crumley 1994:9; original emphasis). Historical ecology provides a “comprehensive, interdisciplinary framework” through which to examine the dialectical relationship between humans and their landscape through fire (Crumley 1994:2). The operation of a fire regime enables humans to not just ensure the continuity of supply of vital resources (i.e. food and fuel) but to actively reduce fuel loads and in effect domesticate fire. An out of control bushfire is perilous on both the short and long term for those living in Australia – a continent which has been fire prone since the Tertiary (Bowman 2003:6-7). Short term, an out of control bushfire cannot be out run. It is fatal. It destroys indiscriminately. It kills animals, destroys plants, pollutes water ways, and damages sacred places. Each of which are a vital resource and a responsibility whose destruction has long term consequences. Through their mitigation of deadly fuel loads, Indigenous Australians effectively domesticated fire and allowed humans to thrive in the ‘fire continent’ (Balee 1998:16; and see also Gammage 2011; Pyne 1998;). The construction of niches through fire produced an ‘ecological inheritance’ that dramatically reshaped the human landscape of Australia.

1.3 Outline of chapters

This introductory chapter has discussed the rationale for this research and outlined the key research foci of the thesis. Each of these foci will be carefully considered and critiqued in the subsequent chapters.

Research aim one will be established in Chapter 2 (Literature review) through an examination of the anthracology literature, particularly focused on the use of charcoal from archaeological sites. Chapter 3 (Landscape, archaeology and ecology) will examine the large scale landscape evolution of the Alligator Rivers region and associated changes in ecology and vegetation. In Chapters 4 and 5 the taxonomic composition of the Madjedbebe hearths will be presented and methods used to achieve these identifications will be outlined. Following which, Chapter 6 (Discussion) will detail the taxonomic changes which have occurred in the Madjedbebe hearths.

Research aim two will be furthered in Chapter 2 (Literature Review) through an exploration of key anthracology literature. It has been demonstrated by a range of authors that hearths are often single or short use contexts which represent fuel wood selection choices. To fully explore selection an environmental baseline will be established in Chapter 3 (Landscape, archaeology and ecology). This independent baseline will provide a sound basis from which to examine selection choices at Madjedbebe over the last 20,000 years. The suitability of the hearth contexts for examining fuel wood selection will be outlined in Chapter 4 (Methods and methodology) and the results will be presented in Chapter 5. Chapter 6 (Discussion) will critically examine the data to determine whether fuel wood selection was operating at Madjedbebe.

Research aim three, examining key methodological issues in Australian anthracology, will be situated in the international and Australian anthracology literature in Chapter 2 (Literature review). One of the challenges of undertaking anthracology in the tropical north of Australia, high taxonomic diversity, will be highlighted in Chapter 3 (Landscape, archaeology and ecology). This challenge will be fully explored in Chapter 4 (Methods and methodology) in which the construction of a reference collection is outlined. This reference collection will be presented in Chapter 5 (Results), as well as the presentation of a compositional comparison of matrix and hearth charcoals. This comparison will be fully explored in Chapter 6 (Discussion), in which the usefulness of matrix charcoal as an analytical tool will be outlined.

Research aim four, the place of fuel in the Madjedbebe economy and as part of fire regime will be explored in Chapter 2 (Literature review) through an examination of the fuel wood and fire regime literature. Signs of management and modification will be presented in Chapter 3 (Landscape, archaeology and ecology) to determine whether there are ecological signs of management in the local environment. Central to this discussion (Chapter 6 – Discussion) will be defining the place of fuel wood in a fire regime and the implications of this for the Madjedbebe wood charcoal assemblage.

The concluding chapter (Chapter 7 – Conclusion) will summarise the outcomes of the thesis. Each of the four research aims will be considered with a brief summary.

Chapter Two – Literature Review

2.1 Introduction

The research aims of this thesis are to examine fuel wood selection and fire use at Australia's earliest known human habitation site, Madjedbebe, and to extend the development of anthracological method and theory in Australian archaeology. To begin, this chapter will explore the relationship humans have developed with fire over hundreds of millennia. This relationship has been beneficial to humans but has also tied them to a dependency on fuel. Accessing and managing fuel in their local landscape and trade relationships has therefore been hugely important for human societies globally. One way archaeologists have explored this relationship is through the analysis and interpretation of assemblages of wood charcoal (anthracology) preserved on archaeological sites. The development of anthracological method and theory will be outlined in section 2.3, including a review of anthracology in the tropics and in Australia. This literature provides the theoretical and methodological basis from which this research is constructed. It is clear from the global anthracology literature that anthropogenic fuel wood selection must be situated in its local ecology and landscape. It is for that reason that the remainder of the chapter will examine the landscape modifying practice of anthropogenic landscape burning and conceptualise these practices as discrete events in the formation of the landscape.

2.2 Fuel: 'it's good for humanity'

The importance of fire to humanity cannot be overstated. Fire, 'the greatest human discovery after language' (Darwin [1871] 1998), has had an immense effect on human evolution, socialisation, and expression. Evidence for initial fire use by *Homo erectus* is speculative. Some claim hominid fire use from the Lower Pleistocene owing to burnt patches of earth at Koobi Fora and Chesowanja (Gowlett 2010:353). Wrangham and Carmody (2010) claim that these early interactions with fire facilitated behavioural and anatomical changes observed in *Homo erectus*. Food softened with fire reduced the need for large molars and nighttime fires provided defense against predators facilitating terrestrial occupancy (Wrangham and Carmody 2010: 190, 196). Substantive evidence of domestic fire use by early hominins, in the form of hearths, come from the Middle Pleistocene at Beeches Pit, Schöningen in northern Europe, and Gesher Benot Ya'aqov in Israel (Gowlett 2010:354).

Once fire was tamed in the hearth (*focus* is Latin for hearth) it became the centre of the domestic space (Gowlett 2010:358; Heizer 1963:187; Pyne 1998:70). This central fire allowed humans to light and heat, to extend their range both spatially (geographically into colder clines) and temporally (extend day length via artificial light) (Gowlett 2016:2, 7). Through cooking, fire aided social and dietary transformations. Fire did not just detoxify poisonous foods but softened them and allowed humans to extract more energy from each meal than they were able to previously (Pausas and Keeling 2009:297). Cooking also facilitated extra-somatic digestion, which softened food for the elderly and greatly extend their lifespan. Pausas and Keeley (2009:587) claim that this innovation has implications for Hawkes' (2004) 'grandmother hypothesis' in which elderly females contributed to the evolutionary success of their bloodline by caring for their grandchildren.

> *"Fire, once obtained, could never again be parted with, for its benefits*
> *were too great…"* (Lippert 1931:130)

Fire, so often seen as a destructive force has facilitated the expression of human creativity (Pyne 2016:1). Control over fire allowed humans to extend their day into the night. This extra time provided a forum for increased socialisation, conversation, and storytelling, all of which are important for the development of language and culture (Dunbar 2014:14013-14014; Gowlett 2010:357; Wiessner 2014:14027). Fire has also allowed humans to transform materials and construct complex objects and structures. The use of fire has been key to the heat treatment of stone to improve its flaking properties (Brown et al. 2009), the heating of adhesives for the construction of composite tools (Koller et al. 2001), the transformation of plastic clay into hard ceramic (Kuzmin 2013), and the conversion of ore into metal (Heiss and Oeggl 2008). What began as a beneficial interaction quickly became a relationship of great dependency. Fire established itself as the essential human transformative tool, but fires needed to be continually fed, and fuel needed to be continually provided.

This interaction has deep roots, which stretch back to the earliest interaction of hominids and fire. There are many archaeological examples of fuel exploitation, depletion and how humans respond (Fall et al. 2002; Longford et al. 2009; Willcox 1974; Wright *in press*). As fuel supply diminished humans are known to broaden their selection preferences (exploiting taxa which were initially non-preferred) (Shackleton and Prins 1992), shift from renewable (dead wood, branch wood) to non-renewable sources (cutting down trees – trunks and roots) (Wright 2016), expand their foraging range (Willcox 1974), and ultimately change from wood to another source of fuel (Longford et al. 2009:130; Miller 1984). The interaction of humans with fuel, however, does not necessarily have to end in depletion and crisis. Dendrological research in Eurasia has demonstrated that through coppicing and pollarding practices humans were able to manage fuel wood supply and the longevity of woodland (Deforce and Haneca 2015). This interaction between humans and fuel sources can be studied archaeologically through the examination of wood charcoal. Anthracology explores the taxonomic and dendrological features of archaeological charcoal to examine patterns of fuel use and landscape management.

2.3 Anthracology

2.3.1 Introduction

The study of wood charcoal is defined and constrained by archaeological context and taphonomy. Both of these key concepts need to be thoroughly understood before a sound anthracological investigation can be conducted (Asouti and Austin 2005; Chabal 1992; Chabal et al. 1999; Thery-Parisot et al. 2010). Anthracology can be applied to examine primary archaeological contexts, secondary archaeological contexts, and non-archaeological contexts. Each of these different context types is useful for interpreting human activities and environmental impacts. Charcoal bearing primary archaeological contexts are typically single- or short-lived activity areas, such as a fire hearth or cooking pits. They may also relate to building materials, pottery kilns, or metallurgical apparatus. Primary contexts are useful for examining firewood collection and selection patterns because they contain the products of single events or choices. Secondary contexts offer a broader mix of archaeological charcoals often representing the residues of multiple fuel selection events and activity types. These contexts are often the accumulation of residues in rubbish pits and middens, but may also relate to dispersed charcoals. These secondary contexts produce more taxonomically rich charcoal assemblages which are better suited to palaeoenvironmental reconstruction and examining woodland management practices. This is because their higher taxon richness provides a more accurate representation of past woodland composition and structure. The investigation of non-archaeological charcoal contexts is known as pedoanthracology. Pedoanthracological samples provide palimpsests of woodland vegetation that are not based on archaeological samples, which minimizes bias from anthropogenic fuel selection activities. These samples can be used to reconstruct palaeoenvironments and the impact of anthropogenic activities within them.

Hearth charcoals will be employed in this thesis to examine fuel wood selection patterns at Madjedbebe. The primary focus of this research will not be the reconstruction of palaeoenvironments, because hearths are heavily biased by human selection. Charcoal from hearths can, however, provide an insight into the vegetation communities present near a site at a given point in time. These hearths, however, provide an insight into anthropogenic fuel wood management and selection practices – the focus of this thesis. Because different charcoal bearing context types are affected by a range of different taphonomic processes these need to be taken into consideration when interpreting a charcoal assemblage.

2.3.2 Anthracology method and theory

Anthracological researchers at the University of Montpellier have extensively explored the impact of taphonomic processes on the representativeness of anthracological assemblages. This body of research has come to be known as the Montpellier School (Asouti and Austin 2005:1). The Montpellier School is focused on reconstructing the palaeoenvironments of the Western Mediterranean. Mainly published in French the Montpellier School adopt strict sampling protocols, sample multiple sites in an area, use modern vegetation descriptions and other sources of palaeoenvironmental data to reconstruct the palaeoenvironment (Chabal 1988, 1992, 1997, Chabal et al. 1999; for English translations and interpretations see Asouti and Austin (2005), Dotte-Sarout et al. (2015) and Figueiral and Mosbrugger (2000). This approach is argued to enable them to produce a proportional representation of the palaeoenvironment while mitigating against the effects of taphonomy and human selection bias.

Their reconstructions are based on a number of core assumptions. First, they hold that fuel wood is collected in accordance with the principle of least effort (PLE). PLE states fuel wood will be collected in direct proportion to its occurrence in the woodland surrounding a site. Wood charcoal therefore provides researchers with an accurate palaeoenvironmental sample for the local woodland. Second, they maintain that Chabal's (1988, 1992) 'Law of Fragmentation' means that charcoal will fragment into a high number of small fragments and a low number of large fragments, and that fragmentation is driven by extrinsic factors not species type (Asouti and Austin 2005:2-3). The Law of Fragmentation mitigates against particular taxa fragmenting more than others (owing to their intrinsic characteristics – anatomy and/or chemistry) and disproportionally swamping the sample, destroying the representativeness of the assemblage. Finally, they state that any random biases that do occur in species representations can be compensated for by a rigorous sampling protocol.

To produce a sound and representative reconstruction of the palaeoenvironment four sampling safeguards need to be ensured. (1) Only sample long-lived, multi-episodic contexts. Hearths are not suitable because they may represent only one or a few fuel wood selections. Pits, middens, ash dumps are better suited to accurately capture the full floristic diversity of the local environment. (2) Only sample domestic fuel, not specialty/industrial contexts. This is because specialist/industrial activities use specific fuel types, which can skew the composition of the assemblage. (3) All fragments ≥ 2mm must be included because smaller calibre woods and rarer taxa may only be represented by small fragments. (4) Large sample sizes need to be analysed to capture the full floristic diversity of the area. This final measure is dictated by the predicted vegetation type with 200-400 fragments per stratigraphic unit or context being required, higher in tropical areas where larger sample sizes are required due to higher floristic diversity. Critical to anthracology sampling is knowing what context the charcoal came from, and how the context was formed (Asouti and Austin 2005:3; Chabal 1992; Chabal et al. 1999). Maintaining these strict methods is of critical importance to the Montpellier School because they state that archaeological wood charcoal can be used to produce a compound picture or "...a slightly distorted representation of the actual proportions between woody taxa in the past vegetation" (Chabal 1992:221 cited by Dotte-Sarout et al. 2015:4; also Asouti and Austin 2005:4).

The assumption on which the 'Law of Fragmentation' is based, that charcoal will fragment into a high number of small fragments and a low number of large fragments, has been called into question by recent scientific inquiry. Recent experimental work by Chrzazvez et al. (2014:37) examining the fragmentation of ten common European taxa has demonstrated that physical characteristics play a more important role than charring temperature. They examined how 2 cm cubes of charcoal fragmented when crushed in a hydraulic traction compression testing machine. This test demonstrated that the pressure needed to crush a specimen varied between taxa. The authors noted that this would mean different taxa in the same archaeological context would be differentially affected by pressure and therefore bias the composition of any subsequent charcoal assemblage (Chrzazvez et al. 2014:39-40). They tested specimens charred at 400, 500 and 750^{o} C for 30 minutes for each of the ten taxa (Chrzazvez et al. 2014:32). Their results demonstrated that there is a statistically significant difference between fragmentation rates for the individual taxa examined (Chrzazvez et al. 2014:35). The authors concluded that the differential fragmentation observed in the assemblage could be attributed to the physical characteristics of the source wood. For example, the large multiseriate rays and porous early wood zone on the transverse plane of *Quercus* sp. are conducive to the initiation of a large number of cracks under low pressure (Chrzazvez et al. 2014:39). These physical features led to the over representation of *Quercus* sp. in the >4 mm size class, demonstrating that all size classes need to be sampled for representative results (Chrzazvez et al. 2014:38, 39). The results also demonstrate that taxa, such as *Carpinus* sp. and *Corylus* sp., whose vessels are large and arranged in long radial files produce more fragments. This is in contrast to homogenous woods (small isolated vessels or homoxylates) which produce the least number of fragments (Chrzazvez et al. 2014:38). The research of Chrzazvez et al. (2014) demonstrates that the physical, and possibly chemical, components of taxa can differentially affect how it fragments and therefore proportionally changes its representation in the charcoal assemblage.

> "*The palaeoenvironmental significance of a charcoal diagram is based on three main assumptions: the taxonomic richness, the reproducibility of charcoal spectra, and the assumption that ratios between species in the spectra are the same as those in the present environment." (Heinz and Thiebault 1998:57)*

The four key rules developed by the Montpellier School have greatly improved the anthracological method. However, the work of Chrzazvez et al. (2014) and others have demonstrated that differential taphonomic impacts can adversely affect the representativeness of a charcoal assemblage. The Montpellier School stress that inter- and intra-site reproducibility of results is essential for sound palaeoenvironmental reconstruction. The other issue this approach faces is that it assumes that the ratios between species in the anthracological spectra are the same as the present ecological communities and that it uses this assumption to directly reconstruct the past environment (Heinz and Thiebault 1998:57). ; This assumption fails to acknowledge that the vegetation communities of the present may have been dramatically altered by anthropogenic impacts or alternatively the vegetation communities of the past may have been under anthropogenic management that has since ceased, meaning there is no modern correlate of a vegetation community of that composition. Asouti and Kabukcu (2014:178) stress that a reliance on modern ecology and woodland composition to reconstruct past environments is problematic because of the impacts of anthropogenic activity on a landscape and the changes this may have wrought in the composition and distribution of woodland species.

While not all researchers fully agree with every aspect of their approach, the Montpellier School should be credited with being at the forefront of global methodological and theoretical developments in anthracology. Their research into fragmentation and differential preservation, and core sampling criteria, has led to a better understanding of the representativeness of wood charcoal assemblages and their veracity in palaeoenvironmental reconstruction. The methods developed by the Montpellier School remain central to the reconstruction of palaeoenvironments. There remains, however, some contention between researchers regarding how specific these reconstructions can be, a point which is further explored in section 2.3.3 (*Palaeoenvironmental reconstruction*).

2.3.2.1 The four filters – from woodland to anthracology spectra

According to Thery-Parisot et al. (2010a:143) wood passes through four filters as it moves from past living vegetation to anthropogenic wood charcoal assemblage. These four filters are, the societal filter, the combustion filter, the depositional/post-depositional filter, and the archaeological/anthracological filter. At each of these stages different factors shape the composition of the final anthracological reconstruction. It is therefore essential to fully interrogate each of these filters before interpreting an anthracological assemblage and reconstructing the past vegetation. Each of these four filters will now be discussed in more detail.

The selection and collection of fuel wood from the past vegetation is first conditioned by the societal filter. Henry and Thery-Parisot (2014a:69) state that the satisfaction of a group's fuel needs "is an expression of socio-ecological context." They outline four main elements of the societal filter: (1) the organisation of the group: group size, site size, occupation duration – these factors are important for considering the impact of anthropogenic fuel use on the woodland resource; (2) social organization: division of labour, procurement frequency, subsistence practices – similar to the organisation of the group, these factors will impact upon the amount and supply of fuel wood available; (3) collection techniques: collection tools, knowledge of the location, and properties of different fuels – the decisions being made about which taxa to collect and the technology employed to extract them; and (4) ideological factors: perceptions of the environment, habits, preferences and taboos – the cultural considerations, including ontology, preferences, and taboos which shape selection decisions including avoidance of particular taxa. These four parts of the societal filter shape how taxa are extracted from the past vegetation, at what frequency and intensity, and why particular taxa may be preferentially selected while others are avoided. These are the set of selection criteria that condition the wood from the past vegetation that is put to fire.

When wood is put to fire it is thermally, chemically, and physically altered (Thery-Parisot et al. 2010a:146). In a low-oxygen environment wood is carbonized and turned into charcoal (charcoalified) (Braadbaart and Poole 2008:2435 Fig. 1). In the presence of oxygen, however, charring can occur leading to the production of charcoal and ash. Incomplete charring will produce charcoal, while complete charring will produce ash (Braadbaart and Poole 2008:2435 Fig. 1). Ash is granular and powdery, lacking the anatomical features required for taxonomic identification. Charcoal by comparison preserves the lignified anatomical features of its source wood, including important diagnostic microstructures (Thery-Parisot et al. 2010a:146). These anatomical features are used by anthracologists to determine a taxonomic identification. The charcoalification process does cause retraction, fusion and cracking and the wood undergoes substantial mass reduction during this process. Thery-Parisot et al. (2010a:146) refer to combustion as a double filter, "…firstly by limiting the taxonomical information, and secondly by falsifying the real quantity of initially burned wood and therefore the representativeness of the assemblage." This process causes wood to undergo substantial mass reduction and fragmentation, and can cause vitrification and radial cracking.

Thery-Parisot et al. (2010a:147) claim that Chabal's law of fragmentation demonstrates that fragmentation is uniform across taxa. However, they state this law only holds for an anthracological assemblage, which has passed through both the combustion and post-depositional filters, not combustion alone; the latter describing an experimental assemblage. They maintain that there has been substantial debate and experimentation but there is no clear consensus on how combustion affects fragmentation in isolation. Research published after Thery-Parisot et al.'s 2010a paper has demonstrated that different taxa do in fact fragment differentially. The research of Chrzavzez et al. (2014), as discussed above, demonstrated that the physical anatomy of taxa plays a significant role in how it fragments (Chrzavzez at el. 2014:40). Taxa such as *Quercus* sp., which have large multi-seriate rays and a porous early wood zone are more likely to fragment along these natural fault lines than those taxa which have a more homogenous internal anatomy (Chrzavzez et al. 2014:37-38). The transformative charcoalification process is a distortive filter whose affects are not yet fully understood (Thery-Parisot et al. 2010a:147). However, experimental research is starting to unpack some of the complexity of this process and highlight that its effects are species and hence regionally specific. The combustion filter may distort our understanding of the wood put to fire, however, this process is essential for converting organic wood into inert and resilient charcoal available for anthracological analysis.

The third filter which charcoal passes through from woodland to anthracological reconstruction is intrinsically archaeological. The effects of depositional and post-depositional processes affect the preservation of charcoal in the archaeological record in much the same way they affect other artefact classes (Thery-Parisot et al. 2010a:148). Following firing, charcoal could be trampled, reworked, or cleaned away in the daily activities of the site. A range of atmospheric and climatic phenomena impact on the preservation of charcoal including rainfall, wind, and flooding. These and other seasonal occurrences such as freeze-thaw and huge fluctuations in precipitation can alter contexts and the charcoals contained within them. The effects of earth worms, burrowing animals, roots, and termites can also facilitate the movement of charcoal in the archaeological site (Thery-Parisot et al. 2010a:148). Owing to charcoals inert organic state microbial attack is slowed but not completely defeated. Nor are the effects of pH insignificant, as charcoal preservation is affected by acidic and alkaline sediments, with a more neutral pH conducive to its survival (Braadbaart et al. 2009). Thery-Parisot et al. (2010a:150) claim these post-depositional factors do not differentially benefit one taxon over another. They claim differential preservation, if any, has more to do with the state of the wood put to fire (i.e. healthy or decayed) than its taxonomy (Thery-Parisot et al. 2010a:15). The impact of all of these factors needs to be considered when interpreting an anthracological assemblage, including an assessment of whether healthy or decayed wood was put to fire. This will be further explored below, in section 2.3.5, through a discussion of dendrology and an examination of the work of Marguerie and Hunot (2007).

The final filter charcoal phases through, according to Thery-Parisot et al. (2010:143), is the archaeo-anthracology filter. The sampling strategy and field recovery techniques employed on an archaeological site will dramatically alter the representativeness of the final archaeobotanical assemblage. Systematic sampling of all contexts as well as ‘dispersed’ charcoal will produce a more representative anthracological assemblage. The employment of a flotation tank will greatly increase the recovery of botanical remains. However, flotation can fragment and even destroy wood charcoal. Hand-picking can bias a charcoal assemblage towards large fragments which in turn affects representativeness. Some researchers combine hand-picking with flotation, recovering as many pieces of charcoal as possible by hand before floating the residue (Allué et al. 2007; Badal et al. 2003; Zapata 2002 cited by Allué et al.

2017:3). Allué et al. (2017:3) choose to hand pick all charcoal encountered as part of their excavation of Abric Romani in Spain. The authors were confident that their method, coupled with fine-grained three-dimensional plotting of all artefact size classes, would produce a representative anthracological assemblage.

2.3.3 Palaeoenvironmental reconstruction

The veracity of palaeoenvironmental reconstruction based on charcoal data has been questioned since the earliest applications of the technique. Godwin and Tansley (1941) were highly critical of Salisbury and Jane's (1940) analysis from Maiden Castle in Dorset. Salisbury and Jane (1940) had used the Maiden Castle charcoal assemblage to produce a proportional reconstruction of the palaeoenvironment. Godwin and Tansley (1941) questioned the accuracy of this approach. The core of this debate was whether the observed frequencies in the charcoal assemblage accurately reflected the actual proportions in the past environment (Asouti and Austin 2005:1). Smart and Hoffman (1988) offer a more recent critique of the approach. The authors claim that it is difficult to reconstruct the past environment from a charcoal assemblage because of differential fragmentation and mass reduction between taxa and the sampling bias of anthropogenic fuel wood selection strategies (Smart and Hoffman 1988:190). The methodological and theoretical developments of the Montpellier School, outlined above, have dealt in part with some of these limitations. There does, however, remain a division between how different researchers quantify an anthracological assemblage. There are those who believe qualitative measures should be used (ubiquity, presence/absence of taxa) to interpret wood charcoal assemblages because of the limitation of the method (Smart and Hoffman 1988; Thompson 1994; Willcox 1974). The majority of researchers, however, use some form of quantitative approach based on frequency data. The quantitative group can be further split into those who assert that under the right circumstances an anthracological assemblage can be held as a compound picture of the past woodland and those who interpret anthracological data in conjunction with uniformitarian assumptions to reconstruct the palaeoenvironment.

The case studies presented below explore the two major methods for quantitative anthracology in palaeoenvironmental reconstruction. In the first wood charcoal data has been used to determine the proportional composition of past woodland, and in the second it has been used to demonstrate the presence or absence of particular taxa and interpret this using uniformitarian assumptions.

2.3.3.1 Case Study 1: French Pyrenees

Heinz's (2002) research in the French Pyrenees provided the first charcoal sequence for the region. She states, "…using charcoal data we can trace the evolution of the plant cover and the changes in the vegetation…from about 13,000 BP to 7000 BP" (Heinz 2002:95). Her research demonstrates how wood charcoal data can be used to create very specific reconstructions of the past environment. Heinz's method complies with the approach outlined by Chabal and others of the Montpellier School. She sampled charcoal relating to domestic fire wood use, avoiding construction and specialty tasks (Heinz 2002:95). Her samples were sourced from dispersed charcoals related to long-term activities (avoiding short or single use contexts such as hearths) (Heinz 2002:95-96). She also employed saturation curves to ensure her sample size was large enough to capture the full floristic diversity of the area (Heinz 2002:96).

Confident that this rigorous sampling protocol would ensure an unbiased charcoal assemblage, Heinz makes quite specific claims about the composition of the palaeoenvironment. She states that *Juniperus* predominates in the surrounding environment in phase T1 (13,000 BP – c. 11,000 BP) and that in phase T3 (c.10,000 BP – c. 7,500 BP) *Pinus sylvestris* makes up about 10% of the local woodland (Heinz 2002: 97, 99). She confidently concludes that these results correlate well with the palynological record for the region and that this justifies the method (Heinz 2002:100). This analysis fails to question the veracity of the palynological record as a sound local baseline. As Wright et al. (2015) found in Central Anatolia, pollen sequences do not necessarily represent the composition of the local woodland. This analysis also fails to consider the alternative explanations for temporal change in the composition of the local woodland. Heinz concludes that shifts in taxa abundance are driven by climatic factors but she does not consider the other factors that may be altering the composition of the local woodland in the past. The work of Asouti and Kabukcu (2014) in Central Anatolia demonstrates that concepts such as 'climax vegetation' do not consider the impact of anthropogenic activities on the local landscape and therefore should not be assumed.

In contrast to Heinz and the Montpellier approach, Asouti et al. (2015) and Wright et al. (2015) focus on reconstructing the past woodland through anthracology, providing insights into the presence of particular woodland types and proposed distribution. They discuss the dominance of particular species but do not offer percentages of its occurrence in the local woodland.

2.3.3.2 Case Study 2: Southern Levant

Asouti et al.'s (2015:1566) aim was to reconstruct the vegetation catchment managed by the Pre-Pottery Neolithic (PPN) inhabitants of the southern Levant. Investigating whether these changes were tied to anthropogenic or climatic impacts. They employed the methods outlined by Chabal et al. (1999), sampling all charcoal >2 mm in size from long-use dispersed contexts (Asouti et al. 2015:1577). The authors quantify their data using raw and percentage counts and ubiquity across sampled sites. In contrast to Heinz (2002), the authors discuss the dominance of particular taxa as part of the wood charcoal assemblage, not the local woodland (Asouti et al. 2015:1569). For example, *Pistacia* dominates the PPNA charcoal assemblage (>70%). This does not necessarily mean it dominates the woodland vegetation at that time. Similarly, the distribution of a particular taxa is discussed more in relation to its presence in the wood charcoal assemblage rather than the local woodland (Asouti et al. 2015:1568).

This wood charcoal assemblage demonstrates that *Pistacia* woodland was present at sites to the east and south of the Jordan Rift Valley in the early Holocene (Asouti et al. 2015:1571), an area which is currently treeless. The occurrence of this woodland type also suggests the area had higher precipitation in the early Holocene than it does currently (Asouti et al. 2015:1571). There is a shift from charcoal assemblages dominated by *Pistacia* in the PPNA (i.e. >70%) to those in the LPPNB/PPNC dominated by riparian woodland taxa (>70%) with *Pistacia* only making up a minor component (~6%) (Asouti et al. 2015:1569-70). The decline of *Pistacia* is not seen as a sign of deforestation because the taxa remain ubiquitous in the LPPNB/PPNC assemblage (13 out of the 19 sampled contexts) (Asouti et al. 2015:1570). This conclusion is further supported by the limited use of dung as fuel during this period (Asouti et al. 2015:1576). The authors claim this change is due to a shift in fuel wood selection tied to an intensification of horticultural activities in the riparian biome (Asouti et al. 2015:1574). They go on to hypothesize the ongoing presence of *Pistacia* woodland is probably due to woodland management (Asouti et al. 2015:1577).

Asouti et al.'s study of wood charcoal from the southern Levant successfully straddles palaeoenvironmental reconstruction while remaining cognisant of the biasing effects of anthropogenic wood selection. The authors trade the specificity of the Heinz (2002) approach for a more general approach which allows for the acknowledgement of anthropogenic influences affecting the fidelity of the assemblage.

2.3.3.3 Case Study 3: Kaman-Kalehöyük

Wright et al. (2015) follow a very similar method to Asouti et al. (2015). The authors use the wood charcoal assemblage from Kaman-Kalehöyük to provide a clear local signature of woodland composition in Central Anatolia during the Bronze and Iron Ages (Wright et al. 2015:219). This was a period of social and political upheaval in the region, however, existing pollen data provides a poor insight into the local ecology. The authors used standard anthracological procedures, sampling rubbish pit contexts, to evaluate changes in the wood resource and hence tree cover (Wright et al. 2015:221). All identified wood taxa were quantified using ubiquity, relative and absolute abundance following Asouti and Austin (2005) and Smart and Hoffman (1988). These presence, abundance, and ubiquity data were discussed as part of contexts rather than representing the frequency/proportion of past woodland (Wright et al. 2015:223).

The authors use vegetation communities to group particular taxa and discuss their habits rather than assigning them an absolute proportion in the environment. Correspondence analysis and chi-squared tests were employed to demonstrate that there is a significant shift in the composition of the wood charcoal assemblage diachronically (Wright et al. 2015:225). These tests and the wood charcoal data demonstrate that open oak woodland was present around the site throughout the Bronze and Iron Ages. There is, however, a shift in the type of oak woodland present based on the decline of minor taxa in the assemblage. This shift in composition is from well-established oak woodland (described by Davis 1965-85; Zohary 1973) 'to a more low-diversity highly disturbed oak-dominated woodland (described by Asouti and Kabukcu 2014). Oak remains ubiquitous throughout the wood charcoal assemblage with the spike in pine charcoal during the Iron Age interpreted as a shift in fuel wood selection following the collapse of the Hittite Empire.

The biasing effects of human selection can impact upon the fidelity of a palaeoenvironmental reconstruction based on wood charcoal. Research by Chabal and others from the Montpellier School have dealt with some of the concerns raised by Godwin and Tansley (1941) and Smart and Hoffman (1988). A division does still remain between those who employ wood charcoal to create a compound picture of the past woodland based on frequency, and those researchers who use the presence and ubiquity of taxa coupled with uniformitarian understandings of vegetation communities and habit to reconstruct a hypothesized past woodland.

2.3.4 Pedoanthracology

Concerned by the effect cultural filters may have on palaeoenvironmental reconstructions based on anthracology, Thinon (1978) responded by moving his wood charcoal analysis outside of archaeological sites. Thinon (1978) deliberately targeted non-archaeological, or 'natural', sites to reconstruct the palaeoenvironment. He termed the practice pedoanthracology to distinguish it from archaeo-anthracology (i.e. anthracology). The basis of pedoanthracology is that the charcoal fragments found in soil record past fire events and the past woody vegetation (Nelle et al. 2013:1). These fragments can be extracted, quantified (charcoal concentration per weight of soil) and taxonomically identified. These identifications are usually accompanied by radiocarbon dating (Nelle et al. 2013:1). A sound chronological understanding of the soil profile and the identification of individual fire events temporally aid in identifying fire history and diachronic vegetation change. Pedoanthracology can offer a spatially finer-grained palaeoenvironmental analysis than other palaeoenvironmental proxies, including pollen (Nelle et al. 2013:1). In the tropics pedoanthracology can struggle to capture the full floristic diversity of an area and larger sampling efforts may need to be employed.

Pedoanthracology has been widely applied in Europe (Adamek et al. 2015; Carcaillet and Thinon 1996; Delhon et al. 2009; Favilli et al. 2010; Touflan and Talon 2009). North America (Asselin and Payette 2005; de Lafontaine and Payette 2011; de Lafontaine et al. 2014; Talon et al. 2005), South America (Allevato et al. 2013; Di Pasquale et al. 2008; Di Pasquale et al. 2010), and Africa (Hubau et al. 2012; Hubau et al. 2013). To date, pedoanthracology has had a limited application in Australia with only one published study (Hopkins 1990, 1993) and another in preparation (Larsen et al. *in prep*).

2.3.5 Fuel wood collection, selection and management

The collection of fuel wood is one of the enduring daily landscape practices undertaken by humans (Picornell-Gelabert et al. 2011:375; see also Picornell-Gelabert et al. 2017). It is therefore important to identify and discuss each element of this practice and its expression in the archaeological record as a charcoal-bearing context (i.e. a hearth, earth oven, kiln, or smelter). In Australia the primary archaeological context of fuel collection is the hearth. Therefore the hearth will be the main focus of this discussion. A hearth is a fire of short-lived or single use, and is often the concentrated product of a single fuel wood selection. Hearths do not provide the long use life and cumulative buildup of 'dispersed charcoal' contexts that are required for reconstructing the full floristic diversity of the palaeoenvironment. Hearths provide an insight into fuel wood collection, selection, management, and depletion (Thery-Parisot et al. 2010a:145).

In the early 1990s Shackleton and Prins (1992) identified that the principle of least effort (PLE) was increasingly a core assumption of anthracological interpretations. Shackleton and Prins (1992) offered a critique of PLE and outlined a conceptual model to test whether the PLE assumption held in different socio-economic and environmental circumstances. The definition the authors offered for PLE was, “In essence the PLE assumes that past people collected fuelwood that was closest to the homestead, and that all species were collected in direct proportion to their occurrence in the surrounding environment” (Shackleton and Prins 1992:632). They found that in certain circumstances, when fuel wood availability was high and population numbers were low (i.e. a new settlement, or an intermittently occupied site), the principle of least effort did not hold (Shackleton and Prins 1992:633-634). People chose dry wood and were selected preferred fuel wood taxa. In contrast, in those situations where large sedentary populations depleted the preferred fuel wood (i.e. dry dead wood, or particular taxa), there was a shift to non-preferred fuel types (including felling of fresh wood and finally a shift to other fuel sources, i.e. dung [see Miller 1984]). Shackleton and Prins’ (1992) modeling demonstrated that the collection of fuel wood was informed by the socio-cultural and economic pressures of the local area. The authors also acknowledged that further research was required to full understanding fuel wood selection under different local circumstances (Shackleton and Prins 1992:633).

The principle of least effort (PLE) has, however, continued to be a core assumption of the Montpellier method and is also used by many other researchers when interpreting wood charcoal assemblages (cf. Chabal 1988, 1992, 1997; Chabal et al. 1999 [all in French]; for English translation and interpretations of Chabal see Asouti and Austin 2005; Dotte-Sarout et al. 2015; Figueiral and Mosbrugger 2000). The PLE assumption is central to the conceptualization of a wood charcoal assemblage as a proportional representation of the past environment, a key aspect of the Montpellier approach (Asouti and Austin 2005:2).

There is a recent shift in the literature away from the ecologically utilitarian and environmentally deterministic principle of least effort (PLE) towards ‘a historically constituted and socially mediated’ interpretation (Picornell-Gelabert et al. 2011:376). This is an approach originally suggested by Shackleton and Prins (1992:632-633) in their PLE article in which they state fuel wood will be collected in direct proportion to that in which it occurs in the environment surrounding a site until depletion, often driven by economic pressures, will force a change. It is clear from the anthracology literature that the collection of fuel wood is defined by socio-cultural concerns and economic conditions (Asouti and Austin 2005; Dufraisse 2011; Marston 2009; Picornell-Gelabert et al. 2011). A reliance on the PLE to interpret fuel wood collection misrepresents the complex cultural and economic considerations that shape fuel wood selection decisions (Picornell-Gelabert et al. 2011). This thesis will focus on the selection of fuel wood for domestic hearths at Madjedbebe.

> *"…it is necessary to recognize that fuel remains represent the material residues of a complex interplay between long-term environmental change, localised ecological/vegetation processes, economic production and cultural formation."* (Asouti and Austin 2005:9)

It is understandable, for the reasons that are outlined above, that fuel wood selection is as variable as the population being studied (Thery-Parisot 2002a:243). This variability is evident in ethnographic accounts of fuel wood selection globally (Hiezer 1963; Picornell-Gelabert et al. 2011; Smart and Hoffman 1988:168-169). Fuel wood procurement needs to be conceptualised on a local scale – situated within its socio-ecological context (Henry and Thery-Parisot 2014a:69). Therefore, essential for interrogating fuel wood archaeologically is establishing the socio-economic basis and environmental baseline for the study area. The selection criteria, extraction techniques, and management considerations for a sedentary agrarian site are quite different to that of a mobile hunter-gatherer population.

A further complication to understanding how fuel wood is selected are the classificatory systems researchers employed to make sense of the taxa under investigation. The organisation and evaluation of taxa in accordance with a Linnean classificatory system is not necessarily consistent with the ontology of the population being investigated (Thery-Parisot 2002a:244; Thery-Parisot et al. 2010a:144). In fact, the ethnographic literature suggests this is a misleading approach (Hiezer 1963; Picornell-Gelabert et al. 2011; Smart and Hoffman 1988:168-169), with fuel wood selection being directed by whether wood was dry, its calibre, scent, smoke production, or cultural dictum or taboo, rather than its Linnean organisation (Hiezer 163; Picornell-Gelabert et al. 2011; Thery-Parisot 2002a:244; Thery-Parisot et al. 2010a:144; Smart and Hoffman 1988:168-169).

Ethnographic research has demonstrated that the concept of 'good' fuel wood is highly variable (Thery-Parisot et al. 2010a:144). Aside from taxonomic characteristics, there are physical features preserved in charcoal that are indicative of the wood that was collected as fuel. The study of these non-taxonomic features is termed dendrology. Dendrology studies the physical signatures indicative of formative processes through which wood has passed from tree to charcoal. Reaction wood is indicative of strong winds or other forces acting upon the tree in its life, the imprints of fungal hyphae are suggestive of fungal infiltration common in deadwood, the presence of tyloses suggest the charcoal is from trunk or large branch wood, and excessive radial cracking may suggest green wood rather than dry wood was put to fire (Henry and Thery-Parisot 2014a:76; Marguerie and Hunot 2007). Examining other features can indicate anthropogenic intervention in the plant's growth and development. Consistent growth rings and wood calibre could be suggestive of woodland management including coppicing and pollarding (Deforce and Haneca 2015; Marguerie and Hunot 2007). When these features are present they provide an additional source of information about human behaviour and resource management.

Ethnographic research has demonstrated that the principle of least effort (PLE) does not necessarily stand when interpreting fuel wood selection. Fuel wood is often selected based on whether it is dry or green, healthy or decayed, or the calibre of the individual piece of wood (Thery-Parisot 2002a; Thery-Parisot 2002b; Thery-Parisot et al. 2010a). Researchers agree that humans will usually minimize the distance between their place of residence and fuel wood source (Asouti and Austin 2005:8-9; Dufraisse 2012:70; Thompson 1992:107). As Thompson (1992:107) states, wood is a heavy and awkward commodity, it is not conveniently portable and therefore humans generally limit the distance over which it needs to be transported. In the end this resource is going to be destroyed by fire, hence she asked if there is a suitable candidate in close proximity why transport wood in from a distance? Only exceptional circumstances (i.e. depletion) or specific requirements (i.e. cultural obligation or a task requiring specific fuel requirements) would motivate people to transport wood over longer distances.

The management of fuel wood, in response to or to mitigate against depletion, is a common aspect of anthropogenic interactions with woodland. These management activities can be observed archaeologically through dendrological features preserved in charcoal but may also be indicated by the taxonomic composition of the wood charcoal assemblage. Fuel wood management is a balancing act between the energetic needs of the settlement and the resources that are locally available (Thery-Parisot et al. 2010a: 146 Fig. 4). The energetic needs will be dictated by the size of the site, its function, occupation duration, and the nature and intensity of the fuel use activities at the site (Allué et al. 2017:2; Henry and Thery-Parisot 2014a:69). These factors are directly related to socio-cultural and economic requirements specific to the community under study. When energetic requirements outweigh resource availability the community needs to respond through management or deal with the consequences of depletion. The local environment will have a certain carrying capacity, which if breached, will lead to a shift in fuel wood selection behaviour. Shackleton (1998) calculated deadwood was generated at 17 kg/ha per ton of live biomass annually in the semi-arid lowveld of South Africa. If the inhabitants of the lowveld increase their extraction beyond 17 kg/ha annually, the difference would need to be made up by an increase in their collection area, the importation of fuel wood from outside of the lowveld, or a shift in collection strategy to the felling of trees or the use of a less preferred fuel (i.e. dung). Management options can range from 'incipient management', as termed by Dufraisse (2012:67), in which fuel wood collection areas are rotated to avoid depletion, to more intensive management practices such as coppicing and pollarding in which humans actively intervene in the growth habit of woodland taxa to increase the biomass production rate for wood in an area (i.e. Deforce and Haneca 2015). Management and depletion are key factors when considering fuel wood and need to be included under the societal filter proposed by Thery-Parisot et al. (2010:142 Fig. 1). The management of fuel wood is essential for all societies, and not just sedentary and agrarian settlements. All human groups affect the environment around them, and through their activities and landscape management practices will deplete natural resources. Fuel wood needs to be considered as an essential element when interrogating the landscape management practices of the past.

2.3.5.1 Case Study 1: Abric Romani

Fuel wood selection strategies were investigated at the Middle Palaeolithic (40-70k BP) site of Abric Romani using the methods of anthracology. Daily provisioning of fuel wood at Abric Romani was based on the collection of deadwood in close proximity to the site (Allué et al. 2017:7). *Pinus sylvetris* was the dominant woodland cover surrounding Abric Romani at the time of occupation (Allué et al. 2017:6). This taxon produces large quantities of deadwood twigs and branches. The fuel wood selection pattern at Abric Romani would suggest the collection of fuel wood was dictated by the state of the wood rather than the intrinsic properties of the taxa, with dead but not decayed wood selected for use (Allué et al. 2017:5, 6). The absence of riparian species in most layers suggests they were avoided, or fuel collection pressures did not require the inhabitants to venture down slope to collect wood

(Allué et al. 2017:7). Imprints of wood, preserved in the travertine, have been interpreted by researchers as the remains of wood storage at the site (Allué et al. 2017:7; Allué et al. 2012:383). The inhabitants of Abric Romani may have been forced to cure green wood after the local deadwood supply had been depleted (Allué et al. 2017:8). Alternatively, they may have stockpiled fuel wood in preparation for their return to the site (Allué et al. 2017:8). Researchers have also been able to demonstrate through SEM imaging that some of the travertine impressions are of wooden tools (Allué et al. 2012:383).

Pinus sylvetris type was the dominant fuel wood identified at Abric Romani in both the hearths and in the wood stockpile (Allué et al. 2017:6; Allué et al. 2012:377). The anthracological assemblage at Abric Romani is indicative of a localised fuel wood selection strategy based on the collection of deadwood. *Pinus sylvestris* type is the dominant taxa, it has a ubiquity of 100% and along with *Pinus* sp. are the only taxa in ten of the fourteen layers analysed (Allué e et al. 2017:5). This assemblage suggests other taxa, especially riparian taxa were avoided, even though the lithics assemblage demonstrates human were extracting resources from the river valley (Allué et al. 2017:7). The authors suggest fuel availability may have played an important role in the occupation of Abric Romani, with inhabitants leaving the site when locally available deadwood was depleted (Allué et al. 2017:8).

2.3.5.2 Case Study 2: Pınarbaşı

The fuel wood selection strategy at Pınarbaşı in Central Anatolia is also locally focused. Asouti (2003) investigated the fuel wood selection strategies at Pınarbaşı through an examination of archaeological charcoal. Pınarbaşı is divided into Site A, early Neolithic and Site B, late Neolithic/Chalcolithic. The faunal assemblage and lack of permanent habitation structures suggest the site was inhabited on a seasonal basis by hunter-gatherers and herders (Asouti 2003:1186). There is no major temporal change in the taxonomic composition of the Pınarbaşı charcoal assemblage. Asouti (2003:1199) claims this stability indicates that the mobile hunter-gatherer/herders that inhabited the area applied very little pressure on fuel wood availability. Woodcutting and animal browsing was minimal, with fuel wood sourced opportunistically from the surrounding environment requiring very little tree cutting if any. This fuel selection strategy and the mobility of the population allowed enough time for the woodland to regenerate between periods of occupation (Asouti 2003:1199-1200).

The Pınarbaşı anthracological assemblage is indicative of selective localised fuel wood gathering (Asouti 2003:1199-1200). Terebinth (*Pistacia* sp.) and almond (*Amygdalus* sp.), both known to have desirable burning properties, dominate the assemblage (Asouti 2003:1200). This selective behaviour of locally available taxa is coupled with a negligible use of oak (*Quercus* sp.) and juniper (*Juniperus* sp.), available in the volcanic uplands near the site, nor tamarisk (*Tamarix* sp.) and ash (*Fraxinus* sp.) from the lakeside (Asouti 2003:1200). This fuel wood use pattern suggests the inhabitants of Pınarbaşı could selectively extract desired taxa from the local environment from an abundant and undiminished fuel wood resource.

2.3.6 Tropical anthracology

Key theoretical and methodological problems in anthracology become acute when encountered in the tropics. The development, arrangement, and description of reference collections, appropriate sampling protocols, the production of representative results, and issues of preservation are all central to anthracology. These issues, however, are amplified in the tropics.

The tropics support a diverse flora – hard to fully capture in a reference collection and even more difficult to describe and manage. This diversity, and the short history of anthracology in many tropical locations, means the development and description of a diverse reference collection is an essential first step in any research project (Asouti and Fuller 2008). The diversity of the flora also means sampling protocols need to be reassessed and broadened to account for the wider range of taxa expected in archaeological samples. Tailoring the sampling protocol to the floral diversity ensures the results of the research are representative of the floristic diversity that is present in the sample (Asouti and Austin 2005:7). Samples are a product not just of their environment and archaeological context but the preservation conditions of the site. Tropical anthracology, and tropical archaeobotany more generally (Hather 1994), has to effectively deal with issues of sample preservation and recovery in order to produce accurate and representative results.

One of the best examples of anthracological research in the tropics is the extensive research undertaken by Scheel-Ybert in Brazil (2000, 2001, 2002a, 2002b; Scheel-Ybert and Dias 2007; Scheel-Ybert et al. 2014; Bachelet and Scheel-Ybert 2017). Scheel-Ybert has explored palaeoenvironmental reconstruction (2000, 2001; Scheel-Ybert et al. 2014), the pairing of anthracology with isotopic data (2003), examining the relationship between woodland and agriculture (Scheel-Ybert and Dias 2007), the use of bark in ritual hearths (Beauclair et al. 2009), comparing dispersed charcoal to combustion features (Bachelet and Scheel-Ybert

2017), and questioning the validity of the interpretative methods used in anthracology (2002a). Her work has even extended anthracology into the world of law enforcement (Goncalves and Scheel-Ybert 2012). Scheel-Ybert's work is based on a comprehensive reference collection, initially collated as part of her PhD research (Scheel-Ybert 2016), and a thorough application of anthracological method.

Scheel-Ybert has used wood charcoal from archaeological contexts to reconstruct the palaeoenvironment and palaeoethnobotany of Tupiguarani hunter-fisher-gatherers in southeastern Brazil. In her 2014 paper with colleagues, she examined the charcoal assemblage from the site of Morro Grande (Scheel-Ybert et al. 2014:97). Dispersed and concentrated charcoals were examined as part of the study. Charcoal from funerary and domestic hearths and funerary urns/vessels (concentrated) and the dispersed charcoals were examined and interpreted separately (Scheel-Ybert et al. 2014:103). The domestic hearths demonstrated very low taxon diversity and the predominance of one or a few taxa (Scheel-Ybert et al. 2014:105). This is not unusual for a hearth context that may represent a single (or limited) fuel wood selection. The funerary hearths were similarly restrained. They contained extremely high frequencies of bark, which is peculiar and demonstrates a preference for this element as fuel (see also Beauclair et al. 2009).

Recent research conducted by Bachelet and Scheel-Ybert (2017) at the Santa Elina rock shelter in Central Brazil, demonstrated dispersed charcoal had a higher taxon richness than the charcoal assemblage from the combustion features. Their research demonstrated that as sample size increased taxon richness also increased (Bachelet and Scheel-Ybert 2017:5). This finding is very important for tropical anthracologists who work in areas of higher taxonomic diversity. It demonstrates that an adequate sample size needs to be employed to fully capture the floristic diversity of the assemblage. The authors also hypothesised that the hunting and gathering inhabitants of Santa Elina would have collected fuel wood in the immediate vicinity of the rock shelter (Bachelet and Scheel-Ybert 2017:8). Focusing specifically on the available necromass (deadwood) rather than felling trees for fuel. They also suggest that hearths with a higher taxon richness may have been used multiple times. This is in contrast the hearths with low taxon richness which they interpret as probably a single use feature (Bachelet and Scheel-Ybert 2017:7).

The composition of these concentrated contexts is in contrast to the dispersed charcoals. Dispersed charcoal is seen as an accumulation of multiple fuel wood collections preserved outside of a defined combustion feature. Generally the taxon richness is higher in the dispersed charcoal (Scheel-Ybert et al. 2014:107). The authors state that this higher richness indicates random fuel wood collection (Scheel-Ybert et al. 2014:107). They do however concede that the inflated levels of *Myroxylon* sp. and *Handroanthus* sp. does suggest preferential selection of these taxa. Going further to suggest that these taxa were selected for reasons other than as fuel (Scheel-Ybert et al. 2014:109). This leads one to question whether the over-representation of these taxa in the charcoal assemblage may diminish the representativeness of this assemblage for palaeoenvironmental reconstruction. Scheel-Ybert et al. (2014:109) dismiss this issue stating that previous research has dispelled any concerns regarding the environmental representativeness of anthropogenically transported fuel wood. The authors do not explicitly cite the literature to which they refer. However, one can assume they refer to Chabal and other members of the Montpellier School who have conducted extensive research into the usefulness of archaeological charcoal in environmental reconstructions. The work of Scheel-Ybert in Brazil has been pivotal in the development of tropical anthracology. It has informed and inspired research in other tropical locales, including the Pacific.

Forest management was the focus of Dotte-Sarout's PhD research in New Caledonia, Western Pacific (2010; 2013:122). Her research focused on the Tiwaka valley northeastern Grande Terre. Dotte-Sarout followed the methods of Scheel-Ybert acknowledging the importance of the latter's pioneering work in Brazil, especially in relation to tropical anthracology (2013:123). Three sites in the Tiwaka valley were investigated as part of this anthracological assessment. Pwadaunu is a typical high altitude site (c.500 m elevation) on the side of a mountainous massif, Tiaboue a low altitude site (100 m) located in a deep valley on an artificial terrace, and Komijien, which is located at the end of the valley on the alluvial flood plain. Each of these sites was purposefully selected to target different settlement locales and variable ecologies (Dotte-Sarout et al. 2013:123).

Diachronically there were signs of intensifying human occupation and impact on the environment (Dotte-Sarout et al. 2013:133). Firstly, there was an increase in savanna and secondary taxa followed by an increase in economic and symbolic trees. Throughout this period, however, rainforest remains a dominant feature of the anthracological assemblage (Dotte-Sarout et al. 2013:133). The authors claim that the management and access to 'natural' resources (available in the rainforest) remained a central part of the Kanak exploitation system. Finally, the anthracological spectra records the rapid environmental changes wrought by the arrival of Europeans to the island in the 18th and 19th centuries. Importantly, Dotte-Sarout's research demonstrates that there was no large-scale deforestation associated with the slash and burn horticulture of the Kanak cultural complex. It also highlights the benefits of using anthracology in conjunction with other palaeoenvironmental proxies. Especially considering the relative invisibility of rainforest taxa in pollen diagrams for the study area, as opposed to the anthracological record (Dotte-Sarout et al. 2013:134).

Through the alteration of indigenous woodland structure and the introduction of key economic taxa the inhabitants of the Tiwaka valley replaced one type of woodland with another. The data presented in Dotte-Sarout (*in press*) demonstrated human habitation did not lead to deforestation but the creation of an anthropogenic woodland in the Tiwaka valley. The author considers this woodland as an artefact of human actions on the landscape and a dialogue not a dichotomy between humans and the environment.

The utility of using anthracology in the Pacific is further highlighted in the work of Huebert (2015; Huebert and Allen 2016; Hubert et al. 2010) in the Marquesas. Huebert (2015; Huebert and Allen 2016; Hubert et al. 2010) examined charcoal samples from earth ovens, hearths, general living surfaces, and concentrated areas of charcoal. This broad anthracological assessment allowed her to reconstruct past cultural practices and environmental conditions (Huebert et al. 2010:65). In her 2010 paper, Huebert and colleagues, examined charcoal samples from earth ovens to determine whether fuel wood had been preferentially selected for this activity. This investigation considered two alternate hypotheses regarding fuel wood selection. The first centred on the principle of least effort (as discussed by Shackleton and Prins 1992) which states that fuel wood selection is governed by the principle of least effort – woodland taxa would be proportionally sourced from the local environment as fuel. Huebert et al. (2010:65) compared this hypothesis with Allen's (2005) findings that fuel for earth ovens at Tauroa Point, New Zealand, was preferentially selected.

All of the charcoal fragments recovered in the 6.35 mm sieve were examined as part of this study. Huebert et al. (2010:75-76) cautioned against the use of ratio measurements (i.e. frequency) stressing the ubiquity (presence/absence) of a taxa would be a better indication of the taxonomic composition of the assemblage. Being cognisant of the difficulties of quantifying charcoal data (i.e. counts may be affected by the propensity of a certain taxa to over fragment and weight may be skewed by a wood of greater density), Huebert et al. (2010:75-76) statistically tested for a relationship between weight and count data. Using

Pearson’s correlation coefficient they were able to demonstrate that weight and count data for the two most abundant taxa were highly correlated (Huebert 2010:78-79). However, because some samples were quite fragmented weight data was used during analysis.

Huebert et al. (2010:88) found that all of the taxa, except *Alyxia* sp., were sourced from two locally available vegetation communities; that the dominance of *Thespesia populnea* and *Sapindus saponaria* in the ovens demonstrated preferential selection of those taxa as fuel (2010:87, 88); and that the consistency of taxa found in the ovens demonstrated a uniformity of function (2010:79). In light of these findings they cautioned against the use of ovens for environmental reconstruction (Huebert et al. 2010:86). Stressing a wider range of contexts need to be consulted to avoid the bias of preferential selection (Huebert et al. 2010:88).

Huebert’s (2015) examination of the extinction of two Sapotaceae taxa on Nuku Hiva (Marquesas Islands) mitigates against the bias of preferential selection by examining a wide array of contexts. This study examined charcoal from living surfaces, hearths, ovens, and areas of high charcoal concentration (Huebert 2015:1041). Huebert (2015:1043) found Sapotaceae wood was used as fuel early in the occupation sequence, following which there is diachronic decline and eventual local extinction. Huebert (2015:1043) states that the disruption of mutualistic ecological relationships after human colonisation may have contributed to the decline of Sapotaceae on Nuku Hiva and on other islands in Eastern Polynesia.

Through the synthesis of twenty-six different charcoal assemblages from Nuku Hiva Huebert and Allen (2016) were able to diachronically track changes in woodland structure on the island. They found that the lowland forest of Nuku Hiva were ‘significantly modified by early Polynesian colonists’ (Huebert and Allen 2016:91). These early colonists cleared the forest for horticultural and domestic use. This clearance was reflected in the taxonomic composition of the islands anthracological assemblages. The low open forest, composed of woody monocots (palms, *Pandanus* sp.) and numerous hardwoods was replaced by key economic taxa (*Artocarpus* sp., *Inocarpus fagifer*) (Huebert and Allen 2016:91, 94). These changes occurred rapidly. Within two centuries of Polynesian arrival the lowland forests were converted into economically productive agroforests (Huebert and Allen 2016:93). The authors state that this forest mimicked the multi-storied natural forest and actually led to ‘enhanced soil fertility and stability, as well as ecological resilience’ (Huebert and Allen

2016:93). This research demonstrates that the anthropogenic reshaping of woodland may not necessarily be to the detriment of the environment.

Anthracology in the Pacific is not alone in confronting the challenges of tropical anthracology. The anthracological research of Thompson (1992) in Thailand highlights the difficulties of working in tropical Asia. Her PhD focused on rice cultivation in central Thailand and employed anthracology to examine how the local environment changed diachronically (Thompson 1992:69). Samples for this analysis are drawn from undefined context types and are well suited to provide a palimpsest of the local arboreal vegetation (Thompson 1992:73). A total of 750 fragments were identified from 22 samples, between 20-50 fragments per sample. Fragments <0.01 g or <2 mm were avoided due their small size. This was because Thompson (1992:80) was concerned that small fragments would contain too few anatomical features to make an accurate identification (see also Asouti and Austin 2005). Thompson's (1992:115 Fig. 4.6) analysis found there was a shift from Rhizophoraceae dominated vegetation to non-Rhizophoraceae and indeterminate vegetation in the charcoal assemblage. She interpreted this shift as a move towards an increase in taxonomic richness (Thompson 1992:115 Fig. 4.6, 117). Thompson (1992:293) offers three explanations for this shift in taxonomic richness, 1) a shift in vegetation zonation at c.3,400 BP positioning the site in a more riverine (less marine) location, 2) a shift in the course of the river after a flood, or 3) the migration of mangroves downstream as the river prograded due to wide scale marine regression affecting the entire Gulf of Thailand. She concludes that a combination of all three is the likely explanation for the observed change in the anthracological record.

The work of Asouti and Fuller (2008) in South India, as well as the pioneering work of Scheel-Ybert (2000a, 2000b, 2000c, 2001, 2002a, 2002b, Scheel-Ybert and Dias 2007; Scheel-Ybert et al. 2014; Bachelet and Scheel-Ybert 2017), Dotte-Sarout (2013, *in press*), Huebert (2010, 2015, 2016), and Thompson (1992), demonstrates the challenges of anthracological research in the tropics. Anthracological research in the tropics is growing in popularity with extensive working being carried out in Africa (Eichhorn 2007; Ekblom 2008; Ekblom et al. 2014; Hohn 2007; Hohn and Kahlheber 2008; Hohn and Neumann 2012; Kahlheber et al. 2014; Neumann et al. 1998; Schmidt 1997) and South and Central America (Austin [ongoing PhD research] in Belize; Dussol et al. 2016; Thompson et al. 2015), and Australia (Whitau et al. *in press*) in particular. This review highlights some of the main challenges confronting anthracological research in the tropics and the importance of having a well-developed reference collection. These issues are of critical importance to the application of anthracology in the tropical north of Australia.

2.3.7 Australian anthracology

The common belief that botanical material does not preserve in the acidic sandy soils of Australian archaeological sites has resulted in a paucity of archaeobotanical research undertaken in Australia (cf. Clarke 1989:54). Often archaeobotanists are engaged post-excavation, and are therefore precluded from the design and implementation of excavation methods and recovery systems (Denham et al. 2009).

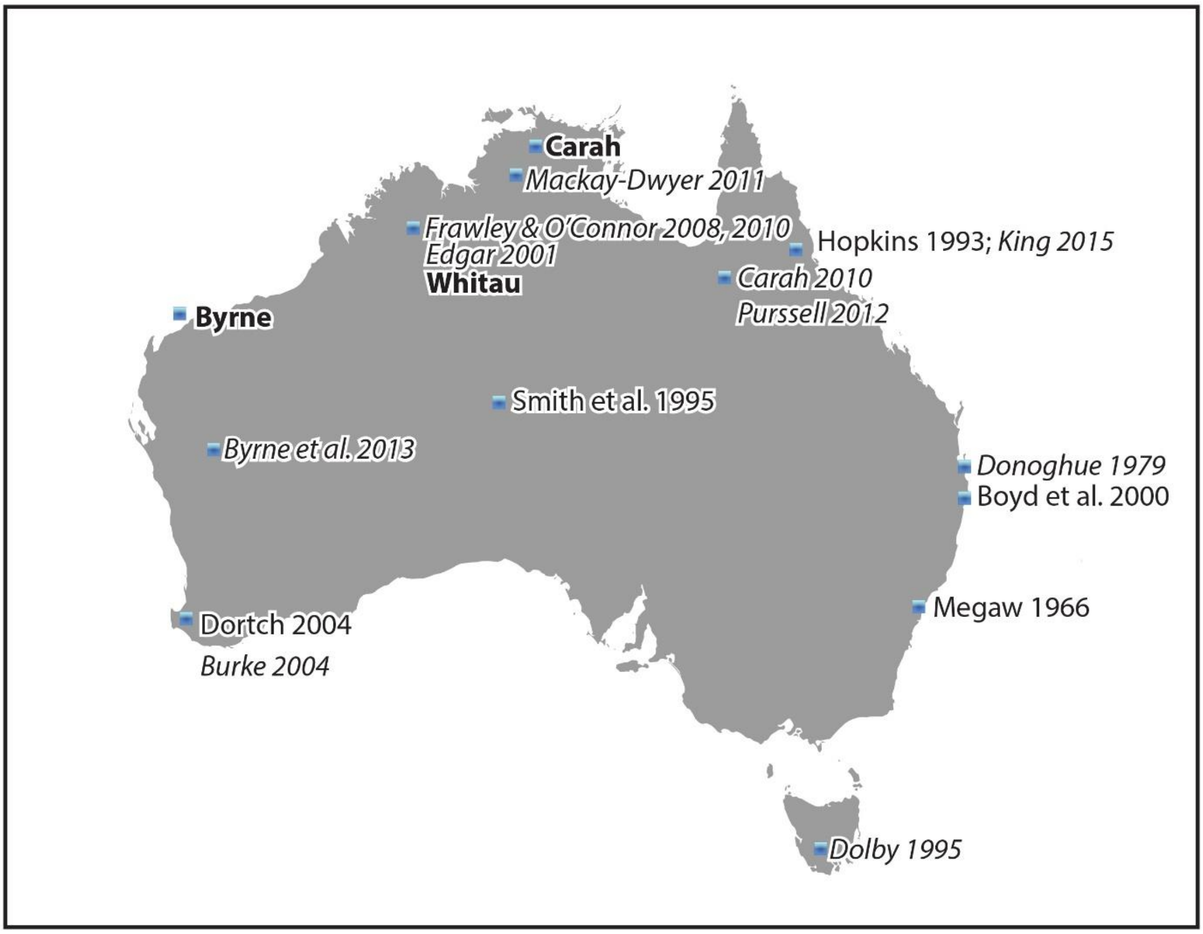


Figure 2.1 Australian anthracology - ongoing PhD theses in bold; masters and fourth-year thesis italicised; general research in plain text.

The treatment of archaeobotanists as post excavation analysts means the samples they are given to work with have not only been constrained by taphonomic factors but also poor archaeological field craft. This poor treatment of archaeobotany has led not only to poor recovery but stagnation in the development of the discipline in Australia. Nowhere has this stagnation been more evident than in the application of anthracology.

Anthracology has been applied sparingly since its first application in Australia in 1966 (Fig. 2.1). Anthracology has often been utilised in fourth-year or Masters dissertations which means it has often been constrained by the time pressure and skill level of that type of research. There are four main issues which reoccur in Australian anthracology, 1) poorly developed reference collections, 2) poor on-site collection and recovery, 3) inadequate sub-sampling for analysis, and 4) insufficient conceptual models, which constrain the technique's interpretative scope.

Three of these issues have clear solutions. 1) Through better curation of open source and freely accessible databases more complete reference sets will accumulate; 2) by applying best practice field sampling and recovery techniques researchers remove sampling bias as a reason for the absence of botanical material; and 3) through the application of robust sub-sampling measures in the laboratory researchers will produce sound data sets. There is however no straightforward solution to the fourth and final issue, which will be discussed further below.

Anthracology in Australia has predominantly been used to reconstruct the palaeoenvironment. Researchers have, however, pursued the Montpellier desire to understand the environment, without concerning themselves with the technical considerations on which the method is built. It is understandable that there are constraining time and skill pressures for younger researchers and that some of these studies were undertaken before key literature was published or published in English. However the non-reference to key literature (i.e. Chabal 1988, 1992, 1997; Chabal et al. 1999; or Austin and Asouti 2005; Figueiral and Mosbrugger 2000) in those studies conducted in the last ten years is concerning.

The lack of consistent in-field sampling and inadequate sub-sampling for analysis are reoccurring issues in Australian anthracology; two key aspects of the anthracological method outlined by Chabal (1992; Chabal et al. 1999) and Asouti and Austin (2005). The limited application of anthracology in Australia is reason enough to excuse the stagnation of the technique here. However, the absence of key methodological and theoretical literature from Australian research is inexcusable. There are aspects of Australian anthracology which need to be refined and conceptualised within the socio-economically distinct milieu of Australian archaeology, however, the solution to many of the issues faced by Australian anthracology can be found in the existing global literature. Too many Australian studies analyse less than 100 fragments per context and are not critical of the contexts from which they sample. A major interpretive issue for Australian anthracology is the utility of 'matrix charcoal'. This charcoal is not defined in a feature but is loose in the surrounding sedimentary matrix of the site. The existing international literature refers to loose non-concentrated charcoal as dispersed charcoal (Asouti et al. 2015:1577). However, the difference between dispersed charcoal and matrix charcoal is that the provenance of dispersed charcoal is known to be anthropogenic. Questions have been raised as to whether matrix charcoal in Australian archaeological sites is necessarily anthropogenic and not the by-product of bushfires burning near the site.

The paucity of reference material and limited development of anatomical description in Australian wood research has left many gaps in our knowledge. For this reason the risk of over identification remains a key concern. Whitau et al. (*in press*) skillfully navigate this issue, making only genus and family level identifications at Riwi Cave in tropical north-western Australia. The authors outline, in detail, their rationale for each identification (Whitau et al. *in press*:6). Their cautious and transparent approach is not just admirable but essential for the development of anthracology in Australia. Such transparency allows for other researchers to build upon their findings and extend the application of anthracology in this continent. Unsurprisingly, species level identifications should not be expected in Australian anthracology. Especially considering that some taxa, in the well-studied European wooded flora, cannot be identified to species level (i.e. Salicaceae).

Previous Australian anthracological studies have found there to be a preference for riparian taxa as fuel wood (Byrne et al. 2013; Smith et al. 1995). However, Whitau et al. (*in press*) found the inhabitants of Riwi Cave consistently utilised taxa that were in close proximity to the site. The authors concluded that the preference for riparian taxa in the earlier studies and the contrasting use of steppe/savanna vegetation at Riwi Cave was because fuel wood collection was closely associated with other foraging activities. This collection habit has been identified elsewhere and reported in the international literature (Asouti and Austin 2005; Dotte-Sarout et al. 2015; Picornell-Gelabert et al. 2011; Salavert and Dufraisse 2014).

2.3.8 Ethnography – fuel and fire in the Alligator Rivers region

The ethnographic records of the Alligator Rivers region offer some insights into fuel wood collection practices. From ethnographic accounts from across northern Australia it is clear people were highly mobile and often responding to seasonal changes in resources and flood waters (Keen 2004; Kelly 1995). Ethnographic accounts from the region surrounding Madjedbebe suggest residency may have been determined by the availability and supply of subsistence resources. Spencer (2008 [1912]:90) observed at Oenpelli, on the eastern side of the East Alligator River, that people moved camp once the lilies, fish, fowl, and honey-bag became scarce in an area. A later ethnography in the area found fuel wood (dry deadwood branches) was collected by the women in the immediate vicinity of the camp site (McCarthy and McArthur 1960:157). Spencer (2008 [1912]:90, 256) found the Traditional Owners of this area constructed two types of fires for cooking – the hearth and the earth oven (see also Chaloupka and Giuliani 1984:66). The hearth was a simple construction and often used for quick meals or at a 'dinner time camps' (Meehan 1982:26). The earth oven however was more carefully constructed. The earth was dug down into, about two feet, in which a fire was lit to heat stones or pieces of termite mound. Followed by a layer of paperbark, grass, and green leaves. The food was placed on this layer and covered by another sheet of paperbark, before being covered by earth (Spencer 2008 [1912]:90). These two different combustion features may be discernible archaeologically and may suggest different cooking practices and therefore subsistence itineraries. Different subsistence itineraries may also be reflected in the taxonomic composition of the feature.

Chaloupka and Giuliani (1984) provide the most detailed ethnobotanical account for the study area. The authors record the uses and moiety affiliations of many of the plants in the Mayali language area. They also discuss the use of fire in the landscape, the timing of these fires, and the reasons for burning. Chaloupka and Giuliani (1984:30, 31-32) recorded landscape fires being set just before the start of the wet season (*gunumeleng* – October-December) and in the early dry season (*yekke* or *yegge* – May-early June). The authors state that after the "…Darwin Woolybut (*Eucalyptus miniata*) ceases to flower, indicating the end of *yekke*, no further fires are lit" – with the exception of some small hunting fires (Chaloupka and Giuliani 1984:31, 70). After the country was 'cleaned' by fire people move out onto the floodplains during *wurrgen* (June-mid August) to hunt file snake, long-necked turtles and collect water lilies and spike rush corms (*Elaeocharis dulcis*) (Chaloupka and Giuliani 1984:32). At the beginning of *gurrung* (mid-August-September) the hunter's attention turn to the large flocks of magpie geese which have congregated on the diminishing wetlands.

Chaloupka and Giuliani (1984:70-73) also recorded in detail different hunting techniques which utilised fire to drive animals towards hunters lying in waiting. They stated that much of the country was burnt as a result of these fires. People saw burning ('cleaning the country') as a responsibility and would burn right up to the neighbouring clan's boundary (Chaloupka and Giuliani 1984:70). The authors recorded that these burning practices produced and maintained distinct ecological niches in the landscape that were repeatedly re-enforced by regular burning (Chaloupka and Giuliani 1984:70).

The Mayali ethnobotany also provides an insight into fuel wood selection in the study area. What is most striking about the list of fire wood recorded by Chaloupka and Giuliani (1984, Table 33) is the breadth of taxa present (Appendix A). The informants stated that specific taxa were selected for different purposes – *Jacksonia dilatata* was selected for unattended fires, *Terminalia carpentarie* was used when cooking fish, *Callitris intratropica* was used to drive mosquitos away and *Erythrophloeum chlorostachys* was used to smoke newborn babies and the deceased (Chaloupka and Giuliani 1984:65-66, 67). Each element of the landscape was incorporated into the Mayali ontology. Grasses that burnt well were assigned a fire moiety, plants which were leached before cooking had a water moiety, and the emu shared a moiety with the plant whose flowers it consumed (Chaloupka and Giuliani 1984:26-27). This ontological arrangement also extended to fire wood and highlights the limitations of understanding fuel wood collection through a Linnean organisation (i.e. Thery-Parisot 2002a:244; Thery-Parisot et al. 2010a:144). The Mayali language speakers assign the taxa *Grevillea heliosperma* to two separate moieties depending on where it grows. Therefore, it is *andjengerrerr* in the lowlands and *anbadbad* in the escarpment country (Chaloupka and Giuliani 1984:25). The difference in these classification systems highlights the limitations of trying to understand fuel wood selection and preference through a purely Linnean organisation.

As outlined in section 2.3.2 there is a large body of existing literature concerning the methodological development of anthracology. Similarly, Allué et al. (2010), Asouti (2003), Henry and Thery-Parisot (2014a, 2014b), Scheel-Ybert (2001), and Thery-Parisot (2002a, 2002b) have published extensively on conceptualizing fuel wood use in hunter-gatherer societies and the use of these charcoals for palaeoenvironmental reconstruction. While Australian anthracology has been slow to adopt this literature, recent publications have started to reverse this trend (Byrne et al. 2013; Dotte-Sarout et al. 2015; Whitau et al. *in press*). What are still critically lacking in Australian anthracology, however, are conceptual models which consider fuel wood as part of daily landscape practice. Existing literature which considers landscape and resource management practices in Australia is silent on the use of fuel wood.

2.4 ‘Fire-stick farming’, fire ecology, and anthracology

There is renewed interest globally in conceptualising fuel wood in its historically constituted and socially mediated setting (Picornell-Gelabert et al. 2011:376). Ethnographic research has demonstrated that local ecological conditions and particular cultural decisions shape fuel selection practices. These choices are shaped by anthropogenic management of the landscape and its resources. Australian anthracologists need to reconceptualise and in many cases create a place for fuel wood in considerations of landscape management practices on this continent.

The dynamic, intentional, and effective use of fire by Indigenous Australians to curate and manage their land has been a major topic of debate in Australia for over forty years (Bird et al., 2005; Bliege Bird et al., 2008; Bowman, 1998; Bowman et al., 2011; Gammage, 2011; Horton, 1982; Jones, 1969, 1975, 1980a, 1980b; Russell-Smith et al., 1997). The effect these burning practices had on the landscape and its productivity led Jones (1969) to term the practice ‘fire-stick farming’. It is clear that these practices do not equate to agriculture but what has been demonstrated historically, ethnographically, and ecologically is that the Indigenous peoples of Australia curated landscapes for their own economic benefit. This body of research, however, has not considered the place of fuel wood as part of these economic practices. Access to, and management of fuel is an ongoing and central concern to daily life allowing humans to extend their geographical range, broaden their subsistence base, and manufacture complex objects (Brown et al., 2009; Pausas and Keeley, 2009:597; Wrangham et al., 1999:570). The omission of fuel from discussions of landscape practice in Australia needs to be rectified.

The assumption, however, that landscape burning is a homogeneous and universal practice amongst all hunter-gatherers needs to be challenged. This assumption is based on Mellars’ 1976 paper in which he claims landscape burning is universally practiced by all hunter-gatherers. Researchers continue to rely heavily on this claim without critically interrogating the evidence on which is based (i.e. Bishop et al. 2015:66; Rowly-Conwy and Layton 2011:852; Sullivan and Forste 2014:s137). For example, Rowley-Conwy and Layton (2011:852) directly quote Mellars as saying, “the deliberate and systematic burning of vegetation was an almost universal practice among recent hunting and gathering populations occupying forested or shrubland environments”. When in fact, Mellars (1976:16) was referring to ethnographic examples from Australia and referred the reader to Dimbleby (1961, 1962), Simmons (1969), and Smith (1970) for examples of prehistoric populations using fire.

Each of these examples either relied on ethnographic analogy or were discussing activities in particular landscapes – neither of which demonstrates a universal and homogenous global practice. Simmons (1969) stated the taxonomic changes in a series of Mesolithic pollen cores was evidence of anthropogenic landscape burning. He offered ethnographic analogues to justify his interpretation (1969:13-16). To his credit he acknowledges the weaknesses of his reliance on these analogues. Mellars (1976) also refers to Dimbleby (1961, 1962) who presents palaeoecological data from the North Yorkshire moorlands. Dimbleby wanted to define the antiquity of landscape burning in the moorlands, a practice still carried out in the area in 1961. He used pollen and wood charcoal data, to demonstrate ecological disturbances akin to fire in the landscape. The source of this fire is interpreted as anthropogenic which is reasonable considering the landscape would not naturally carry fire (a similar argument to that made by Fairbairn et al. 2006 for the Ivane Valley, PNG). Consistent pollen records across the country in the Mesolithic also support an anthropogenic cause instead of a climatic one.

Dimbleby offers some pollen and charcoal data from Mesolithic Britain which demonstrates the impact of landscape fire on the local ecology. The fire is assumed to be of anthropogenic origin, which is reasonable considering the local environment. However, both Mellars (1976) and Simmons (1969) rely on ethnographic analogy to interpret the past. Simmons (1969) acknowledges the weaknesses in this approach, a fact Mellars (1976) casually omits. Therefore, Mellars' claim that anthropogenic landscape burning is wide spread and an assumed tool of all hunter gatherers is not supported by the evidence. It is therefore concerning that researchers continue to cite Mellars (1976) to demonstrate that landscape fire was a universal and homogenous practice amongst all hunter-gatherer populations globally. Archaeologists need to demonstrate the use of fire in the landscape and ecology in which they are working and should not assume it is so. "What is true of everything may say nothing special about anything. What is universal may become diffuse to the point of obscurity" (Pyne 1998:70). To assume to know the past before we study it undermines our worth as archaeologists and fuels concepts that all hunter-gatherers are static and homogenous, denying them dynamism and innovation (Florin and Carah *in prep*). This is a critical point for fire ecology studies globally but is particularly important in Australia (Hiscock 2014).

2.4.1 'Fire-stick farming'

The concept, termed 'fire-stick farming' by Jones (1969), has influenced research on landscape management, food production, and the history of anthropogenic fire use globally

(Kabo 1985; Mellars 1976; Pyne 1990; Rowley-Conwy and Layton 2011; Scharf 2014). Discussing fire use, particularly by pre-industrial societies, was not initiated by Jones (i.e. Stewart 1956). What Jones offered however was a detailed ethnographic account of the dynamic use of fire as a tool for resource management, an ethnographic analogy that continues to be utilised in research both in Australia and internationally (Anderson et al. 2012; Smith 2011). Jones (1975:28) stated in a later publication that his use of the term 'fire-stick farming' was not entirely tongue in cheek. The processes he had observed ethnographically dramatically altered the local landscape (Jones 1969, 1975, 1980a, 1980b). By suppressing natural climax vegetation with fire the environment was made perpetually immature. The ecological disturbance of fire rejuvenates and increases the productivity of secondary successional taxa (Hammett 1992:128). Anthropogenic burning can also increase biodiversity by interrupting the reproductive rate of slow growing plants, promoting greater diversity (Bliege-Bird et al. 2008:14796).

In 1969 Jones stated six reasons why Aboriginal people burnt the landscape. Many of these reasons have subsequently been confirmed by other researchers. The reasons for burning are: for fun (Jones 1980b:15), signalling (Jones 1969:226), to clear the ground (Bird et al. 2005:445), hunting (Gammage 2011:92), regeneration of plant foods (Russell-Smith et al. 1997:177), and extending human habitat (Jones 1975:26-28). In addition to Jones' six reasons other researchers have suggested a number of other reasons Indigenous people burn the landscape: to reduce/manage fuel loads (Gammage 2011:161), to fulfil cultural/religious obligations (Gammage 2011:137-138), and to 'clean' the domestic space (Russell-Smith et al. 1997:177).

The practices which have been observed ethnographically, historically, and whose effects have been felt ecologically are key to understanding the human impact on the Australian landscape. The following three subsections (2.4.2, 2.4.3, and 2.4.4) will explore this evidence in greater detail.

2.4.2 Ethnographic observations

The three ethnographic case studies presented below each highlight the effective use of fire by Indigenous Australians. All three demonstrate that people apply a particular 'recipe' (time of fire, specific weather conditions, particular spatial extent), driven by specific benefits for subsistence that are foreseen from the outset. These three elements ('recipe', motivation, and foreseen outcome) highlight the significance of these practices.

Jones (1980a, 1980b, 1975) describes fire use and resource management practices he observed during his time living with the Gidjingali people of the Blyth River, northern Arnhem Land. Systematic landscape burning commences in June-August (the start of the dry season) when cool nights and dew subdue the fire by nightfall (Jones 1980a: 124). Jungle thickets [i.e. monsoon vine forest] were protected from fire because they contain important spirits as well as key food plants (i.e. *Dioscorea* sp.) (Jones 1975:25). People would burn fire breaks around these fire sensitive thickets early in the dry season to protect them from later fires (Jones 1980a:124). The intensity, interval, and the extent of burning were all dictated by a desired outcome, one fire was to ‘clean up the country’, another to protect culturally sensitive areas, and yet another to encourage new growth to attract prey animals. Each of these different fires was lit at different times in the year and at different intervals for the desired effect (Jones 1980b:14).

Russell-Smith et al. (1997) describe the use of fire to curate particular resource patches in the Kakadu region of Western Arnhem Land. The authors detail how key resources, and the fire regimes which regulate them, are tied to the six seasons of the year. Early in the dry season people set about ‘cleaning up the country’ setting fire to cured grasslands, reducing fuel loads (Russell-Smith et al., 1997:174). Areas containing bush yams would be left unburnt and *anbirlu yahwurd* - low, creeping, fires would be used around fruit trees, producing a mosaic of burnt and unburnt areas (Russell-Smith et al. 1997:174). During the hottest driest time of year, the use of fire was heavily regulated. Owing to the conditions and warm sea breezes fires could easily escape containment and burn all day and night producing hot and destructive *gabulayongon* (literally, ash) fires (Russell-Smith et al. 1997:175). The observations made by Russell-Smith et al. highlight the specific timing, intensity and interval of fire regimes and how the outcome of each of these types of fire had a foreseeable economic benefit.

Bird et al. (2005) and Bliege Bird et al. (2008) work with the Martu people of the Western Desert (Australia). They explain how the Martu use fire to aid hunting and to maintain biodiversity on a local scale. Fire is used in tracking and hunting prey as well as to rejuvenate food plants. Martu people recognise five stages of vegetative succession after a fire, each stage is defined by its subsistence utility (Bliege Bird et al. 2008: 14797). Bird et al. (2005:454) have been able to demonstrate statistically the value of burning when hunting for goanna amongst the spinifex. Burning the spinifex greatly increased the success rate of procuring a goanna with hunters failing to burn only on the occasion they may impact a sacred site (Bird et al. 2005:454). People take advantage of the wind direction to shepherd fires into natural or previously constructed fire breaks/burnt areas (Bliege Bird et al. 2008:14797). What is important to note from Bliege Bird et al.'s research is that it is only the final two successional stages that contain enough fuel to carry a fire line (2008:14797). The fire regime operated by the Martu people takes into account the immediate, medium term and long term effects of a fire. Each stage of succession is known and named, and its resource value defined. Through their burning practices Martu people are able to produce a local mosaic of resources at different successional stages and intervals between fires (Bliege Bird et al. 2008:14798). It has been demonstrated that this burning practice increases local biodiversity and access to a wide range of wild resources. Bird et al. (2005:459) conclude that the, 'Australian wilderness is a product of a dynamic relationship between people and the physical environment.' They suggest that this relationship may have developed over the entire human occupancy of the Australian continent (45,000 years); however archaeological evidence of this relationship has remained elusive.

In their most recent article Bird et al. (2016) explore how the application of fire is interwoven with ecological understandings and religious/spiritual obligations. Their research over sixteen years has demonstrated that humans and the fire regimes that they operate are a critical component of the ecology of the Western Desert (Bird et al. 2016:66). They found mosaic burning led to increases in species diversity. "Paradoxically, *V. gouldii* populations are higher where Aboriginal hunting is most intense. This effect is driven by an increase in *V. gouldii* densities near successional edges, which is higher in landscapes that experience extensive human burning" (Bliege-Bird et al. 2013:2297). Even though burning will cause local destruction in the short term over the long term the landscape as a whole will benefit. This is because a mosaic burning pattern produces multiple patches at different successional stages each suited to a particular suite of plants and animals (Bird et al. 2016:74). Anthropogenic burning produces an ecological disturbance, which the authors state is 'akin to non-equilibrium theory in ecology', it may be detrimental to some organisms but hugely beneficial for others (Bird et al. 2016:73).

The intimate and complex relationship Australia's Indigenous peoples have with fire is clearly expressed in the ethnographic literature. The practices that have been discussed here are not serendipitous or coincidence. They highlight the intimate knowledge people have of their country, their local ecology, and their ability to use fire to manage their subsistence base.

2.4.3 Historic accounts

The practices that have been noted ethnographically were first observed by the early non-Indigenous colonists and explorers of Australia. There is a large body of historic evidence both written and artistic of Aboriginal land management practices, especially those which employed fire. Gammage (2011) undertook an exhaustive review of this evidence highlighting the diverse and ecologically specialised practices of Australia's Indigenous peoples. He provides multiple accounts where early colonists or explorers described the Australian landscape as 'park-like' (Gammage 2011:5-17 *passim*). Open grasslands with fringing pockets of trees. The ease at which travellers could navigate woodland on horseback and the abundant grasslands on which to run sheep were appreciated by the early Europeans (Enright and Thomas 2008:988-989; Gammage 2011:177). It did not take long however for these favourable conditions to turn sour. European expansion forced Indigenous peoples from their land. With their departure fire regimes ceased and the natural climax vegetation started to re-establish. Some pastoralists recognised the benefits of fire, others tried to replicate it, but none were successful in replicating the complexity of Indigenous land management (Gammage 2011:177, 122). With the cessation of regular burning grassland became overgrown with trees and the 'sweet natural herbage' replaced by 'coarse wiry grasses' (Bowman 2003:9; Gammage 2011:122). Fire had shaped Australia's environment and without its careful application the environment changed rapidly.

The landscape paintings of the 19th century provide an insight into the composition of the Australian vegetation at that time. Scenes of lightly wooded hillsides and open grasslands abound in this early European art. Gammage (2011:37, 47, 51, 53) uses this imagery to highlight the dramatic changes in the Australia landscape over the intervening years. He compares photographs taken from the same vantage point as the artist to demonstrate this dramatic change. As with any text, however, historic accounts need to be accessed in the socio-cultural space in which they were inscribed. Joseph Lycett, one of the painters Gammage refers to, was employed by the British Government to paint appealing landscape scenes to attract British colonists to Australia (Bate 2014). His landscapes were made to appear deliberately like Europe. Potential emigrates would not be attracted by an alien landscape populated by weird flora and fauna, so Lycett painted European landscapes, complete with European flora! His art is not always a true representation of the Australian landscape of his time, the reason it appears 'park-like' or 'like a gentleman's garden in England' is because it was deliberately painted to appear that way (Bate 2014). This should not diminish the weight of evidence presented by Gammage which clearly demonstrates purposeful Indigenous landscape management practice.

The ethnographic and historical literature suggests the use of fire by Australia's Indigenous peoples dramatically shaped the landscape, its fauna and flora. Ecologists too have investigated the impact of fire, its effects on biodiversity and importance in providing habitat for Australian fauna.

2.4.4 Ecological understanding

For many decades Australian ecologists have been aware of the importance of fire to the continent's diverse fauna and flora. Some anthropologists and historians have gone as far as to claim this landscape and its faunal and floral associations have been shaped by human hand and fire stick (Bird et al. 2005:459; Gammage 2011). Ecologists agree with some elements of this proposition but have queried others.

Australia's flora was shaped by a number of factors. The fracturing of the Gondwanan super-continent and associate vicariance separated Australian taxa from the rest of the world. Forty-five percent of Australian flora including Casuarinaceae, Bossiaeeae, Eucalypteae, Proteaceae, Callitroideae, and *Nothofagus*, was originally from Gondwanaland (Crisp and Cook 2013:306). The major portion of Australia taxa (48% of Australian flora), however, migrated to Australia by ocean after the break-up of Gondwanaland, these included *Brachychiton* sp., *Solanum* sp., *Olearia* sp., *Cycas* sp., and *Livistona* sp. The origin of the remaining 7% of the Australian flora is still ambiguous, including *Acacia* sp. This is because these clades have a 'sister group' (clades that share the same common ancestor) elsewhere in the world (Crisp and Cook 2013:306). It is therefore difficult to identify their place of origin. The isolation of the Australian continent allowed clades to establish themselves with limited competition (Crisp and Cook 2013:319). Crisp and Cook (2013:319) claim this allowed Eucalypts and Acacias to dominate Australia's dry forests and woodlands. Through their own advantageous characteristics both were able to maintain their early dominance as other taxa arrived – Eucalypts with their capacity to epicormically resprout after severe fires and Acacias present from the Oligocene used their nitrogen-fixing abilities to establish themselves on Australia's oligotrophic soils. The features which characterise the Australian flora, sclerophylly, xeromorphy, dominance of a few taxa (Myrtaceae, Proteaceae, and genera

Eucalyptus, Acacia and *Triodia*), are not unique to this continent (Crisp and Cook 2013:302, 319). However, their occurrence together and across such a large proportion of the continent is unusual (Crisp and Cook 2013:319).

Defining the antiquity of burning in Australia is a fraught exercise. Considering the organisation of Australia's fire-phyllic and fire-sensitive flora, Bowman (2003:6-7) concludes its distribution was shaped by continental movements in the Tertiary. Pre-human fires in Australia, ignited by lightning, would have produced a 'coarse-grained mosaic' of different habitats across the landscape (Bowman 2003:9-10). This pattern was very different to the fine-grain mosaics of anthropogenic burning, which greatly altered the composition of Australia's flora and fauna (Bowman 2003:10; Jones 1980a:124). These changes could potentially be deleterious to some taxa, with some suggesting burning contributed to the megafauna's demise (Bowman 2003:10; Miller et al. 2005; Price et al. 2011:911). However, many taxa benefited from frequent burning and thrived under human stewardship.

Bolton and Latz's (1978) research in the Tanami Desert (northern Australia) demonstrates the importance of anthropogenic fire regimes for the Western Hare-Wallaby. The survival of the Hare-Wallaby is depended on a fine mosaic of habitat cover at different stages of fire succession (Bolton and Latz 1978:293). The consistent winter burns applied by local Aboriginal groups have provided the necessary forage and habitat cover for Hare-Wallaby survival. However, in areas where burning have ceased the wallaby has become locally extinct (Bolton and Latz 1978:293). The impact of fire cessation is not just confined to Australian fauna, the flora has also been equally affected.

Australia has five endemic *Callitris* species (*C. columellaris, C. glaucophylla, C. intratropica, C. preissi, C. verrucosa*), all are sensitive to fire. Since the cessation of fire regimes across the continent the distribution of these taxa has changed substantially. In the woodland of Arnhem Land the cessation of anthropogenic fire regimes during the mid-20th century led to a build-up in fuel loads (Haynes 1985). The fires that resulted decimated the local *Callitris* population. Research conducted by Bowman and Latz (1993) in the MacDonnell Ranges, Central Australia, concur with Haynes' assessment. They conclude that the cessation of Aboriginal landscape burning decreases the survival rates of Cypress Pine (*C. glaucophylla*) (Bowman and Latz, 1993:223). This is in contrast to New South Wales where the removal of fire from the landscape has seen Cypress Pine (*C. glaucophylla*) takeover grazing land (Hodgkinson and Harrington 1985). It is clear from this research that the proportional use of fire applied by Australia’s Indigenous peoples protected fire sensitive taxa in one area and maintained open grasslands in another.

The ethnographic, historic and ecological literature demonstrates how fire has benefited particular fauna and flora in Australia. There are multiple ethno-historic examples of anthropogenic fire use which benefit key economic food taxa. This research has, however, failed to consider the management of fuel wood as part of these practices.

2.4.5 Anthracology and ‘fire-stick farming’

The ethnographic, historic, and ecological literature clearly demonstrates how people use fire to curate resources in their environment. The practices which have been observed since the 18th century cannot, however, be transposed directly onto the past.

In Hiscock’s (2014) view Gammage (2011) alludes to a great antiquity of fire practice in Australia. He claims that there is an assumption in Gammage’s work that the practices which have been observed ethno-historically have been applied by Indigenous Australians, across the continent, for many millennia. Hiscock opposes this view claiming it treats the ‘impressively transformative Aboriginal cultures’ of Australia as static and unchanging, inflexible, and universal in their practice and law. Hiscock (2014) reacts against this application of analogy and claims Gammage’s argument removes human decision making from this process. It disenfranchises humans as the active agent in these processes. Direct historic analogy makes the dangerous assumption that human behaviour is unchanging and ontologically uniform.

Hiscock (2014) does not oppose the idea that people used fire in the landscape. He simply warns against the use of ethno-historic observations as the sole interpretation of archaeological data. Some of the palaeoenvironmental data discussed by Hiscock highlights both the need for landscape burning in Australia and the signals these practices have produced. The need to manage fuel loads in the landscape has been tied to the mass extinction of Australian megafauna in the Pleistocene (see Bowman et al. 2016:2-3). Without these large herbivores recycling biomass the potential for large conflagrations was immensely dangerous (Flannery 1994). Alternatively, the initiation of fire regimes may have been in response to increasing biomass post-LGM as increasing rainfall and atmospheric CO_2 fed growth (Reeves et al. 2013a:24; Reeves et al. 2013b:102). In any case, through the application of fire humans were able to reduce the risk of larger deadly bushfires. This application of fire in the landscape is reflected in the geomorphological record. Hope et al.

(1985) demonstrate the formation of sand sheets in Kakadu National Park, over the last 20,000 years. They claim anthropogenic burning in the surrounding landscape mobilised the sand sheets which now fill the river valleys.

Fluctuations in burning have also been tracked by Mooney et al. (2011) who found that there was no distinct change in fire regimes corresponding to the arrival of humans in Australia (50 ± 10ka) (Mooney et al. 2011:30). Their study found that increased biomass burning correlated with warmer periods with colder periods characterised by less burning (Mooney et al. 2011:31). They also found that an increase in atmospheric CO_2 caused by global industrial output lead to an increase in biomass. This in turn caused an increase in biomass burning in the last 200 years. There is no evidence in the charcoal record of a 'signal' of human arrival in the continent with the authors highlighting that any changes were in the nature of burning not in the magnitude (Hiscock 2014). Bliege-Bird et al. (2016) have called for anthropogenic burning to be studied at the landscape scale. They are critical of Mooney et al. (2011) and Williams et al. (2015) broad brush approach to fire dynamics in Australia. "Anthropogenic fire regimes thus emerge from dynamic interactions between people and climate and are clearly detectable at landscape-level scales, but would not be predicted in an analysis that decouples climate and human drivers of fire regime dynamics" (Bliege-Bird et al. 2016:7).

In archaeology all interpretations need to be considered and tested against the evidence. Anthracology allows archaeologists to examine past fuel wood selection strategies: what taxa were present, from which vegetation communities they were from and, with the aid of other palaeoenvironmental data as a baseline, the proximity of these communities to the site.

If the local landscape is burnt, either by a bushfire or an anthropogenic fire, fuel wood is consumed. The fuel wood which feeds the landscape fire is the same fuel wood which is collected for the hearth. A burnt local landscape means a depression in this essential resource, an unsatisfactory outcome for humans who are reliant on a daily supply of fuel wood. Research suggests an absence of fuel wood in the environment leads to characteristic human responses – a change in fuel wood selection patterns (Shackleton and Prins 1992) or burning of a wood substitute (i.e. dung) (Miller 1984). The absence of any signs that this essential resources was locally depressed would suggest it is being managed with or at the very least protected from landscape fire.

Fire regimes are not homogenous or universal, even in Australia. Ethnographic and historic records have demonstrated they are tailored to specific landscapes and ecologies and directed by foresight and intention (Gammage 2011). The landscape burning practices observed in Australia are specific to place and time (Lewis 1986:47). The creation of discrete ecological and economic patches in a landscape should be considered a form of niche construction.

2.5 Theoretical approach: Niche Construction in Historical Ecology

The generation of energy through the use of fuel has allowed humans to create, cook, and illuminate. The intimate relationship humans have with fuel has allowed them to extend their geographical range, manufacture complex objects and structures, and reshape their environment. Fuel is an essential daily resource (Dufraisse 2012:70). Surprisingly, however, it is absent from the Australian archaeological discourse. One of the major aims of this thesis is to reconceptualise fuel, its access and management, in the Australian archaeological record. A major part of this reconceptualisation is reframing perspectives of fuel and its place in a landscape. Fuel wood, an essential daily resource, should be considered alongside other key resources when discussing fire regimes and other landscape management practices.

Predominantly the principle of least effort (PLE), as discussed by Shackleton and Prins (1992) is employed when interpreting fuel wood selection patterns in the global anthracology literature (Asouti and Austin 2005; Dotte-Sarout et al. 2015). In the last decade, however, there has been a movement away from ecologically utilitarian applications of the principle of least effort toward considerations of subsistence economy (Asouti and Austin 2005:9; Picornell-Gelabert et al. 2011:376). This shift has not yet been reflected in the Australian anthracological literature. This section will present the basis for a new conceptual framework (presented in Chapter 6) for considering fuel wood collection and management in the subsistence economy of Australia. Picornell-Gelabert et al. (2011:376) present dual aims for this approach: 1) ‘to construct frameworks of reference classified by modes of production’, and 2) ‘identify the range of economic behaviours to which firewood exploitation was integrated’. These aims are central to the reconceptualisation of Australian fuel wood presented below.

Fuel wood in Australia needs to be assessed in relation to landscape management practices and specific subsistence economies. One of the predominant landscape management practices proposed for Australia is Jones’ (1969) ‘fire-stick farming’ hypothesis. Historic and ethnographic accounts provide tantalising insights into the complexity and effectiveness of this management practice (Bird et al. 2005; Bliege Bird et al. 2008; Gammage 2011; Jones 1980a, 1980b, 1975; Russell-Smith et al. 1997). Archaeologically, however, this hypothesis still requires further data and testing. One of the major issues arising from the existing literature, however, is the absence of fuel wood from discussions of resources managed by fire. The fuel which is consumed in the landscape fire is the fuel which is gathered for the hearth. It is for this reason that a reconceptualisation of the management and accessibility to fuel wood is being proposed in relation to the ‘fire-stick farming’ hypothesis.

2.5.1 Fire mosaics as a form of niche construction

The intentional and directed use of fire by Indigenous Australians has enabled them to create discrete ecological niches. These practices have been well documented ethnographically (section 2.4.2), historically (section 2.4.3), and have clear ecological outcomes (section 2.4.4). The creation of a mosaic of different ecological niches, each replete with a suite of economic and culturally important resources should be considered a form of niche construction (Odling-Smee et al. 2003; Rowly-Conwy and Layton 2011). There are many examples globally of humans deliberately constructing niches for their own economic benefit (Asouti and Kabukcu 2014; Bishop et al. 2015; Lentfer and Torrence 2007; Lewis 1986; Posey 1998:105; Rowly-Conwy and Layton 2011), including the recognition that the use of fire by Indigenous Australians is a form of niche construction (Bliege-Bird et al. 2013). There is, however, one consistent omission, a detailed consideration of fuel wood in these niche constructing practices.

The proponents of niche construction theory (NCT) claim that all organisms, through their actions, partly create and partly destroy their niche (Odling-Smee et al. 2003:1-2). Odling-Smee et al. (2003; building on the work of Lewontin 1983) are the key proponents of niche construction theory in evolutionary biology. They claim that through niche construction organisms change their environment to enhance their survivability and the survivability of their offspring (Odling-Smee et al. 2003:1-2). Odling-Smee et al. (2003:28) claim that humans should not be seen as passive vehicles for genes because through their niche constructing behaviour they actively modify sources of natural selection in their environment. These authors claim that, “Niche construction should be regarded, after natural selection, as a major participant in evolution” (Olding-Smee 2003:2). They also hold that, through the creation of these ecological niches parents are providing their offspring with an evolutionary advantage in the form of an ecological inheritance. Niche construction theory builds upon and extends traditional ‘dual-inheritance’ models by adding an ecological inheritance to the genes and cultural traits offspring inherit from their parents. It is for this reason that niche construction has been referred to as ‘triple-inheritance’ theory (i.e., genetic, cultural, and ecological inheritance) (Laland and O’Brien 2010:312).

The modification of an organism’s niche by the organism and/or others is an accepted feature of biology. However, proponents of niche construction theory (NCT) claim this has been neglected by traditional neo-Darwinian biologists (Odling-Smee et al. 2003), a claim the latter deny (Scott-Phillips et al. 2013:1233). NCT has been enthusiastically incorporated into the archaeological literature (Boivin et al. 2016; Laland and O’Brien 2010; O’Brien and Laland 2012; Rowley-Conwy and Layton 2011; Smith 2012, 2014), however the theory remains a highly contentious and debated issue in evolutionary biology (Scott-Phillips et al. 2013). This contention mainly revolves around the claim that niche construction is an evolutionary process second only to natural selection. A claim supporters insist justifies the need for NCT to be included in evolutionary debates.

The more traditional neo-Darwinian evolutionary biologists, however, maintain there are only four evolutionary processes which can determine gene frequency (the basis of evolution and in turn fitness outcomes). These are natural selection, genetic drift, mutation and migration – the latter two generate variation, the first two sort it (Scott-Phillips 2013:1232). The neo-Darwinians maintain niche constructing behaviour and environmental change can cause evolutionary change but the processes through which that change occurs remains the same. They do not oppose niche construction but oppose the NCT claim that it is an evolutionary process akin to natural selection.

Therefore, the application of niche construction in this thesis does not suggest niche constructing behaviour was a process in genetic change, but may have acted as an influence of such changes in the traditional neo-Darwinian sense. It is maintained, however, that through their niche constructing/modifying activities humans changed their ecological niche and that these changes to the environment were ‘inherited’ (non-genetic inheritance) by their offspring, in which traditional concepts of fitness acted accordingly.

These niche modifying behaviours may have initially been unintentional or their outcomes (short or long) unforeseen/unforeseeable. However, through trial and error and observation these understandings would have come to be enshrined in law/lore and practice. These laws and practices would have been taught/imitated and transferred from parent to offspring, non-relation to next generation, peer to peer via the process of cultural inheritance (Odling-Smee and Laland 2011:227). Therefore, it is held that these niches once established could be maintained over generations (greater than individual lifetimes) and sustained as long as they met neo-Darwinian thresholds for evolutionary success/fitness expressed through survival facilitated by the established evolutionary processes of natural selection, genetic drift, migration and mutation.

The anthropogenic creation of a niche impacts both humans and the other organisms that share the niche (Odling-Smee et al. 2003:24). The construction of niches through mosaic landscape burning has a direct effect on the allele selection of particular plant communities. Fire will benefit those taxa which are predisposed to burning, those that benefit from fire and thrive in its presence. The taxa which are not genetically predisposed to fire will be impacted by the anthropogenic introduction of fire (fires which are in addition or unlike to the natural occurrence of fire in the landscape). This increased impact will have a detrimental effect on these taxa which will alter the composition of the community. The application of fire could therefore be seen as an all or nothing approach in which taxa are benefited or disadvantaged. If humans, however, apply forethought and intention in their practice, applying what they have learnt, they may choose to intervene in these allele selections through the preferential treatment/protection of desired taxa or communities which have economic or cultural value (see Jones 1975 for an ethnographic example). These practices have led researchers Asouti and Kabukcu (2014:178) to state that the ecological concepts such as ‘climax vegetation’ may need to be reconsidered (see also Balee 2006:77; Newson 1998:48). Through niche construction humans are intervening in the development of woodland vegetation and altering its structure. Through their actions they are maintaining woodland in a perpetually immature state, meaning ecological climax may never actually be realised. This has major affects for how anthracological assemblages are interpreted and means researchers should reconsider their reliance on established ecological models.

2.5.2 Niche construction: events in the history of landscape

The coupling of an evolutionary approach (niche construction) with a historicist framework may seem diametrically opposed. However, the anthropogenic creation of ecological niches across time represents waypoints in the history of the landscape. ‘Landscapes are historic constructs, not immutable givens’ (Balee 1998b:15). An examination of human niche constructing behaviour encourages an interrogation of the historical development of the landscape.

‘the landscape is the place upon which past events have been inscribed’

(Balee 2006:77)

This approach is not without precedent. There are multiple examples of researchers working in an historical ecology paradigm acknowledging the contribution of anthropogenic landscape burning to history of landscape (Balee 2006:77; Pyne 1998; Roos 2008). Even the coupling of niche construction theory and historical ecology has been presented by Roos (2008) in his PhD dissertation. In this he demonstrated the value of understanding the landscape burning of niche constructing Indigenous Americans and how this understanding could aid in applied historical ecology.

Historical ecologists hold that the division of nature and culture should not be seen as a dichotomy but rather a dialogue (Balee 1998b:14). Their research focuses on the ‘interpenetration of culture and the environment, rather than the human adaptation *to* the environment’ (Balee 1998b:14). A sentiment echoed by NCT, humans are active in shaping their environment not just subject to it. For historical ecologists this aim is a reaction to the determinism of cultural ecology, and a recognition that humans actively modify their own environment for their advantage (Balee 1998a:3). The key postulates of historical ecology are outlined by Balee (1998b:14):

1) ‘much if not all of the non-human biosphere has been affected by human activity’

The effects of anthropogenic activity are well documented (at varying scales) in the archaeological, palynological, and palaeoclimatological records as landscape modification (Lentfer and Torrence 2007), pollution (Hong et al. 1994), and climate change (IPCC 2014) to name but a few.

2) ‘human activity does not necessarily lead to species degradation and habitat destruction, nor does it create a more habitable biosphere or increased speciosity’

Humans will ultimately be driven by self-interest and preservation – their actions are for no other than themselves and their kin. Balee (1998b:16; Balee and Erickson 2009:10) considers the dual concepts of the Ecologically Noble Savage (ENS) and *Homo devastans*. The ENS, according to Balee, are Indigenous people who do not impact on the biodiversity of an area and may actively aim to increase it. Their knowledge is greater than Western science could ever attempt to capture. In contrast, *Homo devastans*, are humans who have a negative impact on the environment. Their actions lower biodiversity, they are destructive and polluting.

Neither concept, according to Balee, is correct. In some places anthropogenic modification of the environment may increase biodiversity (i.e. Bliege Bird et al. 2013) but in other areas their actions may be deleterious. Understanding these practices in their own local biosphere and economy are essential, which leads to postulate three.

3) ‘different sociopolitical and economic systems have different effects on the local biosphere and non-human life forms’

The recognition that different subsistence economies have different effects on the landscape is not revolutionary. In some quarters of archaeological inquiry, however, shifts from ecologically utilitarian paradigms to ones based on human agency have been slow to be implemented. This shift is starting to be made in the anthracological literature concerning fuel wood management (cf. Asouti and Austin 2005; Asouti and Kabukcu 2014; Picornell-Gelabert et al. 2011), however more needs to be done especially in Australia.

4) ‘human actions and the landscapes with which they interact should be treated as total phenomena.’

This postulate feeds directly into a core concept of historical ecology, that human action (culture) and environment (nature) should not be seen as a dichotomy but as a dialogue. Humans are an integral part of the environment, especially when considering landscape creation. The concept of pristine wilderness is a false one, the concept of culture without landscape is a myth (Balee 2006:77; Denevan 1992; Graham 1998:128).

Instances of niche constructing behaviour are events that are inscribed on the landscape. These anthropogenic activities shape the landscape and create an ecological inheritance for future generations. Researchers are starting to appreciate the power of these activities in a range of different ecological settings (Boivin et al. 2016; Laland and O’Brien 2010; O’Brien and Laland 2012; Rowley-Conwy and Layton 2011; Smith 2012, 2014). These activities do, however, have an effect on the provisioning of particular resources in an area. These activities do not necessarily always have a positive outcome or lead to increased biodiversity in an area (i.e. *Homo devastans*). Management of key subsistence resources would have been a central concern for landscape modifying humans. Therefore the place of fuel wood will be reconsidered as part of the ‘fire-stick farming’ hypothesis. The fuel which is burnt in the landscape fire is the wood which is collected for the hearth. Niche construction theory provides a broad mechanism – a heuristic model (presented in Chapter Six) – through which to understand and arrange human landscape modifying practices including landscape burning. These instances of niche construction are inscribed on the landscape and contribute to the historical ecology of that landscape. This heuristic model and the thesis as a whole are formulated in the postulates of historical ecology. These postulates frame the overarching philosophy of this research – the dialogue between humans and the environment.

2.6 Synthesis

The literature presented in this chapter demonstrates the utility of using hearth contexts to understanding human fuel wood selection strategies. Much of the literature has until now relied upon the principle of least effort (PLE) for understanding human fuel wood selection, assuming woodland taxa would be collected in equal proportion to how they occur in the environment. This orthodoxy has, however, started to be challenged in recent years. Picornell-Gelabert et al. (2011) have called for fuel wood selection to be understood as 'a historically constituted and socially mediate' process. The authors urge anthracologists to consider fuel wood selection as a practice that is informed by cultural beliefs and economic constraints. That fuel wood collection does not operate in a socio-cultural vacuum but is informed by anthropogenic landscape management and impacts on the environment.

It is for this reason that this thesis is exploring the place of fuel wood within an anthropogenic fire regime, to better understand the management of fuel in an Australian setting. This thesis maintains that anthropogenic fire regimes are a landscape modifying process which are a critical aspect of that landscape's historical ecology. Therefore, if the landscape was being modified through anthropogenic burning then these modifications should be identifiable in the wood charcoal assemblage. These modifications would be visible anthracologically as: changes in woodland structure, represented by woodland forms that were maintenance through firing (i.e. open woodland); the presence of fire-sensitive but economically important vegetation communities, such as monsoon vine forest, close to habitation sites; or the maintenance of the woodland in a perpetually immature state, preventing it from reaching its predicted ecological climax. These indicators, when considered against independent palaeoenvironmental and ecological data sets, may suggest an anthropogenic intervention in the tempo and scale of fire in the landscape. These types of anthropogenic interventions would have a clear impact on the availability and supply of key economic resources such as fuel wood.

Chapter Three – Landscape, Archaeology and Ecology

The Alligator Rivers region has a diverse biota, dynamic climate, and rich cultural bounty. This chapter will explore palaeoenvironmental and climatic changes in this region over the last 30,000 years. It will also examine the geomorphological evolution of the landscape and changing vegetation formations which are critical to this research. These large scale environmental changes provide the backdrop to the rich archaeological record of the Alligator Rivers region and the long history of archaeological research in this area.

3.1 The palaeoenvironment of northern Australia (30ka – present)

The continent of Australia is expansive, covering 60^{o} of latitude and 50^{o} of longitude. In the north it is influenced by the Asian monsoon and in the south the Antarctic winds of the Southern Ocean (Reeves et al. 2013a:21). This review will focus on the northern portion of the Australian continent through the fluctuations of the past 30,000 years. This is a period in which the landscape, climate and vegetation of this area changed dramatically. During this period meridional fluctuations brought the Earth out of the ice age, reshaped the landscape through sea level rise and reconfigured the vegetation. Northern Australia is between two Oceans (Pacific and Indian), the tropical monsoon belt of Southeast Asia and the aridity of central Australia. Its geographic location means it is affected by a range of climatic influences – the El Nino-Southern Oscillation (ENSO), the inter-tropical convergence zone (ITCZ), the Indo-Pacific warm pool (IPWP), the Asian monsoon, and the Indonesian-through-flow (ITF). This area also influences the climate and vegetation of other parts of Australia, with many major Australian river systems being fed by northern Australian rainfall.

Reeves et al. (2013a) divide the last 30,000 years into three distinct climatic periods, the glacial period (30-18 ka cal BP, including the LGM 21-18ka cal BP), the deglacial period (18-12 ka cal BP), and the Holocene (12-0 ka cal BP). Further dividing the Holocene into the early (12-8 ka cal BP), mid (8-4 ka cal BP), and late (4-0 ka cal BP). Their partitioning of time is based on geological and climatic indicators and will be followed in this thesis. Reeves et al. (2013b) review of northern Australian climate synthesise coral, speleothem, ice core, microcharcoal, sea surface temperatures (SST), sea surface salinity (SSS), CO_2 levels, $\delta^{18}O$ ratios and palynological data. This comprehensive review and synthesis was undertaken as part of the Australasian-INTIMATE (**Int**egration of **I**ce-core and **Ma**rine **Te**rrestrial) project (Reeves et al. 2013a).

Unfortunately, the palaeoclimatic and palaeovegetation records specific to the study area are constrained to the Holocene. For this reason data will be collated from the wider region to offer a broader picture of climatic fluctuations and proposed vegetation during the glacial and deglacial periods. After which more geographically constrained data sets will be used to model the climate and vegetation of the study area during the Holocene.

3.1.1 Glacial period (30 ka-18 ka cal BP)

The Glacial period represents the final stage of the last glacial. Williams et al. (2009:2414) suggest a cooling and drying trend commenced around 30 ka, although this is not yet demonstrated uniformly for the whole region. During this period the global climate deteriorated further as the Earth moved into the last glacial maximum (LGM). The LGM, described by Reeves et al. (2013b:100, 108) as a period of reduced precipitation and decreased temperatures, occurred between 22-18 ka. Fossil corals demonstrate a 3^{o}C reduction in sea surface temperature (SST) during the LGM, which coupled with reduced sea surface area led to a decrease in overall rainfall (Williams et al. 2009:2407). Reductions in sea surface temperature, sea surface area, and obstructive exposed continental shelves dramatically altered the effectiveness of the region’s climate systems. Warm equatorial waters were diverted, by the exposed Sahul shelf, northward around New Guinea and southward on the outside of then exposed Great Barrier Reef (Williams et al. 2009:2407). The exposed Sunda and Sahul shelves in the north and the expanded islands of the Indonesian archipelago greatly reduced the movement of water through the archipelago, effectively shutting down the Indonesian Through Flow (ITF) during this time. However, other climate systems, such as the Intra-tropical Convergence Zone (ITCZ), El Nino Southern Oscillation (ENSO) and the Asian Monsoon all remained active during the LGM but often in a much reduced capacity (Ayliffe et al. 2013:3; De Deckker et al. 2002:33). The vegetation of the region was not just impacted by reductions in rainfall and temperature but also decreases in atmospheric CO^2. Reduced CO^2 levels during the LGM reduced the amount of woody vegetation in the region, leading to alterations in the region’s vegetation communities (Reeves et al. 2013a:30).

As global temperatures deteriorated the ice sheets of the Northern Hemisphere expanded (Lambeck and Chappell 2001). This expansion caused global sea levels to drop by up to 130 m during the LGM (Yokoyama et al. 2009:13-14). Climate systems in the region were heavily impacted by this shift in the land to sea ratio. Expanded continental shelves obstructed water circulation and reduced the area of warm shallow sea water available for uptake by the Asian monsoon (De Deckker et al. 2002: 27; Reeves et al. 2013a:30). Evidence for reduced monsoonal activity during the glacial period has been recorded in the Timor Sea (Reeves et al. 2013b:101). This reduction would have led to reduced rainfall over tropical Australia (Reeves et al. 2013b:101).

These reductions led to changes in vegetation across northern Australia. Drought tolerant taxa began to dominate vegetation communities with monsoon vine forest forced into refugia. Models, such as those proposed by Nix and Kalma (1972) and van der Kaars et al. (1991), suggest vegetation communities moved northward in a ‘bow wave’, as the arid zone expanded. These shifts in temperature and rainfall would have affected vegetation zonation during this period, whether this shift was in a ‘bow wave’ movement northward as suggested by these models is yet to be demonstrated on a local scale. Alternatively, the composition of vegetation communities may have stayed the same with the proportions of particular taxa, which were suited to these new conditions, becoming more pronounced at the expense of other taxa. van der Kaars et al.’s (1991) modelling indicates much of northern Australia was covered with grassland and shrubland during this period. Although some researchers claim tropical lowland forest and open woodland would have persisted during the LGM in northern Australia (Markgraf et al. 1992:195; Pickett et al. 2004:1433). As the temperatures decreased ice sheets and glaciers expanded dropping sea levels to their lowest levels in 130-140,000 years (Lambeck et al. 2002:201 Fig. 2a). The exposed Sahulian shelf created a land bridge between the north of Australia and the south coast of New Guinea. Situated on this land bridge was Lake Carpentaria which between 44 ka and 12 ka formed a permanent lake, albeit with major fluctuations in water level (Reeves et al. 2013b:105). Reeves et al. (2008:18) state that for the lake to be maintained during this period, especially 30-22 ka, pluvial conditions would have been required. This coupled with evidence of palaeofloods during this period (Nott and Price 1999) would suggest the arid conditions present in the centre of the continent were not as acute in the tropics (Reeves et al. 2008:18).

In the northwest of Australia van der Kaars et al. (2006:888) noted changes in vegetation composition between 32-20 ka. Herbs and grasses (Asteraceae, Poaceae, and Chenopodiaceae) and *Callitris* came to dominate the vegetation, partly replacing *Eucalyptus* in the landscape. Williams et al. (2009:2409) noted a dominance of Poaceae and decrease in fern spores and *Acacia* sp. pollen, signifying drier conditions. They identify the distinct minimum of *Eucalyptus* between 35-34.4 ka as the likely driest period during the last 35,000 years. Williams et al. (2009:2409) note a brief increase in precipitation marked by an increase in pteridophyte values and a decrease in *Casuarina* around 20.7 ka before a brief return to drier conditions.

3.1.2 Deglacial period (18-12 ka cal BP)

Following the LGM the global climate began to ameliorate, temperatures increased and precipitation exceeded current levels. As global sea levels began to rise water was liberated from melting ice sheets and glaciers flooding the Australian continental shelf. This inundation produced a warm shallow sea fringing the continent (Allen and Barton 1989:10; Shulmeister and Lees 1995:15). This large body of warm water facilitated increases in precipitation and fed the re-emergent Asian monsoon by 13-15 ka. The monsoon was further aided by the re-establishment of the Indonesian Through Flow (ITF) and warmer SST (Reeves et al. 2013b:102). Decreases in sea surface salinity (SSS) were noted at this time, a further sign of increased precipitation in the region (Reeves et al. 2013b:102). The re-intensified and expanded monsoon, supported by the southward movement of the inter-tropical convergence zone (ITCZ) led to higher rainfall in northern Australia (Reeves et al. 2013b:108; Reeves et al. 2013a:28). Precipitation reached levels higher than today.

This increase in rainfall re-invigorated the landscape and fed the growth and expansion of vegetation. *Eucalyptus* came to dominate woodland once more, as herbs and grasses decreased (Williams et al. 2009:2409). De Deckker et al. (2002:32) note signs of flooding in sedimentary records in NW Australia and increased rainfall is noted at Barrow Island with the appearance of Northern nailtail wallaby (*Onychogalea unguifera*) in the zooarchaeological record (Manne and Veth 2015:10). Increases in rainfall were also noted at Lake Carpentaria at 14 ka (Reeves et al. 2008:18). Unlike the northern hemisphere the Younger Dryas was not felt in Australia, with the Antarctic Cold Reversal (ACR) only recorded as a minor blip in temperate Australia (14-13.5ka) (Reeves et al. 2013a:30). Deglaciation at Mt Wilhelm (New Guinea) began at 14.8 ka, with the mountain completely ice free by 9.3 ka (Hope and Peterson 1975). Atmospheric CO_2 levels increased, as it was liberated from melting ice, driving plant growth (Reeves et al. 2013a:24). From 12 ka sea water began to breach the Arafura Sill and by 10.7 ka Lake Carpentaria had returned to marine conditions (Reeves et al. 2013b:105). Palynological coring of the lake has demonstrated (Chivas et al. 2001:33) an increase in woodland pollen after 14 ka.

3.1.3 Holocene (12-0 ka cal BP)

3.1.3.1 Early Holocene (12-8 ka cal BP)

The warmer wetter conditions established in the deglacial period continued into the early Holocene. Sea levels continued to rise; the Gulf of Carpentaria was inundated by 12 ka (Yokoyama et al. 2009:17). Warmer wetter conditions are recorded across the region, the highest SSTs in 30,000 years were recorded at this time (Reeves et al. 2013b:102). This peak in temperature was concurrent with the northern hemisphere thermal maximum. Increasing SST and shallow fringing seas led to increases in precipitation for northern Australia. These conditions supported the re-emergence of sensitive taxa from the refugia of northern Australia. It is during this period that the modern vegetation of northern Australia is established. Specific vegetation community information for the study area will be discussed in section 3.2.

3.1.3.2 Mid-Holocene (8-4 ka cal BP)

The pollen record on Groote Eylandt indicates that effective precipitation (EP) peaked during the mid-Holocene (Shulmeister and Lees 1995:12). The authors suggest a raised water table and optimal vegetation conditions between 7.5-3.8 ka on the island (Shulmeister and Lees 1995:12). This is during a period of increasing climatic variability and the strengthening of the ENSO climate system (Linsley et al. 2010:582; Reeves et al. 2013b:109). Regionally, changes in insolation seasonality led to the northward migration of the ITCZ (Abrams et al. 2009:2798). As the ITCZ moved northward the IPWP followed leading to a strengthening of the Asian monsoon (Abrams et al. 2009:2798, 2802; Reeves et al. 2013b:109). This contraction was recorded in coral records across the region (Reeves et al. 2013b:103). The northward movement of the ITCZ and IPWP would have reduced precipitation levels in northern Australia.

3.1.3.3 Late Holocene (4-0 ka cal BP)

The climate of northern Australia during the late Holocene is dominated by the establishment of the modern El Nino Southern Oscillation (ENSO) climate regime. Records indicate the establishment of the modern ENSO periodicity by 5000 BP, with an abrupt increase in its magnitude at 3000 BP (Gagan et al. 2001:139). The Australian monsoon switched from being a reliable annual event to having stronger and weaker years (Shulmeister and Lees 1995:14). This increase in climatic variability in the late Holocene can be attributed to a strengthening of ENSO, with greater frequency of ENSO events, drought and fire, occasionally interrupted by wetter La Nina conditions (Reeves et al. 2013a:30). Rainfall was more variable, at times precipitation levels were higher than those enjoyed between 7-4 ka, however in some areas there was localised aridity (Reeves et al. 2013b:108,109; Shulmeister and Lees 1995:14). The increased seasonality present during this period was expressed in the pollen records of the region (Reeves et al. 2013b:108). Effective precipitation (EP) was reduced in northern Australia because of the increased variability of the ENSO system (Shulmeister and Lees 1995:14).

3.2 Palaeoenvironment of the Alligator Rivers' region (22 ka - present)

3.2.1 The Last Glacial Maximum (22-18 ka)

W.A. van der Kaars (1991) has hypothesised, based on the constraints of rainfall and temperature that the environment of the Alligator Rivers region would have been very different during the Last Glacial Maximum (LGM). He suggests that 18,000 years ago the vegetation of the region would have been low open woodland (i.e. shrubs and grasses), similar to that which occurs 800 km to the south in the present (van der Kaars 1991:296 Fig. 20). Other research however has suggested tropical lowland forest and open woodland would have been present in northern Australia during this time (Markgraf et al. 1992:195; Pickett et al. 2004:1433). A tentative rainfall map constructed by van der Kaars (1991:295-296 Fig. 22) places Madjedbebe in the 250-500 mm annual rainfall zone during the LGM. A substantial decrease in annual precipitation when compared with modern levels (i.e. 1000-1500 mm) (BOM 2016; van der Kaars 1991:245). Even under these drier conditions Hope et al. (1985) suggest monsoon vine forest would have been able to persist in deep sand areas during this period.

3.2.2 Deglaciation (18-12 ka)

As temperatures and climate ameliorated following the LGM the low open woodland was replaced by woodland and open forest (Nix and Kalma 1972). Rising sea levels flooded the low lying continental shelf producing a warm shallow sea (Allen and Barton 1989:10). The existence of a warm body of water near the continent lead to increased evaporation and wetter conditions. S. van der Kaars et al. (2006) concur with Allen and Barton as their palynological data demonstrates an increase in precipitation and temperature between 14,000-4,000 BP.

3.2.3 Trangressive phase (8-6.8 ka)

In addition to climate and rainfall the landscape underwent large scale geomorphological changes in the early Holocene due to post-glacial marine transgression (Woodroffe et al. 1985). As sea levels rose northern Australia's incised river valleys (i.e. South Alligator, East Alligator, Adelaide, Mary) were inundated producing extensive tidal flats and mangrove forests. This phase has been termed by Woodroffe et al. (1985:712-713) as 'the transgressive phase'. Open Eucalypt woodland along watercourses was replaced by *Rhizophora*-dominated mangrove forest as floodplain vegetation succumbs to hyper saline conditions (Woodroffe 1988:3). Geomorphic data from Magela Creek suggest marine influence had reached as far inland as the Jabiluka Billabong, close to Madjedbebe, by 7.7 ka (Clark et al. 1992:90). Vegetation communities away from these waterways were also undergoing changes at this time. With increased water availability, arid zone communities were pushed south toward their current extent by resurgent closed forest, open forest and woodland formations (Nix and Kalma 1972:87). There is even evidence of monsoon vegetation on Melville Island at this time, where there is presently none (Allen & Barton 1989:10).

3.2.4 Big Swamp phase (6.8-5.3 ka)

Coinciding with the stabilization of sea level there was a brief peak in *Sonneratia* sp. in the mangrove forests. After which Rhizophoraceae quickly reestablished its' dominances before facing a terminal decline (Woodroffe 1988:6-7 Fig. 3). Elsewhere in the environment sediment levees started to accumulate around the mangrove forests, reducing tidal flooding, behind which a large hypersaline swamps/floodplains were produced flanking the river channels (Hope et al. 1985:236). On higher ground away from the river channel and saline swamps Myrtaceous woodlands were present (Clark et al. 1992:88).

3.2.5 Sinuous phase (5.3-2 ka)

In time fresh water additions reduced the level of salinity across the newly formed floodplains and as the salinity dropped the vegetation communities changed. In the mangrove forest *Rhizophoraceae* was replaced by *Avicennia* forests. *Avicennia* sp., which is still present in the region today, can tolerate wider fluctuations in soil water (%) and total extractable salt (TES), than the other taxa it came to dominate (Ball 1988:85 Fig.1). These shifts in mangrove taxa are reflected in the molluscan remains which accumulate in the region's middens during this period (Clarkson et al. 2015:60-62). As conditions allowed on the floodplain grass and sedge communities were established (Clark & Guppy 1988:681-682; Woodroffe et al. 1985:713). These grasses and sedges helped to stabilise the saline clays of the floodplain, leading to the development of black soil (Hope et al. 1985:236). Freshwater lagoons would have also been supported by these developments and a subsequent increase in birdlife would have been observed (Hope et al. 1985:236). It must be noted that these changes did not happen rapidly. Changes in geomorphology and vegetation occurred initially upstream often in the tributaries of major river systems and then progressed towards the mouth (Hope et al. 1985:237; Woodroffe & Mulrennan 1993:61). Freshwater conditions established, first near Mudginberri before 2,500 BP and then at Jabiluka Billabong, near Madjedbebe, between 2-1.7 ka (Clark and Guppy 1988:680; Clark et al. 1992:143-144; Wasson 1992 Figs. 4.21, 4.22) (Appendix B). After the establishment of blacksoil floodplains and suitable groundwater other taxa started to colonise these areas, initially *Melaleuca* (paperbark) and then other Myrtaceae (*Eucalyptus* sp.) (Hope et al. 1985:237). Geomorphological and palynological evidence indicates very little change in vegetation away from the river channel during this time with open Eucalypt woodland and monsoon vine forest persisting (Hope et al. 1985). After 4,000 BP both precipitation and rainfall decrease marginally (van der Kaars et al. 2006:888). It is around this time the current El-Nino Southern Oscillation (ENSO) climate complex establishes. ENSO did not necessarily mean a reduction in rainfall but an increase in its variability (Schulmeister and Lee 1995:14).

3.2.6 Cuspate phase (2 ka – present)

By this time the modern climate system (El Nino Southern Oscillation) had been established and current precipitation and temperature conditions were present in the study area. Away from the rivers and floodplains the vegetation of the region was very similar to present – woodland and open forest formations, dominated by *Eucalyptus* sp. and other Myrtaceae (Nix & Kalma 1975:89-90). Monsoon vine forest was even present on the flood plain edge c.1400 BP before disappearing, probably due to the impacts of fire (Hope et al. 1985:236). Across the region productive freshwater wetlands, replete with fish, turtles, birds, and aquatic plants, established during this period (Jones 1988:18). The river systems of the region would have moved into a cuspate phase (marked by sharp inner bends or meander spurs), although this formation may only apply to sections of the river system (Woodroffe 1988:5).

3.2.7 Localised palaeoenvironmental record

A localised palaeoenvironmental record was produced for Madjedbebe based on the extraction of pollen from the site's sedimentary matrix. These samples were analysed by Assoc. Prof. Patrick Moss (please refer to Appendix C for the full pollen sequence). The Madjedbebe pollen record contains a range of taxa from open Eucalypt woodland, monsoon vine forest, mangrove forest, and *Melaleuca* swamp vegetation communities. *Acacia* sp. pollen is only registered at very low percentages throughout. This is not surprising because *Acacia* sp. is a poor pollen producer and often under-represented in pollen cores. However the pollen which is available for *Acacia* sp. does show a clear increase over the last 1000 years. While open Eucalypt woodland and monsoon vine forest taxa remain ubiquitous throughout the assemblage there are some shifts in the overall composition of the local environment. An increase in aquatic taxa (especially Cyperaceae) may reflect increased freshwater availability over the last 3,000 years (from C4/9). Which is in agreement with other palaeoenvironmental records for the area (Clark and Guppy 1988:680; Clark et al. 1992:143-144; Wasson 1992 Figs. 4.21, 4.22). The increase in *Melaleuca* sp. pollen in the last two centuries of the record may relate to the stabilisation of the wetland edge and establishment of large *Melaleuca* sp. swamps close to the site. This expansion is also supported by the increase in mangrove pollen at this time. In the last two centuries there is a noticeable drop in the amount of Poaceae pollen present in the core. This drop in grassland cover may relate to changing land use practices in the last couple of hundred years, and may perhaps relate to the cessation or alteration of traditional burning practices with the arrival of non-Indigenous occupants to the area. The increase in *Acacia* sp. and decline in the fire sensitive *Callitris* sp. during this time would also suggest the cessation or interruption of traditional burning practices (see Bowman and Panton 1993).

3.2.8 Modern climate and vegetation

Currently the site is located on a large sand sheet surrounded by open Eucalypt woodlands dominated by Darwin woollybutt (*Eucalyptus miniata*) and Darwin stringybark (*E. tetradonta*) (Woodroffe 1988:2, 7). Pockets of monsoon vine forest occur locally against the sandstone escarpment, in depressions and in narrow gorges (Wilson et al. 1996:58). Currently, freshwater wetlands flank the main river channels and tributaries, with seasonally inundated *Melaleuca* forest also occurring between the wetlands and open Eucalypt forest. Mangrove forest are now restricted to prograding sections of coast, shoaling mid-channel island and channel point bars (Woodroffe et al. 1985:711). Owing to the flat low-lying coastal plain tidal influence can reach 105 km up river, particularly in the dry season (Woodroffe 1988:2). The study area receives 1500 mm of rainfall annually, mainly falling between November and May (BOM 2016). A detailed description of the terrestrial vegetation communities of the region are presented in Table 3.1 below.

Table 3.1 Vegetation communities for Kakadu National Park from Wilson et al. 1996

	Vegetation communities	Soil conditions	Canopy dominants	Associated canopy	Understorey	Ground cover
Lowlands	*Eucalyptus* open woodland	Undulating lateritic peneplains with deep, well drained, mainly red or yellow sandy loam soils	*Eucalyptus miniata, E. tetrodonta*	*Eucalyptus porrecta, E. bleeseri, Erythrophleum chlorostachys*	*Acacia oncinocarpa, A. aulacocarpa, Livistona humilis, Buchanania obovata, Terminalia ferdinandiana*, and on sand sheets *Callitris intratropica, Gronophyllum*	*Heteropogon triticeus, Chrysopogon fallax, Sorghum* sp.
	Eucalyptus tectifica woodland	Undulating plains with loam and clay loam soils	*Eucalyptus tectifica*	*Eucalyptus latifolia, E. foelscheana, E. confertiflora, E. tetrodonta*	*Acacia* spp., *Grevillea decurrens, Livistona humilis, Buchanania obovate, Brachychiton paradoxum, Gardenia megasperma, Planchonia careya, Cochlospermum fraseri, Petalostigma quadriloculare, Terminalia ferdinandiana*	*Sorghum* spp., *Heteropogon contortus, Themeda triandra, Sehima nervosum, Eriachne avenacea, Chrysopogon fallax*
	Eucalyptus papuana, Eucalyptus polycarpa woodland	Margins of alluvial plains or the levees of large river systems. Clayey poorly drained soils	*Eucalyptus papuana, E. polycarpa*		*Eucalyptus alba, Melaleuca viridiflora, Erythrophleum chlorostachys, Panadanus spiralis, Planchonia careya, Flueggea virosa, Buchanania obovata*, other *Melaleuca* spp.	*Chrysopogon fallax, Sorghum* ssp., *Sehima nervosum, Themeda avenaea, Heteropogon contortus*
	Melalauca viridiflora- Eucalyptus low open woodland	Poorly drain, texture contrast, colluvial or alluvial soils fringing	*Melaleuca viridiflora*	*Eucalyptus polycarpa, E. latifolia, E. oligantha, Syzygium eucalyptoides*	*Pandanus spiralis, Livisona humilis, Planchonia careya,*	*Chrysopogon fallax, Sehima nervosum, Eulalia aurea, Themeda avenacea,*

		watercourses and drainage depressions			*Grevillea pteridifolia*	*Eriachne* spp., *Sorghum* spp.
	Grevillia, *Banksia* shrubland (heath)	Sand-filled, poorly drained depressions on and adjacent to the escarpment in depressions and drainage lines	*Banksia dentata, Melaleuca nervosa, Grevillea pteridifolia*	*Jacksonia dilatata, Melaleuca symphyocarpa, Verticordia cunninghamii, Acacia* spp.	*Eucalyptus polycarpa, E. ptychocarpa, Melaleuca viridiflora, Lophostemon lactifluus*	*Sorghum* sp., *Eriachne triseta, E. burkitii, E. avenacea, Germainia grandiflora, Leptocarpus spathaceus*
	Melalauca argentea open-forest (riparian forest)	Sandy levee banks of major rivers, upstream from the flood plains	*Melaleuca argentea, M. leucadendra* (*Eucalyptus papuana, E. polycarpa, E. alba* can occur on older levees)	*Lophostemon grandifloras, Barringtonia acutangula, Bambusa arnhemicam, Ficus racemose, Nauclea orientalis, Syzygium forte*	*Pandanus aquaticus, Passiflora foetida, Flagellaria indica*	Grasses and sedges
	Lowland rainforest (Mixed species closed forest)	Often as isolated pockets (<5 ha), associated with perennial moisture – springs, seepages, or where the water table is close to the surface	*Euodia elleryana, Syzygium* spp., *Ficus* spp., *Melaleuca leucadendra, Gmelina schlechteria, Fagraea racemosa, Calophyllum sil, Carpentaria acuminate*	*Acacia auriculiformis, Alstonia actinophylla, Bombax ceiba, Canarium australianum, Dysoxylym oppositifolium, Drypetes lasiogyna, Strychnos lucida, Peltophorum pterocarpum, Diospyros* spp., *Ficus virens, Grewia* spp., *Pouteria sericea, Hibiscus tiliaceus, Maranthes corymbosa, Sterculia quadrifida*		
	Coastal dune complex	Unconsolidated beach sands	*Casuarina equisetifolia* and lowland monsoon rain forest			*Sorghum* spp., *Spinifex* spp., *Ipomoea pes-caprae*

Hills and Escarpment	*Eucalyptus* low open-woodland and heath (*E. dichromophloia, E. miniata* or sandstone low open-woodland/shrubland)	Spatial patterning of this community is complex and can change at the scale of metres	*Eucalyptus dichromophloia, E. arnhemensis, E. miniata*	*Eucalyptus koolpinensis, E. kombolgiensis, E. ferruginea, E. brachyandra, E. herbertiana, E. phoenicea,* on sandy boulder strewn fire protected areas *Callitris intratropica* and *Gronophyllum ramsayi* occur. *Melaleuca magnifica* and *Leucopogon acuminata* can occur on the margins of Tertiary laterite on the Marrawal Plateau in the south of the region	*Vitex acuminata, Terminalia canescens, Blepharocarya depauperata, Boronia lanuginosa, Owenia vernicosa, Grevillea* spp., *Calytrix* ssp., *Jacksonia* spp., *Acacia* spp., in rockier areas *T. carpentariae* and *Ficus leucotricha* also occur	*Plectrachne pungens, Triodia microstachys, Eriachne* spp., *Sorghum* spp., in rockier areas *E. bleeseri, T. procera* also occur, and *Micraira* spp. on sandstone pavements. Seasonally *Mitrasacme, Hibiscus, Utricularia, Tephrosia, Goodenia, Pityrodia, Fimbristylis, Cyperus, Leptocarpus, Stylidium* spp. occur.
	Eucalyptus tetrodonta, E. miniata, E. ferruginea woodland	Remnants of Tertiary laterite overlying Protozoic sandstone on the Marrawal Plateau	*Eucalyptus tetrodonta, E. miniata*	*Eucalyptus bleeseris, E. ferruginea, Erythrophleum chlorostachys, Xanthostemon paradoxus*	*Eucalyptus* spp., *Acacia* spp., *Bossiacea bossiaeoides, Terminalia canescens, Petalostigma quadriloculare, Grevillea* spp., *Calytrix exstipulata*	*Plectrachne pungens, Chrysopogon fallax, Heteropogon triticeus, Sorghum* spp.
	Eucalyptus tintinnans woodland (hill woodland)	Rugged hills near the head waters of the South Alligator river on volcanic and metamorphic geologies	*Eucalyptus tintinnans, E. dichromophloia*	*Erythrophleum chlorostachys, Eucalyptus foelscheana, E. setosa, E. confertiflora, E. latifolia, E. tectifica, Xanthostemon paradoxus*	*Grevillea decurrens, Gardenia megasperma, Brachychiton paradox, Terminalia ferdinandiana, Petalostigma quadriloculare, Calytrix exstipulata, Owenia vericosa*	*Sorghum* spp., *Sehima nervosum, Rottboellia Formosa, Themeda triandra, Eriachne avenacea, Heteropogon triticeus, Plectrachne pungens*

	Escarpment rain forest (*Allosyncarpia* or mixed species closed-forest)	Perennially moist sites near springs or seasonally dry, often rugged, skeletal sandy/rocky soils	*Allosyncarpia ternate* (fire-tolerant), endemic to the eroding northern and western rim of the Arnhem Land escarpment and is often the sole component of the tree layer		*Calophyllum sil, Gmelina schlechteri, Horsfieldia australianum, Ilex arnhemensis, Melaleuca leucadendra, Syzygium angophoroides, Syzygium minutuliflorum, Xanthostemon eucalyptoides, Carpentaria acuminate, Notelaea macrocarpa, Vitex acuminata, Drypetes lasiogyna, Myristica insipida, Maranthes corymbosa, Buchanani arborescens*	

3.3 The archaeology of the Alligator Rivers region

This region provides an extremely rich archaeological landscape in which to explore fuel wood selection and management. Archaeological research in the Alligator Rivers region began in 1948 with the American-Australian Expedition to Arnhem Land. This expedition excavated 12 rock shelter sites near Oenpelli (McCarthy and Setzler 1960). The sites were excavated as a single unit and in their entirety, meaning no artefact sequence or chronology could be produced for these sites (Jones and Negerevich 1985:1). The work of Schrire (formerly White) in the mid-1960s signaled the initiation of scientific excavation in Kakadu. Schrire excavated three sites on the plains, and two sites in the Arnhem Land plateau. Following Schrire, Kamminga and Allen in the 1970s conducted a fact finding survey of the area, aiming to define the archaeological potential of the soon to be National Park. This work was built upon by Jones et al. in the early 1980s, who conducted excavations at wetland, outlier, and plateau valley sites (see Fig. 1.1). Current research focuses on documenting the rich rock art galleries of the region (May et al. 2015; Wesley et al. 2014) and defining the chronology of human occupation (Clarkson et al. 2015). This research will be further discussed below.

3.3.1 Schrire – Plains and Plateau

The first major scientific archaeological investigation of the Kakadu region was conducted by Carmel Schrire (then White 1967a, 1967b, 1971; White and Peterson 1969; Schrire 1982). During her 1964 and 1965 field seasons Schrire excavated five rock shelter sites, three on the plains and two in the plateau country. This pioneering work established the first chronological and archaeological sequence for the region (Jones and Negerevich 1985:9). Unlike previous work, which was narrowly focused or poorly executed, Schrire's contribution to the region's archaeology has left an indelible mark.

On the lowland plains between the East Alligator River and Magela Creek, Schrire excavated three sites, Malangangerr, Nawamoyn, and Paribari, and in the plateau valley of Tin Camp Creek, a further two, Jimeri I and II. Each of the plains sites were capped by a mid-late Holocene shell midden which aided in the preservation of organic remains including, shell scrapers, bone points, botanics, and human remains (Schrire 1982:78; 249). Malanganger, Nawamoyn, and Jimeri II contained a lithic assemblage that could be divided into two distinct sequences (Schrire 1982:237). An early sequence consisting of scrapers, core scrapers, utilised flakes, grindstones and edge ground axes and a later sequence of points, small rectangular scraper-adzes, use-polished flakes, utilised flakes, and edge-ground axes. In the plains sites of Malangangerr, Nawamoyn, and Paribari, as well as Ngarradj Warde Djobkeng (excavated by Harry Allen) and Malakunanja II (excavated by Johan Kamminga), the later lithic sequence occurred within the estuarine midden layer (Schrire 1982:237).

At the plateau site of Jimeri II the two-part lithics sequence found on the plains was repeated. Unlike the plains sites, Jimeri I and II were not capped by a shell midden, so the later sequence was deposited within a sand layer. The absence of a shell midden would also explain the lack of organic remains (wood, bone, shell, etc.) preserved in these plateau sites (Schrire 1982:249). The preservation of organics was not the only feature that separated the plateau from the plains sites. Schrire (1982:249) claimed there is a similar lithic tradition, consisting of an early and later sequence, across the region, however she does note some differences. She claimed that there is a dichotomy between the plains and plateau sites she analysed. Schrire (1982:240) found that in the early lithic sequence tool/waste ratios suggested some tool manufacture at the sites of Malangangerr, Nawamoyn, and Jimeri II. This is in contrast to the later lithics sequence in which tool/waste ratios suggest that far more tools were made and deposited at Schrire's plateau sites (Schrire 1982:242). Schrire (1982:249) claimed the similarity of stone tool traditions across the region may suggest exchange of these materials. White and Peterson (1969:62) were emphatic that this did not mean 'the entire plains population moved *en masse* to the plateau country during the wet season', but did suggest some form of population movement between the two locales.

3.3.1.1 Interpretation and revision

The data that Schrire generated during her PhD research (1964-1967) has been interpreted and re-interpreted by her and other researchers subsequently. Firstly, I will present the multiple interpretations Schrire has offered over the years to explain the archaeology of her plains and plateau sites. Initially, Schrire (then White 1967) explained the perceived difference between her sites through direct ethnographic examples – the plains sites best fitted with the Kakadu people observed by Spencer in 1912, and the plateau sites correlated with the behavior of the Gunjepmi or Djauan people also observed by Baldwin Spencer (2008).

The second explanation she offered came a few years later (White 1971; White and Peterson 1969). Schrire (1982:250) claims the archaeological record can be explained by the movement of groups between the plains (in the dry season) and the plateau (in the wet season) according to resource availability. This resource driven occupancy explains why there are few lithics in the plains sites (and few signs of lithic manufacture) from Schrire's analysis (Schrire 1982:250). She claims this discrepancy exists because when people were on the plains they were using bone-tipped spears to hunt fish and birds, and were using (after 6000 BP) shell, instead of stone, as scrapers and knives (Schrire 1982:250). This was in contrast to the hunting of large mammals during the wet season on the plateau, when people were employing stone-tipped spears, stone knives and scrapers.

Schrire offers a further re-interpretation of her data in her 1982 *Terra Australis* monograph. Firstly, she considers how the impact of feral animals (buffalos and pigs) had reshaped the local landscape and ecology and how this affected her previous interpretations of the region's ancient past (Schrire 1982:250-251). She states that 'minor retreats' to the plateau during the peak of the wet season did not represent major transhumance of the entire plains population (Schrire 1982:251). The occupation of particular sites (whether plains or plateau) was more a, "…reflection of the relative availability of certain resources in relation to particular sites" (Schrire 1982:251).

Considering the more recent work completed at Ngarradj (excavated by Allen in 1972 and 1977, Allen and Barton 1989) and Malakunanja II (excavated by Kamminga in 1972, Kamminga and Allen 1973), Schrire offered a reevaluation of her previous assessment of the region's archaeology. She stated that Malangangerr, Nawamoyn, and Malakunanja II conform to each other in a stratigraphic, technological, and chronological sense owing to their synchronous midden development. Paribari and Ngarradj conform to the regional sequence later than the other three sites. With their residents, according to Schrire (1982:251) acting, "…like people using plateau valley sites, exploiting terrestrial fauna and making stone tools" until midden development commenced. It is only when their inhabitants could locally access estuarine resources did they conform to Schrire's established regional pattern (Schrire 1982:251).

Schrire (1982:251) suggests that the adjustment in technology witnessed across all of the plains sites was in response to their proximity to estuarine environments. As estuarine conditions were established near a site there was a shift away from the exclusive use of stone for scraping and cutting to the utilisation of shell for these purposes (Schrire 1982:251). It is because of this ecological relationship that this process initiated at different sites asynchronously.

3.3.2 Alligator Rivers Region Environmental Fact-finding Survey

Building upon Schrire's earlier research, Kamminga and Allen (1973) were tasked with surveying and defining the archaeological potential of the region. Their research helped to establish the Alligator Rivers region as one of the most important archaeological landscapes in Australia (Kamminga and Allen 1973:v). Their survey focused on a northern transect (similar to Schrire) between the East and South Alligator Rivers. They focused on outliers, valleys, and escarpment margins, giving limited treatment to alluvial and coastal plains sites (Kamminga and Allen 1973:1). Their research was primarily a reconnaissance survey aimed at surveying, identifying and assessing the quality of the archaeological sites of the region. For the sites which they did excavate, including Malakunanja II, they found mainly lithics but also shell, animal bone, human remains (including a cremation pit at Malakunanja II), and one stone lined hearth.

This survey led to the first excavation of Malakunanja II (Kamminga and Allen 1973) and the only excavation of Ngarradj Warde Djobkeng (Allen and Barton 1989). This initial excavation led Kamminga and Allen (1973:46) to claim Malakunanja II was older than 18,000 years BP, a chronology which has since been extended to 55-60 k BP (Clarkson et al. 2015; Roberts et al. 1990a). The chronology proposed by Allen and Barton (1989:29) for Ngarradj is not as reliable. Their chronology is based on an extrapolation of dates from the midden at the site (level I-III), which are used to date the older levels (IV-VII). Their claim that Ngarradj is of a similar age to Malangangerr, Nawamoyn, and Malakunanja II is not supported by the current evidence (Allen and Barton 1989:29). Allen and Barton (1989:117) claim that changes in technology, in the Malakunanja II and Ngarradj lithic assemblages, do not coincided with changes in sea-level as Schrire had proposed.

3.3.3 ANU consultancy

Research led by Rhys Jones in the early 1980s examined 21 sites along a southern transect between Deaf Adder Gorge and the South Alligator River. Their investigation examined sites from plateau valleys (Nauwalabila I, Nauwalabila II, and Djuwarr I), outliers (Anbangbang I, Anbangbang II, Spirit cave, Blue painting site, Yibong rock shelter), and importantly open sites on the wetland margin (Amakada, Biliringba, Bulkin, Indarru, Ki'na, Kumunkuwi, Kun-kundurnku, Lurrukuku, Malakanbalk, Malakarba, Mamutijirra, Mularnani, and Nurrungurrudjpa). This research was significant for three reasons: it provided the first archaeological record for the wetlands (building on the work of Kamminga and Allen 1973), it offered an insight into the archaeology of the southern portion of the Alligator Rivers region; and finally, the methods of excavation and recovery employed by Jones and his team produced an archaeological assemblage unrivalled in the region for its size and range of material remains. Its recovery of botanic remains was particularly impressive, a point I will return to in section 3.3.6 when accessing the archaeobotanics for the region.

Jones and colleagues (1985), and subsequently Brockwell (2001; Brockwell et al. 2001), and Hiscock (1999; 2009) further critique Schrire's regional archaeological sequence through their research. Jones et al. (1985) and Brockwell (2001; Brockwell et al. 2001) demonstrated that Schrire's dichotomous regional scheme, between plains and plateau, was in fact a compression of a trichotomy of site types (i.e. wetland/open [often mounds], outliers/escarpment, and upland/plateau sites). This revision, the authors proposed, was probably owing to their southern transect, as compared to Schrire, and Kamminga and Allen's more northern transects (Brockwell et al. 2001; Jones 1985:294). In the north the escarpment extends to the edge of the river channel and wetlands, this causes a compression in the ecological zones represented there. In the south the ecological zones are more spread out and are therefore better defined along Jones et al.'s southern transect. Schrire's dichotomous understanding of the regional archaeological record was an artefact of her research design, not a feature of the archaeological record.

The research conducted by Meehan et al. (1985), along this expanded transect, provided an insight into the flood plain sites of the South Alligator River. Meehan et al. (1985:106) investigated six major sites in detail (Mularnani, Mamutjirra, Kun-kundunku, Kumunkuwi, Amakada, and Ki'na). The team was directed to these sites by Parks and Wildlife staff, who wanted the sites recorded because they were at risk of destruction by feral buffalos (Meehan et al. 1985:103). Many of the sites were already heavily disturbed by buffalo wallowing and fissures caused by seasonal drying. These six sites were mapped and surveyed to assess their contents (Meehan et al. 1985:106). Following this assessment only the site of Ki'na was deemed suitable for excavation (Meehan et al. 1985:108). Meehan et al. (1985:135) found that all of the sites were a similar distance from each other along the wetland edge and of a large size. Meehan et al. (1985:138) found that there were very few points in the lithics assemblage (both from surface collections and excavated material), and that the points that were recovered were small bifaces and broken tips and butts. Invoking the abundance of points recovered in excavations at Deaf Adder Gorge the authors drew a comparison between their assemblages and those of Schrire elsewhere in the region. Namely, that plains sites contained very few points when compared to plateau sites.

3.3.4 Re-interpretation of the lithics sequence and settlement patterns

Through a number of publications Hiscock (1996, 1999, 2009; Hiscock et al. 1992) reassessed the proposed lithics sequences and settlement patterns for the region. In 1992 Hiscock and colleagues critiqued Meehan et al.'s (1985) claim that sites along the South Alligator floodplain were uniform in size. Hiscock et al. (1992) determined through additional fieldwork in the area that this assertion was a product of sampling method rather than a legitimate feature of the archaeological record (Hiscock et al. 1992). Following this Hiscock (1996) reassessed the seasonally based settlement model originally proposed by White and Peterson (1969), which he claimed was maintained by Meehan et al. (1985) and Brockwell (1989) in their research. White and Peterson (1969) proposed that people occupied the plains in the dry season utilising mainly bone and wood tipped spears, and the uplands in the wet season where they relied upon stone points for hunting large mammals. Hiscock (1996:151) reviewed residential mobility in the region through an examination of bipolar knapping in the lithics assemblage. He claims that differences in the lithics assemblage between his woodland sites (Hiscock et al. 1992) and Meehan et al.'s (1985) floodplain site of Kun-kundurnku 1 near the South Alligator River can be explained by residential mobility. Hiscock's (1996:153) analysis found that the average ratio between bipolar to non-bipolar cores at his woodland sites was 1.5:1, as compared to a ratio of 6.7:1 at Kun-kundurnku 1. He suggested this difference in reduction behaviour was because of a difference in residential mobility at each site rather than the proximity of the occupation site to a source of workable stone (Hiscock 1996:153-154). The lower residential mobility at Kun-kundurnku is expressed through an increase in bipolar knapping, which was employed by its residents to conserve workable stone and limit return visits to the stone source (Hiscock 1996:153-154). The lower levels of bipolar knapping at Hiscock's woodland sites suggested higher residential mobility and therefore more regular encounters with workable stone sources. Through similar analysis on the lithic assemblages from Ngarradj Warde Djobkeng and Paribari Hiscock (1996:156) demonstrated that these sites had greater residential mobility similar to his woodland sites. He also found that the lithics assemblage at Jimeri I and II suggested high residential mobility in proximity to abundant local stone sources.

Schrire's (1982:237) two-phase lithics sequence for the region, based on her 1964-5 excavations, has been thoroughly revised by Clarkson et al. (2015:55), Hiscock (1996; 1999; 2009), and Kamminga and Allen (1973). Schrire (1982:251) claimed the lithics sequence in the region was static until the transformative processes of the marine transgression. She found minimal changes in the types of lithics found or the raw materials used. Recent work by Clarkson et al. (2015:55) has demonstrated that silcrete was misidentified in the Malangengerr and Nawamoyn assemblages, which may challenge this assertion (misidentified silcrete was also found in the Nauwalabila and Ngarradj Warde Djobkeng lithics assemblages). Kamminga and Allen (1973) at Malakunanja II and Jones and Johnson (1985) at Nauwalabila I also found diachronic shifts in the raw materials present there, further challenging Schrire's interpretation. Clarkson et al. (2015:55) have also demonstrated, through a re-analysis of the Malakunanja II lithics assemblage from Kamminga and Allen's (1973) and Roberts et al.'s (1990) excavations, that there were three distinct changes in the raw materials used at Malakunanja II. This re-examination has also demonstrated clear technological shifts from silcrete thinning flakes and quartzite convergent flakes in the lower industry, to bipolar working of white and crystal quartz in the LGM, and finally point production from c.4000 BP (Clarkson et al. 2015:55). This new analysis demonstrates the pre-Holocene lithics sequence of the Alligator Rivers region is diverse and changing.

The appearance of points during the mid-Holocene has been noted at multiple sites in the region (Clarkson et al. 2015; Jones and Johnson 1985; Kamminga and Allen 1973; Schrire 1982). Schrire (1982:237) used this shift in technology to divide her lithic sequence into two phases. She claimed that points occurred in the uplands sites where they were used to hunt large mammals and that on the plains where people hunted birds and fish, with bone or wood tipped spears, there were less stone points. Hiscock (2006; 2009) offers a different assessment of point technology and how to interpret the region's archaeological record. He claims that points are not an end product but an intermediary stage on a reduction sequence. Points are not the terminus but are multi-use tool which double as a portable source of stone flakes. Points should be seen as 'mutable objects which can be transformed from one morphology to another' (Hiscock 2009:83). Initially, the flake is produced, retouched into a unifacial point, further reduced into a bifacial point, and finally it is recycled as another tool 'type', all the while producing usable flakes (Hiscock 2009:85 Fig. 6.3). Hiscock (1999; 2006; 2009) claims point production is a risk minimizing behaviour similar to that proposed by Clarkson (2006) in relation to ENSO intensification. Therefore, the appearance of points during the mid-Holocene in the Alligator Rivers region was owing to the environmental instability of the time (Hiscock 1999:99). Initial point production occurs with the onset of the Big Swamp phase (c.7000-5000 BP), peaking during the transition between Big Swamp and the formation of dry hypersaline mud flats (c.3500-2000 BP) (Hiscock 1999:998). The lithics assemblage of the Alligator River regions has provided an insight into the resource procurement and settlement patterns of humans over millennia. The Alligator Rivers archaeological record, however, contains a wide range of archaeological materials that provide insights into human subsistence and settlement.

3.3.5 Mid-Holocene midden formation

Middens form almost synchronously at sites across the region during the mid-Holocene. These accumulations of estuarine shell are accompanied by fish and animal bones, human burials, and hearths (Clarkson et al. 2015:60-62; Schrire 1982:90-91, 122-124). Before this time taphonomic conditions limited the preservation of organic material. Poor onsite sampling and recovery techniques further limited the retrieval of what was actually present. The mid-Holocene middens at Malangangerr, Nawamoyn, Paribari (Schrire 1982), Ngarradj Warde Djobkeng (Allen and Barton 1989), and Malakunanja II (Madjedbebe) (Clarkson et al. 2015; Roberts et al. 1990a) were formed through the accumulation of molluscan shell. With the establishment of Rhizophoraceae mangrove forests the occupants of these sites exploited the forest fringe for predominately *Polymesoda coaxans* and *Telescopium telescopium*. These two taxa were well suited to the shady Rhizophoraceae forest. As salinity levels increased Rhizophoraceae was replaced by *Brugueira* sp., *Ceriops* sp., and *Avicennia* sp. mangroves. These taxa have smaller leaves and provided less canopy cover which was preferred by *P. coaxans* and *T. telescopium* (Ball 1988:96). *Cerithidea* sp. thrived under these conditions, however, because of their capacity to climb mangrove trunks and shelter on the shaded side (Hiscock 1999:95). This shift in species dominance in the mangrove forests was reflected in the middens of the region, with taxa representation shifting from *P. coaxans* and *T. telescopium* to *Cerithidea* sp. This change occurred at different times depending on the site's location, as changes in the mangrove forest were in response to the timing of specific geomorphological processes.

These middens aided in the preservation of animal bones including bandicoot, possum, kangaroo, wallaby, goanna, python, freshwater turtle, and fish (Clarkson et al. 2015; Schrire 1982). The preservation of botanical remains was often limited to desiccated material on the surface of the site (Jimeri I and II) or in the midden layer (Paribari) (Schrire 1982). The freshwater wetlands, monsoon vine forest, and woodland vegetation communities are all represented in these botanical remains (Schrire 1982:58-60). Before the 2012 and 2015 excavations at Madjedbebe, only Jones et al. (1985) and Shine et al. (2013, 2015) had utilised flotation in an effort to recover plant remains (this will be further discussed in section 3.3.6).

Very few hearths had been recovered in previous excavations. The presence of hearths has been noted (Schrire 1982:83, 117), solitary hearths were recovered (Kamminga and Allen 1973:11; Schrire 1982:117), but not until the 2012 re-excavation of Madjedbebe had a sequence of hearths been recovered. The Madjedbebe hearth sequence is unrivalled archaeologically anywhere in the Alligator Rivers region.

3.3.6 Regional archaeobotany

The region's archaeobotanical remains have on the whole been poorly recovered and inadequately studied. One notable exception is the work of Clarke (1985) at the site of Anbangbang I, an outlier site on the edge of the South Alligator wetlands. Clarke (1985:77) employed a systematic onsite recovery strategy coupled with bucket flotation of the 3 mm dry sieve residue (Johnson and Jones 1985:33). Each sample was 20% sub-sampled for analysis with larger pieces preferentially selected (Clarke 1985:78-79). The preservation of botanical remains was spatio-temporally arranged with more recent samples at the back of the rock shelter better preserved than older samples at the front (Clarke 1985:77, 82). The vast majority of botanical material dates to the last few hundred years (Clarke 1985:82). These plants were sourced from wetland (*Bambusa arnhemica*, *Nymphaea violacea, Phragmites karka*), woodland (*Banksia dentata*, *Pandanus spiralis, Terminalia carpentariae*), monsoon vine forest (*Livistonia humilis*), and swamp (*Melaleuca* sp.) vegetation communities. No wood identification was attempted on the Anbangbang I materials (Clarke 1985:78). The assemblage was interpreted as the product of human subsistence activities and some contributions from rodents (Clarke 1985:96).

In addition to Clarke (1985) recent research conducted by Shine et al. (2013, 2015) used flotation to recovery botanical materials. The analysis on these botanical materials is ongoing (Shine et al. 2013:72).

3.3.7 Madjedbebe (Malakunanja II)

Kamminga's original excavation was located adjacent to the rock shelter wall at Malakunanja II (Kamminga and Allen 1972). This initial excavation showed potential for very old occupation. An auger core of the site and subsequent thermoluminescence dating, conducted by Rhys Jones, Richard 'Bert' Roberts, and Chris Chippendale, demonstrated that artefacts were associated with 50,000 year old sediments. This intriguing chronology led Roberts et al. (1990a) to re-excavate the site in 1989. Their 1.5 x 1 m excavation was placed, with a small baulk, at the western end of Kamminga's trench (Clarkson et al. 2015:47). Roberts et al.

(1990a) announced the oldest artefacts at Malakunanja II dated between 52 ± 11 and 61 ± 13 ka (Roberts et al. 1990a). This proposed chronology extended the antiquity of human occupation in Australia back 15-20k years. This new chronology for the continent was vigorously scrutinised by Allen and O'Connell (2003, 2014), Bowdler (1990), and Hiscock (1990). Roberts et al. (1990b, 1990c; 1998) defended their original claim but the absence of a full site report left many lingering questions. Acknowledging the importance of Malakunanja II in the region's chronology and its significance in understanding the first modern humans to enter the continent Clarkson et al. (2015) launched a renewed research effort at Malakunanja II in 2012.

Following consultation with the Traditional Owners, the Mirarr people, the site was renamed Madjedbebe. The 2012 and subsequent 2015 excavations at Madjedbebe were designed to thoroughly assess all aspects of human occupation at the site and interrogate the chronology proposed by Roberts et al. (1990a). In 2012 a 4 x 3 m trench was excavated (inclusive of Kamminga and Roberts et al.'s existing soundings). Additional 1 x 1 m squares were added as the rock shelter wall receded with depth (Fig. 1.3). This extensive excavation allowed for 'living floors' to be uncovered during excavation, a liberty not provided by the tight confines of a solitary 1 x 1 m test pit. The site was capped by a mid-late Holocene midden that contained a large amount of fish and animal bone (not dissimilar to those elsewhere in the region). The midden also contained 19 human burials, which were carefully excavated and studied by Colin Pardoe before being reinterred (Pardoe 2013). Human burials were also found in the midden layers at Malangangerr, Nawamoyn, and Paribari by Schrire (1982). A range of doctoral and postdoctoral research is currently being undertaken on the Madjedbebe materials, including the manufacture and use of bone points (A. Basiaco), the use and sourcing of ground haematite (D. Cox, J. Huntley), residue and use wear on grindstones and ground edge axes (E. Hayes), the analysis and interpretation of molluscan shell (K. Woo) and the analysis and interpretation of macrobotanical remains (S.A. Florin). Ground penetrating radar was also used at the site prior to the 2012 excavation in an attempt to identify subsurface features, such as burials (Lowe et al. 2014).

The research of Hayes (2015) and Florin (2013) has indicated a shift in subsistence practice at the site during the late Holocene. The analysis of grindstones undertaken by Hayes (2015) demonstrated there was shift from the processing of starchy plants to the exploitation of grass seeds between 5.3-2 k BP. This shift was echoed in the work of Florin (2013) who noted an increase in *Pandanus* sp. drupe during the late Holocene. These changes in subsistence practices coincide with the formation of the freshwater wetlands in Kakadu during the late Holocene.

3.3.8 Archaeological conclusions

Previous research in the Alligator Rivers region has focused on defining the antiquity and extent of human occupation. This research has highlighted the impact large scale geomorphological changes have had on subsistence and site use. After an initial assessment as a simple dichotomy the lithics sequence of the region has been reinterpreted as dynamic and changing. Previous research has disproportionally focused on lithics to interrogate resource procurement strategies and settlement patterns. These studies have provided a great deal of insight into the human past in this landscape and will be furthered by the research outlined above (section 1.2).

The sequence of hearths recovered during the 2012 excavation of Madjedbebe provide an unrivaled sample through which to explore fuel wood selection and management in the Alligator Rivers region. These fourteen hearths, further discussed in Chapters 4, 5 and 6, are the first to be analysed using anthracology in the region.

3.4 Synthesis

The palaeoenvironmental and archaeological data presented in this chapter provides the basis for the hypotheses presented in Chapter Four. These hypotheses were generated to test fuel wood selection strategies at Madjedbebe over the last 20,000 years. Based on the established palaeoenvironmental data presented above it is highly unlikely that fuel wood supply would have been compromised by environmental changes during the occupation of the site (see sections 3.1, 3.2). It is clear from the palaeoenvironmental data that there were large scale shifts in the local landscape structure and associated vegetation diachronically. However, these changes would not have equated to a reduction in the available woody biomass near the site and therefore would not have negatively impacted upon human fuel wood supply. These shifts in ecological zonation, however, may have influenced people’s fuel wood selection decisions, as particular vegetation communities moved in and out of proximity to the site (i.e. the encroachment and then retreat of mangrove forest).

Changes in climate and vegetation would have also lead to changes in biomass accumulation in the environment. Increases in biomass, driven by post-LGM increases in atmospheric carbon and increased rainfall, would have contributed to larger fuel loads and bushfire potential in the landscape (Reeves et al. 2013a:24). This increasing threat of bushfires may have triggered the initiation of anthropogenic fire regimes in the landscape at that time. The initiation of an anthropogenic fire regime in the landscape which differed in its tempo and scale to that of the natural bushfire regime would have had an effect on the composition and structure of the local woodland. These changes in vegetation and structure would be visible in the wood charcoal assemblage.

The archaeological record of the Alligator Rivers region suggests people were highly mobile, although much of the early record for the region is only represented by rock shelter sites. With the establishment of the freshwater wetlands in the last 1000-1500 years settlement patterns changed. The inhabitation of wetland edge sites for long periods during the dry season led to resource stress clearly indicated by the adoption of bipolar knapping (Hiscock 1996:153-154). These periods of increased sedentism may have also placed a strain on local fuel wood availability. In periods of increased resource stress fuel wood collection strategies may have shifted from preferential/targeted towards collection based on a principle of least effort, where by all wood in close proximity to the camp site was collected. As the local resource was depleted the foraging range of the inhabitants would have had to increase and may be represented in the wood charcoal assemblage as non-local vegetation communities starting to be access for fuel wood (Shackleton and Prins 1992:634).

The palaeoenvironmental and archaeological records for the Alligator Rivers region presented in this chapter provide the foundation for an investigation of the Madjedbebe wood charcoal assemblage. These records provide the environmental and archaeological parameters for this study. An anthracological assessment of the Madjedbebe hearths contexts provides the best way to fully interrogate the fuel wood selection strategies operating at the site. This approach is further developed in Chapter Four.

Chapter Four - Methods and Methodology

4.1 Introduction

The methods employed in this thesis follow those outlined in the existing international anthracology literature (as summarised in Chapter Two). This research endeavours to build upon the methods previously employed in Australian anthracology and extend their application and validity; however additional methodological input was required. The international application of these techniques demonstrated the value of implementing a coherent and consistent program of archaeobotanical analysis (Fairbairn et al. 2014: 802; Summerhayes et al. 2010). This process began well before the excavation of Madjedbebe in June-July 2012, and involved discussions between the author, Andrew Fairbairn, Christopher Clarkson, Lynley Wallis and other project members. These initial discussions defined the nature of the archaeobotany program to be implemented at Madjedbebe, the different macrobotanical and microbotanical remains to be sampled, the size of onsite samples, and the technologies employed to recover and process these samples in the field and laboratory (each of these will be discussed further below).

4.2 Australian anthracology

It is a shared goal of the new generation of Australian anthracology researchers that the development of this technique in Australia be collaborative (pers. comm. Byrne 2014, Dotte-Sarout 2014, Whitau 2014), and that methods and results should be published in a full and transparent fashion (i.e. Whitau et al. *in press*). The work that is required in Australian anthracology is vast and will take many decades to complete but will be aided by collaboration between researchers.

Before Australian anthracology can effectively explore key archaeological concerns such as, fuel selection strategies, land management practices, and anthropogenic deforestation, we must first develop and describe reference collections and define the criteria by which key families, genera, and species can be partitioned and grouped. The criteria generated by the International Association of Wood Anatomists (IAWA 1989, 2003), provide guidelines for the anatomical description of wood. These guidelines are an excellence standard to follow, however, the arrangement of Australian taxa into coherent groups and the definition of achievable levels of identification are still required. Based on our current reference sets and anatomical descriptions it would be ill-advised to pursue species level identifications because of the paucity of key anatomical work completed in Australia. Anthracological method and theory, developed elsewhere, is useful in Australia but the description and arrangement of key flora is reliant on research conducted in this country.

This thesis outlines the methods employed during this research and maintains a level of transparency which will allow for effective critique, revision, and future development. It is recognised that this is a process of slow accumulation which will require many revisions. This thesis offers the first description of wood anatomy for 99 species from northern Australia. As each individual project contributes its own reference material anatomical descriptions will be refined.

4.3 Archaeobotany field strategy

The archaeobotanical field methods employed at Madjedbebe were designed to fit seamlessly with the excavation strategy so as not to delay or inhibit the progress of the excavation and yet produce a comprehensive sample of botanical remains from the site.

The strategy developed followed that of Fairbairn (Fairbairn et al. 2014) with recovery techniques more closely resembling, those employed by archaeobotanists in Europe and the Near East (the heartland of archaeobotany method and theory) than those of Australia.

4.3.1 On-site sampling

This research explored the application of large sample sizes and the use of a cascading 'Ankara-style' flotation tank (French 1971; Nesbitt 1995) (Fig.4.1). The sampling strategy targeted a single 1 x 1 m excavation square, sampling 60L of sediment per excavation unit, which is roughly equivalent to the volume of 1 x 1 x 0.05 m spit. In addition to this column sample every sedimentary feature (or defined context) was collected in its entirety (100%) for flotation. The collection of these flotation samples directly from the ten litre excavation buckets meant no interference with the excavation was necessary. Instead of processing the buckets of sediment through the sieve, the sediment was bagged in a plastic sack and set to one side ready for flotation at a later date. The benefits of collecting samples in this way extended beyond the recovery of botanical remains. The 1 x 1 mm 'heavy' residue mesh used in the flotation tank recovered small bones and artefacts, 100% of all >1 mm inclusions, and 'cleaned' the material, which aided later sorting. The flotation tank added another level of recovery across all artefact classes, especially considering 7 and 3 mm sieves were used on site for standard artefact and faunal recovery.

Figure 4.1 ‘Ankara-style’ flotation tank (French 1971; Nesbitt 1995), in use at the ‘Visiting Officer’s Quarters’ (VOQ), Jabiru 2012. Photo courtesy of Gemma Irving.

4.3.2 Flotation

The flotation tank apparatus used at Madjedbebe was inspired by similar systems I have observed in Turkey. The cascading ‘Ankara-style’ flotation tank was originally designed by French (1971) and modified by Nesbitt (1995). The system consists of one main tank and a number of settling tanks, which allow finer sediments to settle out of solution before the water is recirculated. The Madjedbebe apparatus was made from three ‘44-gallon’ drums that had been retrofitted for the task (Fig. 4.1). Each tank had its lid removed and a spout added to allow water to flow between them in a steady and controlled manner. The main tank at the top of the cascade was also fitted with a branching pipe assembly (with drilled holes), which allowed water to be ‘jetted’ through (Fig. 4.2). This assembly was mounted inside the tank and controlled by a tap on the outside of the tank. A hose (operated by a separate tap) was also installed on the outside of the tank at the same juncture. The tank also had a grate installed (removable to allow for cleaning) above the branched assembly. This grate supported the weight of the heavy residue mesh and prevented the material in the heavy residue mesh from blocking water flow out of the branched assembly. The three tanks were arranged on earthen mounds at different heights to produce a cascade.

Figure 4.2 The branched assembly inside the main tank at the top of the cascade. Photo courtesy of Gemma Irving.

The entire system (tanks and pipes) were filled with water. A submersible pump was placed in the bottom of the lowest (3rd) tank and water was recirculated from here via a length of poly-pipe to the branched assembly in the top (1st) tank, displaced water would cascade from the first tank, to the second, and then the third. A fine mesh was wrapped around the pump's intake to prevent material being recirculated in the water.

Before a sample was added the top tank was lined with a 'heavy residue mesh' (1 mm fly screen mesh), the mesh rested on the grate and was secured around the top lip of the tank with large bulldog clips. At the spout a separate winged piece of metal (the weir) secured the mesh in place. Between the first and second tank a wooden cradle supported a small bucket which was lined with a 'flot bag' – a bag made of chiffon (250 µm mesh), this was positioned below the spout of the first tank but above the water line of the second.

Before a sample was added to the top tank its volume was measured and a sediment sample removed for magnetic susceptibility testing. Sediment was then progressively added to the top tank. As the sediment was agitated by hand the botanics floated to the surface of the water, the heavy residue was liberated from the matrix and the <1 mm matrix fell through the heavy residue mesh settling in the bottom of the top tank. At that point the pump was switched on and the water level began to rise, the weir was removed and the floating material was allowed to flow over the spout into the flot bag below. This process was repeated until the entire sample had been added to the tank. Once all of the botanical material had cleared the top tank a hose was used to clean the heavy residue mesh, each fold was opened and hosed out to liberate any additional material which was directed into the flot bag.

Once all of the botanical material was in the flot bag, the bag was removed from the bucket, a label was placed inside the bag and the bag was tied off and tied to a drying line in the shade. Once the flot bag was hung up the heavy residue mesh was unclipped and gathered together and placed in the shade to dry – a label was tied to the mesh with some garden wire. The heavy residue meshes were moved up to the accommodation block at night to prevent any animal (i.e. dingo) disturbance of the residue. The flot bags were suspended a safe distance above the ground. After a few days (large samples may take 4-5 days, depending on weather conditions, to dry fully – samples need to be completely dry to prevent fungal growth) dried flot samples were double bagged, each bag was labelled with tags in each. A small amount of air was left inside the plastic bag to act as a cushion during transit. The heavy residue was also double bagged with tags included in the plastic sacks. These were tied up with garden wire.

The use of a flotation tank, such as the one described above, allows large samples to be processed in a timely manner (it also avoids the back strain of bucket flotation). The quantity and taxonomic richness of the botanical material recovered from Madjedbebe demonstrate the benefits of processing large sediment samples (see Florin 2013).

4.4 Laboratory methods

The laboratory analysis of materials can be divided into two groups: archaeological material and reference specimens. Although there is some cross-over in the methods employed in the analysis of both of these material types each will be dealt with separately.

4.4.1 Archaeology material

Upon arrival at the University of Queensland archaeology laboratories all flot samples were catalogued. Three research theses utilised the Madjedbebe archaeobotanical material, this thesis which focused primarily on hearth contexts and Florin's 2013 Honours thesis and PhD thesis (ongoing) which examined the other macrobotanical remains present at the site. Florin's Honours research found a wide range of macrobotanical remains preserved, even in the oldest occupation deposits (Florin 2013). These remains included multiple types of tuberous parenchyma, *Pandanus* drupe, and nut shell. Specific samples were targeted for priority sorting because they related to current research interests. Therefore, all hearths were sorted as well as a range of other bulk sediment (general matrix) samples (n=9) which related to Florin's Honours research. Sorting and analysis is ongoing.

4.4.1.1 Sorting

To begin the entire sample was divided by sieve into >4 mm, 2 mm, 1 mm, 500 µm, 250 µm, <250 µm fractions. Each of these fractions was individually stored in a plastic zip-lock bag. As is standard practice in anthracology all charcoal fragments greater than 2 mm in size are included in the charcoal assemblage for analysis. Therefore, the >4 mm and 2 mm fraction sizes were sorted for each hearth examined as part of this thesis. For further discussion of additional macrobotanical sampling refer to Florin (2013).

The fraction sizes were sorted separately and recombined later for sub-sample selection. This is because material of similar size is easier to sort because the eye's focal depth is not stretched too widely. A small amount of sample was placed in a glass petri dish and manipulated with a pair of entomological forceps. A small dissecting microscope (Olympus SZ61) with a bright ring lamp provided the necessary illumination and magnification. Each fraction size was divided into its constituent parts, i.e. charcoal, tuberous material, nut shell, pandanus drupe, intrusive organics, and other materials which may include bird bone and molluscan shell. This process was repeated until the entire sample was sorted. Each constituent material was housed separately in a plastic zip-lock bag or in a plastic vial. Once the sample was sorted the >4 mm and 2 mm charcoal was recombined ready for sub-sampling.

4.4.1.2 Charcoal sub-sampling

Often the quantity of wood charcoal present in a sample is too abundant to be analysed in its entirety and therefore needs to be sub-sampled. A sub-sample needs to be a smaller yet still representative subset of the whole. The size of an anthracological sub-sample should be determined by its predicted floristic diversity (Asouti and Austin 2005:6-7). Therefore, samples from the tropics should be sampled to 200-300 fragments (Scheel-Ybert 2002:14), compared to a sample from the temperature zone which may only be required to be sub-sampled to 100 fragments (Keepax 1988). Owing to Madjedbebe's environmental setting 200 fragments or 100% of charcoal available and >2mm in size was analysed per context. To avoid any selection bias this research used a riffle box to divide the sample into smaller and smaller sub-samples (van der Veen and Fieller 1982:292). All of the charcoal (>2 mm) in a sample was placed on a flat tray and was poured from there into the top of the riffle box. By way of a slotted chute the riffle box divided the sample into two roughly equal sub-samples each into its own bin. The left-hand bin was always selected as the continuing sample (for ease of memory). The right hand division was bagged and labeled in case of future reference. The contents of the left hand bin were again spread out on a flat tray and the process repeated until the desired number of charcoal fragments was left. When close to the desired amount the sample was counted by hand, if the sample was short by a few fragments they were sourced from the other side of the division. If the sample was more than five fragments from the desired number a further division through the riffle box was made.

The decision to use a riffle was informed by a desire to produce a sub-sample with minimal selection bias (van der Veen and Fieller 1982:292). Selecting charcoal fragments by hand, whether in the field or the lab, will over represent larger fragments in the sample (Cartwright and Parkington 1997:61). This is problematic because some taxa will fragment more than others and may only be represented in the smaller fractions. A riffle box avoids the selection bias of hand or 'grab' sampling. A riffle box may, however, cause additional fragmentation of samples, so it is important to re-sieve samples after riffling to remove any <2 mm size fragments.

Once the desired amount of fragments was achieved each individual fragment was housed in a plastic vial and assigned a unique identifier from a sequential list of numbers. Individually housing and weighing each fragment was time consuming and laborious, however, it allowed for better overall control of individual specimens especially in regard to future review and revision.

4.4.2 Anthracology

Anthracology, or the taxonomic identification of individual fragments of charcoal, is a widely utilised technique especially in Europe and the Near East (Allue et al. 2012; Asouti and Kabukcu 2014; Ntinou et al. 2013; Wright et al. 2015). The wooded taxa of those regions have been the subject of study for over 150 years (Asouti 2006). It is there that scientists first started to examine archaeological wood charcoals (Godwin and Tansley 1941; Salisbury and Jane 1940). Current practitioners, working in those regions, are the beneficiaries of this sustained scientific enquiry. In Australia, however, the development of anthracology has been less focused or sustained. Australia has benefited from developments in anthracological method internationally, but its diverse flora and short period of enquiry have limited the field. Anthracology is particularly limited by the description of Australia's diverse wooded flora. Wood anatomy research in Australia has focused for the most part on commercial timbers (Ilic, 1990, 1991). There has however been more comprehensive scientific work undertaken by Dadswell (Dadswell 1972; Dadswell and Burnell 1932; Dadswell and Eckersley 1935, 1938a, 1938b; Dadswell and Ellis 1939, Dadswell and Eckersley 1941) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) but no comprehensive anatomical description or organisation of Australian wooded taxa has been completed, especially for the tropics.

The reason to use anthracology as part of this research is two-fold. Firstly, it provides the best way to assess what fuel wood people were selecting for domestic use, the aim of this research. Secondly, it was a technique which required further development in an Australian setting.

4.4.2.1 Sectioning wood charcoal

Each individual fragment of charcoal was sectioned into its three anatomical planes for examination – transverse, tangential longitudinal, and radial longitudinal (following Leney and Casteel 1975; see also Asouti & Hather 2001; and the International Association of Wood Anatomists [IAWA] 1989; 2002) (see Fig. 4.3, 4.4). Charcoal has a propensity to fragment along its longitudinal axis, because of this the longest side of a fragment is often a longitudinal plane (radial or tangential). Following this logic snapping the fragment between the fingers across its longest axis produces a transverse section. The transverse plane was mounted on a microscope slide with some Blue Tac. Once the transverse section was examined and described a scalpel was used to produce the other two planes by sectioning from the transverse plane down through a ray to produce a radial plane or perpendicular to the rays to produce a tangential plane.

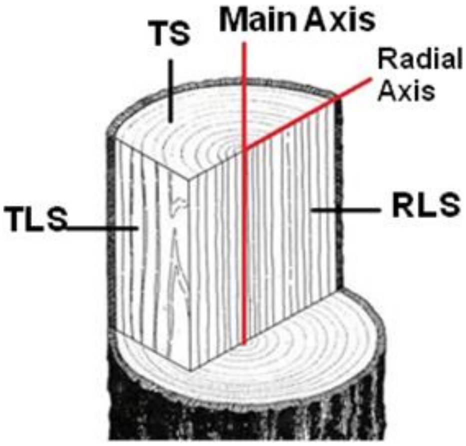


Figure 4.3 The three anatomical planes of wood. TS - transverse, TLS - tangential longitudinal, RLS - radial longitudinal (adapted from Pourtahmasi 2009; see also Wright 2010; Carah 2010).

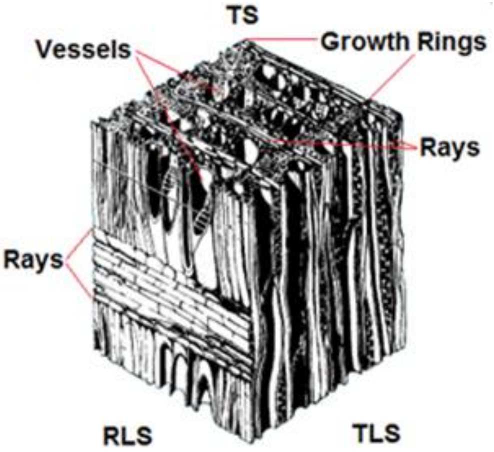


Figure 4.4 Key anatomical structures used in the description and identification of wood and wood charcoal (adapted from USDA 2009; see also Wright 2010; Carah 2010).

4.4.2.2 Typing archaeological specimens

After a charcoal fragment was sectioned the internal anatomy of the plane was examined and described. All anatomical descriptions were entered into the FileMaker pro forma shown in Appendix D. This FileMaker pro forma, which is adapted from Emilie Dotte-Sarout’s PhD thesis (2010) (with permission), contains all 163 features defined by the International Association of Wood Anatomists (IAWA) for the description of wood anatomy. A specimen was assigned to an existing type if it shared the same anatomical features as the type. If a specimen was unlike any existing type and the description of its anatomy supported this conclusion it would be drawn (Fig. 4.5) and assigned to a new type, simply the next number in the sequence.

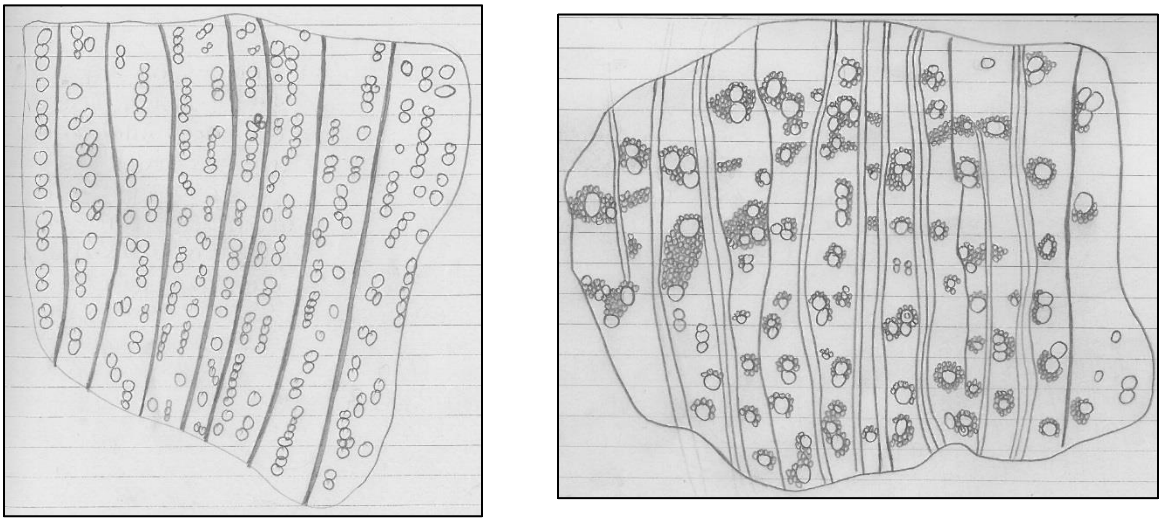


Figure 4.5 Example drawings of type specimens. Type 38 (left) and type 55 (right), transverse plane shown.

A new type was created whenever a new set of anatomical features was encountered. For example, the specimen under consideration could have the same anatomical features as an existing type except for some variation in ray width. The rays of the specimen tend towards multiseriation on the transverse plane, while the existing type's rays were exclusively uniseriate. Therefore the specimen under consideration would be typed as a separate type. This is even though some taxa have multiseriate rays in one part of the stem and uniseriate rays in another (i.e. *Quercus* spp., see Hather 2000:48). Often, because of the small size of an archaeological specimen, you cannot safely assume that all of the taxon's characteristic anatomy is present in each fragment of its charcoal. Typing specimens is not the time to make firm judgments, it is better to split specimens apart into different types at that stage and recombine them later, for the reverse does not allow such liberties.

4.4.2.3 Identifying archaeological specimens

Although not necessary, all of the archaeological specimens were sectioned and typed before any identifications were undertaken. Initially this was because lab analysis of the archaeological specimens commenced before the reference collection was finalised. Before any identifications were attempted the anatomical description of all reference taxa was entered into a separate yet identical FileMaker database. This allowed for the specific anatomical features of a type to be queried against the entire reference set. A number of fields were selected to be queried being mindful that querying too many fields at a time may exclude potential matches unnecessarily. Often vessel group or arrangement, the presence of parenchyma and the formation of the rays were initially used to extract potential reference matches. If a large amount of specimens was initially returned additional fields were added to the search. Once a short list of between 6-8 reference specimens was defined identification moved to direct comparison with the physical specimens. Each reference specimen described on the database has a physical specimen which can be directly compared under a high-powered light microscope (Olympus BX60). The type specimen was compared to each reference specimen individually until an identification was reached. On two occasions (Type 26 and Type 48) an identification was not successfully made, this is because of the current limitations of the reference collection which will only be remedied through the addition of more reference taxa. Each type specimen was subsequently imaged using a scanning electron microscope (details of this method are available in section 4.5.5).

4.5 Reference collection

Anthracology is reliant upon the accumulation and description of a wide range of reference taxa. Archaeological samples cannot be taxonomically identified without reference to a comprehensive set of known wood taxa (see Scheel-Ybert 2016).

4.5.1 Taxa list and field collection

A reference collection needs to contain a wide range of taxa which represent the floristic diversity of the study area. It also needs to account for shifts in ecological zonation which may have occurred over time. The first step in constructing a reference collection is to construct a taxa list which contains all of the wooded taxa present in the study area and any additional ones of interest. For this research Brennan (2007) and Wilson et al. (1996) formed the basis of the taxa list. This list was supplemented by *Vascular plants of the Northern Territory* (Short et al. 2011) and *Plants of the Darwin Region* (Dunlop et al. 1995).

The collection of reference specimens around Madjedbebe proved difficult because the site is located within the World Heritage listed Kakadu National Park. Therefore, alternate collection locations were sought. Fortunately, the George Brown Darwin Botanic Gardens (GBDBG) agreed to assist in the collection of many of the reference specimens. As the premier Northern Territory Botanic Gardens GBDBG hosts many of the taxa present in Kakadu. The added benefit of collecting specimens from the Gardens was that trained staff could offer taxonomic identifications of each specimen ensuring accurate results. In addition to the taxa collected in the Gardens (*n*=67), 39 specimens were collected in the Greater Darwin region with the assistance of Willie Burgess, a botany enthusiast and GBDBG plant donor.

Each of the specimens collected at the GBDBG or with Willie Burgess can be assigned to level three on the HISPID (Herbarium Information Standards and Protocols for Interchange of Data) criteria. This level requires a botanical specimen to be collected by a trained professional.

Initially the intention was to collect both branch and trunk wood for each reference taxa. This is because wood anatomy can differ between the branch, trunk, and root of a single taxon. However this was not always achievable. Where possible reference samples were cut from an established branch of the tree/shrub, however sometimes it was not possible to secure an established branch and thinner material was collected, which is not ideal. Trunk samples were collected using a 300 mm tree ring corer. The branch and trunk sample were placed in a calico bag with a tyvec label which included the taxonomic name, collection location and date. Every evening these bags would be tied up to dry and upon returning to the lab all specimens were placed in a drying oven set to 50^{o}C for a week.

4.5.2 Charring specimens

Particular features of wood are lost during ‘charcoalification’ meaning the wood anatomy of a particular taxa is different from the anatomy of its charcoal (Asouti and Fuller 2008:128). For this reason all reference taxa were ‘charcoalified’. This also allowed archaeological wood charcoal can be identified directly to reference wood charcoal. A piece of wood for each reference taxa (2 cm from the branch, 0.5 cm for the trunk core) was wrapped in aluminum foil and placed in a sand filled crucible. The specimen was covered with sand and the crucible lid. Wrapping the specimens and covering them with sand creates a reducing (low oxygen) environment which aids charcoalification. The crucibles were placed in a Binder muffle furnace set to 350^{o}C for 2.5 hours to ensure the wood was turned to charcoal (Braadbaart & Poole, 2008:2438). Through repeated trials it has been determined that most Australian wood taxa need to be charred at 350^{o}C for 2.5 hours before they will be rendered to charcoal.

4.5.3 Sectioning and mounting

After ‘charcoalification’ each specimen was sectioned into the three anatomical planes of wood – transverse, tangential longitudinal, and radial longitudinal. This was achieved either through snapping the charcoal between the fingers or with a scalpel. Each plane was mounted on an SEM aluminum pin stub with a carbon adhesive dot and some graphite paste. These stubs were stored in a SEM stub box with internal and external labeling.

4.5.4 Accessioning specimens

Once a specimen was sectioned and mounted it was accessioned into the University of Queensland archaeobotany reference collection. The accessioning process includes housing the specimen in archival-quality media, recording the specimen's collection details, and noting any relationships between the specimen and any others present in the collection. Once the specimen is accessioned it is given a University of Queensland Macrofossil (UQM) number and placed in a drawer with other members of its taxonomic family present in the physical reference collection.

4.5.5 Scanning Electron Microscope (SEM)

Each reference specimen was imaged using a desktop JEOL NeoScope JCM-5000 scanning electron microscope (SEM). The JEOL NeoScope does not require specimens to be splutter coated, it also has an extremely short load time (often 3-5 minutes). Owing to these features it is now feasible to image an entire reference collection and archaeological type specimens with an SEM (contra Leney & Casteel 1975:158).

The three anatomical planes of wood are required to make a confident taxonomic identification. Therefore each plane needs to be imaged and described, making special note of the key anatomical features which divide taxa one from another. There are no magnifications required for imaging wood charcoal outlined in the literature; however the images do need to include all of the features used in the description of the wood anatomy. For example, it is common to use a magnification between 15-25x to demonstrate the arrangement of the vessels across the growth ring, a feature which is not always apparent at higher magnification. On the other end of the spectrum images may be taken at 2000x magnification to appropriately capture minute features.

Each reference specimen (including both branch and trunk wood where available) was imaged using the JEOL NeoScope. Primarily the Olympus BX high-powered microscope was used to describe each reference specimens (100x – 500x), with images and observations made with the SEM adding further detail. The description of each reference specimen was entered into a specially made FileMaker Pro database in accordance with the IAWA standards for the description of wood.

4.5.6 University of Queensland Archaeological Reference Collection (UQARC)

The University of Queensland Archaeological Reference Collection (UQARC) is an online and free reference database. This platform was developed by the author and Andrew

Fairbairn with technical assistance from Damien Ayres (UQ ITEE). The core ethos behind the UQARC is to provide reference material on an open and free platform which can be accessed from anywhere in the world. Physical reference material is often locked away in ‘silos’ inaccessible to the greater research community. A platform such as UQARC allows researchers to combine and share reference materials enabling better research outcomes.

The UQARC provides images (both SEM and other depending on the material) and physical descriptions of accessions housed in the UQ archaeobotany reference collection and molluscan reference collection, as well as contributions from other institutions. This platform has been developed during this thesis and the entire reference collection amassed during this research is available on the UQARC (http://uqarchaeologyreference.metadata.net/).

4.6 Research Approach

This research was designed to investigate the aims outlined in Chapter One. They are: 1) to examine fire use at Australia’s oldest known archaeological site, 2) to examine fuel wood selection strategies diachronically, 3) to define the provenance of matrix charcoal, and 4) to conceptualise the place of fuel wood within a fire regime.

The exploration of each of these aims is facilitated by the methods outlined in this chapter. The first three aims of this research are reliant on the taxonomic identification of wood charcoal. These identifications allow for changes in the hearths’ taxonomic composition to be tracked diachronically and the ubiquity of particular taxa to be identified. These identifications provide an insight into the earliest uses of fire at Madjedbebe. Through the examination of the three earliest hearths (D2/30, C4/36A, and C1/43A) the types of wood and vegetation communities being accessed for fuel will be defined. Because of the spatial and temporal limitations of independent palaeoenvironmental data the interpretation of early fire use at Madjedbebe will not extend beyond the identification of taxon and vegetation communities.

The existence of a temporally and spatially specific environmental baseline for the last 20,000 years (outlined in Chapter Three) allows fuel wood selection strategies to be more thoroughly investigated during that period. At the beginning of this research three research hypotheses were established to deductively explore fuel wood selection strategies during the last 20,000 years. These hypotheses established a framework against which the results of the analysis will be compared and tested. Each of the hypotheses proposes an alternate fuel wood selection strategy which may have operated in the past. Ultimately, all of these hypotheses may prove to be incorrect or correct at different points in time but each provide a way of critically interrogating the data. The three hypotheses are:

1) Hypothesis one proposes that the principle of least effort would have governed fuel wood collection over the last 20,000 years. Fuel wood was collected in close proximity to Madjedbebe and a wide range of species were collected in direct proportion to how they occurred in the environment. The focus of the fuel selection strategy was ease of collection not preferential taxon selection. This strategy would be archaeologically visible as wide range of taxa from the local environment present in the hearth material.
2) Hypothesis two proposes a targeted local selection of wood fuel taxa focused on particular preferred fuel wood taxa. These taxa were preferentially selected from within the immediate vicinity of the site. This strategy would be archaeologically visible as a narrow range of taxa from the local environment present in the hearth material.
3) Hypotheses three proposes that people purposefully targeted particular ecological niches throughout the landscape to exploit particular wood types, over the last 20,000 years. This would include vegetation communities such as mangrove forest, *Melaleuca* sp. swamp, and *Allosyncarpa* sp. rainforest. Fuel wood was collected away from the site. This will be archaeologically visible as a narrow range of taxa from different ecological niches present in the hearth material.

These hypotheses will be tested by comparing the taxonomic frequency, ubiquity and richness data from the Madjedbebe hearths to independent palaeoenvironmental and modern botanical data to define the fuel wood selection strategy in operation. This independent palaeoenvironmental data was outlined in Chapter Three (sections 3.1, 3.2). By defining the vegetation community fuel wood was sourced from (based on modern botanical and ecological data) and then the location of those vegetation communities in the landscape over time (palaeoenvironmental records) diachronic changes in fuel wood selection will be defined. Correspondence analysis (CA) will be used as an exploratory statistical approach to test for variance within this assemblage of hearths and highlight any temporal or compositional patterns. Spearman’s rho rank order correlation coefficient will be employed to test whether any of these patterns in the data are a linear trend and whether the trend is statistically significant.

The third research aim, defining the provenance of matrix charcoal, will also be explored through the taxonomic identification of wood charcoal. This analysis will compare the taxonomic composition of hearth charcoal (C3/4A), the charcoal from the sedimentary matrix of square C3/4, and charcoal drawn from an environmental transect local to the site. The taxonomic composition of each of these samples will be used to determine the provenance of the matrix charcoal. Initially, correspondence analysis will be used to explore variance between the different charcoal samples. A chi-squared analysis and accompanying p-values will then be used to statistically determine whether the taxonomic composition of matrix charcoal is more similar to hearth charcoal or environmental charcoal.

The fourth research aim, the conceptualisation of fuel wood within a fire regime provides a heuristic model for interpreting the patterns found within the data. This conceptual model will be built on the premise that anthropogenic landscape burning is a form of niche construction and that these fires form instances in the historical ecology of landscapes. This will provide the first model for understanding fuel wood management in Australia.

In addition to the established research aims the veracity of the method employed in this thesis will also be tested. In particular, the sample size chosen for this analysis – 200 fragments or 100% of charcoal per context – will be tested through the use of a saturation curve. This saturation curve will highlight whether the sampling effort employed in this research was sufficient for capturing the full floristic diversity of the sample.

4.7 Conclusion

The research methods and approach outlined in this chapter establish how the research aims outlined in Chapter One will be pursued in this thesis. The methodology employed in this thesis has its foundations in the international literature and best practice archaeobotanical sampling and analysis. The methods outlined here will produce a representative and sound assessment of the Madjedbebe wood charcoal assemblage. The results of which will be presented in the Chapter Five.

Chapter Five – Results

5.1 Introduction

This chapter presents the data generated through the field collection and laboratory component of this research. It is divided into five sections, each of which contribute to exploring the research aims outlined in Chapter One. The first section (section 5.2) contains data related to the construction, curation and description of the reference collection. Assembling a reference collection is an essential first step in anthracological research. The second section (section 5.3) describes the archaeological specimens encountered during the analysis and the key analytical decisions behind their taxonomic identification. This is followed by the third section (5.4), which presents data relating to the taxonomic composition of the entire Madjedbebe hearth assemblage. This data provides an insight into the earliest uses of fire at Madjedbebe (research aim one) and fuel wood selection strategies (research aim two). The fourth section (section 5.5) presents a statistical assessment of the eleven post-LGM hearths exploring and testing diachronic trends in fuel wood selection strategies (research aim two). The final section (section 5.6) explores the provenance of matrix charcoal (research aim three) through a comparison of hearth, matrix, and environmental charcoal. This comparison, based on the taxonomic composition of the three different charcoal samples, provides a basis upon which to determine the provenance of matrix charcoal.

5.2 Wood Reference Collection

The first step in undertaking any wood charcoal analysis is to establish an extensive reference collection which captures the full floristic diversity of the study area. The specimens contained in this collection were all sourced from the George Brown Darwin Botanic Gardens or the Greater Darwin area. They were identified by trained botanists at the point of collection and assigned a HISPID identification flag. Appendix E contains the taxonomic information of the entire wood reference collection, including the UQM number, and box number in which the mounted specimen is stored.

All reference specimens have been described in accordance with the International Association of Wood Anatomists (IAWA) guidelines for wood description (IAWA 1989, 2004). These anatomical descriptions have been recorded in a FileMaker Pro database specifically designed for this purpose (adapted from Dotte-Sarout 2010 – Appendix D). In addition to the physical specimens stored at the University of Queensland (UQ), images and a full anatomical description for each reference specimen is available in an open source and free online database (http://uqarchaeologyreference.metadata.net/archaeobotany/) (Appendix F). In time, the entire UQ archaeobotany reference collection will be uploaded to this online platform. The online database allows researchers from across the globe to consult the UQ archaeobotany reference collection and to contribute their own accessions. This database facilitates the accumulation of reference material in a single location and mitigates against the loss of reference material when research programs conclude. The database was designed by the author and Assoc. Prof. Andrew Fairbairn, with technical assistance from Damien Ayers (UQ ITEE). This reference collection contains 131 accession representing 33 families, 67 genera, and 99 species.

The taxa contained in this reference collection are often only represented by a single accession. This is because of the difficulties in sourcing appropriate material and the absence of established reference collections for the study area. Nearly all of the accessions contained within the reference collection were identified to species level at the point of collection. Based on their anatomical features, most species in a genus can be distinguished within the reference collection. However, great limitations do remain when identifying archaeological specimens, and for that reason species level identifications have not been sought. Species level identifications have been purposefully avoided for three major reasons: firstly, the taxa within the reference collection are represented by single accessions – these individual specimens which have had a particular life history and growth habit (i.e. may have an idiosyncratic appearance not completely representative of all individuals within their species); secondly, not all species within the genera in the study area or larger region are represented in the reference collection – species within a genera may be indistinguishable and therefore specific identifications should not be sought until all species are accounted for and their distinguishing anatomical features are fully known; third, there are some species within the thoroughly studied Eurasian flora which cannot be identified to species or even genus level (i.e. Salicaceae) – at this early stage of Australian anthracology it would be ill advised to seek species level identifications when so much remains unresolved in the anatomical description and partitioning of Australian wooded taxa.

5.3 Description and identification of archaeological specimens

Archaeological specimens were initially typed based on observed anatomical differences (Appendix G, H). This approach split any specimen displaying anatomical features not previously observed into a new type. In the early stages of the analysis, before the full range of anatomical configurations had been defined, this approach meant many types were added. Thirty-five types occurred in the first context analysed (C3/4A). In total eleven types were deemed indeterminate, however ten of these occurred in the first context. This high number of indeterminate types can be explained by the need to split anatomical anomalies into separate types, therefore leading to a proliferation of these types in the early stages of the analysis. The only indeterminate type outside of the first analysed context was Type 36.

In addition to the anatomical description of the archaeological charcoals, dendrological feature were also noted during analysis. These dendrological features are the remains of stresses endured by the plant during its growth (both natural and anthropogenic), its growth habit, its environment, and how it was collected. There were five main dendrological features that reoccurred across the assemblage, often in very small quantities (Appendix I). They are: vitrification (melted wood anatomy due to temperatures exceeding 500^{o}C); knots (caused by branching – more prevalent in branch wood); radial cracking (often caused when wood is burnt green or at very high temperatures); fungal hyphae (remnants of fungal growth which occurs when wood has been lying on the ground); and tyloses (vessel infilling – more prevalent in trunk and large branch wood). These observed features can, through comparison with each other and correlation to taxonomic identification, offer an insight into anthropogenic woodland management and fuel collection strategies. Unfortunately, the observed dendrological features in the MJB assemblage were limited and can only offer novel insights into fuel collection at MJB. They are used here mainly to discuss the physical condition of the assemblage.

Tyloses and vitrification are the most prevalent of the observed dendrological features in the MJB assemblage. Tyloses and vitrification are ubiquitous across all eleven post-LGM hearths and on average occur in 42% and 25% of all fragments respectively. Fungal hyphae only occurs in one context C3/4A, its absence may suggest fuel wood was not lying on the ground very long before collection or that the collection environment was not moist enough to support fungal growth. Knots are very rare in the MJB assemblage, on average only 1.8% of fragments per context contained knots. Radial cracking also had a low occurrence, on average 5.8% of fragments per context.

Radial cracking could be due to wood being burnt green, or at very high temperatures, or could be due to the anatomy of the particular taxon put to fire. A correlation between radial cracking and vitrification (high temperatures) demonstrates a very low positive correlation (0.66) between these two features. The occurrence of radial cracking could therefore be better explained by factors other than high temperature in particular the physical structure of particular taxon. A comparison of radial cracking and multiseriate rays demonstrates no correlation (<0.00001) between these two variables. Similarly uni-seriate to bi-seriate rays also had no correlation to radial cracking (-0.08). *Brachychiton* sp., the taxon which has the highest occurrence of radial cracking (14.2%) only contains uniseriate rays, which would not suggest a propensity to radially crack. In the MJB assemblage taxon anatomy (ray width), therefore does not explain the occurrence of radial cracking. This result may suggest the use of green wood in the MJB hearths but high burning temperature (vitrification) should also be considered a possibility (0.66 - very low positive correlation).

The presence of tyloses, fungal hyphae, and knots can offer an insight into how fuel wood collection was undertaken. In the MJB assemblage tyloses is ubiquitous across the most recent eleven hearths (E3/5A-E4/22A). Through a taxonomic examination it is clear all of the taxa which do not contain tyloses in the MJB assemblage either do not contain vessels (the gymnosperm - *Callitris* sp.), are shrubs (*Calytrix* sp., *Grewia* sp.), or have a growth habit which could be as a shrub (*Alstonia* sp., *Lophostemon* sp.). Therefore, the occurrence of tyloses in all other taxa may be indicative of the use of large branches or trunk wood. Fungal hyphae and knots only occur in very low percentages in the MJB assemblage, often one or two fragments in a context. In such low numbers these dendrological features cannot be relied upon to demonstrate anthropogenic selection behaviour.

In addition to human selective behaviour, the reason a specimen was indeterminate and therefore not assigned a specific taxonomic identification, can often be linked to dendrology. Knots, which swirl and distort wood anatomy, on average, only account for <4% of indeterminate specimens per context. Radial cracking, which can fracture an anatomical plane, was associated with ~10% of indeterminate specimens. However, on average vitrification occurred in >50% of indeterminate specimens per context. In some cases (C4/9A, D3/16B) 100% of indeterminate specimens were vitrified.

In addition to dendrological features such as vitrification and radial cracking, which can limit description and identification, the size of a fragment can also be a limiting factor in identifying an archaeological specimen. A small specimen may not contain enough anatomical features to reach an identification or the limited amount of anatomical features present may mean it cannot be confidently assigned to a higher taxonomic level. For these reasons and those outlined above in regard to the limitation of the current reference collection (section 5.2) identifications in this analysis were only made to genus level. It was found throughout the analysis that there was enough anatomical difference to separate different genera within a family, for example in the family Myrtaceae *Eucalyptus* sp., *Corymbia* sp., and *Asteromyrtus* sp., could be confidently separated based on their observed anatomical features, but inter-specific identifications were not achieved.

Three taxa were assigned a *confer* (*cf.*) classification because their identification could not be guaranteed based on the existing reference material. These taxa, *Thespesia* sp., *Flueggea* sp., *Pavetta* sp. are from the families Malvaceae, Euphorbiaceae, and Rubiaceae respectively. They were assigned a *cf.* classification because these taxa matched the anatomical criteria for their respective taxa but did not contain all the anatomical features required to make a firm identification to genus level. All archaeological specimens were identified to genus level except members of the Proteaceae family. This is because members of Proteaceae have very similar anatomical features and there has not yet been sufficient anatomical description to separate them archaeologically. This is has been recognised in the literature by Whitau et al. (*in press*) who did not split *Grevillea/Hakea* sp. (Proteaceae) into separate genus classifications.

5.4 The taxonomic analysis of all Madjedbebe hearths

The taxonomic data for all fourteen Madjedbebe hearths is presented below (Fig. 5.2, Tab. 5.3). The fourteen hearths can be divided into four chronological groups. The five most recent hearths date between 240-7 yr cal BP (E3/5A) and 2860-2760 yr cal BP (C4/9A). These hearths will be referred to as 'the late Holocene' hearths. The next five post-LGM hearths in the Madjedbebe sequence date between 8600-8460 yr cal BP (D3/16B) and 12810-12710 yr cal BP (E3/20A; D3/21A is not dated). These hearths will be referred to as the 'terminal Pleistocene-early Holocene' hearths. E4/22A dates to 18690-18410 yr cal BP and will be known as the LGM hearth. The remaining three hearths (D2/30, C4/36A, C1/43A) are the oldest and will be known as the pre-LGM group (all calibrated dates are presented in Appendix J). Across these four chronological groups the average number of taxa (taxon richness) per hearth fluctuates (see Table 5.1 and Figure 5.1). The most recent five hearths (the late Holocene group) have the highest taxon richness of any group. The pre-LGM group ($\bar{x}$ NTAXA = 3.6) has the lowest taxon richness closely followed by the terminal Pleistocene-early Holocene group ($\bar{x}$ NTAXA = 4.6). Diachronically there is a trend towards increased taxon richness. This trend will be further discussed and statistically tested in section 5.5.

Table 5.1 The average NTAXA of the four MJB hearth groups. The hearth groups have been arranged chronologically.

Hearth Group	**Number of hearths**	**Average NTAXA**
Late Holocene	5	12
Terminal Pleistocene-early Holocene	5	4.6
Last Glacial Maximum (LGM)	1	11
Pre-LGM	3	3.6

Acacia sp. in the most ubiquitous taxon in the Madjedbebe wood charcoal assemblage (Table 5.2). It is present in thirteen of the fourteen Madjedbebe hearths, four more than the next most ubiquitous taxon, cf. *Pavetta* sp., which only occurs in nine of the hearths. The least ubiquitous taxon present in the Madjedbebe hearths is *Coelospermum* sp. which only occurs in one hearth, D2/21A.

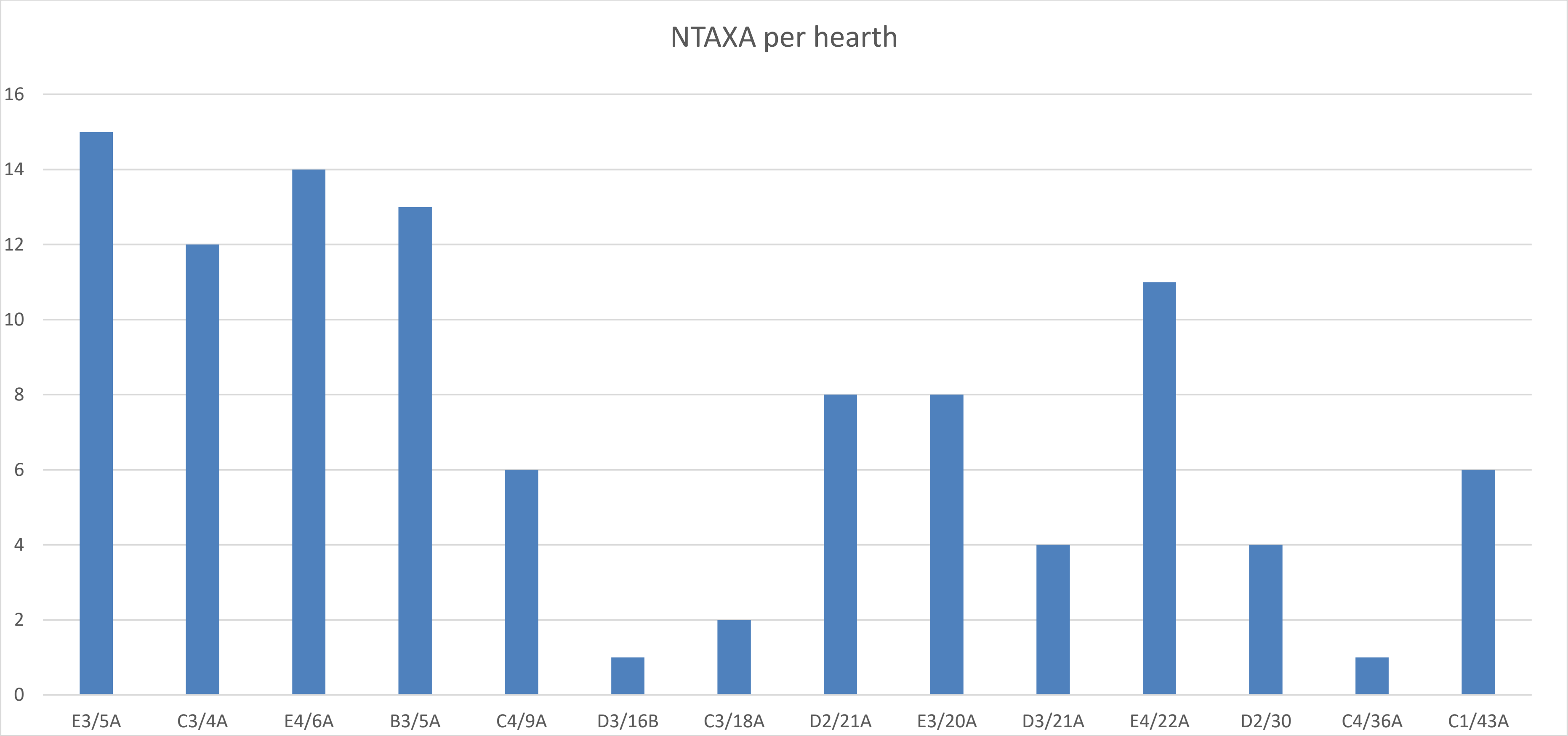


Figure 5.1 NTAXA per hearth – number of taxa in each of the fourteen Madjedbebe hearths arranged in chronological order (L-R).

Table 5.2 Ubiquity of taxa in the Madjedbebe hearths. Taxon arranged based on ubiquity from most ubiquitous (*Acacia* sp.) at the top to least ubiquitous (*Coelospermum* sp.) at the bottom.

	E3/5A	C3/4A	E4/6A	B3/5A	C4/9A	D3/16B	C3/18A	D2/21A	E3/20A	D3/21A	E4/22A	D2/30	C4/36A	C1/43A	**Ubiquity**
Acacia sp.	1	1	1	1	1	1	1	1	1	1	1	1	0	1	13
cf. *Pavetta* sp.	1	1	1	1	1	0	1	1	0	0	1	0	0	1	9
Corymbia sp.	1	1	1	0	0	0	0	1	1	1	1	0	0	1	8
Eucalyptus sp.	1	1	1	1	0	0	0	0	1	0	1	0	0	1	7
Ficus sp.	1	1	1	1	1	0	0	0	1	0	1	0	0	0	7
Proteaceae	1	1	1	1	0	0	0	1	1	0	1	0	0	0	7
cf. *Thespesia* sp.	1	1	1	1	1	0	0	0	0	1	0	0	0	1	7
Alphitonia sp.	1	1	0	0	1	0	0	0	0	1	1	0	0	1	6
Terminalia sp.	1	1	1	1	0	0	0	0	1	0	1	0	0	0	6
Asteromyrtus sp.	1	1	1	1	0	0	0	1	0	0	0	0	0	0	5
Callitris sp.	0	0	1	0	0	0	0	0	1	0	1	1	1	0	5
Calytrix sp.	1	0	0	1	0	0	0	1	0	0	1	0	0	0	4
cf. *Flueggea* sp.	1	1	1	1	0	0	0	0	0	0	0	0	0	0	4
Type 48	0	0	0	0	0	0	0	1	1	0	1	1	0	0	4
Brachychiton sp.	1	0	1	0	1	0	0	0	0	0	0	0	0	0	3
Grewia sp.	1	0	1	0	0	0	0	0	0	0	0	1	0	0	3
Alstonia sp.	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2
Lophostemon sp.	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
Type 24	0	1	0	1	0	0	0	0	0	0	0	0	0	0	2
Coelospermum sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1

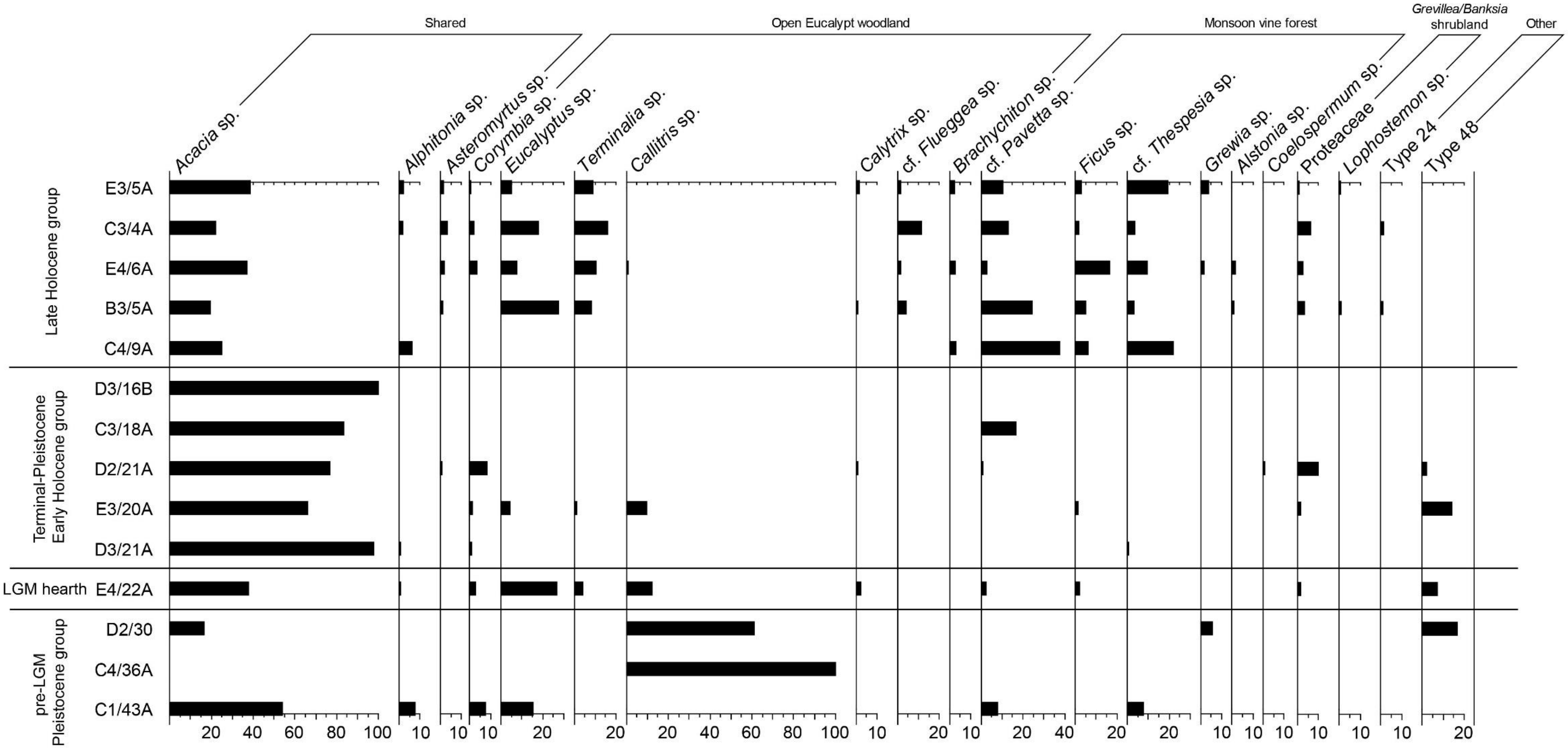


Figure 5.2 All fourteen Madjedbebe heaths arranged chronologically. Note the four distinct temporal groups also relate to shifts in taxonomic composition diachronically. The x-axis is arranged by ubiquity with each vegetation community – except the unidentified archaeological types which are sequentially arranged.

Table 5.3 Total Madjedbebe hearth assemblage – percentage frequency (%*f*), actual count frequency (A*f*), ubiquity, taxon count, and sample sizes presented.

		Hearth																														
		E3/5A		**C3/4A**		**E4/6A**		**B3/5A**		**C4/9A**		**D3/16B**		**C3/18A**		**D2/21A**		**E3/20A**		**D3/21A**		**E4/22A**		**D2/30**		**C4/36A**		**C1/43A**		**Total**		
		7-240 cal BP		**0-260 cal BP**		**450-300 cal BP**		**720-650 cal BP**		**2860-2760 cal BP**		**8600-8460 cal BP**		**9130-9000 cal BP**		**9398-9034 cal BP**		**12810-12710 cal BP**		**No date**		**18690-18410 cal BP**		**No date**		**24970-24340 cal BP**		**No date**				
Vegetation communities	**Taxon**	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	U	A*f*
Open Eucalypt woodland	*Corymbia* sp.	0.74	1	1.93	5	3.45	4	0	0	0	0	0	0	0	0	8.21	11	1.41	1	0.81	1	2.90	4	0	0	0	0	7.69	1	1.94	8	28
	Eucalyptus sp.	5.19	7	17.76	46	7.76	9	27.55	27	0	0	0	0	0	0	0	0	4.23	3	0	0	26.81	37	0	0	0	0	15.38	2	7.48	7	131
	Terminalia sp.	8.89	12	15.83	41	10.34	12	8.16	8	0	0	0	0	0	0	0	0	1.41	1	0	0	4.35	6	0	0	0	0	0	0	3.50	6	80
	Callitris sp.	0	0	0	0	0.86	1	0	0	0	0	0	0	0	0	0	0	9.86	7	0	0	12.32	17	61.11	22	100	94	0	0	13.15	5	141
	Calytrix sp.	1.48	2	0	0	0	0	1.02	1	0	0	0	0	0	0	0.75	1	0	0	0	0	2.17	3	0	0	0	0	0	0	0.39	4	7
	cf. *Flueggea* sp.	1.48	2	11.58	30	1.72	2	4.08	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.35	4	38
	Brachychiton sp.	2.22	3	0	0	2.59	3	0	0	3.13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.57	3	7
Monsoon vine forest	cf. *Pavetta* sp.	10.37	14	13.13	34	2.59	3	24.49	24	37.50	12	0	0	16.67	2	0.75	1	0	0	0	0	2.17	3	0	0	0	0	7.69	1	8.24	9	94
	Ficus sp.	2.96	4	1.93	5	16.38	19	5.10	5	6.25	2	0	0	0	0	0	0	1.41	1	0	0	2.17	3	0	0	0	0	0	0	2.59	7	39
	cf. *Thespesia* sp.	19.26	26	3.47	9	9.48	11	3.06	3	21.88	7	0	0	0	0	0	0	0	0	0.81	1	0	0	0	0	0	0	7.69	1	4.69	7	58
	Grewia sp.	3.70	5	0	0	1.72	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.56	2	0	0	0	0	0.78	3	9
	Alstonia sp.	0	0	0	0	1.72	2	1.02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	2	3
	Coelospermum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	1	0	0	0	0	0	0	0	0	0	0	0	0	0.05	1	1
Shared taxa (open Eucalypt and monsoon vine forest)	*Acacia* sp.	38.52	52	22.01	57	37.07	43	19.39	19	25.00	8	100	35	83.33	10	76.87	103	66.20	47	97.56	120	37.68	52	16.67	6	0	0	53.85	7	48.15	13	559
	Alphitonia sp.	2.22	3	1.93	5	0	0	0	0	6.25	2	0	0	0	0	0	0	0	0	0.81	1	0.72	1	0	0	0	0	7.69	1	1.40	6	13
	Asteromyrtus sp.	1.48	2	3.09	8	1.72	2	1.02	1	0	0	0	0	0	0	0.75	1	0	0	0	0	0	0	0	0	0	0	0	0	0.58	5	14
Grevillea/ Banksia shrubland	Proteaceae	0.74	1	6.18	16	2.59	3	3.06	3	0	0	0	0	0	0	9.70	13	1.41	1	0	0	1.45	2	0	0	0	0	0	0	1.79	7	39
	Lophostemon sp.	0.74	1	0	0	0	0	1.02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	2	2
Other	Type 24	0	0	1.16	3	0	0	1.02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	2	4
	Type 48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.24	3	14.08	10	0	0	7.25	10	16.67	6	0	0	0	0	2.87	4	29
	Total	100	135	100	259	100	116	100	98	100	32	100	35	100	12	100	134	100	71	100	123	100	138	100	36	100	94	100	13	100		1296
	Number of taxa	15		12		14		13		6		1		2		8		8		4		11		4		1		6				

5.4.1 Late Holocene hearths

The late Holocene hearths have the highest taxon richness both individually (E3/5A) and collectively (x̅ NTAXA = 12) of any of the hearth groups. All of hearths in this group contain taxa from open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland (except C4/9A which does not contain the latter). The archaeological Type 24 and the taxon *Alstonia* sp. only occur in this group and in no other in the assemblage. Unlike the terminal Pleistocene-early Holocene group the late Holocene hearths are not solely dominated by *Acacia* sp. (B3/5A and C4/9A are dominated by *Eucalyptus* sp. and cf. *Pavetta* sp. respectively).

5.4.1.1 Hearth E3/5A

Hearth E3/5A was directly radiocarbon dated with a result of 240-7 yr cal BP (Wk43609).

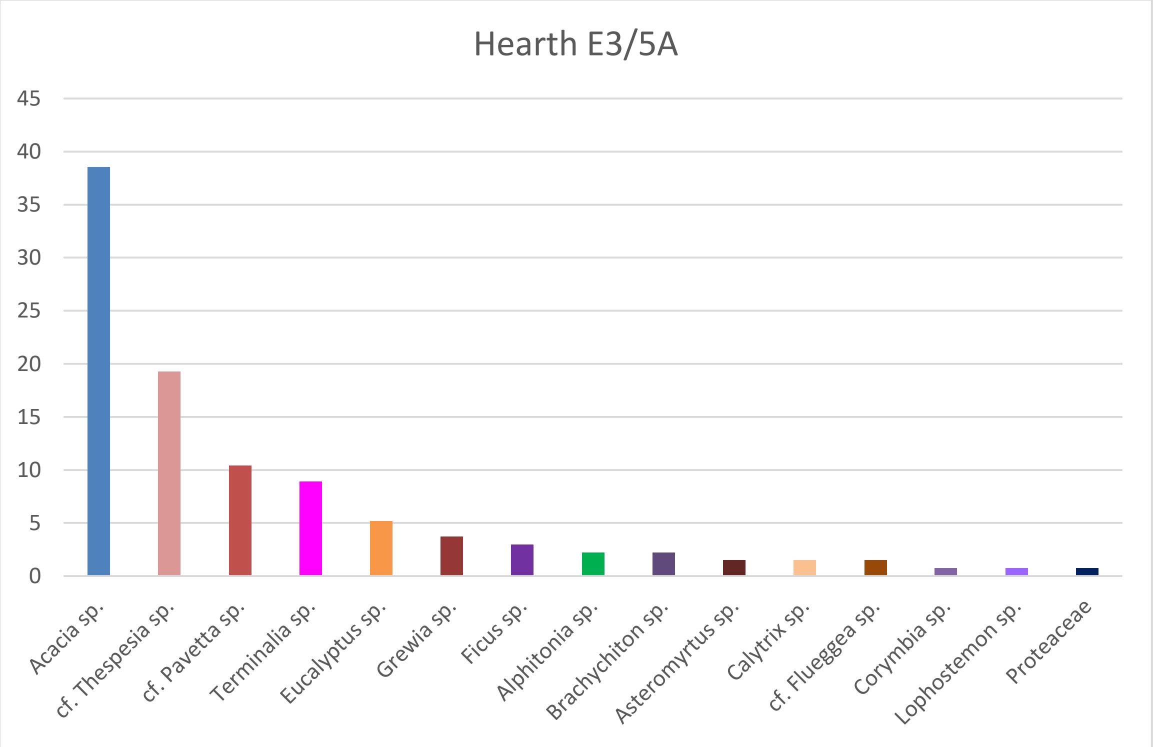


Figure 5.3 Hearth E3/5A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth E3/5A is the most recent hearth in the Madjedbebe (MJB) sequence, it dates between 240-7 yr cal BP. This hearth contains 15 taxa which is the highest taxon richness of any of the MJB hearths. Of the 200 fragments analysed from this hearth just over a third (32%) were indeterminate due to size or preservation (Appendix K). With the indeterminate specimens removed from the sample *Acacia* sp. taxa make up 38% of the identified assemblage (Fig. 5.3). cf. *Thespesia* sp. (19%) and cf. *Pavetta* sp. (10%) are the only other taxa which contribute more than 10% to the E3/5A wood charcoal assemblage. This hearth contains taxa from open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities.

5.4.1.2 Hearth C3/4A

C3/4 was radiocarbon dated with a result of 260-0 yr cal BP (OZQ464).

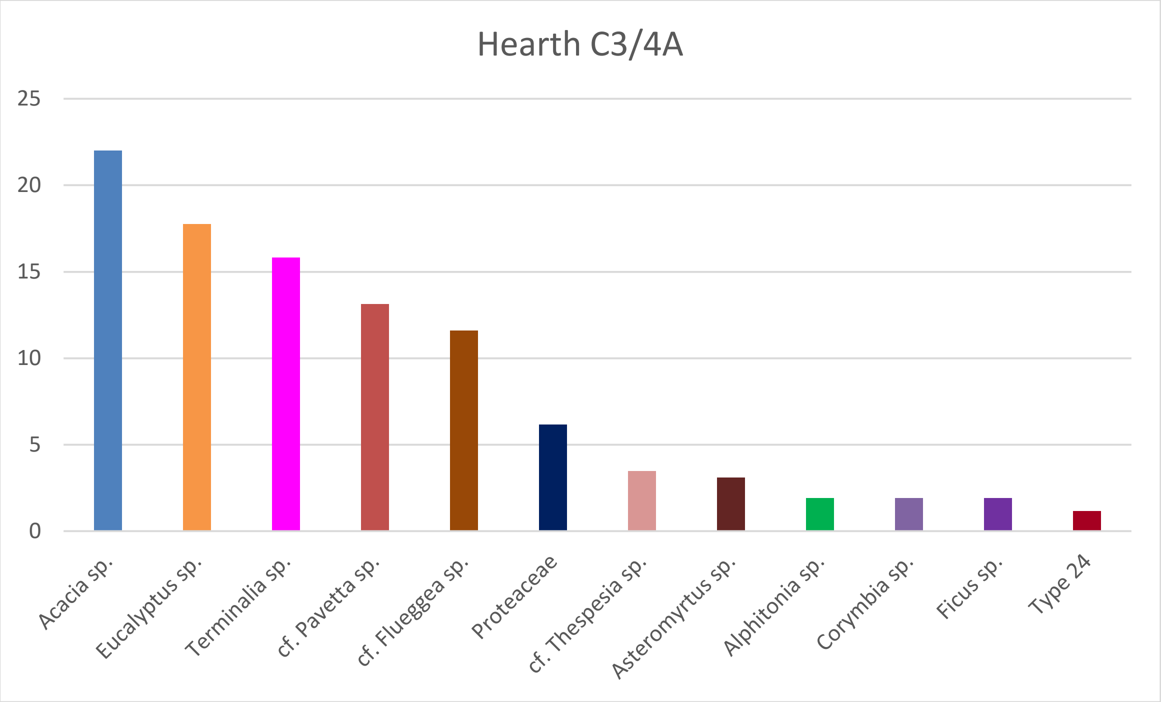


Figure 5.4 Hearth C3/4A taxonomic composition as percent. Indeterminate specimens excluded.

The date 260-0 yr cal BP provides a *terminus post quem* (TPQ) for hearth C3/4A. This is because the date is based on a charcoal sample recovered from the sedimentary matrix (C3/4) surrounding the hearth. The sample therefore could be from the hearth or may have already been present when the hearth was constructed. This hearth has a taxon richness of twelve. Of the 400 charcoal fragments analysed from this hearth 35% were indeterminate due to size or preservation (Appendix K). With the indeterminate specimens removed *Acacia* sp. taxa make up 22% of the total identified assemblage (Fig. 5.4). *Eucalyptus* sp. (17%), *Terminalia* sp. (15%), cf. *Pavetta* sp. (13%), and cf. *Flueggea* sp. (11%) make up more than ten percent of the total identified assemblage. This hearth also contains three fragments of Type 24, an unidentified archaeological type. Open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities are all represented in the C3/4A wood charcoal assemblage.

5.4.1.3 *Hearth E4/6A*

Hearth E4/6A was directly radiocarbon dated with a result of 450-300 yr cal BP (OZQ460).

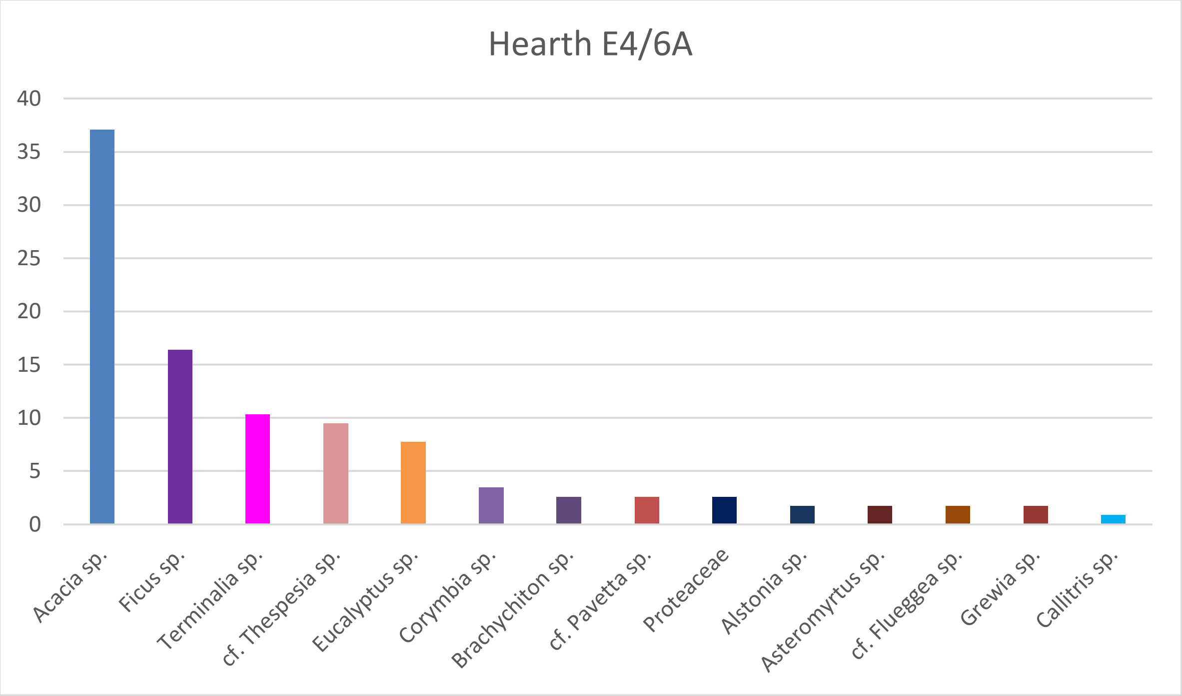


Figure 5.5 Hearth E4/6A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth E4/6A contains 14 taxa, which is the second highest taxon richness for a hearth in the MJB assemblage. Of the 200 charcoal fragments analysed 42% were indeterminate due to size or preservation (Appendix K). *Acacia* sp. taxa make up 37% of the total identified charcoal assemblage, with *Ficus* sp. (16%) and *Terminalia* sp. (10%) the only other taxa to reach above 10% (Fig. 5.5). E4/6A is the only late Holocene hearth to contain *Callitris* sp. wood charcoal. It is also only one of two MJB hearths to contain the monsoon vine forest taxa *Alstonia* sp. The E4/6A wood charcoal assemblage contains taxa from open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities.

5.4.1.4 *Hearth B3/5A*

B3/5 was radiocarbon dated with a result of 720-650 yr cal BP (OZQ474).

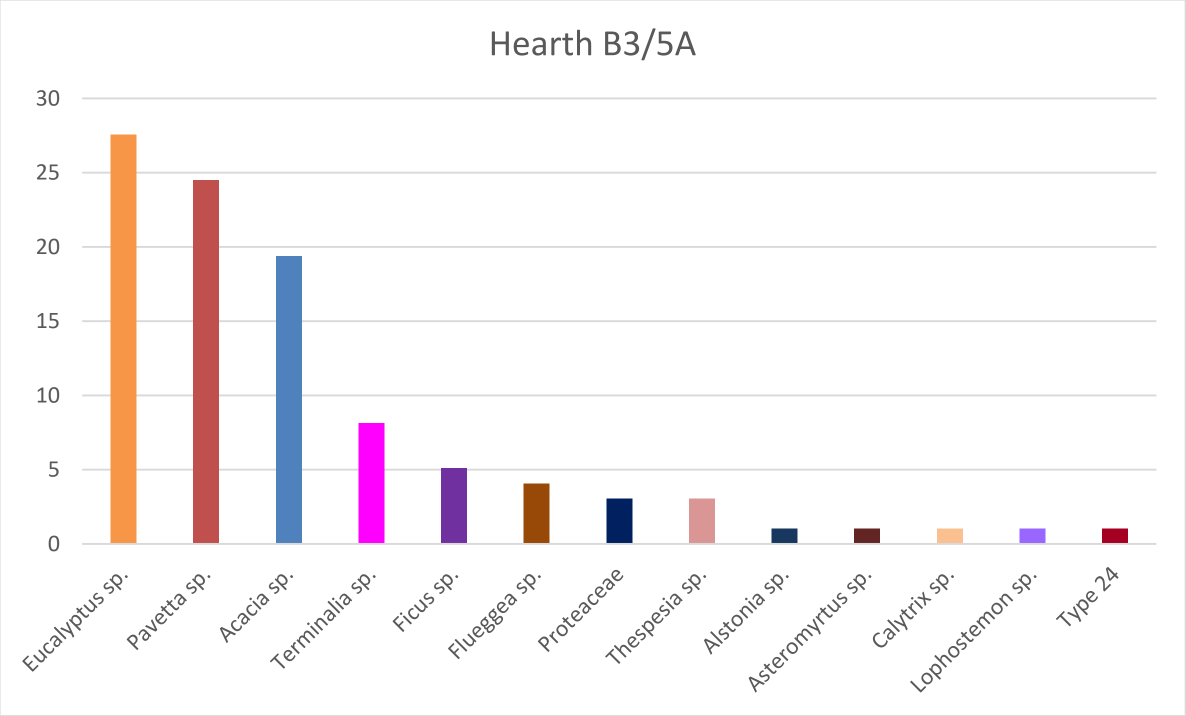


Figure 5.6 Hearth B3/5A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth B3/5A has the third highest taxon richness of any of the MJB hearths (*n* = 13). Of the 200 charcoal fragments analysed for B3/5A 51% were indeterminate due to size or preservation (Appendix K). With indeterminate taxa removed *Eucalyptus* sp. (27%), cf. *Pavetta* sp. (24%), and *Acacia* sp. (19%) make up the majority of the assemblage (Fig. 5.6). B3/5A is only one of two hearths (see also E4/6A) which contains the monsoon vine forest taxa *Alstonia* sp. It is also only one of two of the late Holocene hearths in which *Acacia* sp. is not the dominant taxa (see also C4/9A). The B3/5A wood charcoal assemblage contains taxa from open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities.

5.4.1.5 Hearth C4/9A

Hearth C4/9A was directly radiocarbon dated with a result of 2860-2760 yr cal BP (Wk43604).

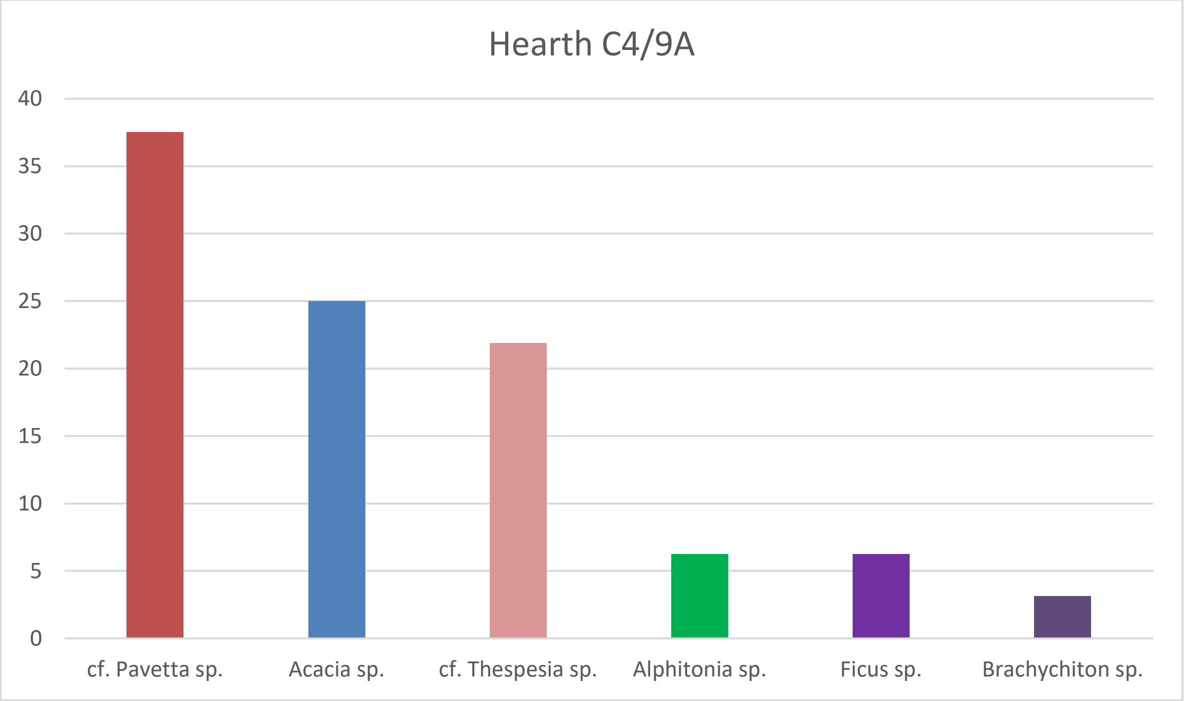


Figure 5.7 Hearth C4/9A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth C4/9A is the oldest of the late Holocene hearths, it dates between 2860-2760 yr cal BP. Of the 57 charcoal fragments analysed, 100% of the charcoal present in the hearth, 43% were indeterminate (Appendix K). cf. *Pavetta* sp., the most abundant taxa in the hearth, makes up 37% of the identified wood charcoal assemblage (Fig. 5.7). *Acacia* sp. (25%) and cf. *Thespesia* sp. (21%) are the only other taxa to make up more than ten percent of the total identified assemblage. Only open Eucalypt woodland and monsoon vine forest vegetation communities are represented in the C4/9A wood charcoal assemblage.

5.4.2 Terminal Pleistocene-early Holocene hearths

The terminal Pleistocene-early Holocene group of hearths are dominated by *Acacia* sp. which is dissimilar to any of the other groups. This group of hearths also has a lower overall taxon richness than the groups of hearths which come before and after it with an average taxon richness of just 4.6. Only two hearths in this group contain taxon from *Grevillea/Banksia* shrubland (D2/21A, E3/20A), with open Eucalypt woodland and monsoon vine forest taxa dominating the assemblage. This group of hearths are however the only ones to contain the taxon *Coelospermum* sp. which was represented by a single fragment in D2/21A.

5.4.2.1 Hearth D3/16B

Hearth D3/16B was radiocarbon dated with a result of 8600-8460 yr cal BP (Wk43607).

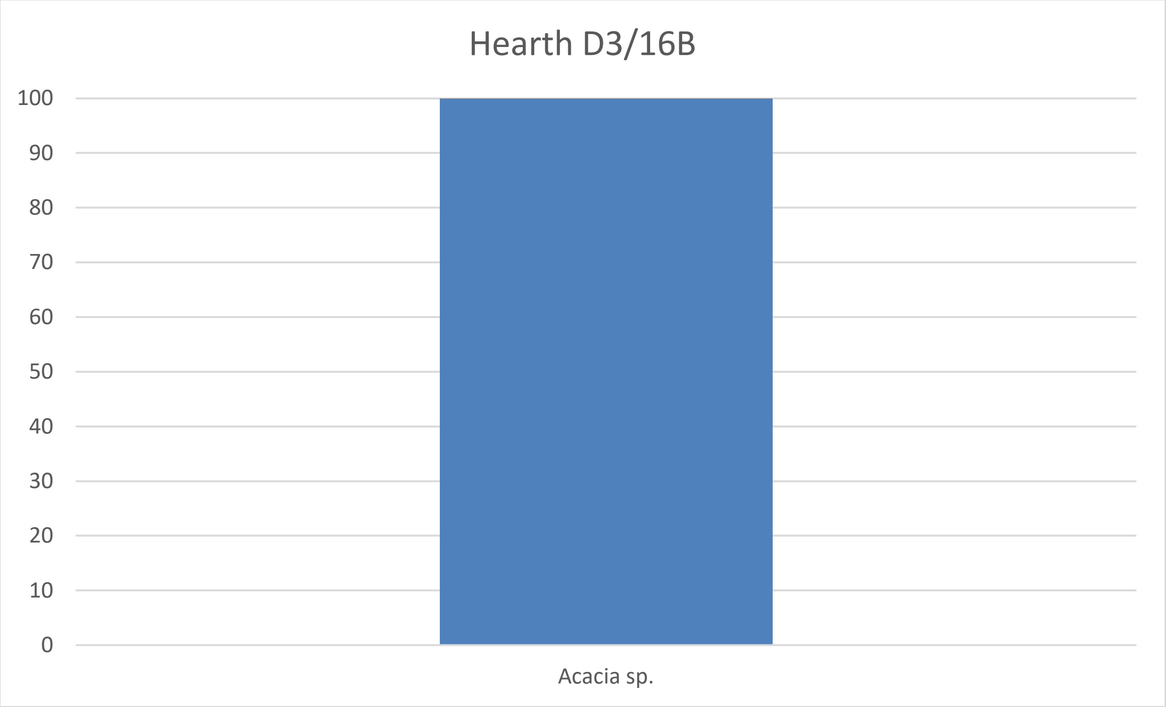


Figure 5.8 Hearth D3/16B taxonomic composition as percent. Indeterminate specimens excluded.

This hearth is the only early Holocene hearth to contain a single taxon. Of the 37 fragments analysed only 5% were indeterminate due to size or preservation (Appendix K). With a taxon richness of one this hearth probably represents a single use feature (Fig. 5.8). As *Acacia* sp. are found across both open Eucalypt woodland and monsoon vine forest technically both of these vegetation communities are represented in this hearth.

5.4.2.2 Hearth C3/18A

Hearth C3/18A was directly radiocarbon dated with a result of 9130-9000 yr cal BP (Wk43603).

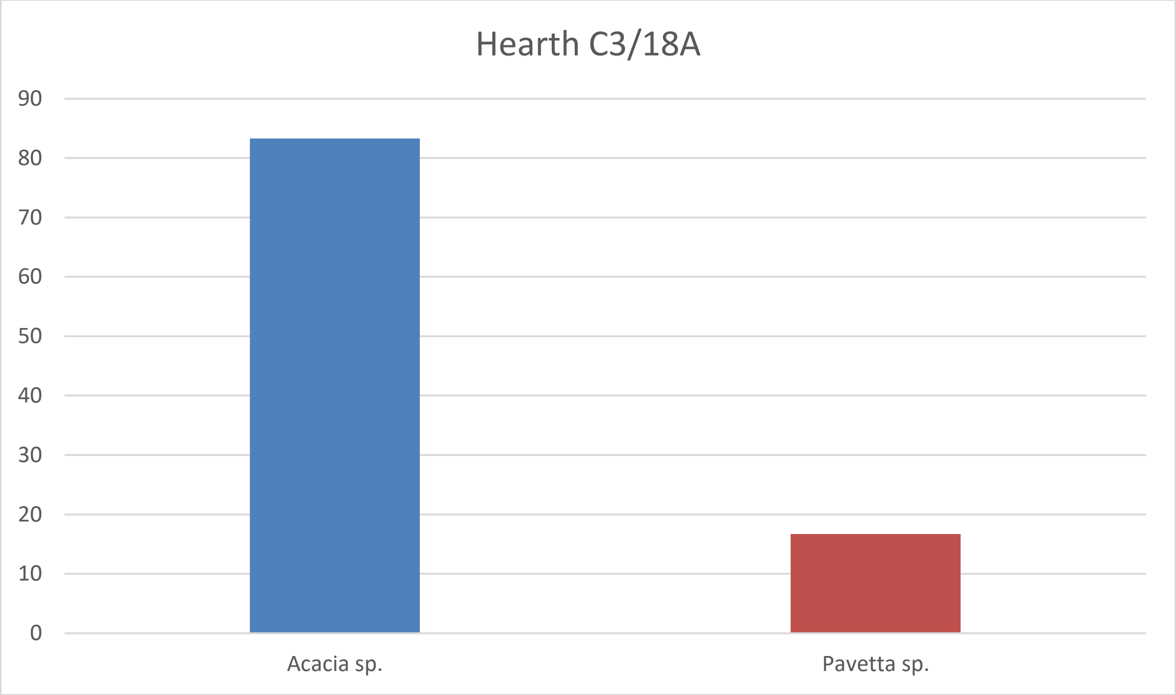


Figure 5.9 Hearth C3/18A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth C3/18A dates between 9130-9000 yr cal BP. Of the 25 charcoal fragments analysed 52% were indeterminate due to size or preservation (Appendix K). *Acacia* sp. (83%) is by far the dominant component of C3/18A with cf. *Pavetta* sp. making up the remaining 17% of the identified specimens (Fig. 5.9). With a taxon count of two this hearth has far lower taxon richness than the early Holocene hearths presented previously. Even though it only contains two taxa both open Eucalypt woodland and monsoon vine forest communities are represented.

5.4.2.3 *Hearth D2/21A*

Hearth D2/21A was directly radiocarbon dated with a result of 9398-9034 yr cal BP (Wk43606).

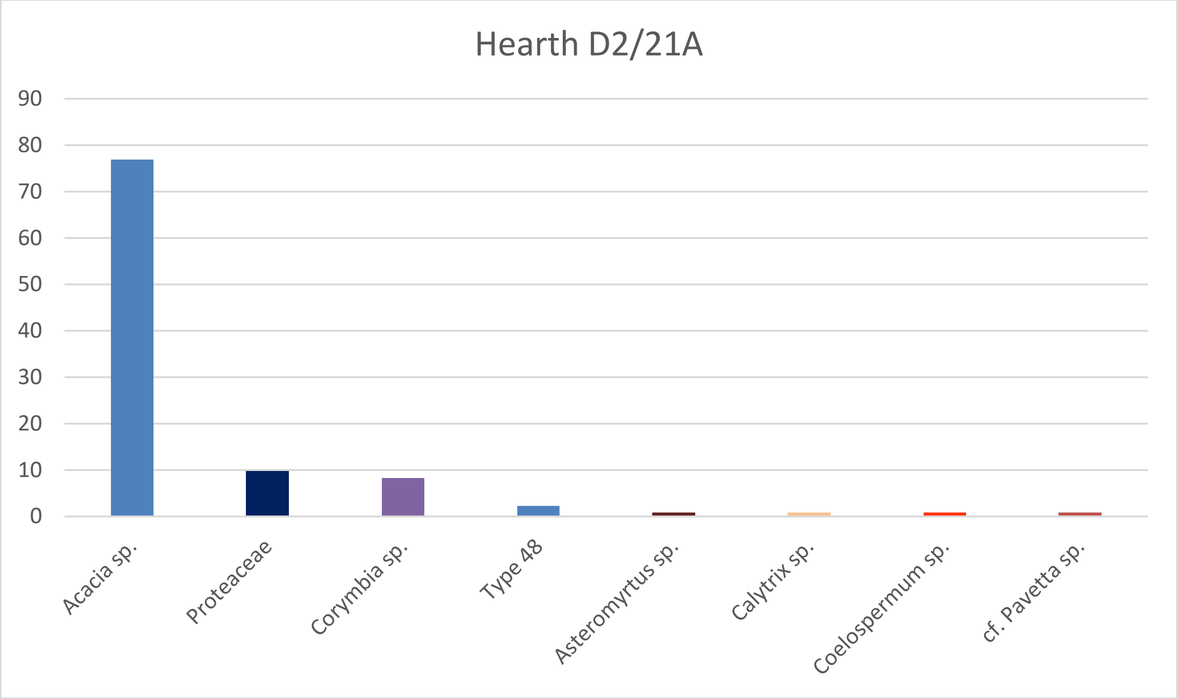


Figure 5.10 Hearth D2/21A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth D2/21A has the equal second highest taxon richness of the terminal Pleistocene-early Holocene hearths. It contains seven identified taxa and one unidentified archaeological type (Type 48). Type 48 does not appear in any of the late Holocene hearths presented above. Of the 200 charcoal fragments analysed, 33% were indeterminate because of size or preservation (Appendix K). *Acacia* sp. makes up 76% of the identified wood charcoal assemblages with all other taxa making a minor contribution (<10%) (Fig. 5.10). This hearth contained a single fragment of *Coelospermum* sp., the only hearth in the MJB assemblage to contain this taxon. The taxa present in hearth D2/21A are sourced from open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland vegetation communities.

5.4.2.4 Hearth E3/20A

Hearth E3/20A was directly radiocarbon dated with a result of 12810-12710 yr cal BP (Wk43610).

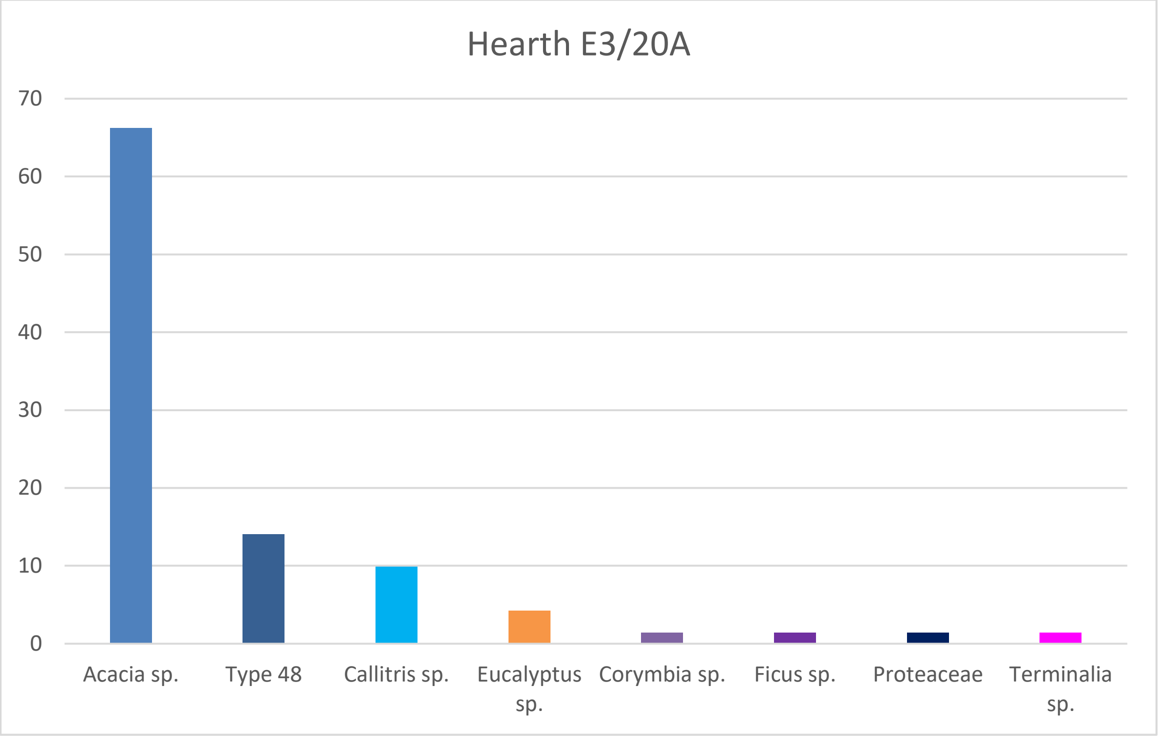


Figure 5.11 Hearth E3/20A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth E3/20A contains eight taxon, seven identified and one unidentified archaeological type (Type 48). Of the 121 charcoal fragments analysed 41% were indeterminate due to size or preservation (Appendix K). *Acacia* sp. (66%) was the dominant taxon. Only Type 48 (14%) reached greater than 10% of the total identified charcoal assemblage (Fig. 5.11). The charcoal assemblage contained taxa from open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland.

5.4.2.5 Hearth D3/21A

A date for this context was not obtained due to repeated sample failure.

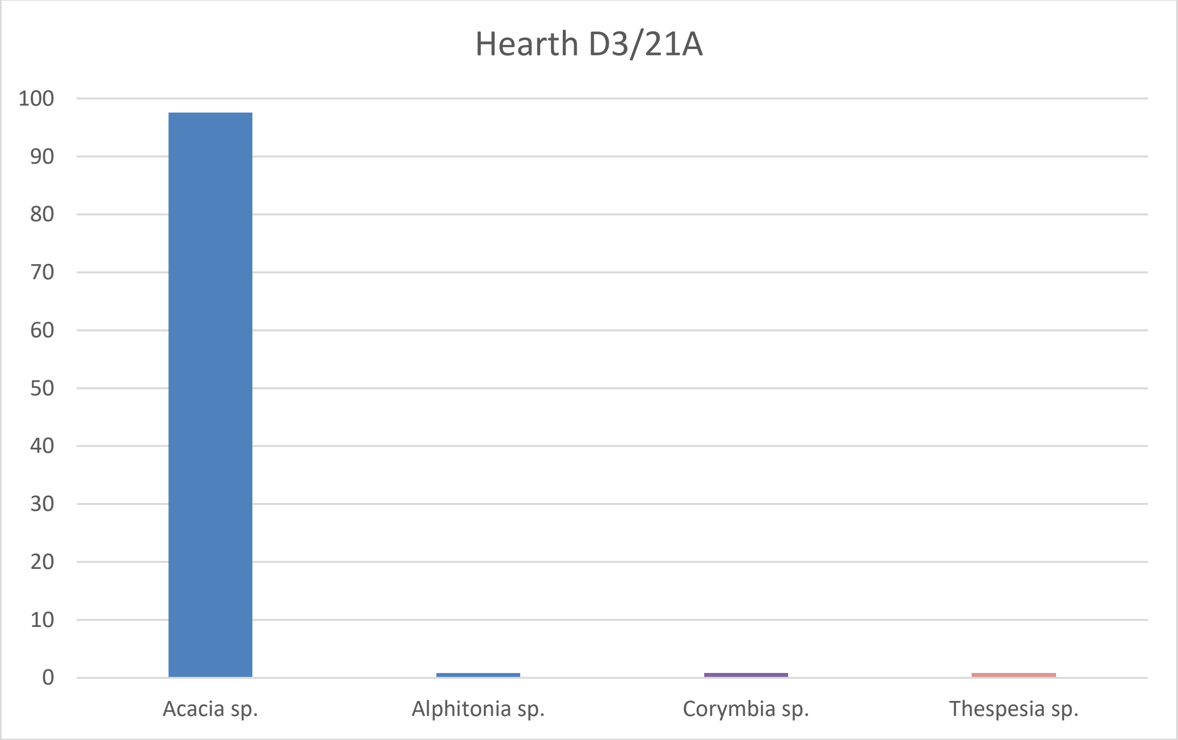


Figure 5.12 Hearth D3/21A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth D3/21A contains only four taxa and is dominated by *Acacia* sp. Of the 160 charcoal fragments analysed for this hearth 23% were indeterminate due to size or preservation (Appendix K). *Acacia* sp. makes up 97% of the total identified assemblage, with minor contributions from *Alphitonia* sp., *Corymbia* sp., and cf. *Thespesia* sp. (Fig. 5.12). The taxa present in this hearth represent open Eucalypt woodland and monsoon vine forest.

5.4.3 Last Glacial Maximum (LGM) hearth

Hearth E4/22A is the only hearth in this group. It has been separated from the other terminal Pleistocene-early Holocene hearths because it is 6,000 years older than the oldest hearth of the terminal Pleistocene-early Holocene group – E3/20A (12810-12710 yr cal BP). This temporal division is however also reflected in a compositional difference between this hearth, the hearths of the terminal Pleistocene-early Holocene and the pre-LGM group. E4/22A have a much higher taxon richness than both of these groups – $\bar{x}$ NTAXA = 4.6 and $\bar{x}$ NTAXA = 3.6 respectively.

5.4.3.1 Hearth E4/22A

Hearth E4/22A was directly radiocarbon dated with a result of 18690-18410 yr cal BP (Wk43611).

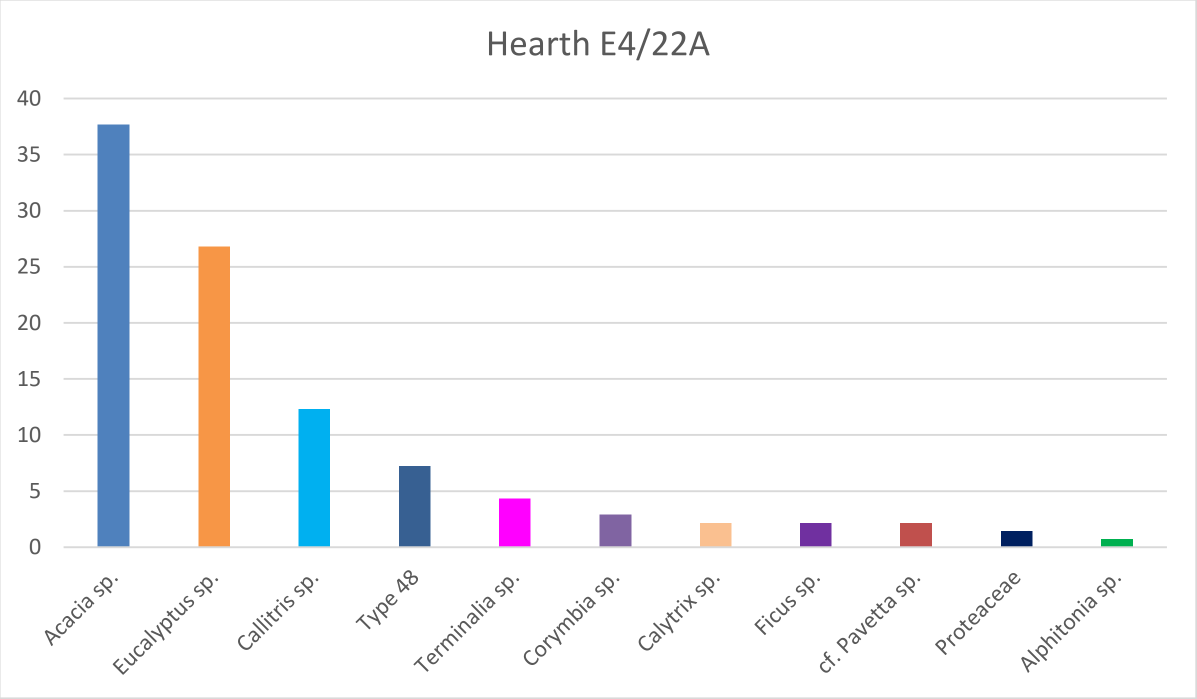


Figure 5.13 Hearth E4/22A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth E4/22A has a higher taxon richness than the terminal Pleistocene-early Holocene hearths with eleven taxa present. It dates between 18690-18410 yr cal BP. Of the 200 charcoal fragments analysed, 31% were indeterminate due to size or preservation (Appendix K). *Acacia* sp. (37%) and *Eucalyptus* sp. (26%) were the two dominant taxa present in hearth E4/22A, with *Callitris* sp. (12%) the only other taxon with >10% of the total assemblage (Fig. 5.13). The E4/22A assemblage represents open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland vegetation communities.

5.4.4 Pre-LGM hearths

The pre-LGM group of hearths contain a high percentage of the fire-sensitive pine *Callitris* sp. This taxon does occur in later hearths (E4/6A – 0.86%; E3/20A – 9.86%) but not in the quantities in which it appears in the pre-LGM hearths (D2/30 – 61%; C4/36A – 100%). This group has the lowest taxon richness of any group of hearths ($\bar{x}$ NTAXA = 3.6) and do not contain any taxa from *Grevillea/Banskia* shrubland which is unlike all of the other hearth groups.

5.4.4.1 Hearth D2/30

A radiocarbon sample has been submitted for analysis.

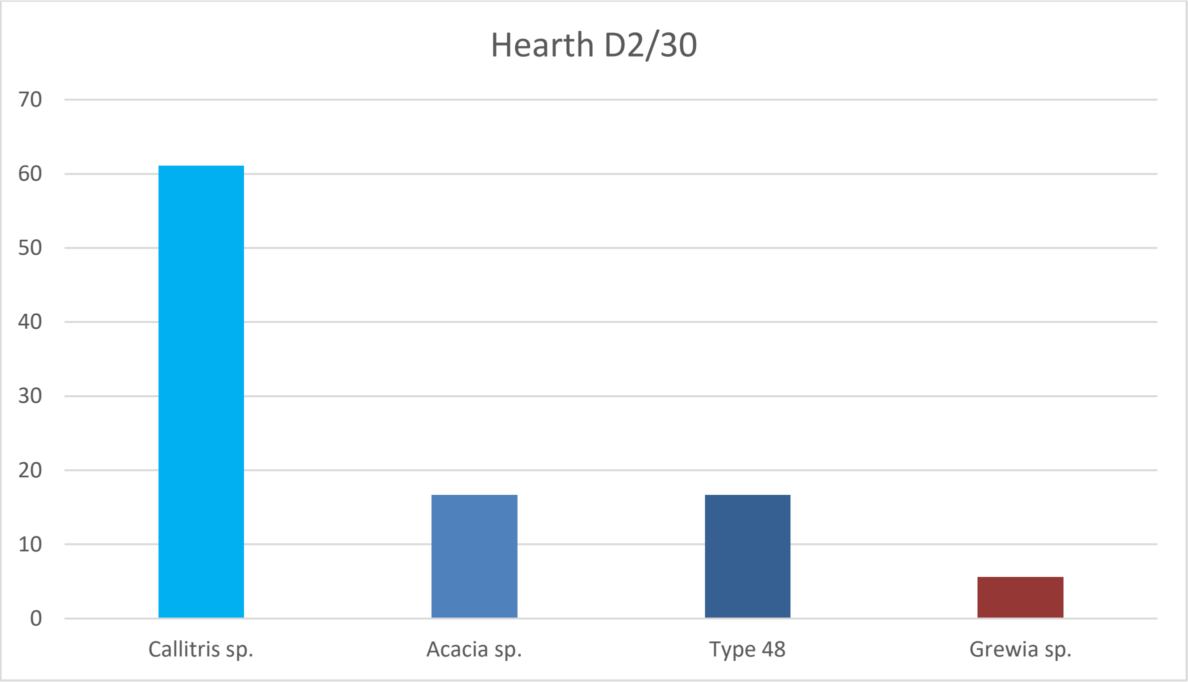


Figure 5.14 Hearth D2/30 taxonomic composition as percent. Indeterminate specimens excluded.

Hearth D2/30 is one of two hearths in the MJB sequence which is dominated by *Callitris* sp. Of the 47 charcoal fragments analysed, 23% were indeterminate due to size or preservation (Appendix K). *Callitris* sp. made up 61% of the identified wood charcoal assemblage with *Acacia* sp. (16%) and the unidentified archaeological Type 48 (16%) with >10% of the total (Fig. 5.14). Of the three MJB hearths which contain *Grewia* sp. D2/30 is the only one in the Pleistocene. The taxa present in hearth D2/30 represent open Eucalypt woodland and monsoon vine forest vegetation communities.

5.4.4.2 Hearth C4/36A

Hearth C4/36A was directly radiocarbon dated with a result of 24970-24340 yr cal BP (Wk43605).

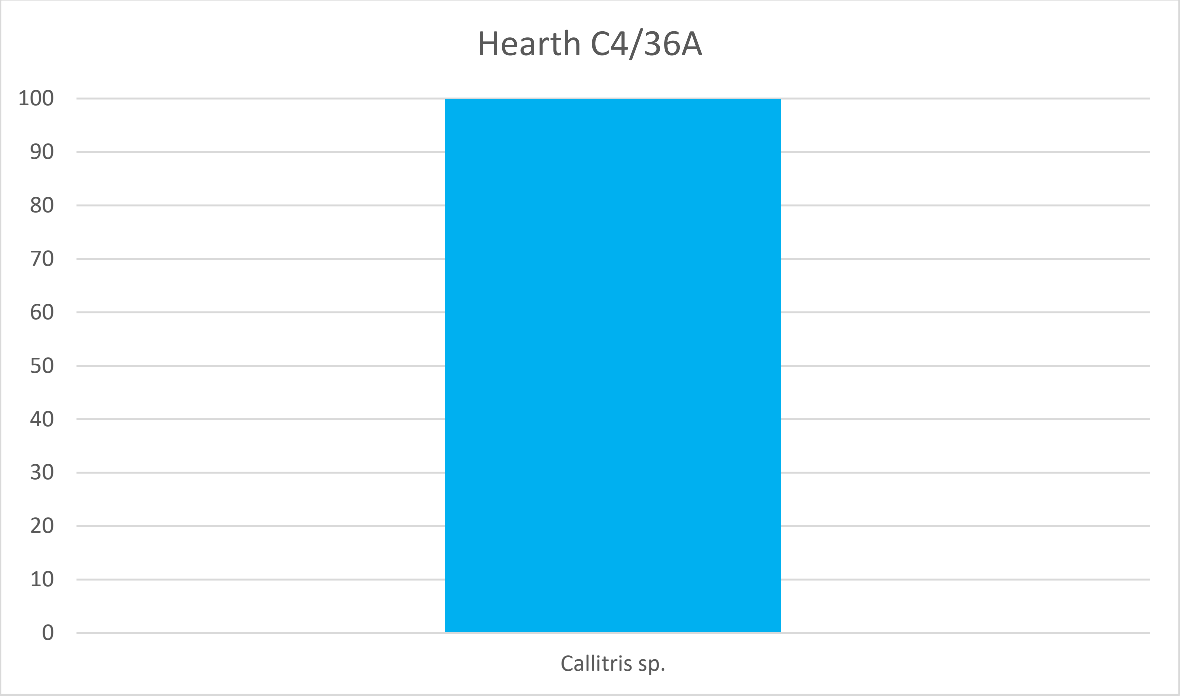


Figure 5.15 Hearth C4/36A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth C4/36A is composed solely of the fire-sensitive pine *Callitris* sp. Of the 99 charcoal fragments analysed only 5% were indeterminate due to size or preservation (Appendix K). Out of all the MJB hearths C4/36A is the only one to contain greater than 50% *Callitris* sp. (Fig. 5.15). It is also the only hearth in the MJB sequence not to contain *Acacia* sp. The taxonomic homogeneity of hearth C4/36A may indicate that it was a single use context or used for a specific purpose, perhaps to repel insects.

5.4.4.3 Hearth C1/43A

There was not enough material available to date this context.

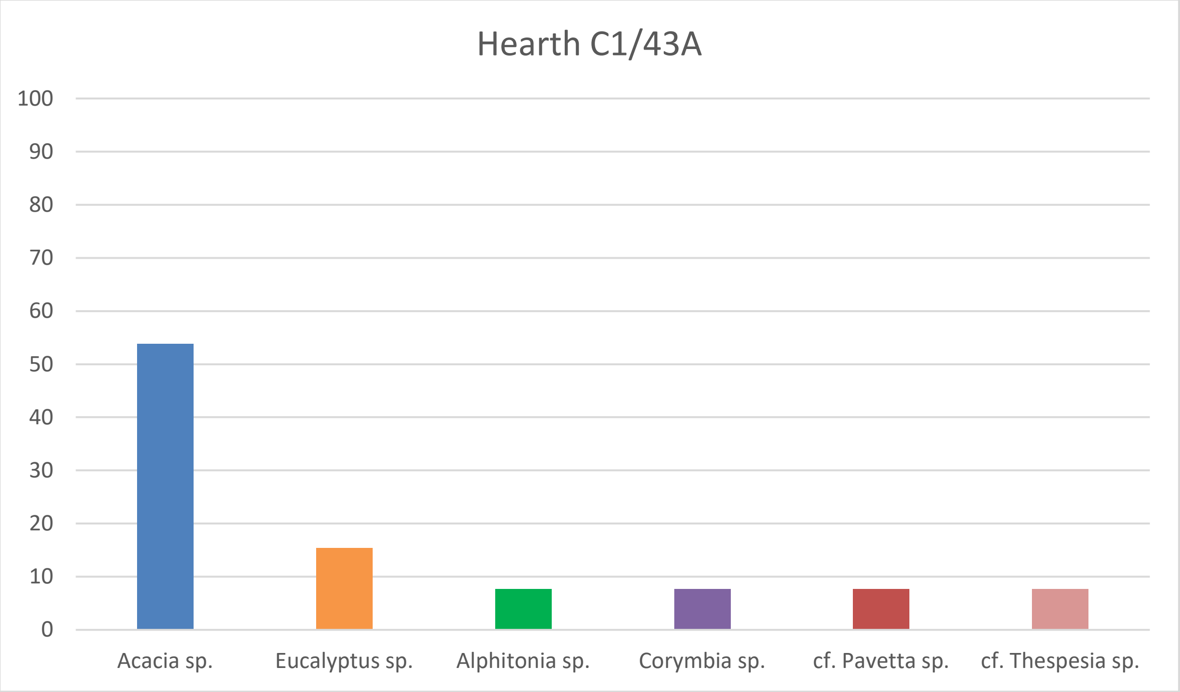


Figure 5.16 Hearth C1/43A taxonomic composition as percent. Indeterminate specimens excluded.

Hearth C1/43A is the oldest hearth in the MJB sequence. Its estimated age based on an OSL chronology is 55,000 years old. This hearth was very small and only contained 19 charcoal fragments of which 31% were indeterminate due to size or preservation (Appendix K). Over fifty percent of the identified specimens were *Acacia* sp. (53%), the only other taxa with >10% was *Eucalyptus* sp. (Fig. 5.16). The hearth contained taxa from open Eucalypt woodland and monsoon vine forest vegetation communities.

5.4.5 Vegetation communities

The taxa identified in the fourteen Madjedbebe hearths are derived predominately from open Eucalypt woodland and monsoon vine forest, with minor contributions from *Grevillea/Banksia* shrubland. Open Eucalypt woodland and monsoon vine forest are represented in every hearth, except C4/36A which contains a single open Eucalypt woodland taxon (*Callitris* sp.). Because hearth D3/16B solely contains the shared taxa *Acacia* sp. it also technically contains taxa from both open Eucalypt woodland and monsoon vine forest. *Grevillea/Banksia* shrubland occurs in seven of the fourteen hearths, but only in three of the oldest ten hearths. It only occurs in two Pleistocene hearth, E3/20A and E4/22A. E4/22A has the highest taxon richness of any of the Pleistocene hearths.

5.4.5.1 Palaeoenvironment

The palaeoenvironmental record provided by the MJB hearths is not a complete or representative record of the local palaeoenvironment. Because hearths are often single use and the product of specific selection choices their taxonomic richness is often constrained. Contexts which are a composite of multiple inputs and activities produce far better records of the palaeoenvironment. However, the MJB hearths do provide some insight into the palaeoenvironment at the time of their use.

5.4.5.1.1 *Grevillea/Banksia* shrubland

The occurrence of *Grevillea/Banksia* shrubland in only three of the oldest hearths compared to its occurrence in all four of the most recent hearths may suggest it was not present or limited in its distribution in the local environment during the Pleistocene-early Holocene. This vegetation community grows in poorly drained depressions and drainage lines, its limited distribution or absence in the local environment may suggest lower precipitation during the Pleistocene. An increase in freshwater availability during the late Holocene, as suggested by the MJB pollen record (presented in section 3.2.7), would support its expansion at this time.

5.4.5.1.2 Monsoon vine forest

During the late Holocene there is a clear increase in monsoon vine forest taxa in the Madjedbebe hearths. In the late Holocene group of hearths monsoon vine forest taxa on average make up 37.2% of the total assemblage, between 18.5% and 65.6% in each of the five hearths. In the proceeding nine hearths from the pre-LGM Pleistocene to the early Holocene monsoon vine forest taxa make up on average 5.1%, between 0% and 16.6% of the taxa in each of the hearths. This increase in monsoon vine forest in the late Holocene may be because of a change in fuel selection practices or it may reflect a change in the local environment supported by increased precipitation. A change which is echoed by the increase in *Grevilllea/Banksia* shrubland taxa in the MJB hearths and the increasing presence of Cyperaceae pollen in the MJB pollen record suggesting increased availability of freshwater in the landscape.

5.4.5.1.3 Shared taxa and *Acacia* sp.

Unfortunately, because *Acacia* species taxa occur in both open Eucalypt woodland and monsoon vine forest vegetation communities, and the fact that *Acacia* sp. taxa cannot yet be speciated (see section 4.2 and 6.6.2), this taxon cannot be assigned to a particular vegetation community. Fig. 5.17 below suggests there was a consistent and preferential selection of shared taxa across the Madjedbebe hearths. However, *Acacia* sp. constitutes a large portion of the shared taxa category (Tab. 5.4, Fig. 5.18). When *Acacia* sp. is subset from the shared taxa category (Tab. 5.5, Fig. 5.19) it is clear that shared taxa only constitute a minor portion of the total assemblage (Fig. 5.18, 5.19). The prevalence of the drought tolerant *Acacia* sp. in the terminal Pleistocene-early Holocene hearths could reflect drier conditions in the environment. However, offshore pollen records suggest an increase in precipitation in northern Australia during this time (Reeves et al. 2013b:108; Reeves et al. 2013a:28; Shulmeister and Lees 1995:15; van der Kaars et al. 2006). The increase in *Acacia* sp. during terminal Pleistocene-early Holocene therefore may relate to a change in anthropogenic fuel selection patterns.

Table 5.4 Vegetation communities represented in the Madjedbebe hearths.

	Open Eucalypt woodland		**Monsoon vine forest**		**Shared taxa**		***Grevillea/ Banksia* shrubland**	
	%*f*	#taxa	%*f*	#taxa	%*f*	#taxa	%*f*	#taxa
E3/5A	20	6	36.30	4	42.22	3	1.48	2
C3/4A	47.10	4	18.53	3	27.03	3	6.18	1
E4/6A	26.72	6	31.90	5	38.79	2	2.59	1
B3/5A	40.82	4	33.67	4	20.41	2	4.08	2
C4/9A	3.13	1	65.63	3	31.25	2	0	0
D3/16B	0	0	0	0	100	1	0	0
C3/18A	0	0	16.67	1	83.33	1	0	0
D2/21A	8.96	2	1.49	1	77.61	2	9.70	1
E3/20A	16.90	4	1.41	1	66.20	1	1.41	1
D3/21A	0.81	1	0.81	1	98.37	2	0	0
E4/22A	48.55	5	4.35	2	38.41	2	1.45	1
D2/30	61.11	1	5.56	1	16.67	1	0	0
C4/36A	100	1	0	0	0	0	0	0
C1/43A	23.08	2	15.38	2	61.54	2	0	0

Table 5.5 Vegetation communities represented in the Madjedbebe hearths with *Acacia* sp. separated from shared taxa.

	***Acacia* sp.**		**Open Eucalypt woodland**		**Monsoon vine forest**		**Shared taxa**		***Grevillea/Banksia* shrubland**	
	%*f*	#taxa	%*f*	#taxa	%*f*	#taxa	%*f*	#taxa	%*f*	#taxa
E3/5A	38.52	1	20	6	36.30	4	3.70	2	1.48	2
C3/4A	22.01	1	47.10	4	18.53	3	5.02	2	6.18	1
E4/6A	37.07	1	26.72	6	31.90	5	1.72	1	2.59	1
B3/5A	19.39	1	40.82	4	33.67	4	1.02	1	4.08	2
C4/9A	25	1	3.13	1	65.63	3	6.25	1	0	0
D3/16B	100	1	0	0	0	0	0	0	0	0
C3/18A	83.33	1	0	0	16.67	1	0	0	0	0
D2/21A	76.87	1	8.96	2	1.49	1	0.75	1	9.70	1
E3/20A	66.20	1	16.90	4	1.41	1	0	0	1.41	1
D3/21A	97.56	1	0.81	1	0.81	1	0.81	1	0	0
E4/22A	37.68	1	48.55	5	4.35	2	0.72	1	1.45	1
D2/30	16.67	1	61.11	1	5.56	1	0	0	0	0
C4/36A	0	1	100	1	0	0	0	0	0	0
C1/43A	53.85	1	23.08	2	15.38	2	7.69	1	0	0

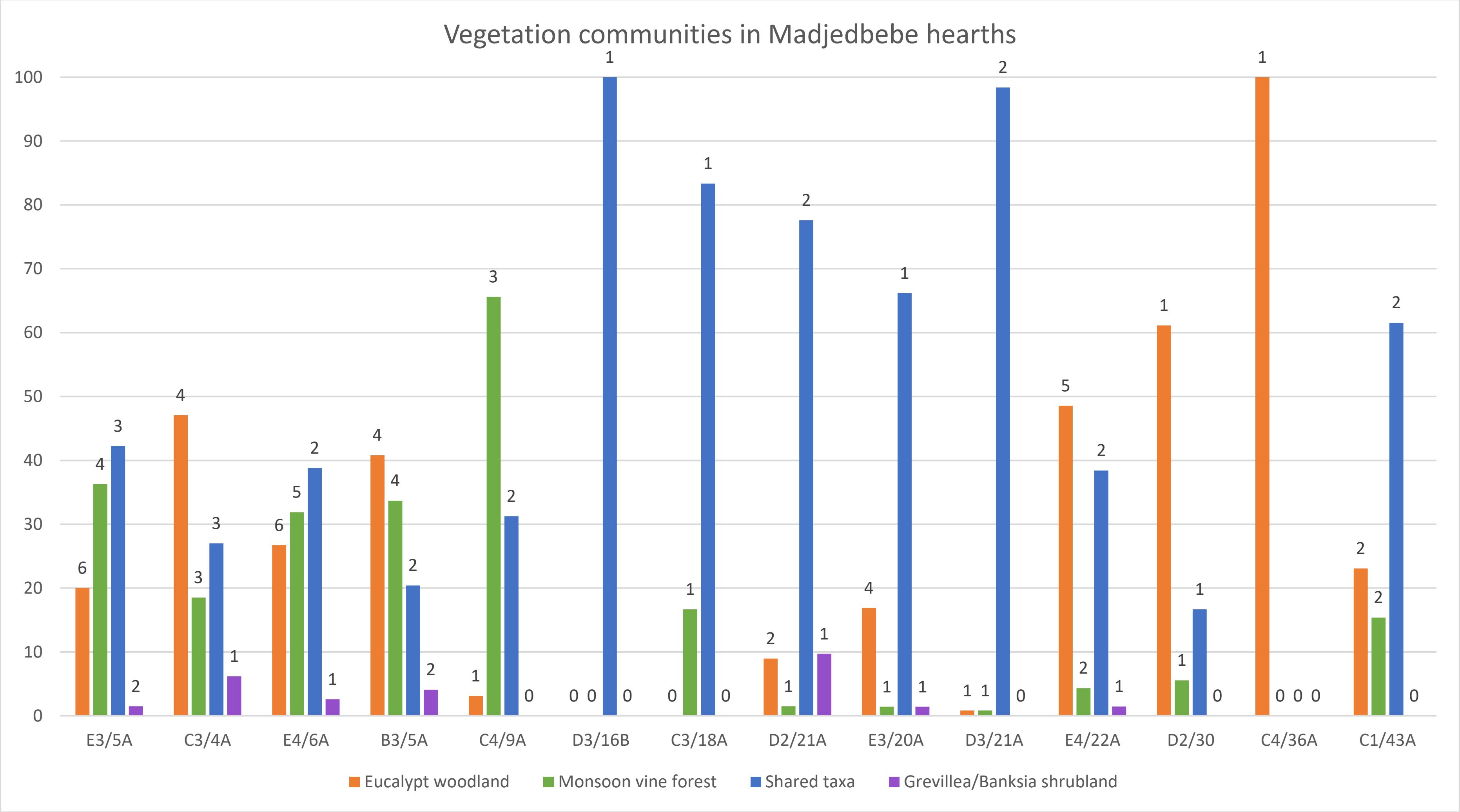


Figure 5.17 Vegetation communities represented in Madjedbebe hearths with number of taxa per vegetation community included in data labels. Note C3/4A, B3/5A, D2/21A, E3/20A, E4/22A, D2/30 contain type specimens (Type 24, Type 48), therefore their totals do not match those presented in Table 5.3 because unidentified types cannot be assigned to a vegetation community.

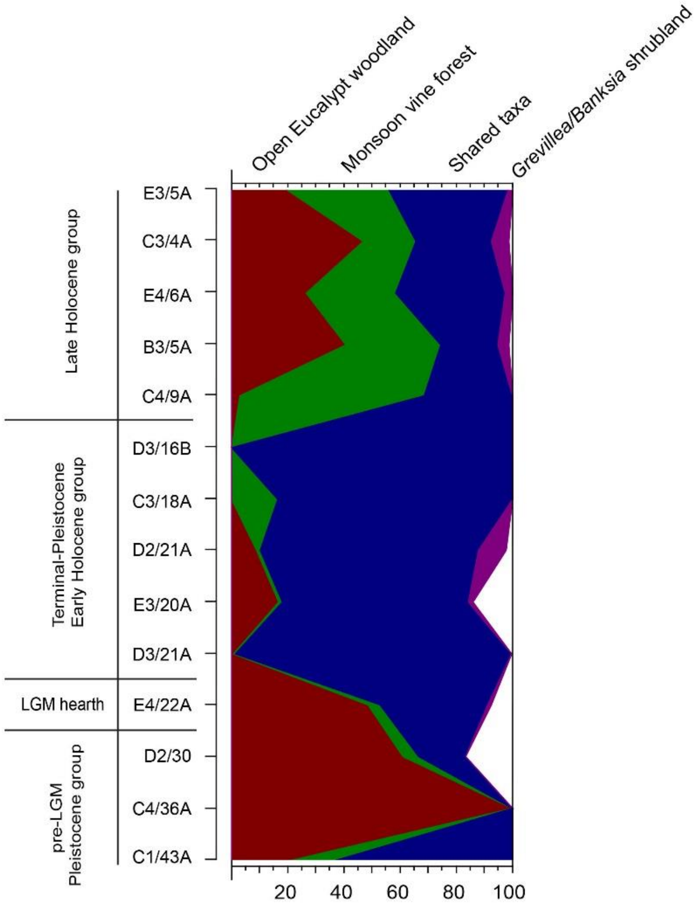


Figure 5.18 Vegetation communities represented in all fourteen Madjedbebe hearths. Note not all contexts reach 100% because they contain unidentified archaeological type specimens which cannot be assigned to a vegetation community.

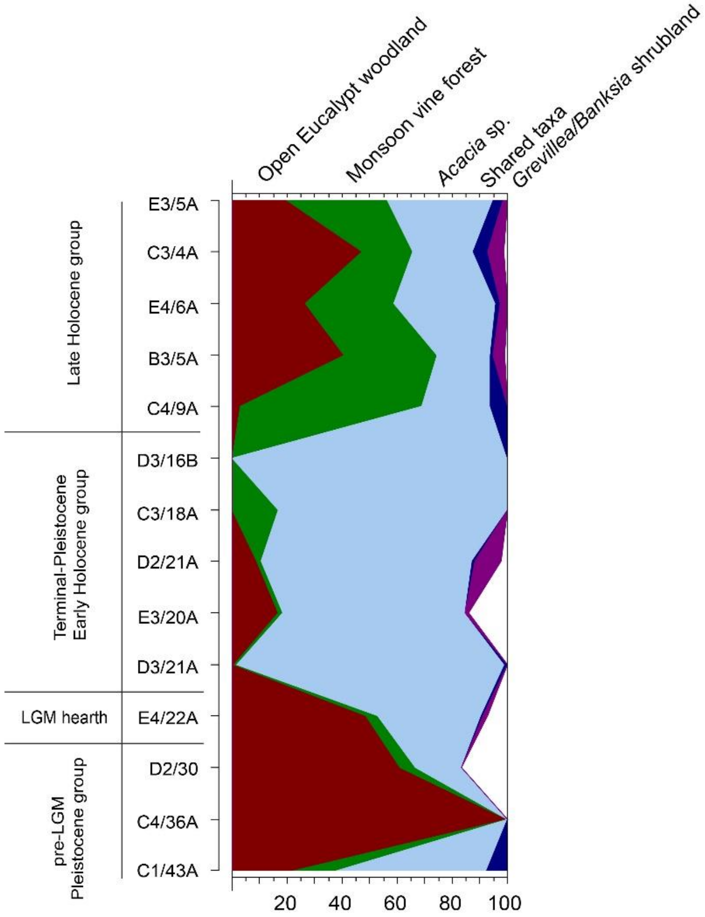


Figure 5.19 Vegetation communities represented in all fourteen Madjedbebe hearths with *Acacia* sp. separated from all other shared taxa. The figure clearly demonstrates *Acacia* sp. contribution to the shared taxa category. Note not all contexts reach 100% because they contain unidentified archaeological type specimens which cannot be assigned to a vegetation community.

5.4.6 Testing sample size

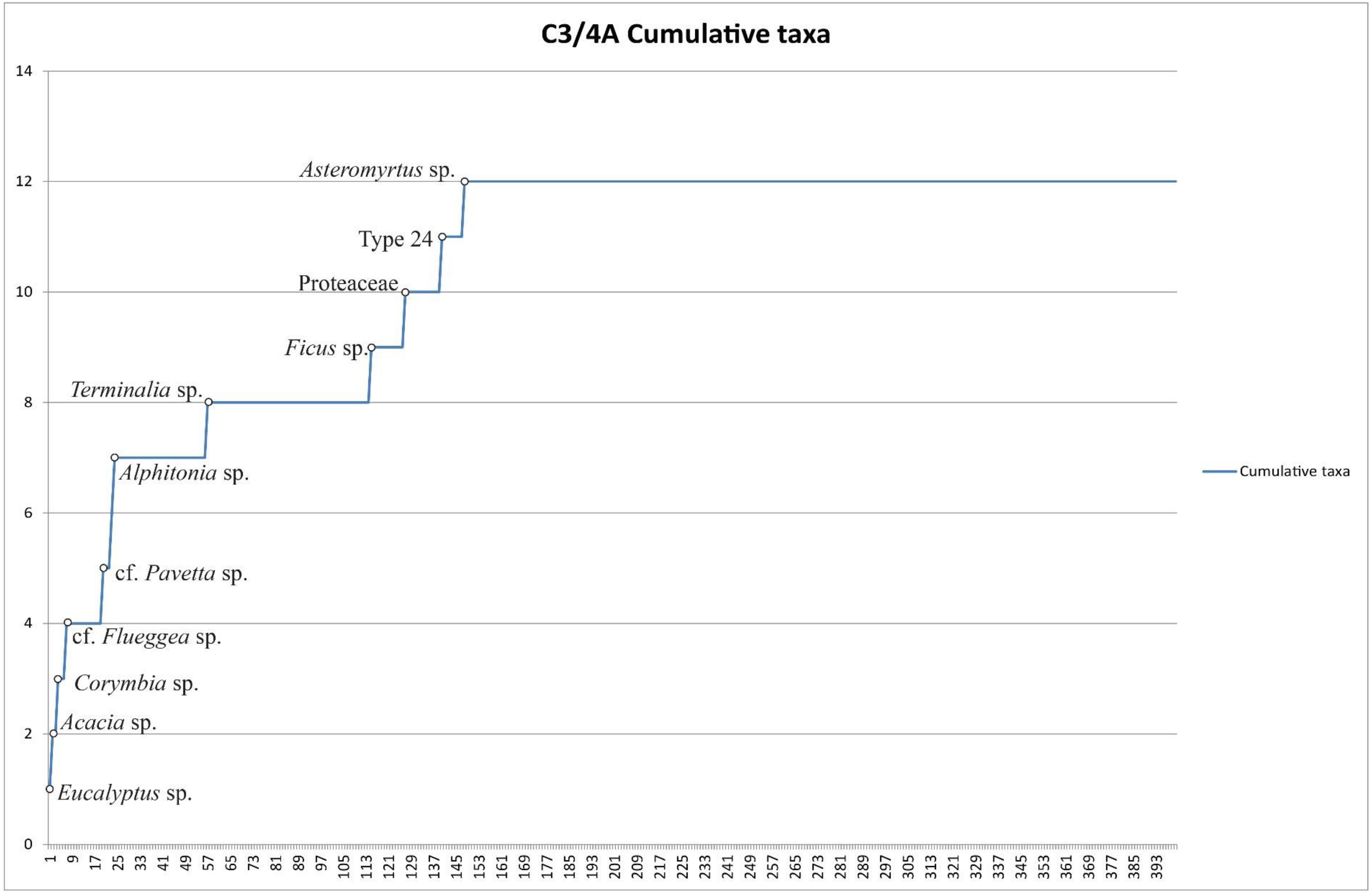


Figure 5.20 Cumulative plot of identified and unidentified taxa (Hearth C3/4A) demonstrating ideal sampling outcome. Taxon saturation was reached well within sampling effort.

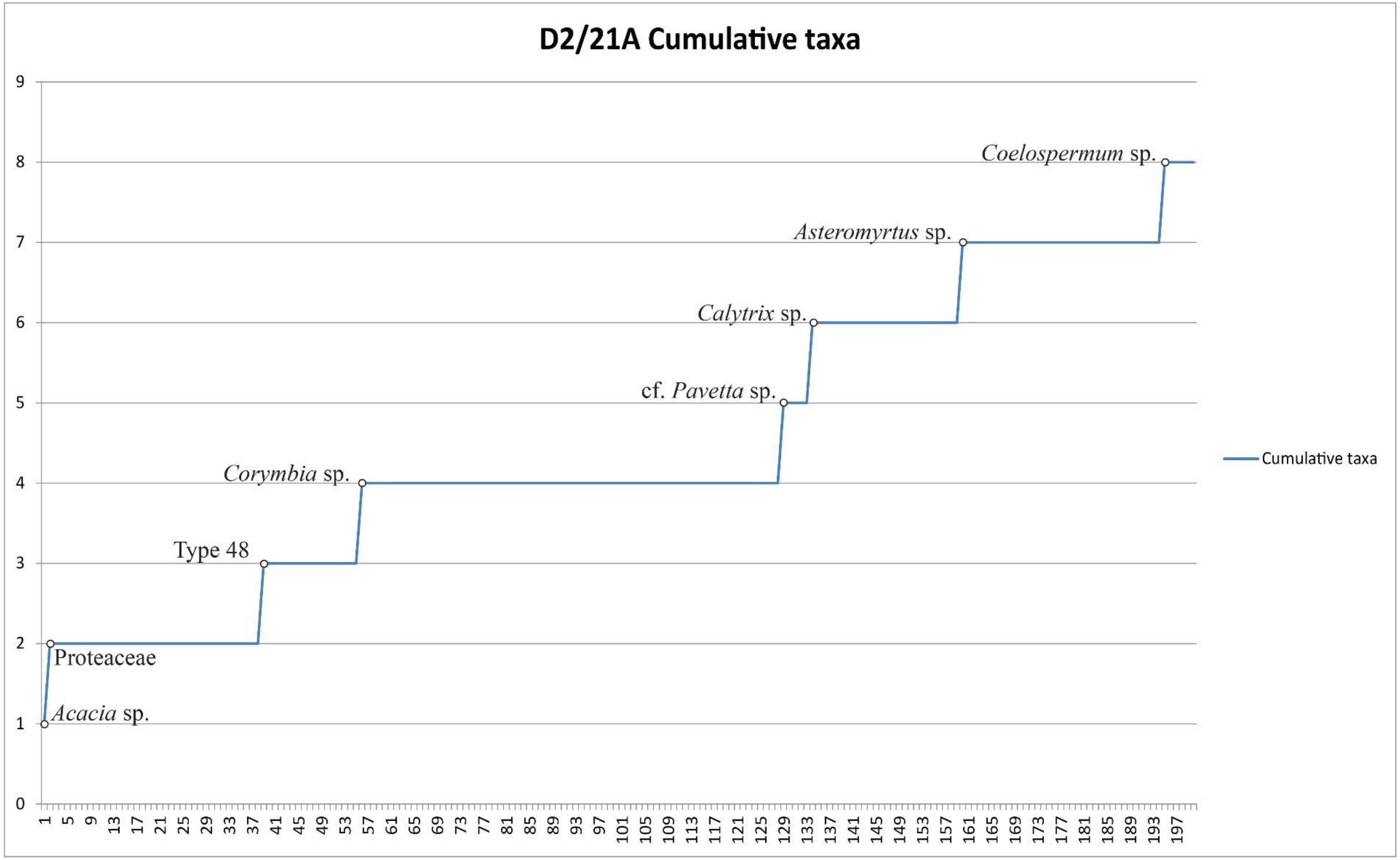


Figure 5.21 Cumulative plot of identified and unidentified taxa (Hearth D2/21A) demonstrating less than ideal sampling outcome. Note *Coelospermum* sp. is an extremely rare taxa.

The data presented above demonstrate the sampling effort employed in this research was adequate to capture the full floristic diversity of the sampled contexts. Each hearth was sampled to 200 fragments or 100%, except C3/4A, which was sampled to 400 fragments. Ten of the fourteen hearths analysed reach a plateau in taxon diversity within the first 75% of the total sample. Hearth C3/4A demonstrates the ideal outcome (Fig. 5.20) with its taxon saturation reaching a plateau at specimen 148. In contrast hearth D2/21A is not the ideal outcome with the final taxon, *Coelospermum* sp., not encountered until specimen 195 (Fig. 5.21). See Appendix L for saturation curves for the other hearths. Of the four hearths which did not plateau (until over 85% of the sample had been analysed), two were 100% samples (D3/21A n = 160; C1/43A n = 19) (Tab. 5.6). D2/21A was sampled to 200 fragments but the final taxon was identified at specimen 195. This taxon, however, was the extremely rare *Coelospermum* sp. (only one fragment of this taxon was identified in the entire MJB assemblage), which demonstrates the sampling effort was already adequate. The fourth hearth with an inadequate sample size E3/5A, the most recent hearth, which has the highest taxon richness of any of the MJB hearths. This outcome demonstrates the sampling effort for this research was adequate but could be increased to account for increased floristic diversity in more recent hearths.

Table 5.6 Sampling effort and taxon saturation for all fourteen Madjedbebe hearths.

	Total	**Plateau**	**Percent**	**Reason**
E3/5A	200	175	87.5	Floristic diversity
C3/4A	400	148	37	-
E4/6A	200	141	70.5	-
B3/5A	200	143	71.5	-
C4/9A	57	20	35.1	100%
D3/16B	37	1	2.7	100%
C3/18A	25	16	64	100%
D2/21A	200	195	97.5	*Coelospermum* sp.
E3/20A	121	57	47.1	100%
D3/21A	160	150	93.8	100%
E4/22A	200	93	46.5	-
D2/30	47	7	14.9	100%
C4/36A	99	1	1.0	100%
C1/43A	19	18	94.7	100%

5.5 Testing for diachronic change in fuel selection

As stated earlier (Chapter One), an analysis of selective behaviour is reliant on an independent environmental baseline from which selective tendencies can be measured. This statistical interrogation of fuel selection was therefore constrained to the most recent eleven hearths because they are temporally aligned with palynological and geomorphological data sets from which the local environment can be reconstructed (Fig.5.22) (see sections 3.1, 3.2). Correspondence analysis (Fig. 5.23) was used to explore the relationship between the eleven most recent MJB hearths and their taxonomic composition. This exploratory approach visually demonstrates the split between the terminal Pleistocene-early Holocene group (*n*=6) and the more recent late Holocene group of hearths (*n*=5). Compositionally the LGM hearth, E4/22A is situated between these two groups (Fig. 5.23).

Indeterminate (Indet.) specimens were not included in any statistical analysis. All percentage values have been adjusted to reflect their absence. Indeterminate specimens were removed because the statistical analyses presented in this section relate to the taxonomic composition of the MJB hearths – identified taxa and unidentified types. These analyses are concerned with the diachronic shifts in the hearths taxonomic composition and how these shifts relate to changes in fuel wood selection patterns.

Comparing the data presented in Table 5.7 there is a clear temporal trend in the Madjedbebe hearths. While *Acacia* sp. taxa are ubiquitous in all eleven hearths there is a diachronic shift towards less *Acacia* sp. in each hearth in percentage terms. This pattern was tested first through correspondence analysis and then statistically tested through a Spearman's rho rank order correlation coefficient. An exploration of axis one scores from correspondence analysis (Fig. 5.24) demonstrates there is a clear temporal fluctuation in the data. Moving from right to left (oldest to youngest) the values decrease from almost 0 into negative values and then between D3/16B and C4/9A cross the axis into positive values. It is clear from Fig. 5.25 that this shift from negative to positive values in the axis one scores mirrors a shift from *Acacia* sp. dominance to higher taxon richness within the hearths. When percentage *Acacia* sp. is plotted against rarefied taxon richness (NISP=32) a significant statistical relationship is demonstrated ($r_2 = 0.8116$, $p < 0.0001$) (Fig. 5.26) (Note – hearth C3/18A was not included in the rarefied sample due to an insufficient sample size). A Spearman's rho rank order correlation coefficient was used to demonstrate that this relationship was a statistically significant diachronic trend. While the hearths are not ranked youngest to oldest (right to left)

(Fig. 5.26), the Spearman's rho does give a significant result for a temporal trend (R_s = -0.733, p = 0.016).

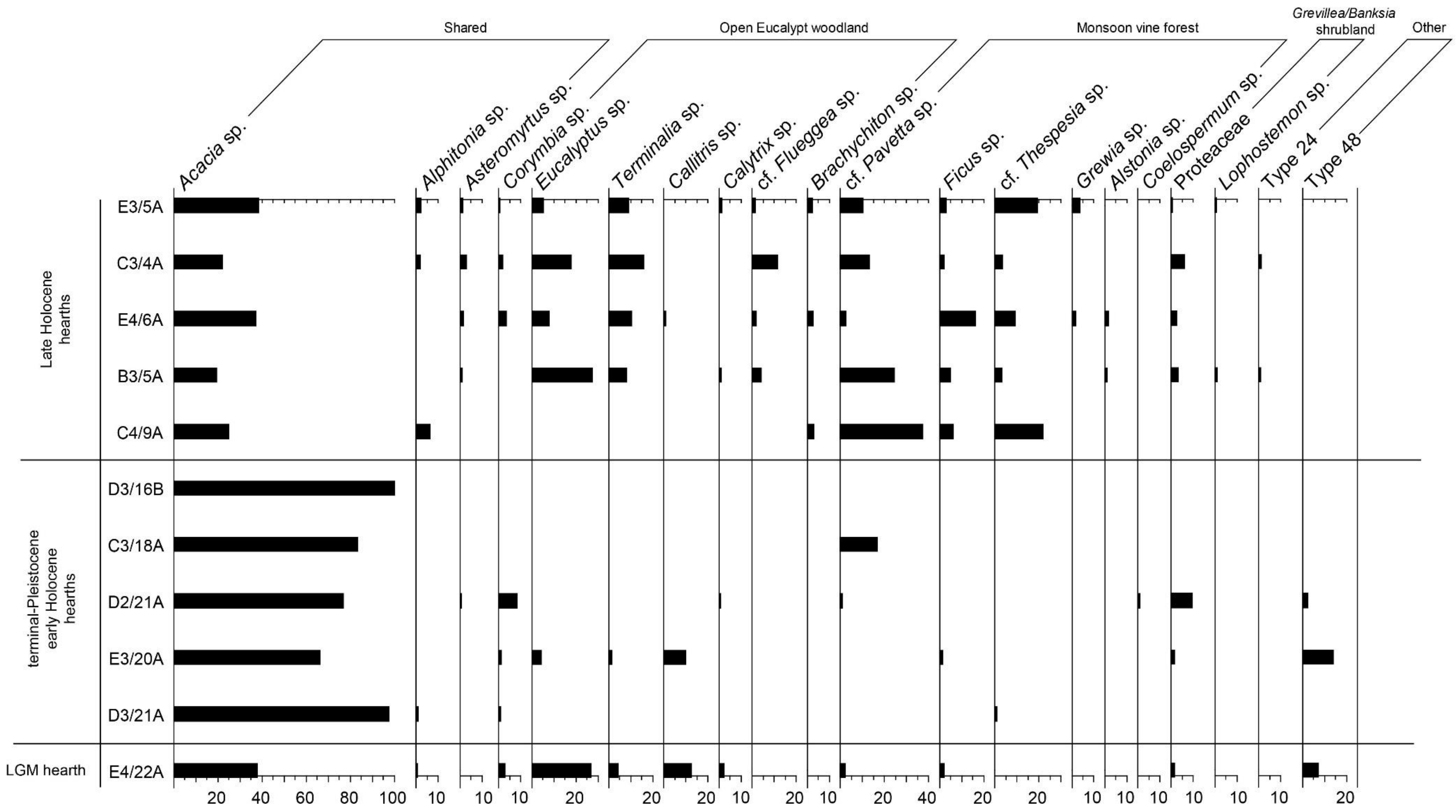


Figure 5.22 The eleven most recent Madjedbebe hearths taxonomic composition.

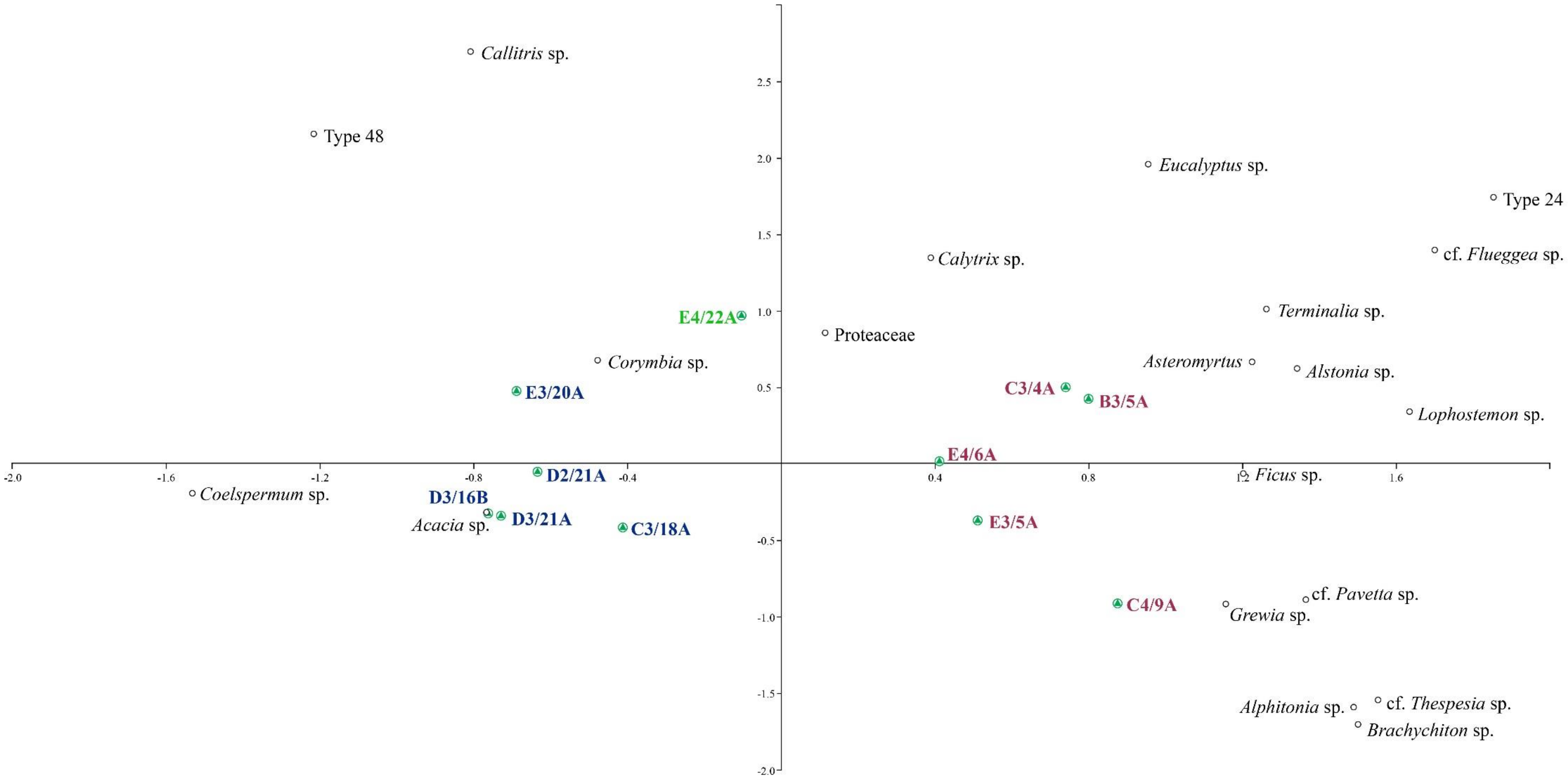
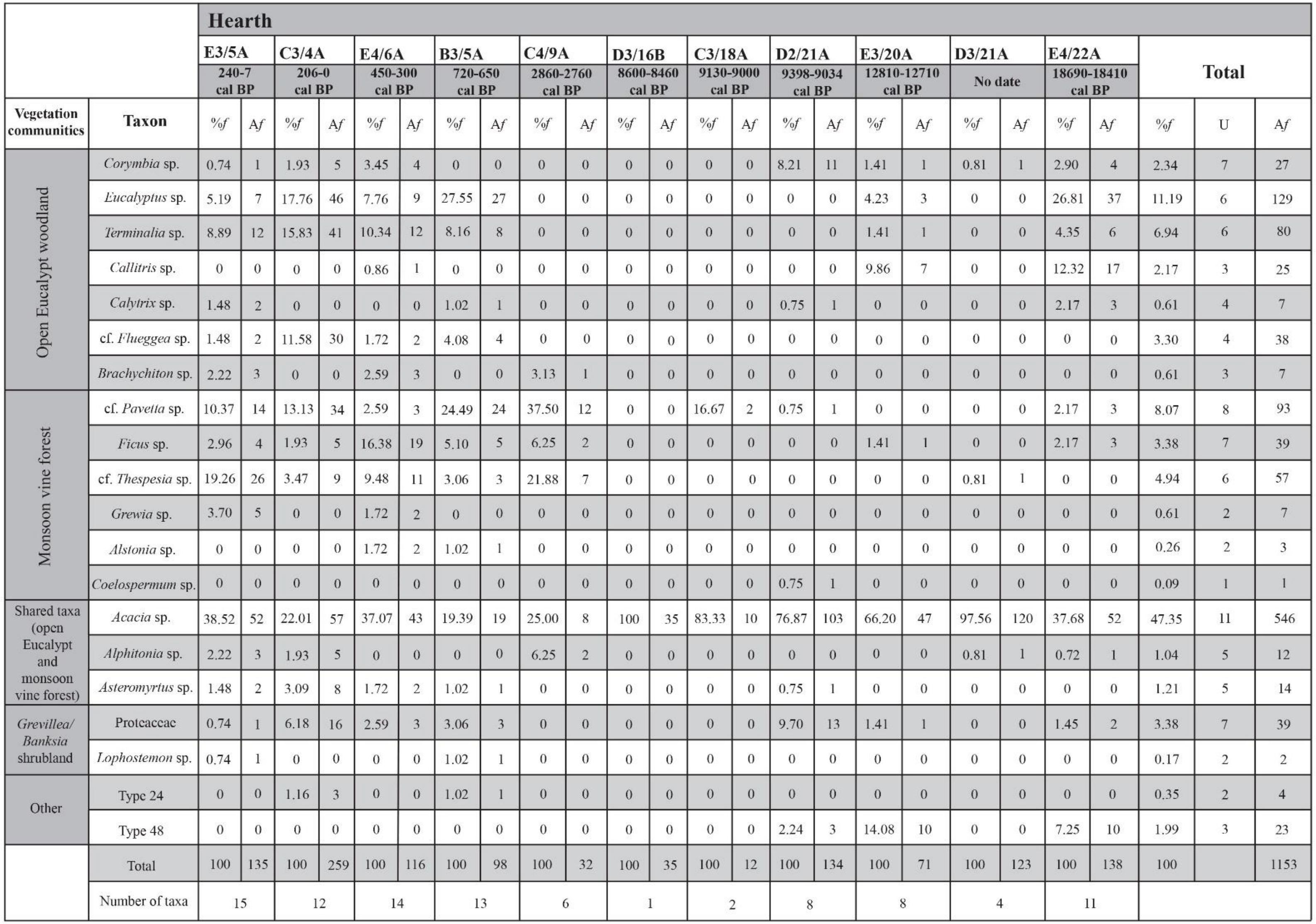


Figure 5.23 Correspondence analysis of the eleven most recent hearths at Madjedbebe (LGM –green; terminal Pleistocene-early Holocene – blue; late Holocene – red).

Table 5.7 The eleven most recent Madjedbebe hearths - percentage frequency (%*f*), actual count frequency (A*f*), ubiquity, taxon count, and sample sizes presented.



		Hearth																								
		E3/5A 240-7 cal BP		**C3/4A** 206-0 cal BP		**E4/6A** 450-300 cal BP		**B3/5A** 720-650 cal BP		**C4/9A** 2860-2760 cal BP		**D3/16B** 8600-8460 cal BP		**C3/18A** 9130-9000 cal BP		**D2/21A** 9398-9034 cal BP		**E3/20A** 12810-12710 cal BP		**D3/21A** No date		**E4/22A** 18690-18410 cal BP		**Total**		
Vegetation communities	**Taxon**	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	U	A*f*
Open Eucalypt woodland	*Corymbia* sp.	0.74	1	1.93	5	3.45	4	0	0	0	0	0	0	0	0	8.21	11	1.41	1	0.81	1	2.90	4	2.34	7	27
	Eucalyptus sp.	5.19	7	17.76	46	7.76	9	27.55	27	0	0	0	0	0	0	0	0	4.23	3	0	0	26.81	37	11.19	6	129
	Terminalia sp.	8.89	12	15.83	41	10.34	12	8.16	8	0	0	0	0	0	0	0	0	1.41	1	0	0	4.35	6	6.94	6	80
	Callitris sp.	0	0	0	0	0.86	1	0	0	0	0	0	0	0	0	0	0	9.86	7	0	0	12.32	17	2.17	3	25
	Calytrix sp.	1.48	2	0	0	0	0	1.02	1	0	0	0	0	0	0	0.75	1	0	0	0	0	2.17	3	0.61	4	7
	cf. *Flueggea* sp.	1.48	2	11.58	30	1.72	2	4.08	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.30	4	38
	Brachychiton sp.	2.22	3	0	0	2.59	3	0	0	3.13	1	0	0	0	0	0	0	0	0	0	0	0	0	0.61	3	7
Monsoon vine forest	cf. *Pavetta* sp.	10.37	14	13.13	34	2.59	3	24.49	24	37.50	12	0	0	16.67	2	0.75	1	0	0	0	0	2.17	3	8.07	8	93
	Ficus sp.	2.96	4	1.93	5	16.38	19	5.10	5	6.25	2	0	0	0	0	0	0	1.41	1	0	0	2.17	3	3.38	7	39
	cf. *Thespesia* sp.	19.26	26	3.47	9	9.48	11	3.06	3	21.88	7	0	0	0	0	0	0	0	0	0.81	1	0	0	4.94	6	57
	Grewia sp.	3.70	5	0	0	1.72	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.61	2	7
	Alstonia sp.	0	0	0	0	1.72	2	1.02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.26	2	3
	Coelospermum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	1	0	0	0	0	0	0	0.09	1	1
Shared taxa (open Eucalypt and monsoon vine forest)	*Acacia* sp.	38.52	52	22.01	57	37.07	43	19.39	19	25.00	8	100	35	83.33	10	76.87	103	66.20	47	97.56	120	37.68	52	47.35	11	546
	Alphitonia sp.	2.22	3	1.93	5	0	0	0	0	6.25	2	0	0	0	0	0	0	0	0	0.81	1	0.72	1	1.04	5	12
	Asteromyrtus sp.	1.48	2	3.09	8	1.72	2	1.02	1	0	0	0	0	0	0	0.75	1	0	0	0	0	0	0	1.21	5	14
Grevillea/ Banksia shrubland	Proteaceae	0.74	1	6.18	16	2.59	3	3.06	3	0	0	0	0	0	0	9.70	13	1.41	1	0	0	1.45	2	3.38	7	39
	Lophostemon sp.	0.74	1	0	0	0	0	1.02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	2	2
Other	Type 24	0	0	1.16	3	0	0	1.02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35	2	4
	Type 48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.24	3	14.08	10	0	0	7.25	10	1.99	3	23
	Total	100	135	100	259	100	116	100	98	100	32	100	35	100	12	100	134	100	71	100	123	100	138	100		1153
	Number of taxa	15		12		14		13		6		1		2		8		8		4		11				

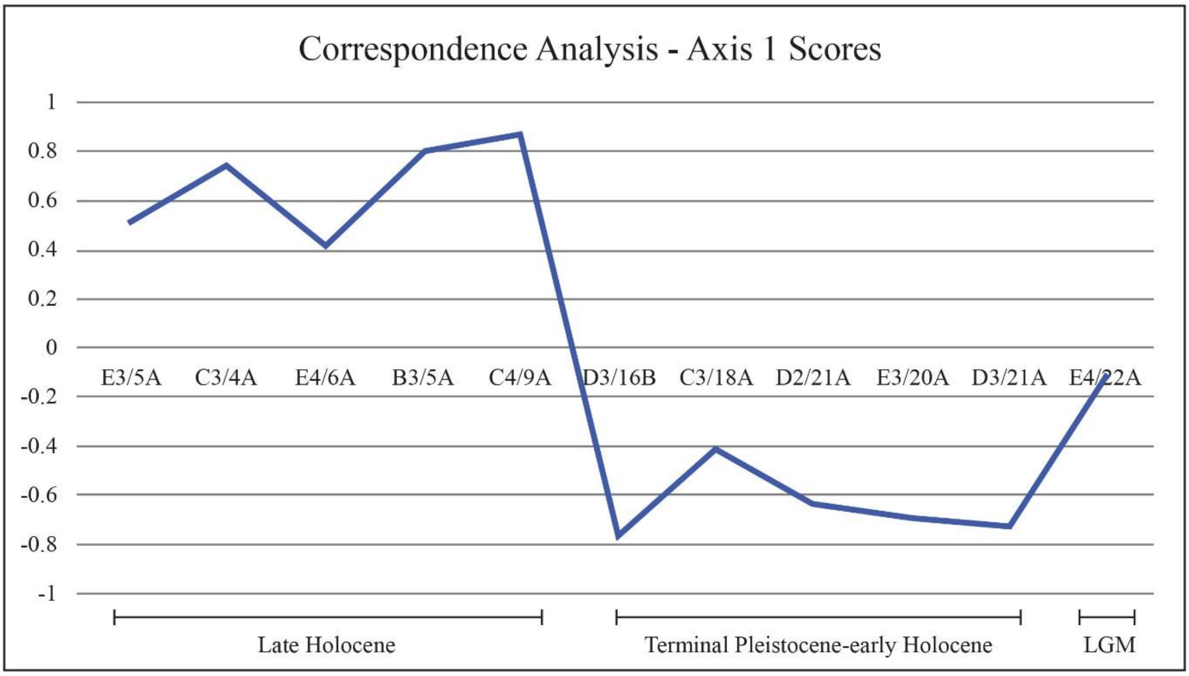


Figure 5.24 Correspondence analysis axis one scores of the Madjedbebe hearths.

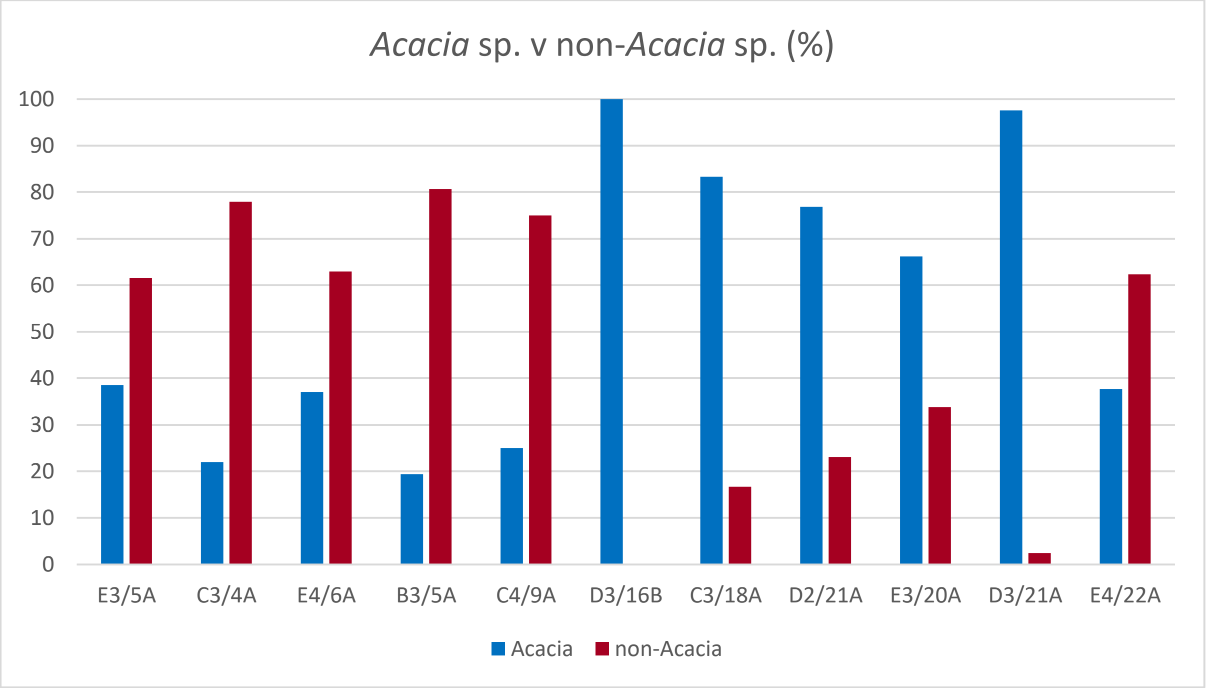


Figure 5.25 *Acacia* sp. versus non-*Acacia* sp. taxa across the eleven post-LGM Madjedbebe hearths.

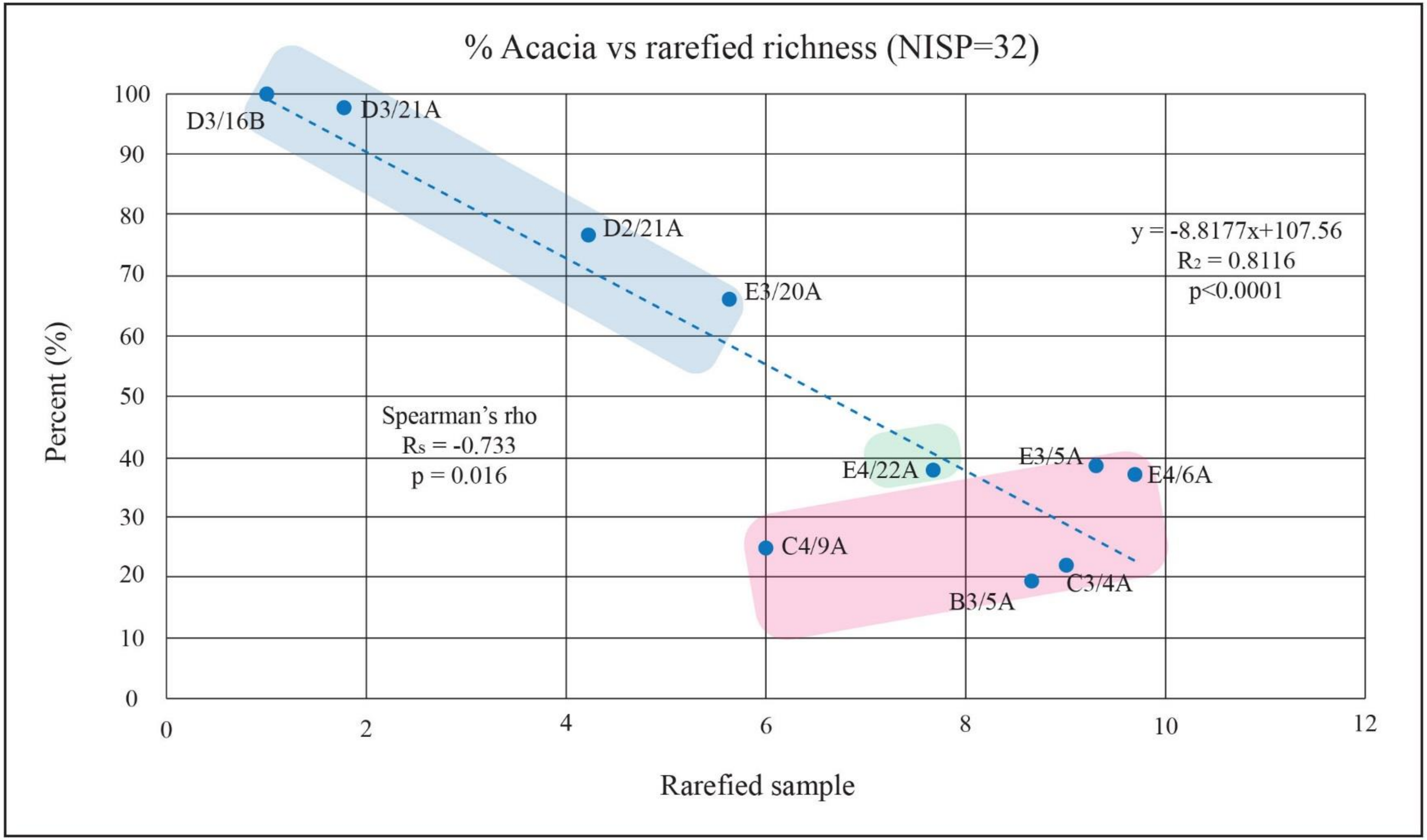


Figure 5.26 The percentage of *Acacia* sp. plotted against rarefied richness (NISP=32) for ten of the eleven most recent Madjedbebe hearths. The linear regression demonstrates there is an inverse relationship between percent *Acacia* sp. and rarefied richness. This is a statistically significant relationship ($p<0.0001$). The terminal Pleistocene-early Holocene group (blue) and the late Holocene group (pink) are clearly separated.

5.6 Matrix charcoal

The charcoal found on Australian archaeological sites outside of defined features has here been termed matrix charcoal. This charcoal is different to the dispersed charcoal discussed in the Eurasian literature. The former refers to charcoal in the general sedimentary matrix of the site, it is undefined and unbounded. The latter refers to charcoal which is not in a concentration but which is known to be anthropogenic in origin. The potential contribution of bushfire debris into the Australian anthracological record has led to a need to define the place of matrix charcoal as either anthropogenic or natural in origin. The data presented below provides a pilot study into the provenance of matrix charcoal. This study compared matrix charcoal from C3/4 (200 fragments) to a hearth (C3/4A – 400 fragments) and environmental charcoal (200 fragments), which were of similar age (i.e. within the last 200 years).

5.6.1 Three way comparison

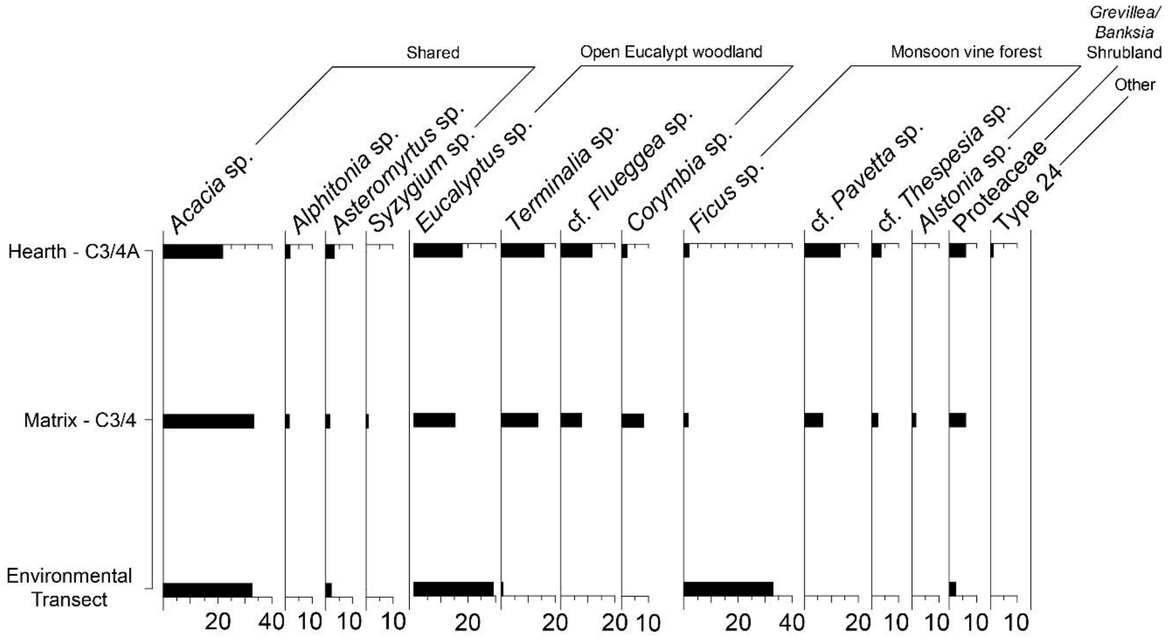


Figure 5.27 Tilia plot of the taxonomic composition of matrix (C3/4), hearth (C3/4A) and environmental charcoal.

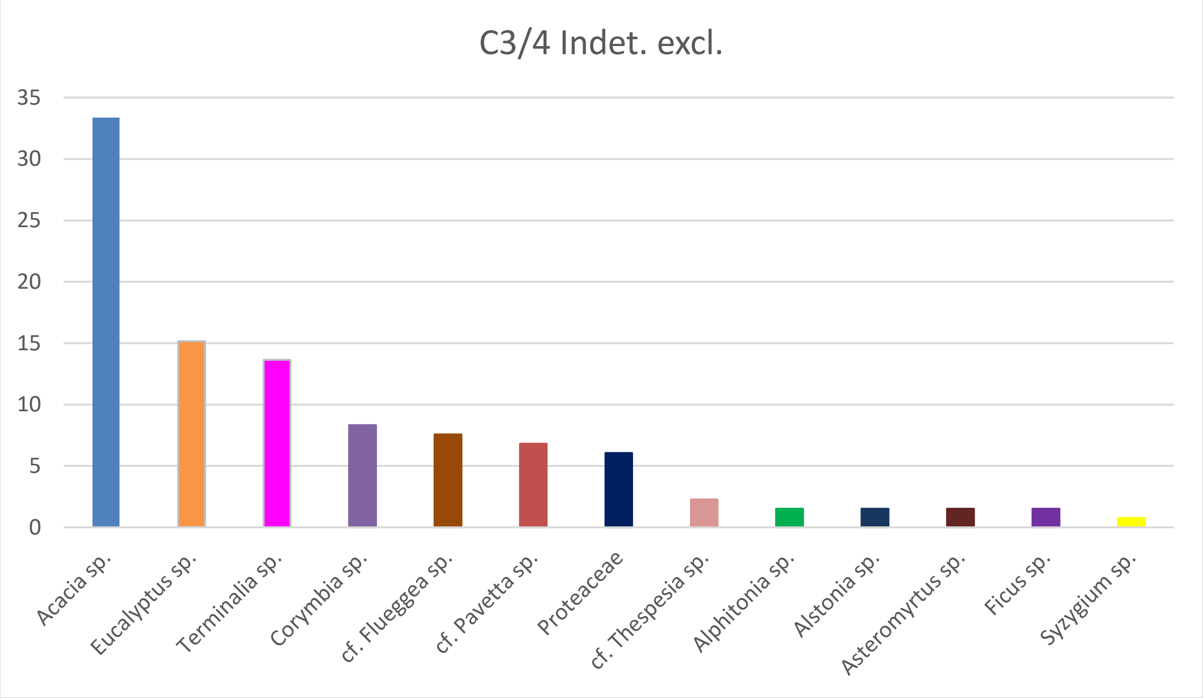


Figure 5.28 Matrix sample C3/4 taxonomic composition as percent. Indeterminate specimens excluded.

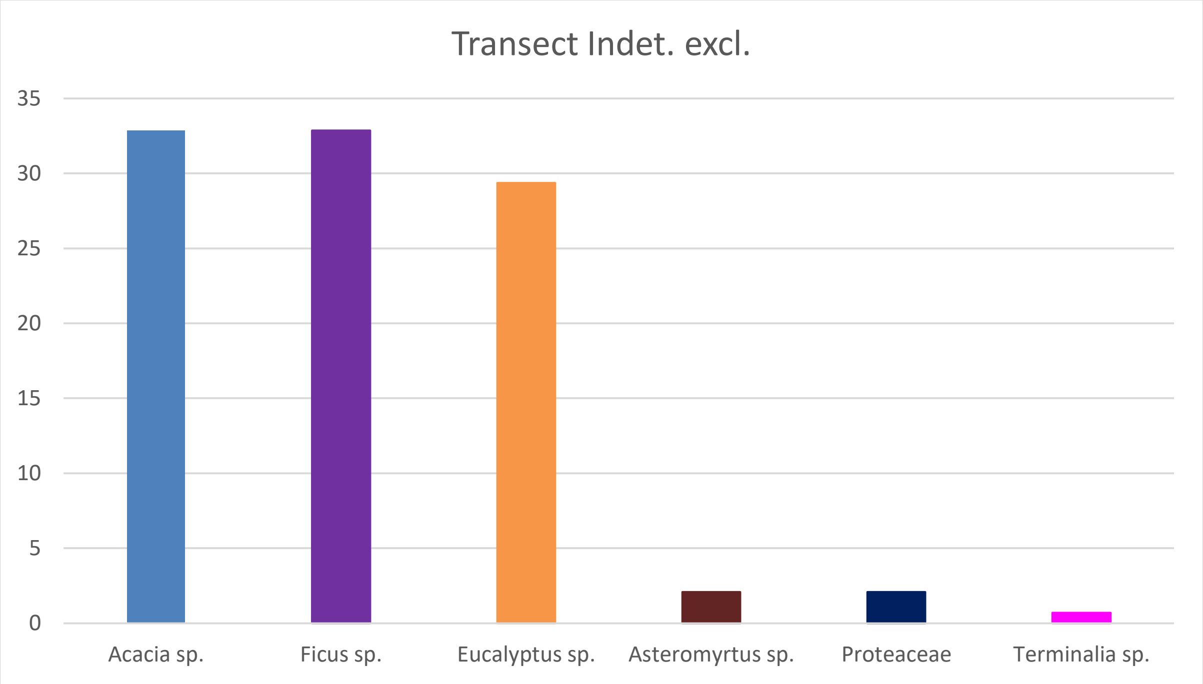


Figure 5.29 Environmental transect taxonomic composition as percent. Indeterminate specimens excluded.

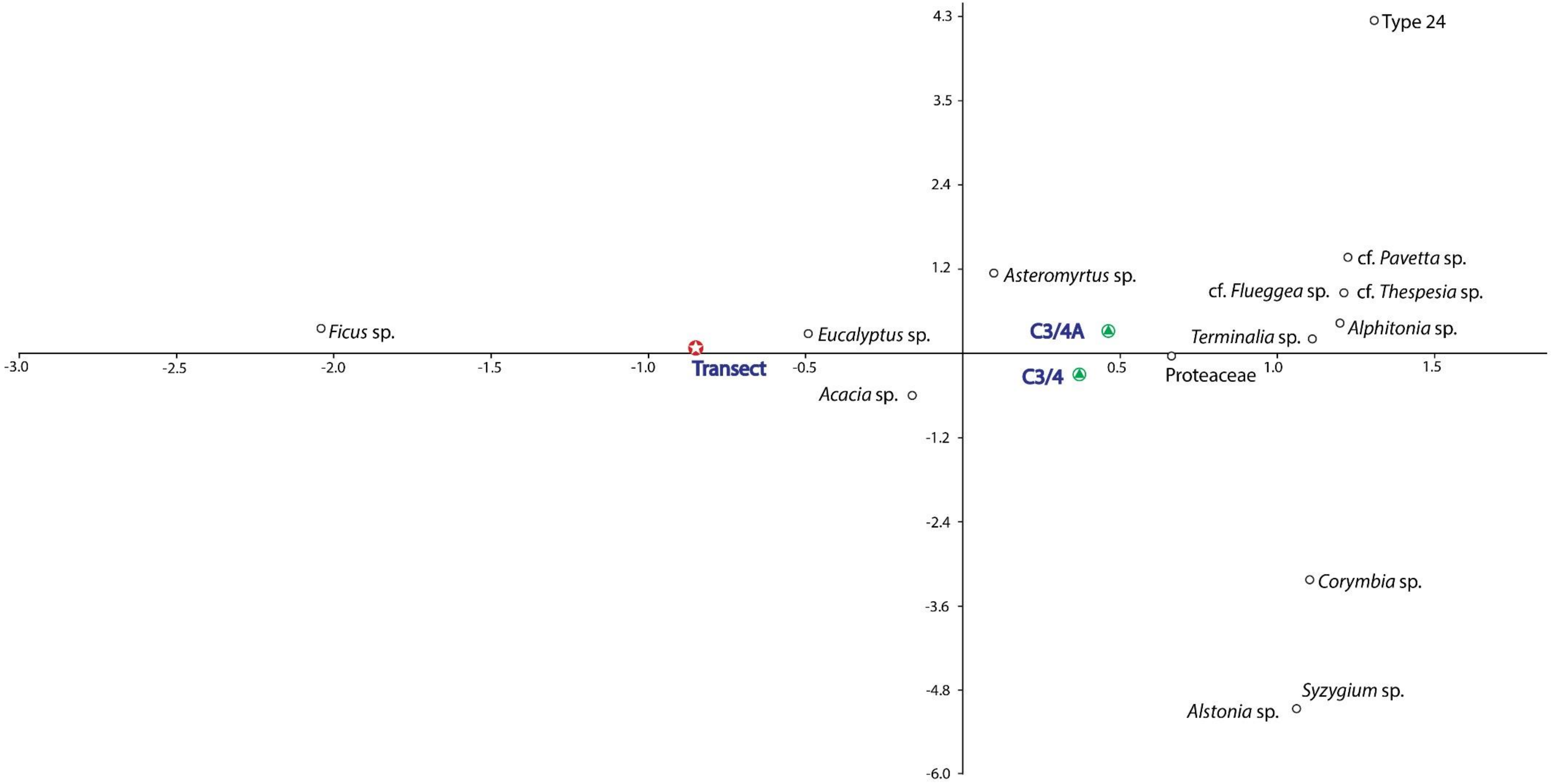


Figure 5.30 Correspondence analysis data plot – C3/4 matrix sample, C3/4A hearth sample, and environmental transect charcoal.

Table 5.8 Chi-squared tests for hearth, matrix, transect comparison

Contexts	Chi-Squared	p-value
Hearth V Matrix	27.115	0.012
Matrix V Transect	104.6426	<0.0001

It is clear from an initial assessment of the three groups of samples that the environmental transect contained very little charcoal (for transect location see Appendix M). Collections made close to but outside of the site of Madjedbebe (between 10-50 m) contained fourteen fragments from SS1, twenty-nine fragments from SS2, nine fragments from SS4, and sixteen fragments from SS5, all from roughly two litres of sediment each. In terms of density of charcoal per litre of sediment, these samples contain 0.03-0.08 grams per litre. Samples further from the rock shelter but still within 100 m of the site contained more charcoal (around 50 pieces), 0.2-1.4 grams per litre of sediment. Note sample SS10 (1.4 g per L) was associated with a burnt fallen tree and therefore contains a lot more charcoal than any other transect sample. Comparing the transect charcoal density to that found in the site of Madjedbebe (C3/4 – 43 L = 12.69 g; C3/4A – 7.5 L = 44.06 g), it is clear the archaeological site has richer charcoal record than the surrounding environment.

The taxonomic composition of three different charcoal bearing contexts was explored and tested (Fig. 5.27). A hearth context (C3/4A) and its associated sedimentary matrix was intentionally selected to control for compositional changes being driven by shifts in local woodland cover and taphonomic conditions. The composition of hearth C3/4A (Fig. 5.4), matrix C3/4 (Fig. 5.28), and an environmental transect (Fig. 5.29) were compared through correspondence analysis (Fig. 5.30). Taxonomically the hearth and matrix charcoal samples are very similar. These archaeological contexts have a far higher taxon richness (C4/3 =13; C3/4A = 12) than the environmental transect (*n* = 6). All three sample groups contain taxa from open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland. Unlike both of the archaeological contexts, a large proportion (>38%) of the environmental sample was made up of *Ficus* sp. taxa. *Ficus* sp. makes up on average <2.6% of the wood charcoal in the Madjedbebe hearths. Correspondence analysis demonstrates a clear separation between the environmental transect and the two archaeological samples. This relationship was tested through a chi-squared test which demonstrated that although the matrix and hearth samples were statistically different they are far more similar in composition than either are to the transect charcoal. Table 5.8 contains the chi-squared and p-values for these tests. This result means that compositionally matrix charcoal is far more similar to hearth charcoal than it is to the charcoal in the environment. These findings demonstrate that it is far more likely that matrix charcoal is the accumulation of anthropogenic activities rather than bushfire debris.

5.7 Conclusion

The data presented in this chapter explores early fire use, diachronic shifts in fuel wood selection, and the provenance of matrix charcoal. These data contribute to answering the research questions outlined in Chapter One. Taxonomic identification were facilitated through the construction of a taxonomically diverse reference collection. This collection of reference woods allowed for shifts in taxonomic frequency and ubiquity to be tracked diachronically at Madjedbebe. These identifications provided insights into early domestic fire use at Madjedbebe (research aim one), shifts in fuel wood selection post-LGM (research aim two), and the taxonomic composition of matrix charcoal (research aim three). These data will be further explored and their implications discussed in Chapter Six.

Chapter Six – Discussion

6.1 Introduction

The data from Madjedbebe (MJB) presented in Chapter Five provides the first insights into fire hearths in the Alligator Rivers region. This discussion is divided into five sections: 1) an examination of the oldest hearths at MJB; 2) an investigation of fuel wood selection practices at Madjedbebe LGM-late Holocene; 3) a reconceptualisation of fuel wood in the Australian archaeological record; 4) a critical examination of the provenance of matrix charcoal; and 5) a critique of the methods employed in this research. The site of Madjedbebe provides the perfect setting for examining key methodological and theoretical questions in Australian anthracology. The site provides a sequence of hearths through which fuel wood selection strategies can be investigated and from which a reconceptualisation of fuel wood in Australian archaeology can be proposed.

6.2 The oldest Madjedbebe hearths

The fourteen Madjedbebe hearths represent the longest sequence of hearths analysed anywhere in Australia. The three oldest hearths (D2/30, C4/36A, and C1/43A) provide an insight into fire use in the Alligator Rivers region during the Pleistocene. Each of these three hearths has a different taxonomic composition, unfortunately owing to unreliable palaeoenvironmental proxies, which are not spatially and temporally aligned (see Chapter Three for a full discussion), a determination of fuel wood selection strategies cannot be offered for these three hearths. They do, however, offer an insight into fire use between 55-24,000 years ago at Madjedbebe (research aim one).

Hearths D2/30 and C4/36A are both dominated by *Callitris* sp. wood charcoal. D2/30 also contains taxa from open Eucalypt woodland and monsoon vine forest and *Pandanus* sp. drupe which may have functioned as a heat retainer. C4/36A, however, only contains *Callitris* sp. wood charcoal and no other macrobotanical remains. The hearth was also encircled by retaining stones. The selection of *Callitris* sp. may have been because it was dominant in the woodland at the time or occurred close to site. The arrangement and taxonomic homogeneity of C4/36A is, however, unlike any other hearth recovered at Madjedbebe. The hearth may represent a single fuel wood selection, in which only *Callitris* sp. was selected. This is not dissimilar to hearth D3/16B which was solely composed of *Acacia* sp. wood charcoal. However, D3/16B also contained *Pandanus* sp. drupe and vegetative parenchyma macrobotanical remains and was not accompanied by retaining stones (Florin 2013:48). The taxonomic uniformity of C4/36A wood charcoal and the absence of other macrobotanical remains may suggest this hearth was a single use heating feature which did not involve any cooking or that it served another purpose entirely. For instance, ethnobotanical research conducted in the study area recorded *Callitris intratropica* wood was burnt to repel mosquitos from a campsite (Chaloupka and Giuliani 1984:67).

Hearth C1/43A was also associated with a retaining stone however contained a wider range of taxa (*n* = 6). C1/43A, the oldest hearth at Madjedbebe, was dominated by *Acacia* sp. (53%) wood charcoal (Fig. 5.16). It also contained wood taxa from open Eucalypt woodland and monsoon vine forest communities. Florin (2013:48 Table 4) also found vegetative parenchyma within this hearth which may relate to food remains. The composition of this hearth means it is not dissimilar to those of the terminal Pleistocene-early Holocene – dominated by *Acacia* sp., containing taxa from open Eucalypt woodland and monsoon vine forest communities, but with a low overall taxon richness. While it is difficult to determine the proximity of these vegetation communities to the site, at the time the hearth was in use, it is clear that the same vegetation communities which were used in the LGM and late Holocene at Madjedbebe were being accessed for fuel wood from very early on in its occupation.

Palaeoclimate and vegetation records for this period are only available on the regional scale. Therefore caution must be exercised when interpreting their applicability to the study area. These records do however indicate conditions which were conducive for the growth of the vegetation communities present at MJB between 40-20k BP. Oceanic coring off the northwest Australian coast suggest *Callitris* sp. came to dominate the vegetation between 32-20ka, replacing *Eucalyptus* sp. (van der Kaars et al. 2006:888). This increased prevalence of *Callitris* sp. in the northern Australian environment may explain its occurrence in D2/30 (66%) and C4/36A (100%). Similarly, Reeves et al. (2008:18) found that conditions at Lake Carpentaria between 30-22ka suggested higher rainfall in the tropical north at that time. These wetter conditions may explain the ongoing presence of both open woodland and monsoon vine forest around MJB leading up to and during the LGM.

6.3 Fuel wood selection – LGM-late Holocene Madjedbebe

In addition to understanding early fire use the archaeological record at Madjedbebe provides a sequence of hearths to investigate fuel wood selection strategies operating during the last

20,000 years (research aim two). In this discussion, the three hypotheses presented in Chapter Four, will be investigated through an interrogation of the archaeological data and environmental evidence for the study area. The hypotheses were proposed to better understand fuel wood selection patterns at the site of Madjedbebe. This analysis has been constrained to the last 20,000 years because it is reliant upon the establishment of an independent environmental baseline off which human selective tendency can be measured. Prior to 20,000 years ago the scale and catchment of the palaeoenvironmental records in the region are ill-suited to providing a consistent and accurate environmental baseline.

As stated in Chapter Five the eleven most recent hearths at Madjedbebe fall into three distinct groups defined by chronology and taxonomic composition. The five most recent hearths date between 240-7 yr cal BP (E3/5A) and 2860-2760 yr cal BP (C4/9A), these will be referred to as late Holocene hearths. The terminal Pleistocene-early Holocene hearths in the Madjedbebe sequence date between 8600-8460 yr cal BP (D3/16B) and 12810-12710 yr cal BP (E3/20A – note D3/21A is not dated due to repeated ^{14}C sample failure), with E4/22A representing the LGM and dating to 18690-18410 yr cal BP.

6.3.1 Environmental context

Independent palaeoenvironmental and ecological records have been used to establish an environmental baseline from which human fuel wood selection can be assessed. The eleven hearths discussed here have been divided into late Holocene, terminal Pleistocene-early Holocene, and LGM phase hearths. The terminal Pleistocene-early Holocene phase is characterised by a landscape and vegetation in transition, recovering from the aridity of the LGM and reacting to the encroachment of rising sea levels (see Appendix N). Temporally, the earliest part of this phase occurs in the terminal Pleistocene. As climate began to ameliorate the continental shelf was inundated which produced a warm shallow sea. This in turn increased precipitation in the region. As precipitation and temperature increased the composition of the vegetation would have shifted. The maps provided in Appendix O are a hypothetical proposal of vegetation communities in the study area during the terminal Pleistocene (c.16k BP), mid-Holocene (c.7k BP), and late Holocene (c.1k BP). These maps are based on established palaeoenvironmental data but are subject to future testing and palaeoenvironmental coring. Grassland and shrubland, proposed by van der Kaars (1991) for the LGM, would have been replaced by open woodland as arid sensitive taxa emerged from refugia (Appendix O - c.16k BP). Although some researchers claim tropical lowland forest and open woodland would have persisted during the LGM in northern Australia (Markgraf et al. 1992:195; Pickett et al. 2004:1433). In the terminal Pleistocene, northern Australia had wetter and warmer conditions than at present, which would have supported the re-establishment of tropical savannah woodlands and monsoon vine forest in the area. As sea levels continued to rise, saline conditions would have encroached upon the site. By 7,700 cal BP mangrove forest would have been within 1 km of Madjedbebe at the Jabiluka Billabong (Clark et al. 1992:90). Saline conditions forced *Melaleuca* and Eucalypt woodlands away from the river and creek channels in the region. These vegetation communities were relegated to higher ground as mangrove taxa progressively established along the river and creek channels (Appendix O - c.7k BP).

Between the terminal Pleistocene-early Holocene hearths and late Holocene hearths there is a temporal gap of 5,500 years. In the late Holocene phase the local vegetation was very similar to the contemporary environment (Appendix O - c.1k BP). Between 2000-1,700 cal BP freshwater wetlands were established at the Jabiluka Billabong close to Madjedbebe (Clark and Guppy 1988:680; Clark et al. 1992:143-144). At this time mangrove taxa were already in rapid retreat towards the mouth of the East Alligator River. The freshwater wetlands were flanked by natural levees, which according to Hope et al. (1985:236) may have at that time supported monsoon vine forest. In low lying areas the wetland fringe was accompanied by *Melaleuca* swamp which gave way to open Eucalypt woodland, which contained stands of the economically important *Pandanus spiralis*. In more sheltered areas, around outliers and on the escarpment margin, monsoon vine forest was located. These ‘fire shadow’ areas would have also provided a refuge for fire sensitive taxa such as *Callitris intratropica*, which has been decimated elsewhere in Arnhem Land following the cessation of traditional burning practices in the mid-20th century (Haynes 1985:212). This independent palaeoenvironmental evidence provides a solid baseline from which human selective tendencies can be interrogated.

6.3.2 Statistical analysis and interpretation

Exploratory and explanatory statistical approaches demonstrate the division between the late Holocene and the terminal Pleistocene-early Holocene/LGM hearths (see Fig. 5.23, Fig. 5.26). It is clear that based on percentage of identified specimens the terminal Pleistocene-early Holocene hearths are dominated by *Acacia* sp., whereas non-*Acacia* sp. make up a higher proportion of the identified specimens in the late Holocene hearths (Fig. 5.25). This inverse relation is clearly expressed in Fig. 5.24 in which the Axis 1 scores from correspondence analysis (CA) show negative values (low taxon richness, i.e. high percent

Acacia sp.) for the terminal Pleistocene-early Holocene/LGM hearths and positive values (high taxon richness) for the late Holocene hearths. The almost positive value of E4/22A is intriguing and will be discussed further below. To statistically demonstrate that a relationship exists, %*Acacia* sp. was plotted against rarefied richness (NISP=32) for ten of the eleven hearths (r_2 = 0.8116, p <0.0001) (Fig. 5.26). C3/18A was omitted from this comparison because the number of identified specimens (*n* = 12) in this sample was too low to produce a statistically sound outcome. Figure 5.26 demonstrates that there is a statistically significant inverse relationship between %*Acacia* sp. and rarefied richness. A Spearman's rho rank order correlation coefficient demonstrates this is a statistically significant diachronic trend (R_s = -0.733, p = 0.016). These statistical tests explain the change in taxonomic composition between the late Holocene and terminal Pleistocene-early Holocene/LGM hearths. A comparison of *Acacia* sp. and non-*Acacia* sp. across all fourteen Madjedbebe hearths demonstrates *Acacia* sp. dominance is a feature of the terminal Pleistocene-early Holocene group of hearths and that the late Holocene hearths and the oldest four hearths (E4/22A, D2/30, C4/36A, and C1/43A) have a higher percent of non-*Acacia* sp. compared with *Acacia* sp.

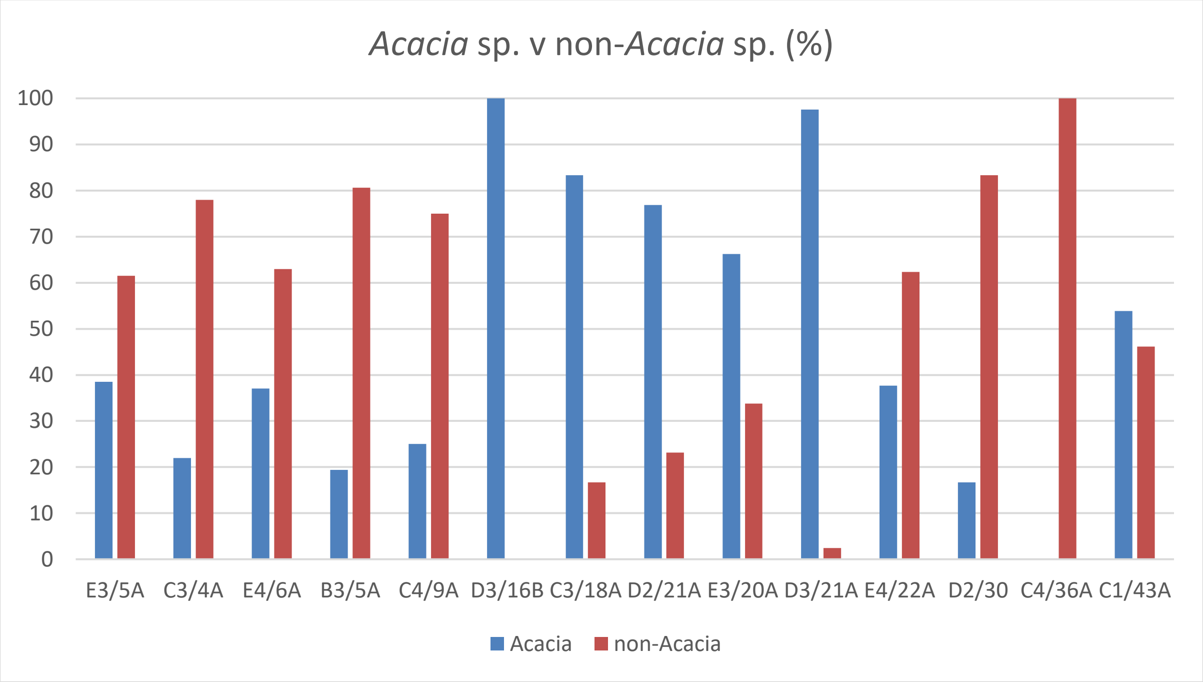


Figure 6.1 Comparison of Acacia sp. to non-Acacia sp. as a percent of identified specimens across all fourteen Madjedbebe hearths.

Fig. 6.1 clearly demonstrates this fluctuation in percent *Acacia* sp. versus non-*Acacia* sp. It is clear from this comparison that E4/22A, has a higher percent of non-*Acacia* sp. taxa than the hearths in the terminal Pleistocene-early Holocene group. This could be explained by the fact that E4/22A is nearly 6,000 yrs older than the hearths in the terminal Pleistocene-early Holocene group. E4/22A's *Acacia* sp. to non-*Acacia* sp. percentage is more similar to the hearths from the late Holocene group.

Even though there is a clear taxonomic and temporal shift in the composition of the Madjedbebe hearths, all fourteen hearths contain taxa from only two vegetation communities, with minor contributions from a third. All fourteen hearths contain taxa from either open Eucalypt woodland or monsoon vine forest vegetation communities. With seven hearths containing taxa from the *Grevillea/Banksia* shrubland vegetation community. *Grevillea/Banksia* shrubland is found in poorly drained depressions and drainage lines in the region and may indicate these landscape features occurred close to the site.

6.3.3 Hypothesis testing

A Spearman's rho rank order correlation coefficient (R_s = -0.733, p = 0.016) (Fig. 5.26) demonstrates that the fuel wood selection strategy at Madjedbebe has changed diachronically. The eleven hearths under discussion here can be separated into three distinct groups based on their age and taxonomic composition. The three hypotheses, proposed in Chapter Four, postulate alternate fuel wood selection strategies (research aim two). They are:

4) Hypothesis one proposes that the principle of least effort would have governed fuel wood collection over the last 20,000 years. Fuel wood was collected in close proximity to Madjedbebe and a wide range of species were collected in direct proportion to how they occurred in the environment. The focus of the fuel selection strategy was ease of collection not preferential taxon selection.
5) Hypothesis two proposes a targeted local selection of wood fuel taxa focused on particular preferred fuel wood taxa. These taxa were preferentially selected from within the immediate vicinity of the site.
6) Hypotheses three proposes that people purposefully targeted particular ecological niches throughout the landscape to exploit particular wood types, over the last 20,000 years. This would include vegetation communities such as mangrove forest, *Melaleuca* sp. swamp, and *Allosyncarpa* sp. rainforest. Fuel wood was collected away from the site.

The hearths of the terminal Pleistocene-early Holocene phase are dominated by *Acacia* sp. which makes up 66-100% of the identified wood charcoal. By the time these hearths were in use open Eucalypt woodland was replacing the grass/shrubland of the LGM. *Acacia* sp., a part of both open Eucalypt woodland and monsoon vine forest, would have been present close to Madjedbebe but would not have been a dominant feature of these vegetation communities. Its high percentage in the terminal Pleistocene-early Holocene hearths therefore is a result of a preferential fuel wood selection strategy akin to hypothesis two. E4/22A has a higher taxon richness than the five hearths in the terminal Pleistocene-early Holocene group. This broader selection of fuel wood is closer to hypothesis one in which a less targeted fuel wood selection strategy was in operation. The wood charcoals identified in the terminal Pleistocene-early Holocene/LGM hearths are all from taxa which grew close to Madjedbebe. The hearths do not contain taxa from either mangrove forest or *Melaleuca* swamp vegetation communities. Even though during this phase (in particular hearth D3/16B) mangrove forests would have been within 1 km of Madjedbebe and that mangrove wood is known ethnographically as a good fuel (Levitt 1981:88-89). It can also be assumed that the monsoon vine forest taxa which are present in all of the hearths were collected from lowland rainforests not the *Allosyncarpa ternata* dominated rainforests of the escarpment gorges. This assumption is based on the absence of *Allosyncarpa* sp. from the charcoal assemblage even though it is the canopy dominant of this vegetation community, and is often the sole component of the tree layer (Wilson et al. 1996). There is no evidence in this assemblage which supports the postulates of hypothesis three that particular ecological niches away from Madjedbebe were targeted for fuel wood collection.

The hearths of the late Holocene have far higher taxon richness than those of the terminal Pleistocene-early Holocene group. They contain taxa from both open Eucalypt woodland and monsoon vine forest vegetation communities, with minor contributions from *Grevillea/Banksia* shrubland. All of these vegetation communities would have occurred within a few hundred metres of Madjedbebe, on the sand sheet, along the escarpment, and in drainage lines and depressions. Just like the terminal Pleistocene-early Holocene/LGM hearths the fuel for these hearths was sourced locally. There is no evidence that the inhabitants of Madjedbebe sourced fuel from the *Melaleuca* swamp near the wetlands or *Allosyncarpa* sp. rainforests on the escarpment. Preliminary zooarchaeological data demonstrates the inhabitants of Madjedbebe were accessing the escarpment and wetlands for subsistence. However, the charcoal data demonstrates this did not extend to fuel wood collection. Bachelet and Scheel-Ybert (2017:8) found at Santa Elina rock shelter in Brazil that the deadwood available around the site were selected as fuel even though other vegetation communities were being accessed for subsistence resources. Unlike the terminal

Pleistocene-early Holocene phase hearths these hearths were not dominated by a single taxon. The composition of the late Holocene hearths fits with the postulates of hypothesis one that fuel wood was collected locally with very little selection bias. This may represent a principle of least effort selection strategy which was driven by an increase in population pressure in the late Holocene. However, it must be remembered that not all vegetation communities or taxa from the local environment are represented in these hearths. Therefore the base assumption of the principle of least effort (PLE), that fuel wood was collected in direct proportion to how it occurred in the local environment, does not hold. These hearths probably represent a single fuel wood selection but the paucity of dendrological features identified in the wood charcoal assemblage constrains a more thorough understanding of collection practices at Madjedbebe (i.e. deadwood collection versus felling).

There is clear evidence at Madjedbebe that particular vegetation communities and taxa were avoided and that taxa, known ethnographically as good fuel wood, were absent or only made up a minor component of the total assemblage. The species *Calytrix achaeta* is known ethnographically as a good fuel wood that can be lit even when wet (Russell-Smith 1985:249). However, *Calytrix* sp. was only identified in four of the Madjedbebe hearths. Other notable absences are mangrove forest and *Melaleuca* sp. swamp taxa as well as *Allosyncarpa* sp., the canopy dominant of escarpment gorge rainforest. Ethnographic observations from the study area suggest fuel wood collection was a localised activity focused on fallen deadwood (McCarthy and McArthur 1960:157, 159). This could explain why these more distant vegetation communities were absent from the fuel wood selected at Madjedbebe. It is clear from the local and international literature, however, that complex social constructs govern human selective behaviour (Picornell-Gelabert et al. 2011), and that value systems do not necessarily comply with Linnean classifications (Thery-Parisot 2002a:244; Thery-Parisot et al. 2010a:144). For example, Chaloupka and Giuliani (1984:25) have demonstrated that the ontological organisation of plants by Mayali language speakers in the study area differs from Western taxonomic classifications. The taxon *Grevillea heliosperma* is classified by the Mayali language group as two different plants depending on where it grows (i.e. lowlands or escarpment). Internationally, Picornell-Gelabert et al. (2011:381) found that Fang villagers of Equatorial Guinea avoided certain taxa because of strict social taboos. Concepts of 'good fuel' may not be based on certain taxonomies but rather the physical characteristics of the wood – whether it is dry, decayed, close to the site, and/or its calibre – Linnean taxonomy may matter very little in other ontologies (Picornell-Gelabert et al. 2011:381).

6.3.4 Explanation of diachronic changes

There are three potential explanations for the diachronic changes observed in the Madjedbebe wood charcoal assemblage. The shifts observed in the taxonomic composition of the eleven hearths could be explained by shifts in local vegetation, differential preservation of particular taxa, or changes in human selection and/or management behaviour. It is clear from the data presented in Chapter Three and summarised above that while the landscape and vegetation of the study area has changed diachronically the same vegetation communities, from which fuel wood was collected, have remained locally available. Interestingly, the preferential selection of *Acacia* sp. during the terminal Pleistocene-early Holocene phase came after open Eucalypt woodland had re-established. Prior to this time, during the aridity of the LGM, arid tolerant *Acacia* sp. taxa would have been more abundant as a percentage of wooded taxa. The peak in *Acacia* sp. in the terminal Pleistocene-early Holocene phase hearths therefore cannot simply be explained by an increase in *Acacia* sp. in the local environment. Interestingly, the Madjedbebe pollen sequence (see section 3.2.7) demonstrates there is an increases in *Acacia* sp. taxa in the last 1000 years. During this time there is an increase in *Acacia* sp. in the MJB hearths but it is not accompanied by a reduction in species richness as is seen the terminal Pleistocene-early Holocene group.

The terminal Pleistocene-early Holocene and late Holocene hearths are not only temporally and compositionally distinct but also occur in very different depositional environments (Fig. 1.2). The late Holocene hearths all occur in the shell midden which caps the site of Madjedbebe. This is in contrast to the terminal Pleistocene-early Holocene hearths which are located in the sand sheet below the midden. These very different depositional environments correlate directly with the composition of the post-LGM Madjedbebe hearths. Namely, the higher taxon richness of the late Holocene hearths could be explained by the more conducive preservation conditions of the midden. This is in contrast to the terminal Pleistocene-early Holocene hearths in which it could be assumed that the differential preservation of taxa and subsequent decrease in taxon richness gives the illusion that the hardier *Acacia* sp. are more prevalent. However, this correlation does not explain the compositional differences between the terminal Pleistocene-early Holocene and late Holocene hearths. This is because three of the four oldest hearths in the Madjedbebe sequence (E4/22A, D2/30, and C1/43A) contain a rich mixture of taxa. The assumption that the sand sheet differentially preserved taxa, therefore conditioning the composition of the terminal Pleistocene-early Holocene hearths does not hold.

The abundance of *Acacia* sp. taxa may not be explained by differential preservation but perhaps differential fragmentation. If *Acacia* sp. taxa had a higher propensity to fragment than the other taxa put to fire in the Madjedbebe hearths then it may be over-represented in the charcoal assemblage. Unfortunately a comprehensive analysis of differential fragmentation among Australian taxa has not been undertaken. However, based on the findings of Chrzazvez et al.'s (2014) research into key European taxa, the anatomical features of *Acacia* sp. (uniseriate rays, dense fibre tracheids, and no defined growth ring boundary) do not suggest a propensity to fragment. It is unlikely therefore that the increased abundance of *Acacia* sp. in the terminal Pleistocene-early Holocene hearths was owing to fragmentation (see also Appendix P).

The difference between the composition of the terminal Pleistocene-early Holocene and late Holocene hearths could be explained by a shift in subsistence practices, as evidenced by faunal and molluscan remains in the midden and archaeobotanical remains throughout. The shift in diet from woodland resources such as macropods and yams to fish, turtles, and molluscs could explain the corresponding shift in hearth taxonomic composition. A shift in subsistence practices has been noted by both Hayes (2015) in her doctoral research and Florin (2013) in her Honours thesis. Hayes (2015:270) found through her analysis of grinding stones from MJB that there was a shift from the processing of starchy plants to the exploitation of grass seeds during the sinuous phase (5.3-2k BP). Similarly, Florin (2013:61-62) noted an increase in *Pandanus* sp. drupe remains in the late Holocene which she suggests was tied to the formation of the freshwater wetlands. It is apparent from the dominance of *Acacia* sp. in the terminal Pleistocene-early Holocene hearths that it was preferentially selected. Perhaps the burning properties of *Acacia* sp. were desired when cooking woodland resources. Therefore, when subsistence gathering shifted from the woodland toward the freshwater wetlands in the late Holocene, the required fire wood changed accordingly. Hearth C4/9A with its lower taxonomic richness and temporal separation from the other late Holocene hearths may represent this transition for *Acacia* sp. dominance (terminal Pleistocene-early Holocene) to higher taxon richness (late Holocene). Huebert et al. (2010:87, 88) found particular taxa were preferentially selected for particular cooking activities on Nuku Hiva, Marquesas Islands and preferential selection has been demonstrated ethnographically in the study area (Chaloupka and Giuliani 1984:65-66, 67). However, this simple correlation between hearth composition and cooking practice does not explain the higher taxon richness of the hearths which proceed the terminal Pleistocene-early Holocene group, in particular E4/22A, D2/30 and C1/43A. These hearths are older than the terminal Pleistocene-early Holocene group but were in use when subsistence resources were very similar – woodland and riverine. If the wood used in the terminal Pleistocene-early Holocene hearths was tied directly to the types of foods being cooked, then why do the older hearths (E4/22A, D2/30, C1/43A) have higher taxon richness? Perhaps, the preference for *Acacia* sp. had not yet developed or the Madjedbebe hearths were not all cooking features and their fuel composition related to differences in function (see section 6.2).

Critical to interpreting shifts in fuel wood selection is understanding the pressures of residential mobility and population size, both of which can affect the availability of fuel in the landscape. Ethnographic observations and archaeological data demonstrate that the population size and residential mobility of the inhabitants of the Alligator Rivers region was quite variable. Depending on the season and location residential mobility could range from sedentary to highly mobile. Based on her excavation data and ethnographic observations, Schrire (1982) proposed a seasonal movement of people between the lowlands in the dry season to the uplands in the wet. This model has been repeatedly critiqued and reworked by its author and others but does not fully explain the complexity of human occupation in the Alligator Rivers region.

Hiscock (2009) has demonstrated through the reduction sequence of stone points that people moved from the uplands to the lowlands. He was able to demonstrate through an analysis of bipolar lithic technology that residential mobility was extremely low at wetlands sites which were occupied during the dry season (March-November) (Hiscock 1996). The utilisation of bipolar knapping was in response to resource depletion (i.e. access to raw stone). As a product of low residential mobility the inhabitants of the wetland sites were forced to reduce their cores to a stage where the core’s weight was insufficient for free hand knapping (Hiscock 2009:87). The employment of bipolar knapping, therefore, demonstrates people were willing to greatly reduce their cores, and utilise another knapping technique, to avoid having to source new raw material. This behaviour demonstrates that, remaining at the wetland sites during the dry season was more valuable than travelling to access raw stone. An anthracological analysis, of charcoal remains from these wetland sites, would help to refine the foraging range of the inhabitants during this period of sedentism. A sustained sedentary presence may have led to local resource depletion and an alteration in fuel selection behaviour.

The residential mobility of the inhabitants of Madjedbebe is not yet fully understood. Ongoing research into the lithics assemblage will provide insights into the residential mobility of the site's inhabitants. However, there is nothing evident in the Madjedbebe wood charcoal assemblage to suggest the local fuel wood supply was depleted during the period under investigation. Sedentism at wetland sites was supported by the abundant resources provided by the freshwater wetlands. In many parts of the Alligator Rivers region these wetlands have only been present for the last 1500-1000 years. Jones (1985) hypothesised that the establishment of these hyper-productive wetlands would have led to an increase in the region's population during the late Holocene. As evidenced by the faunal remains at Madjedbebe the site's inhabitants accessed a cornucopia of resources from the Magela Creek freshwater wetlands. This increase in the region's population would have placed additional stress on the local subsistence resources during the late Holocene.

The earliest hearth of the late Holocene group, C4/9A has the lowest taxon richness of any of the hearths in its group (*n* = 6). Its compositional difference is probably explained by the fact that C4/9A is 2000 years older than the other four hearths in the late Holocene group. It was in use just before the establishment of the freshwater wetlands at the Jabiluka Billabong. Through the remaining four hearths of the late Holocene group the taxon richness rises to 15 in the most recent hearth E3/5A. This increase in taxon richness could be as a result of a broadening of fuel selection criteria (Shackleton and Prins 1992:634). This broadening may be driven by increased pressure on the local fuel wood resource due to increases in population or group sedentism. However, in a woodland environment in which populations moved seasonally it is unlikely that the local fuel wood resource would be depleted so dramatically. Asouti (2003) found in her study of fuel wood selection at Pınarbaşı, Central Anatolia, that mobile hunter-gatherers and herders applied very little pressure to the fuel wood resource. Over time their fuel wood selection strategy did not change, it remained locally focused, preferentially selected particular taxa (terebinth [*Pistacia* sp.] and almond [*Amygdalus* sp.]) and even avoided whole vegetation communities (Asouti 2003:1199-1200).

Firstly, ethnographic evidence suggests the people of the Alligator Rivers region collected fallen deadwood branches rather than felling trees for fuel (McCarthy and McArthur 1960:157, 159). Also, there is no dendrological evidence in the Madjedbebe assemblage which would suggest felling was occurring. Therefore, the depletion of *Acacia* sp. fuel wood would be a depletion of the local deadwood resource. Deadwood is a renewable resource which regenerates, replenishing supply. Meaning it is unlikely this was the case. Secondly, any perception that a shift from a preference for *Acacia* sp., in the terminal Pleistocene-early Holocene hearths, to increased taxon richness and a broadening of selection criteria in the late Holocene hearths are directly related should be contextualised temporally. There are over 6,000 years between the terminal Pleistocene-early Holocene and late Holocene hearths – a period of huge environmental change (see section 3.2). It does not appear that the shift from *Acacia* sp. dominance to taxon richness between the early and late Holocene hearths, or the increase in taxon richness across the late Holocene hearths was driven by depletion of the local fuel wood resource.

6.3.5 Vegetation communities and fire ecology

The vegetation communities which have been identified in the Madjedbebe hearths provide an insight into the local fire ecology and potentially landscape management practices. Monsoon vine forest is, theoretically, the climax vegetation of the study area (Bowman et al., 1988:230). This is surprising considering its limited distribution in the current landscape. There is even evidence of monsoon vine forest being present on the edge of the floodplain at 1,400 BP, where none currently exists (Hope et al. 1985:236). Monsoon vine forest is a fire sensitive community, and if not actively protected from fire can be eliminated from the landscape (Russell-Smith and Bowman 1992). The burning of fire breaks around monsoon vine forest early in the dry season, to protect it from later burns, has been observed ethnographically elsewhere in Arnhem Land (Jones 1980:14). Jones was informed by Aboriginal people that monsoon vine forest was protected because it contained important spirits and key economic food taxa (*Dioscorea* sp. yam). In areas where it is not actively protected monsoon vine forest can be relegated to hollows, lowland springs, rocky outcrops and other protective topography (Russell-Smith 1991:273; Wilson et al. 1996:58). The ongoing presence of monsoon vine forest taxa in the Madjedbebe hearths may suggest this community was subject to favourable fire conditions. Especially considering the other key resources (i.e. *Dioscorea* sp. yam, *Ficus* sp. fruit) it can provide to the subsistence economy.

In contrast to monsoon vine forest, open Eucalypt woodland needs to be burnt regularly to maintain its structure. Burgess et al. (2015:66) suggest a fire every four years or less, and >2 fires in a twelve year period, are required to suppress understorey growth and maintain open woodland. It remains unclear however how regularly open Eucalypt woodland needs to be burnt to prevent the colonisation of monsoon vine forest on its fringe. An ecological study found that after thirteen fire free years monsoon vine forest taxa had not colonised a patch of open Eucalypt woodland in the Northern Territory, Australia (Bowman et al. 1988). The unburnt patch of open Eucalypt woodland, however was not bordered by monsoon vine forest. Lonsdale and Braithwaite (1991) questioned Bowman et al.'s (1988) interpretation and claimed the results may have been different if monsoon vine forest was able to encroach via 'edge creep' into the open Eucalypt woodland patch. Open woodland has other benefits also, it is easier to traverse than closed forest and the grass understorey attracts prey animals to graze. The presence of these vegetation communities in the Madjedbebe hearths may be indicative of some form of landscape management by anthropogenic burning.

6.4 Conceptualising fuel wood in a fire regime

The post-LGM rise in precipitation and atmospheric carbon would have led to an increase in biomass in the northern Australian landscape (Reeves et al. 2013a:24). It is proposed here that this increase necessitated the use of fire by humans to manage fuel loads. This anthropogenic intervention in the natural fire regime made fire more predictable, allowing Indigenous Australians to effectively 'domesticate' fire in their landscape. Responding to the calls from the international literature to conceptualise fuel within the interplay of society and landscape, this conceptual model is the first to situate fuel wood selection and management within Australian Indigenous land use practices (research aim four) (Asouti and Austin 2005:9; Picornell-Gelabert et al. 2011:376). There are three factors which are critical for conceptualising fuel wood as part of a fire regime. First, fuel in the environment can be potentially deadly and fuel loads need to be managed to avoid catastrophic fires (Gammage 2011). Australia is a fire prone continent (Mooney et al. 2011:28), environments need to be managed not just for economic benefit but to suppress potentially dangerous fuel loads. The accumulation of fuel in a landscape can occur rapidly, especially in the tropics. Second, fire can be used by humans to curate and shape ecological niches for their own economic benefit (Jones 1980b). Third, the fuel which is consumed by the landscape fire is also the fuel which is used in the hearth. Any fire consumes this valuable resource; if people require access to fuel wood they need to protect it in some way from both anthropogenic and natural bushfires. Fuel wood needs to be considered alongside the other aspects of a fire regime (i.e. fuel load, fuel, etc.).

Several factors need to be taken into consideration when investigating fuel wood management as part of a fire regime. Firstly, many Australian wooded taxa have a better branch 'drop rate' (deadwood) following a fire, with 'production' decreasing over time (Dolby 1995:35; Gammage 2011:116; see also Millington and Chaney 1973:194). Secondly, any fire regime needs to allow a 'fallow' period in which juvenile trees can establish as part of the vegetation community before the next fire (Enright and Thomas 2008:988-989). If fires occur too regularly there will be no facility for older trees to be replaced by juveniles, preventing replenishment of the community (Cheal 2010). To maintain a fire regime and a local supply of fuel wood an area cannot be burnt too regularly or left unburnt for too long. This concept is termed the 'tolerable fire interval' by fire ecologist (Cheal 2010:16). Alcorn (1981), in Mexico, observed the Huastec people leaving areas 'fallow' (as part of agricultural practices) to allow for fuel wood production. This concept is very similar to one proposed by Dufraisse (2012:67) which she termed 'incipient management'. Dufraisse (2012:67) claims that the maintenance of particular preferred fuel wood taxa and "…the rotational use of different gathering areas…" was a form of 'incipient management' of the fuel wood resource. The mosaic burning pattern which has been observed ethno-historically in Australia also allows for areas to be left fallow, allowing for fuel wood production, while maintaining a regular burning practice (see section 2.4).

If a fire regime was in operation the preservation of fuel wood in the local landscape could be accommodated as part of those practices. An area would have to be burnt semi-regularly to encourage branch drop and to reduce dangerous fuel load accumulation, but left fallow long enough to allow replenishment of the community's individual trees (i.e. tolerable fire interval). A mosaic burning practice allows different ecological niches to be managed on an individual basis. The effective use of fire can protect the edge of monsoon vine forest, maintain open woodland, protect yams (*Dioscorea* sp.), and lure grazing animals out into the open. Mosaic burning produces a patchwork of habitats at different successional post-fire stages and can actually increase species diversity (Bird et al. 2016:s69). The productivity of each of these successional stages has been demonstrated ethnographically, historically, and ecologically (section 2.4). The management of fuel wood could be easily accommodated as part of these practices.

As has been identified elsewhere in the literature Indigenous Australian landscape burning is a niche modifying practice (Bliege-Bird et al. 2013). The application of fire to curate patches of economic and ecological importance is recorded in multiple accounts across the continent.

What is clear in each of these different instances of landscape burning is that they are tied to a specific landscape and its ecological components. This is why it is important to understand fire regimes on a landscape scale (Bliege-Bird et al. 2016:17). Each time an area is burnt its ecological succession is reset. This action is an instance in the history of the landscape (Balee 2006:77; Crumley 1994:9). The mosaic of patches burnt in a landscape, at different scales and tempos, form a tapestry of historic instances in the formation of that landscape. Key economic resources require different burning regimes. Open woodland needs to be burnt every four years or less to remain open, monsoon vine forest needs to be protected from fire, while some Proteaceae require fire to set seed (Burgess et al. 2015; Cheal 2010; Russell-Smith and Bowman 1992). The inclusion of fuel wood in the list of resources provided in a fire regime require certain criteria to be met.

One of the major challenges for Australian anthracology is understanding the place of fuel wood in the archaeological record. Increasingly, in the international literature, researchers have called for a shift away from primarily understanding fuel wood selection through universal laws such as the principle of least effort (PLE) towards understanding this selection as a 'historically constituted and socially mediated' landscape practice (Picornell-Gelabert et al. 2011). In the Australian archaeological literature the Indigenous use of landscape fire to manage resources has been proposed as a landscape management practice. These practices, termed provocatively by Jones (1969) as 'fire-stick farming', have a rich and diverse ethno-historic application however their antiquity remains undefined. The use of fire to purposefully manage subsistence resources has been debated by generations of Australian archaeologists and widely reported in the literature (Gott 2005; Hiscock 2014; Horton 1982; Jones 1969). This research, however, has omitted any consideration of fuel wood as a resource in these practices. Reconceptualising fuel wood as part of landscape management practices in the Australian environment is an essential next step for Australian anthracology.

It is hypothesised that the inclusion of fuel wood in a fire regime would require a designated 'fuel wood reserve' in which fire (natural or anthropogenic) is excluded, and that the 'fuel wood reserve' near a site was only burnt when people departed the area ('burn on departure'). The 'fuel wood reserve' would be protected in the mosaic pattern alongside all other resources. This resource would be protected when it was productive, and burnt when necessary to do so. Fig. 6.2 provides a graphical representation of the 'burn on departure' model. This form of 'incipient management', as termed by Dufraisse (2012:67) would allow for an area to be used and then rotated/replenished before its next use. This model assumes fuel wood use by the occupants would not greatly affect the fuel load in the environment. This is because the fuel load for an area is composed of all combustible materials and therefore will increase even if fuel wood is being removed (DNPRSR 2012). Once fuel loads reached a dangerous level the area would be burnt and the occupants would depart. Only returning to the area after essential subsistence resources (food and fuel) had recovered post-fire.

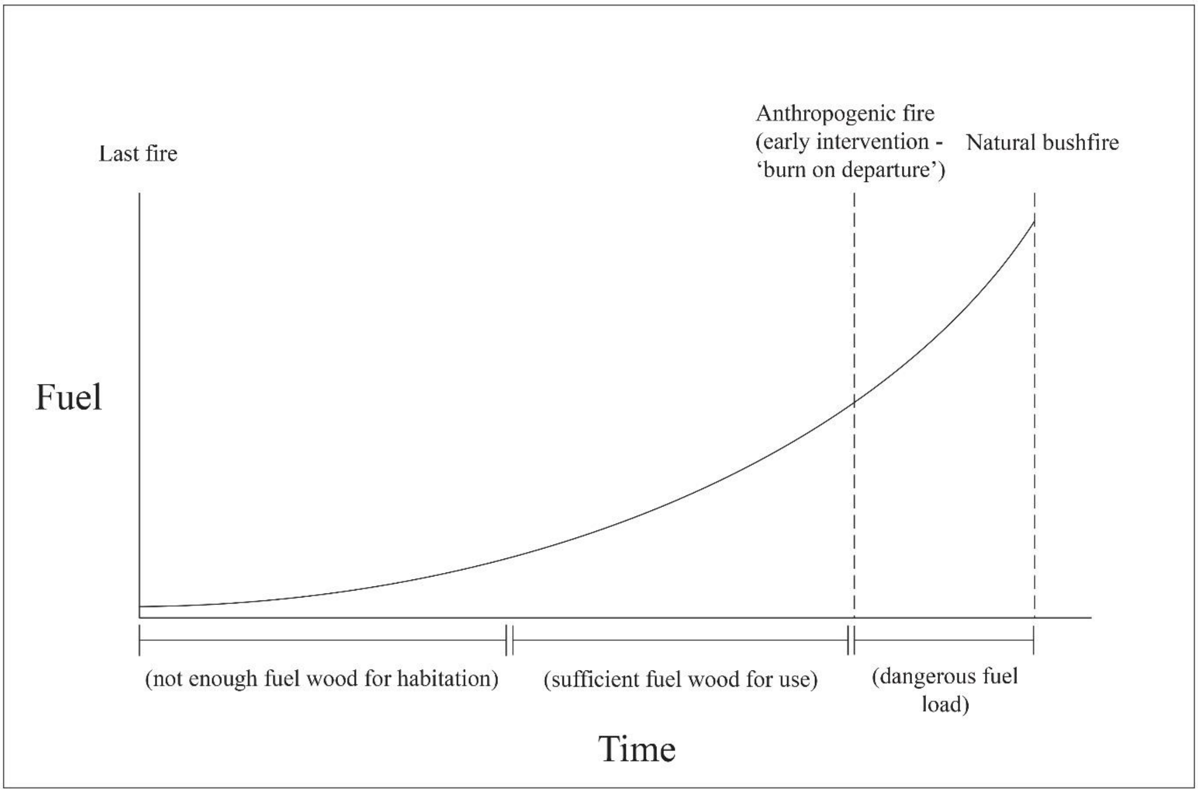


Figure 6. 2 'Burn on departure' fuel provisioning model. This model tracks the build-up of the fuel load ('the dry weight of combustible materials') in an area (DNPRSR 2012), this includes more than just wood collected as fuel. Increasing fuel load is tracked across time and in relation to fuel wood availability and proposed human action.

The ethnographic literature of the study area provides an insight into how this model may apply (Chaloupka and Giuliani 1984). This model does however remain heuristic in nature and does not assume that these practices and seasonal itineraries were diachronically static. In fact the seasonal itineraries described below would only be relevant to the last 1500-1000 years, after the establishment of the freshwater wetlands. Chaloupka and Giuliani (1984:30-31) provide a detailed account of anthropogenic burning practices in the study area. These practices were tied specifically to seasonal and environmental conditions and were directed by ecological cues. People would burn just before the start of the wet season and then again at the start of the dry. Very few burns were conducted outside of these times. An area would be burnt at the start of the dry season before fuel loads could cure and pose a danger. At this time people would depart from the woodland and move out on to the floodplains/wetlands to hunt file snake, long-necked turtle, and collect spike rush corms. At the end of the dry season people would begin to target the large flocks of magpie geese which had congregated on the diminishing wetlands. The coupling of burning to suppress fuel loads in the woodland with seasonal movement onto the floodplain to access resources fits perfectly into the ‘burn on departure’ model presented above. An area would be burnt as people departed and left for a number of seasons or years before return. This occupancy interval allowed the resources of the burnt area to regenerate but also meant people could subsist on resources elsewhere in the intervening months or years.

Palaeoenvironmental records (section 3.2) demonstrate that over the last 20,000 years Madjedbebe (MJB) would have been situated within a woodland environment. The MJB and regional archaeological records suggest for most of this period the site would have been intermittently occupied by small populations with high residential mobility (section 3.3). These conditions would not lead to the depletion of the local fuel wood resource (Asouti 2003; Asouti and Austin 2005:9; Shackleton and Prins 1992:633-634). This settlement pattern however shifted in the last 1,500-1000 years with the establishment of freshwater wetlands close to the site. Archaeological and ethnographic records (section 3.3 and this section) demonstrate increases in local population coupled with periods of low residential mobility associated with seasonal exploitation of the wetland edge. Madjedbebe is not a wetland edge site however this increase in population and change in residential mobility in the local landscape could have impacted upon fuel wood availability. It must be remembered however that Madjedbebe is situated in a highly productive tropical woodland and while residential mobility may have been seasonally low it does not equate to a permanent population at the site. These factors would not support the assertion that fuel wood supply at Madjedbebe was depleted by over exploitation. However, there may be other processes in operation which were adversely affecting the quantity of fuel available for use at the site. There are signs in the Madjedbebe wood charcoal assemblage that suggest fuel wood supply may have been under pressure in the late Holocene. There is a shift from a targeted fuel wood selection strategy during the terminal Pleistocene-early Holocene phase to a broadening of fuel taxa (a PLE selection) during the late Holocene. This diachronic change may be a result of increasing in population during the late Holocene or an anthropogenic fire regime which was not prioritizing fuel wood as a resource and therefore impacting adversely on local supply.

To fully test this hypothesis the antiquity and impact of anthropogenic fire regimes needs to be established. As discussed in Chapter Two (section 2.4.5) the necessity to manage fuel loads in the northern savannah may have been initiated by the demise of the megafauna or increases in rainfall and atmospheric CO_2 post-LGM (Bowman et al. 2016:2-3; Reeves et al. 2013a:24; Reeves et al. 2013b:102). Definitive evidence, however, remains elusive and requires renewed research effort. There are examples in the literature however where researchers have been able to utilise localised palaeoenvironmental records to reconstruct anthropogenic landscape management practices. Lentfer and Torrence (2007) were able to successfully demonstrate, through phytolith analysis, that fire was used to hold vegetation in a perpetually immature state on Garua Island, PNG. Huebert and Allen (2016), through a comprehensive anthracological study, identified similar woodland modification on Nuku Hiva, Marquesas Islands, coinciding with Polynesian arrival. This form of ecological suppression is identifiable by changes in the compositional structure of the woodland vegetation communities. In addition to phytolith studies (currently being undertaken at MJB) the matrix charcoal at archaeological sites provides another palaeoenvironmental sequence (which is tied in space and time to the archaeological record) through which woodland structure can be determined. As is demonstrated in Chapter 5 and further explored in section 6.5 the matrix charcoal at Madjedbebe provides a taxonomically rich palaeoenvironmental dataset. It is foreseen with the addition of other palaeoenvironmental sequences from Malangangerr and Ngarradj Warde Djobkeng (soon to be re-excavated) (Fig. 1.1) that a comprehensive palaeoenvironmental reconstruction for the local landscape and its fire regimes can be constructed.

Once the scale and antiquity of fire regimes has been defined in a landscape then a full exploration of the impact of these practices on resource procurement can be pursued. It is essential for the development of anthracological theory in Australia that fuel wood is understood as part of Australian landscapes and Australian landscape management practices.

6.5 Matrix charcoal – is it anthropogenic in origin?

The provenance of the detrital charcoal loose in the sediment matrix of a site is not defined. In Australia's north where bushfires are a common occurrence the inclusion of charcoal in an archaeological assemblage may not necessarily be a product of anthropogenic behaviour. This 'matrix charcoal', found outside of defined contexts could be the product of a bushfire or may, as suggested by the international literature, be the displaced remains of a hearth

(Figueiral and Mosbrugger 2000:399). The archaeological record at Madjedbebe provided an ideal setting to examine the provenance of this charcoal class (research aim three). Madjedbebe contains fourteen hearths, ubiquitous matrix charcoal, and a landscape which is regularly burnt. Through a compositional comparison of these three sources of charcoal the provenance of matrix charcoal was defined.

In the international literature charcoal found outside its primary context is termed 'dispersed' charcoal (Asouti et al. 2015:1577; Figueiral and Mosbrugger 2000:399). Matrix charcoal however does not fit this established definition because its provenance is undefined. It is therefore important to make a distinction between 'dispersed' charcoal as defined in the international literature and the charcoal recovered in the sediment matrix of a site. Dispersed charcoal is not in its primary context, it is dispersed in archaeological sediments but is anthropogenic provenance is not questioned. This is in contrast to matrix charcoal which is loose in the sedimentary matrix of the site but whose provenance is undefined.

The provenance of the matrix charcoal at Madjedbebe was examined through a comparison of matrix charcoal (C3/4) with hearth charcoals from a comparable chronology (C3/4A) and charcoal collected from the environment along a transect from the site. These charcoals were processed, analysed, and identified following the methods outlined in Chapter Four. Once quantified the data for each context type was examined through correspondence analysis (CA) (Fig.5.30). It is clear in Fig. 5.30 that the taxonomic composition of the matrix charcoal is more similar to that of the charcoal for the hearth than the environmental charcoal. The correspondence analysis produced a very stark division between the archaeological samples and the environmental sample. This division was proven to be statistically significant through a chi-squared analysis of the three assemblages. While the chi-squared test demonstrated there was a statistically significant difference in the taxonomic composition of the hearth and matrix charcoal ($X_2 = 27.115$, $p = 0.012$) the difference in chi-squared values between the matrix and environmental charcoal was substantially larger ($X_2 = 149.286$, $p < 0.0001$) (Table 5.8). These results clearly demonstrate the taxonomic makeup of matrix charcoal is very similar to hearth charcoal and therefore it can be assumed the latter is the source of the former. However, matrix charcoal is a composite of multiple hearths and by extension fuel wood selections. It is more taxonomically rich than the hearth charcoal assemblage and therefore better suited to palaeoenvironmental reconstruction. The representativeness of hearth charcoal is constrained by anthropogenic selection biases, as a single or short use context its taxonomic composition is constrained and therefore not representative of the full floristic diversity of the area.

The statistically significant difference between the matrix and the hearth charcoal demonstrates the analytic value matrix charcoal can offer to Australian anthracology. The international literature maintains that this charcoal is the dispersed residue of hearths and that it provides a palimpsest of the local wooded environment (Figueiral and Mosbrugger 2000:399). Similar to dispersed charcoal matrix charcoal is a composite of multiple fuel wood selections. This charcoal, the product of many hearths mixed together produces a more taxonomically rich charcoal assemblage. In fact, the statistically significant difference between the matrix and hearth assemblages was produced by the presence of two additional taxa in the matrix sample (i.e. *Alstonia* sp. and *Syzygium* sp.). *Syzygium* sp. is not found in any of the MJB hearths and *Alstonia* sp. is only found in two MJB hearths, both in the late Holocene group. Bachelet and Scheel-Ybert (2017:5) present similar results for their comparison of dispersed charcoal and combustion features at Santa Elina rock shelter. The authors found the dispersed samples had high taxon richness and contained additional unique taxa. Much like dispersed charcoal, matrix charcoal provides an excellent source of palaeoenvironmental data which can be utilised for reconstructing the local palaeoenvironment. This research had demonstrated that matrix charcoal and dispersed charcoal are the same class of material and should be interpreted uniformally.

6.6 Veracity of method

The limited application of anthracology in Australia has led to a deficit in the development of method and theory in this continent. It is important, therefore, to be explicit about the methods, assumptions, and limitations involved in this research and highlight what aspects of this approach need to be improved in the future.

6.6.1 Sampling effort

The application of an appropriate sampling effort is critical to determining the taxonomic composition of a sample. In Australia, sampling for anthracology has been variable and often insufficient to fully capture the floristic diversity of a sample and an assemblage as a whole. Researchers have sampled 20-60 fragments per context or less than 100 across an entire assemblage (Burke 2004:63; Frawley and O’Connor 2010:309-310; Megaw 1966:48). This sampling effort is insufficient especially when some of these studies were attempting to reconstruct the palaeoenvironment. Internationally, researchers have defined minimum sample sizes for palaeoenvironmental reconstruction dependent on the study area – in temperate areas 100 fragments per sample is appropriate, 250 for the Mediterranean, and in tropical regions 200-300 fragments are required (Asouti and Austin 2005:7). These minimums however are designed to capture the full floristic diversity of an area so that past woodland composition can be accurately modelled.

At Madjedbebe, 200 fragments or 100% of the charcoals present in the hearth were analysed (except C3/4A sampled to 400 fragments). This sampling effort met the minimum requirements for sampling in the tropics but were also a feasible amount of material to analyse for a virgin study area. Eight of the fourteen hearths analysed contained less than 200 fragments of charcoal. These lower totals, 100% of the charcoal present, cannot be avoided. To test the veracity of this sampling regime the initial appearance of a taxon in a sample was plotted against the amount of samples analysed. *Asteromyrtus* sp. is the eleventh and final taxon to be identified in hearth C3/4A at specimen 148 (Figure 5.20). This means the full floristic diversity of this sample is captured within 148 specimens, no further taxa were identified even though C3/4A was sampled to 400 fragments. The plateau from specimen 148 onwards in Fig.5.20 is an ideal outcome and demonstrates the sample size was appropriate. In contrast Fig. 5.21 is not the ideal sampling outcome, even though this hearth was sampled to 200 fragments the failure of the line to plateau before the 195th specimen demonstrates that this sample size did not capture the full floristic diversity of the hearth. Note, however, that *Coelospermum* sp. identified as specimen 195 in D2/21A was the only fragment of *Coelospermum* identified in the entire Madjedbebe assemblage. This would suggest it is a very rare taxa and was only captured due to an already healthy sampling effort.

The other three hearths which did not plateau are C1/43A which was 100% sampled (*n* = 19), D3/21A which was 100% sampled (*n* = 160), and E3/5A the most recent and floristically diverse (*n* = 15) of all the hearths. This would suggest the sampling regime utilised in this research was adequate but could be increased in future research to deal with excessive floristic diversity.

6.6.2 Typing specimens, reference collections, and identification

The unknown parameters of a new study area's floristics diversity were evident in the proliferation of types in the first analysed context (C3/4A), 35 types out of a total of 61. Typing of archaeological specimens is a method used to group anatomically or morphologically similar specimens together. In anthracology specimens are typed according to their shared anatomical features as defined by the International Association of Wood Anatomists (IAWA 1989, 2003). In geographic areas where there is a long history of anthracology the grouping of specimens based on their anatomical features may conclude with a firm taxonomic identification. In areas, such as Australia, where there is an intermittent or short application of anthracology, typing is an essential stage for organising a sample and attempting to attain a taxonomic identification.

These anatomical criteria can be used to identify an archaeological type specimen in relation to a reference set. Therefore, the efficiency and specificity of the process is tied directly to the quality of the reference collection. A total of 118 reference specimens were collated and described for this research, including seven which had both branch and trunk wood collected. When compared to previous studies in Australian anthracology this is a substantial reference collection. However, Australian wood charcoal collections cumulatively do not cover the full floristic diversity encountered – with many species absent from the description of a genus, and many genera absent from the description of a family.

The species level identifications made by Byrne et al. (2013) in their study in the Weld Ranges, Western Australia, are concerning (see also Frawley and O'Connor 2010; Smith et al. 1995). This level of specificity was achieved through expert anatomical description and the curation of a detailed reference collection. However, this reference collection did not contain all of the *Acacia* sp. present in the study area today nor did it contain all of the *Acacia* sp. which occur in Australia or even in arid Australia (Byrne et al. 2013:97). The authors claim they can identify *Acacia* sp. taxa to species or cf. species level because of observable anatomical differences in the pore arrangement and vessel pit shape (Byrne et al. 2013:99). However, without a full reference set how can we know these features are not shared with one of the taxa omitted from the reference collection? Therefore species level identifications should not be made until all taxa in a genus have been described. This is because inter- and intra-specific variation can be quite pronounced, or alternatively non-existent, complicating identifications. This level of anatomical description has not yet been achieved for Australia's wooded flora, therefore a cautious approach is advised.

The cautious and transparent research conducted by Whitau et al. (*in press*) at Riwi Cave, Western Australia, is an exemplar of this approach. Whitau et al. (*in press*) limited all of their identifications to genus and family level. They found that there was intergeneric differences within the Myrtaceae family – *Corymbia* sp. could be confidently split from *Eucalyptus* sp. (a confidence shared by this study) (Whitau et al. *in press*). However, the authors refrained from providing interspecific identifications for these two genera. They noted *Eucalyptus* sp. could be split into a type A and type B based on observed differences in porosity and the abundance of axial parenchyma (Whitau et al. *in press*). However, these differences were not used to speciate the Eucalypts because such features could be related to divergent environmental habits (Schweingruber et al. 2008:136). As has been highlighted by Whitau et al. (*in press*) the current level of wood anatomical description currently available in Australia limits the specificity in identification. Because of this, all identifications in this thesis have been limited to genus and family level.

The factors which limit taxonomic specificity to genus level also constrain the application of dendrology in Australia. A yet to be defined understanding of taxa presence and intra and inter-species/genus variation, coupled with a limited number of reference specimens means determining dendrological factors can be difficult. In this research dendrological features were noted when encountered. However, the results presented in Chapter Five demonstrate that few of these features were present – aside from vitrification and tyloses. This non-occurrence could be because these features were absent or may relate to the limited application of this method in Australia. The nature of Australian wood charcoal also limits the applicability of dendrology in Australia. Dendrological measures such as growth ring width, used to determine the calibre of wood put to fire or management practices such as coppicing and pollarding, are not consistently present in Australian taxa. Growth rings are formed by the contrast between late and early wood growth as dictated by distinct growth seasons (i.e. a period of slow or no growth during winter, followed immediately by a period of rapid growth during spring). In the tropics where seasons are less distinct annual growth rings are often absent or inconsistent. Therefore measures based on this anatomical occurrence cannot be consistently applied.

6.7 Conclusion

This chapter has progressed the four research aims outlined in Chapter One through an exploration of the Madjedbebe hearth data. The MJB wood charcoal assemblage demonstrates that from the very earliest hearths at the site people were collecting fuel locally from open Eucalypt woodland and monsoon vine forest vegetation communities (research aim one). Diachronically, however, there is a statistically significant shift in the fuel used at Madjedbebe. From the terminal Pleistocene-early Holocene to the late Holocene the taxa selected as fuel shifts from *Acacia* sp. dominance to higher taxon richness (research aim two). This shift does not correlate with a change in the local vegetation nor can it be explained by taphonomy. This increase in taxon richness during the late Holocene could reflect a shift to a principle of least effort (PLE) fuel selection strategy driven by increased population pressure. Although this explanation remains unlikely because of the seasonal movement of local populations.

This chapter also presented the first conceptual model for understanding fuel wood management in an Australian anthropogenic fire regime (research aim four). There has been a consistent call in the literature for fuel to be understood as part of the interplay of society and landscape (Asouti and Austin 2005:9; Picornell-Gelabert et al. 2011:357). This model considers how fuel could be managed when the landscape was being regularly burnt by humans. The use of fire in the landscape may also explain the shift to a PLE selection strategy in the late Holocene. If burning practices adversely impacted upon local fuel supply the inhabitants of Madjedbebe may have had to broaden their selection criteria to source enough fuel. This explanation however requires fire regimes in the landscape to be better defined.

Matrix charcoal has been used widely in Australian anthracology to reconstruct the palaeoenvironment. However, until now this charcoal class did not satisfy one of the key criteria need for its use in palaeoenvironment reconstruction. This is because Chabal (1992; Chabal et al. 1991; see also Asouti and Austin 2005:3) states that the context and how the context was formed need to be fully understood before it can used in a palaeoenvironmental reconstruction. Until now the provenance of matrix charcoal remained undefined (research aim three). The discussion presented in this chapter demonstrates that matrix charcoal is anthropogenic in origin and can be used to better understand the palaeoenvironment, including defining the initiation and scale of anthropogenic fire regimes.

Chapter Seven – Conclusion

The site of Madjedbebe provided the perfect opportunity to extend the application of anthracology in Australia. The extensive excavations undertaken at Madjedbebe during the 2012 and 2015 field seasons provided an extensive archaeological sample through which to examine human behaviour. This excavation strategy provided a sequence of hearths unrivalled in their number and temporal span anywhere in Australia. The fourteen Madjedbebe hearths and associated archaeological record have allowed key questions in Australian anthracology to be answered.

Each of the Madjedbebe hearths provided an insight into human fuel wood selection in the Alligator Rivers region (research aims one and two). The oldest three hearths (D2/30, C4/36A, C1/43A) indicated a preference for *Callitris* sp., which may have been purposefully selected for its mosquito repelling smoke. Following the earliest three hearths the preference for fuel wood shifted from *Callitris* sp. to *Acacia* sp. in the terminal Pleistocene-early Holocene hearths. These hearths contained wood from both open Eucalypt woodland and monsoon vine forest communities, with minor contributions from *Grevillea/Banksia* shrubland. Their low taxa richness however was in contrast to the late Holocene hearths. The five most recent hearths from the late Holocene contained taxa from the same three vegetation communities, but had a higher overall taxa richness. The most recent eleven hearths (late Holocene, terminal Pleistocene-early Holocene, and LGM) confirmed fuel wood selection at Madjedbebe remain locally focused during the human occupation of the site.

Anthracological method and theory has progressed a great deal as a result of sustained research and experimentation over the last five decades. Much of this research has been conducted in Europe and the Near East (Asouti and Austin 2005; Chabal 1992; Chabal et al. 1999; Dufraisse 2012; Thery-Parisot et al. 2010) with more recent contributions from the tropics (Dotte-Sarout 2013 et al.; Dotte-Sarout et al. 2015; Huebert and Allen 2016; Scheel-Ybert 2001, 2014). These international developments are increasingly being recognised and utilised in Australian anthracology, although implementation has been slow (for exceptions, Byrne et al. 2013, Dotte-Sarout et al. 2015; Whitau et al. *in press*). There remain, however, limitations in Australian anthracology which cannot be remedied by the international literature. Many of these limitations – such as under-developed reference sets, limited anatomical description, issues of sampling and recovery – will be fixed through future research effort. However, there are issues in Australian anthracology which will require sustained theoretical engagement by Australian anthracologists. Core among these problems is the absence of fuel wood in discussions of landscape management practices in Australian archaeology. Picornell-Gelabert et al. (2017: 1) have called for fuel to be incorporated in archaeological narratives especially in the ‘arena of society and environmental interactions’. This thesis has placed fuel wood within the historical ecology and socio-economic milieu of the Alligator Rivers region.

This PhD thesis is the first to be completed in Australian anthracology. It provides a comprehensive analysis and examination of fuel wood selection strategies at Madjedbebe as well as extending the application of anthracological method and theory in Australia. In addition, it highlights the potential of Australian anthracology moving forward.

This thesis has contributed the first analysis of fuel wood selection in the Alligator Rivers region. The analysis of charcoal from fourteen hearths at Madjedbebe has provided the first insights into fuel wood selection and provisioning in this important archaeological landscape. The basis of this research was the application of best practice field sampling and archaeobotanical processing in the field. As well as the construction of a bespoke collection of reference specimens (http://uqarchaeologyreference.metadata.net/archaeobotany/). This reference collection represented the first wood reference collection constructed for the study region and offers the first anatomical description of 99 wooded taxa. This reference collection has been digitally archived (open access and free online), a first for Australian wood charcoal. This will allow other researchers to access this key resource and contribute additional accessions to build its capacity.

A key focus of this research was to determine the provenance of matrix charcoal (research aim three). This ubiquitous charcoal class has great interpretative potential but its provenance remained unclear. Through the comparison of hearth, matrix and environmental charcoal assemblages this research was able to clearly demonstrate that matrix charcoal is anthropogenic in origin. Based on the methodological research conducted overseas on ‘dispersed charcoal’ the confirmation of matrix charcoal as anthropogenic allows it be fully incorporated in palaeoenvironmental reconstruction. The value of a palaeoenvironmental reconstruction which is tied in space and time with the archaeological record is significant. Limitations such as finding temporally aligned or spatially specific palaeoenvironmental records are overcome by matrix charcoal. These samples are tied directly to the chronology of the site and are locally focused in their scale. The limitations of a fire regime study like

Mooney et al.'s (2011) is that it offers a regional synthesis with broad strokes and implications. If archaeologists are going to define the antiquity and effects of local fire regimes then their understandings need to be situated within the landscape in which they are practiced. Many of the critical elements of a fire regime – vegetation communities, topography, precipitation, fuel load – are innate to the landscape in which it is located. These practices are only going to be defined within their own landscape. An anthropogenic application of fire will alter the woodland structure, holding it in a perpetually immature state which can be identified in palaeoenvironmental records (Lentfer and Torrence 2007). Through the investigation of multiple anthracological sequences in a landscape the characteristic impacts of fire on woodland structure can be identified.

Palynological and anthracological records provide complimentary data which should be used together to reconstruct palaeoenvironments. Identifying the wooded taxa (anthracology) in a woodland is complemented by identifying non-woody shrubs and grasses (palynology). Anthracology provides a localised signature than the more regional focus of palynology. Poor pollen producing taxa (i.e. *Acacia* sp.) are also often better represented in anthracological assemblages, thereby filling a gap in palynological records. This emerging research will provide Australian archaeologists, anthracologists, and ecologists the opportunity to critique the anthropogenic nature of Australian woodland communities. Asouti and Kabukcu (2014) have highlighted the importance of critiquing ecological concepts such as 'climax vegetation' in landscapes in which humans have been effecting the woodland structure for millennia. This collaborative approach will be a new research direction for Australian anthracology.

Finally, this thesis has presented the first conceptual model for fuel use in the Australian archaeological record (research aim four). The inclusion of fuel in discussions of fire regime landscape management practice is an essential addition. The absence of this key subsistence resource from these critical discussions was a huge oversight. This model recognises anthropogenic fire regimes as a form of niche modification, an activity which leads to the creation of anthropogenic landscapes. Fire has been a constant element in the Australian environment since the Tertiary (Bowman 2003:6-7). While the antiquity of anthropogenic fire management remains undefined the practices developed by Indigenous Australians, by the time of European colonisation, had a transformative impact on the Australian environment. The provisioning of fuel wood as part of these practice would have been an essential consideration. It is therefore important that Australian anthracologists test hypotheses which consider the impact of fire regimes on the access and supply of this essential resource.

To fully interrogate the place of fuel wood in a fire regime first the antiquity of anthropogenic fire regimes needs to be defined. Therefore, the next stage of research in Australian anthracology needs to employ matrix charcoal on a landscape scale to identify the initiation and nature of anthropogenic landscape burning. The provisioning of key subsistence resources will only be fully conceptualised once landscape management practices are sufficiently well-defined.

This thesis has presented an anthracological assessment of fuel selection and management at the site of Madjedbebe. The fourteen MJB hearths provided an unrivalled sequence of hearths with which to consider these issues. This research found fuel wood selection was a locally focused activity. Consistently, two vegetation communities where accessed for fuel, open Eucalypt woodland and monsoon vine forest, with minor contributions from a third – *Grevillea/Banksia* shrubland. In addition to examining fuel wood selection this research also defined the provenance of matrix charcoal – a ubiquitous charcoal class in Australian archaeology, which has powerful analytical potential for reconstructing the palaeoenvironment. Finally, and most significantly, this research has developed the first conceptual model for fuel wood management which is situated in the ecological, socio-cultural, and economic landscape of Australia. Fuel wood is an essential resource, tied to people's daily itineraries, and it is thus an essential component of their landscape modifying practices.

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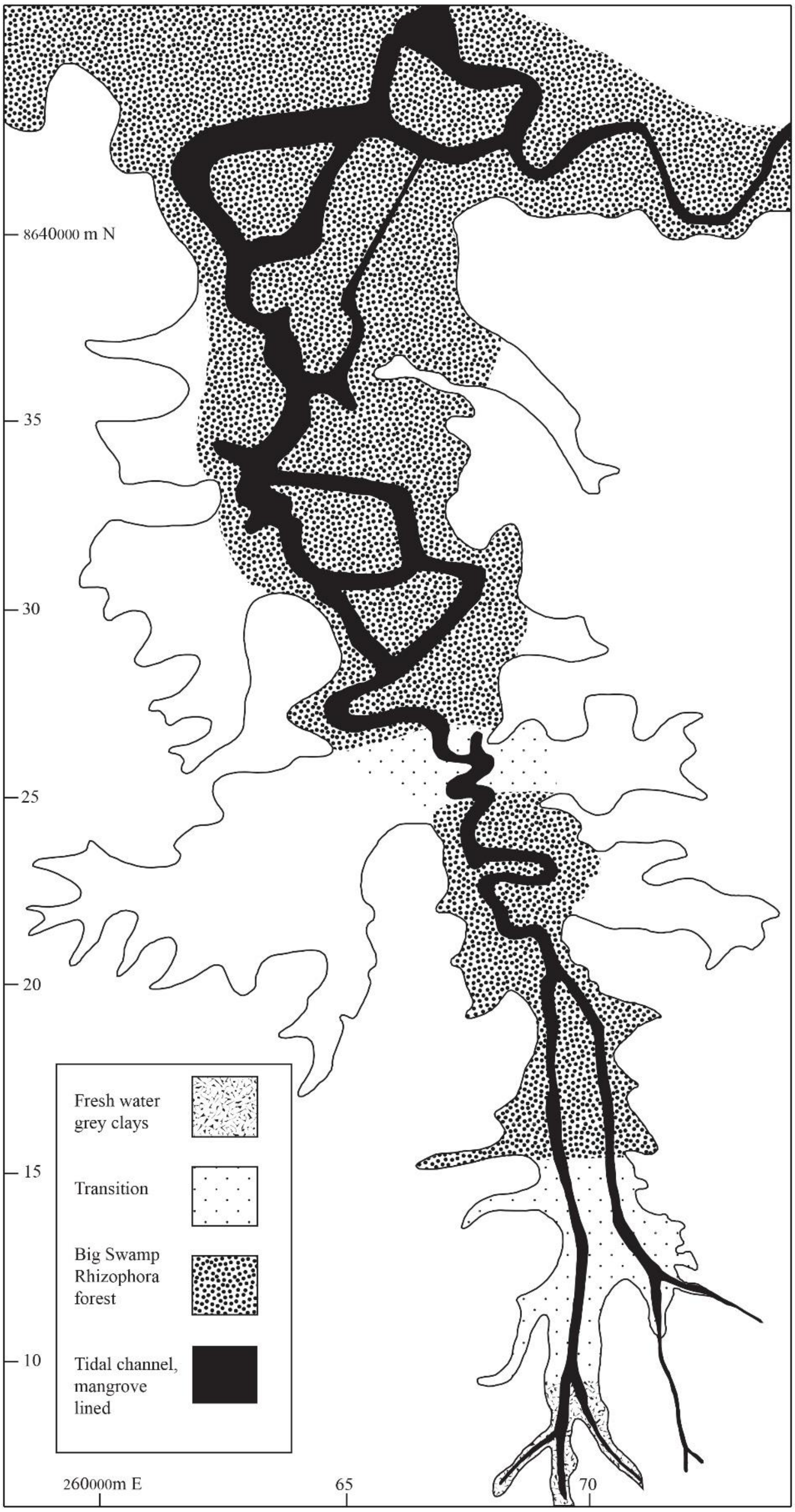
Appendix A – Mayali language group fuel wood preferences

Mayali language group ethnobotany – fuel wood. Adapted from Chaloupka and Giuliani (1984 – Table 33). Please note: *Gudjewg* = December to March; *Banggerreng* = April; *Yegge/Yekke* = May to mid-June; *Wurrgeng* = mid-June to mid-August; *Gurrung* = mid-August to mid-October; *Gunumeleng* = mid-October to late December (http://www.mirarr.net/seasons)

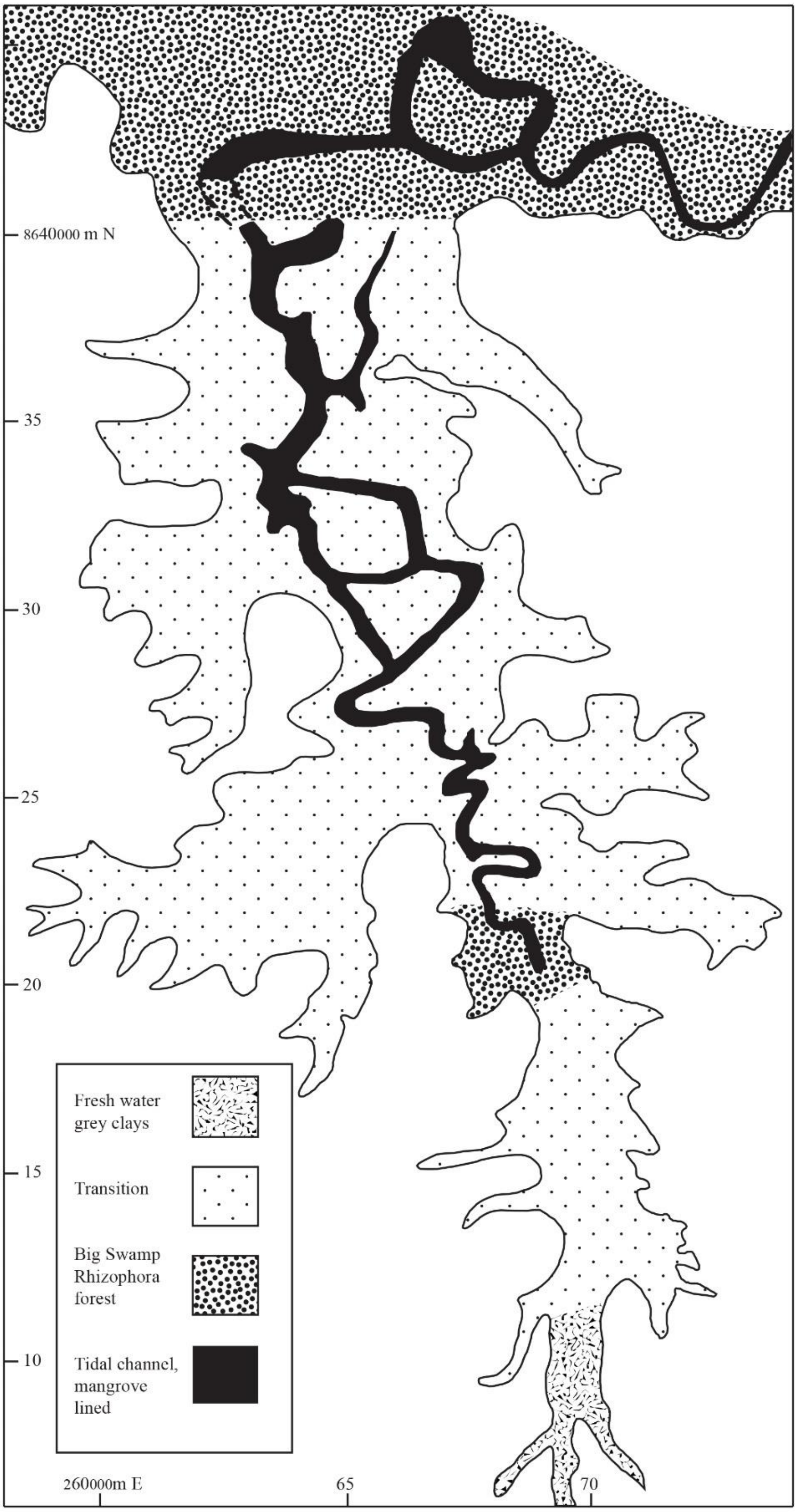
Mayali name	Linnean name	Use/Comments
Anbadbad/andjengerrer	*Grevillea heliosperma*	Long lasting coals
Anbalindja	*Vitex acuminata*	
Anbalindja	*Vitex* sp. new	Kindling only
Anbamberre	*Eucalyptus ptychocarpa*	Long lasting coals
Anbandarr	*Calytrix arborescens*	Good firewood
Anbandarr	*Calytrix exstipulata*	Preferred during *gudjewg* and in stone ovens
Anbedja	*Petalostigma pubescens*	Long last coals
Anbenben	*Eucalyptus papuana*	Preferred during *gudjewg* and in stone ovens
Anbunbe	*Eucalyptus* sp.	Long lasting coals
Anbunuy	*Eucalypts polycarpa*	Long lasting coals
Andangdang	*Eucalyptus ferruginea*	Produces coals quickly
Andangud	*Pouteria sericea*	Burns slowly, preferred during *gudjewg*
Andjo	*Acacia difficilis*	Produces coals quickly
Andjolkbirro	*Syzygium bleeseri*	Long lasting coals
Andjomdji	*Melaleuca punicea*	Slow burning, long lasting coals
Andjone	*Terminalia pterocarya*	Log will burn two days
Andjumbak	*Calytrix brownie*	Tinder during *gujewg*
Andjungurrg	*Gardenia fucata*	Long lasting coals
Andorrok	*Eucalyptus latifolia*	Produces coals quickly
Andubang	*Erythrophloeum chlorostachys*	Long lasting coals
Anganbirr	*Acacia oncinocarpa*	Good to start a fire
Angandolk	*Bombax ceiba*	Slow burning

Mayali name	**Linnean name**	**Use/Comments**
Angbudj/bandad	*Lophostemon grandiflora*	Slow burning
Angirribuy	*Syzygium suborbiculare*	Slow burning
Angod/andol	*Melaleuca leucadendron*	Good for unattended fires
Angolpon	*Lophopetalum arnhemicum*	Long lasting coals
Angomborrlo	*Eucalyptus dichromophloia*	Long lasting coals, used in stone ovens
Angudu	*Strychnos lucida*	Long lasting coals
Angununj	*Jacksonia dilatata*	Slow burning, good for unattended fires
Anjawugo	*Eucalyptus tectifica*	Preferred during *gudjewg* and in stone ovens
Anjulurr	*Calytrix brachycheata*	Excellent tinder during *gudjewg*
Anlarr	*Callitris intratropica*	Preferred during *gudjewg*
Anmalak	*Terminalia ferdinandiana*	Slow burning, used in stone ovens
Anmarrabula	*Terminalia carpentarie*	Preferred to cook fish on and in stone oven
Anwurrben	*Lophostemon lactifluas*	Slow burning, log may burn several days
Anmokulurr	*Maranthes corymbosa*	Log will burn for two-three days
Anmuludum	*Acacia leptocarpa*	Produces coals quickly, preferred to cook fish
Anngal	*Eucalyptus porrecta*	Good firewood

Appendix B – Magela Creek late Holocene transition



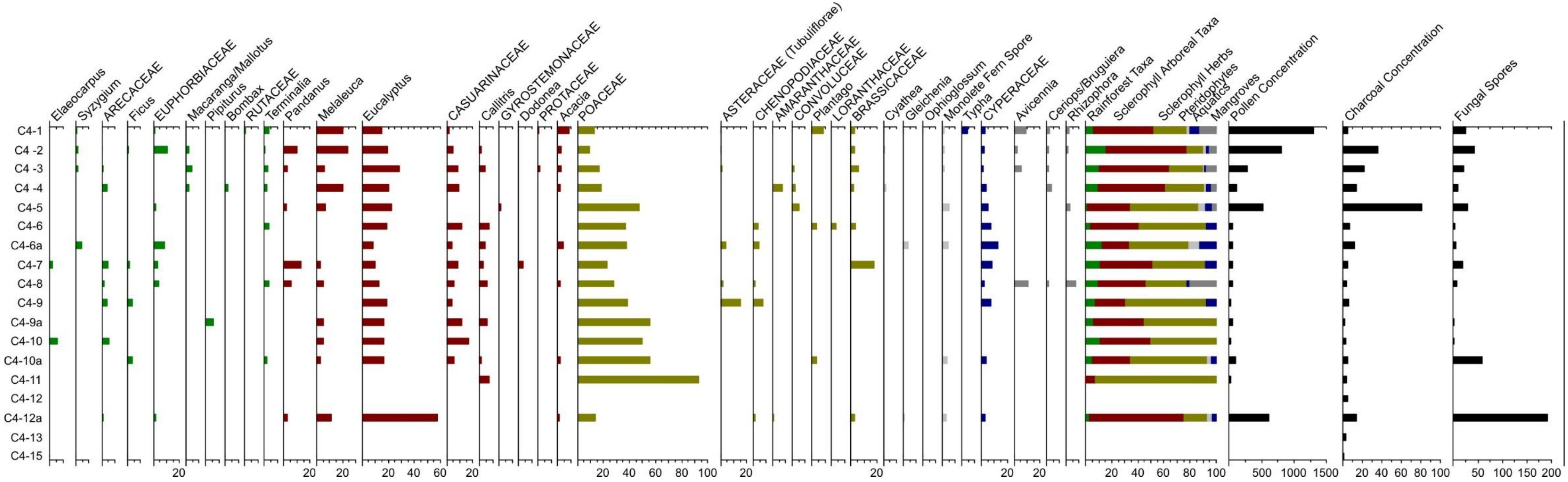
Magela Creek and associated floodplains at 3,500 cal BP. Note the extensive mangrove forest present at this time (redrawn from Wasson 1992:143, Fig. 4.21)



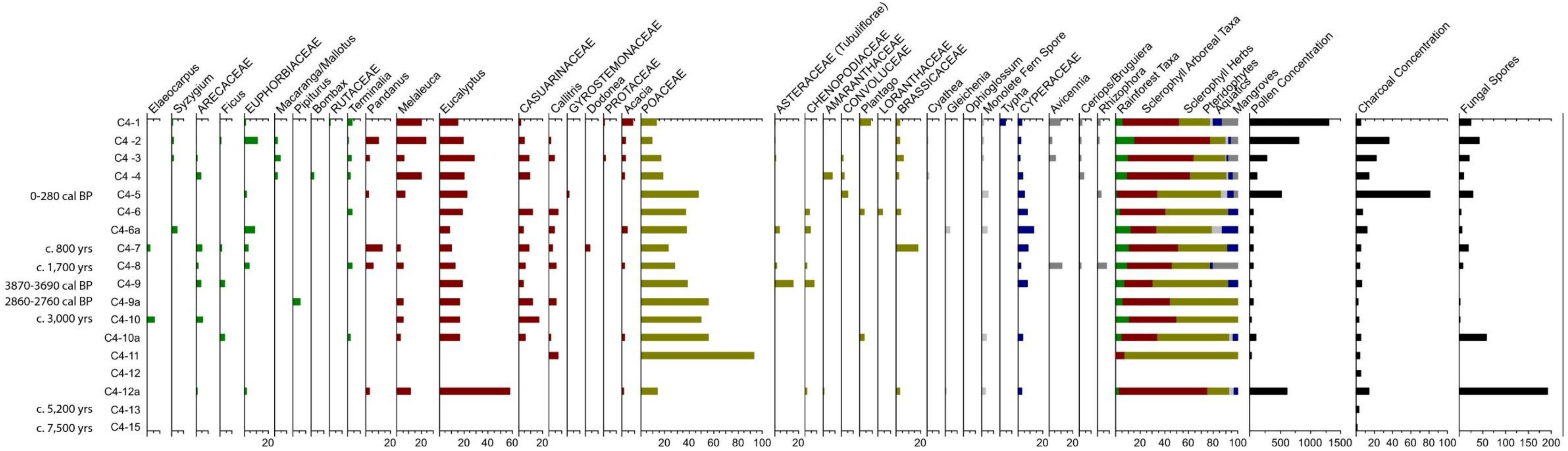
Magela Creek and associated floodplains at 2,500 cal BP. Note the contraction of mangrove forest at this time (redrawn from Wasson 1992:144, Fig. 4.22)

Appendix C– Madjedbebe palynological sequence

A locally-focused and temporally-specific palaeoenvironmental sequence was produced for the site of Madjedbebe. Pollen was extracted from the sedimentary matrix of site through an analysis of samples from contexts C4/1 – C4/15. This analysis was undertaken by Assoc. Prof. Patrick Moss of The University of Queensland.



Madjedbebe pollen sequence extracted from the site's sedimentary matrix. C4/1 – C4/15 were sampled. A version of the pollen diagram containing dates is available below.

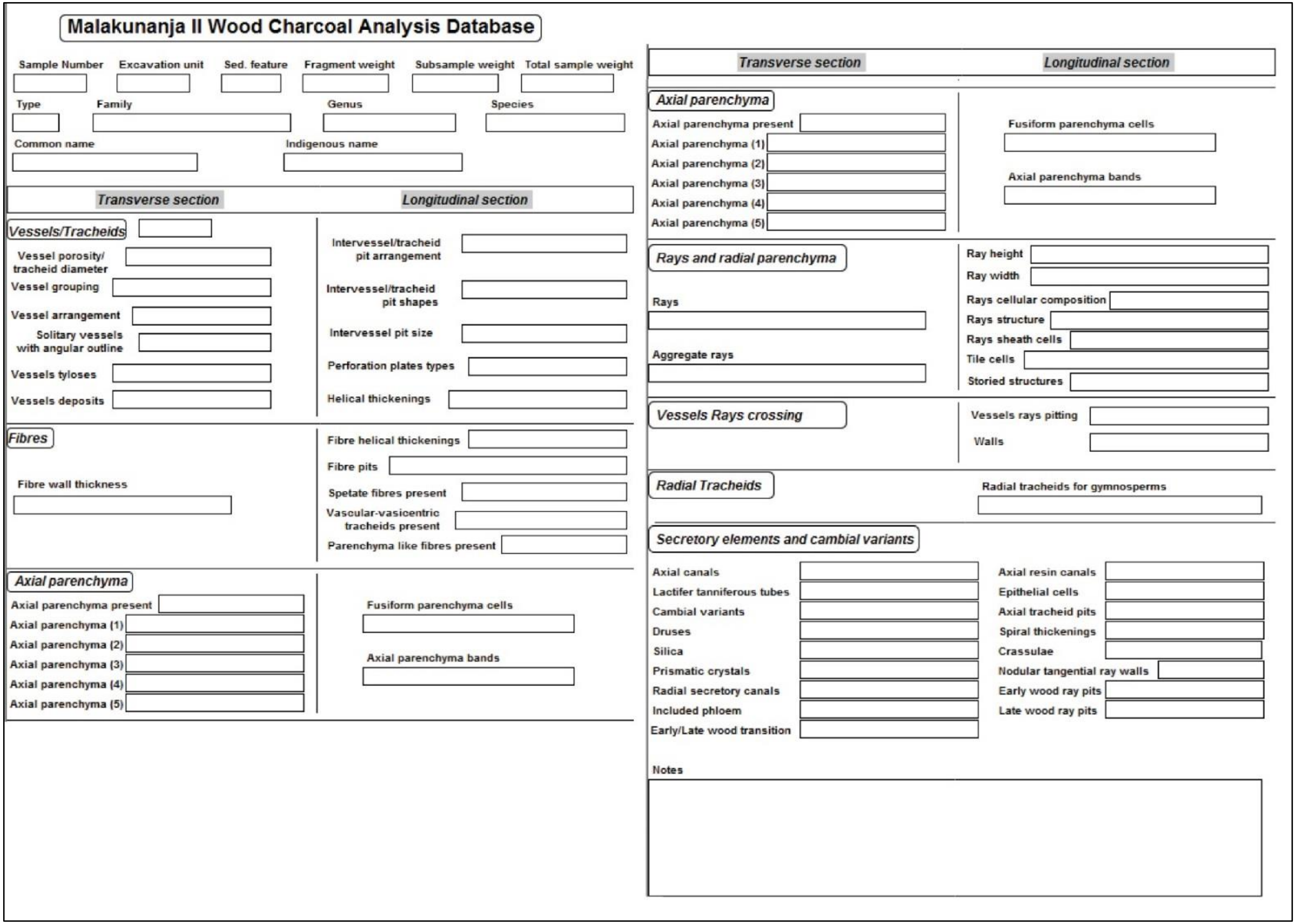


The Madjedbebe pollen sequence with dates. The sequence of dates is mainly based on an age-depth curve, some calibrated dates are also included.

Appendix D – FileMaker pro forma for the description of wood charcoal

Following page.

The FileMaker pro forma used to record and catalogue all charcoal specimens and reference materials. Each field is a drop-down menu populated with the IAWA anatomical criteria. Adapted from Dotte-Sarout (2010).



Malakunanja II Wood Charcoal Analysis Database

Sample Number
Excavation unit
Sed. feature
Fragment weight
Subsample weight
Total sample weight

Type
Family
Genus
Species

Common name
Indigenous name

Transverse section

Longitudinal section

Vessels/Tracheids

Vessel porosity/ tracheid diameter
Vessel grouping
Vessel arrangement
Solitary vessels with angular outline
Vessels tyloses
Vessels deposits

Intervessel/tracheid pit arrangement
Intervessel/tracheid pit shapes
Intervessel pit size
Perforation plates types
Helical thickenings

Fibres

Fibre wall thickness

Fibre helical thickenings
Fibre pits
Spetate fibres present
Vascular-vasicentric tracheids present
Parenchyma like fibres present

Axial parenchyma

Axial parenchyma present
Axial parenchyma (1)
Axial parenchyma (2)
Axial parenchyma (3)
Axial parenchyma (4)
Axial parenchyma (5)

Fusiform parenchyma cells
Axial parenchyma bands

Transverse section

Longitudinal section

Axial parenchyma

Axial parenchyma present
Axial parenchyma (1)
Axial parenchyma (2)
Axial parenchyma (3)
Axial parenchyma (4)
Axial parenchyma (5)

Fusiform parenchyma cells
Axial parenchyma bands

Rays and radial parenchyma

Rays
Aggregate rays

Ray height
Ray width
Rays cellular composition
Rays structure
Rays sheath cells
Tile cells
Storied structures

Vessels Rays crossing

Vessels rays pitting
Walls

Radial Tracheids

Radial tracheids for gymnosperms

Secretory elements and cambial variants

Axial canals
Lactifer tanniferous tubes
Cambial variants
Druses
Silica
Prismatic crystals
Radial secretory canals
Included phloem
Early/Late wood transition

Axial resin canals
Epithelial cells
Axial tracheid pits
Spiral thickenings
Crassulae
Nodular tangential ray walls
Early wood ray pits
Late wood ray pits

Notes

Appendix E – Wood charcoal reference collection

UQM	Family	Genus	Species	Sub-species	HISPID Flag	Box
2683	Acanthaceae	*Avicennia*	*marina*		3	13
2668	Anacardiaceae	*Buchanania*	*obovata*		3	13
2613	Apocynaceae	*Alstonia*	*actinophylla*		3	13
2704	Apocynaceae	*Carissa*	*lanceolata*		3	13
2739	Apocynaceae	*Tabernaemontana*	*orientalis*		3	14
2740	Apocynaceae	*Tabernaemontana*	*orientalis*		3	14
2727	Arecaceae	*Carpentaria*	*acuminata*		3	12
2721	Arecaceae	*Livistona*	*benthamii*		3	12
2669	Arecaceae	*Livistona*	*humilis*		3	12
2639	Arecaceae	*Livistona*	*inermis*		3	12
2688	Bixaceae	*Cochlospermum*	*fraseri*		3	13
2644	Burseraceae	*Canarium*	*australium*		3	14
2649	Caesalpiniceae	*Erythrophleum*	*chlorostachys*		3	14
2652	Celastraceae	*Denhamia*	*obscura*		3	14
2730	Celastraceae	*Denhamia*	*obscura*		3	15
2653	Chrysobalanaceae	*Maranthes*	*corymbosa*		3	15
2711	Chrysobalanaceae	*Parinari*	*nonda*		3	15
2705	Combretaceae	*Lumnitzera*	*racemosa*		3	9
2734	Combretaceae	*Macropteranthes*	*sp.*		3	9
2710	Combretaceae	*Terminalia*	*carpentaria*		3	8
2662	Combretaceae	*Terminalia*	*ferdinandiana*		3	8
2702	Combretaceae	*Terminalia*	*grandiflora*		3	8
2675	Combretaceae	*Terminalia*	*microcarpa*		3	8
2742	Combretaceae	*Terminalia*	*platyphylla*		3	9
2658	Combretaceae	*Terminalia*	*platyptera*		3	8
2642	Cupressaceae	*Callitris*	*intratropica*		3	15

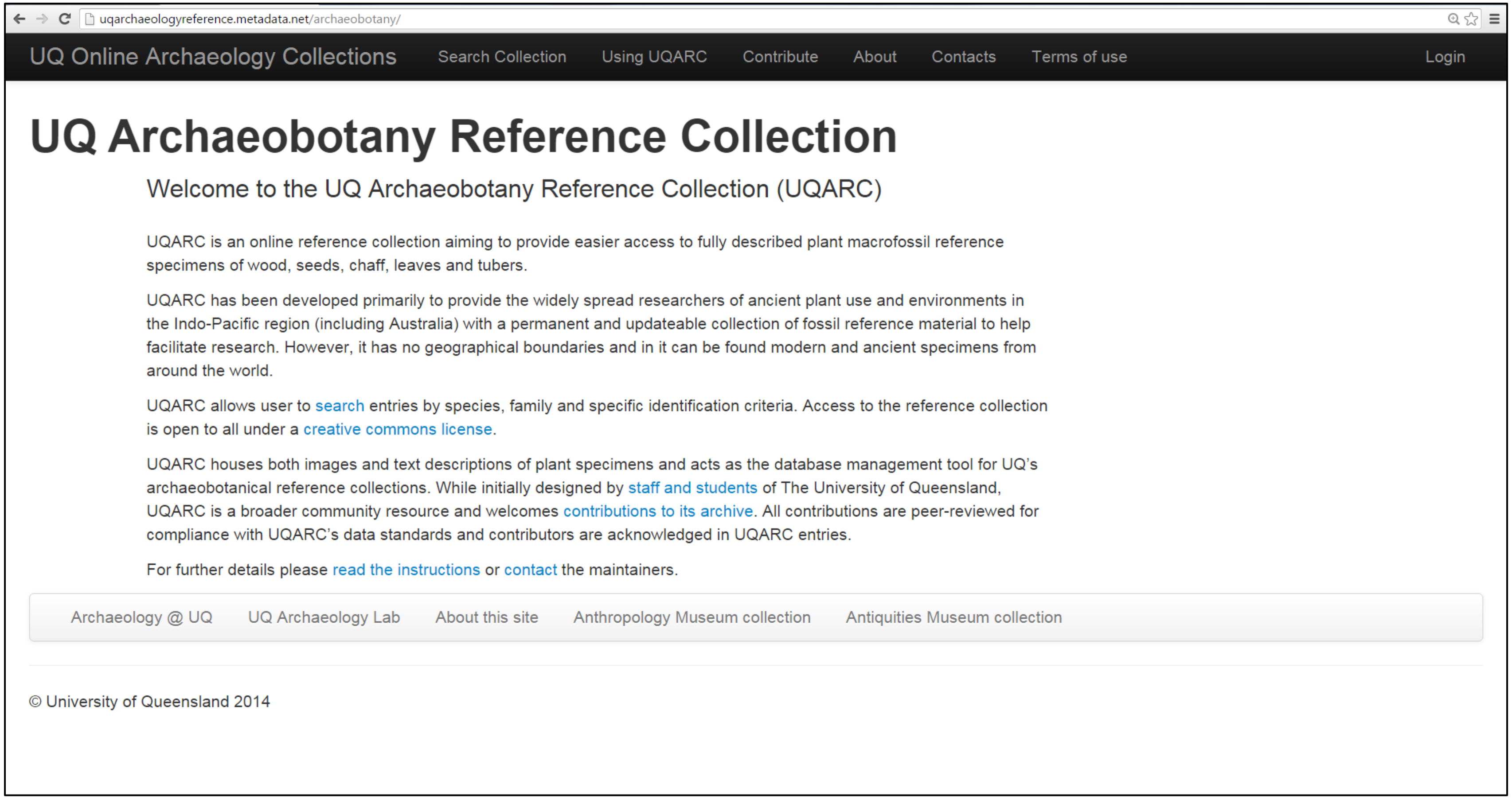
UQM	**Family**	**Genus**	**Species**	**Sub-species**	**HISPID Flag**	**Box**
2713	Dilleniaceae	*Hibbertia*	*brownii*		3	16
2735	Ebenaceae	*Diospyros*	*humilis*		3	16
2682	Ebenaceae	*Diospyros*	*littorea*		3	16
2618	Euphorbiaceae	*Breynia*	*cernua*		3	16
2677	Euphorbiaceae	*Flueggea*	*virsa*		3	16
2655	Fabaceae	*Erythrina*	*vespertilio*		3	16
2746	Lamiaceae	*Clerodendrum*	*floribundum*		3	17
2666	Lecythidaceae	*Barringtonia*	*acutangula*		3	17
2718	Lecythidaceae	*Planchonia*	*careya*		3	17
2699	Loganiaceae	*Strychnos*	*lucida*		3	17
2724	Malvaceae	*Gossypium*	*sp.*		3	18
2706	Malvaceae	*Grewia*	*sp.*		3	18
2749	Malvaceae	*Hibiscus*	*meraukensis*		3	9
2684	Malvaceae	*Hibiscus*	*sabdariffa*		3	9
2707	Malvaceae	*Hibiscus*	*tiliaceus*		3	9
2725	Malvaceae	*Sida*	*sp.*		3	18
2719	Malvaceae	*Sterculia*	*quadrifida*		3	18
2700	Malvaceae	*Thespesia*	*populneoides*		3	17
2726	Malvaceae	*Urena*	*sp.*		3	18
2709	Melastomataceae	*Melastoma*	*sp.*		3	19
2737	Meliaceae	*Owenia*	*vernicosa*		3	19
2657	Mimosaceae	*Acacia*	*auriculiformis*		3	6
2743	Mimosaceae	*Acacia*	*cf. lamprocarpa*		3	7
2736	Mimosaceae	*Acacia*	*difficulis*		3	6
2738	Mimosaceae	*Acacia*	*dimidiata*		3	7
2685	Mimosaceae	*Acacia*	*holosericea*		3	6
2741	Mimosaceae	*Acacia*	*mountfordiae*		3	7
2745	Mimosaceae	*Acacia*	*oncinocarpa*		3	7

UQM	Family	Genus	Species	Sub-species	HISPID Flag	Box
2670	Mimosaceae	*Acacia*	*plectocarpa*		3	6
2701	Mimosaceae	*Acacia*	*shirleyi*		3	6
2712	Mimosaceae	*Cathormion*	*umbellatum*		3	6
2646	Moraceae	*Ficus*	*racemosa*		3	19
2715	Moraceae	*Ficus*	*scobina*		3	19
2614	Moraceae	*Ficus*	*virens*		3	19
2674	Myrtaceae	*Allosyncarpa*	*ternata*		3	4
2689	Myrtaceae	*Asteromyrtus*	*symphyocarpa*		3	3
2647	Myrtaceae	*Calytrix*	*exstipulata*		3	4
2650	Myrtaceae	*Corymbia*	*bleeseri*		3	4
2661	Myrtaceae	*Corymbia*	*polycarpa*		3	5
2617	Myrtaceae	*Corymbia*	*polysciada*		3	4
2748	Myrtaceae	*Corymbia*	*porrecta*		3	5
2654	Myrtaceae	*Corymbia*	*ptychocarpa*		3	5
2640	Myrtaceae	*Eucalyptus*	*alba*		3	1
2671	Myrtaceae	*Eucalyptus*	*miniata*		3	1
2660	Myrtaceae	*Eucalyptus*	*phoenicia*		3	1
2703	Myrtaceae	*Eucalyptus*	*racemosa*		3	1
2651	Myrtaceae	*Eucalyptus*	*tetradonta*		3	1
2694	Myrtaceae	*Lophostemon*	*lactifluus*		3	3
2733	Myrtaceae	*Lophostemon*	*lactifluus*		3	19
2678	Myrtaceae	*Melaleuca*	*leucadendra*		3	3
2656	Myrtaceae	*Syzygium*	*armstrongii*		3	2
2665	Myrtaceae	*Syzygium*	*eucalyptoides*	*ssp.bleeseri*	3	2
2680	Myrtaceae	*Syzygium*	*eucalyptoides*	*ssp.eucalyptoides*	3	2
2716	Myrtaceae	*Syzygium*	*forter*	*ssp.potamophilum*	3	2
2641	Myrtaceae	*Syzygium*	*suborbiculare*		3	2
2697	Myrtaceae	*Verticordia*	*sp.*		3	3

UQM	Family	Genus	Species	Sub-species	HISPID Flag	Box
2676	Mytraceae	*Calytrix*	*brownii*		3	5
2673	Mytraceae	*Melaleuca*	*viridifolia*		3	3
2619	Pandanaceae	*Pandanus*	*spiralis*		3	12
2720	Pandanaceae	*Pandanus*	*spiralis*		3	12
2592	Phyllanthaceae	*Antidesma*	*ghesaembilla*		3	20
2708	Phyllanthaceae	*Bridelia*	*tomentosa*		3	20
2729	Phyllanthaceae	*Glochidion*	*sp.*		3	20
2659	Picrodendraceae	*Petalostigma*	*pubescens*		3	7
2692	Picrodendraceae	*Petalostigma*	*quadriloculare*		3	7
2645	Proteaceae	*Banksia*	*denata*		3	11
2717	Proteaceae	*Grevillea*	*decurrens*		3	11
2616	Proteaceae	*Grevillea*	*dryandri*		3	10
2744	Proteaceae	*Grevillea*	*heliosperma*		3	12
2664	Proteaceae	*Grevillea*	*parallela*		3	10
2648	Proteaceae	*Grevillea*	*pteridifolia*		3	10
2696	Proteaceae	*Grevillea*	*striata*		3	11
2679	Proteaceae	*Hakea*	*arborescens*		3	11
2731	Proteaceae	*Hakea*	*arborescens*		3	11
2695	Proteaceae	*Persoonia*	*falcata*		3	11
2691	Proteaceae	*Stenocarpus*	*acacioides*		3	11
2690	Rhamnaceae	*Alphitonia*	*excelsa*		3	20
2693	Rhamnaceae	*Alphitonia*	*excelsa*		3	20
2681	Rhizophoraceae	*Bruguiera*	*gymnorrhiza*		3	21
2615	Rhizophoraceae	*Carallia*	*brachiata*		3	20
2698	Rhizophoraceae	*Carallia*	*brachiata*		3	21
2687	Rhizophoraceae	*Rhizophora*	*stylosa*		3	21
2723	Rubiaceae	*Coelospermum*	*reticulatum*		3	21
2747	Rubiaceae	*Cyclophyllum*	*schultzii*		3	22

UQM	Family	Genus	Species	Sub-species	HISPID Flag	Box
2722	Rubiaceae	*Gardenia*	*megasperma*		3	21
2732	Rubiaceae	*Pavetta*	*brownii*		3	22
2728	Rubiaceae	*Psydrax*	*odorata*		3	22
2686	Santalaceae	*Exocarpus*	*latifolius*		3	22
2714	Sapotaceae	*Pouteria*	*sericea*		3	22
2663	Sterculiaceae	*Brachychiton*	*diversifolius*		3	22
2667	Sterculiaceae	*Brachychiton*	*paradoxum*		3	23
2672	Verbenaceae	*Premna*	*acuminata*		3	23

Appendix F – The University of Queensland Archaeobotany Reference Collection



UQ Archaeobotany Reference Collection

Welcome to the UQ Archaeobotany Reference Collection (UQARC)

UQARC is an online reference collection aiming to provide easier access to fully described plant macrofossil reference specimens of wood, seeds, chaff, leaves and tubers.

UQARC has been developed primarily to provide the widely spread researchers of ancient plant use and environments in the Indo-Pacific region (including Australia) with a permanent and updateable collection of fossil reference material to help facilitate research. However, it has no geographical boundaries and in it can be found modern and ancient specimens from around the world.

UQARC allows user to search entries by species, family and specific identification criteria. Access to the reference collection is open to all under a creative commons license.

UQARC houses both images and text descriptions of plant specimens and acts as the database management tool for UQ's archaeobotanical reference collections. While initially designed by staff and students of The University of Queensland, UQARC is a broader community resource and welcomes contributions to its archive. All contributions are peer-reviewed for compliance with UQARC's data standards and contributors are acknowledged in UQARC entries.

For further details please read the instructions or contact the maintainers.

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The University of Queensland Archaeobotany Reference Collection (UQARC) welcome page screen shot. http://uqarchaeologyreference.metadata.net/archaeobotany/

Appendix G – Anatomical description of archaeological type specimens

Madjedbebe charcoal archaeological type specimens with anatomical description. Note only observed anatomy was described.

Type	Vessel porosity	Vessel grouping	Vessel arrangement	Apotracheal parenchyma	Paratracheal parenchyma	Ray width	Ray height	Ray cellular composition	Ray structure	Ray sheath cell	Intervessel/tracheid pit arrangement	Intervessel/vessel-ray pitting	Identification	Type specimen
1	diffuse porous	exclusively solitary/90% or more	wide spread	apotracheal diffuse	in narrow bands (up to 3 cells wide)	uni to biseriate	5-8	homogeneous	all procumbent	procumbent	alternate	Tyloses filled not observed/not observed	Eucalyptus sp.	1
2	diffuse porous	in radial clusters	wide spread		paratracheal unilateral	uni to biseriate	7-22	homogeneous	all upright/square	upright/square	alternate	bordered pits, not vestured/not observed	Acacia sp.	2
3	diffuse porous	solitary	wide spread			exclusively uniseriate	2-5	heterogeneous	mixed cellular composition	upright/square	opposite	bordered pits/not observed	Indet.	3
4	diffuse porous	solitary	wide spread		paratracheal unilateral, paratracheal winged aliform, in narrow bands (up to 3 cells wide)	exclusively uniseriate	3-10	heterogeneous	mixed cellular composition	procumbent	alternate	bordered pits/not observed	Corymbia sp.	4
5	diffuse porous	solitary	wide spread	apotracheal diffuse	paratracheal unilateral	uni to biseriate	4-7	homogeneous	all procumbent	procumbent	opposite	bordered pits, not vestured/not observed	Acacia sp.	6
6	diffuse porous	clusters common (2 to 3)	radial pattern			exclusively uniseriate	4-6				alternate	bordered pits, not vestured/not observed	Flueggea sp.	7
7	diffuse porous	solitary	wide spread								opposite	bordered pits/not observed	Indet.	9
8	diffuse porous	clusters common (3 or more)	wide spread		in narrow bands (up to 3 cells wide), paratracheal unilateral			homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Indet.	10
9	diffuse porous	clusters common (2 to 3)	radial pattern			exclusively uniseriate	3-7	homogeneous	all upright/square	upright/square	alternate	bordered pits/not observed	Flueggea sp.	14
10	diffuse porous	solitary	wide spread			exclusively uniseriate	4-7	homogeneous	all upright/square	upright/square	alternate	bordered pits/not observed	Indet.	15
11	diffuse porous	solitary	wide spread								alternate	bordered pits/not observed	Indet.	19
12	diffuse porous	solitary	wide spread	apotracheal diffuse		uni to biseriate	3-5	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Pavetta sp.	20
13	diffuse porous	in radial clusters	radial pattern	apotracheal diffuse		exclusively uniseriate	3-7				alternate	bordered pits/not observed	Alphitonia sp.	23
14	diffuse porous	exclusively solitary/90% or more	wide spread			uni to biseriate	3-9	homogeneous	all procumbent	procumbent	opposite	bordered pits, vestured pits/not observed	Terminalia sp.	24
15	diffuse porous	solitary	wide spread			exclusively uniseriate	3-4				alternate	bordered pits/not observed	Indet sp.	31
16	diffuse porous	solitary	wide spread			uni to biseriate	6-9	homogeneous	all procumbent	procumbent	opposite	bordered pits, vestured pits/ not	Terminalia sp.	47

Type	Vessel porosity	Vessel grouping	Vessel arrangement	Apotracheal parenchyma	Paratracheal parenchyma	Ray width	Ray height	Ray cellular composition	Ray structure	Ray sheath cell	Intervessel/tracheid pit arrangement	Intervessel/vessel-ray pitting	Identification	Type specimen
												observed		
17	diffuse porous	in radial clusters	radial pattern			uni to triseriate	5-9	homogeneous	all procumbent	procumbent	alternate	bordered to scalariform, vestured pits/not observed	Ficus sp.	57
18	diffuse porous	solitary	wide spread	apotracheal diffuse		exclusively uniseriate	3-4	heterogeneous	body ray cell procumbent with several rows of upright/square marginal cells	upright/square	opposite	bordered pits/not observed	Eucalyptus sp.	60
19	diffuse porous	in radial clusters	radial pattern			exclusively uniseriate	3-4	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Indet.	94
20						uni to biseriate	4-7						Indet.	111
21	diffuse porous	exclusively solitary/90% or more	wide spread			3 to 10 seriate	17-48+				alternate	bordered pits/not observed	Proteaceae	115
22	diffuse porous	solitary	wide spread	apotracheal diffuse	paratracheal confluent, paratracheal unilateral, paratracheal vasicentric	bi to triseriate	13-30	heterogeneous	body ray cell procumbent with several rows of upright/square marginal cells	upright/square	alternate	bordered pits/not observed	Proteaceae	118
23	diffuse porous	clusters common (2 to 3)	wide spread			uni to triseriate	3-13	homogeneous	all procumbent	procumbent	alternate	bordered pits, not vestured/not observed	Proteaceae	121
24	diffuse porous	solitary	radial pattern	apotracheal diffuse		uni to biseriate	5-12	heterogeneous	body ray cell procumbent with row of upright/square marginal cells	upright/square	alternate	bordered pits/not observed	Type 24	127
25	diffuse porous	solitary	radial pattern	apotracheal in aggregates	paratracheal vasicentric, paratracheal confluent, paratracheal unilateral	uni to triseriate	4-12	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Acacia sp.	134
26	diffuse porous	solitary	wide spread			bi to triseriate	3-5	homogeneous	all procumbent	procumbent		Not observed/not observed	Thespesia sp.	140
27	diffuse porous	solitary	wide spread			uni to triseriate	4-8	heterogeneous	body ray cell procumbent with several rows of upright/square marginal cells	upright/square	alternate	bordered pits, not vestured/not observed	Asteromyrtus sp.	148
28	homogeneous	solitary	diagonal patterns	apotracheal diffuse		exclusively uniseriate	3-10	homogeneous	all procumbent	procumbent	alternate	bordered pits/reduced borders to apparently simple	Eucalyptus sp.	204
29	diffuse porous	solitary	diagonal patterns		paratracheal winged aliform, paratracheal unilateral	exclusively uniseriate	4-7	heterogeneous	body ray cell procumbent with row of	upright/square	alternate	Simple/not observed	Indet.	225

Type	Vessel porosity	Vessel grouping	Vessel arrangement	Apotracheal parenchyma	Paratracheal parenchyma	Ray width	Ray height	Ray cellular composition	Ray structure	Ray sheath cell	Intervessel/tracheid pit arrangement	Intervessel/vessel-ray pitting	Identification	Type specimen
									upright/square marginal cells					
30	diffuse porous	solitary	radial to diagonal pattern	apotracheal diffuse	paratracheal unilateral	bi to triseriate	4-40	heterogeneous	all upright/square	procumbent	alternate	bordered pits/not observed	Proteaceae	244
31	diffuse porous	clusters common (3 or more)	radial pattern	apotracheal diffuse		exclusively uniseriate	3-6	homogeneous	all upright/square	upright/square	alternate	bordered pits/not observed	Indet.	245
32	diffuse porous	solitary	radial pattern		paratracheal unilateral	bi to triseriate	8-10	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Terminalia sp.	285
33	diffuse porous	solitary	radial pattern		in large bans (more than 3 cells wide)	exclusively uniseriate	4-6	homogeneous	all procumbent	procumbent	alternate	Simple, vestured pits/not observed	Terminalia sp.	288
34	diffuse porous	solitary	wide spread		paratracheal unilateral	uni to biseriate	4-10	homogeneous	all procumbent	procumbent	opposite	bordered pits, vestured pits/ reduced borders to apparently simple	Eucalyptus sp.	349
35	diffuse porous	exclusively solitary/90% or more	wide spread	apotracheal in aggregates	in narrow bands (up to 3 cells wide), paratracheal vasicentric, paratracheal unilateral	uni to biseriate	4-10	homogeneous	all upright/square	upright/square	alternate	simple to scalariform/not observed	Terminalia sp.	400
36	diffuse porous	solitary	wide spread			exclusively uniseriate	5-10	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Indet.	418
37	homogeneous	clusters common (2 to 3)	radial pattern	apotracheal diffuse	paratracheal unilateral	exclusively uniseriate	3-10	heterogeneous	all upright/square	procumbent	alternate	simple to scalariform/not observed	Terminalia sp.	472
38	homogeneous	clusters common (3 or more)	radial pattern			bi to triseriate	14-22	homogeneous	all procumbent	procumbent	alternate	Scalariform, not vestured/similar in size and shape to intervessel pits	Alstonia sp.	530
39	ring porous	solitary	tangential bands			uni to biseriate	4-7	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Lophostemon sp.	540
40	diffuse porous	clusters common (2 to 3)	radial to diagonal pattern			uni to biseriate	3-7	homogeneous	all upright/square	upright/square	alternate	bordered pits/not observed	Calytrix sp.	543
41	diffuse porous	in radial clusters	radial pattern		paratracheal vasicentric, paratracheal unilateral	exclusively uniseriate	6-20	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Acacia sp.	608
42	diffuse porous	clusters common (2 to 3)	radial pattern			uniseriate						Simple, not vestured/not observed	Brachychiton sp.	652
43	diffuse porous	clusters common (2 to 3)	radial pattern			3 to 10 seriate	13-30	heterogeneous	body ray cell procumbent with row of upright/square marginal cells	upright/square	alternate	bordered pits, vestured/not observed	Grewia sp.	662
44	diffuse porous	clusters common (2 to 3)	radial pattern		paratracheal unilateral	uni to biseriate	7-10	homogeneous	all procumbent	procumbent	alternate	bordered pits, vestured/not observed	Corymbia sp.	808
45	homogeneous					exclusively	3-4	homogeneous	all	procumbent			Callitris sp.	840

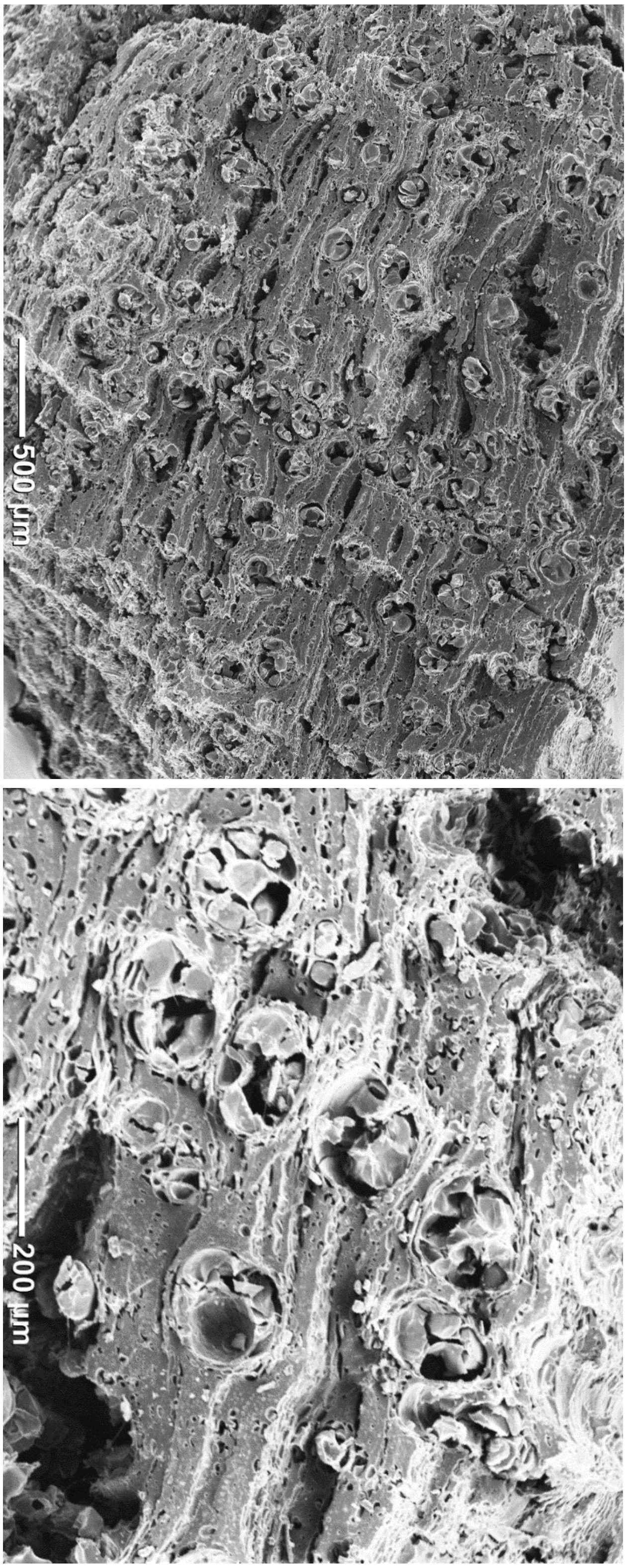
Type	Vessel porosity	Vessel grouping	Vessel arrangement	Apotracheal parenchyma	Paratracheal parenchyma	Ray width	Ray height	Ray cellular composition	Ray structure	Ray sheath cell	Intervessel/tracheid pit arrangement	Intervessel/vessel-ray pitting	Identification	Type specimen
						uniseriate			procumbent					
46	diffuse porous	clusters common (2 to 3)	radial pattern	apotracheal diffuse	paratracheal unilateral	uni to biseriate	7-13	homogeneous	all procumbent	procumbent	opposite	bordered pits/not observed	Alphitonia sp.	1016
47	diffuse porous	in radial clusters	radial to diagonal pattern		paratracheal vasicentric	uni to triseriate	3-10	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Acacia sp.	1133
48	diffuse porous	in radial clusters	wide spread	apotracheal diffuse	paratracheal unilateral	uni to biseriate	3-5	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Type 48	1163
49	diffuse porous	in radial clusters	radial pattern	apotracheal diffuse	paratracheal vasicentric, paratracheal unilateral	uni to biseriate	9-42	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Acacia sp.	1241
50	abrupt change in tracheid diam	clusters common (2 to 3)	wide spread	apotracheal diffuse	paratracheal vasicentric, paratracheal confluent, paratracheal unilateral	uni to biseriate	4-11	homogeneous	all procumbent	procumbent	alternate	bordered to scalariform/not observed	Corymbia sp.	1296
51	diffuse porous	clusters common (3 or more)	radial pattern			uni to biseriate						Not observed/not observed	Coelospermum sp.	1345
52	diffuse porous	in radial clusters	radial pattern	apotracheal diffuse	paratracheal vasicentric, paratracheal unilateral	bi to triseriate	9-11	homogeneous	all procumbent	procumbent		Not observed/not observed	Acacia sp.	1454
53	diffuse porous	solitary	radial to diagonal pattern			uni to biseriate	6-15	heterogeneous	body ray cell procumbent with several rows of upright/square marginal cells	upright/square	alternate	bordered pits/ similar in size and shape to intervessel pits	Eucalyptus sp.	1621
54	diffuse porous	in radial clusters	radial pattern	apotracheal diffuse	paratracheal unilateral	uni to biseriate	4-15	homogeneous	all procumbent	procumbent	opposite	bordered pits/not observed	Eucalyptus sp.	1625
55	diffuse porous	in radial clusters	radial pattern		paratracheal vasicentric, paratracheal confluent, paratracheal unilateral	3 to 10 seriate	10-12	heterogeneous	body ray cell procumbent with several rows of upright/square marginal cells	upright/square	alternate	bordered to scalariform, vestured pits/not observed	Proteaceae	1633
56	diffuse porous	solitary	wide spread		in narrow bands (up to 3 cells wide)	exclusively uniseriate	4-6	homogeneous	all procumbent	procumbent	alternate	bordered pits/not observed	Corymbia sp.	1590
57	diffuse porous	solitary	wide spread			bi to triseriate	14-30	homogeneous	all procumbent	procumbent	alternate	Simple/not observed	Ficus sp.	1869
58	semi-ring porous	solitary	radial pattern	apotracheal diffuse	paratracheal confluent, paratracheal unilateral	uni to biseriate	4-14	homogeneous	all procumbent	procumbent	alternate	Simple, vestured pits/ not observed	Acacia sp.	1880
59	abrupt change in tracheid diam	in radial clusters	tangential bands	apotracheal diffuse	paratracheal unilateral	uni to biseriate	4-7	heterogeneous	body ray cell procumbent with several rows of	upright/square	alternate	bordered pits/not observed	Syzygium sp.	2067

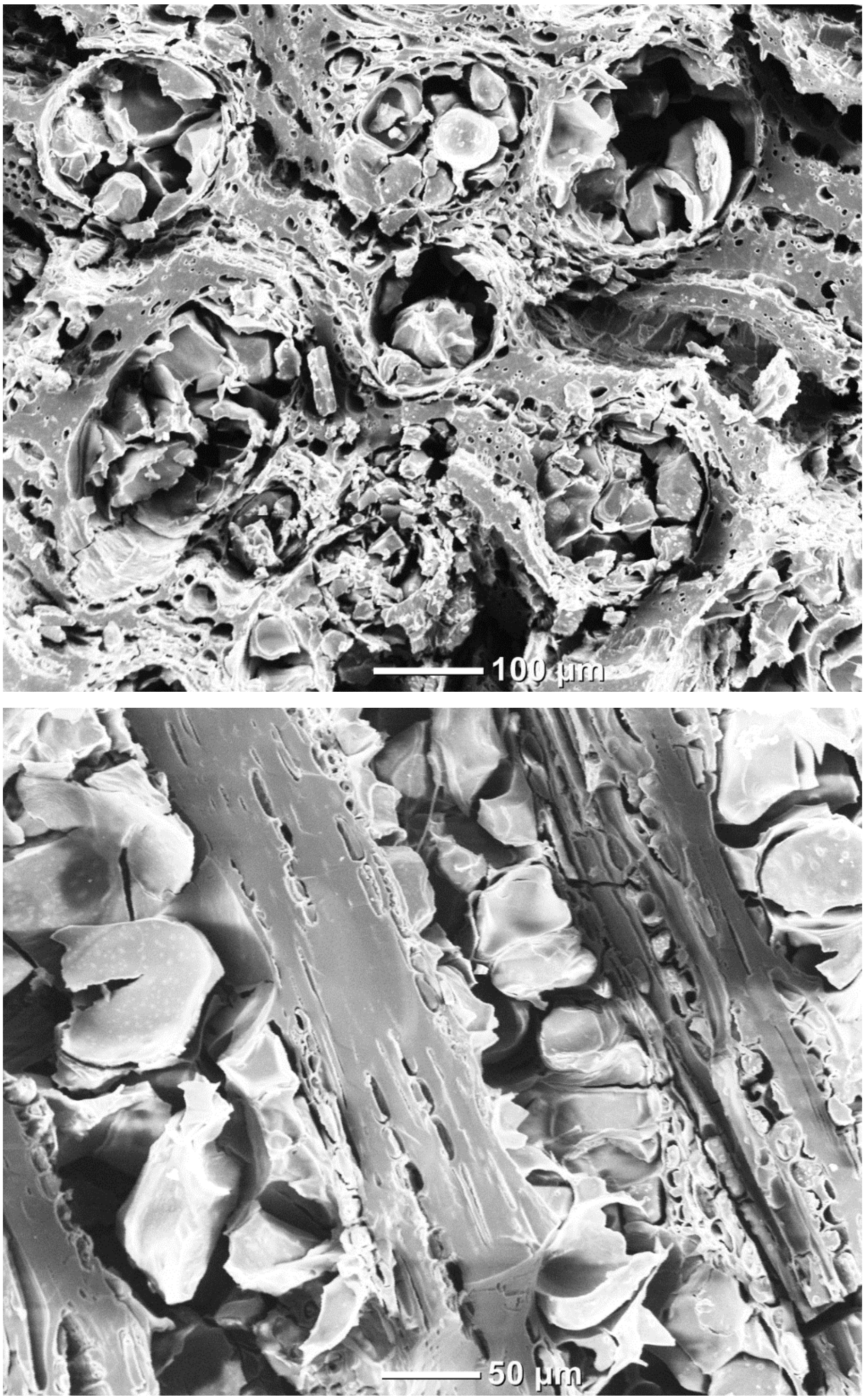
Type	Vessel porosity	Vessel grouping	Vessel arrangement	Apotracheal parenchyma	Paratracheal parenchyma	Ray width	Ray height	Ray cellular composition	Ray structure	Ray sheath cell	Intervessel/tracheid pit arrangement	Intervessel/vessel-ray pitting	Identification	Type specimen
									upright/square marginal cells					
60	diffuse porous	clusters common (2 to 3)	radial to diagonal pattern		paratracheal confluent, apotracheal diffuse	exclusively uniseriate	4-17	heterogeneous	mixed cellular composition	upright/square	alternate	Simple/not observed	Corymbia sp.	2124
61	semi-ring porous	in radial clusters	radial pattern		in narrow bands (up to 3 cells wide), paratracheal confluent, paratracheal unilateral	exclusively uniseriate	4-10	homogeneous	all procumbent	procumbent	alternate	Simple/not observed	Corymbia sp.	2182

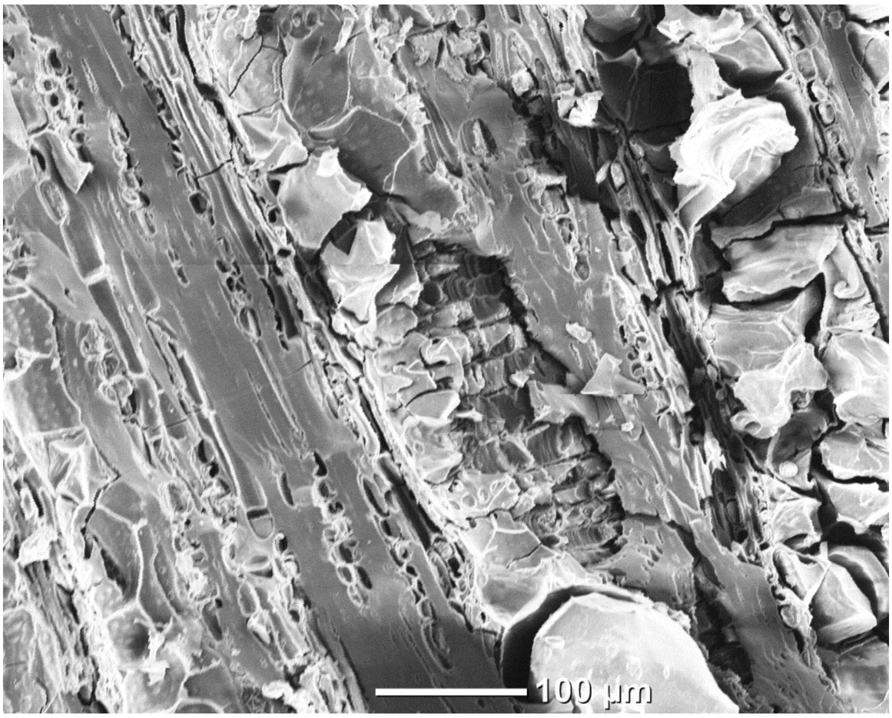
Appendix H – SEM images of archaeological type specimens

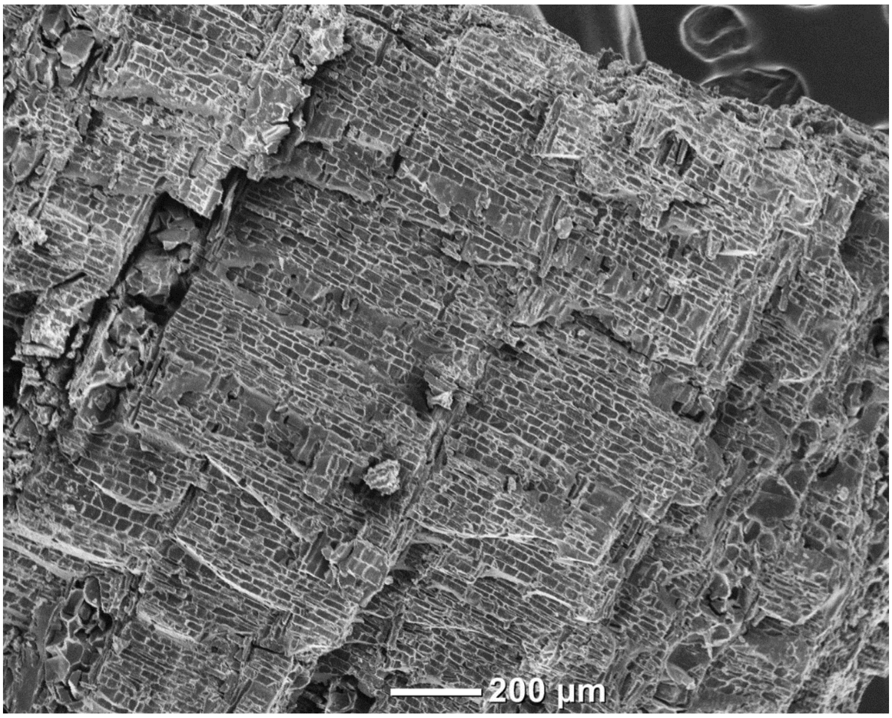
Madjedbebe archaeological type specimen scanning electron microscope (SEM) images.

Myrtaceae – *Eucalyptus* sp. (Type 1)

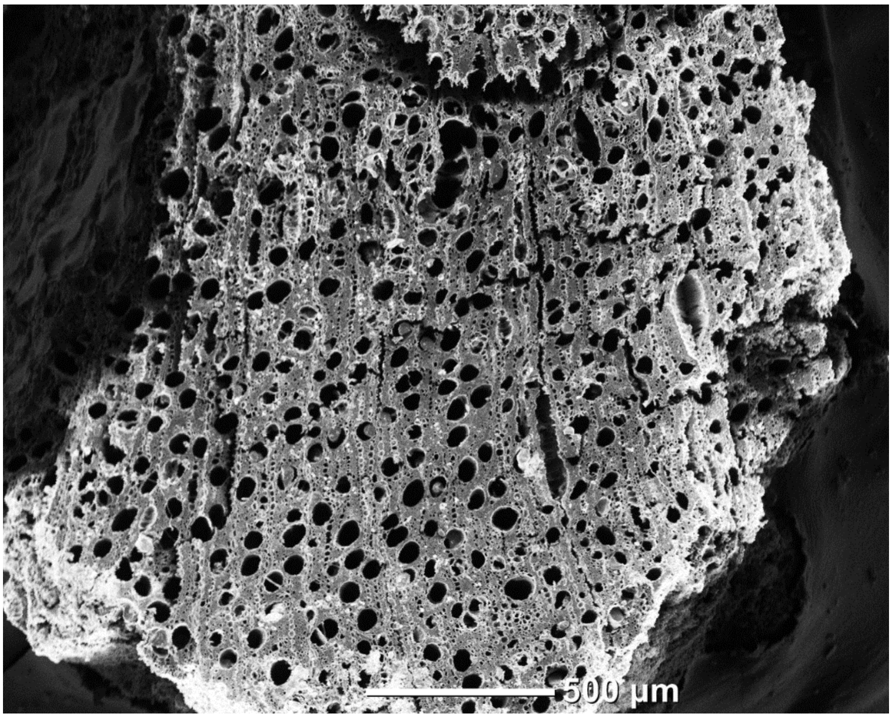


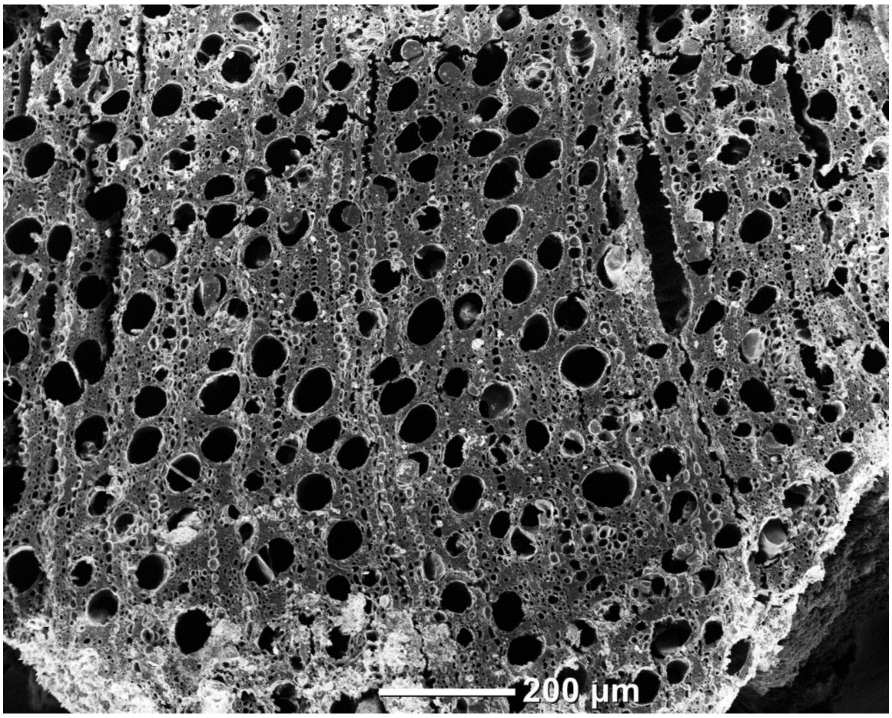

100 µm
50 µm

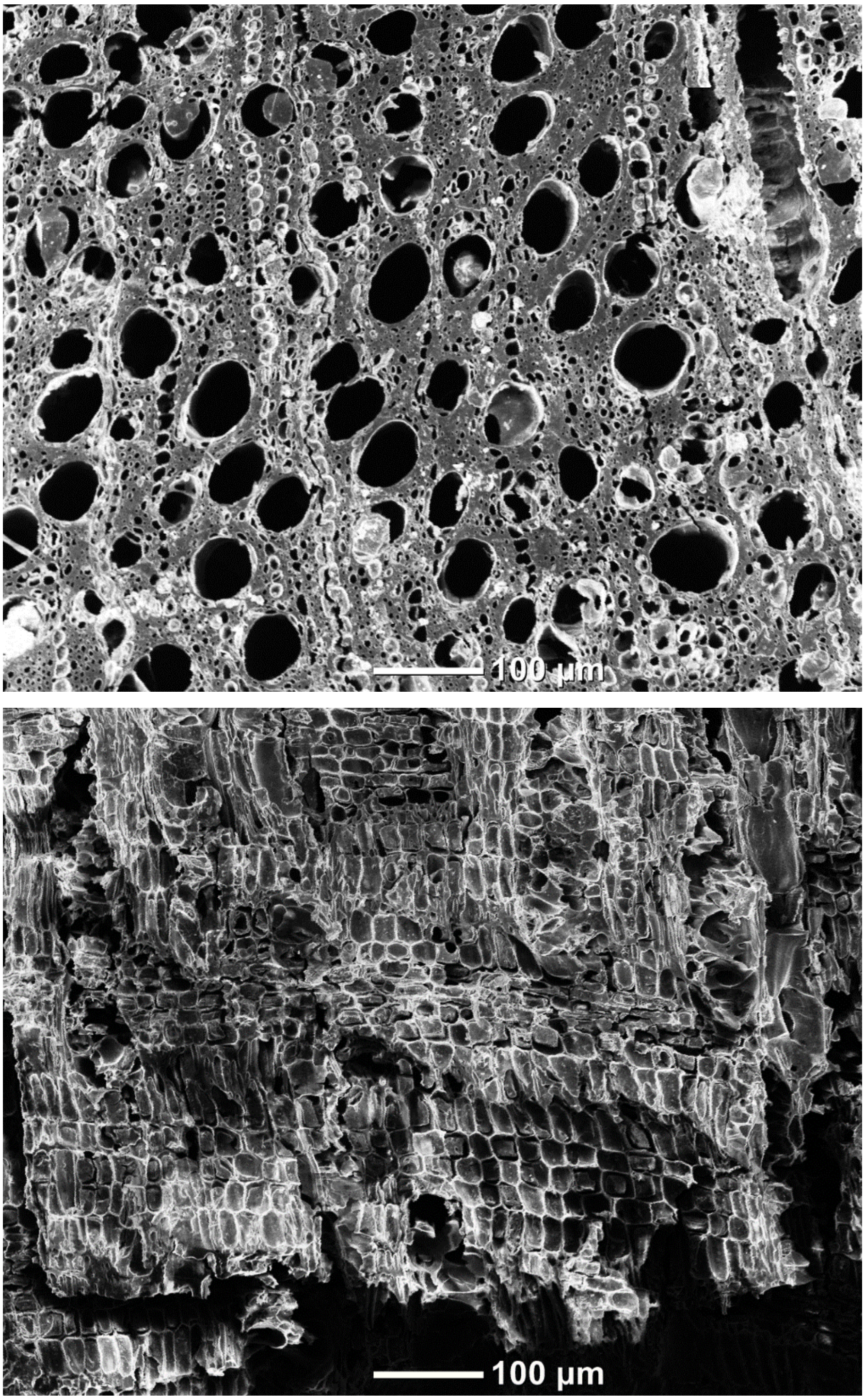

100 µm


200 µm

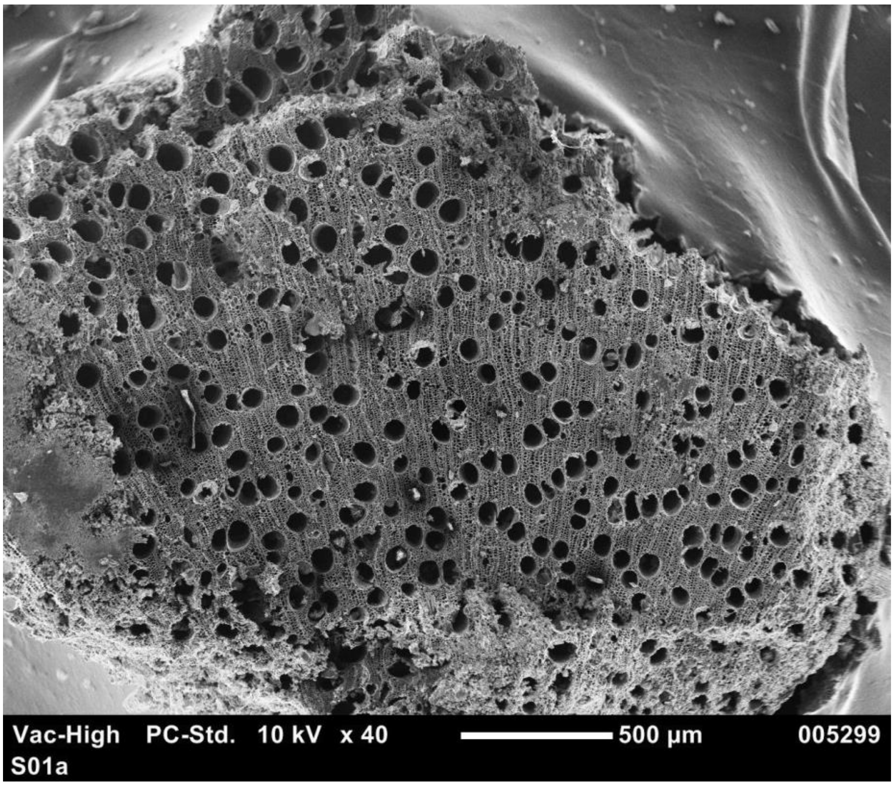
Myrtaceae – *Eucalyptus* sp. (Type 18)

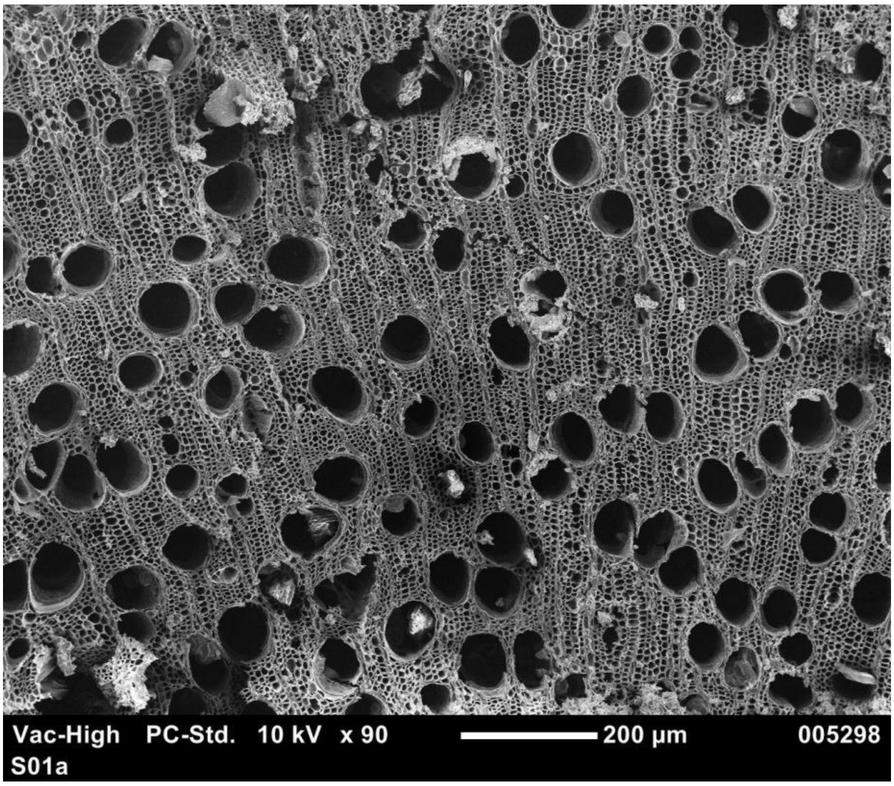


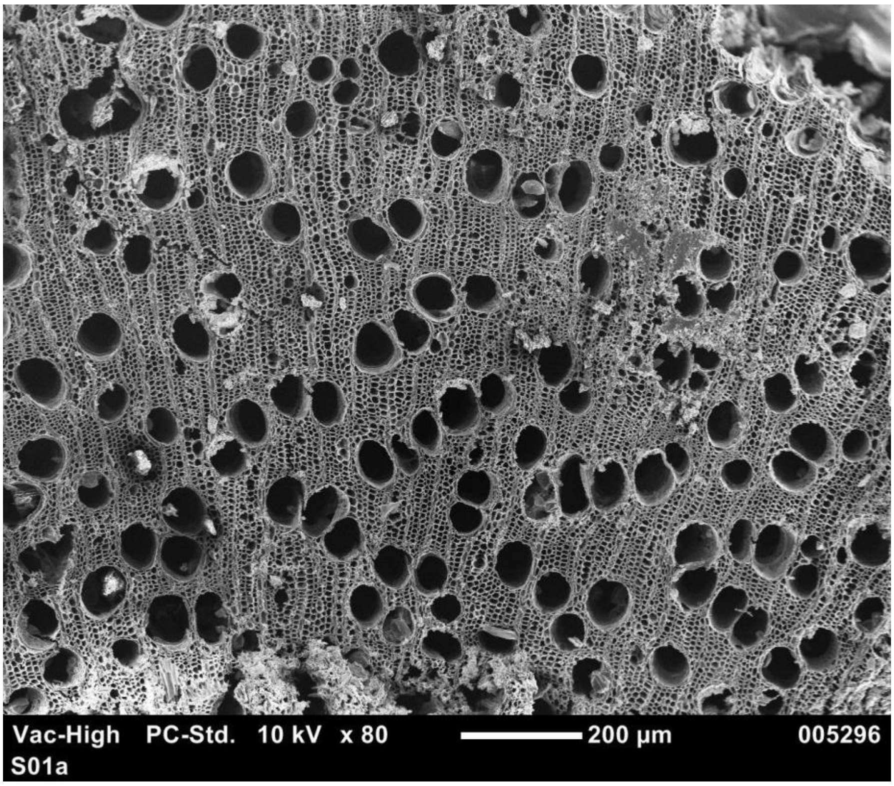


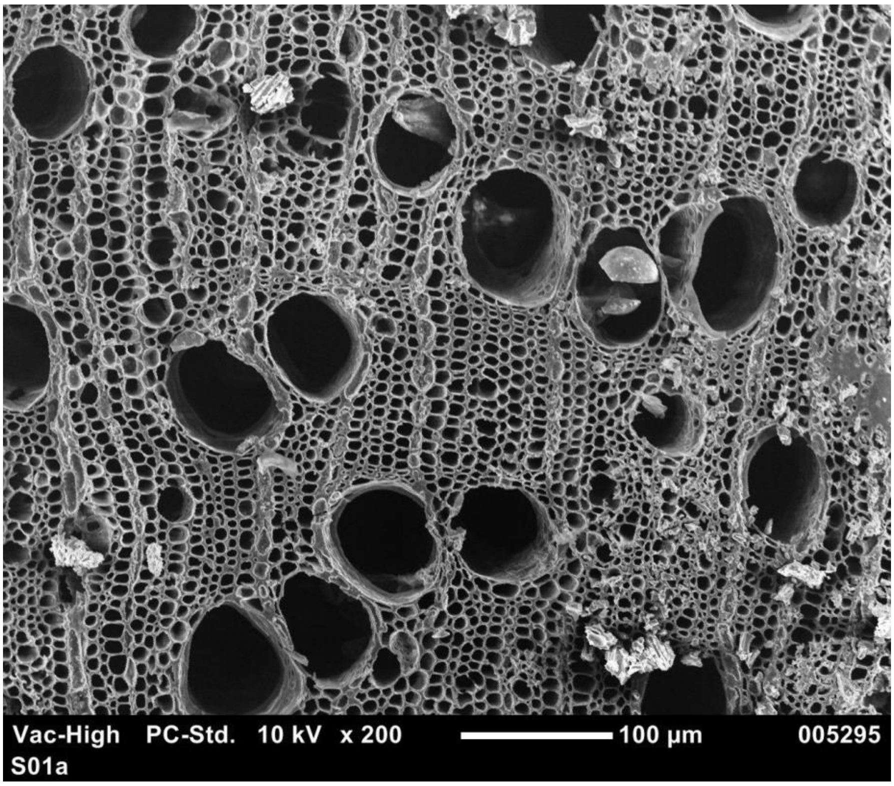

100 µm
100 µm

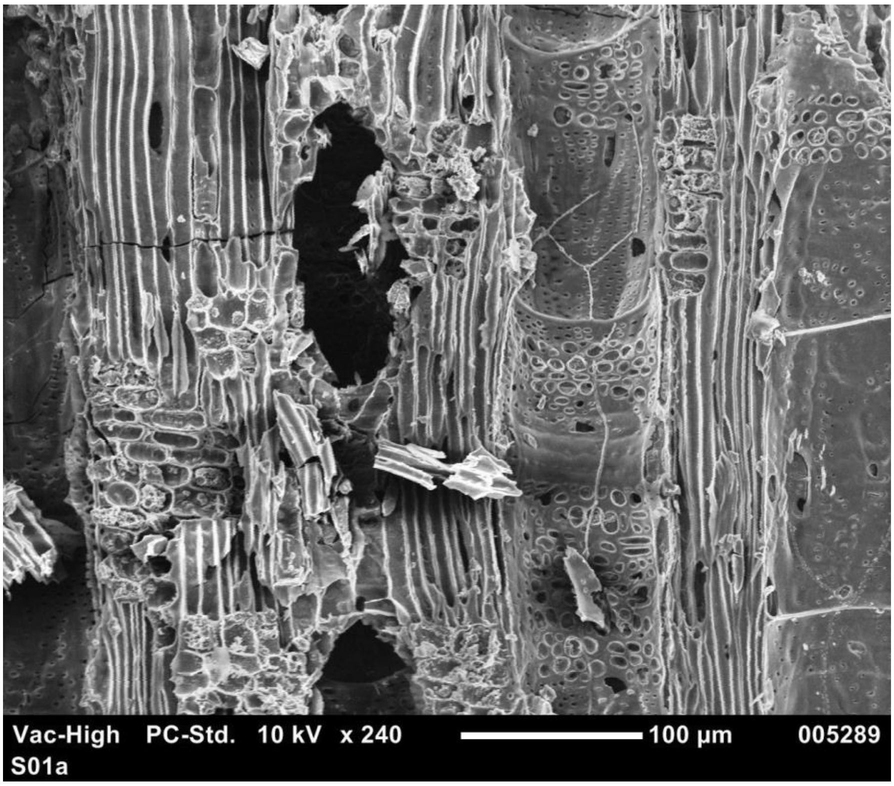
Myrtaceae – *Eucalyptus* sp. (Type 28)



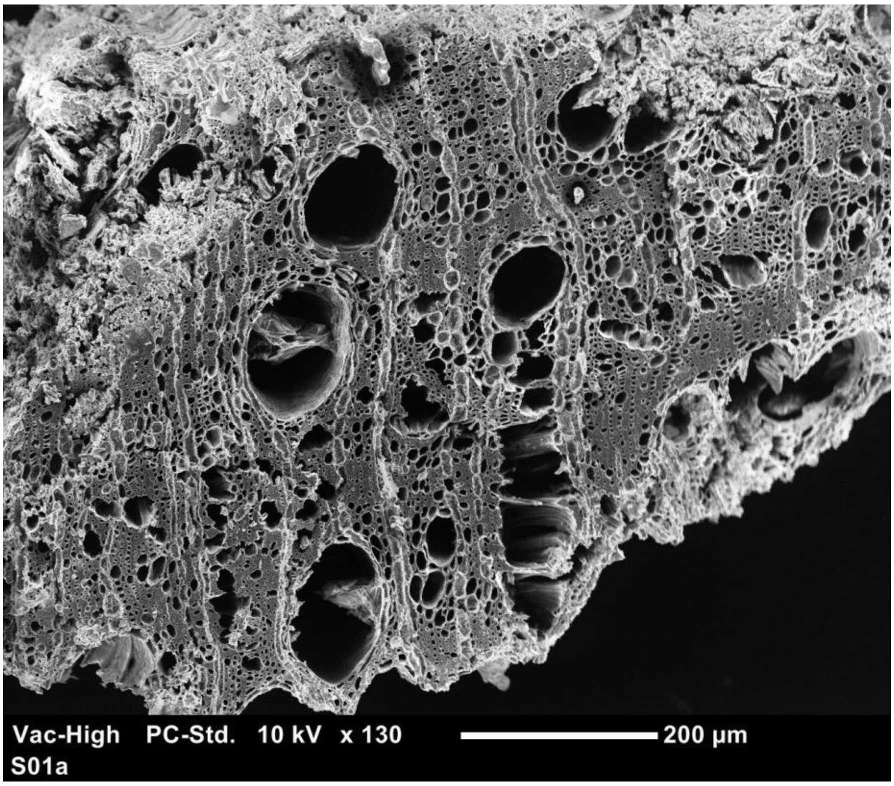


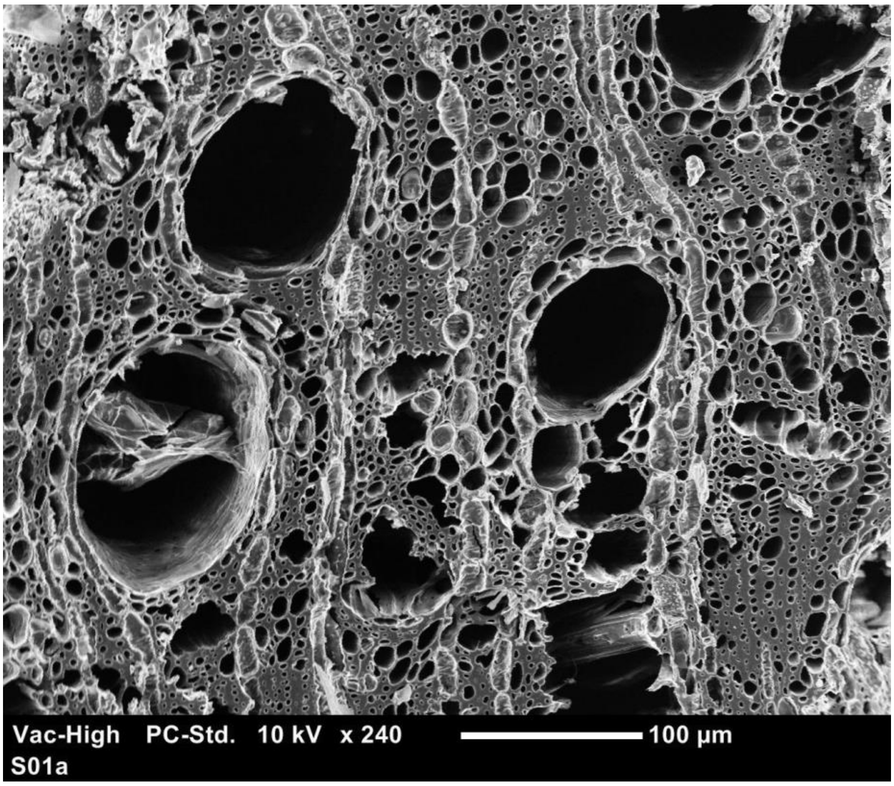

Vac-High PC-Std. 10 kV x 80
200 µm
005296
S01a

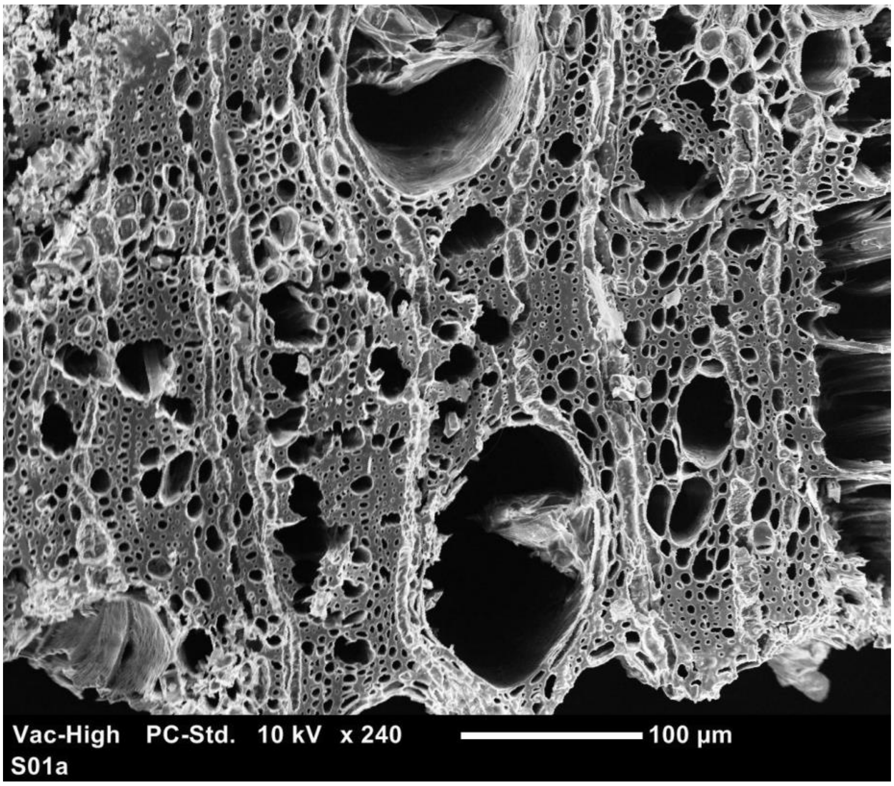

Vac-High PC-Std. 10 kV x 200
100 µm
005295
S01a

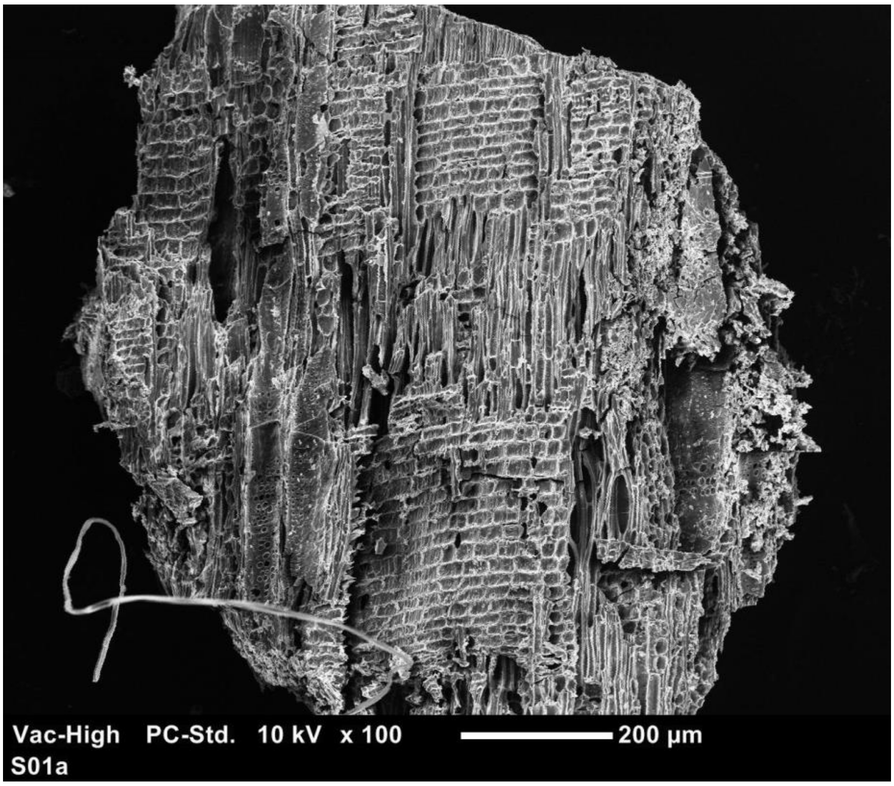

Vac-High PC-Std. 10 kV x 240
100 µm
005289
S01a

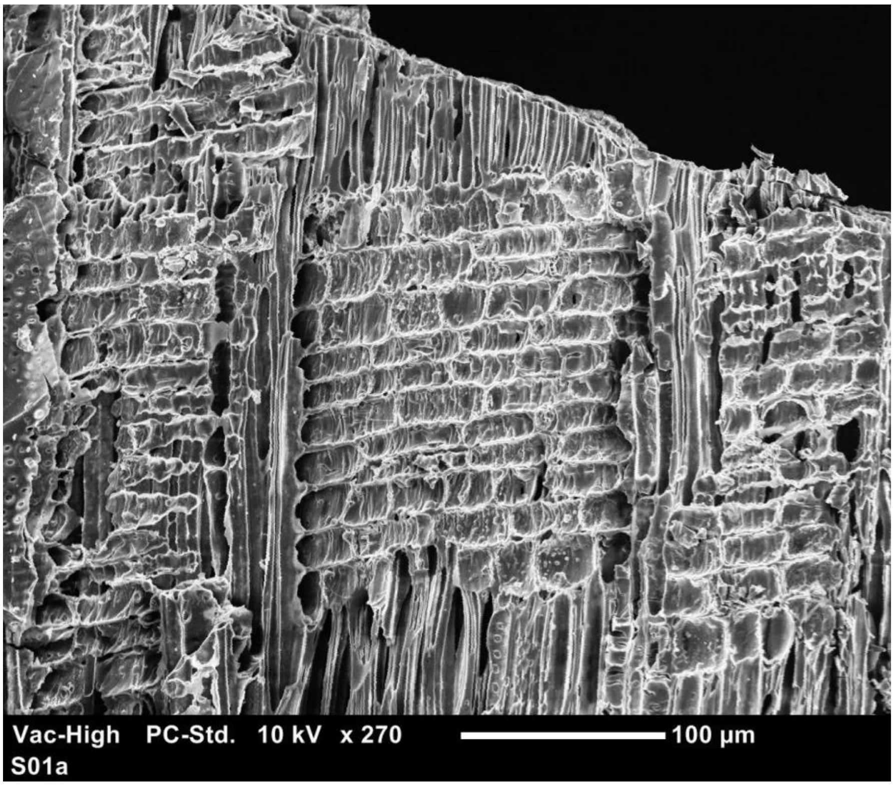
Myrtaceae – *Eucalyptus* sp. (Type 34)

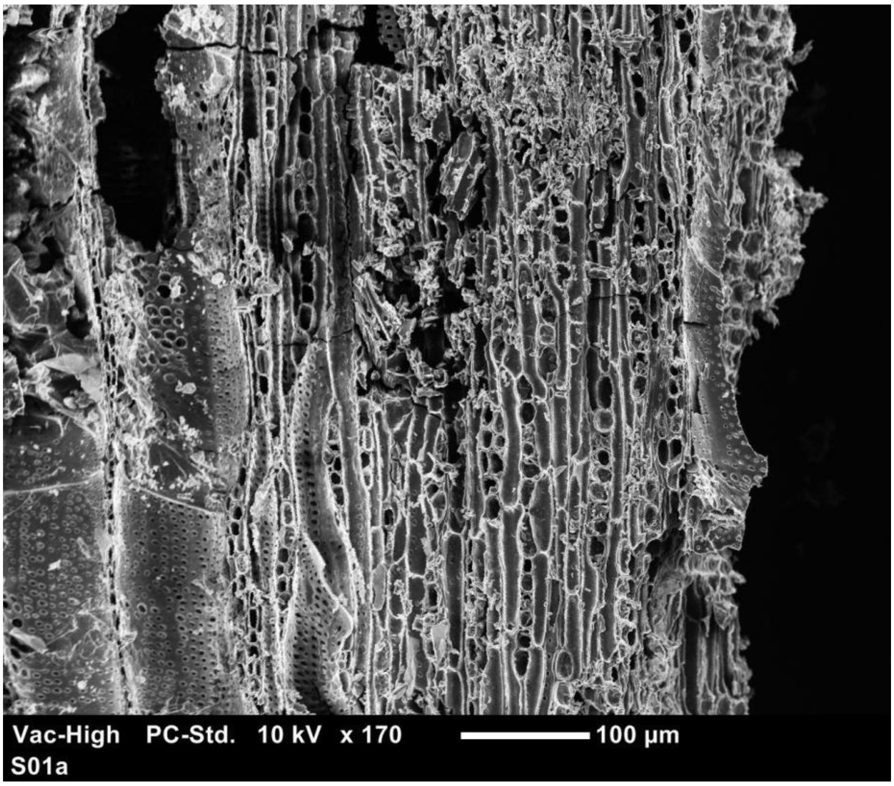




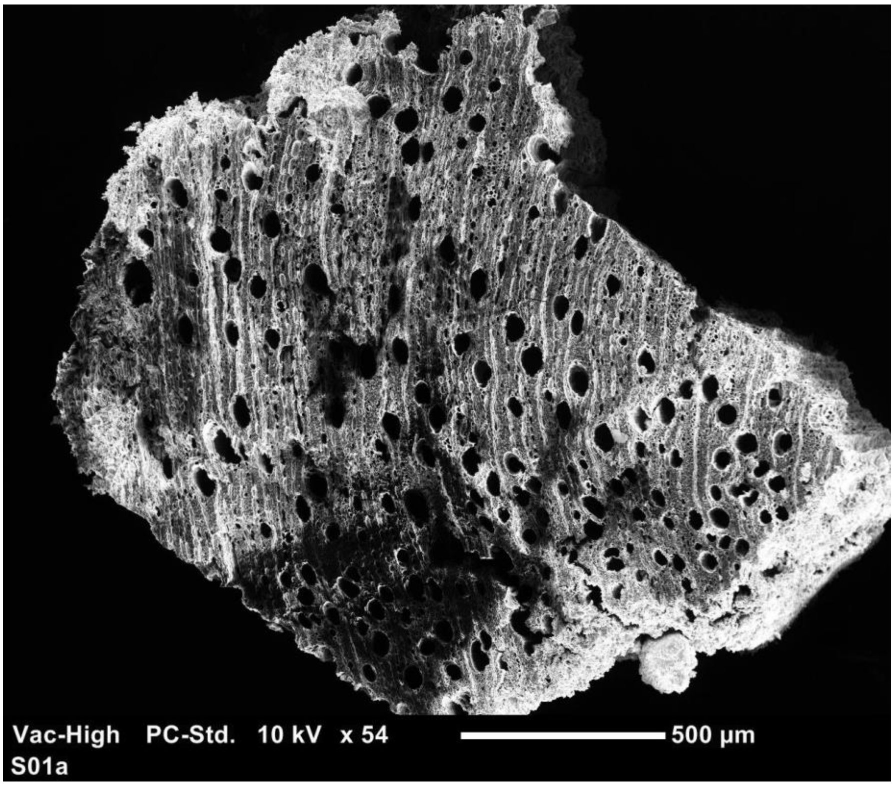

Vac-High PC-Std. 10 kV x 240
100 µm
S01a

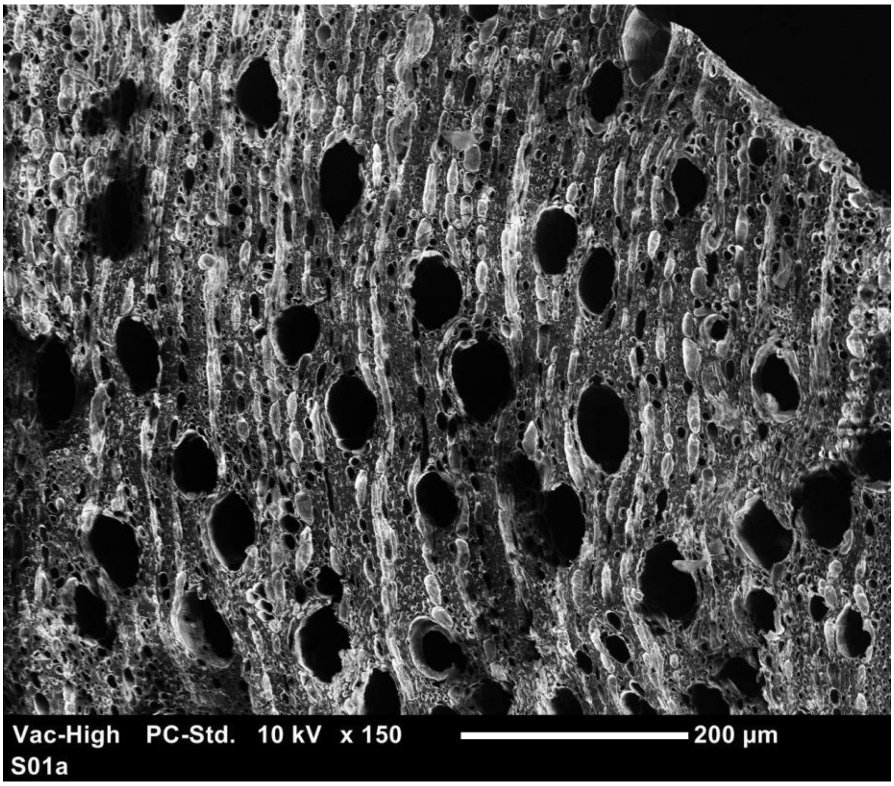

Vac-High PC-Std. 10 kV x 100
200 µm
S01a

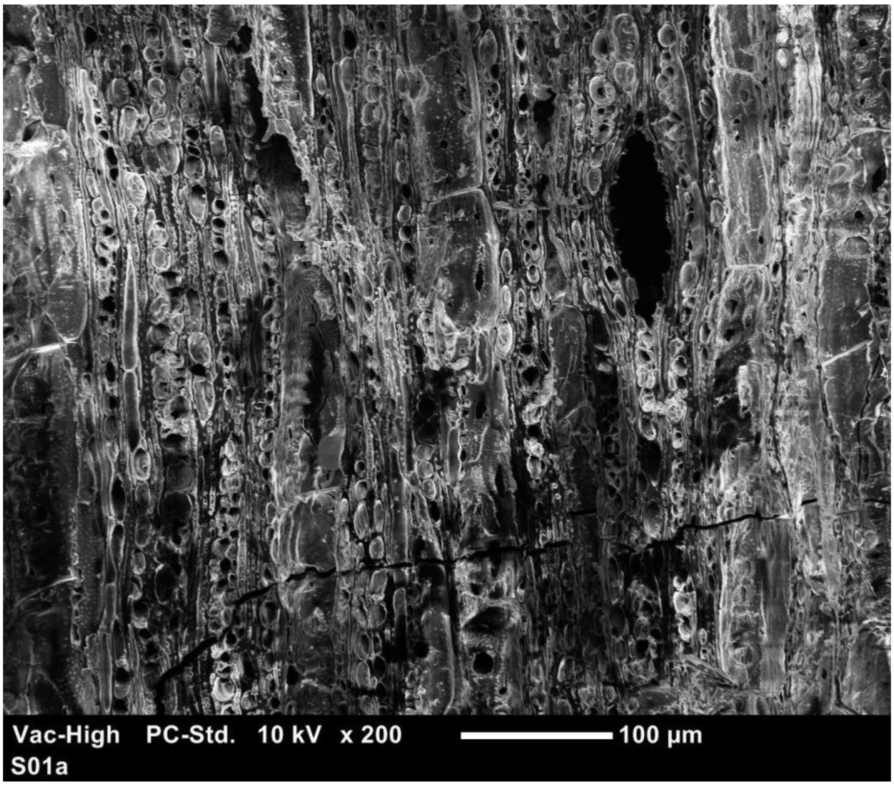

Vac-High PC-Std. 10 kV x 270
100 µm
S01a

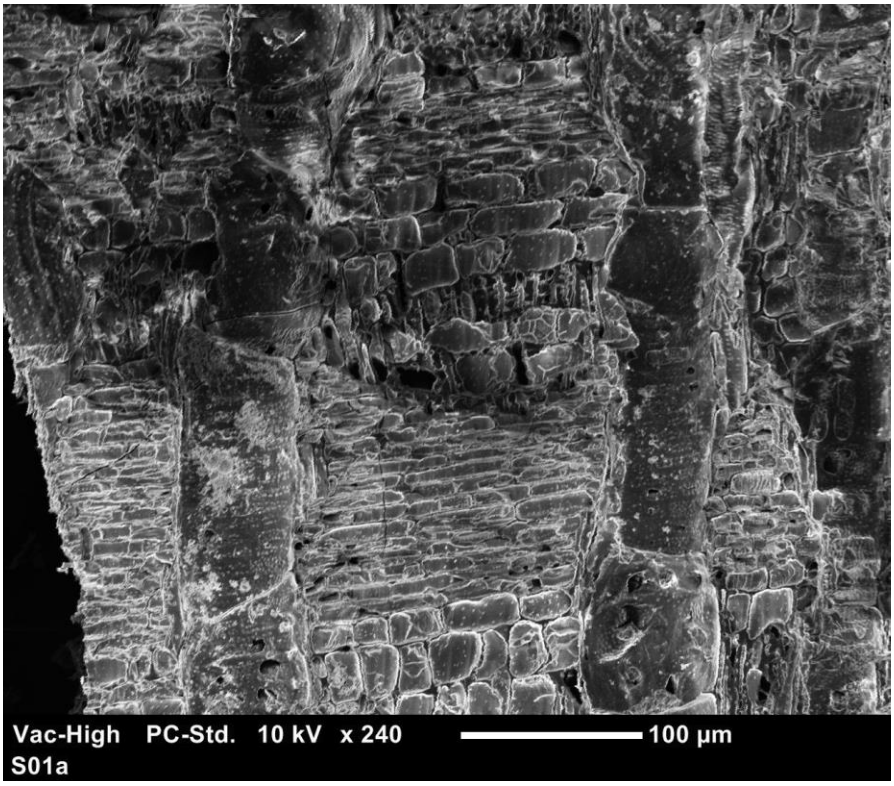

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

Myrtaceae – *Eucalyptus* sp. (Type 53)

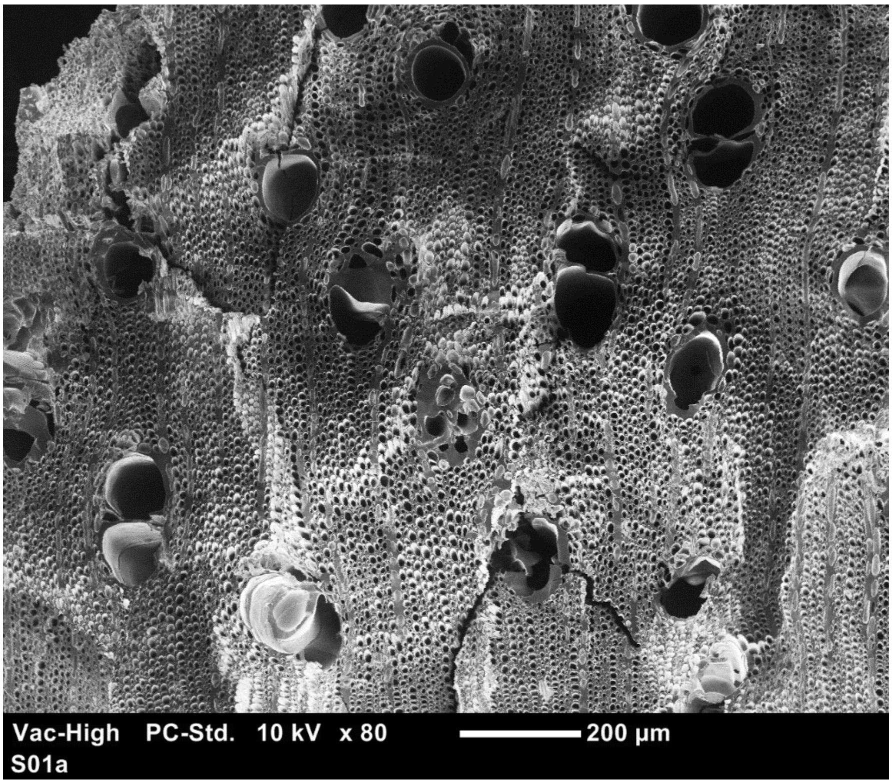


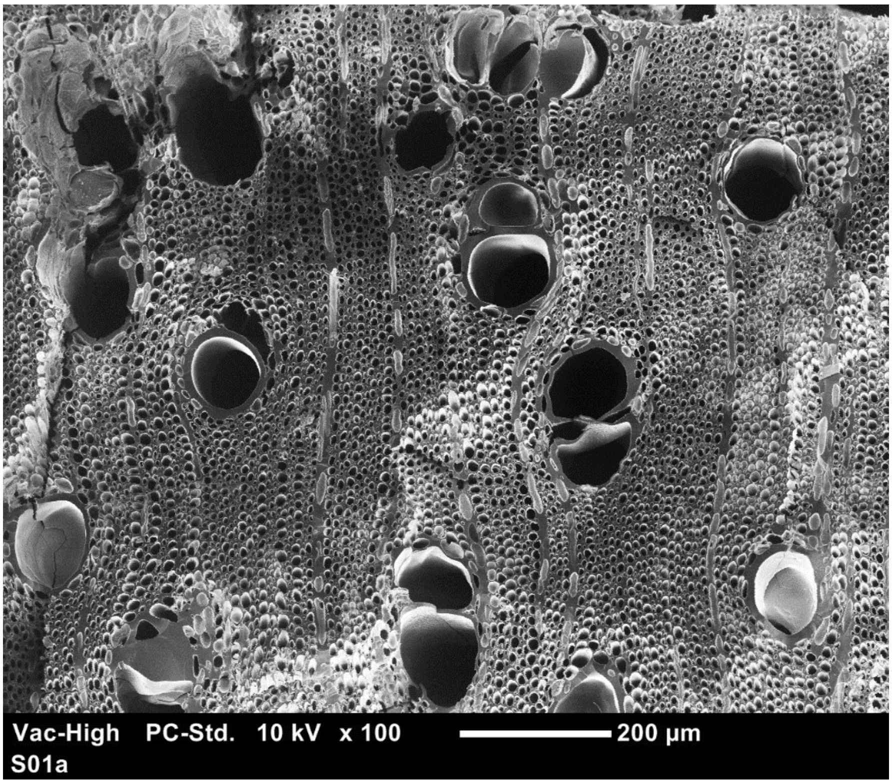


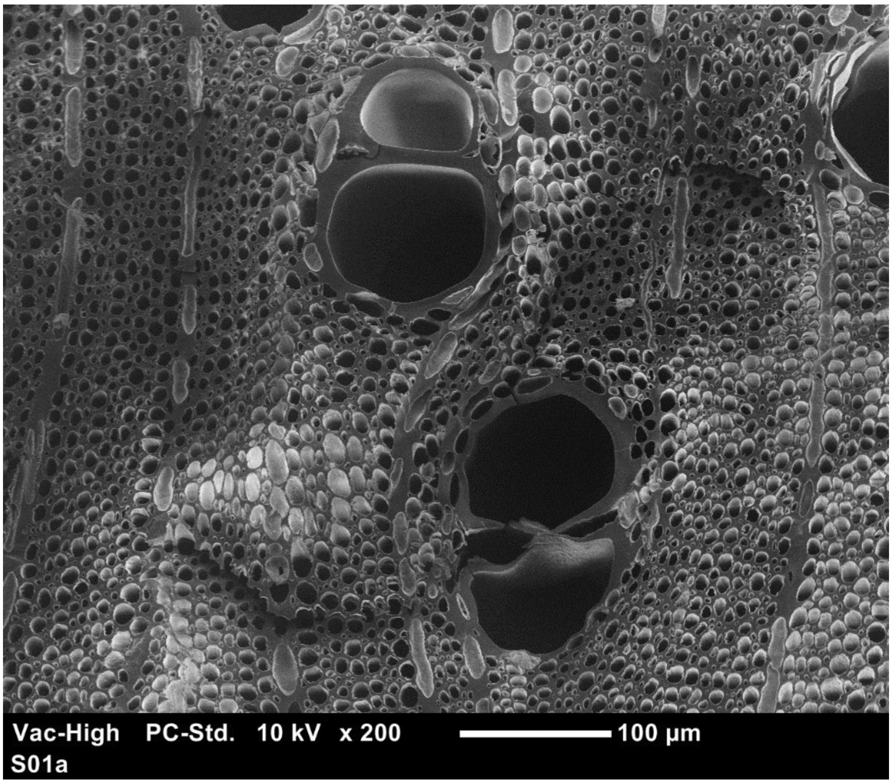

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

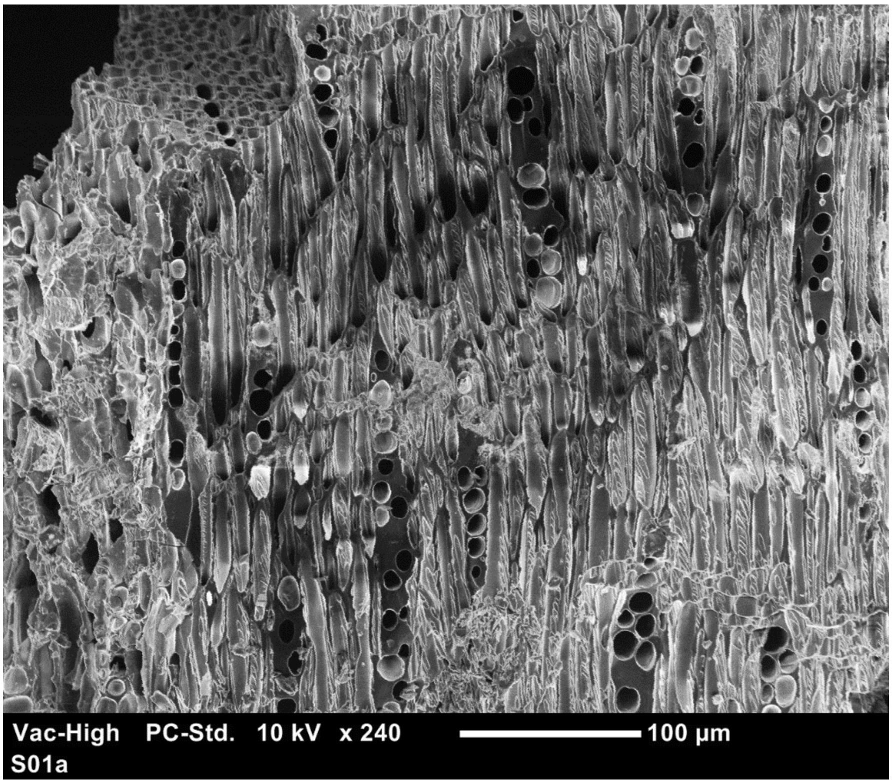

Vac-High PC-Std. 10 kV x 240
100 µm
S01a

Myrtaceae – *Eucalyptus* sp. (Type 54)

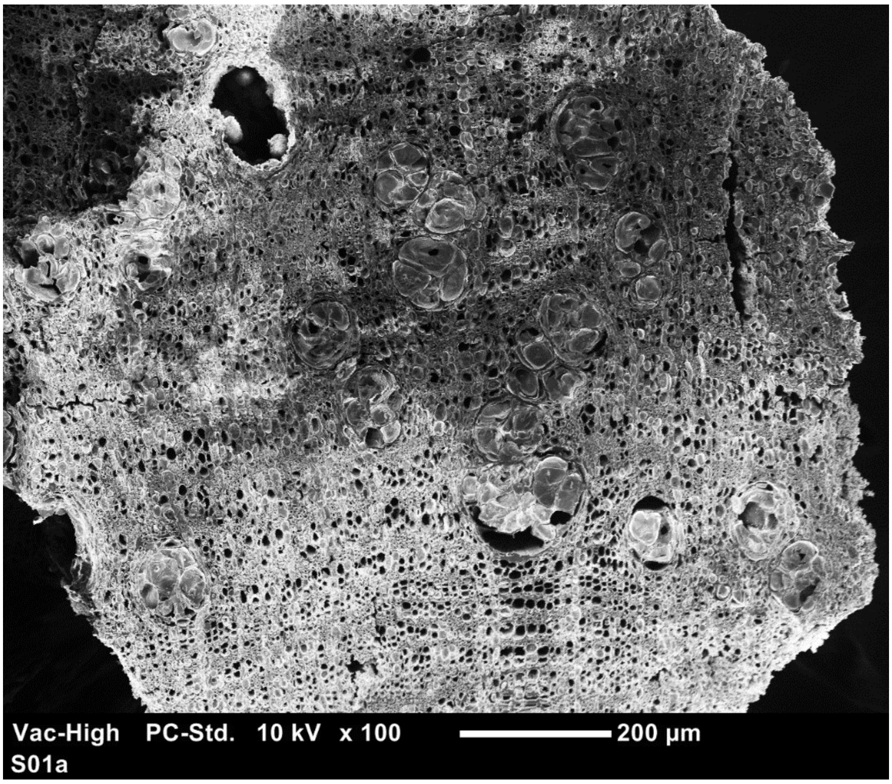


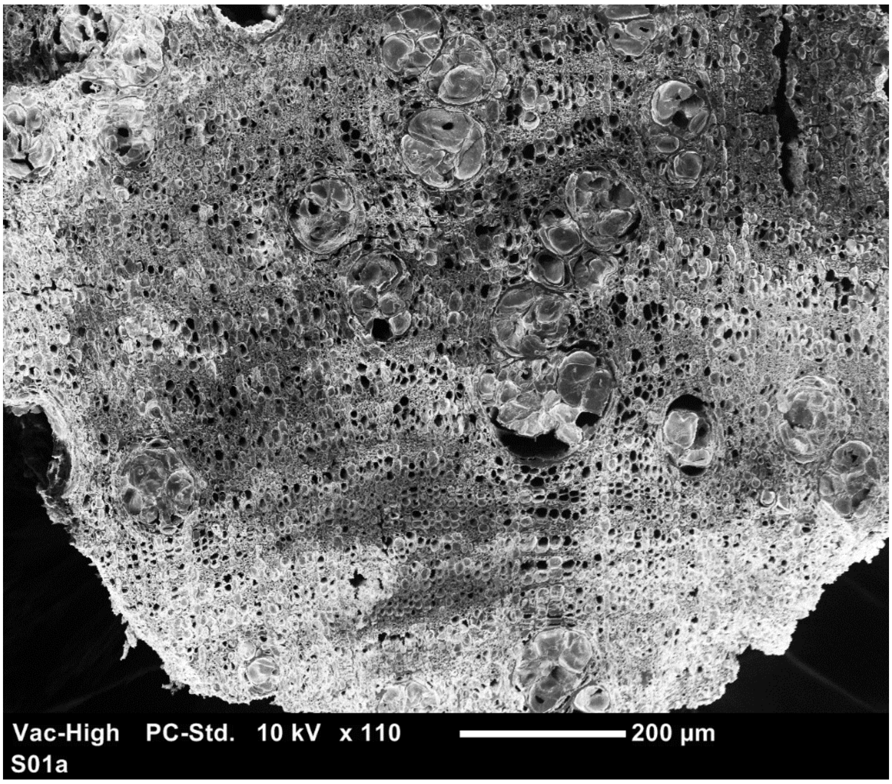


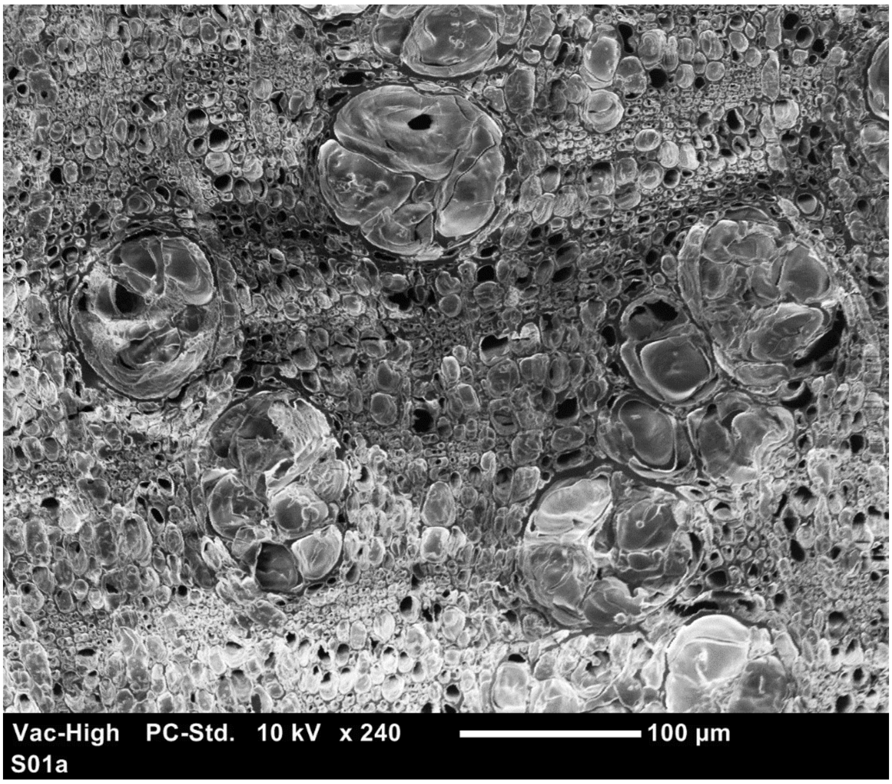

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

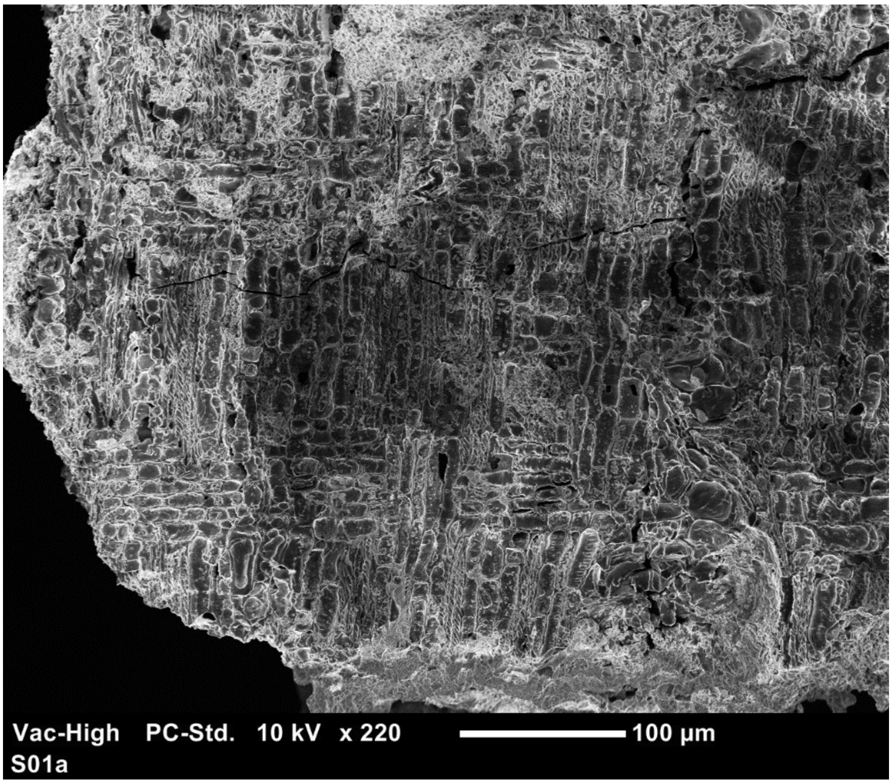

Vac-High PC-Std. 10 kV x 240
100 µm
S01a

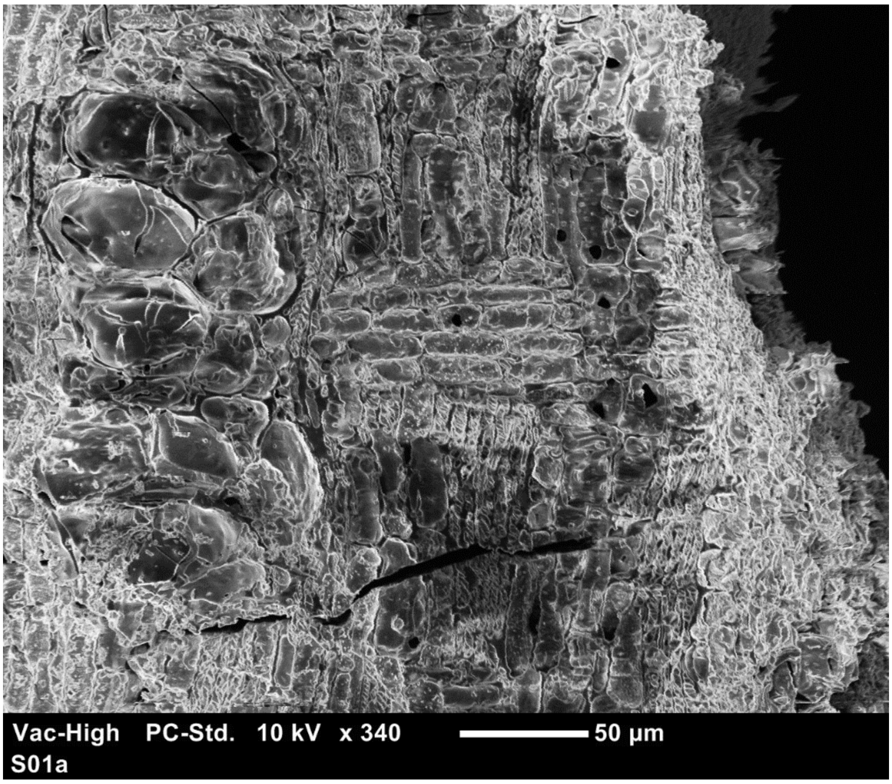
Myrtaceae – *Corymbia* sp. (Type 56)



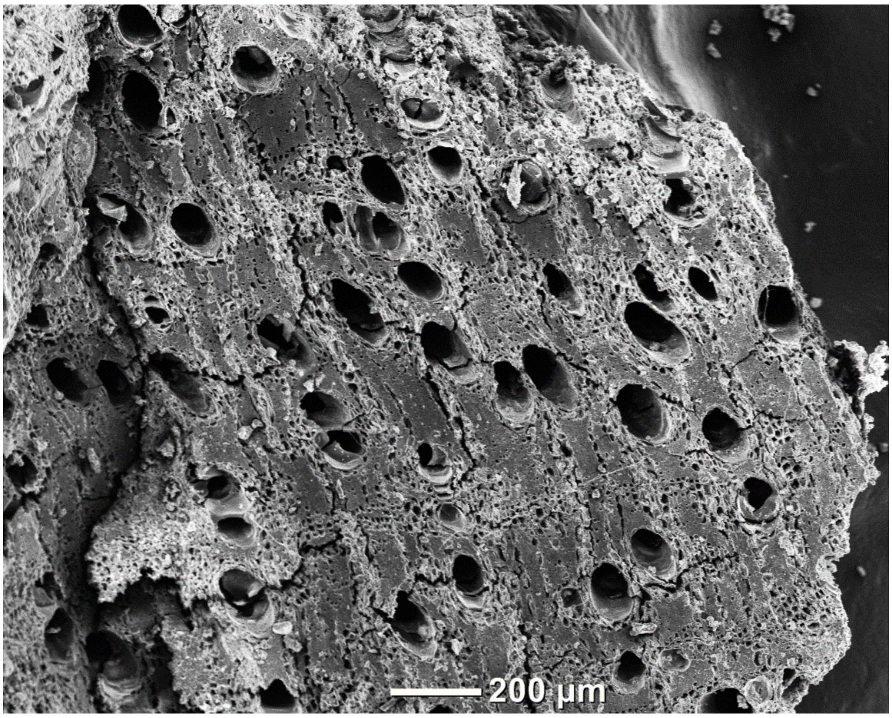


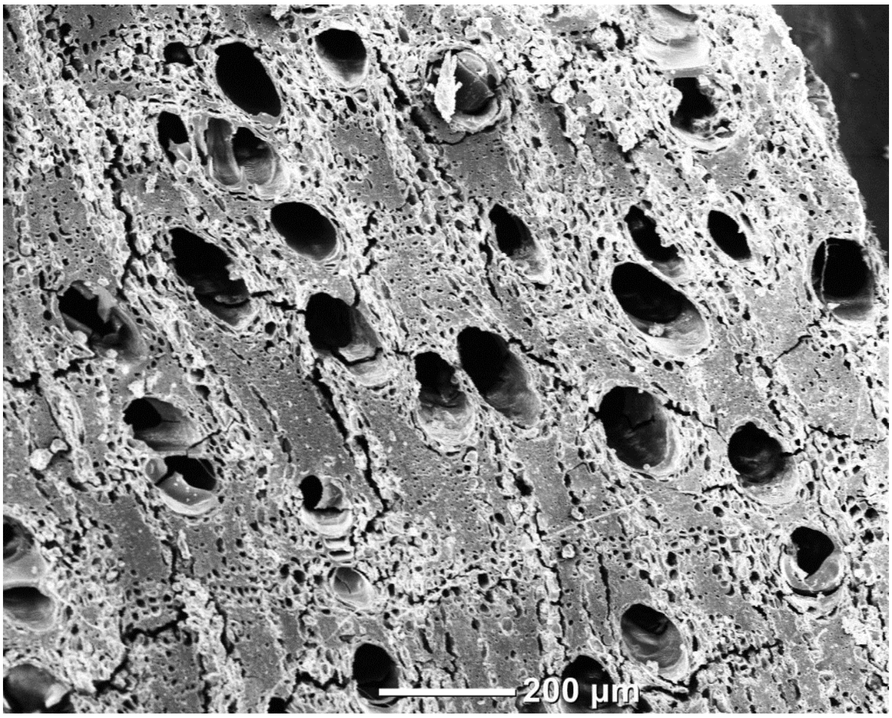

Vac-High PC-Std. 10 kV x 240
100 µm
S01a

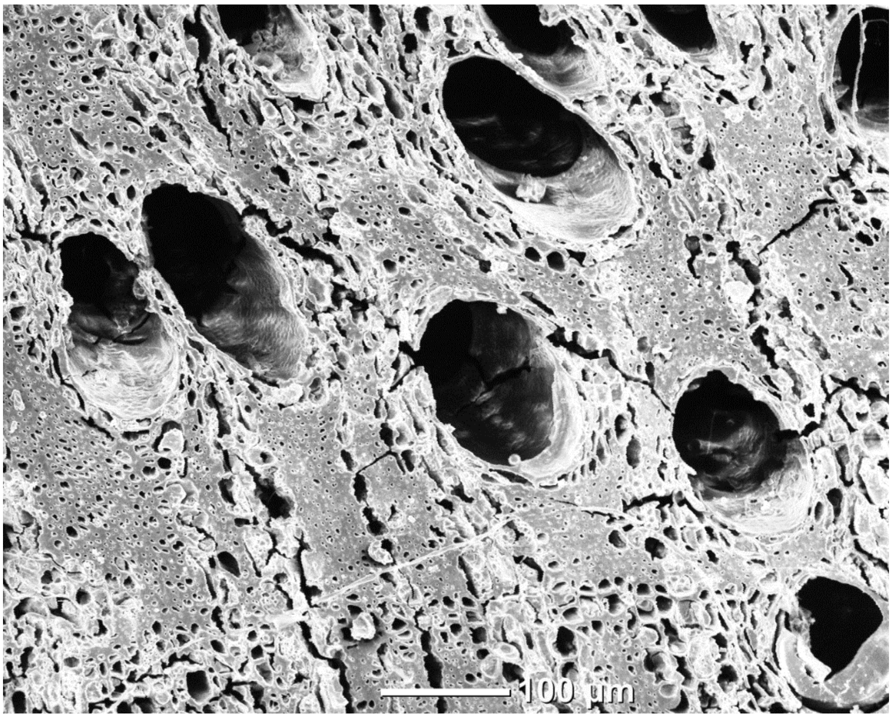

Vac-High PC-Std. 10 kV x 220
100 µm
S01a

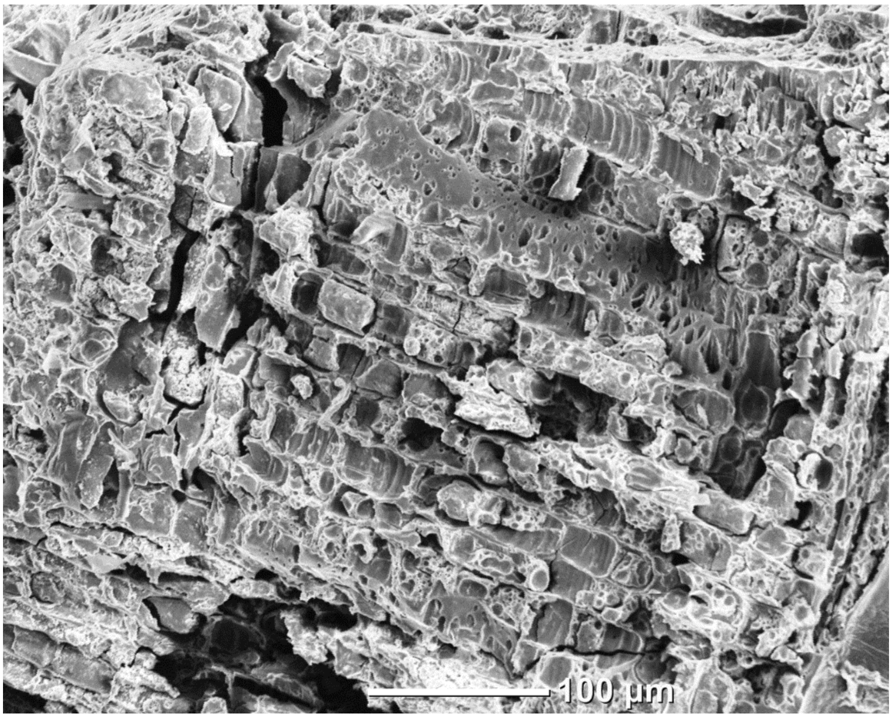

Vac-High PC-Std. 10 kV x 340
50 µm
S01a

Myrtaceae – *Corymbia* sp. (Type 4)



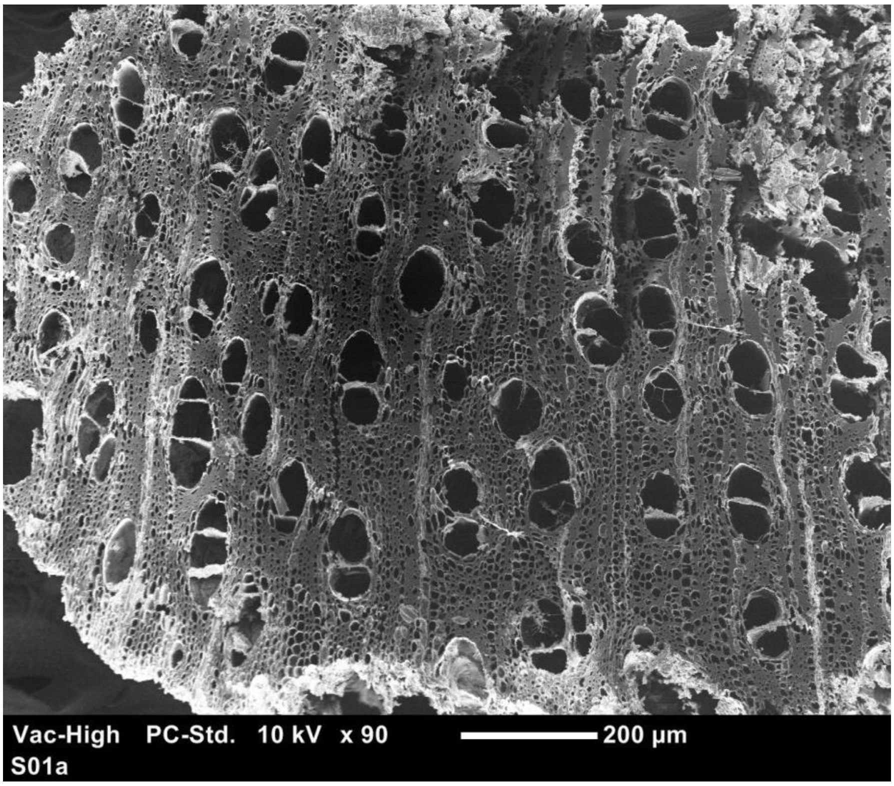


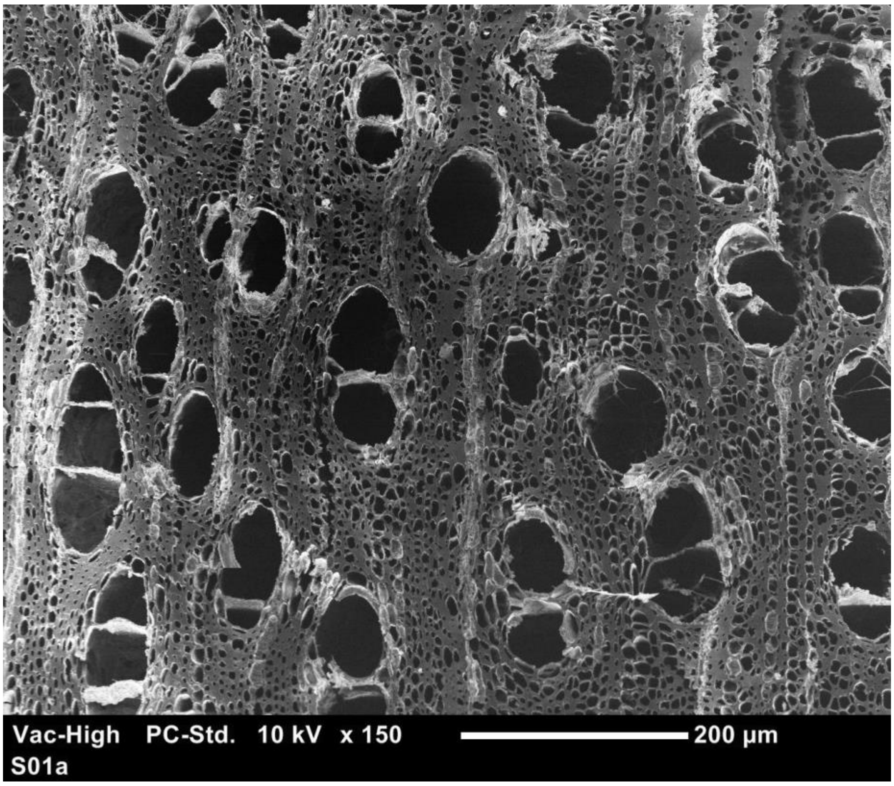

100 µm

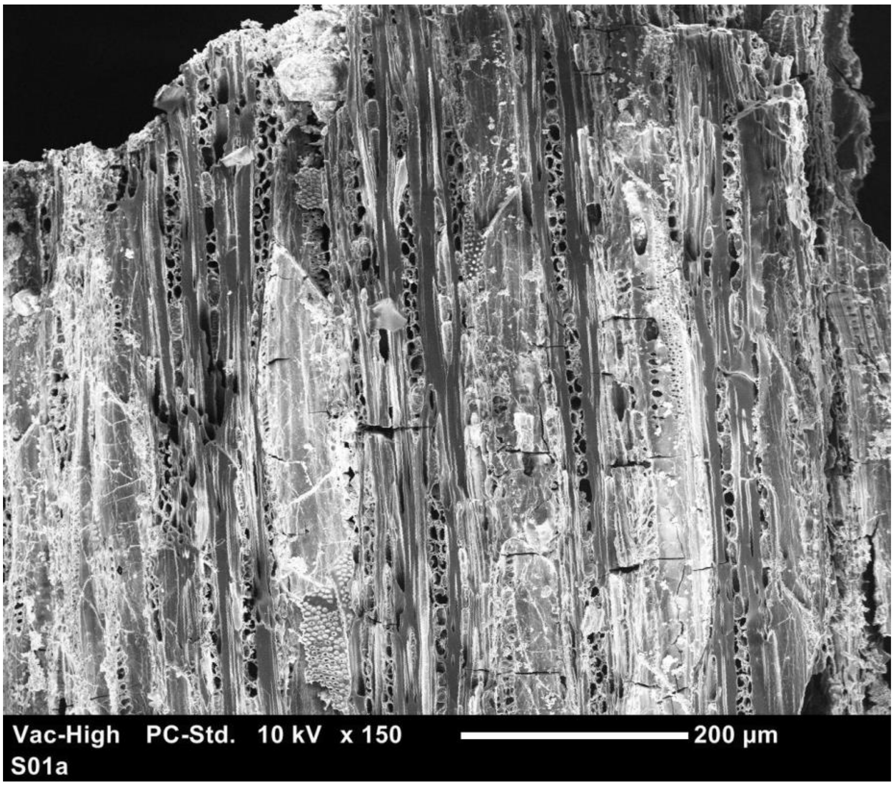

100 µm

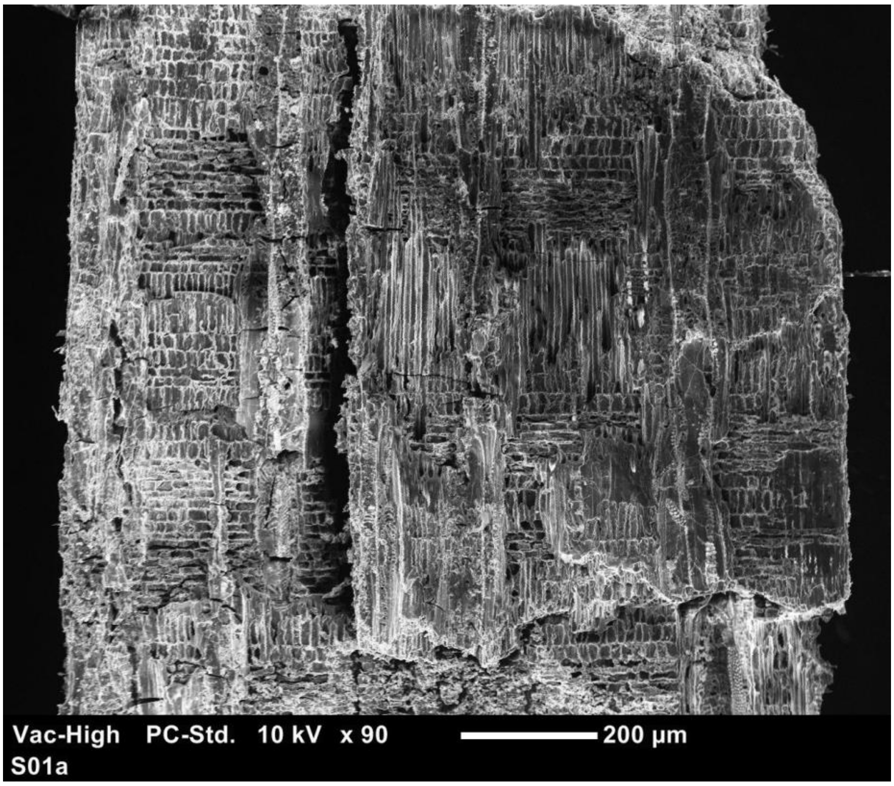

100 µm

Myrtaceae – *Corymbia* sp. (Type 44)

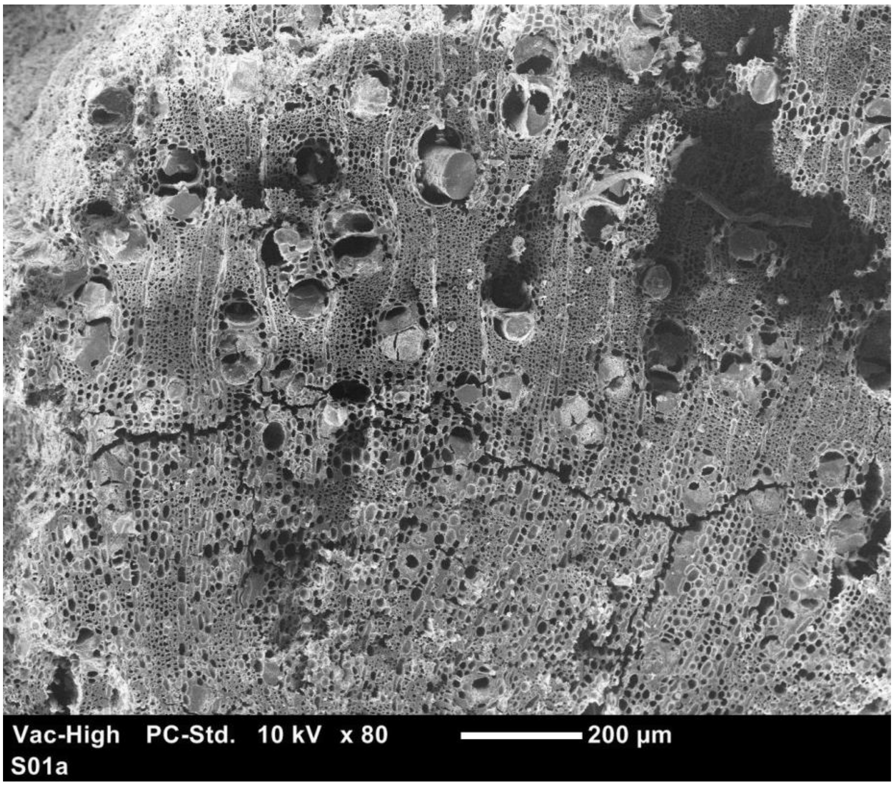


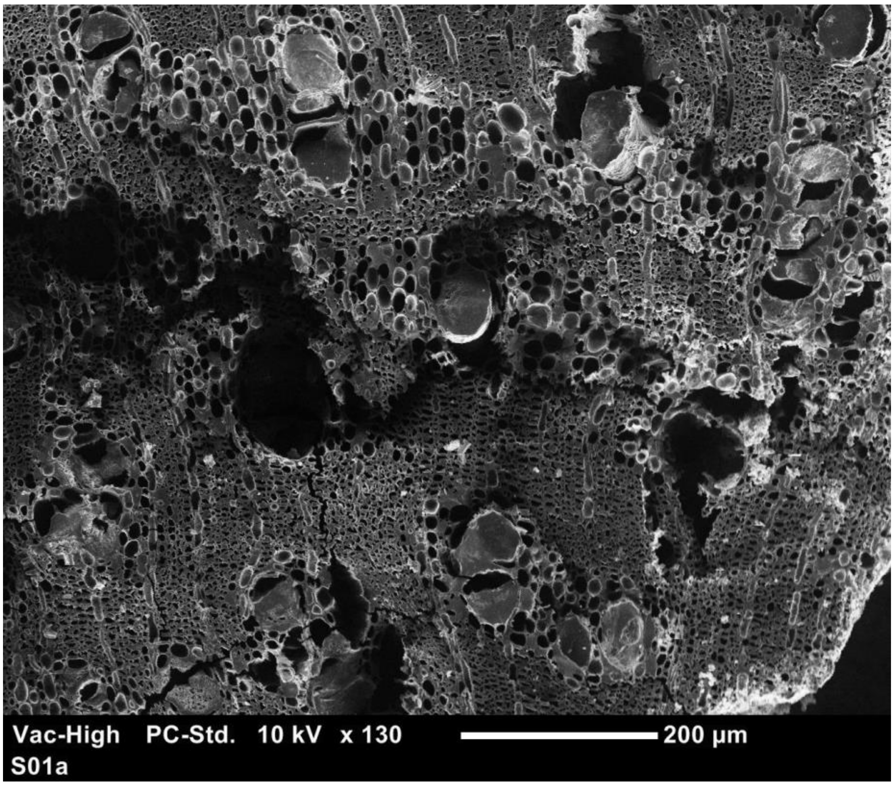


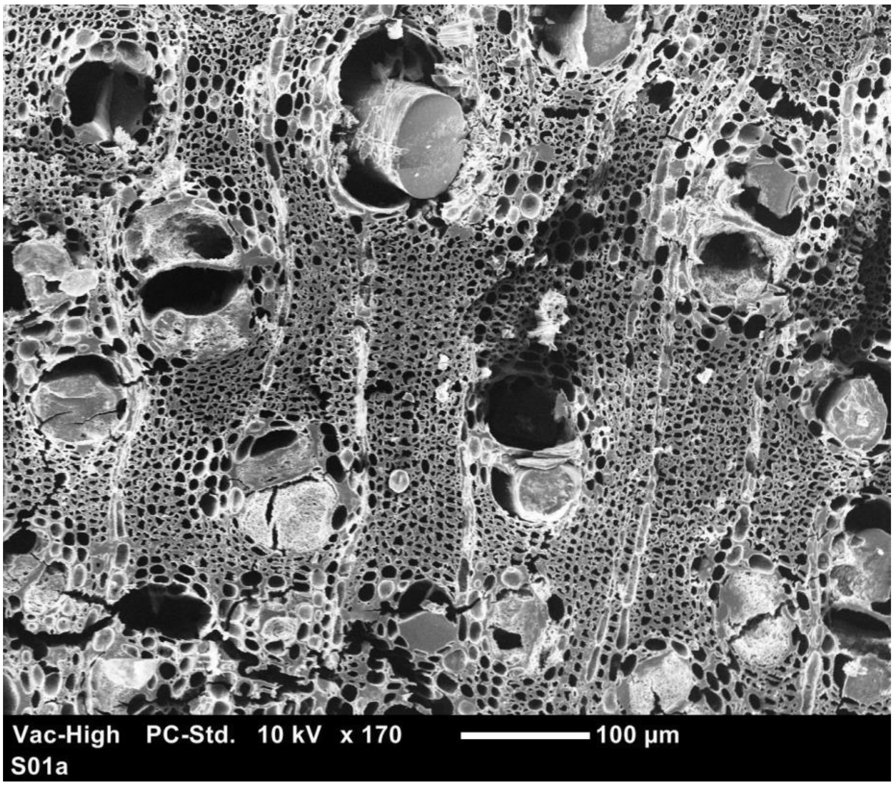

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

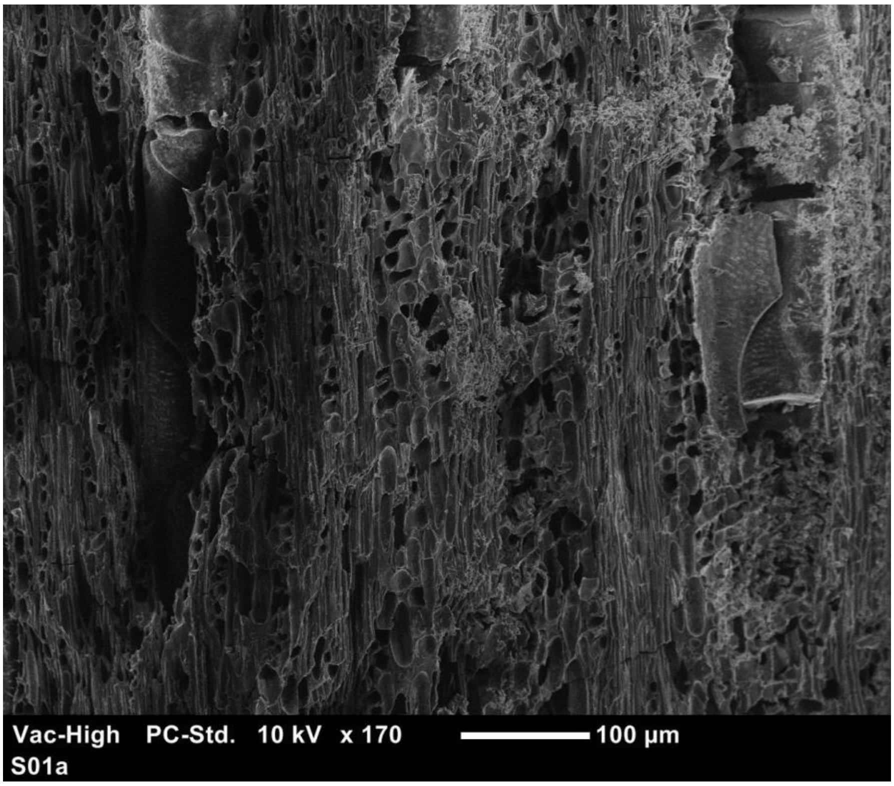

Vac-High PC-Std. 10 kV x 90
200 µm
S01a

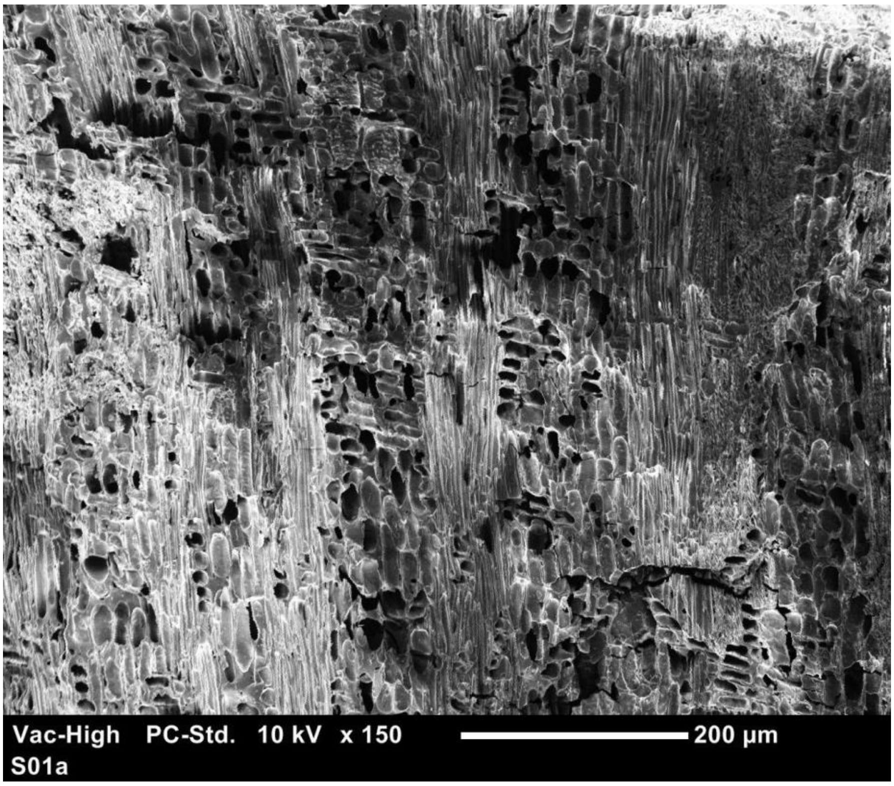
Myrtaceae – *Corymbia* sp. (Type 50)



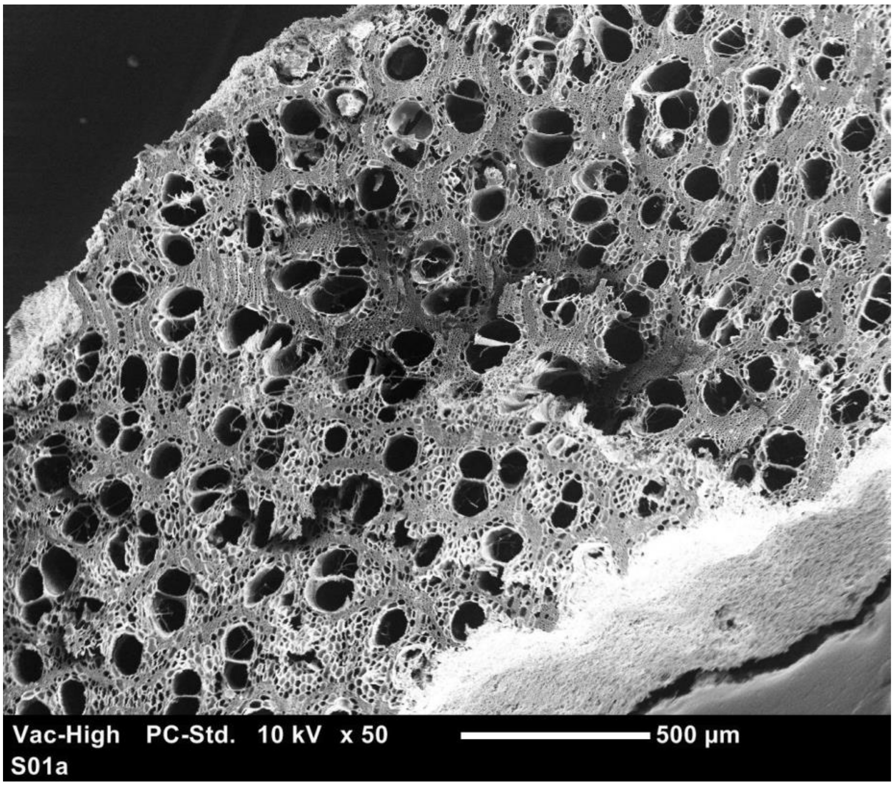


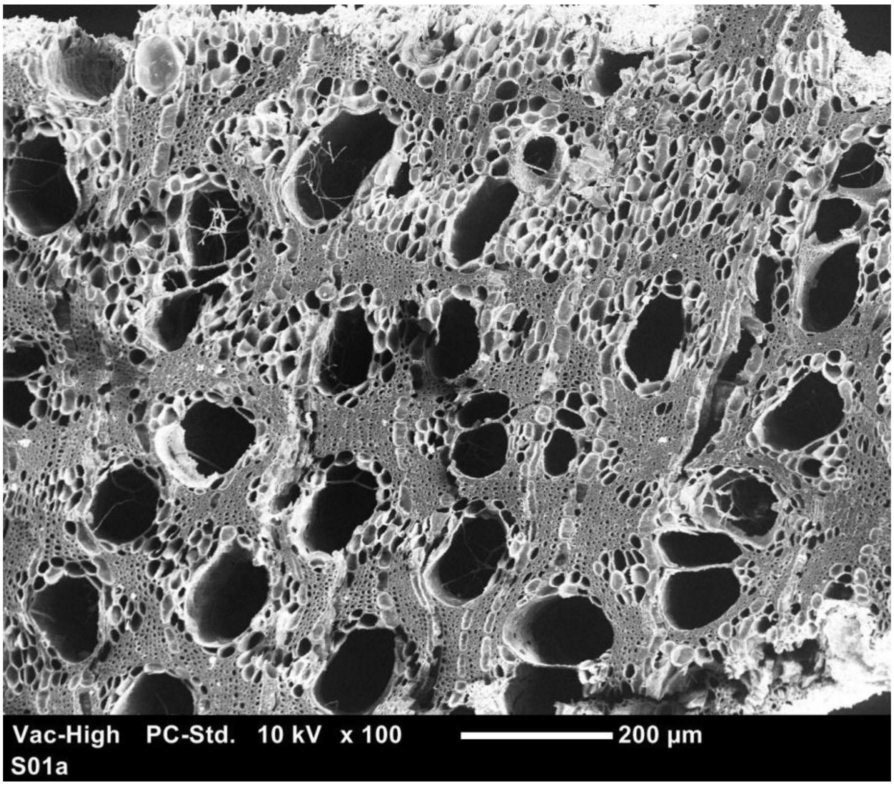

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

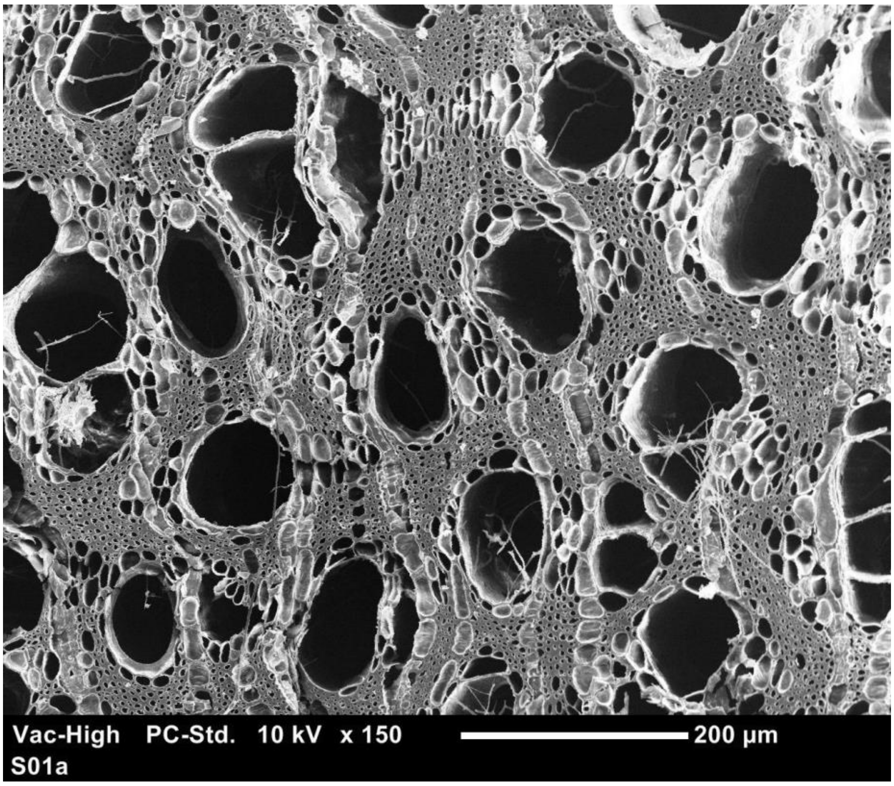

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

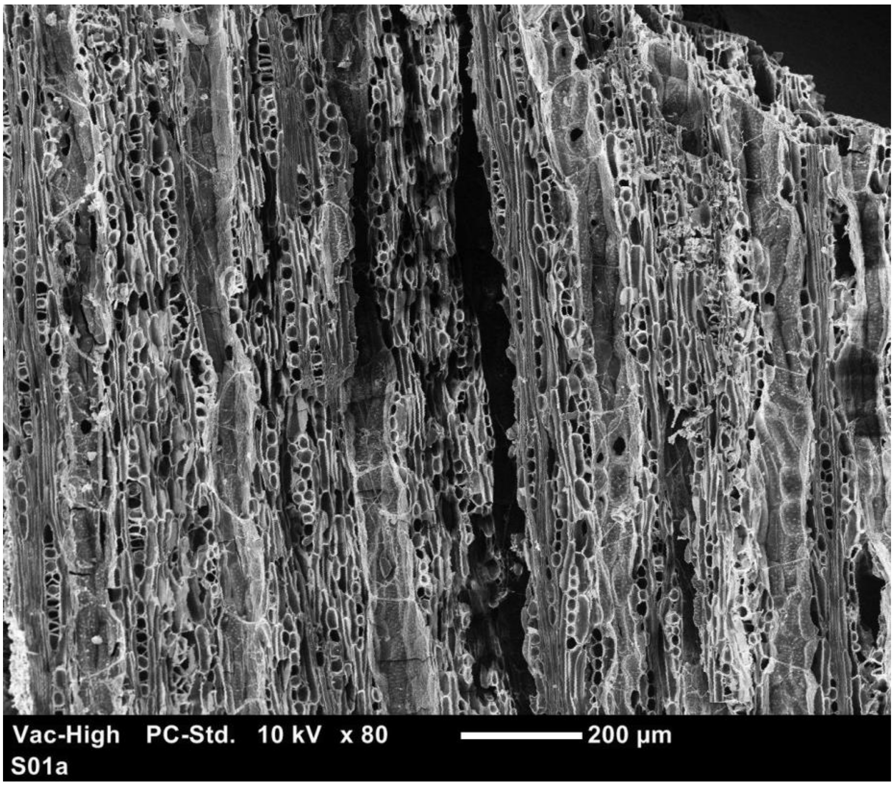

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

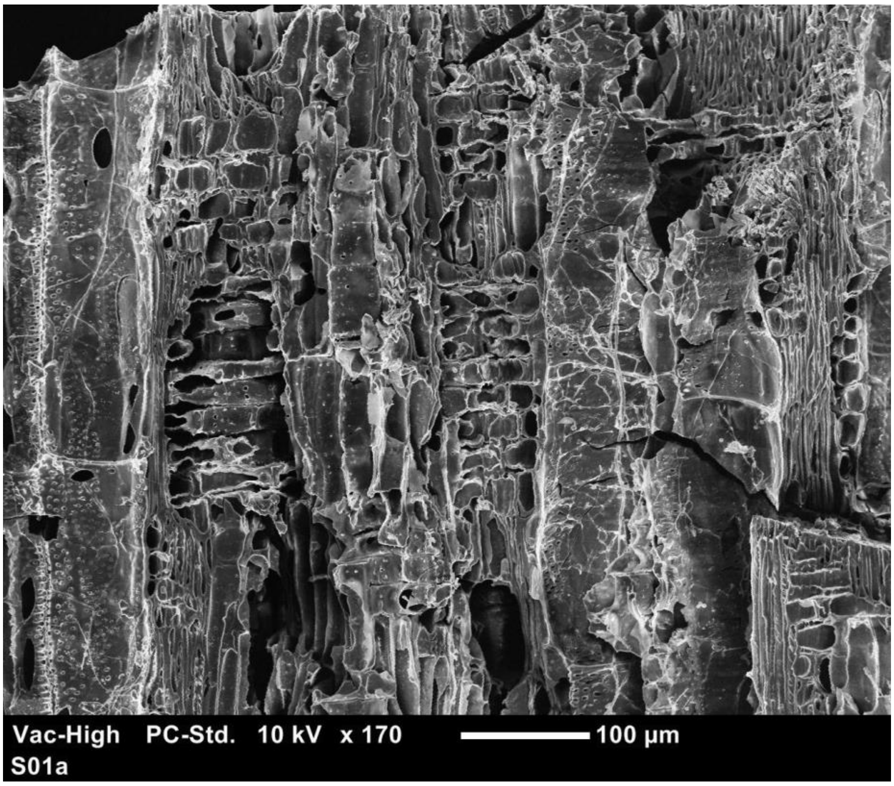
Myrtaceae – *Corymbia* sp. (Type 60)



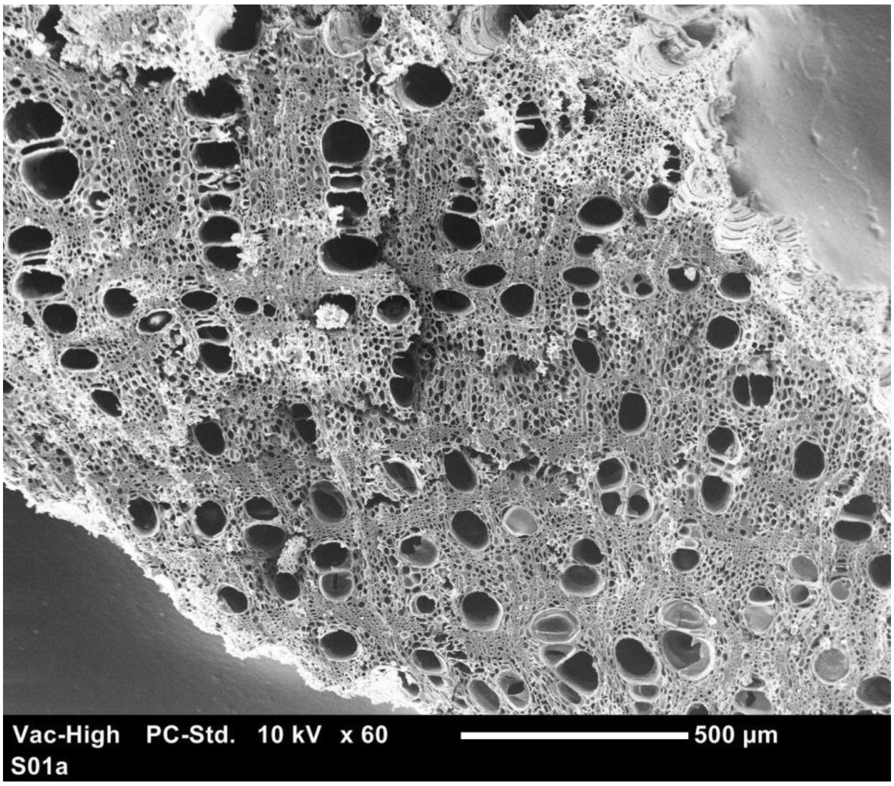


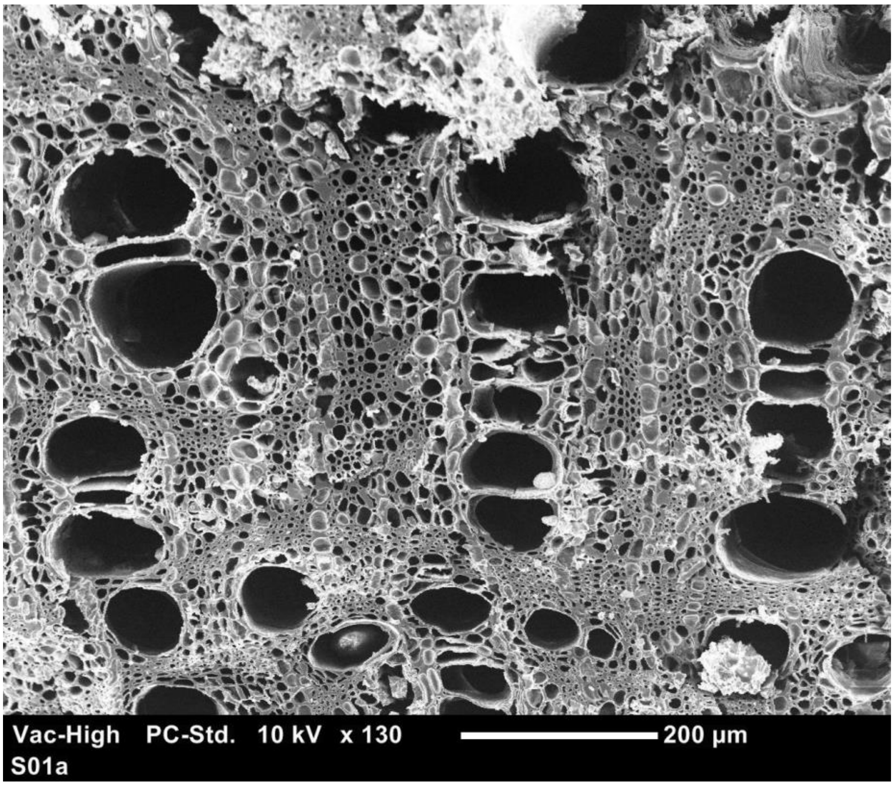

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

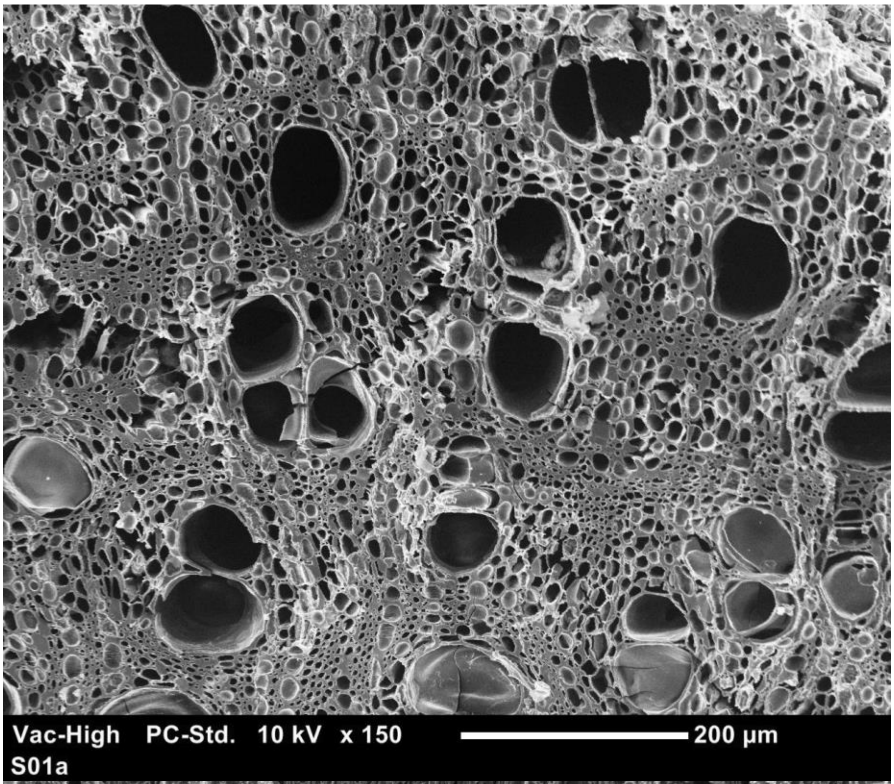

Vac-High PC-Std. 10 kV x 80
200 µm
S01a

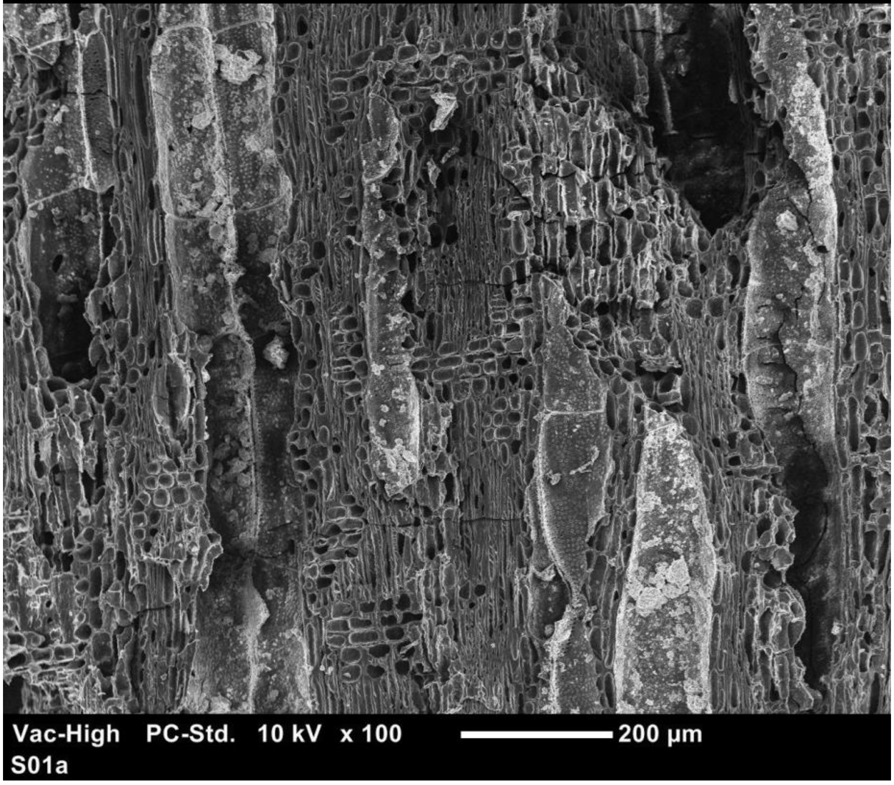

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

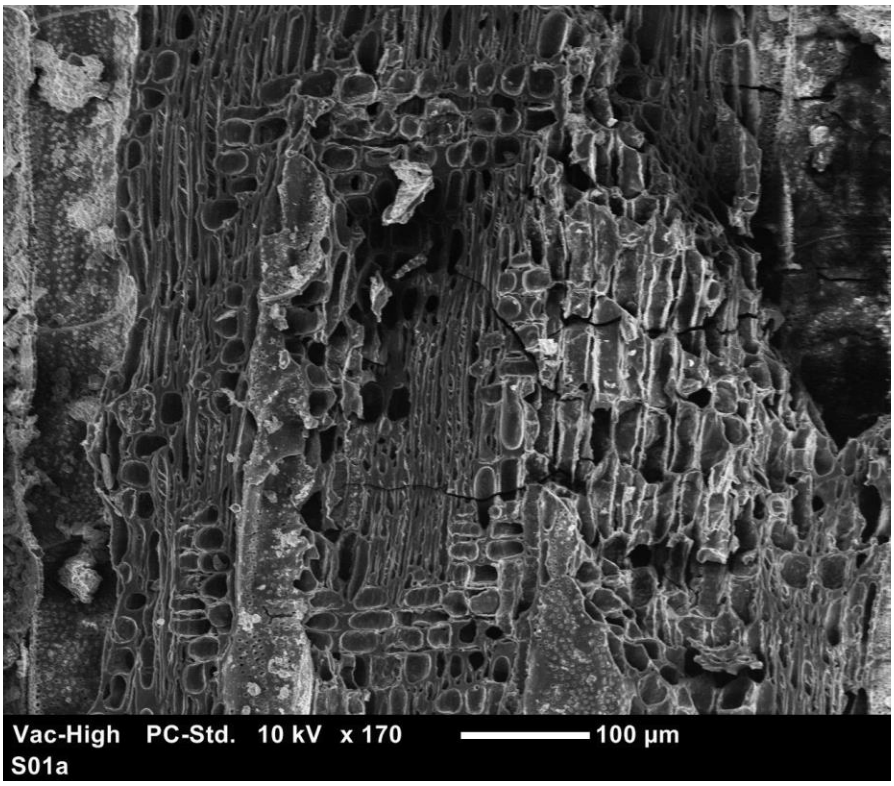
Myrtaceae – *Corymbia* sp. (Type 61)

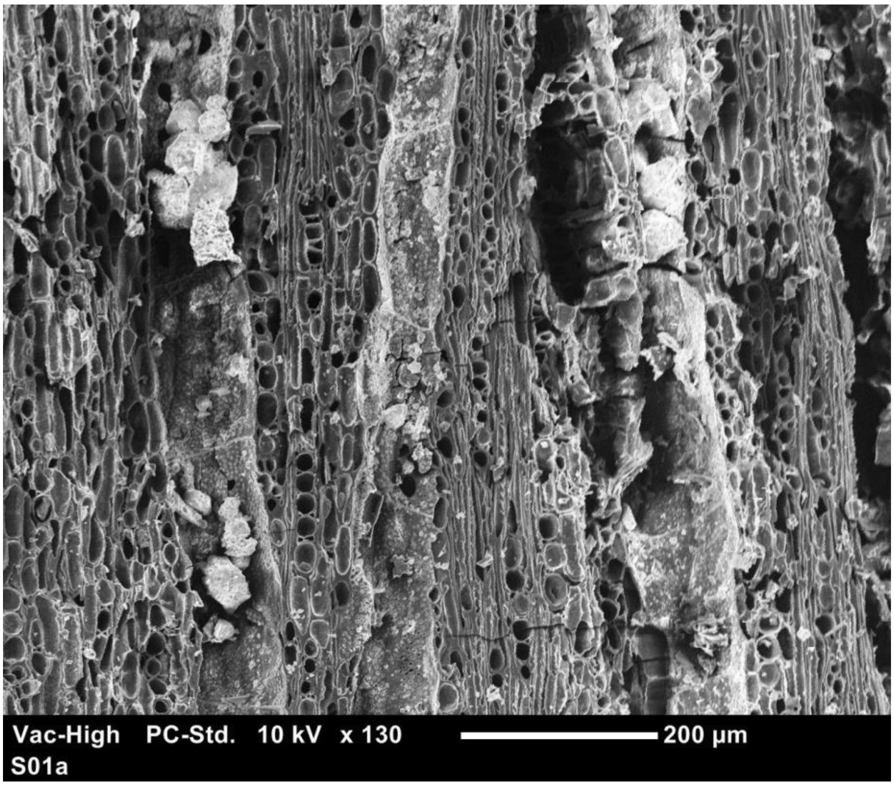




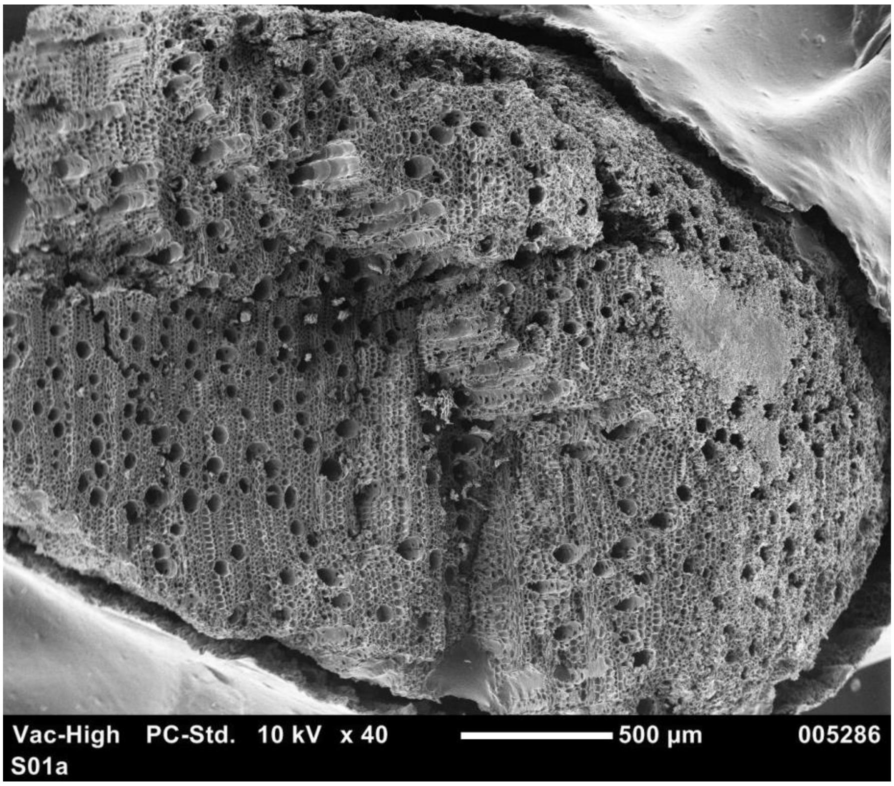

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

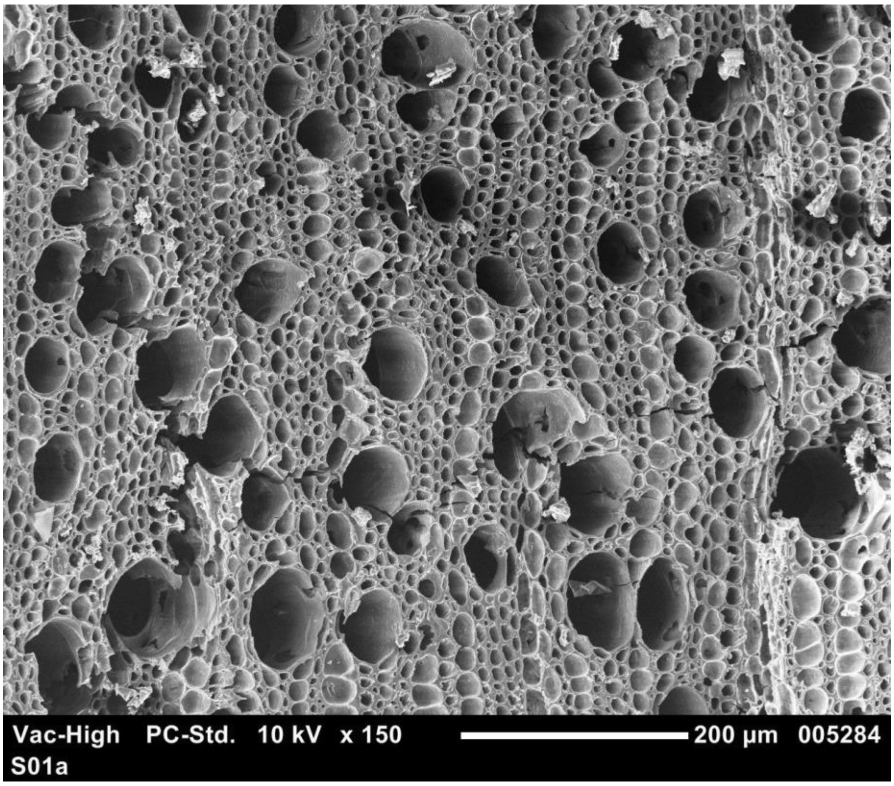

Vac-High PC-Std. 10 kV x 100
200 µm
S01a

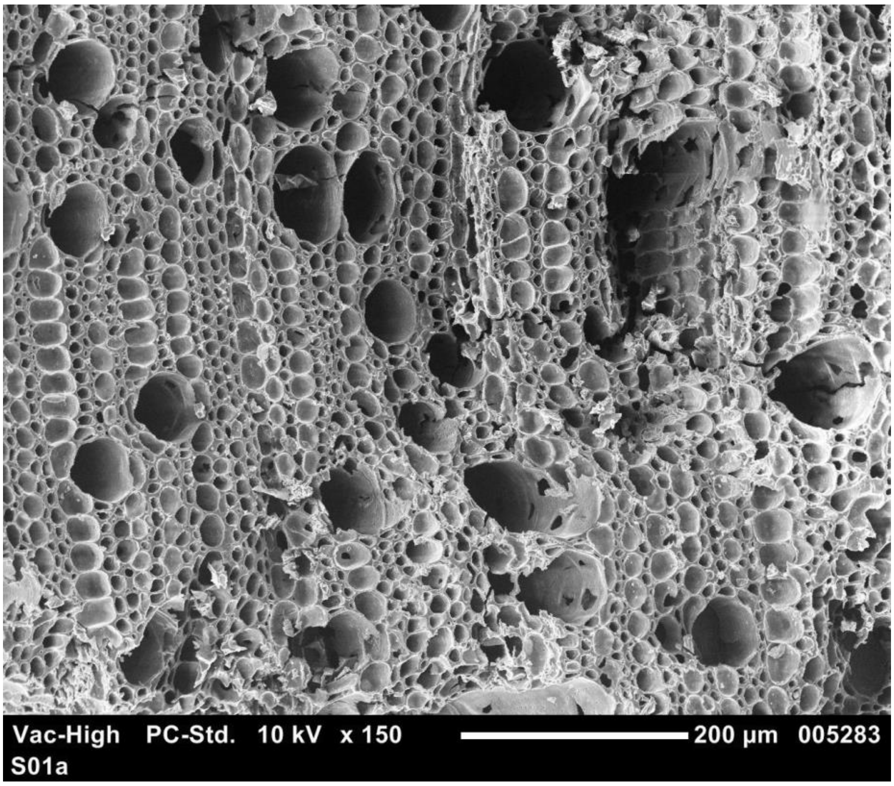

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

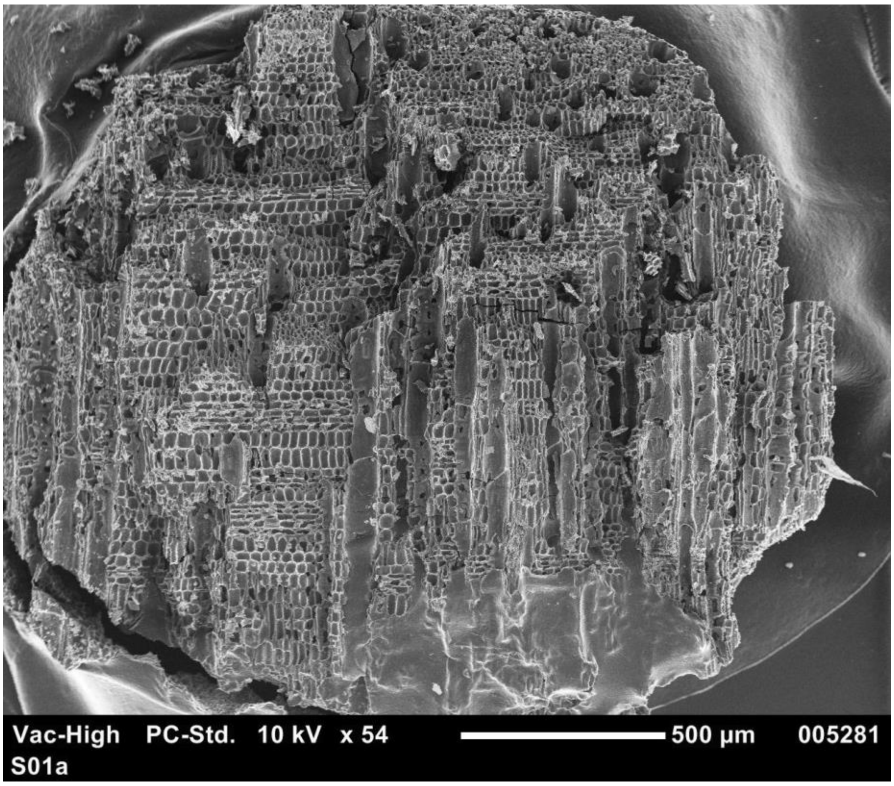

Vac-High PC-Std. 10 kV x 130
200 µm
S01a

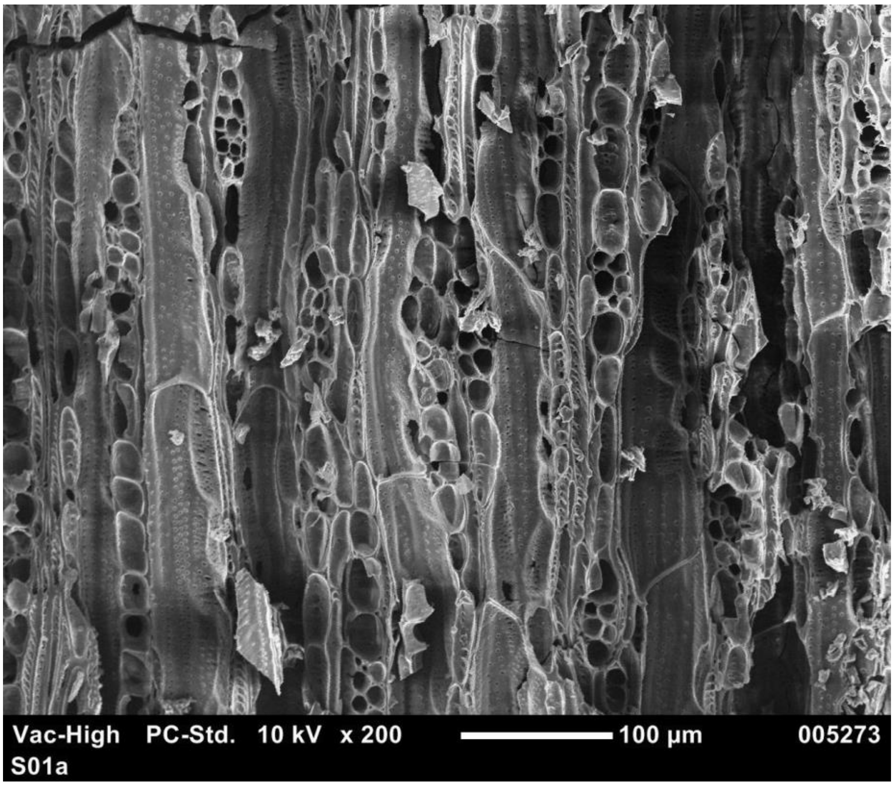
Myrtaceae – *Asteromyrtus* sp. (Type 27)



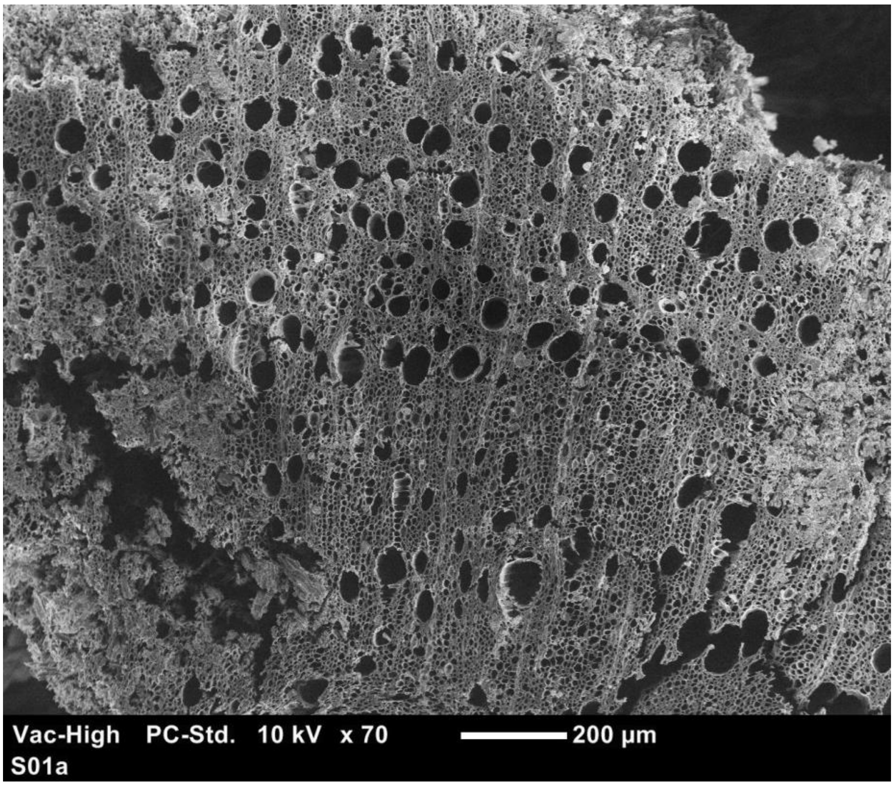


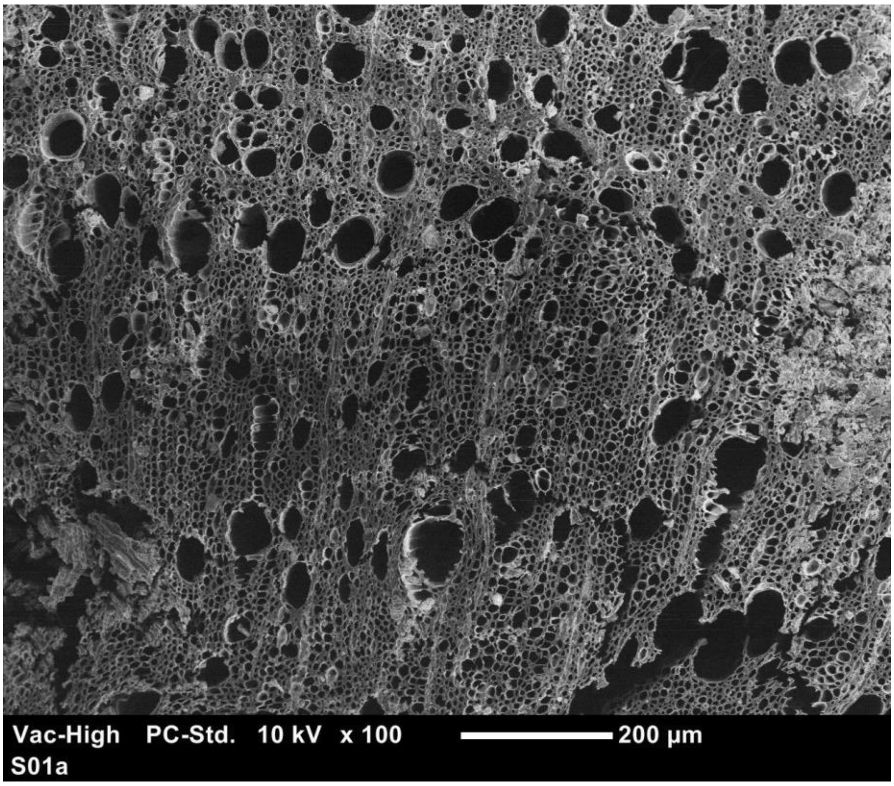

Vac-High PC-Std. 10 kV x 150
200 µm 005283
S01a

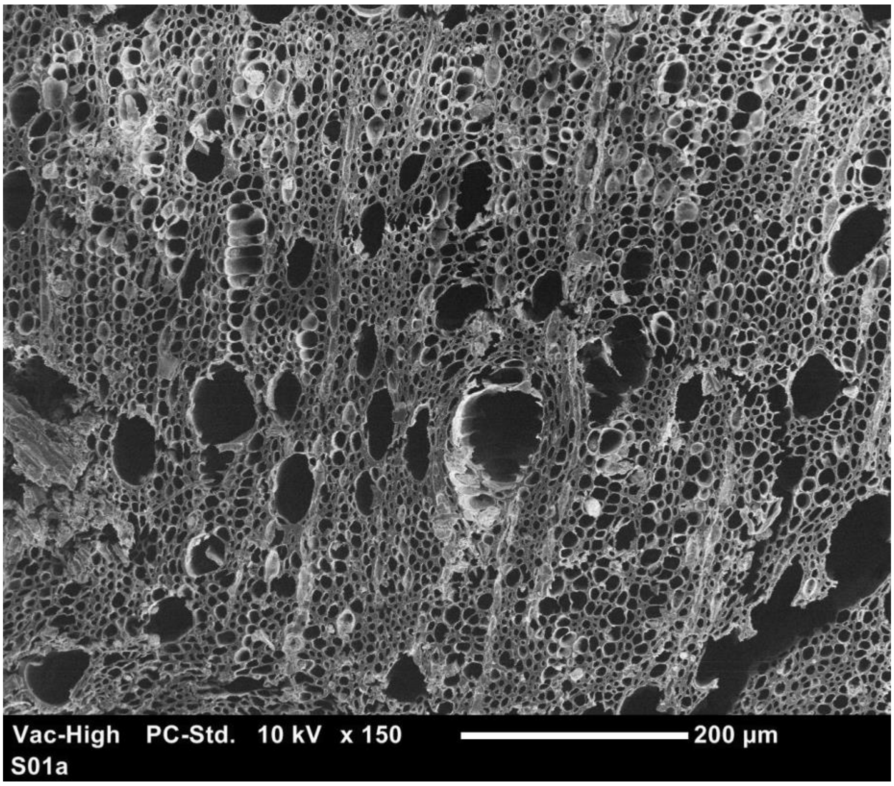

Vac-High PC-Std. 10 kV x 54
500 µm 005281
S01a

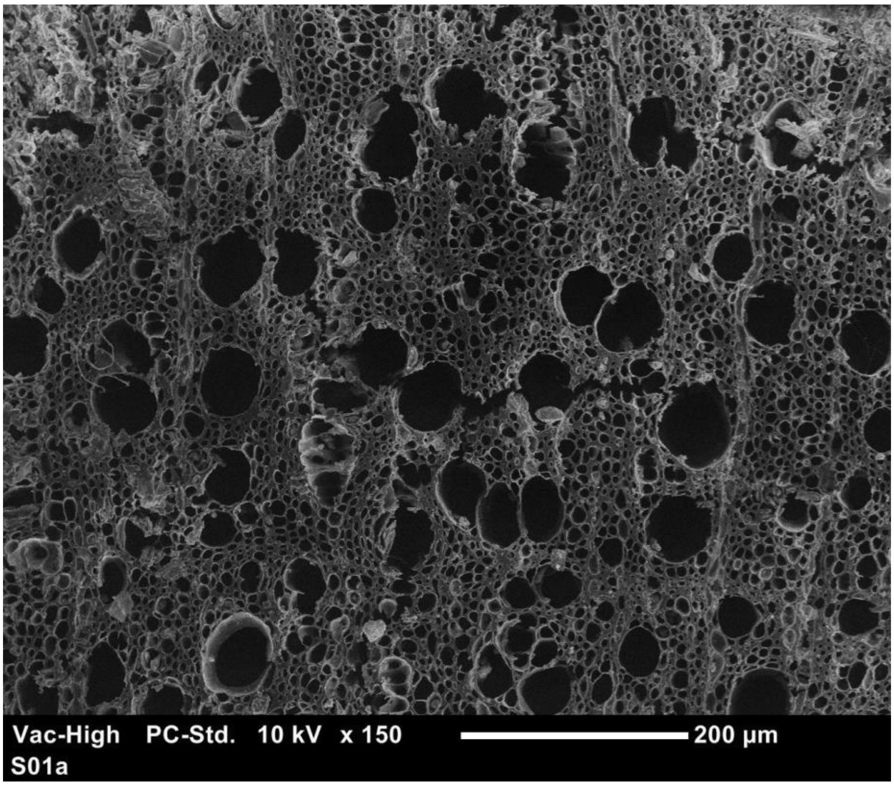

Vac-High
PC-Std.
10 kV
x 200
100 µm
005273
S01a

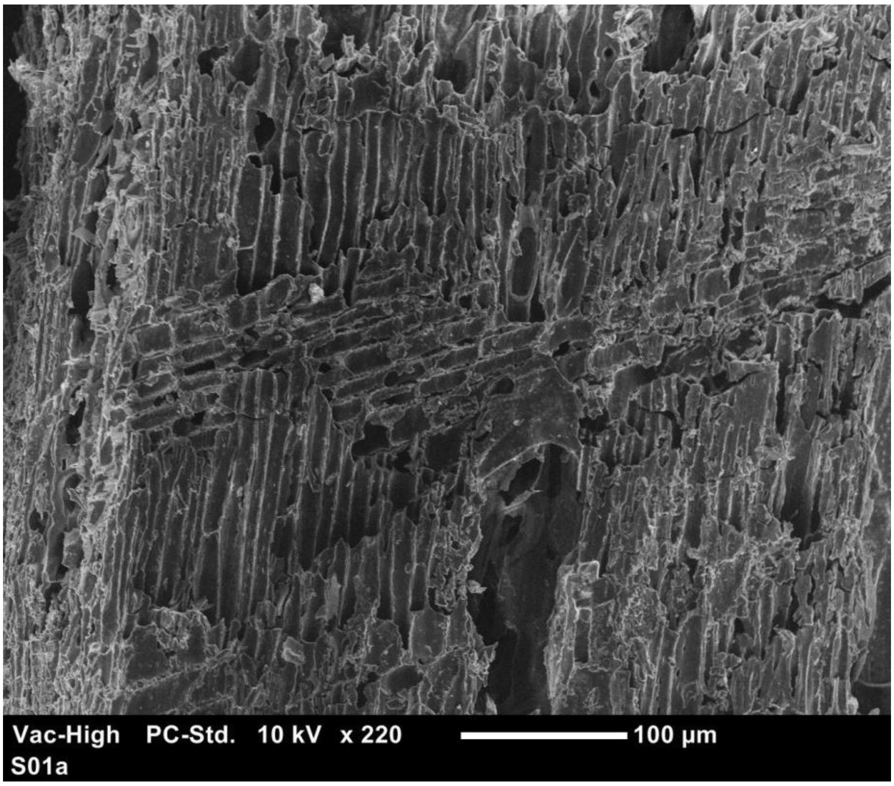
Myrtaceae – *Lophostemon* sp. (Type 39)

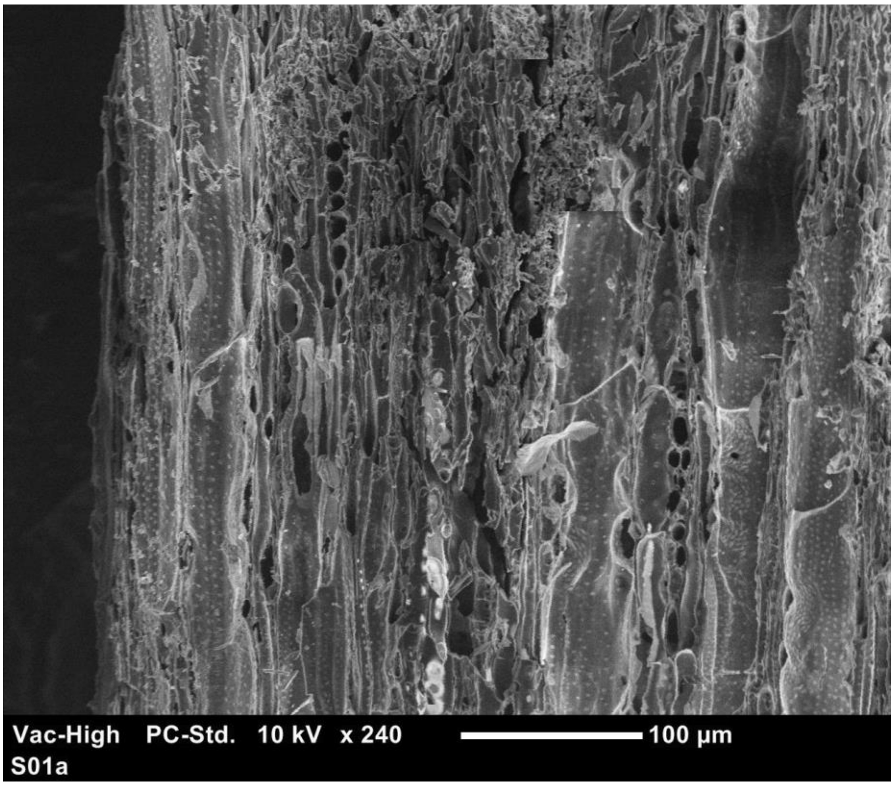




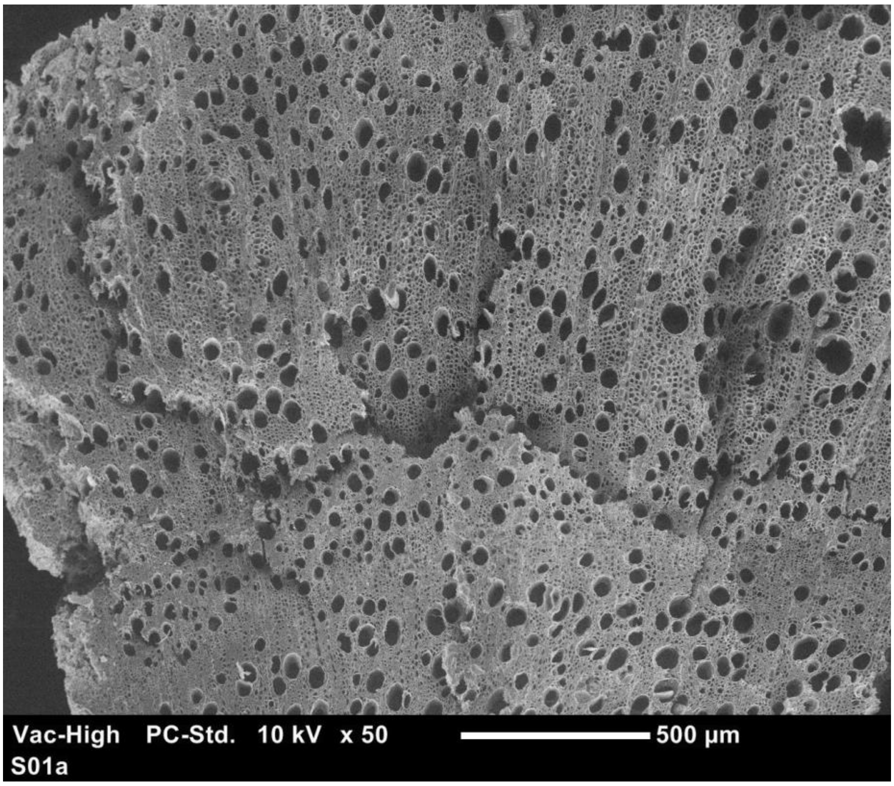

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

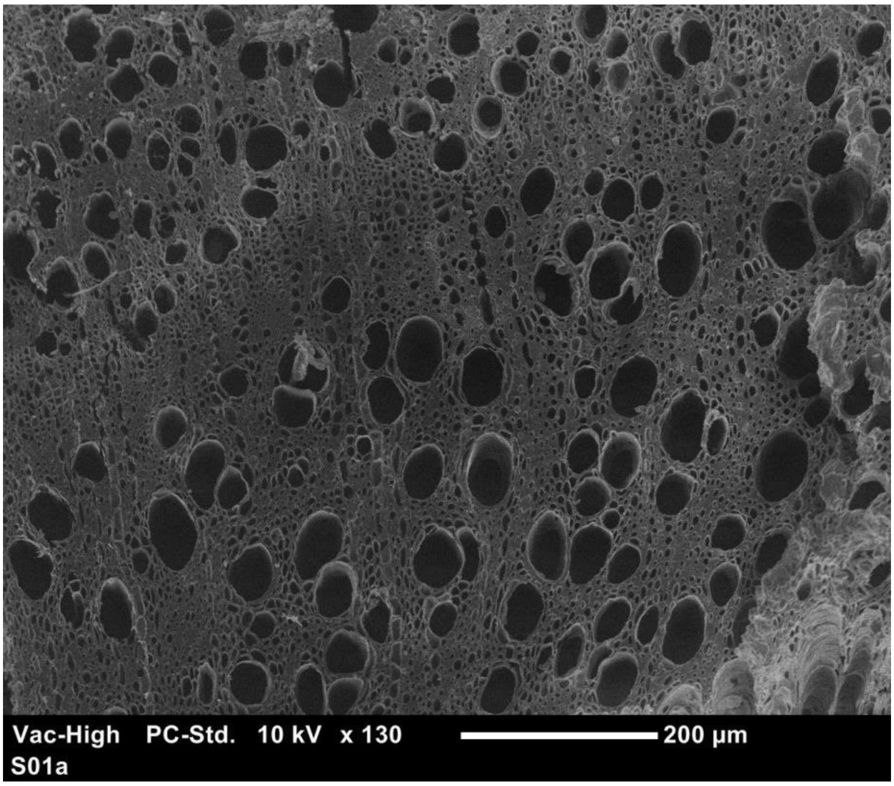

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

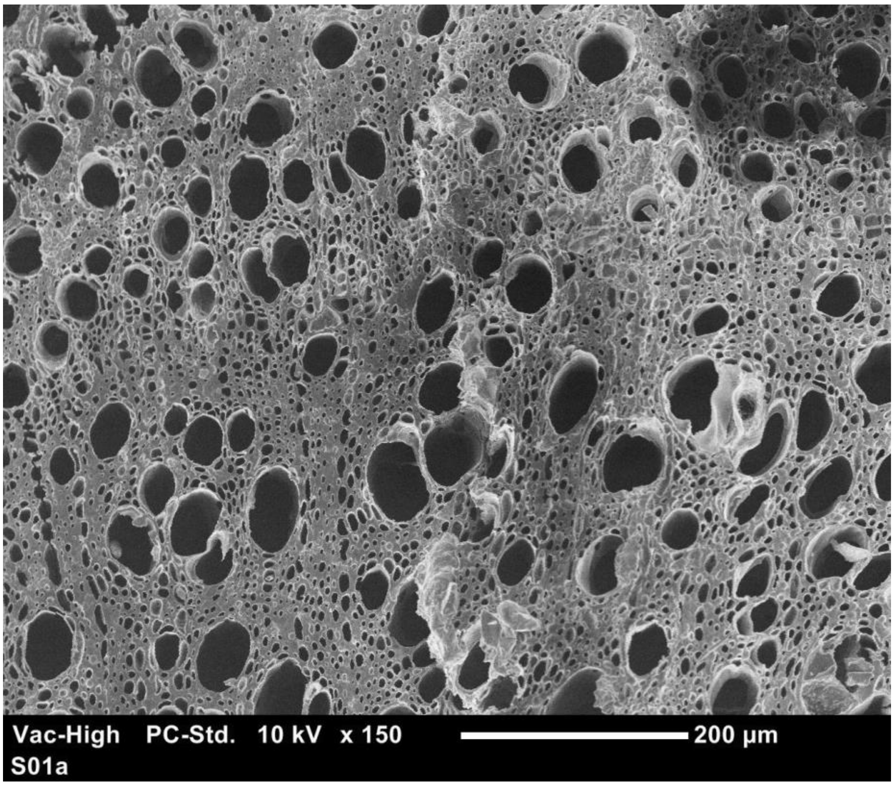

Vac-High PC-Std. 10 kV x 220
100 µm
S01a

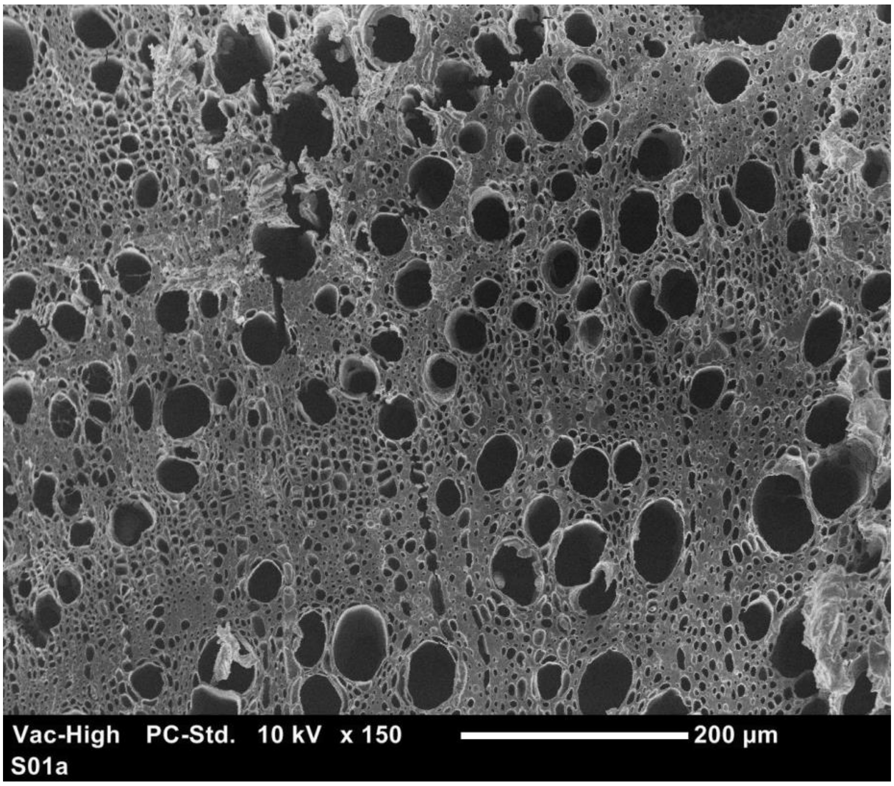

Vac-High PC-Std. 10 kV x 240
100 µm
S01a

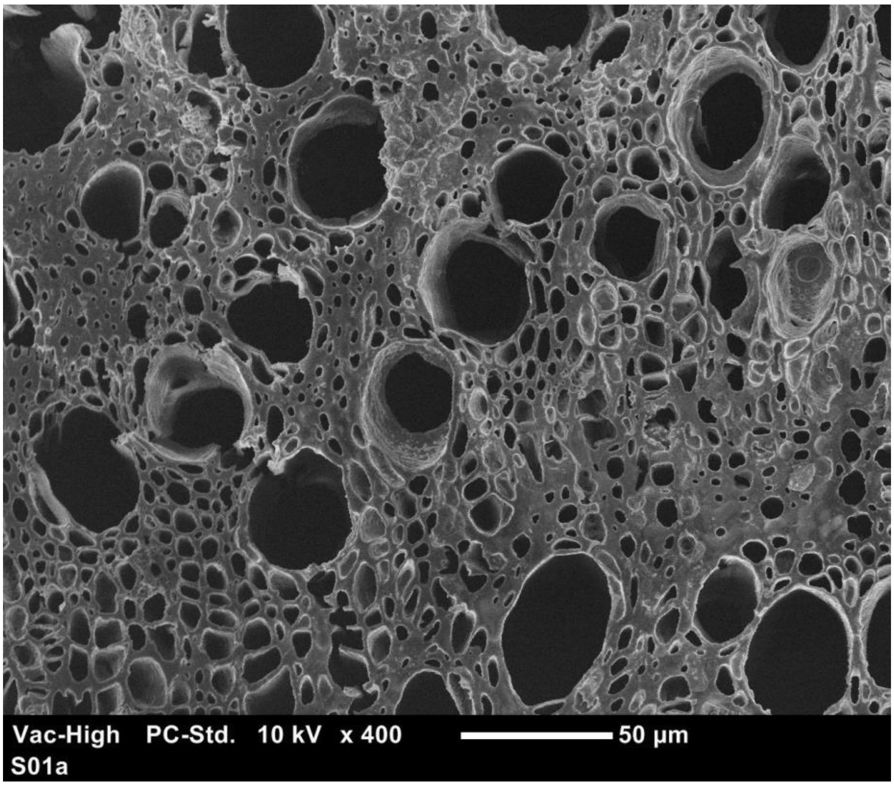
Myrtaceae – *Calytrix* sp. (Type 40)



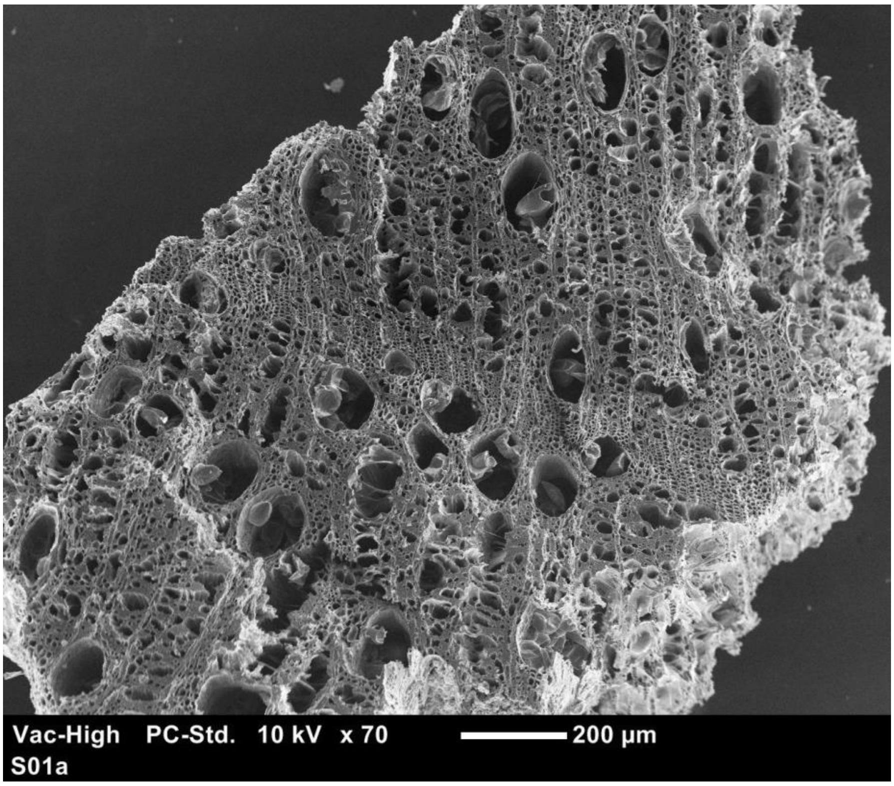


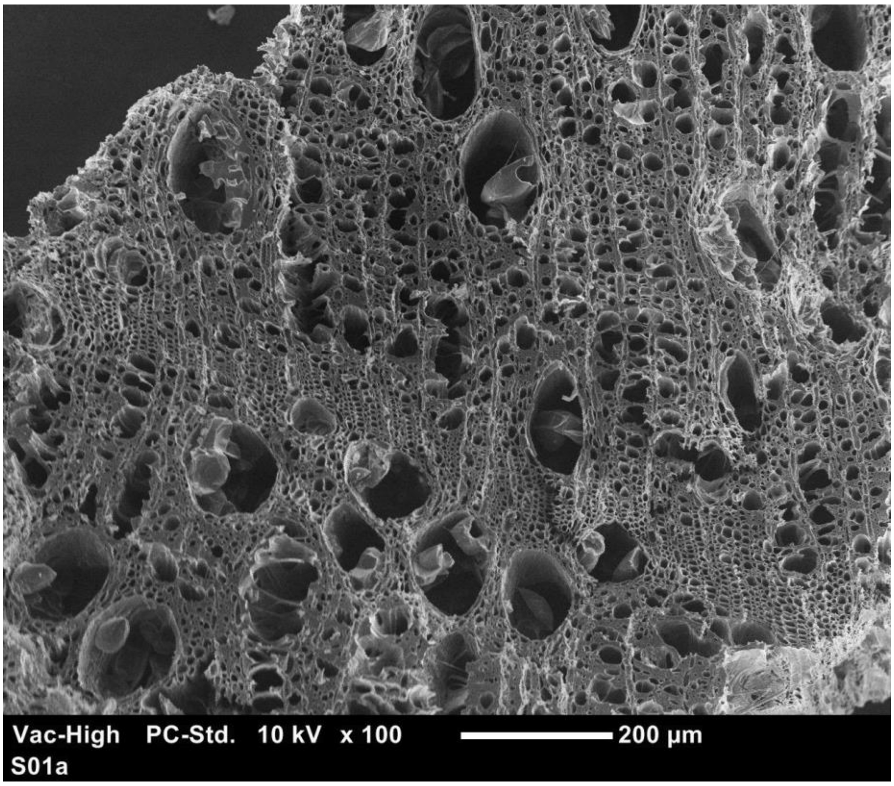

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

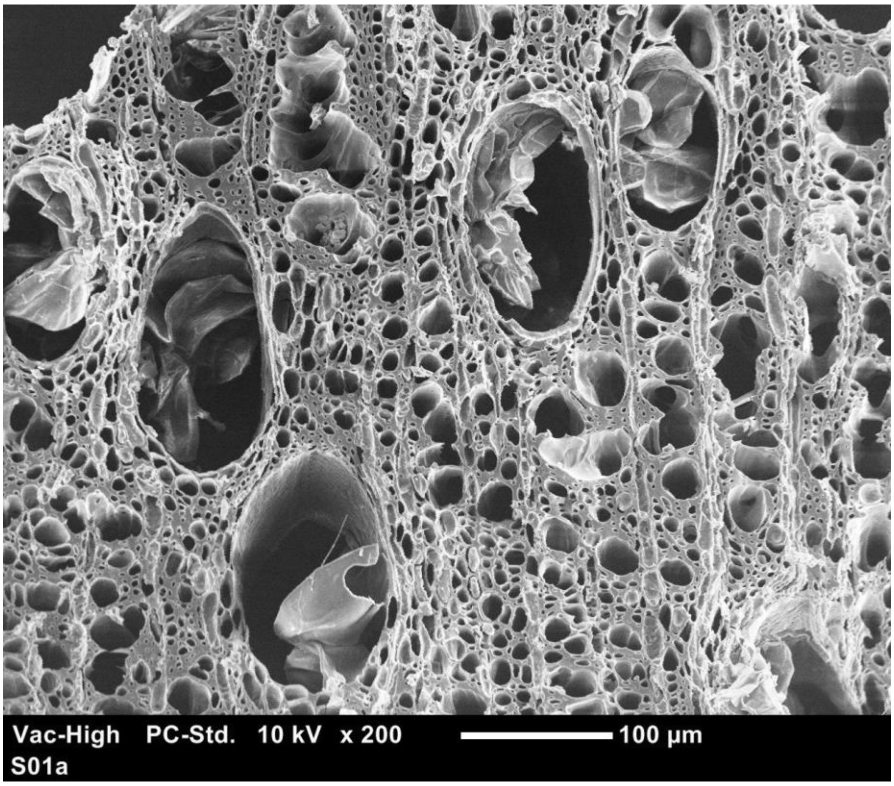

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

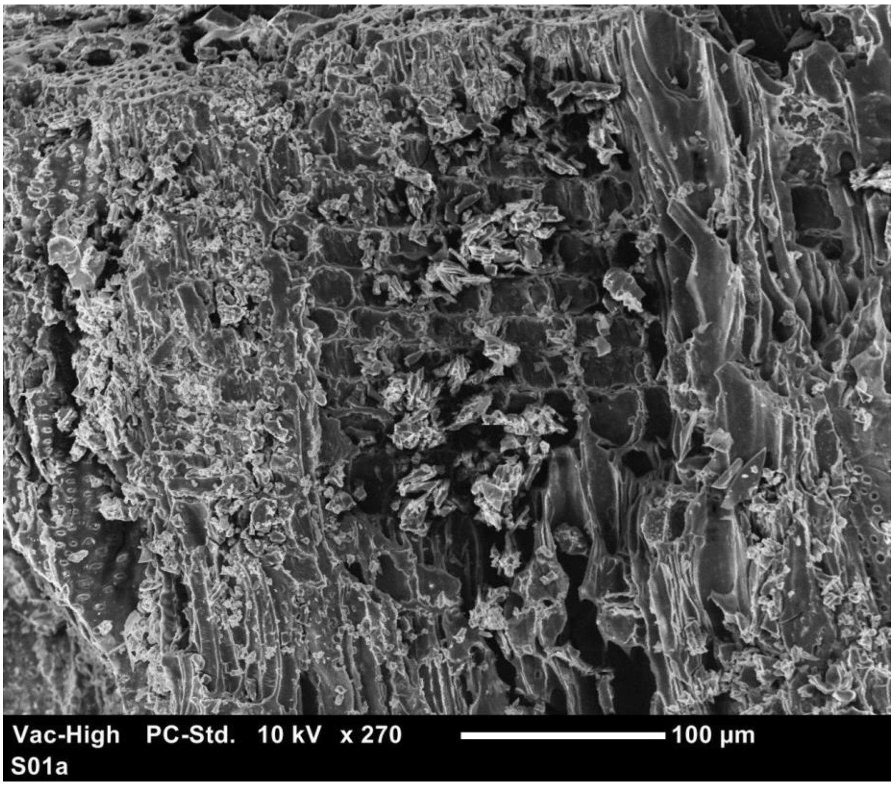

Vac-High PC-Std. 10 kV x 400
50 µm
S01a

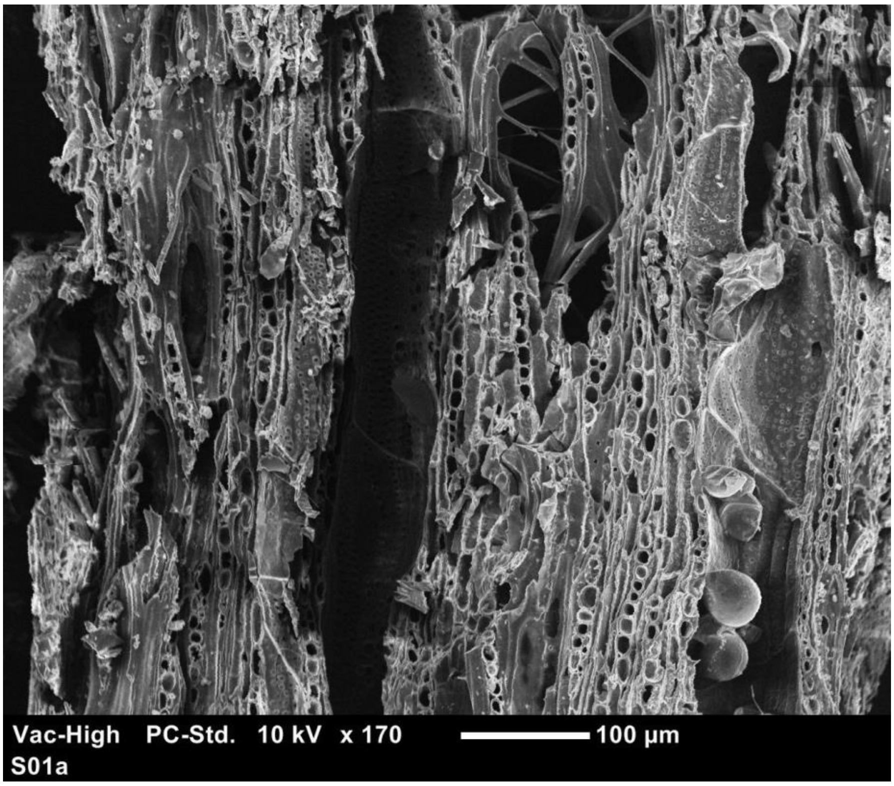
Myrtaceae – *Syzygium* sp. (Type 59)



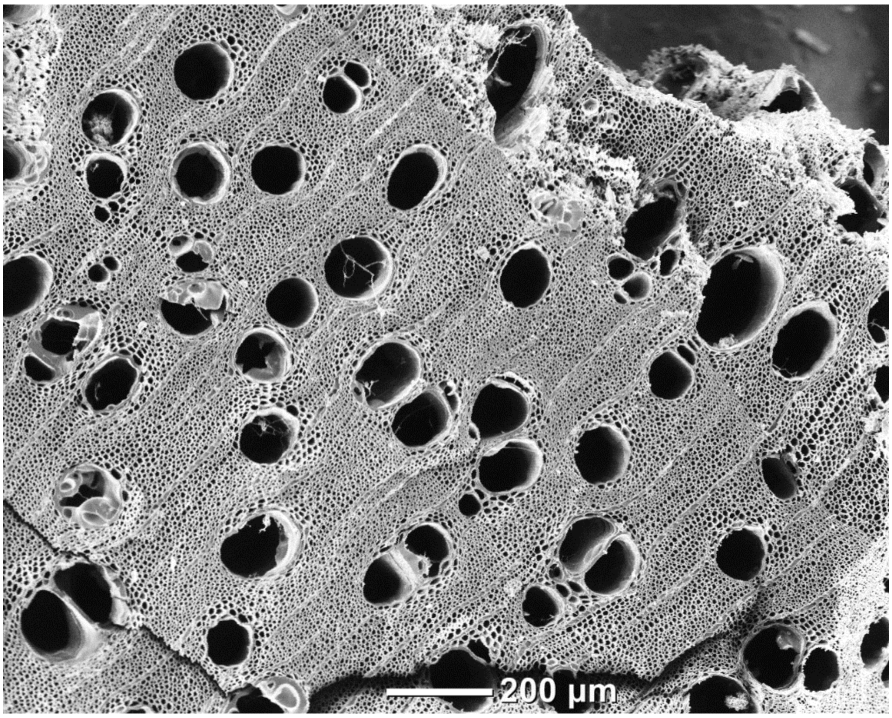


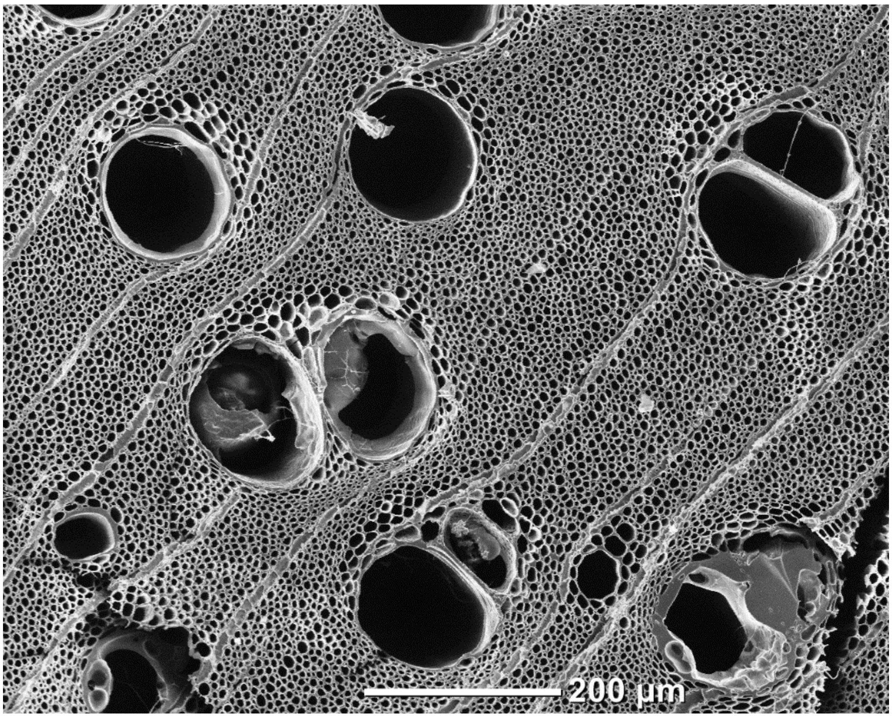

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

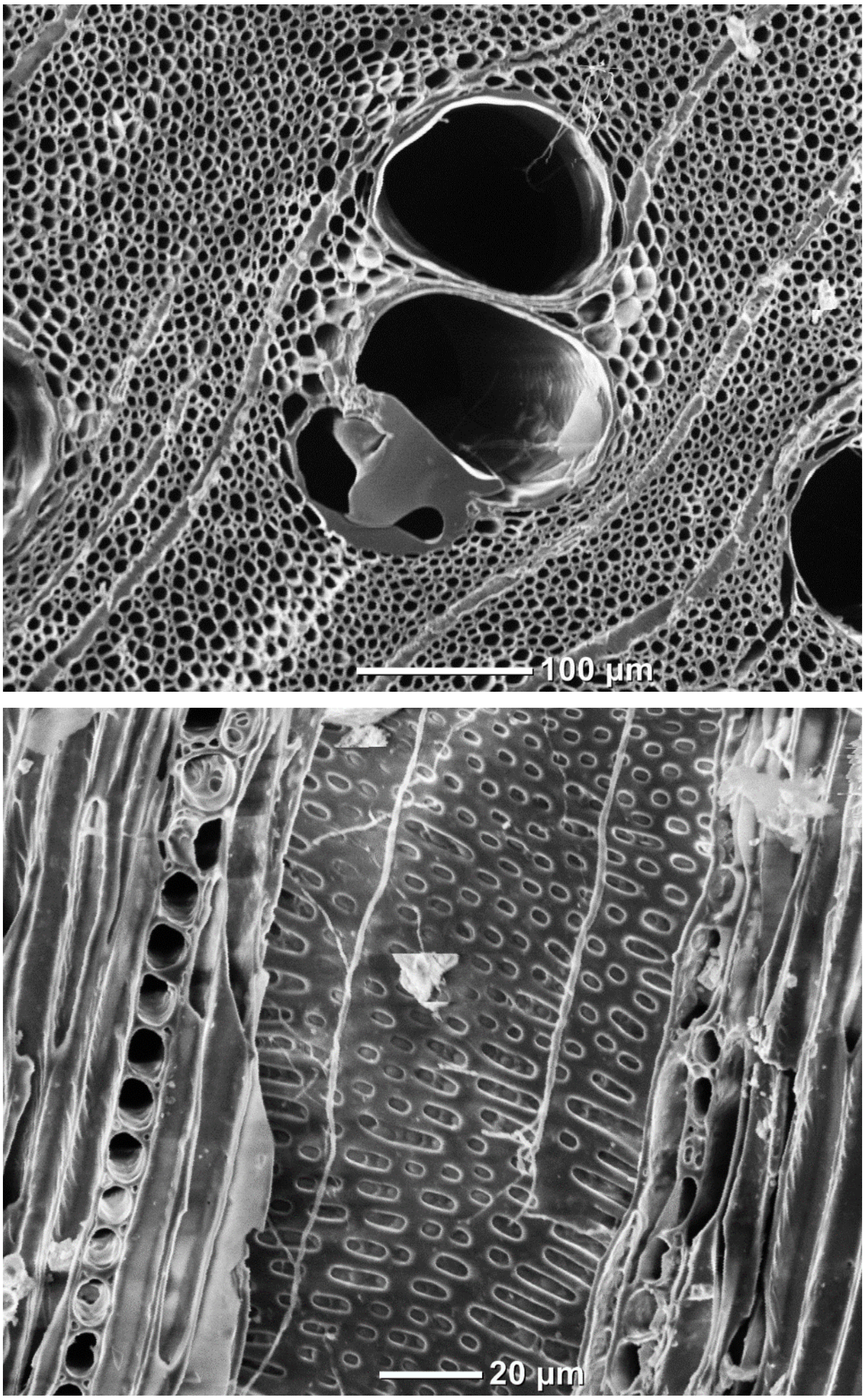

Vac-High PC-Std. 10 kV x 270
100 µm
S01a

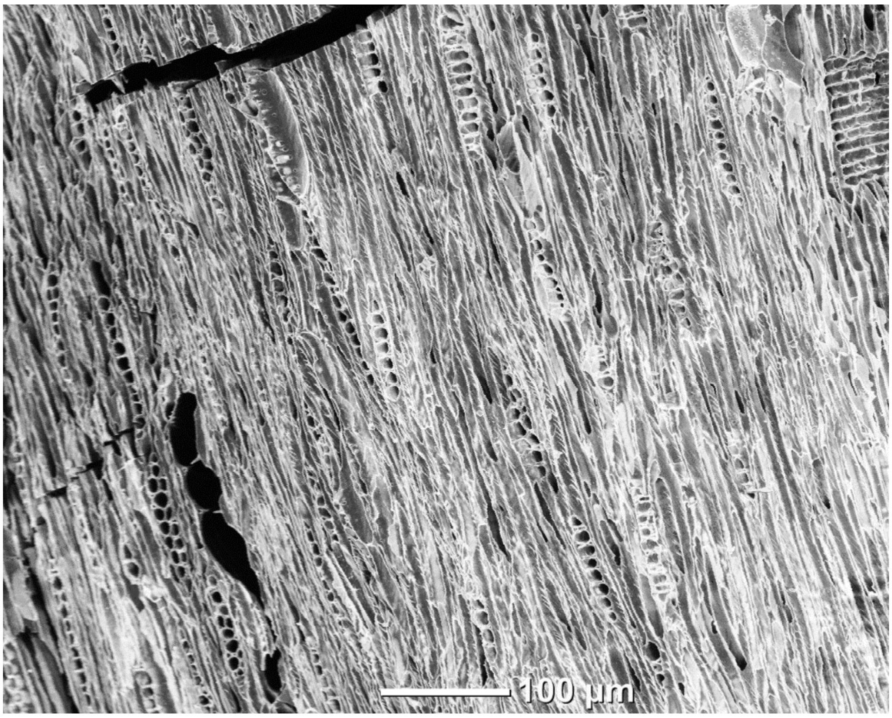

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

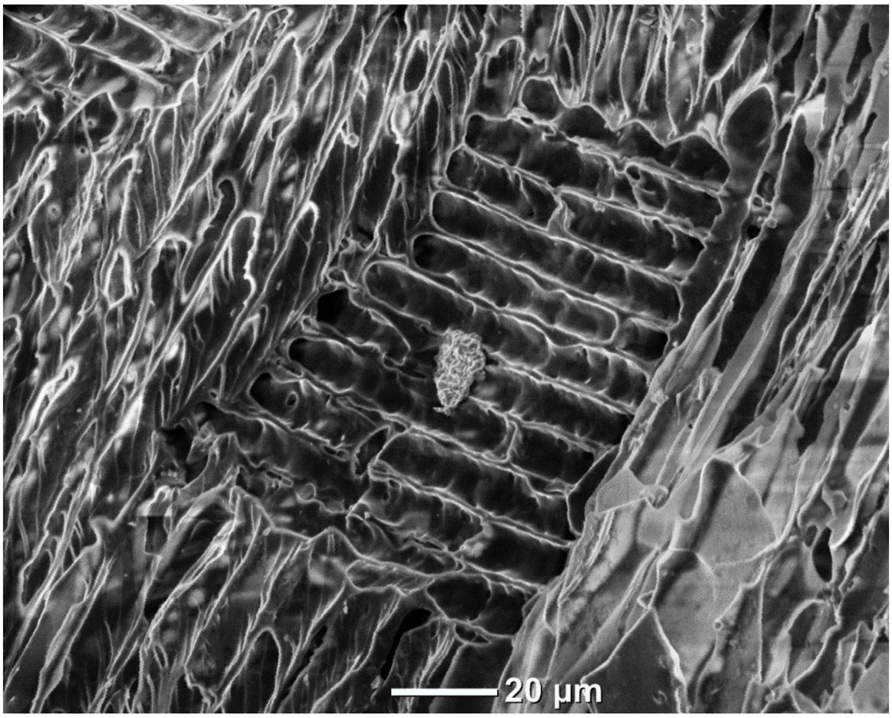
Mimosaceae – *Acacia* sp. (Type 2)



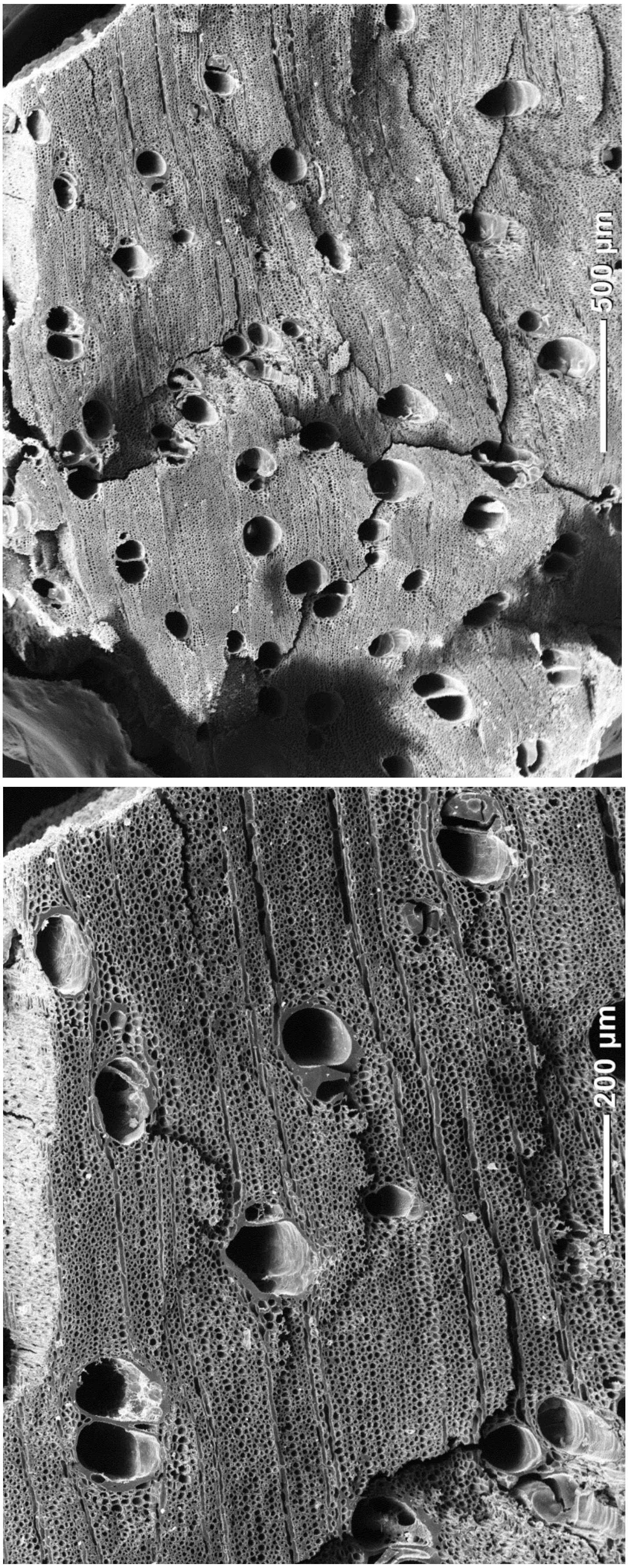


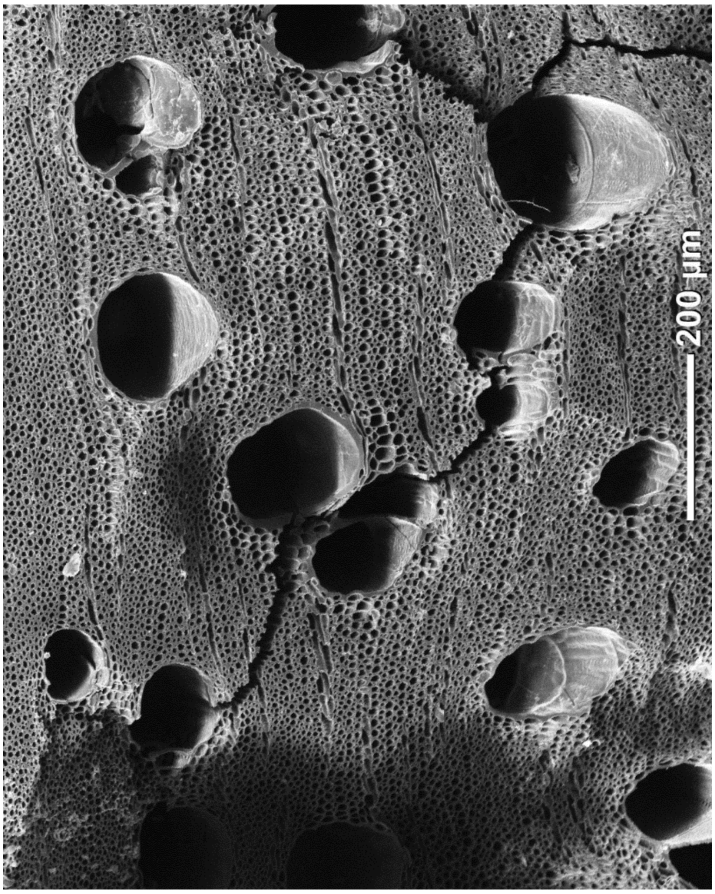

100 µm
20 µm

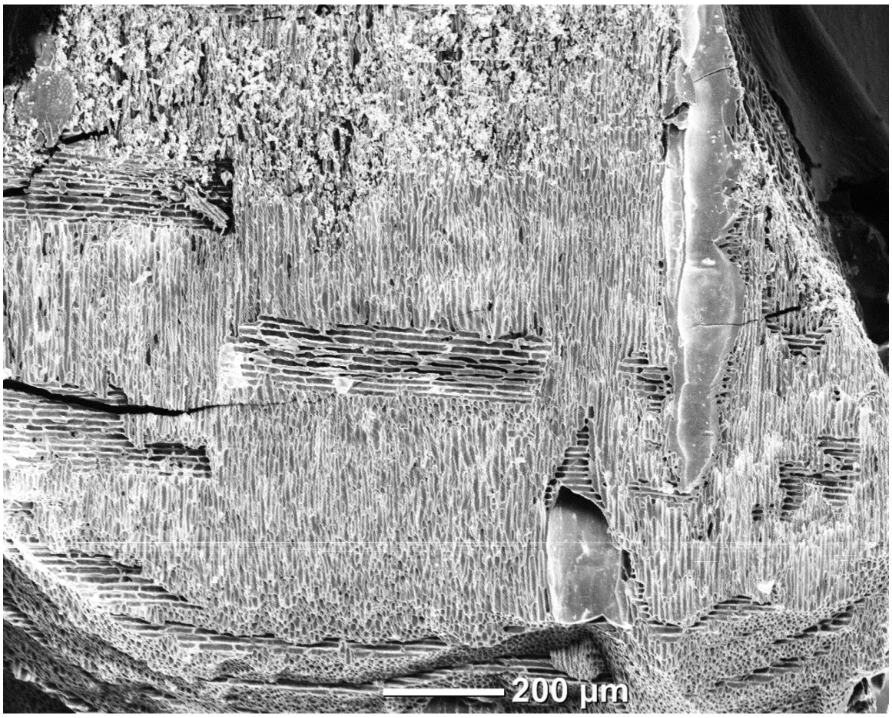

100 µm

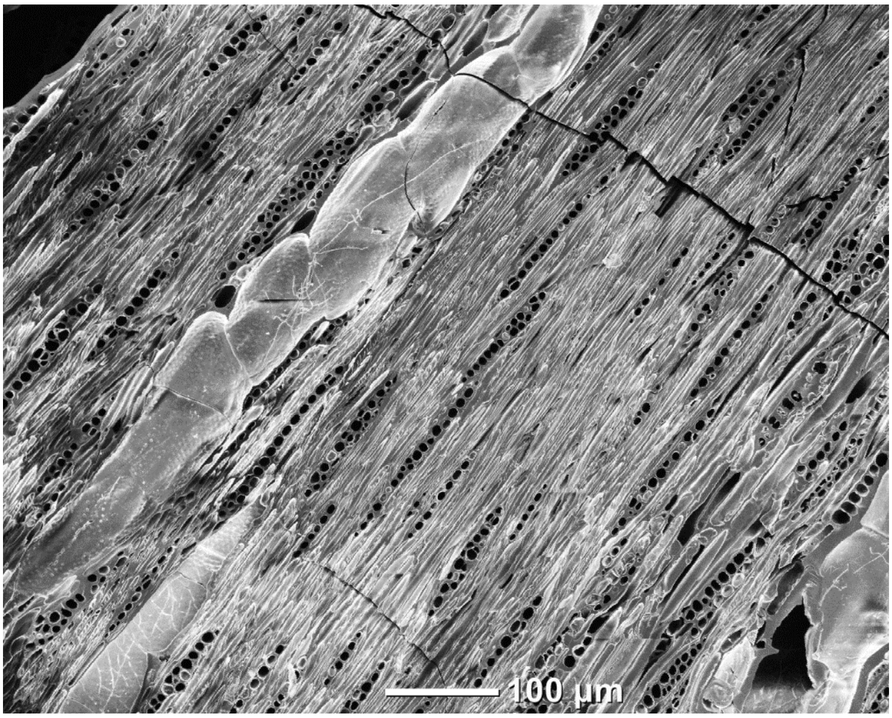

20 µm

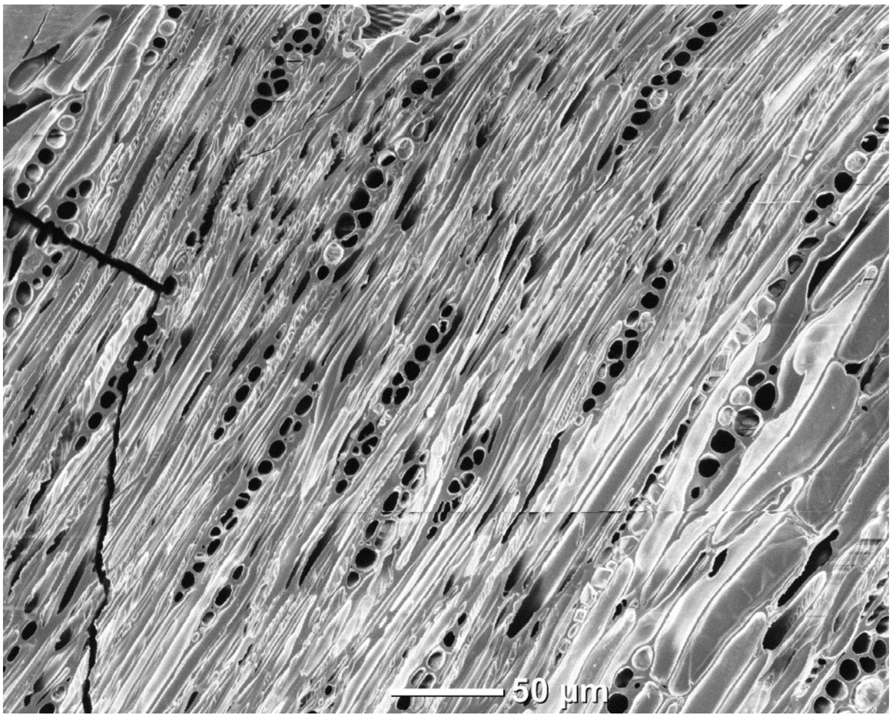
Mimosaceae – *Acacia* sp. (Type 5)



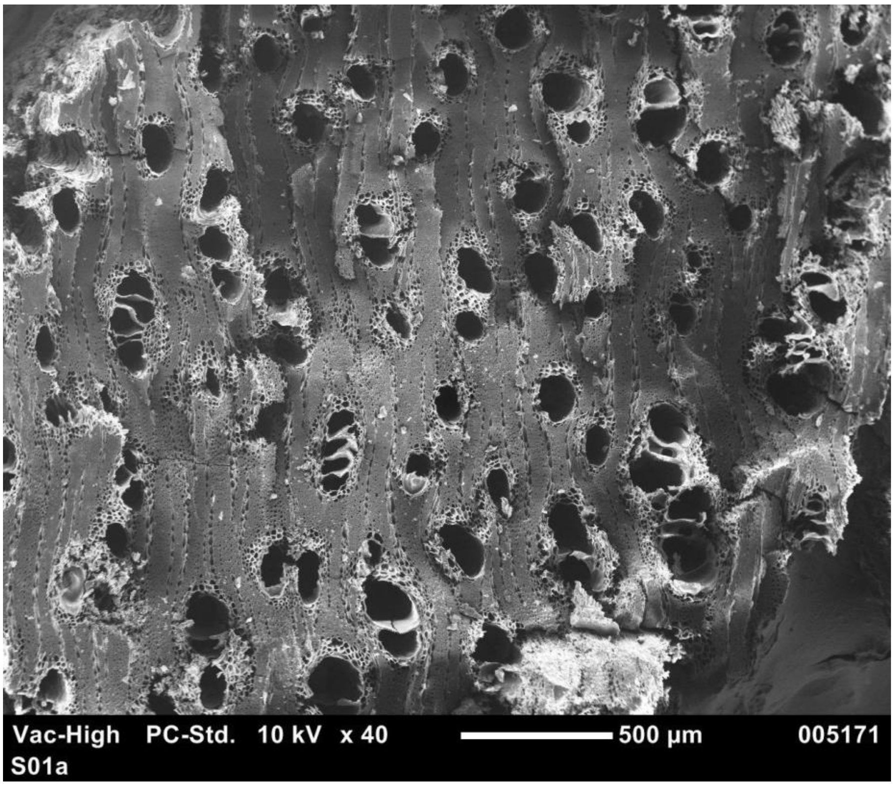

200 µm

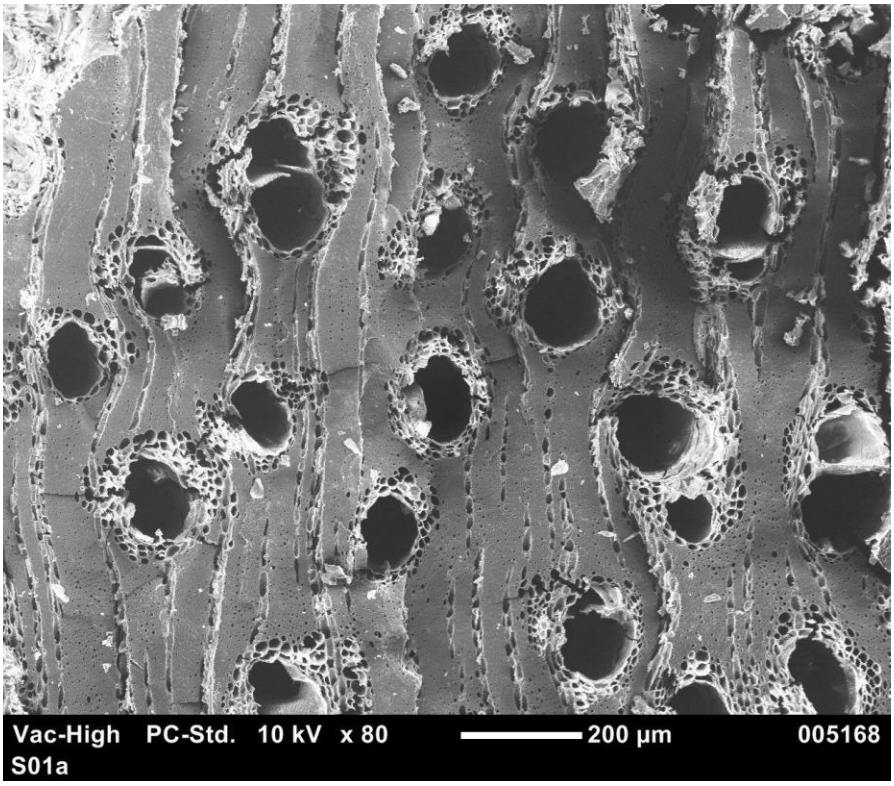

200 µm

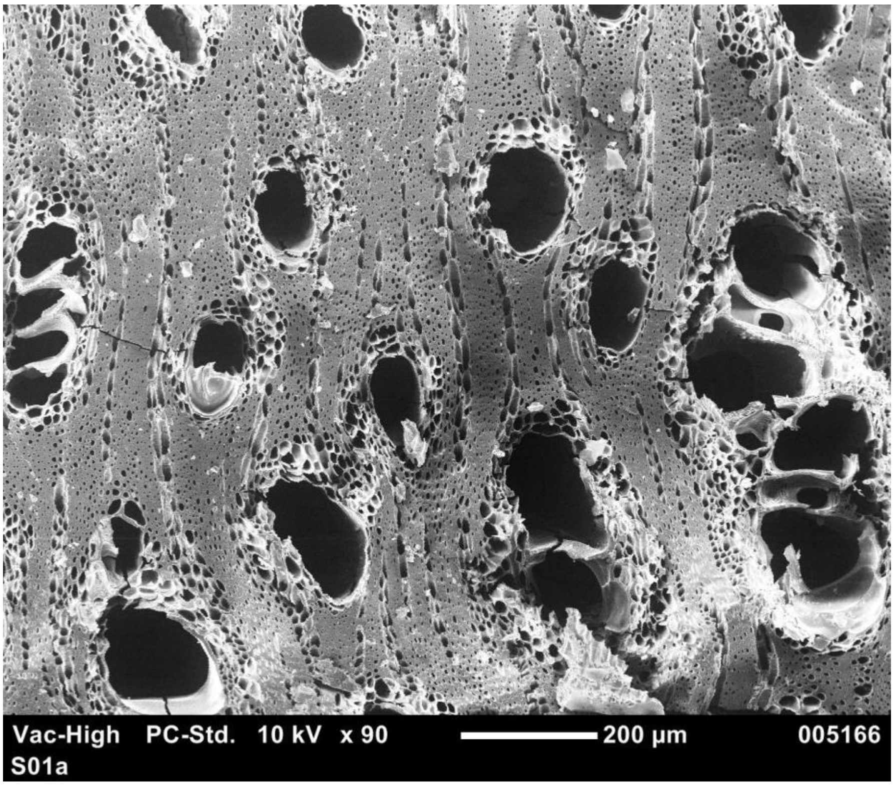

100 µm

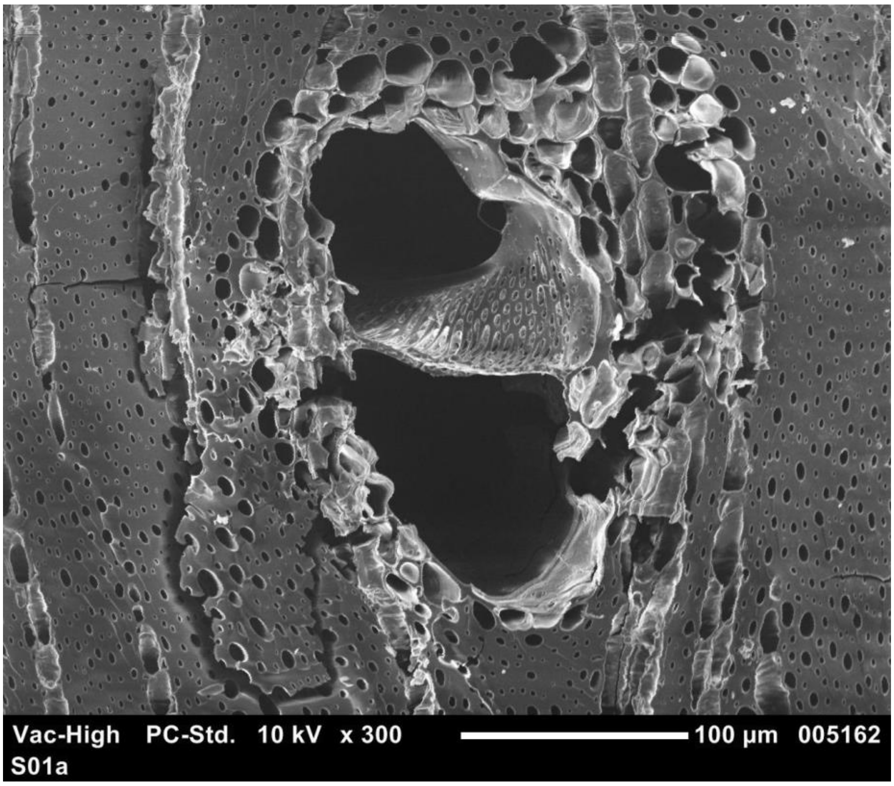

50 µm

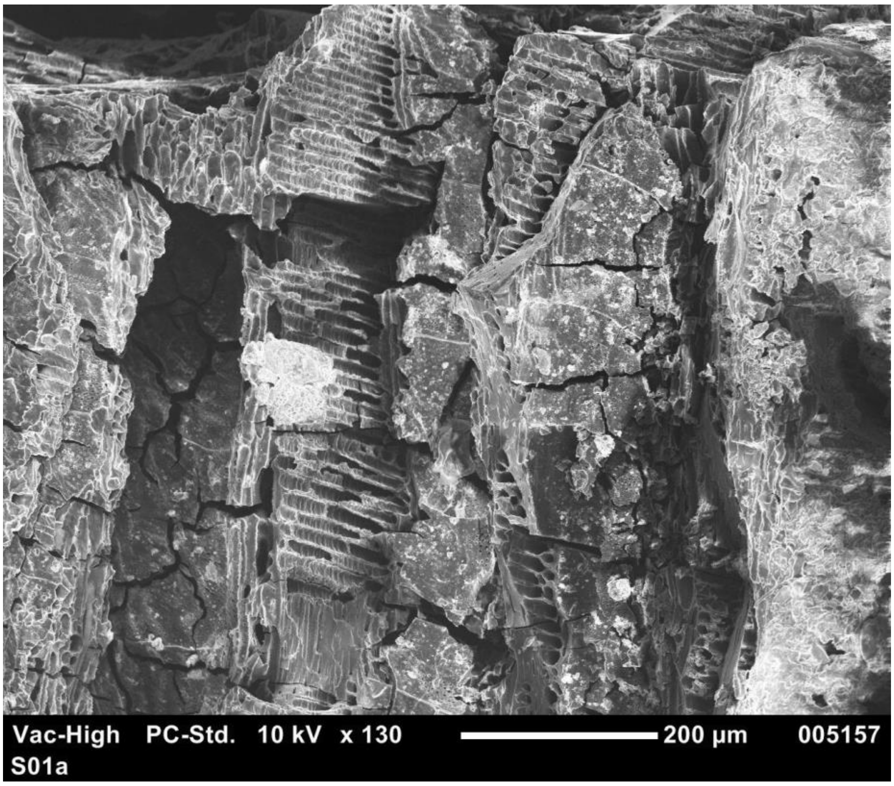
Mimosaceae – *Acacia* sp. (Type 25)

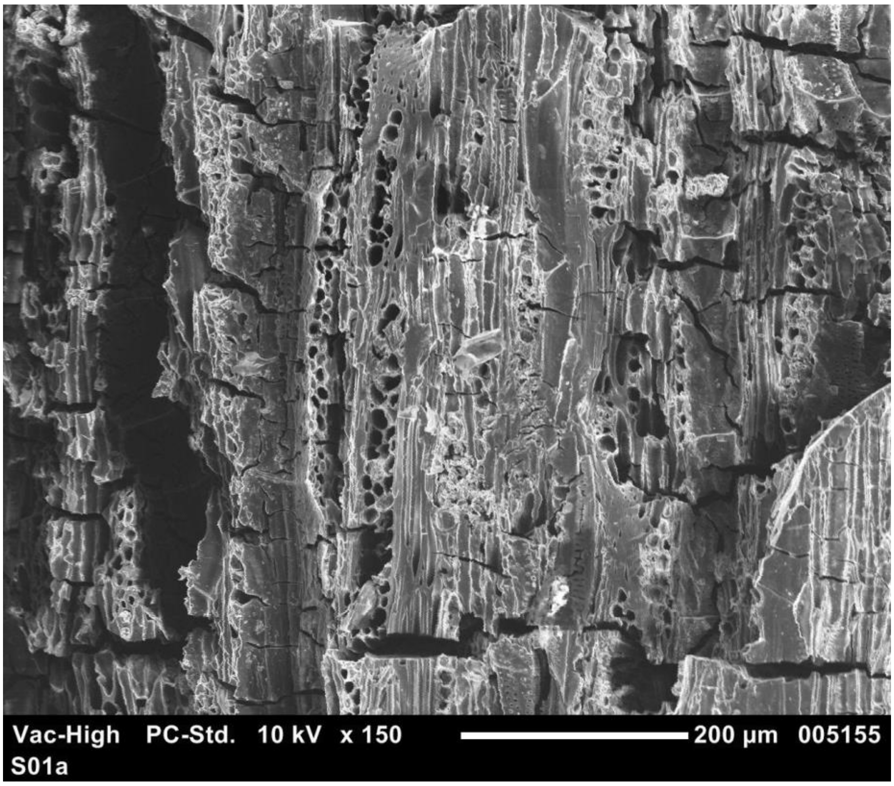




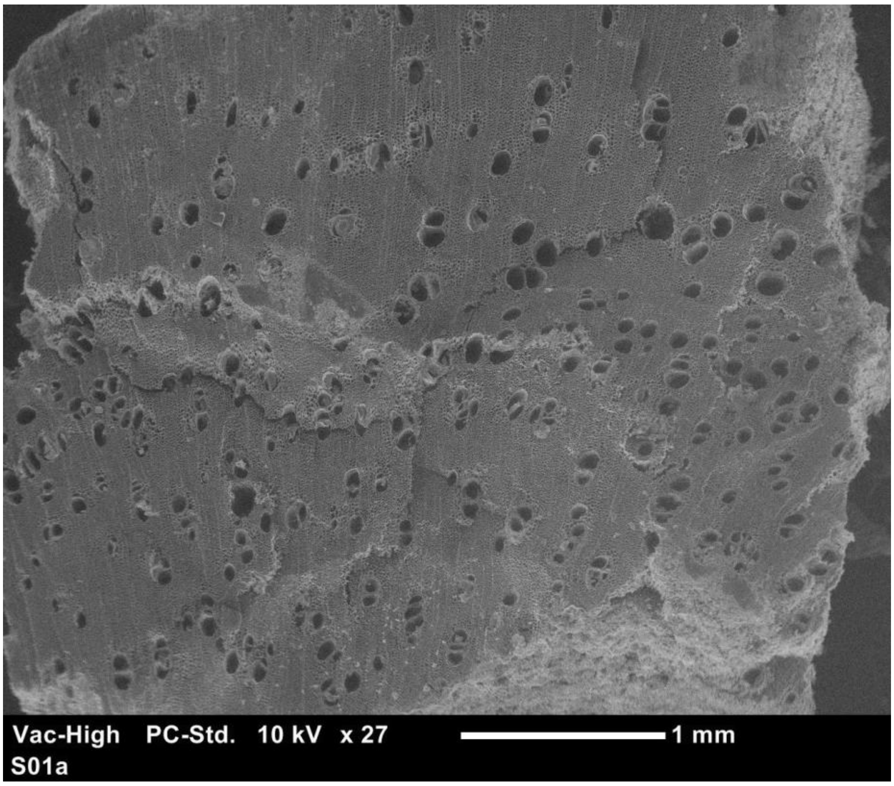

Vac-High PC-Std. 10 kV x 90
200 µm
005166
S01a

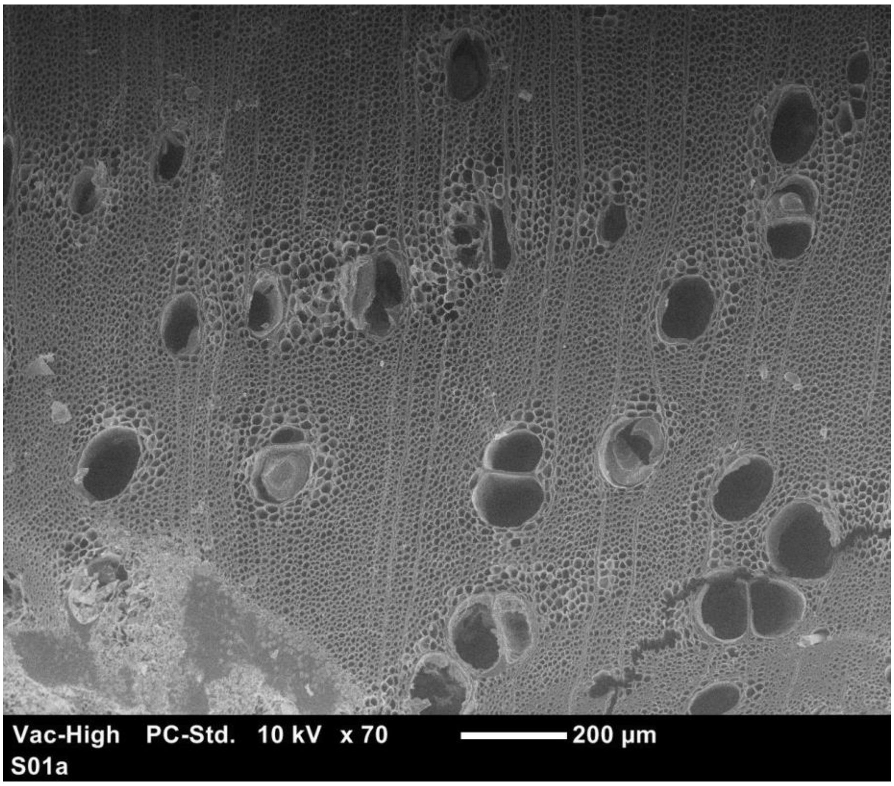

Vac-High PC-Std. 10 kV x 300
100 µm
005162
S01a

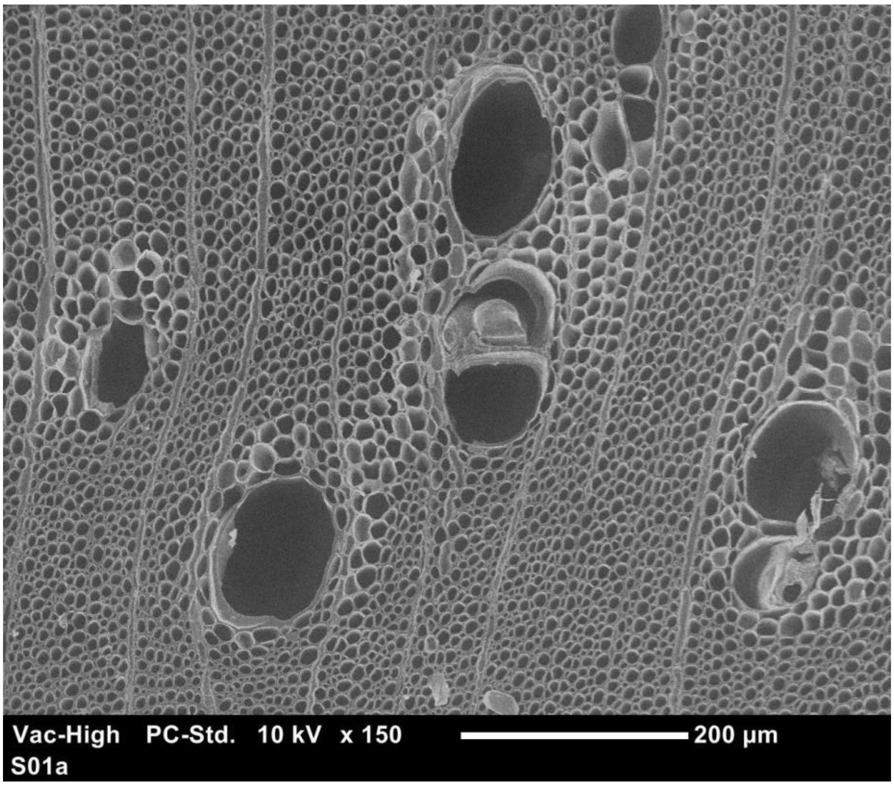

Vac-High PC-Std. 10 kV x 130
200 µm 005157
S01a

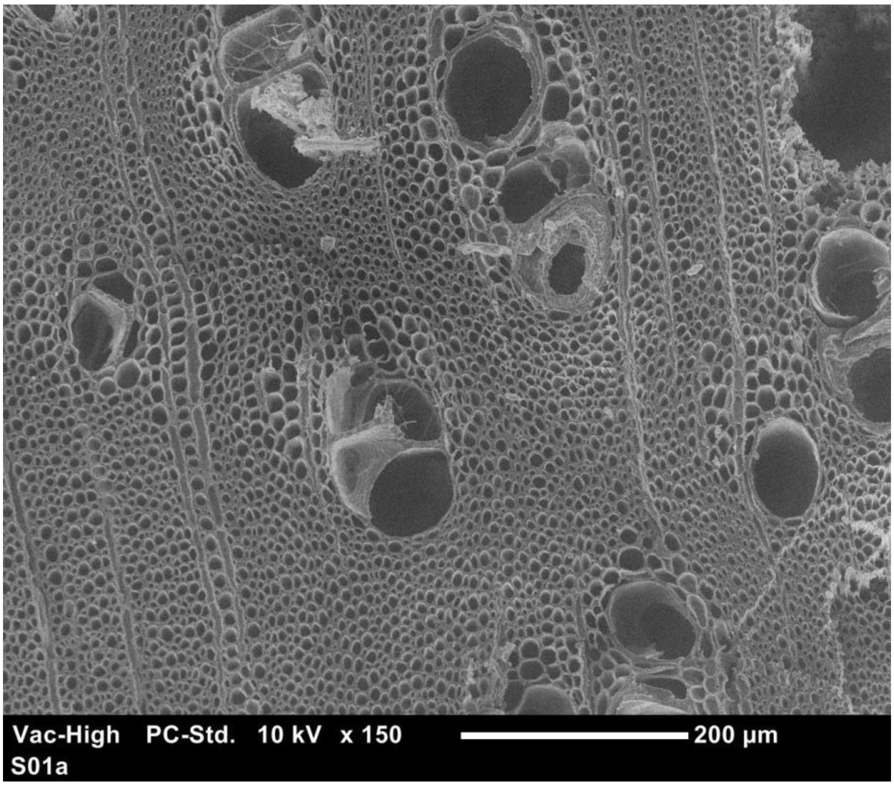

Vac-High PC-Std. 10 kV x 150
200 µm 005155
S01a

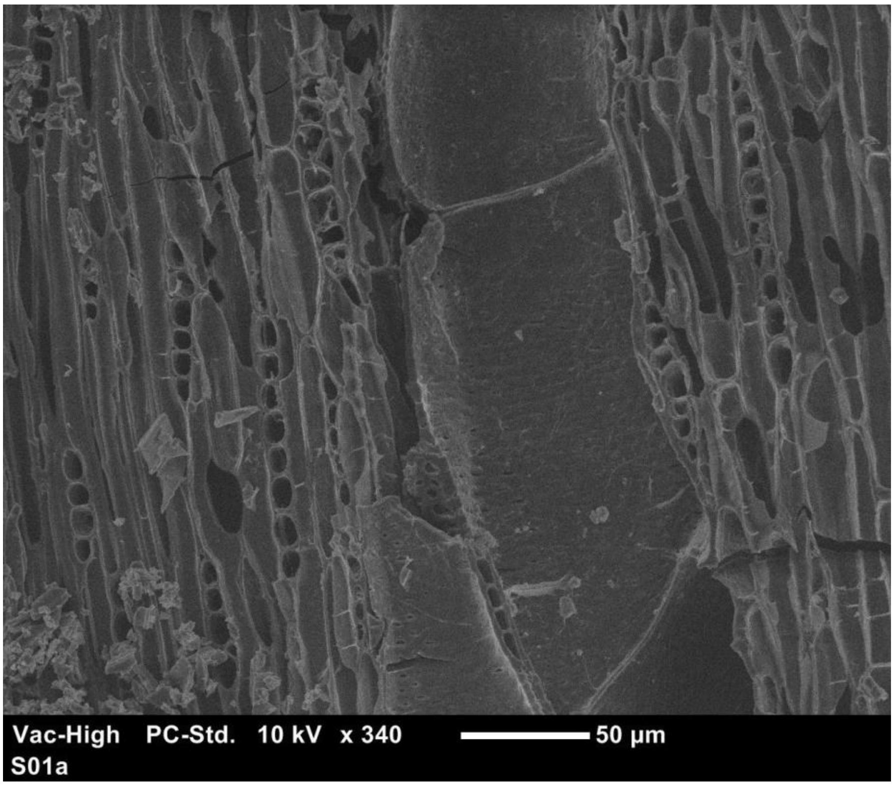
Mimosaceae – *Acacia* sp. (Type 41)

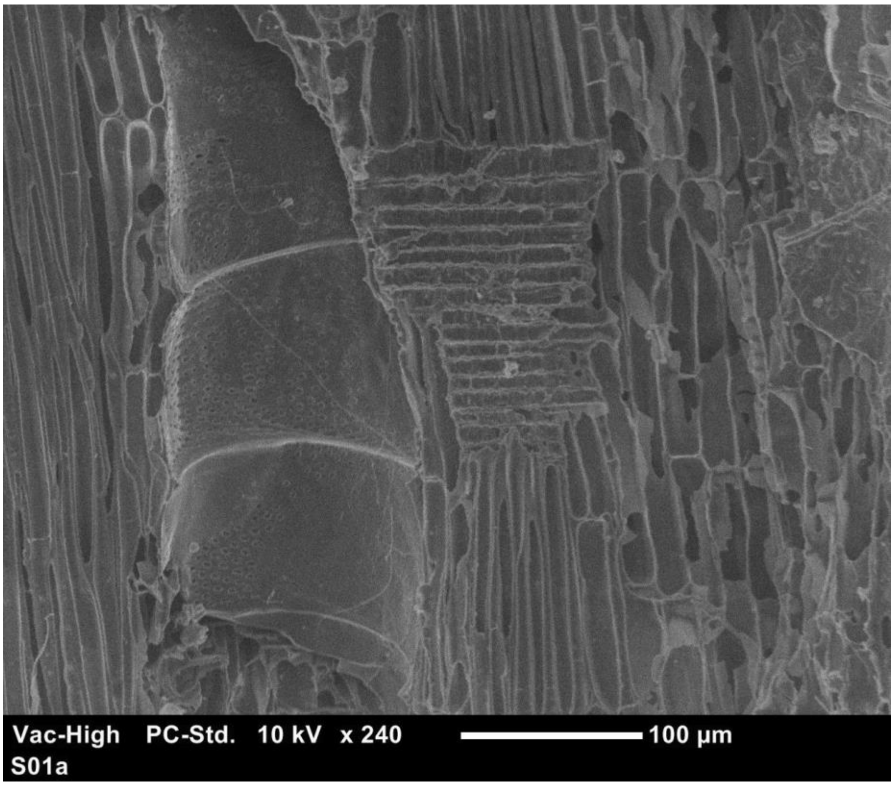




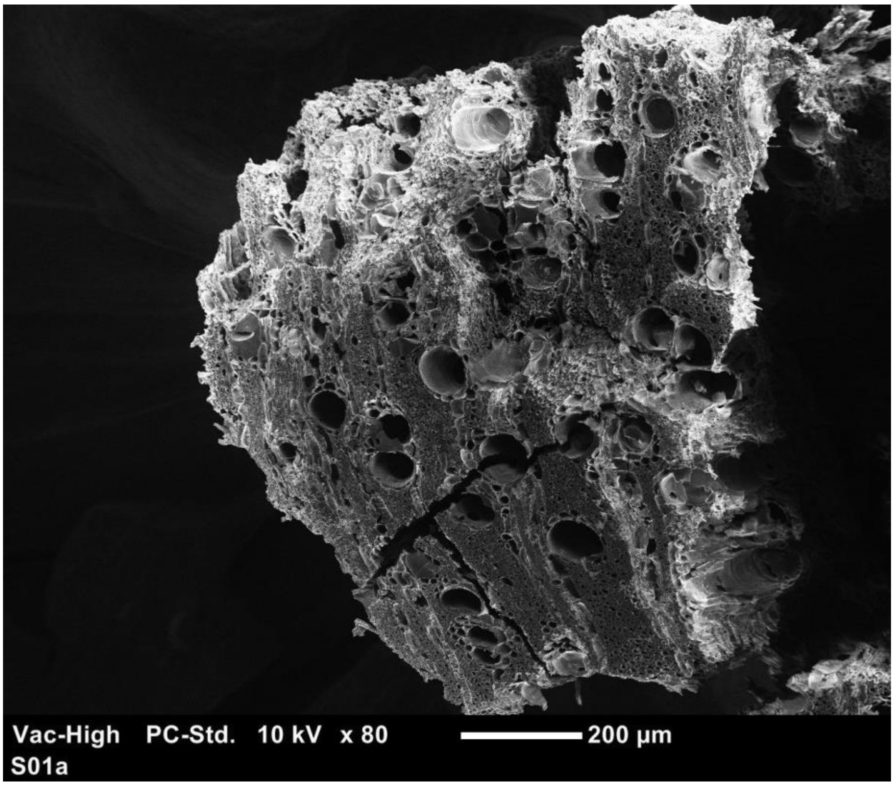

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

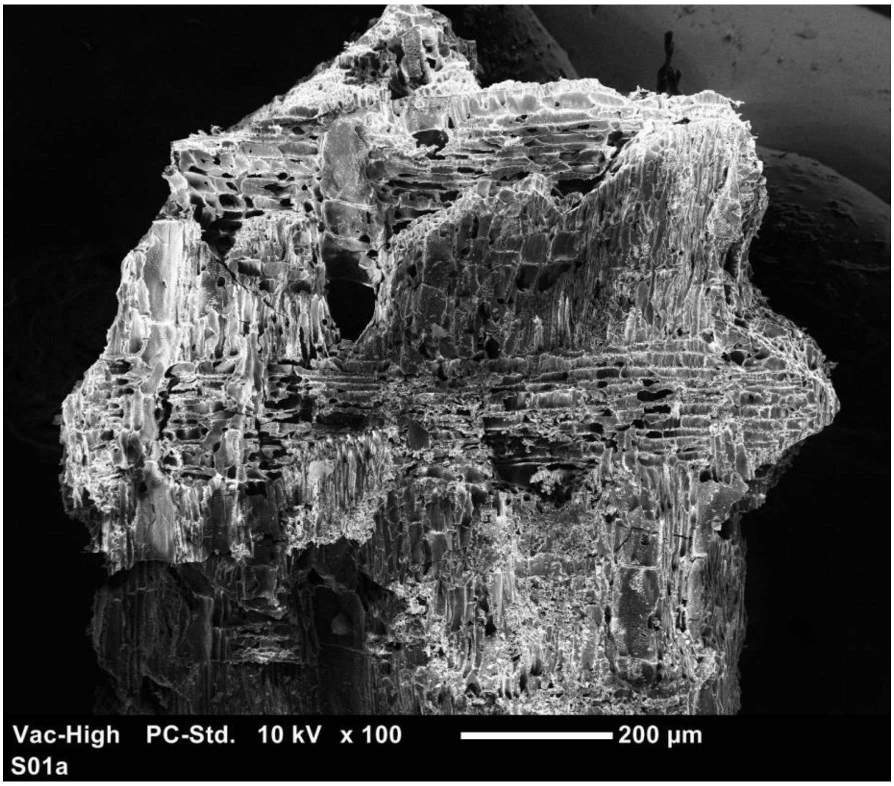

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

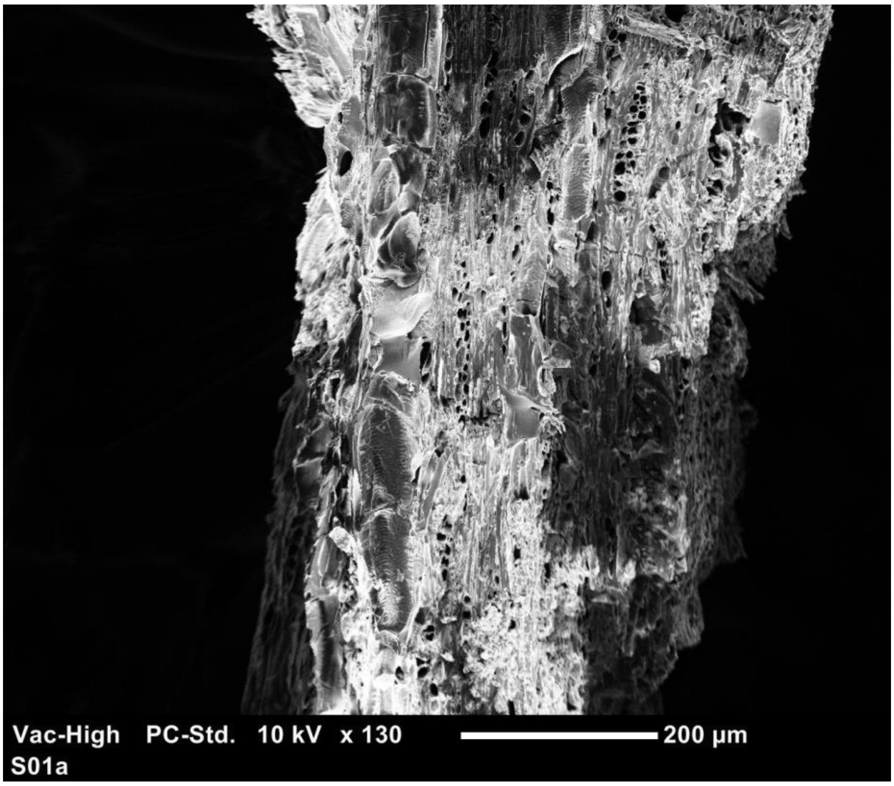

Vac-High PC-Std. 10 kV x 340
50 µm
S01a


Vac-High PC-Std. 10 kV x 240
100 µm
S01a

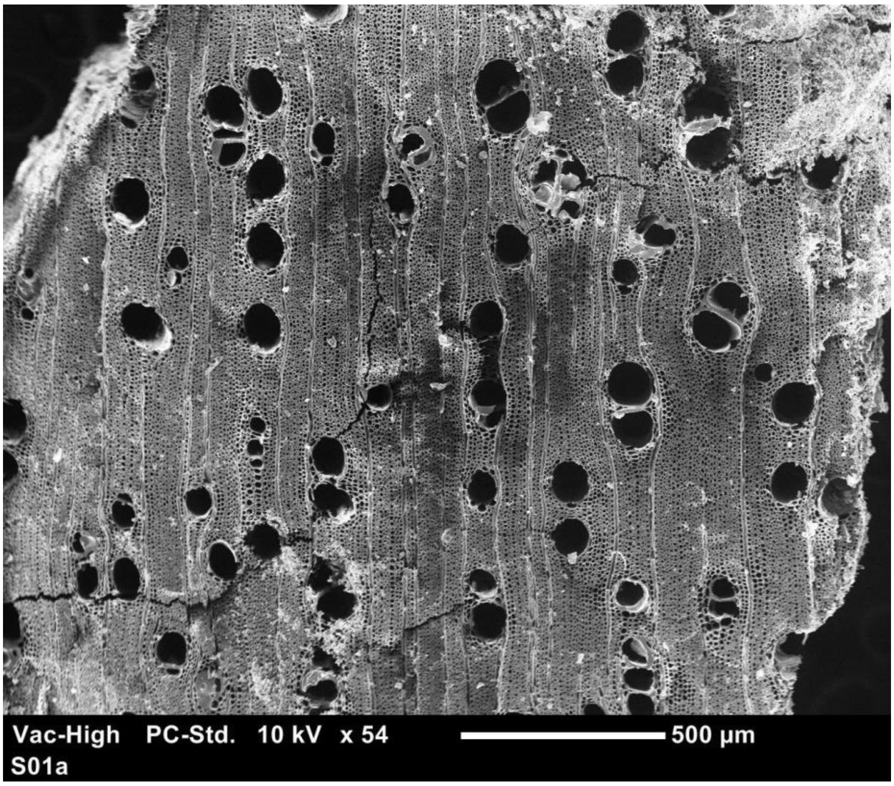
Mimosaceae – *Acacia* sp. (Type 47)

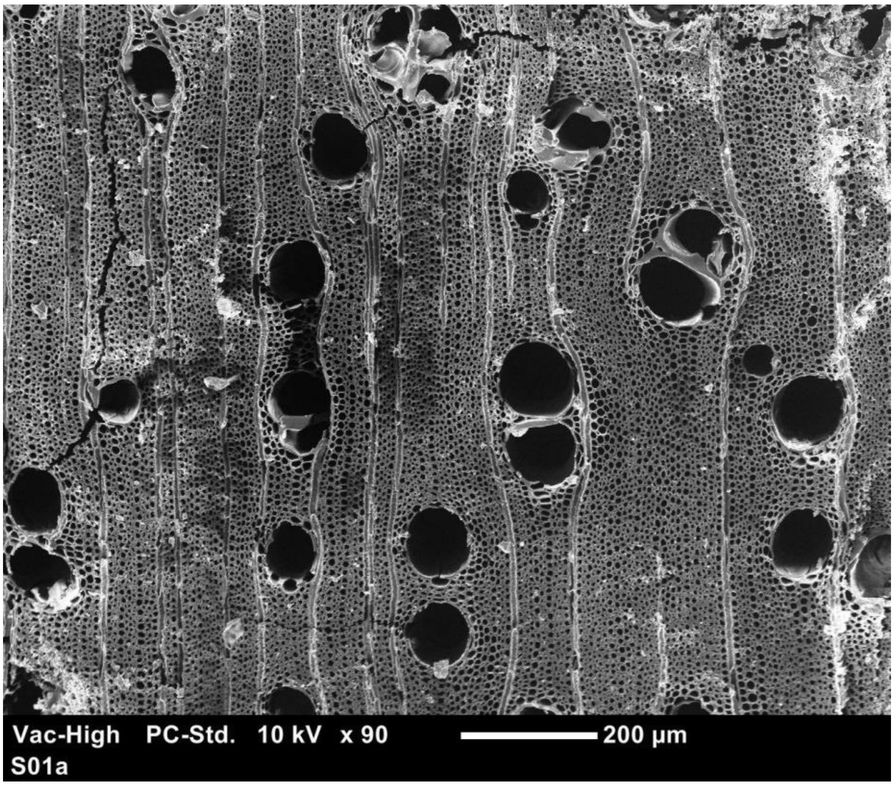


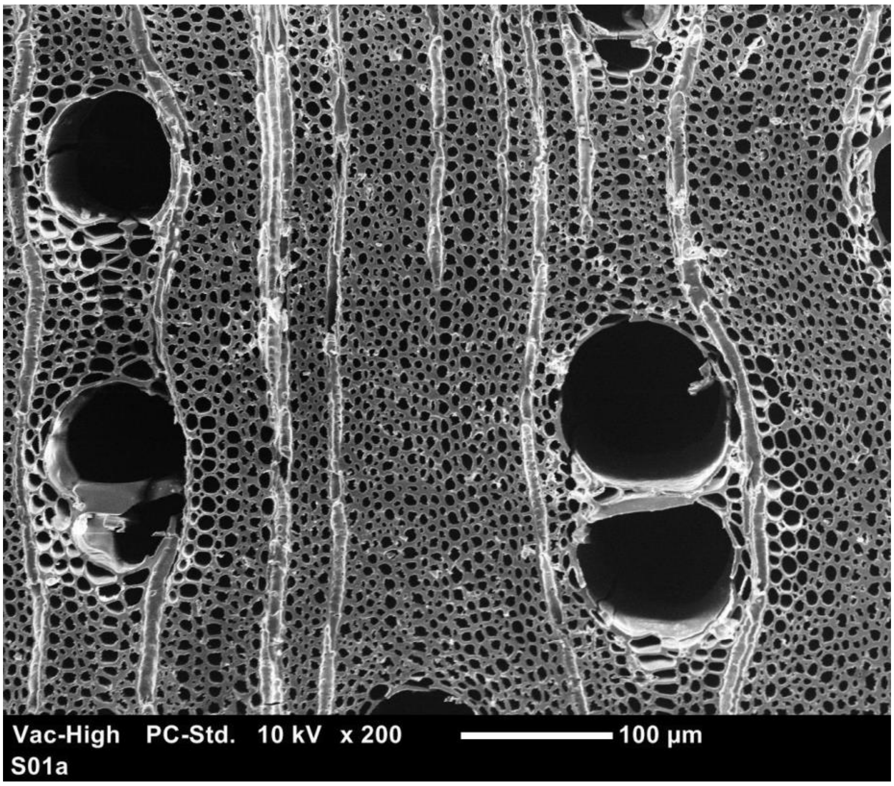


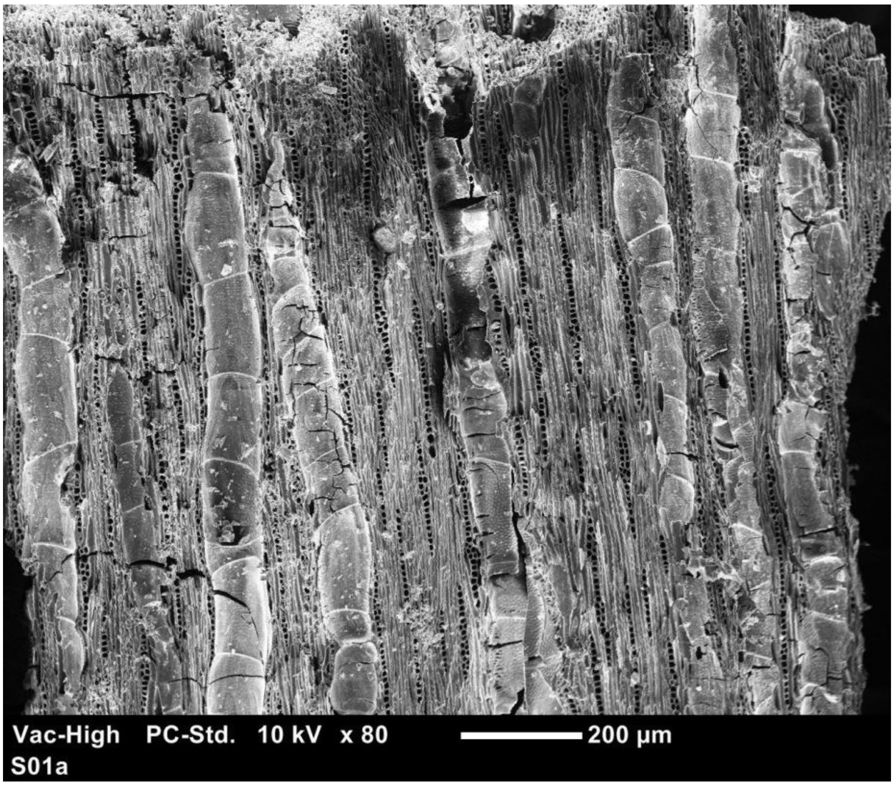

Vac-High PC-Std. 10 kV x 130
200 µm
S01a

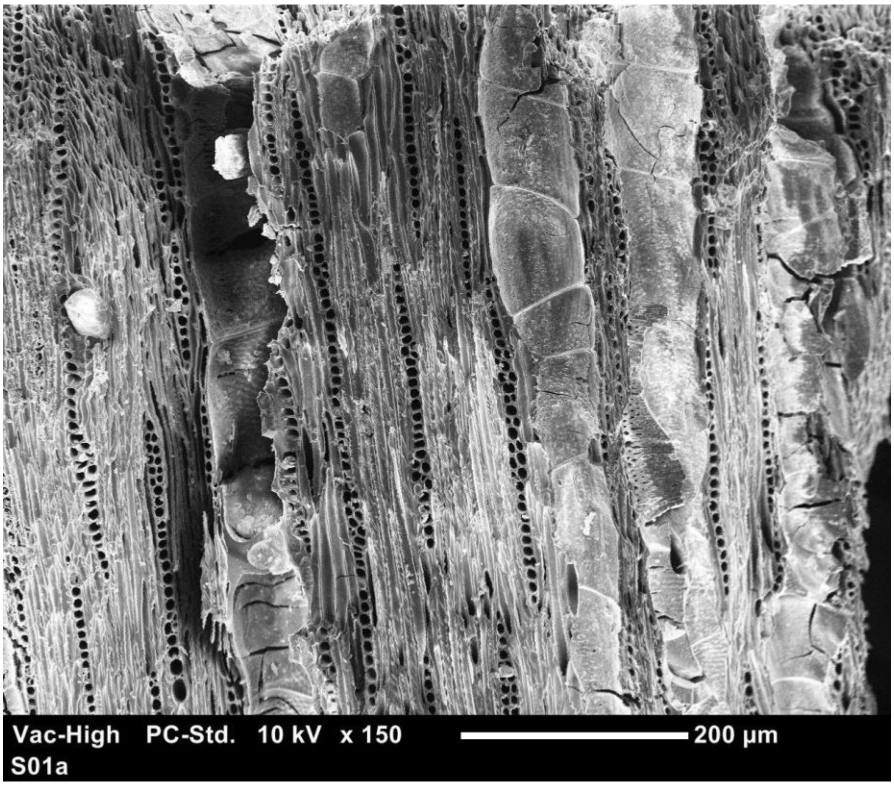
Mimosaceae – *Acacia* sp. (Type 49)

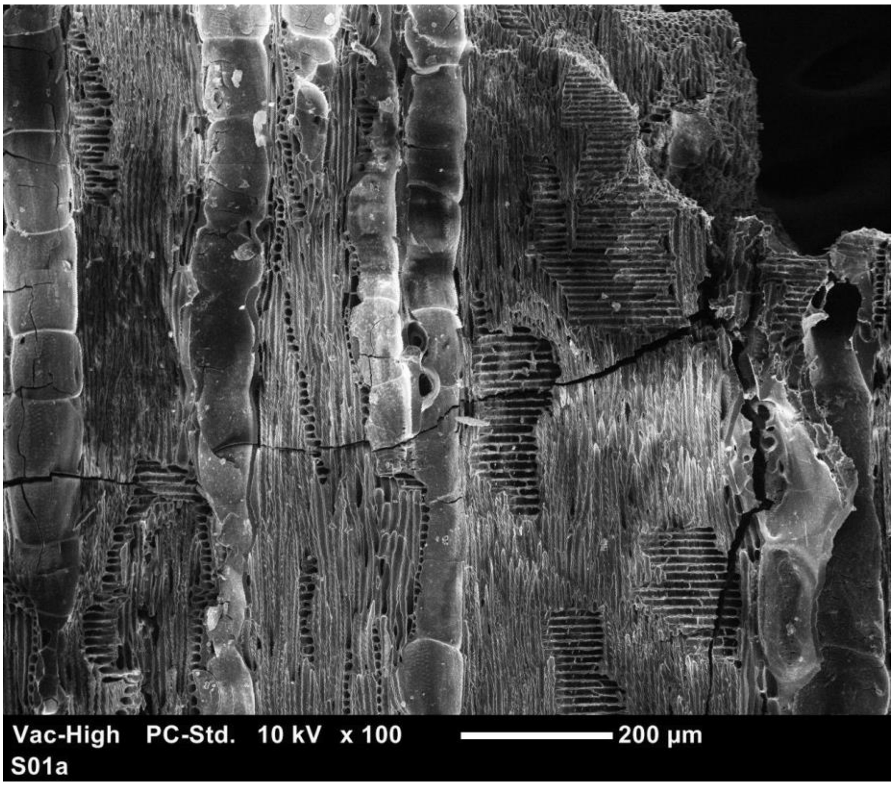




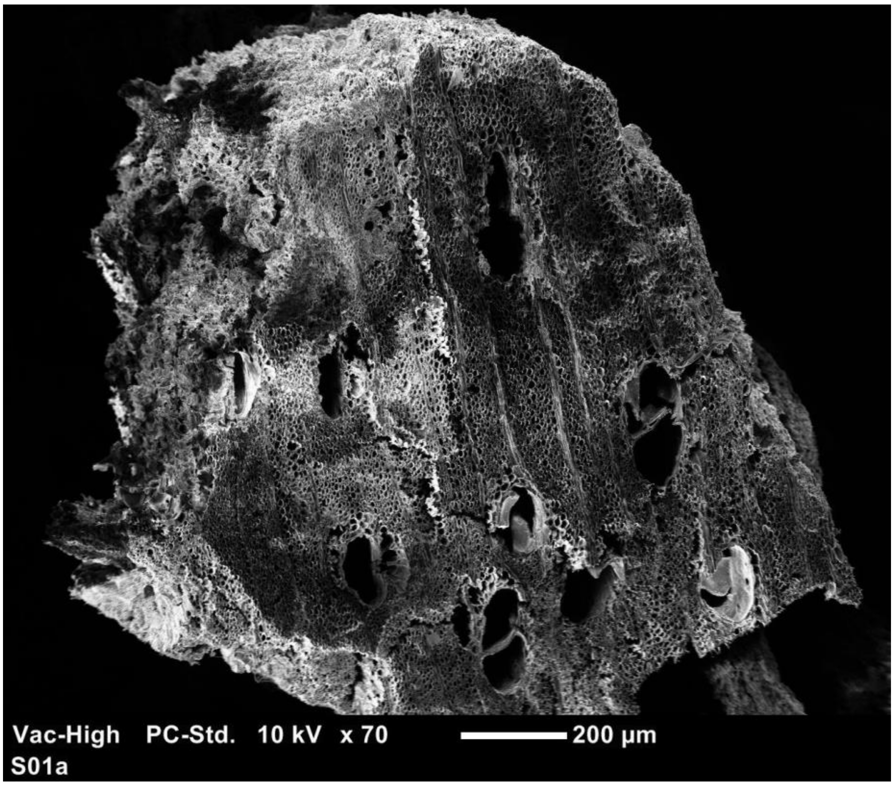

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

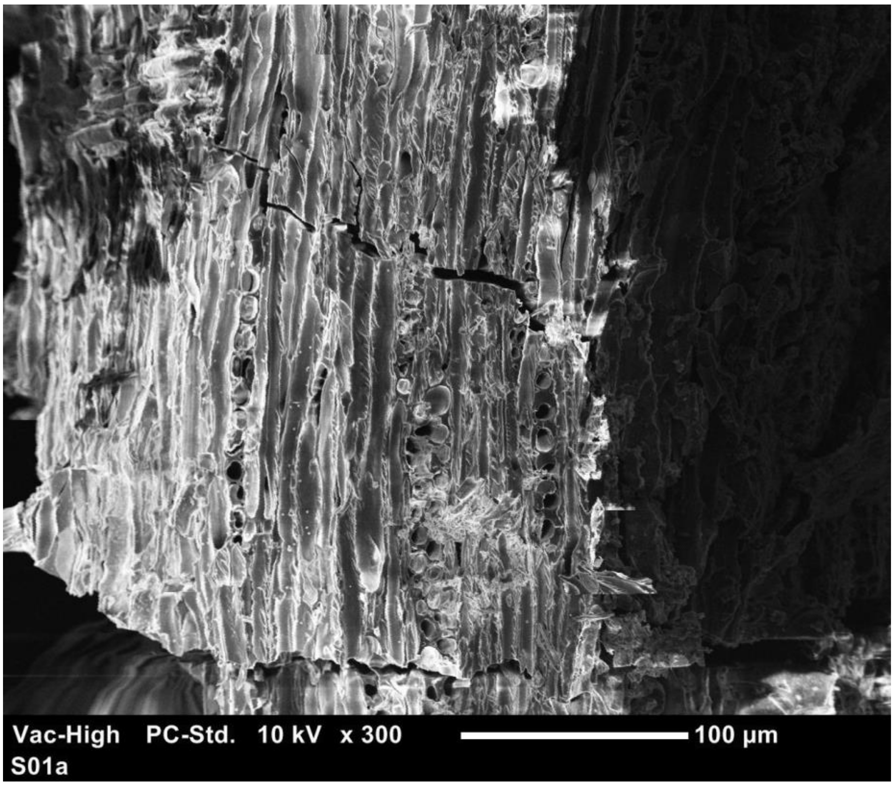

Vac-High PC-Std. 10 kV x 80
200 µm
S01a


Vac-High PC-Std. 10 kV x 150
200 µm
S01a

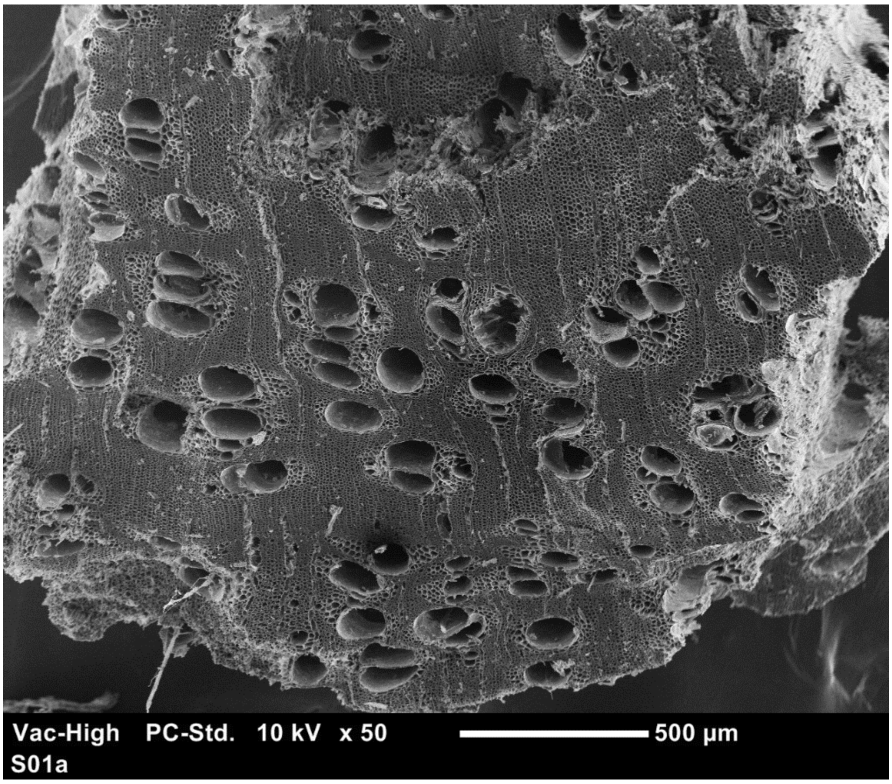

Vac-High PC-Std. 10 kV x 100
200 µm
S01a

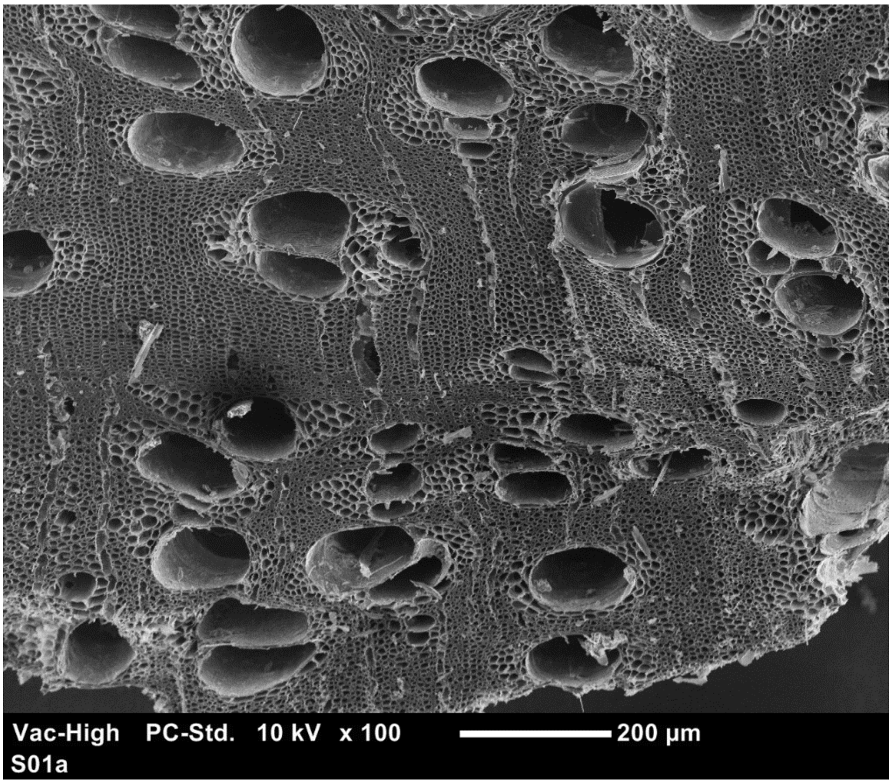
Mimosaceae – *Acacia* sp. (Type 52)

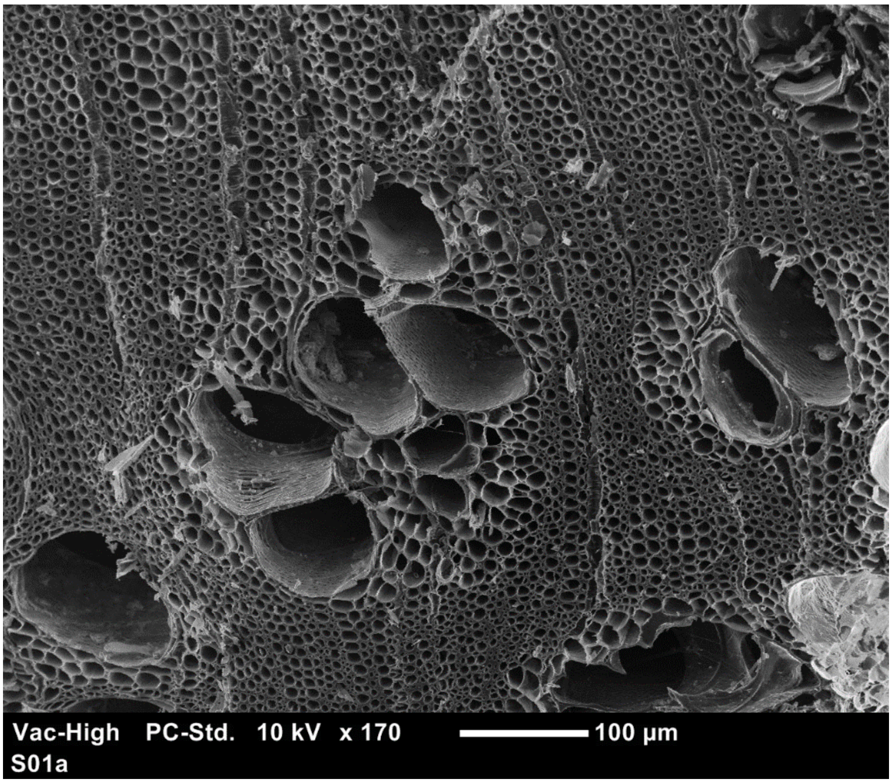


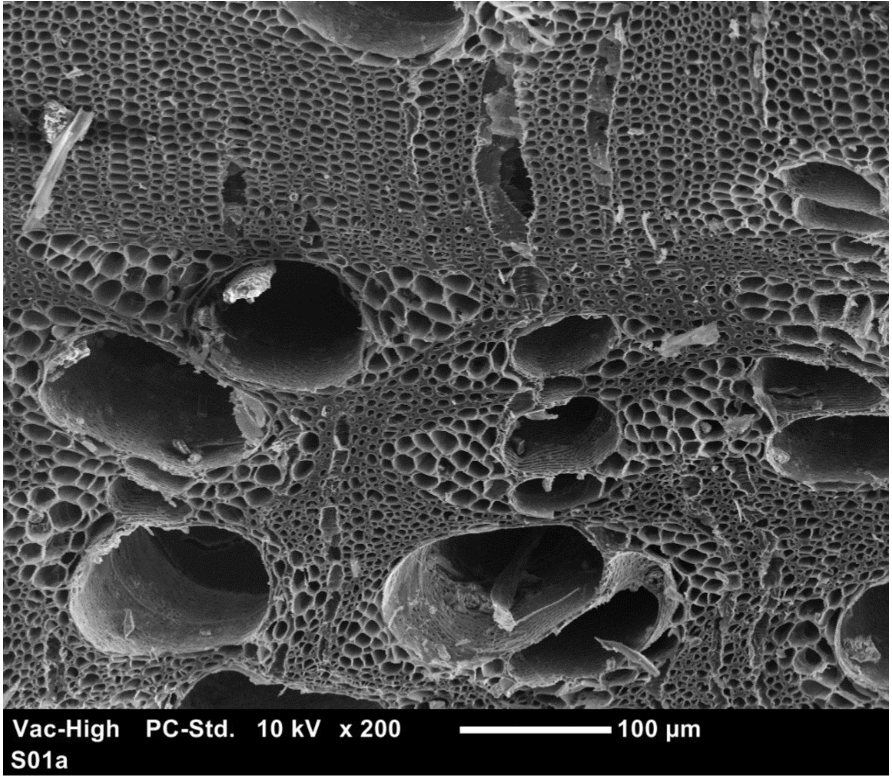


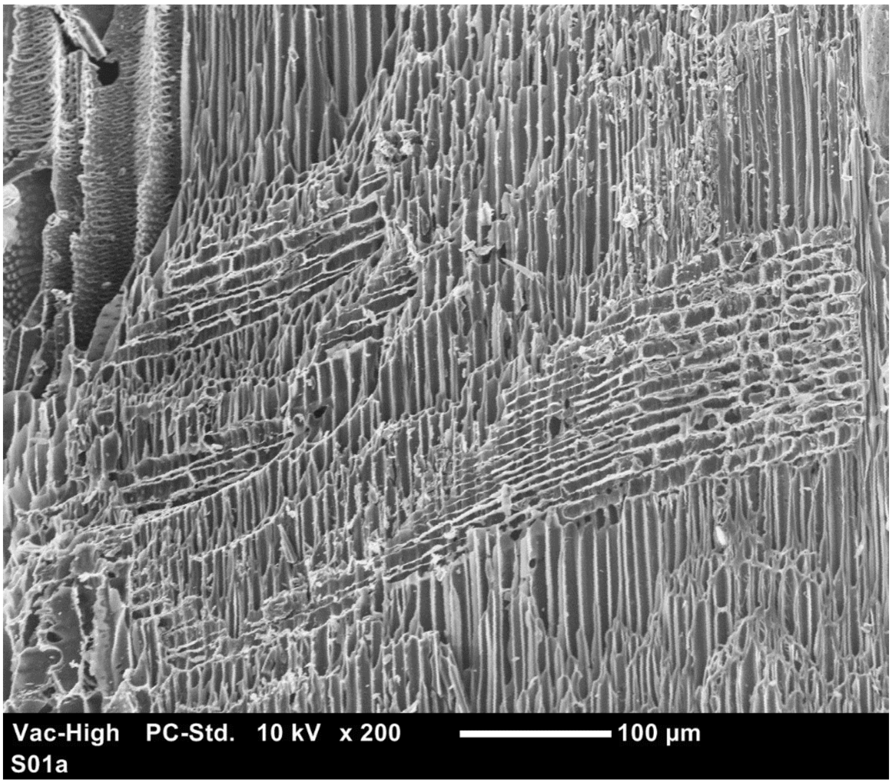
Mimosaceae – *Acacia* sp. (Type 58)

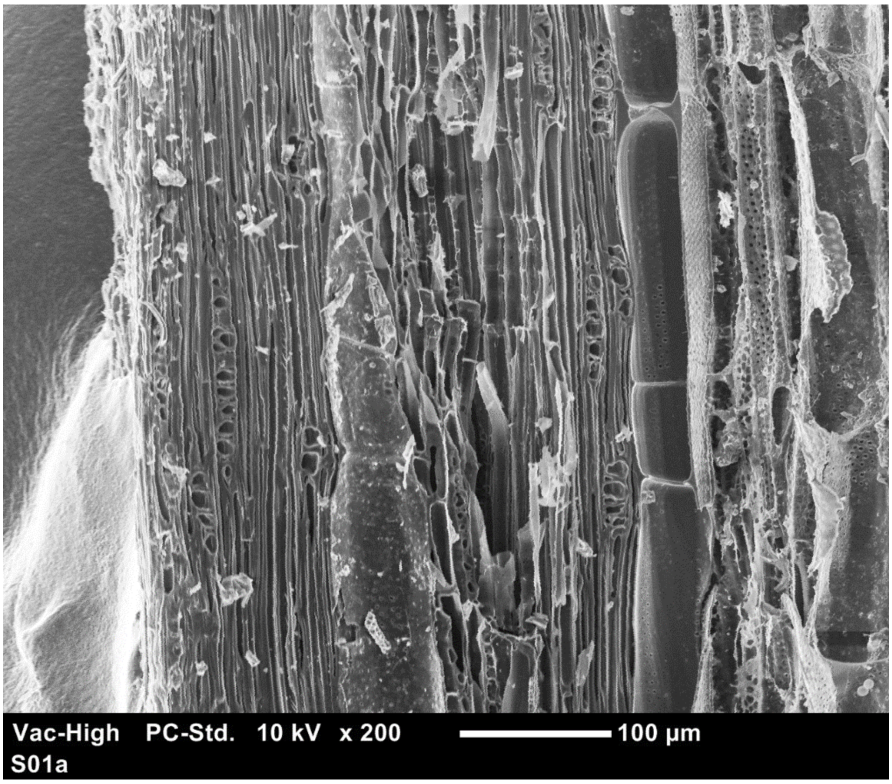




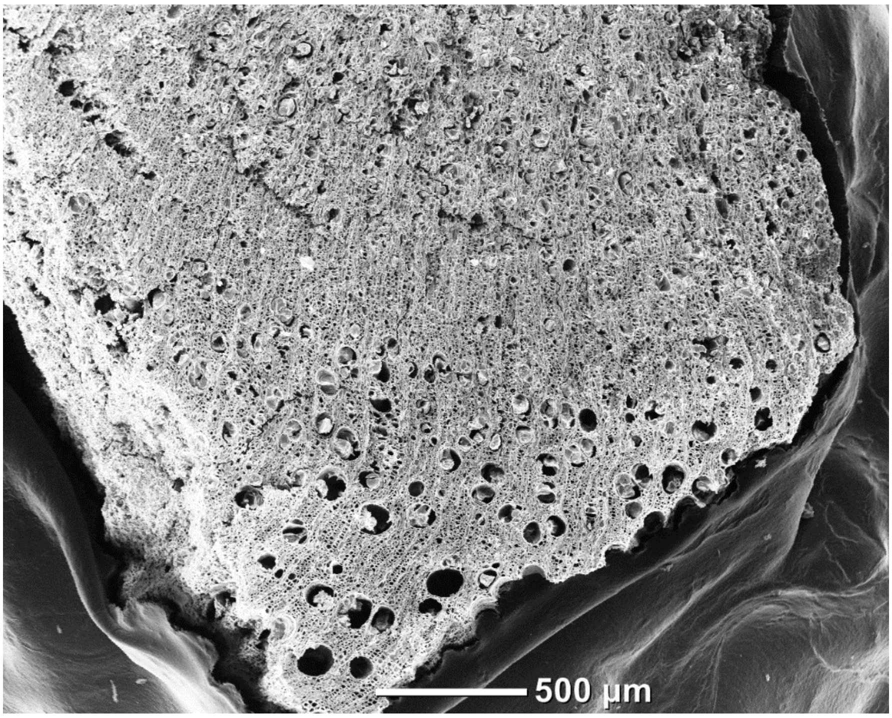

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

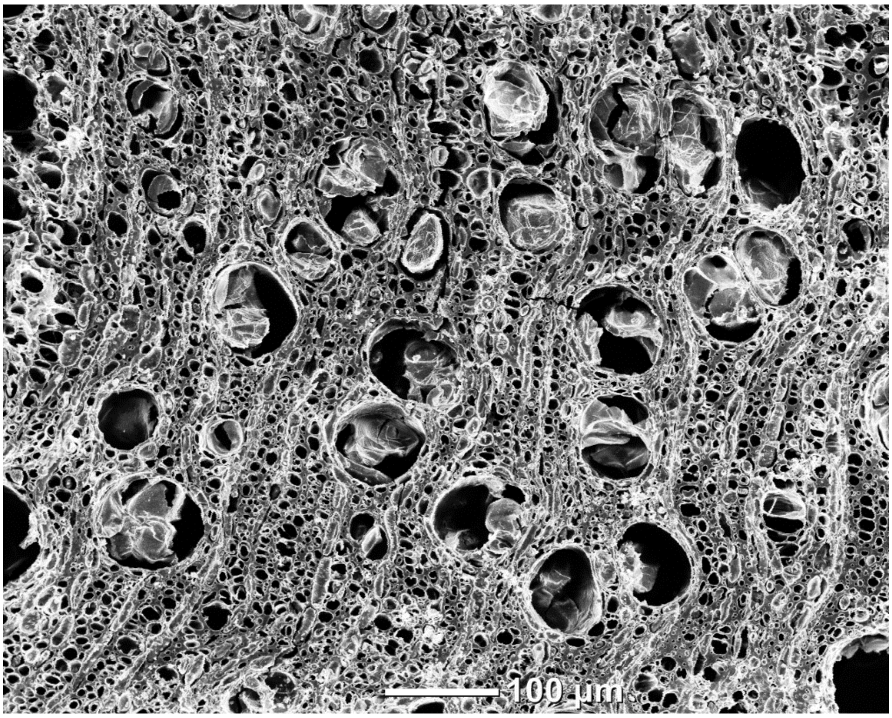

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

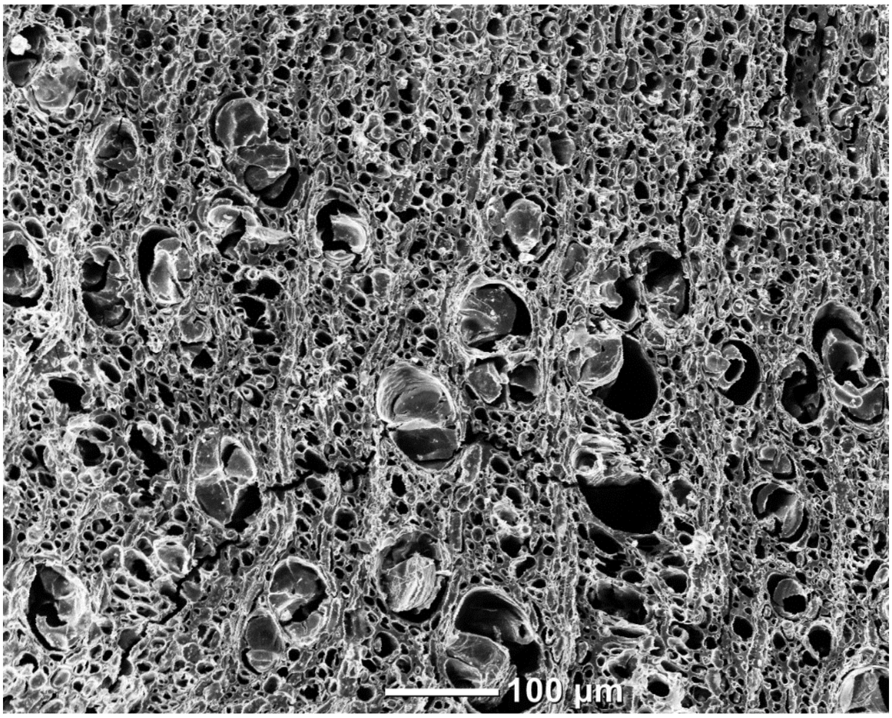

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

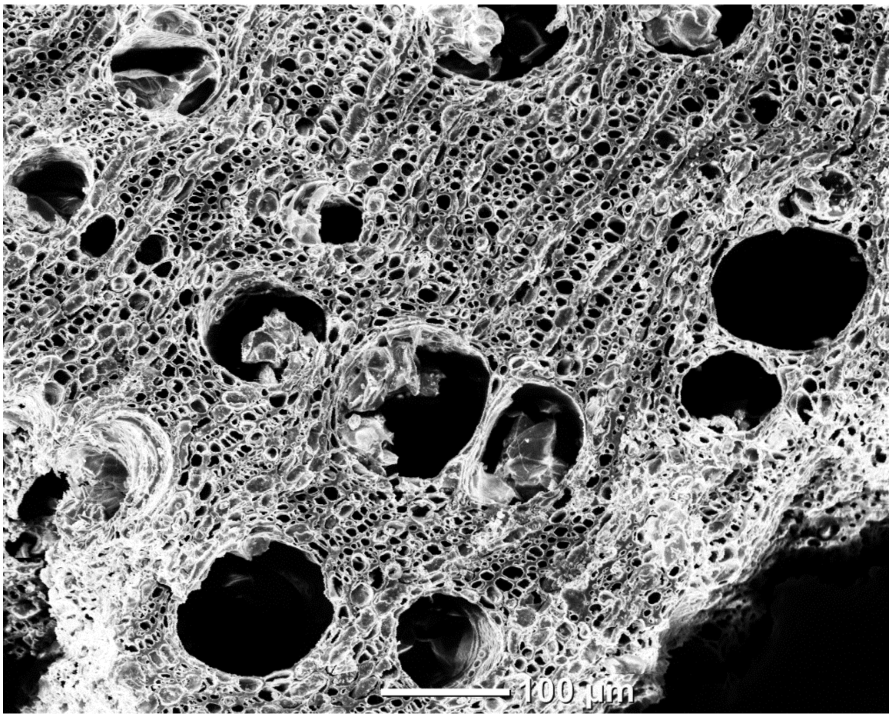

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

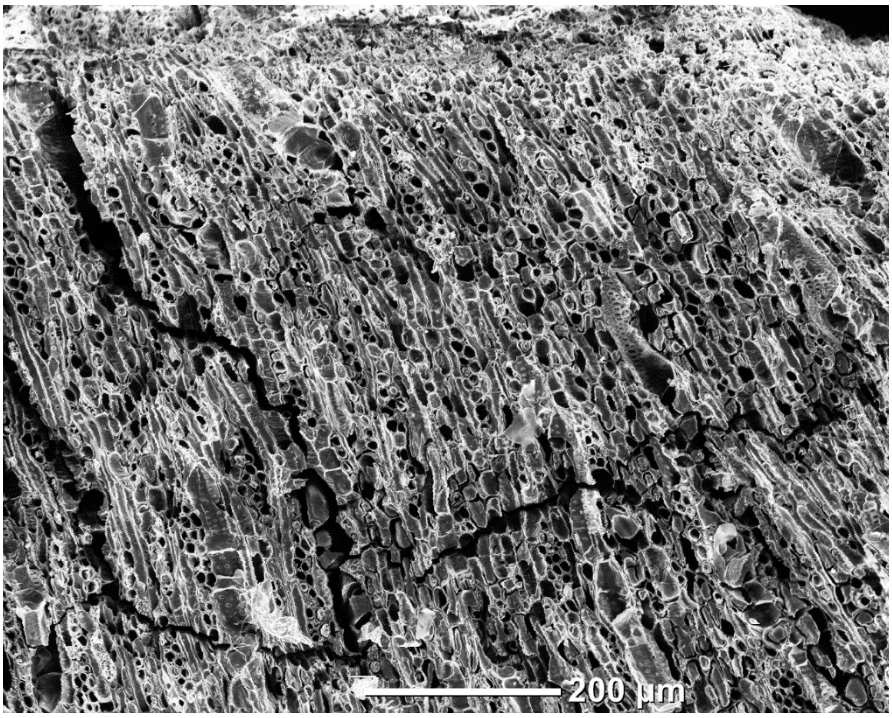
Combretaceae – *Terminalia* sp. (Type 14)

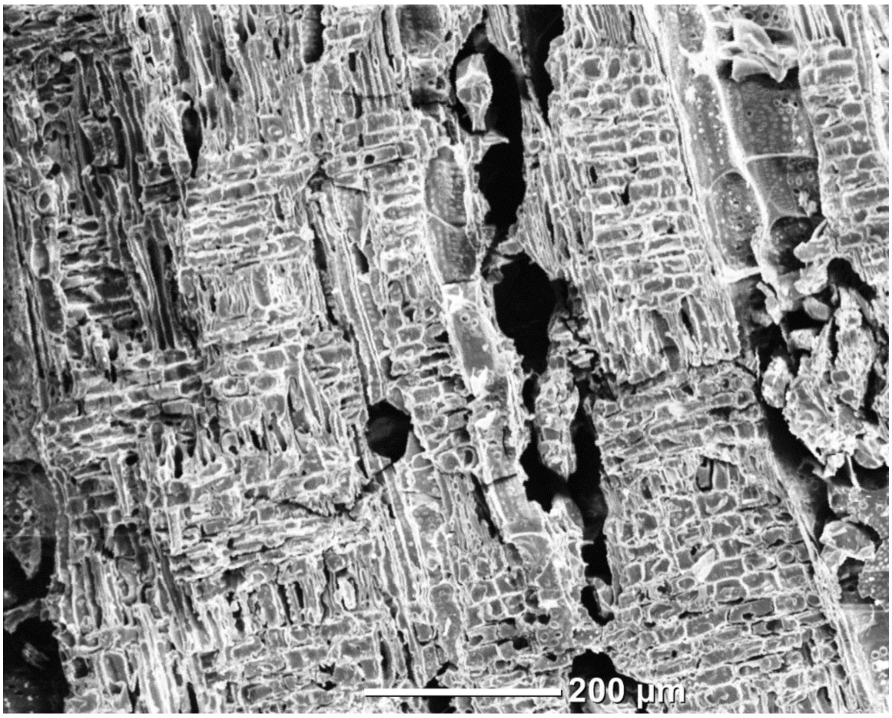




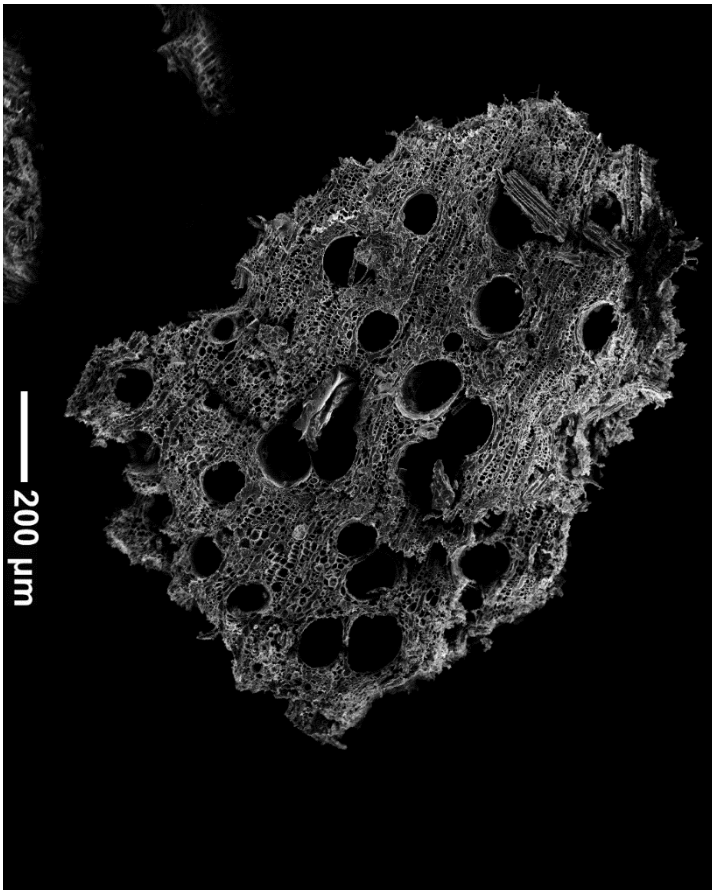

100 µm

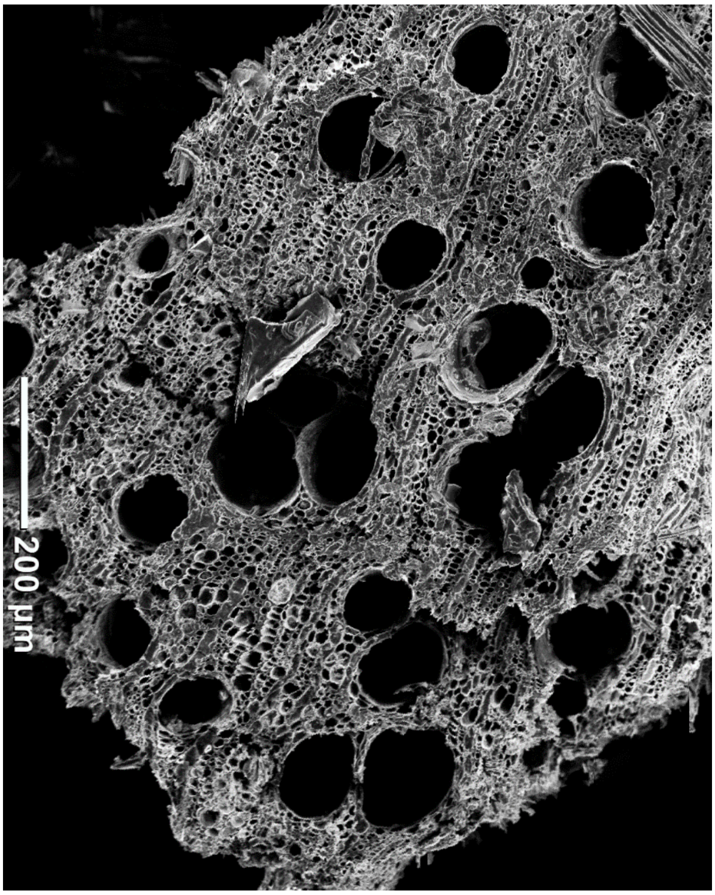

100 µm

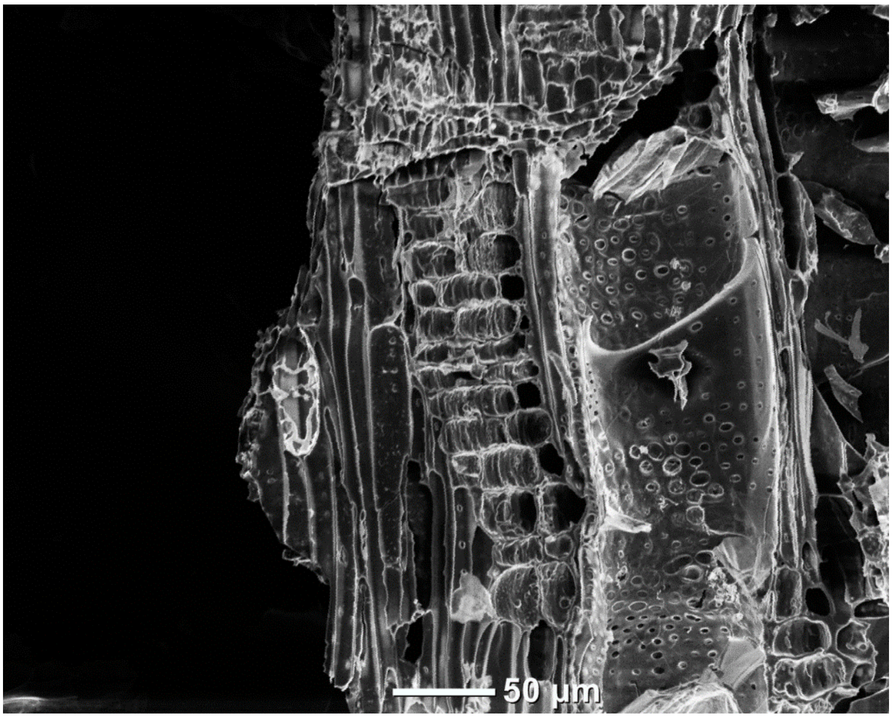

200 µm

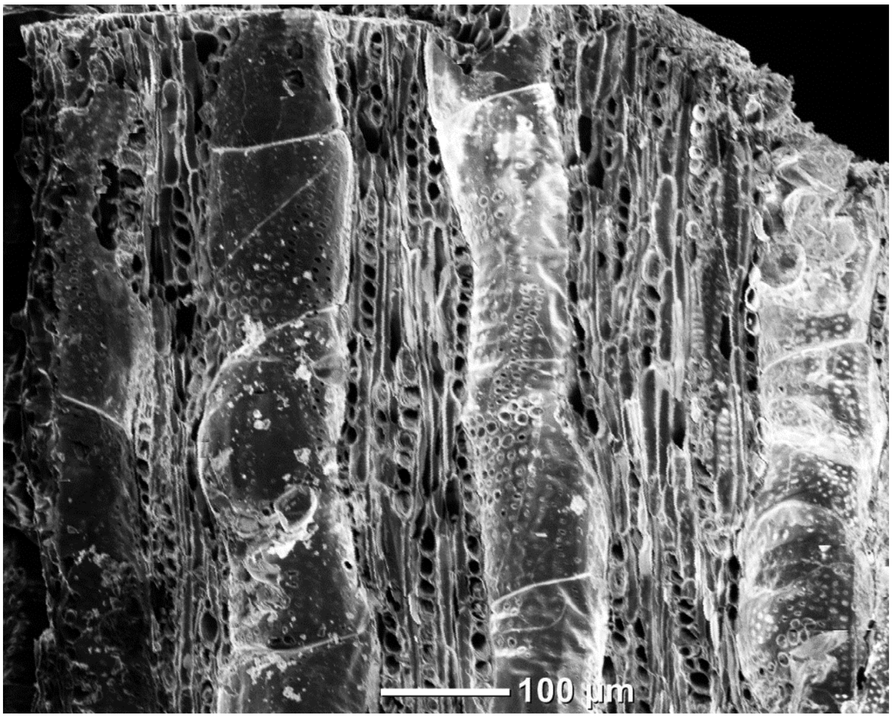

200 µm

Combretaceae – *Terminalia* sp. (Type 16)

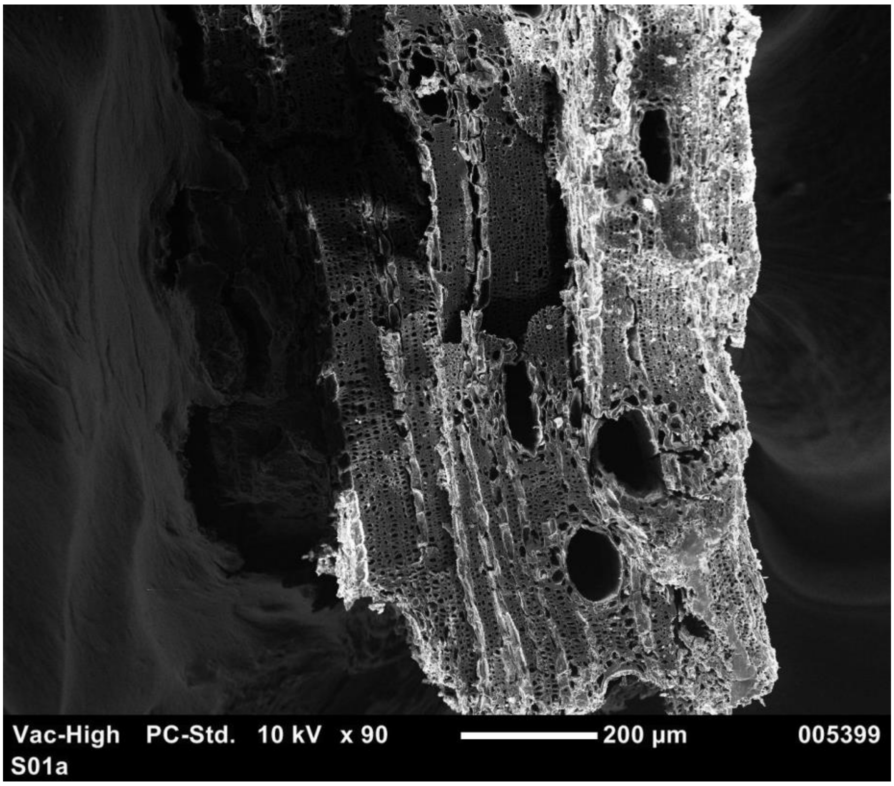


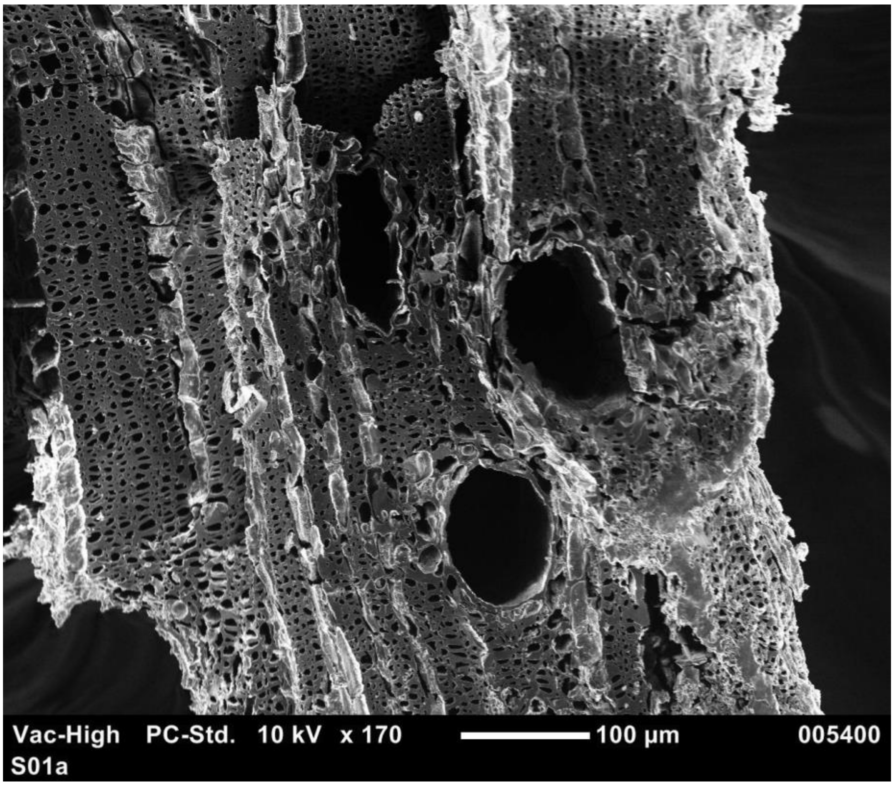


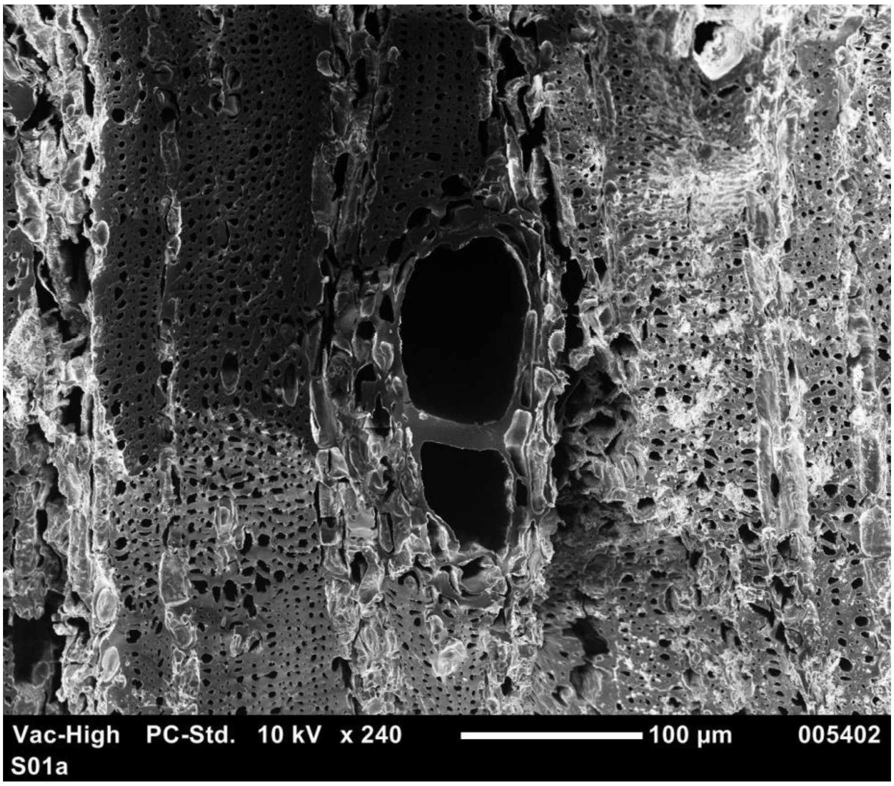

50 µm

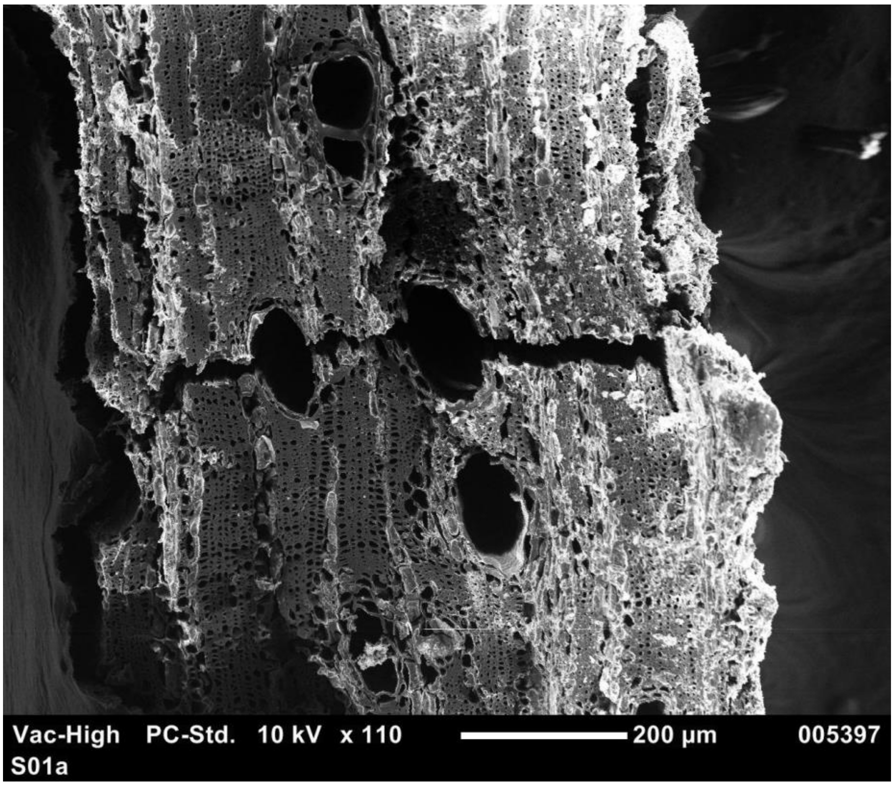

100 µm

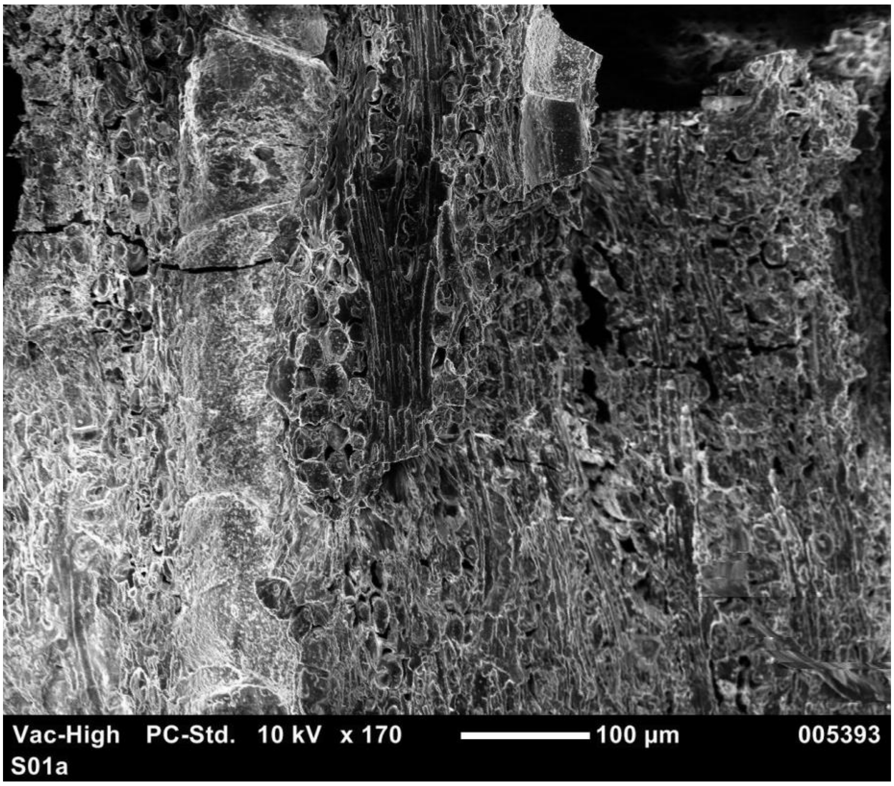
Combretaceae – *Terminalia* sp. (Type 32)

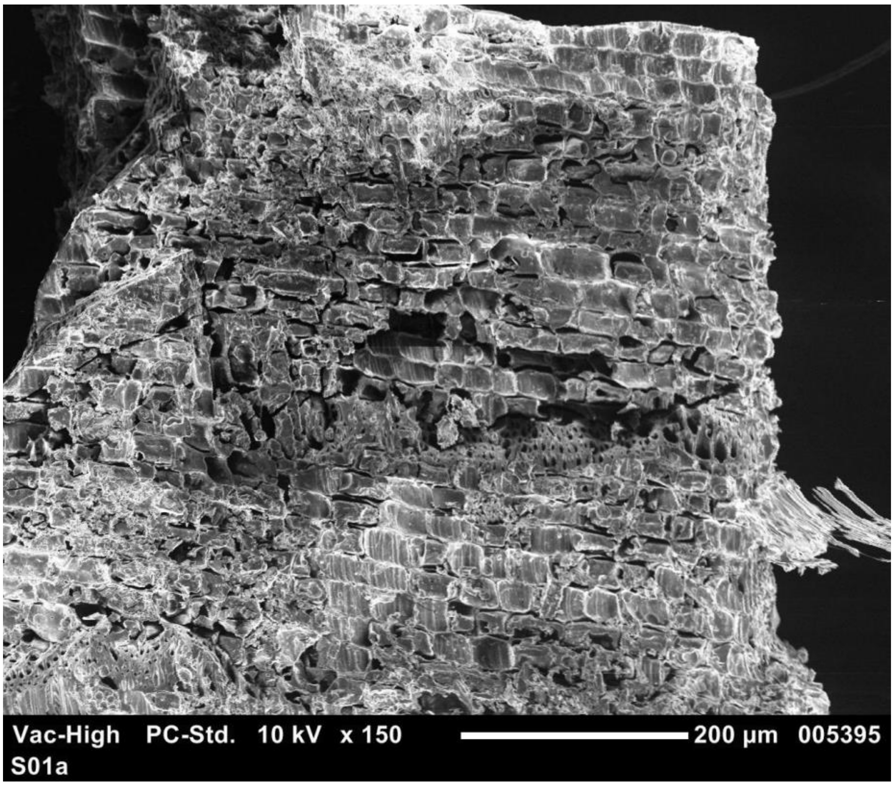




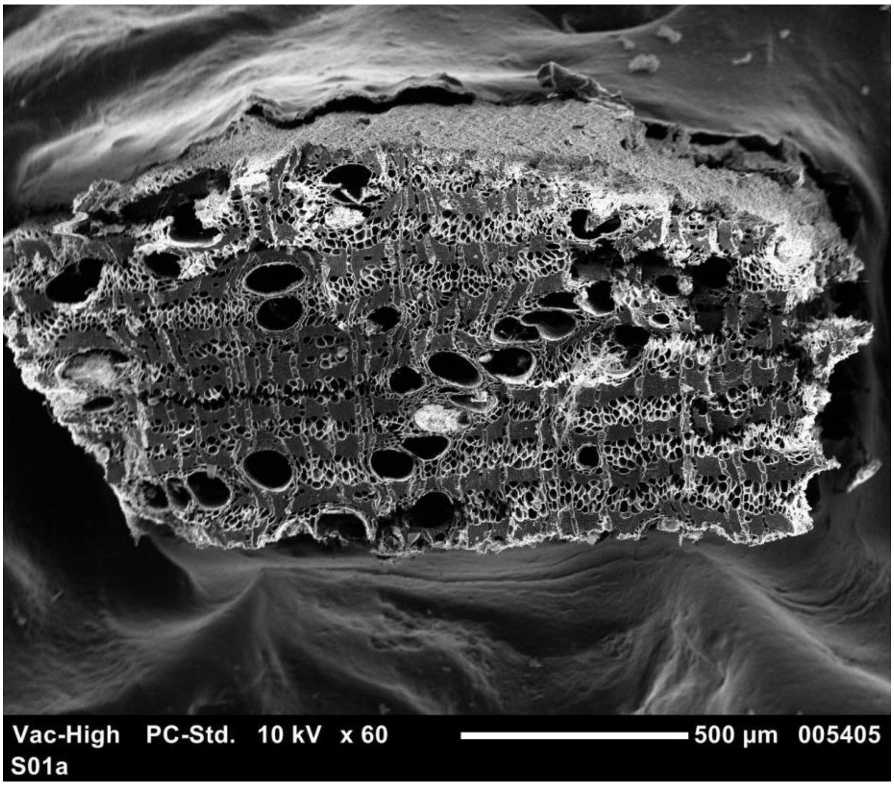

Vac-High PC-Std. 10 kV x 240
100 µm
005402
S01a

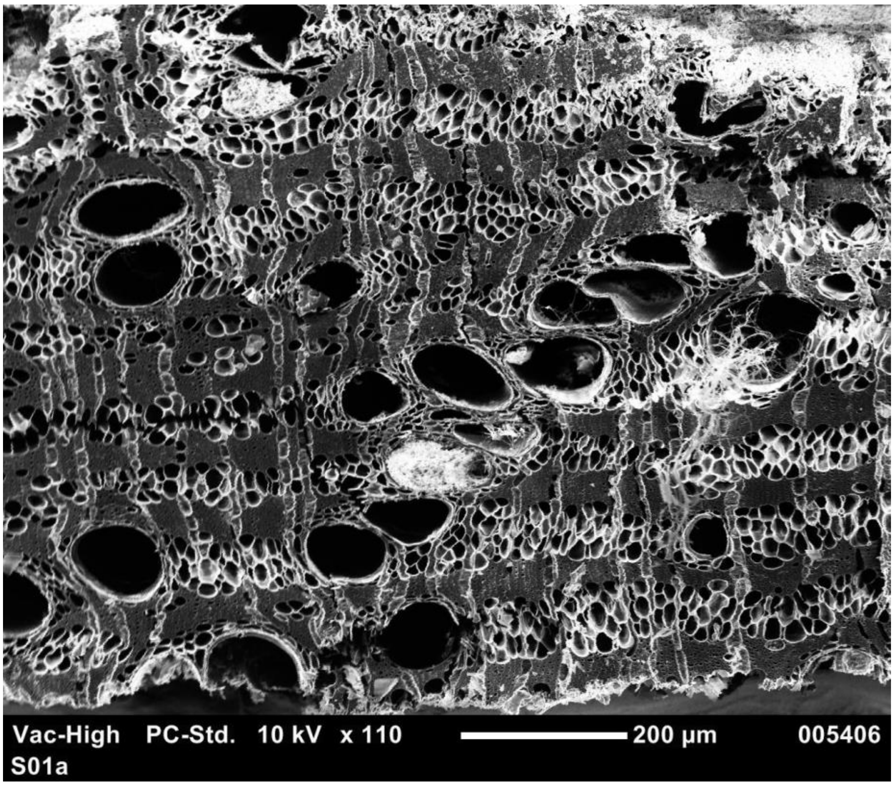

Vac-High PC-Std. 10 kV x 110
200 µm
005397
S01a

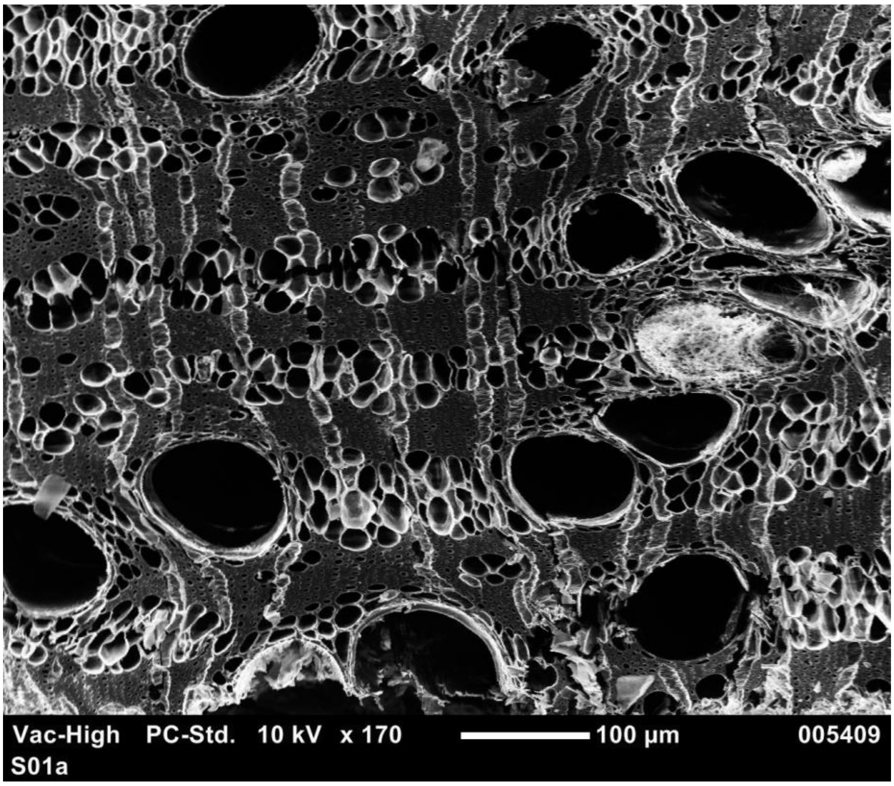

Vac-High PC-Std. 10 kV x 170
100 µm
005393
S01a

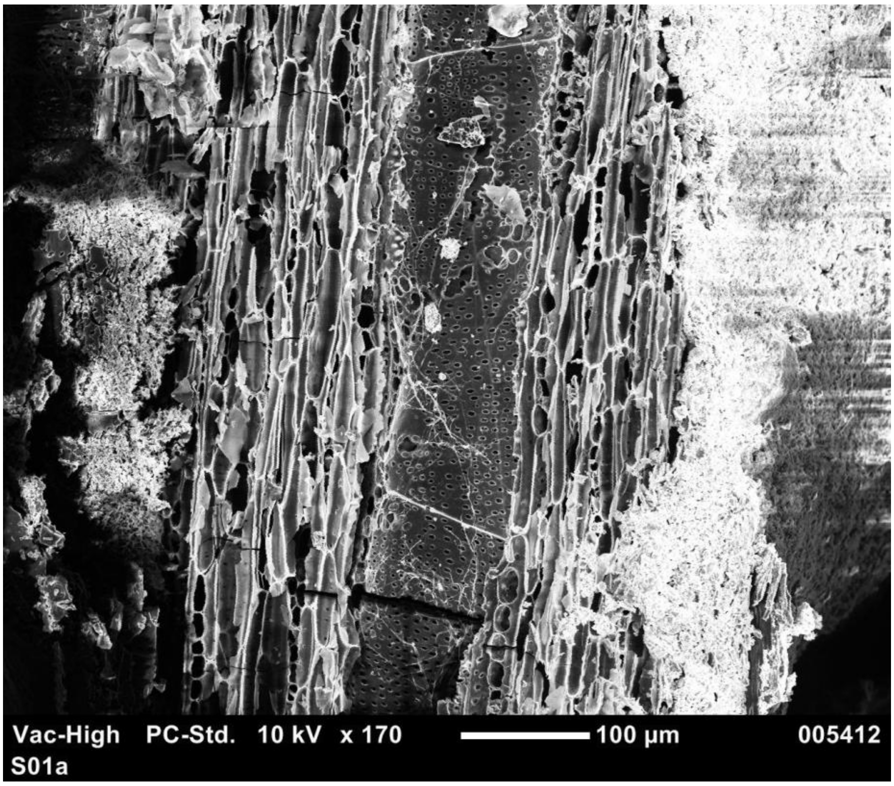

Vac-High PC-Std. 10 kV x 150
200 µm
005395
S01a

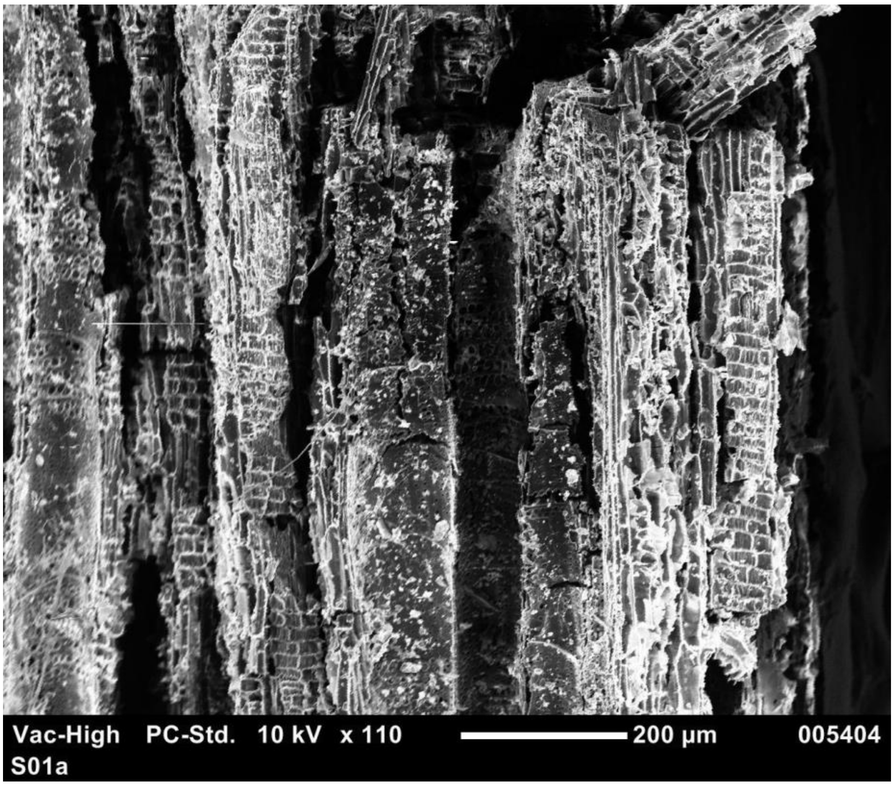
Combretaceae – *Terminalia* sp. (Type 33)



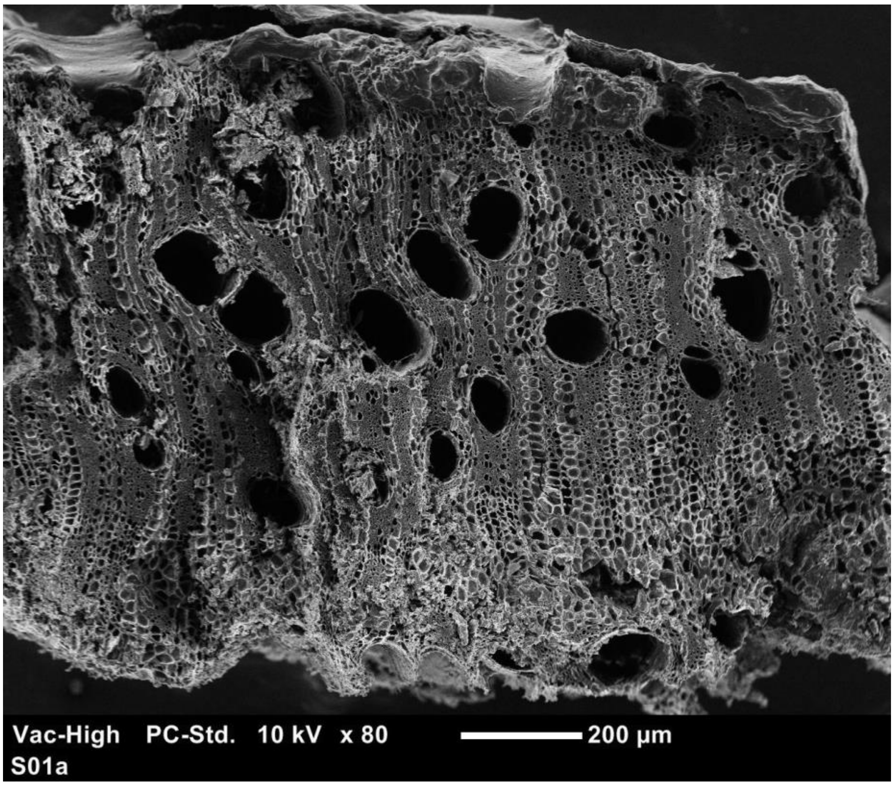


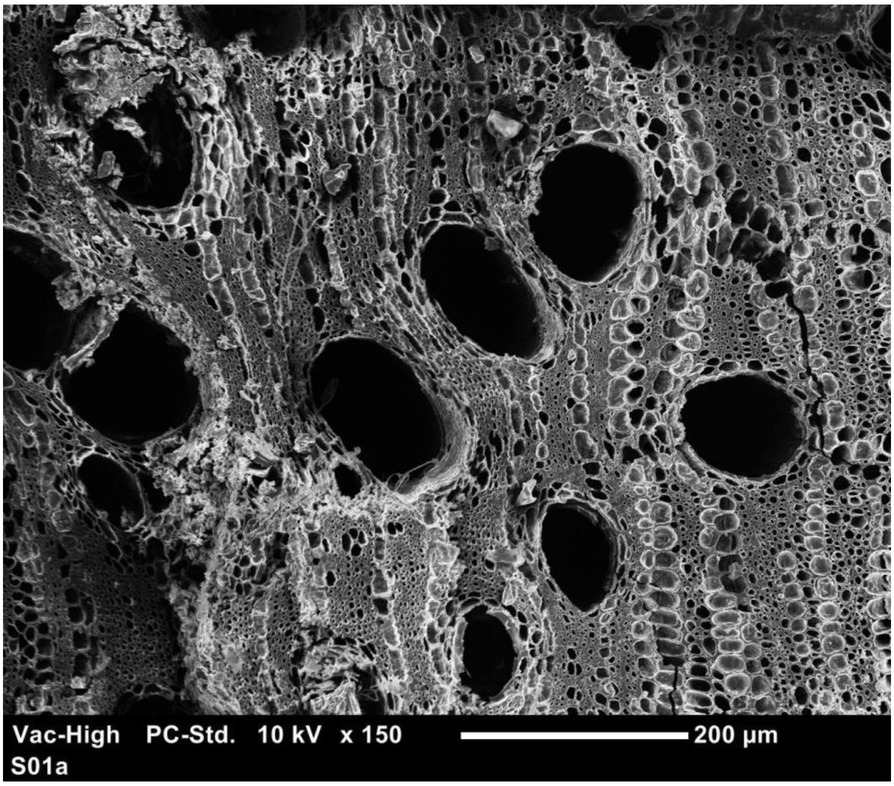

Vac-High PC-Std. 10 kV x 170
100 µm
005409
S01a

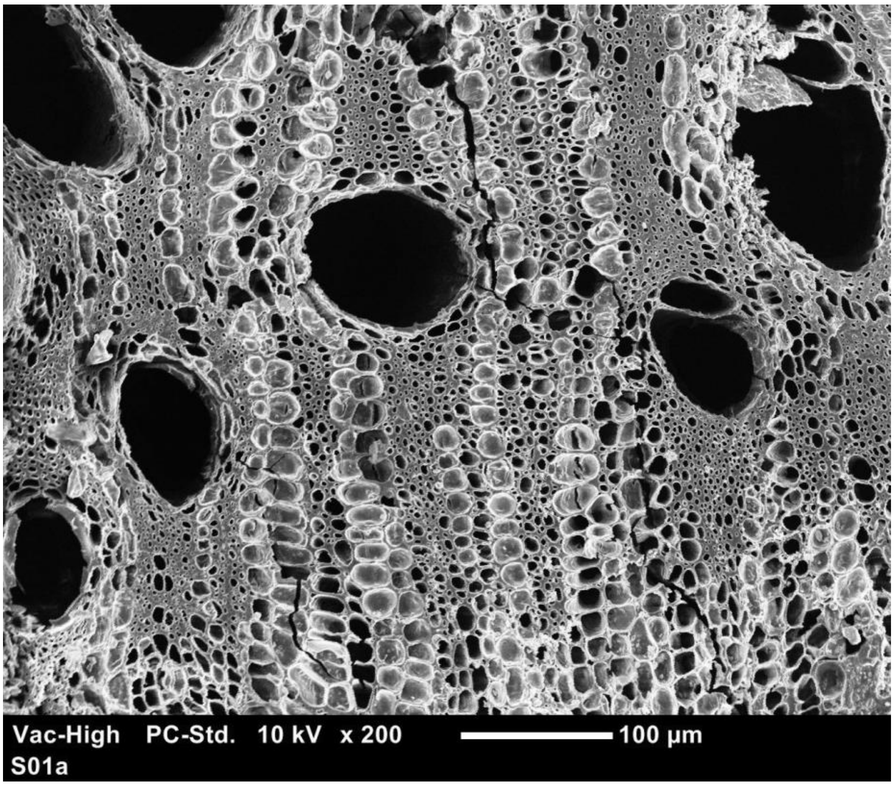

Vac-High PC-Std. 10 kV x 170
100 µm
005412
S01a

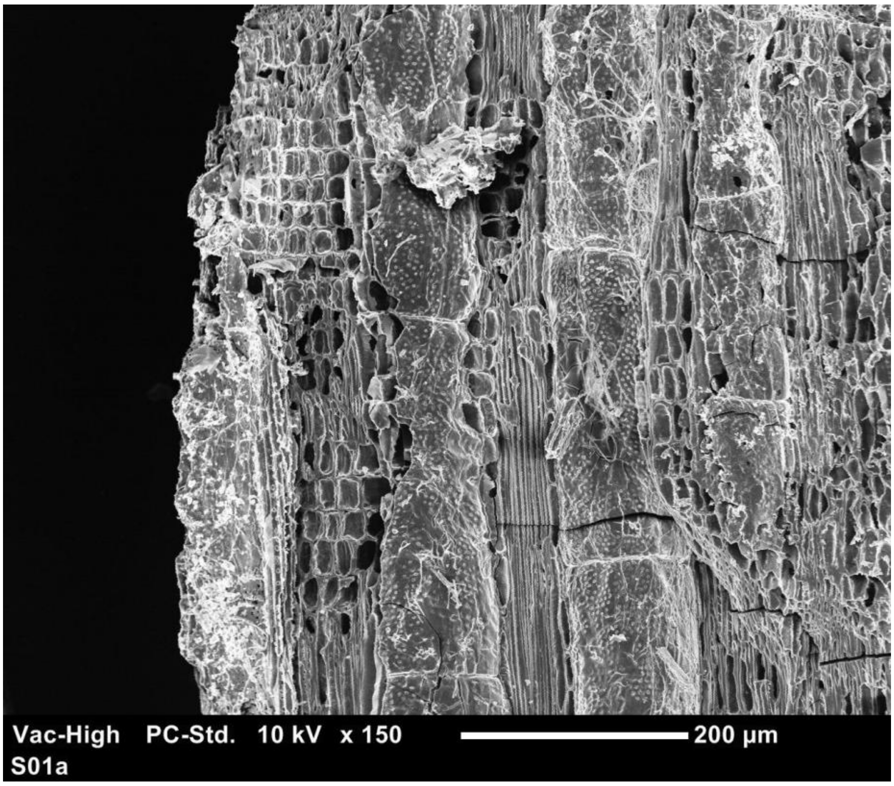

Vac-High PC-Std. 10 kV x 110
200 µm
005404
S01a

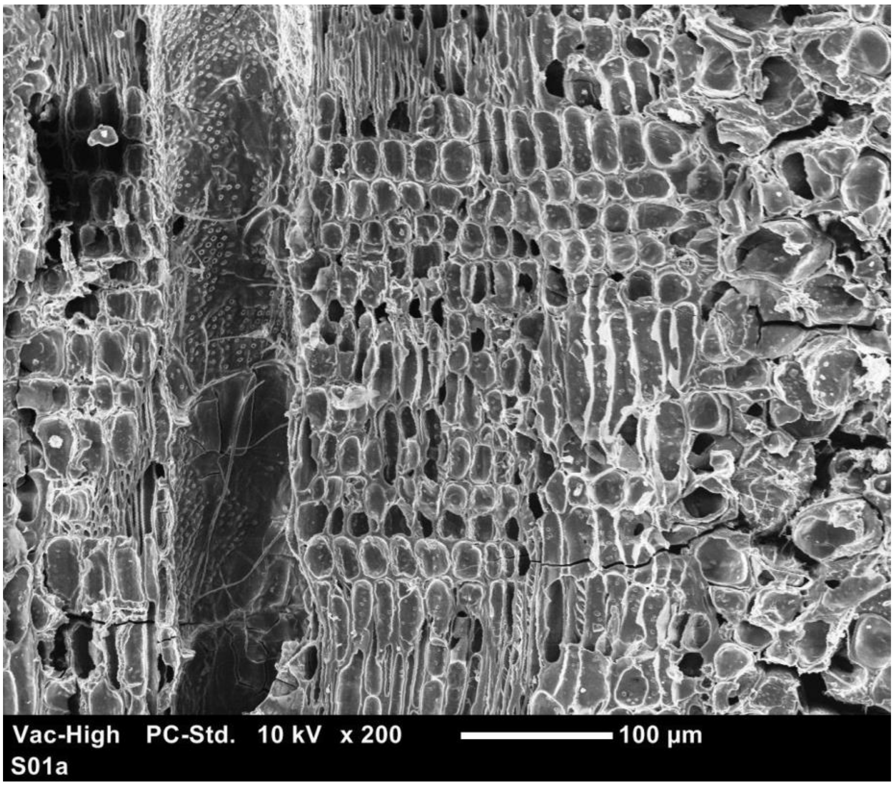
Combretaceae – *Terminalia* sp. (Type 35)

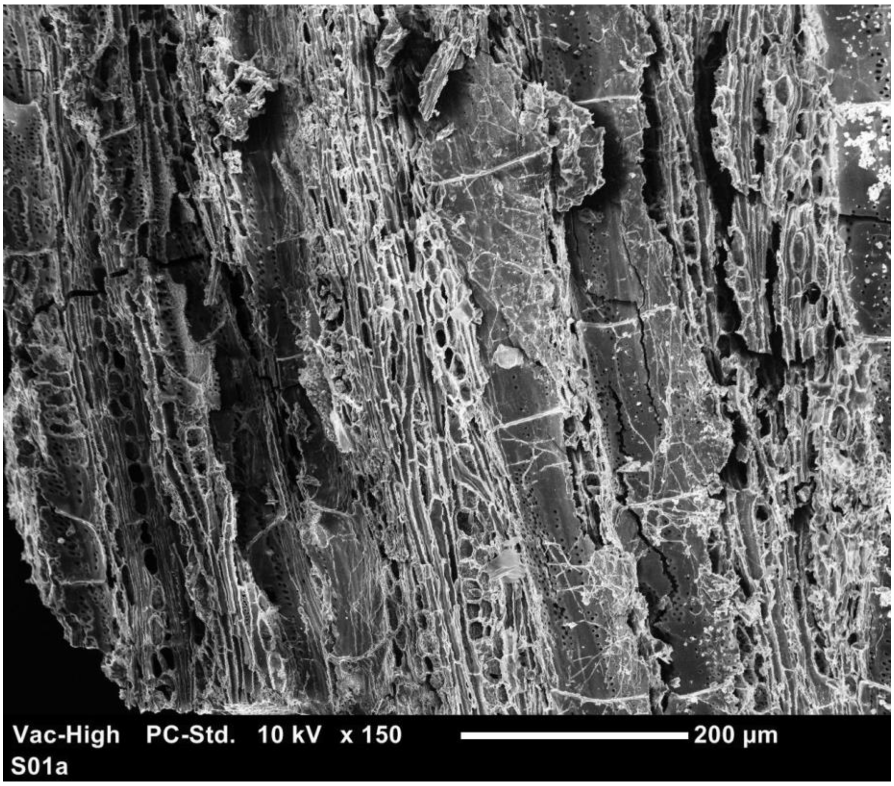




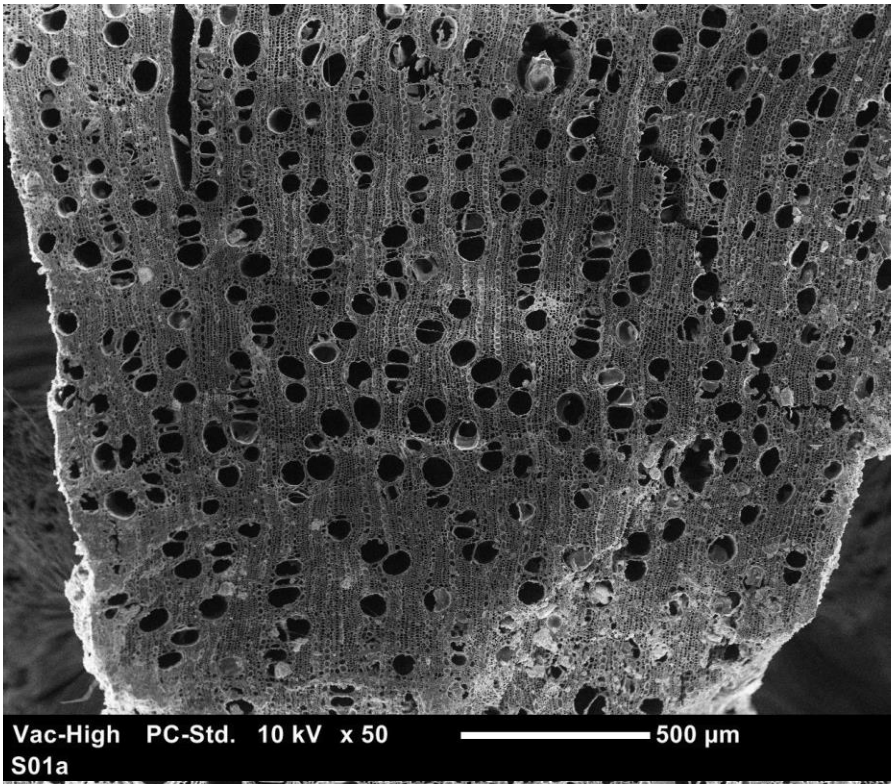

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

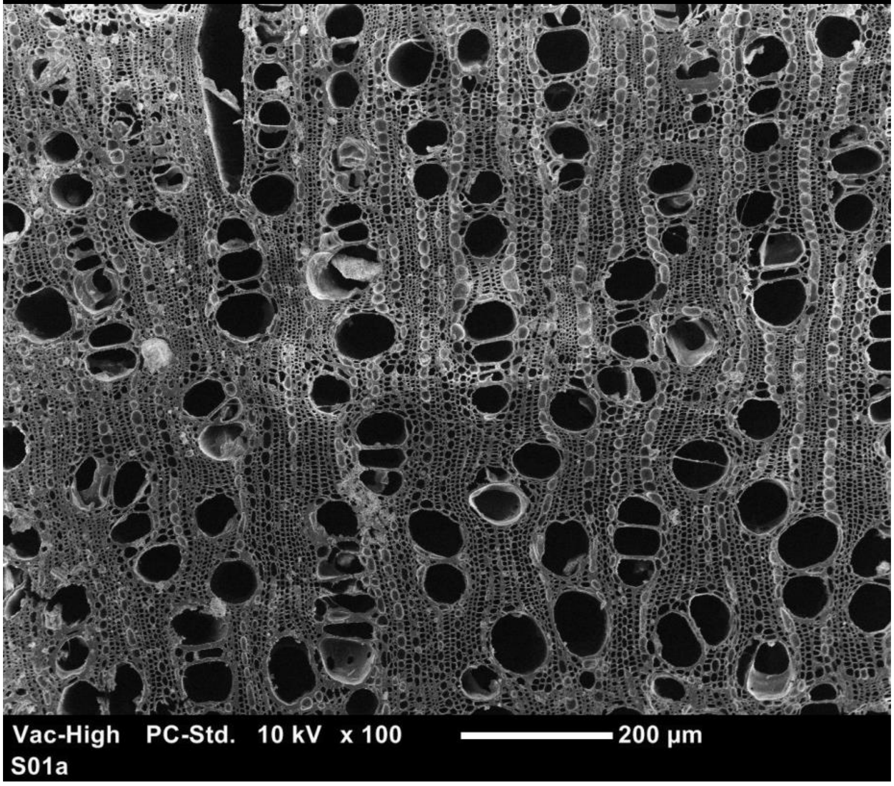

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

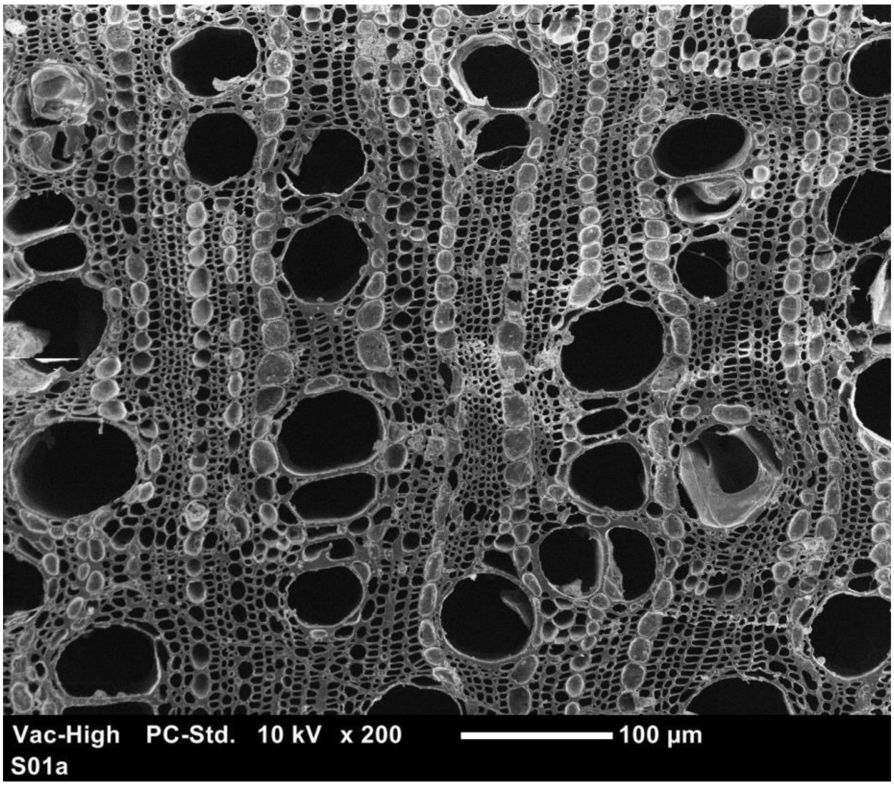

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

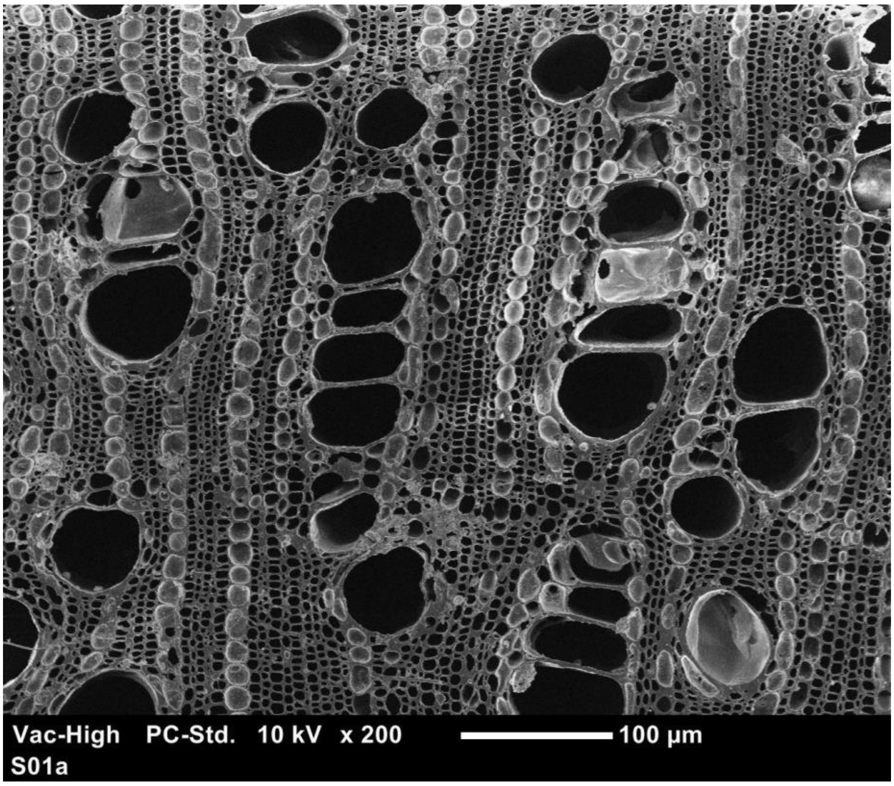

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

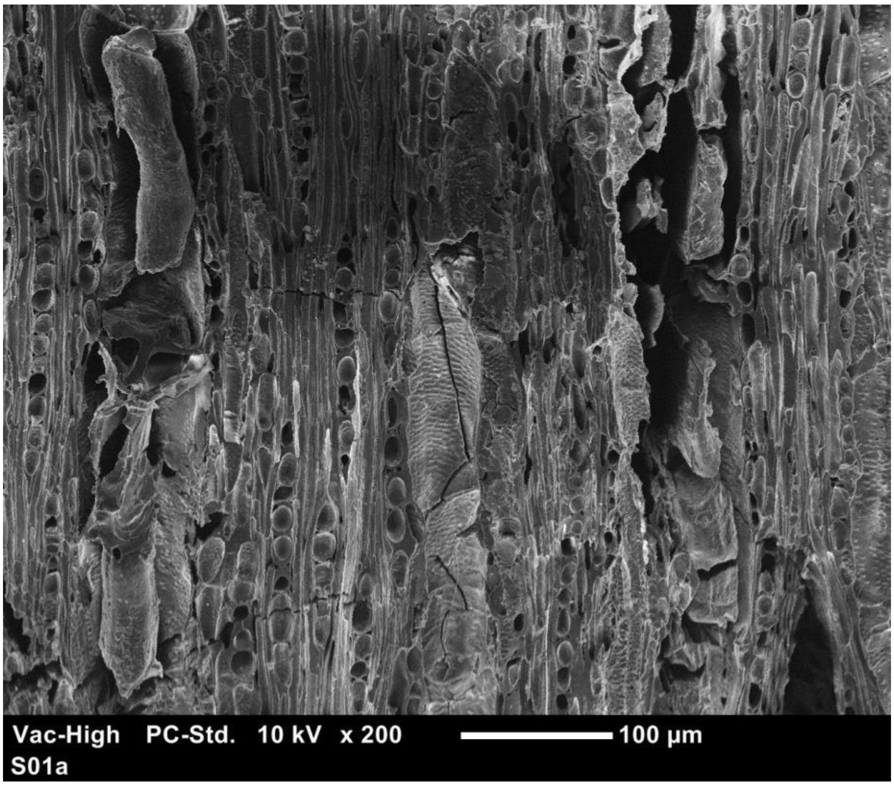
Combretaceae – *Terminalia* sp. (Type 37)

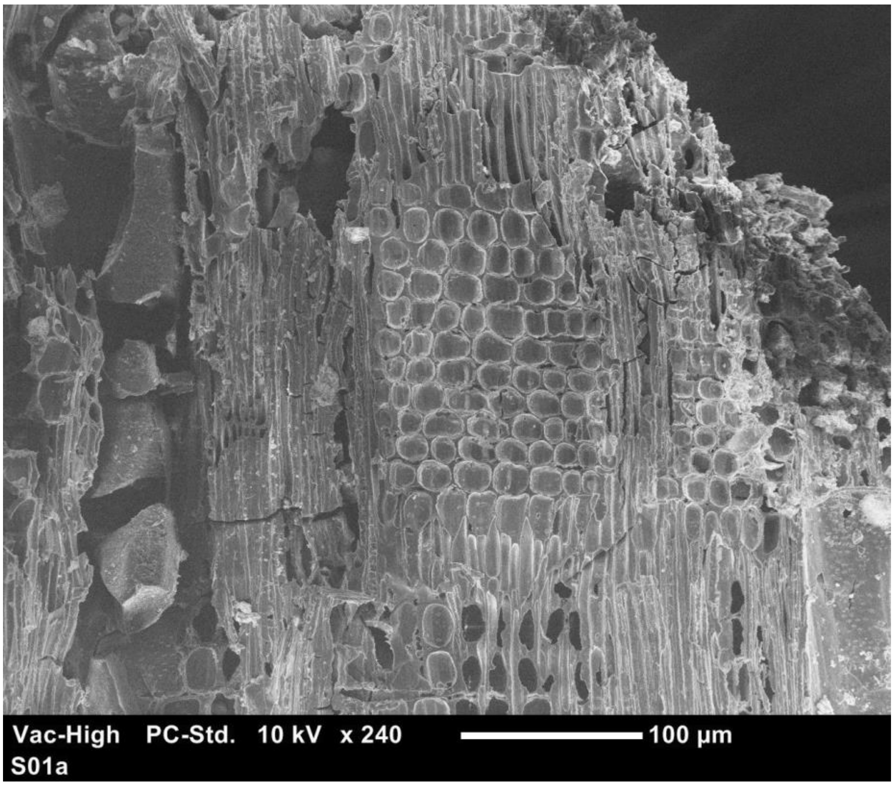




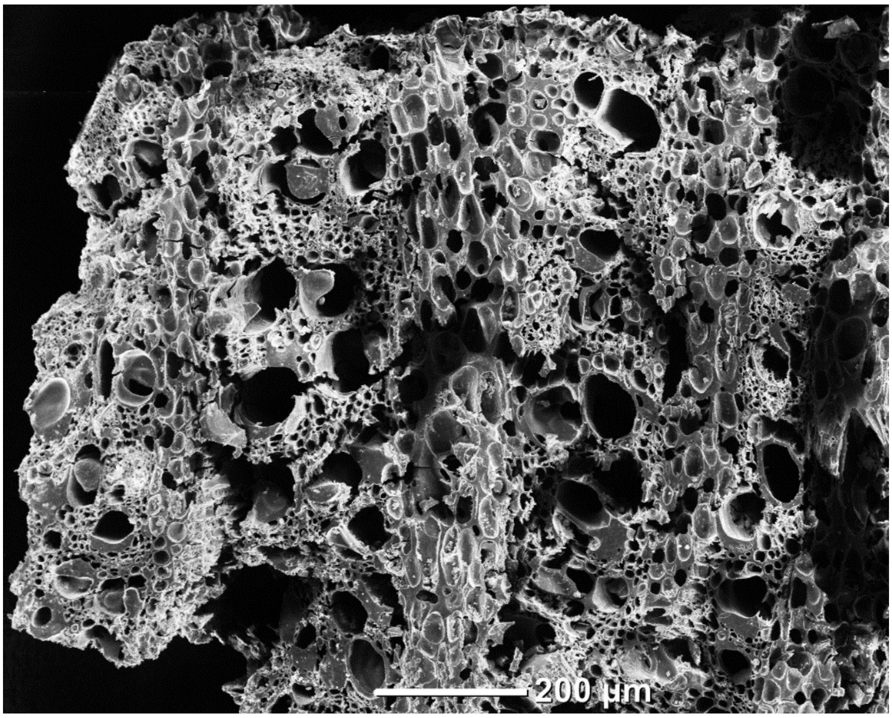

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

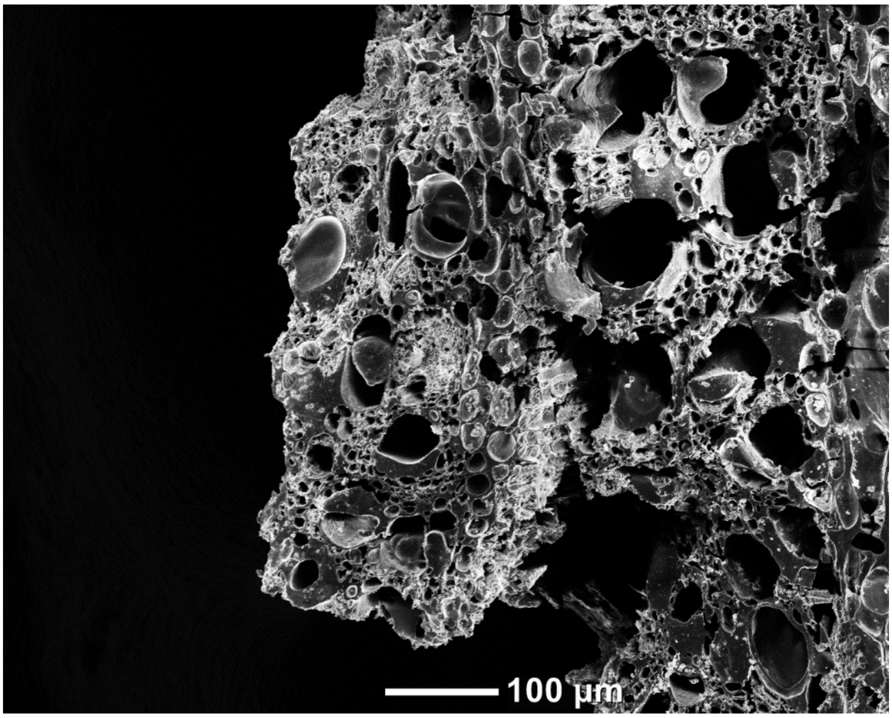

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

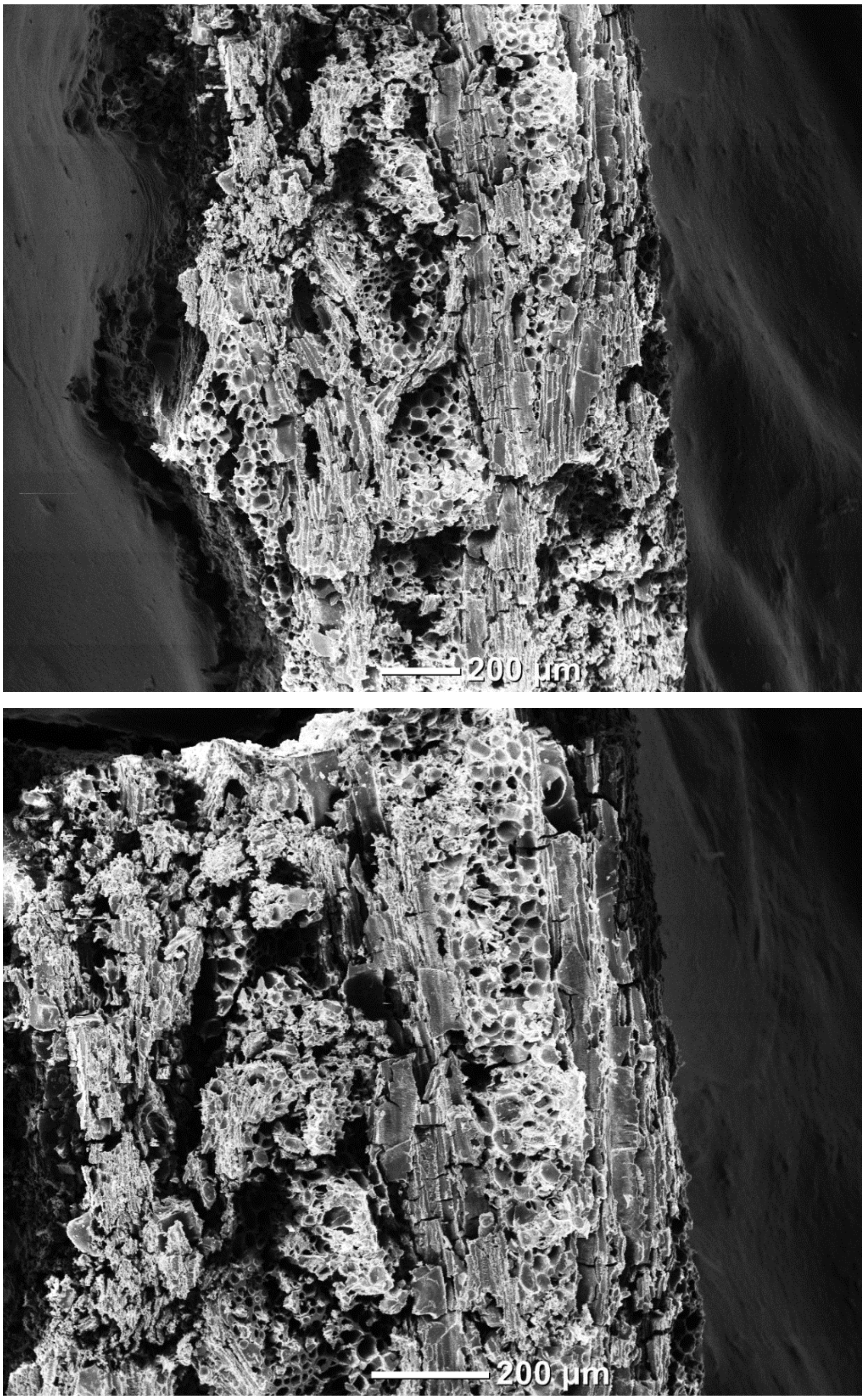

Vac-High PC-Std. 10 kV x 200
100 µm
S01a


Vac-High PC-Std. 10 kV x 240
100 µm
S01a

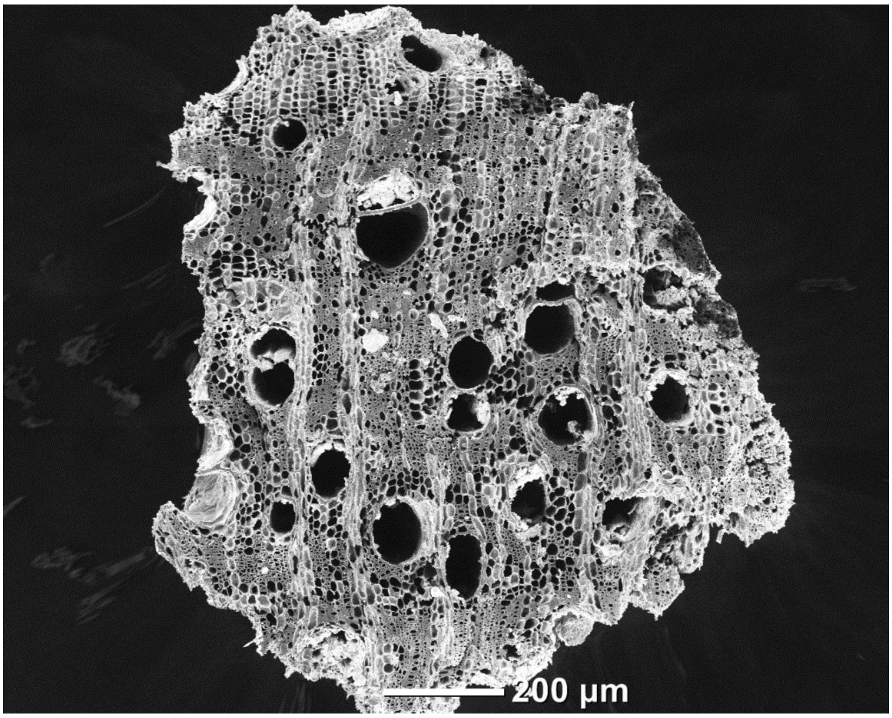
Proteaceae (Type 21)

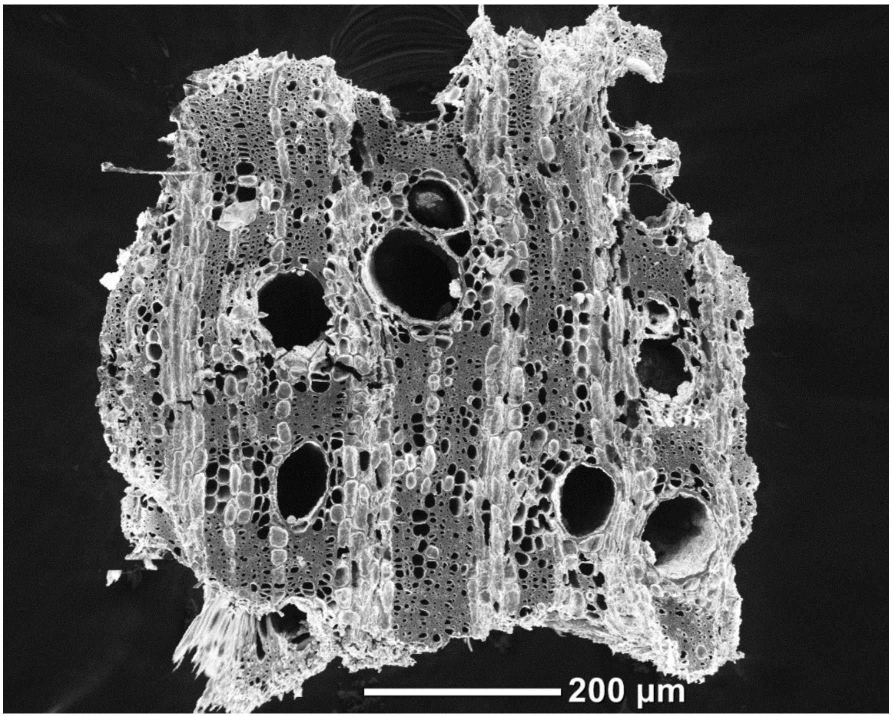


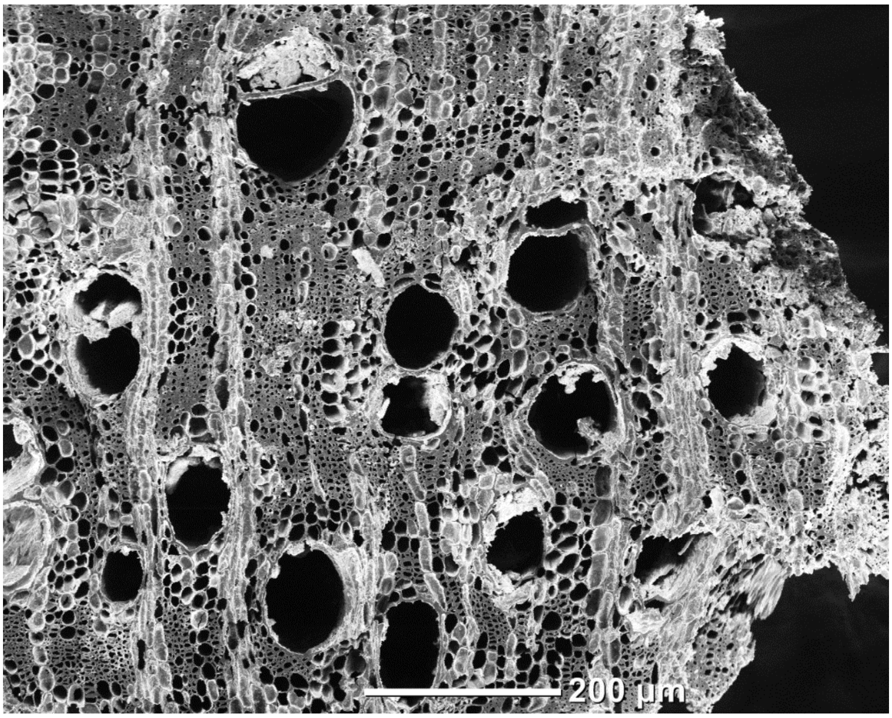


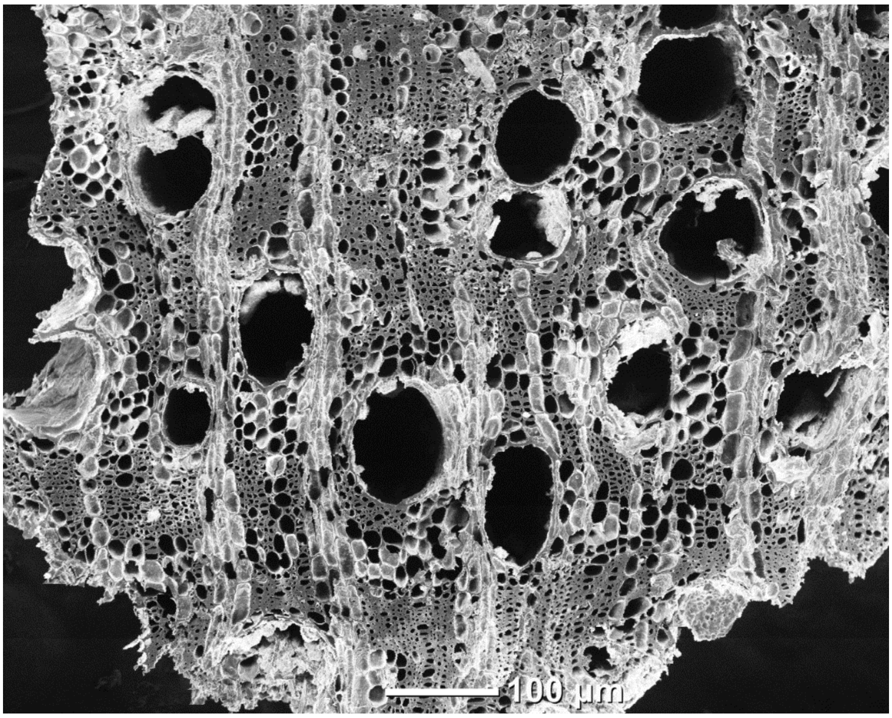

200 µm
200 µm

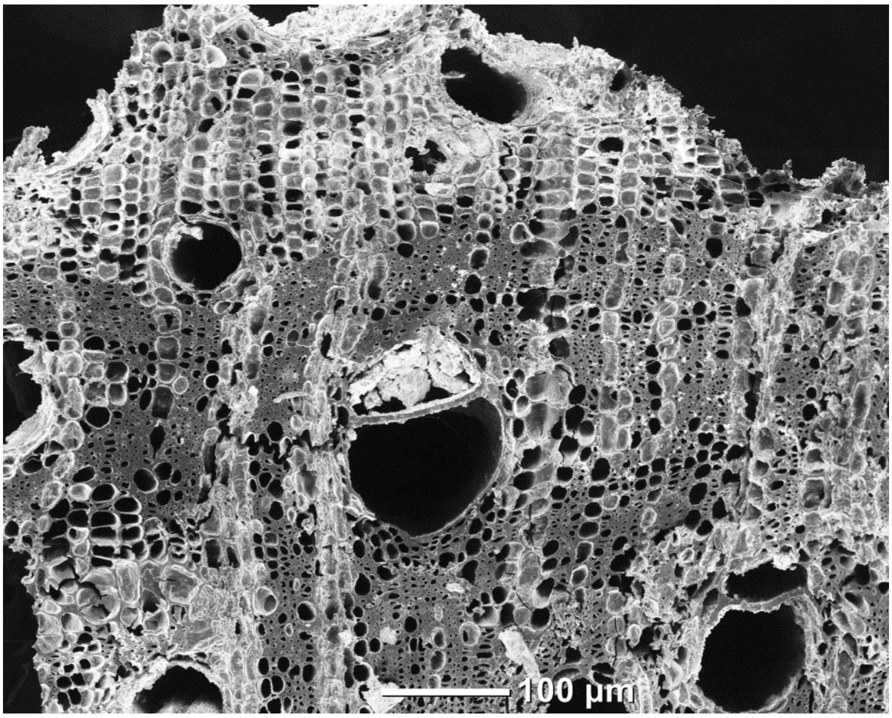
Proteaceae (Type 22)



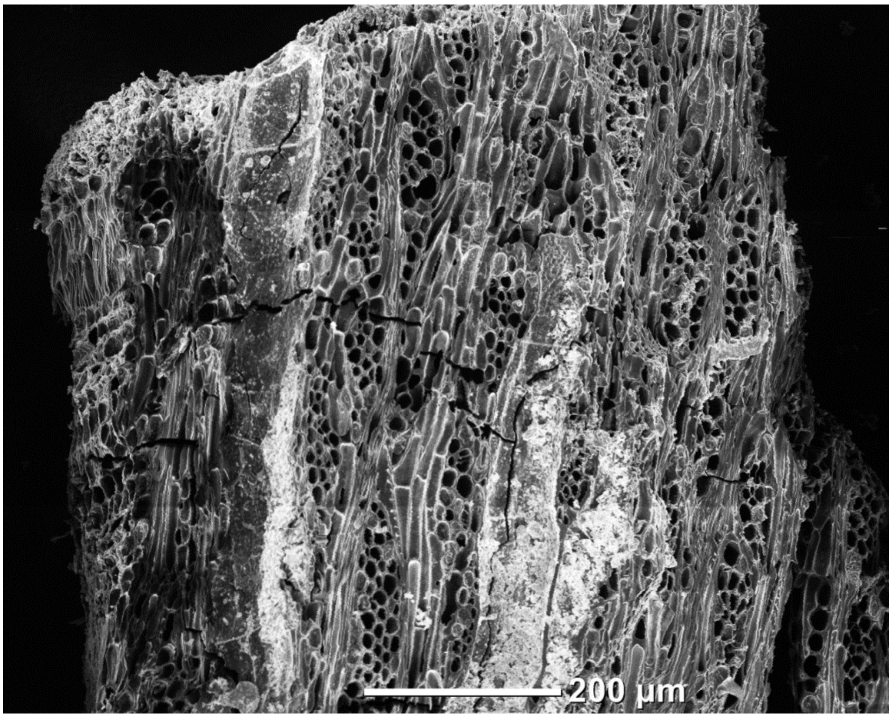



200 µm


100 µm

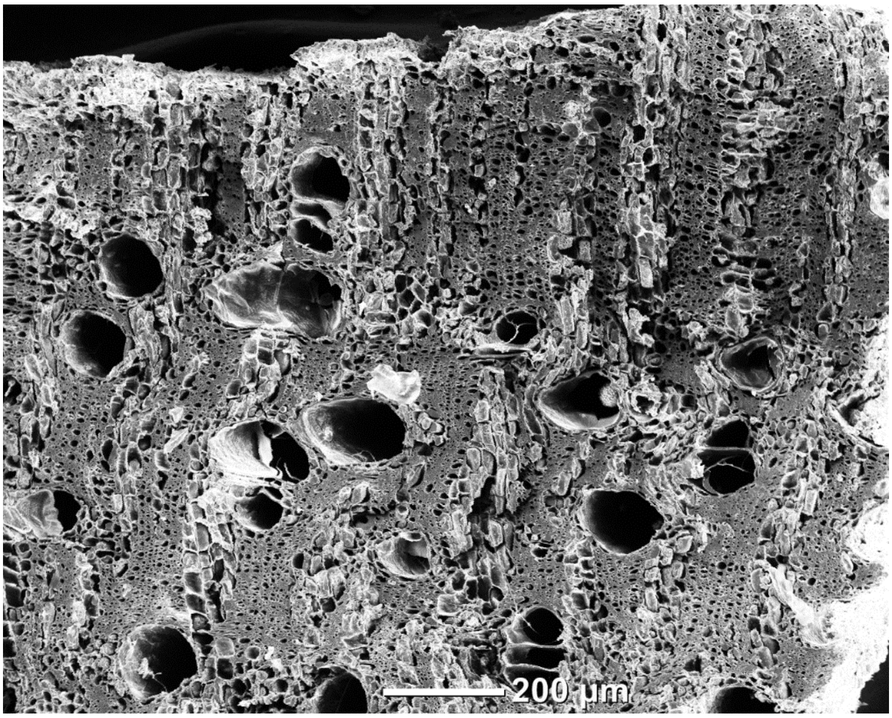


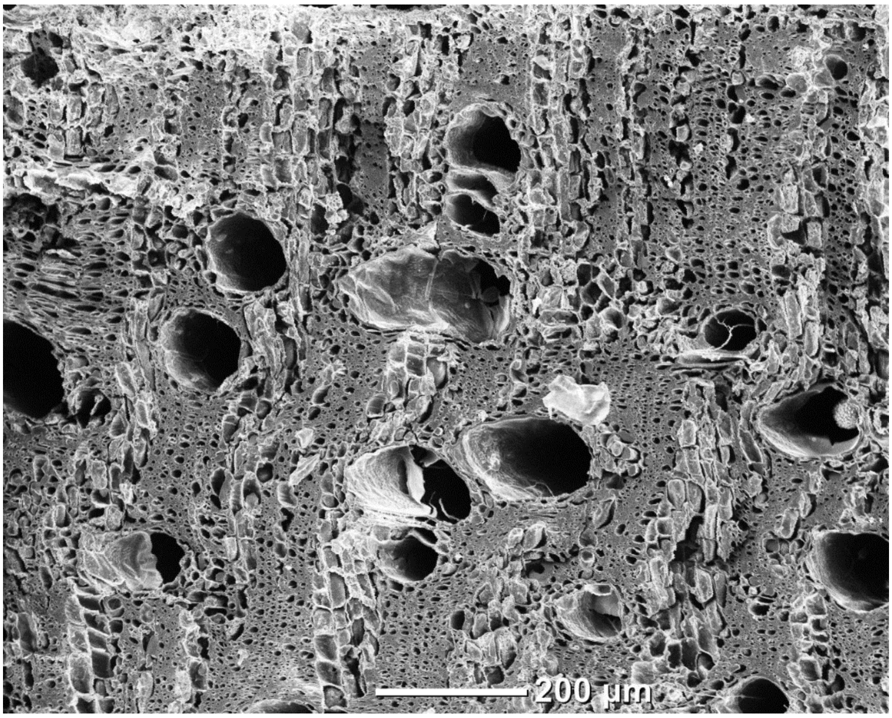
100 µm

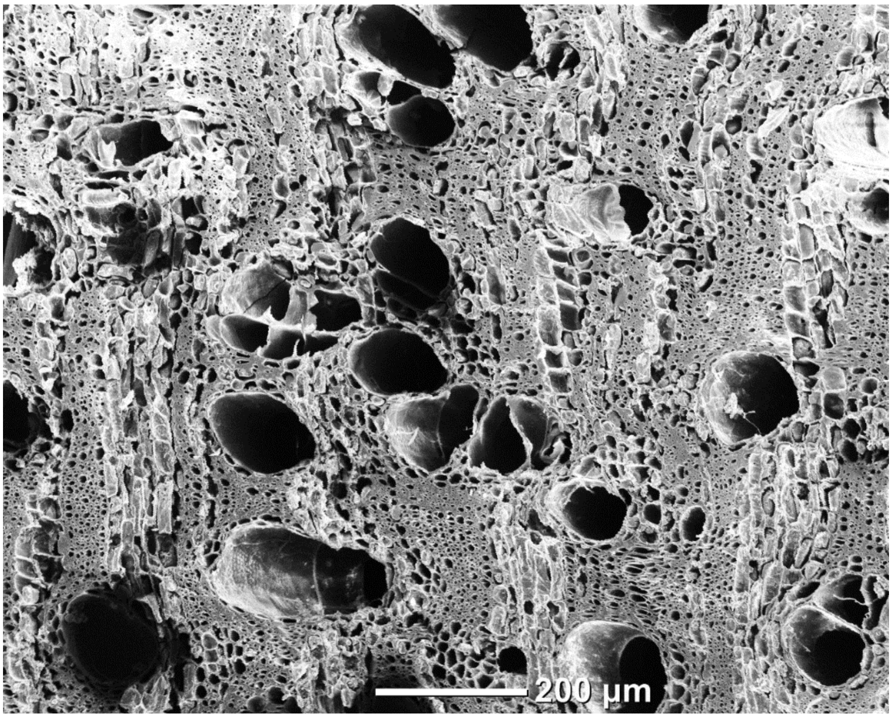


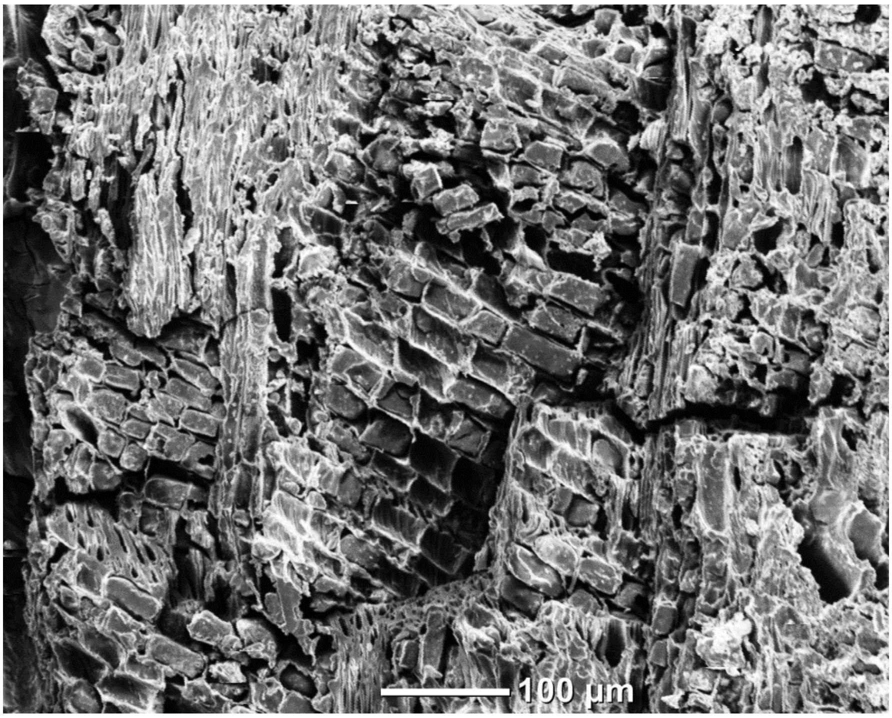
200 µm

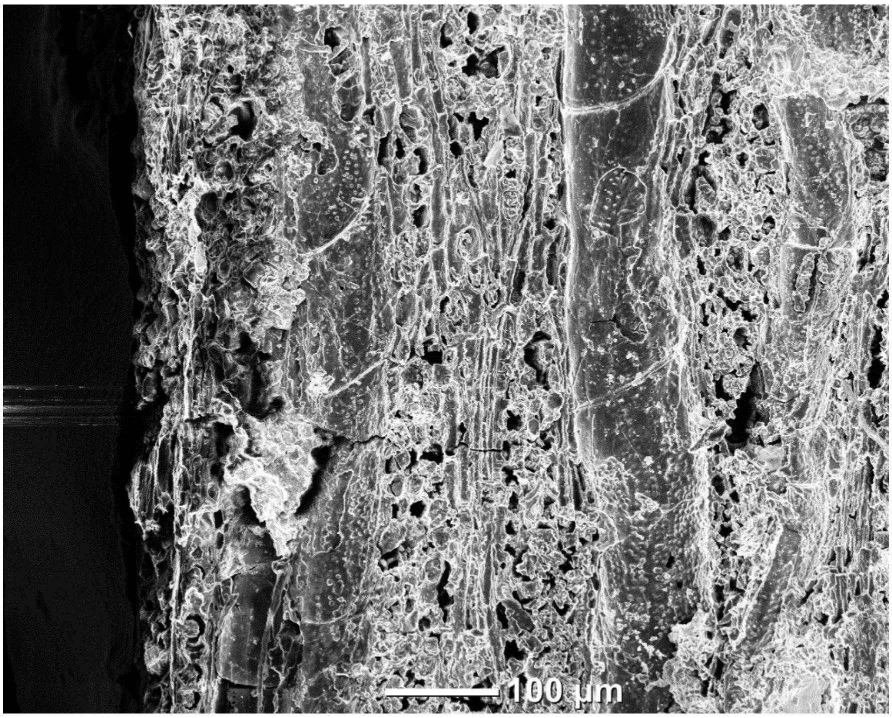
Proteaceae (Type 23)



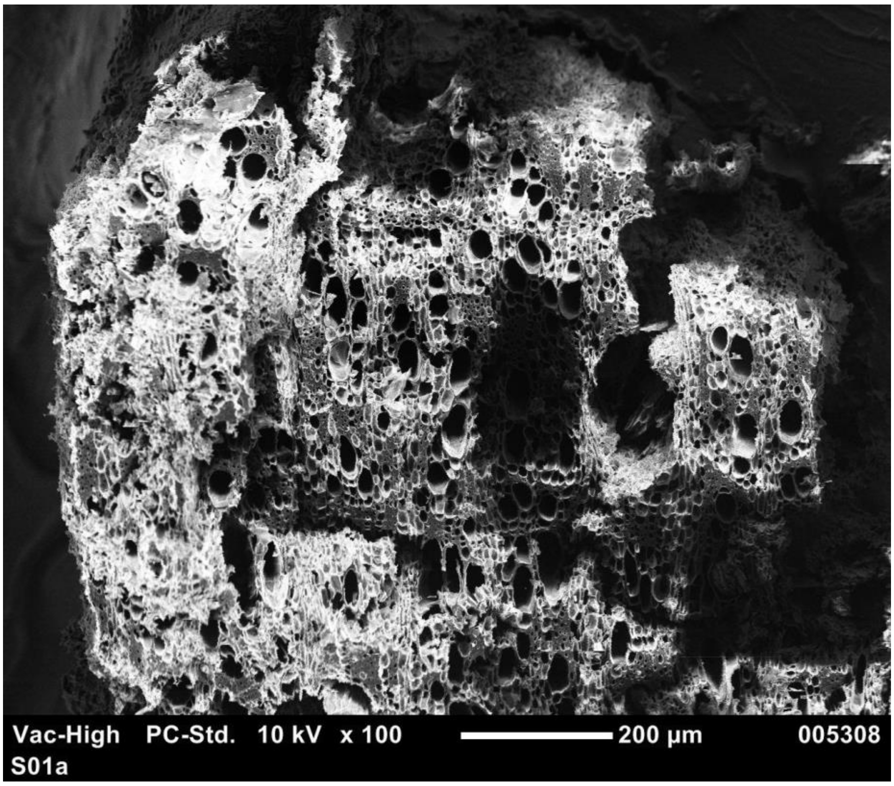


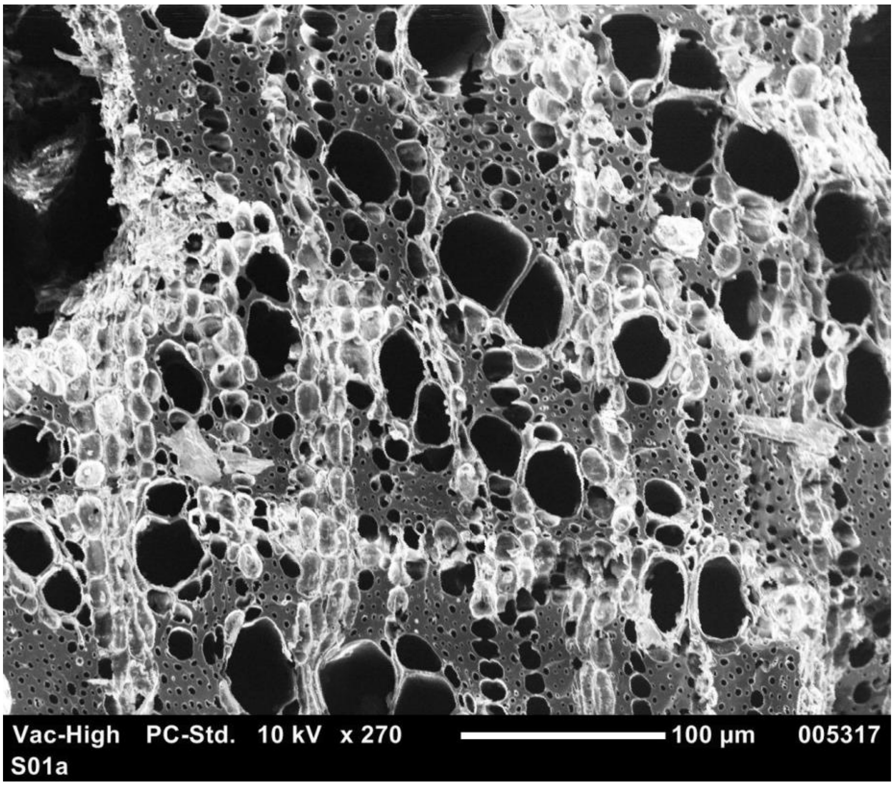

200 µm

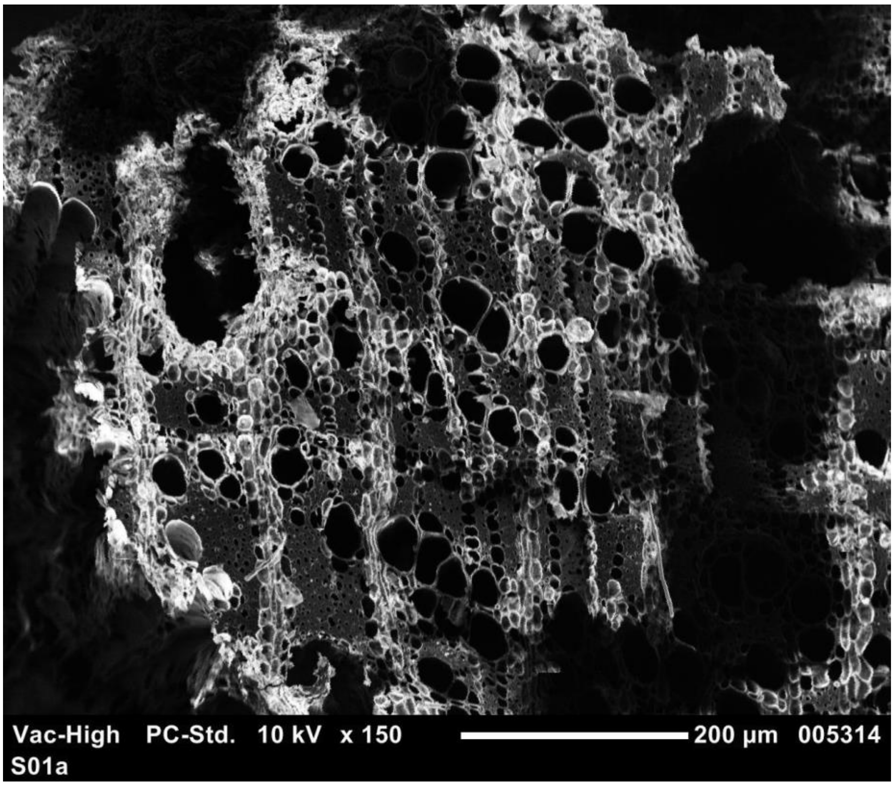

100 µm


100 µm

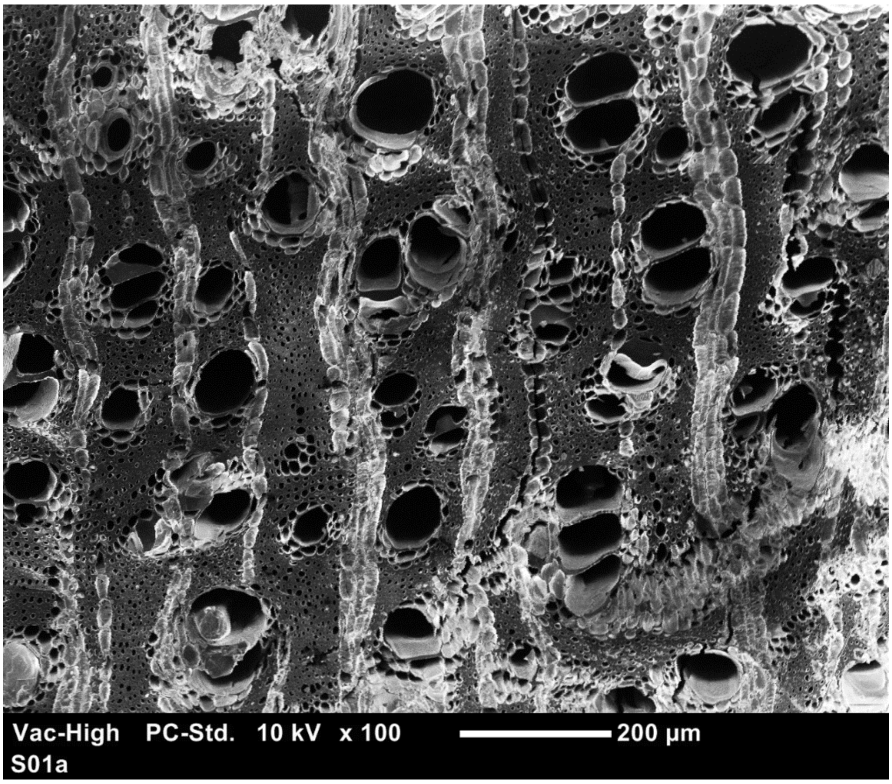
Proteaceae (Type 30)

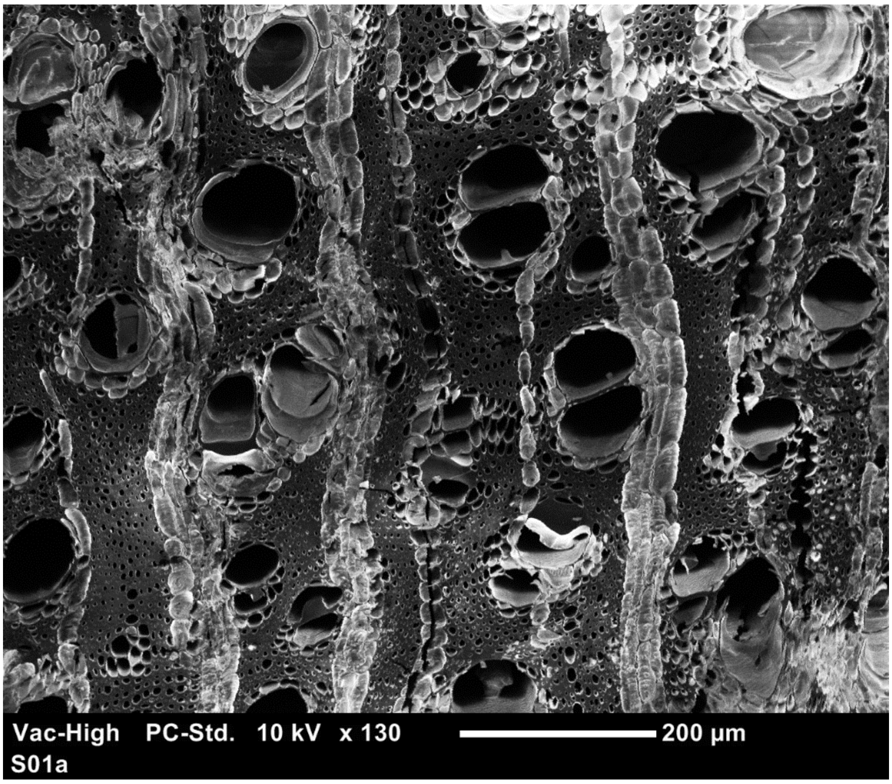


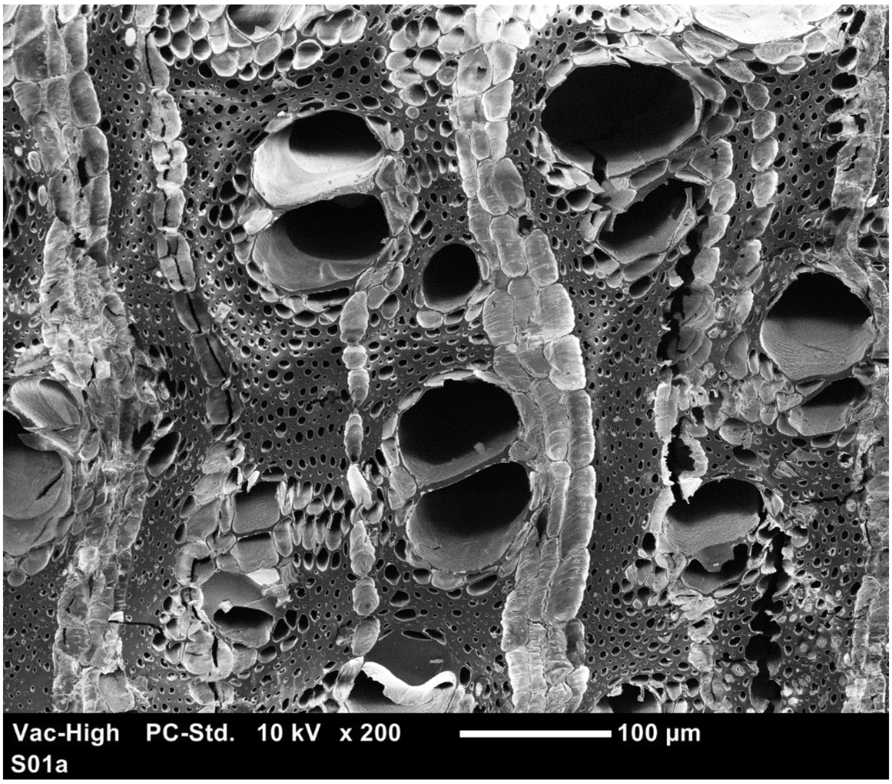


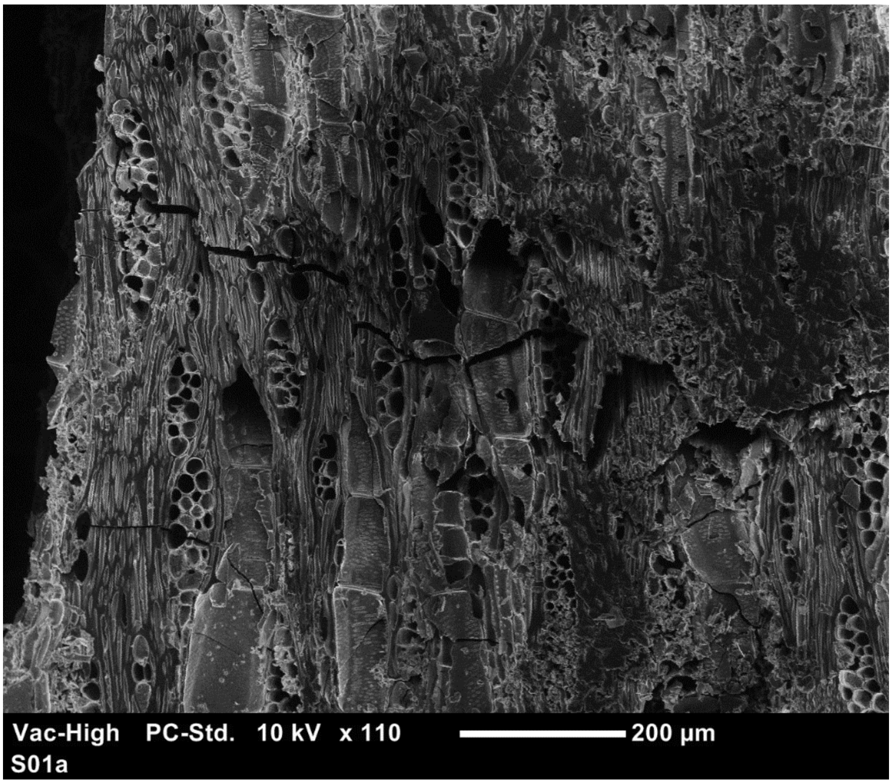

Vac-High PC-Std. 10 kV x 150 200 µm 005314
S01a

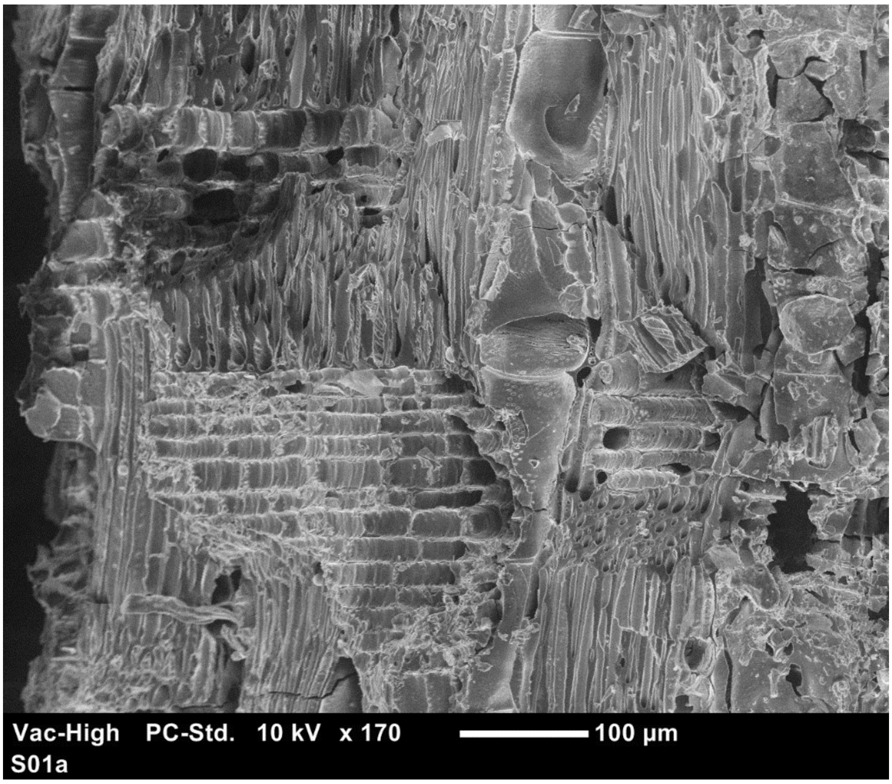
Proteaceae (Type 55)



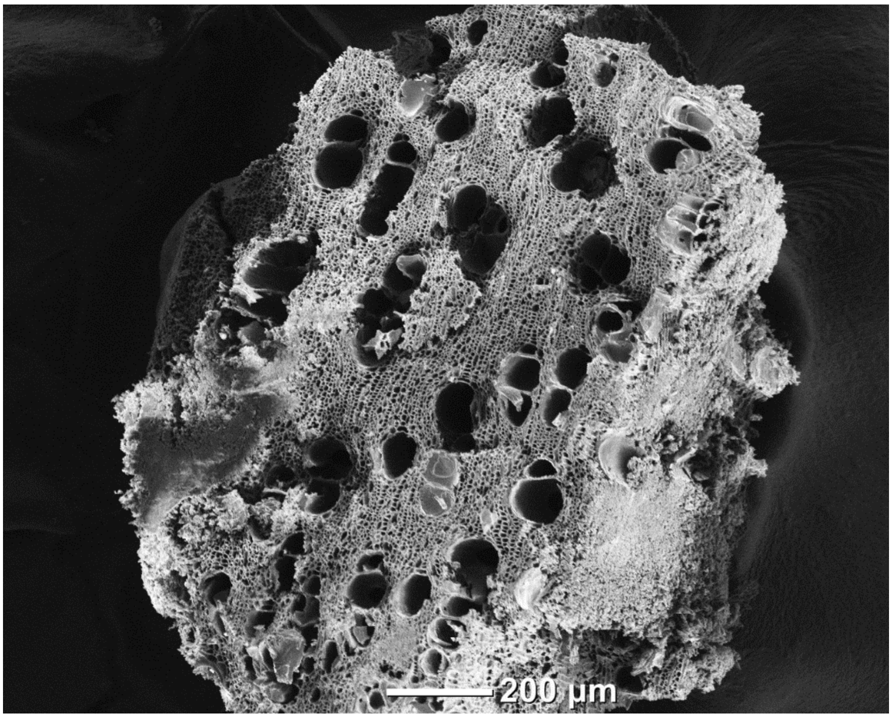


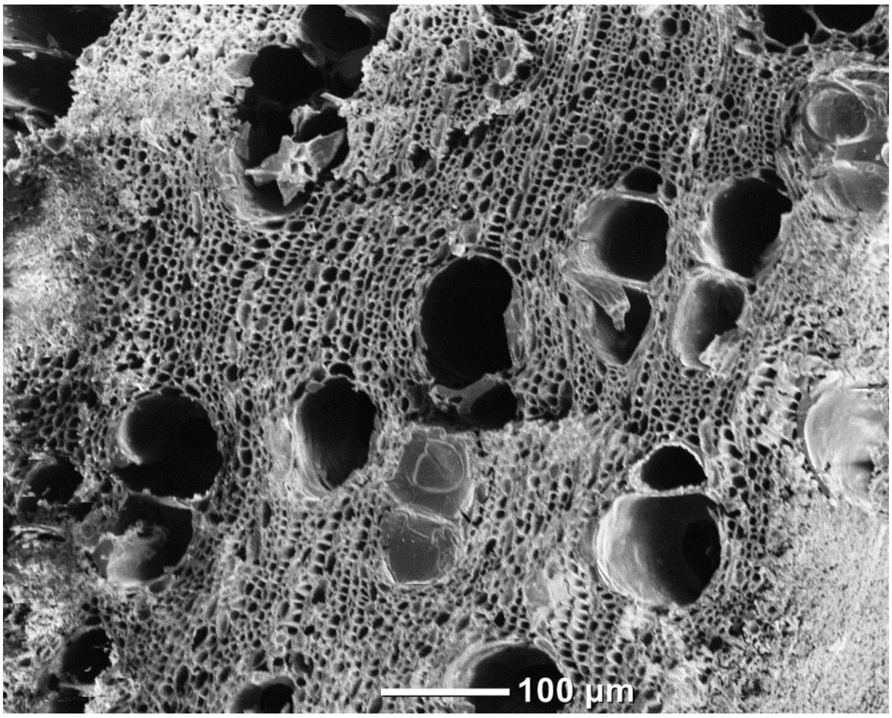

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

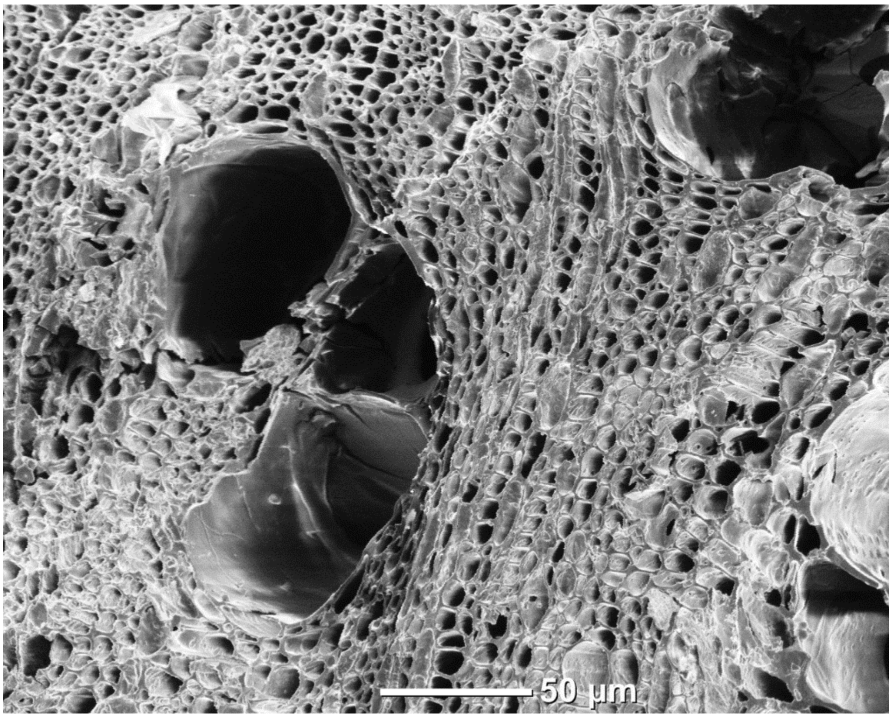

Vac-High PC-Std. 10 kV x 110
200 µm
S01a

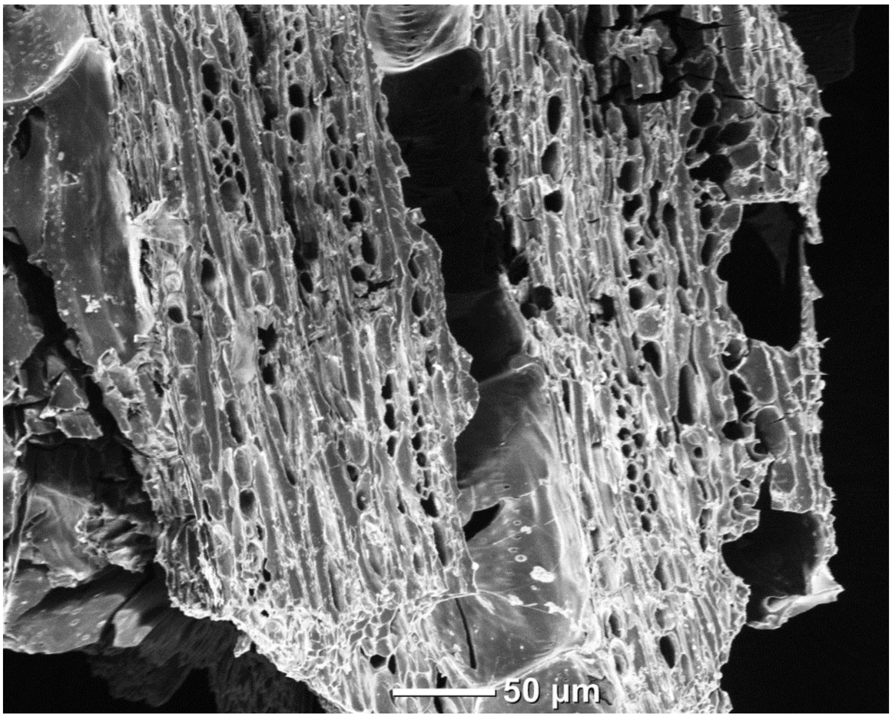

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

Rhamnaceae – *Alphitonia* sp. (Type 13)

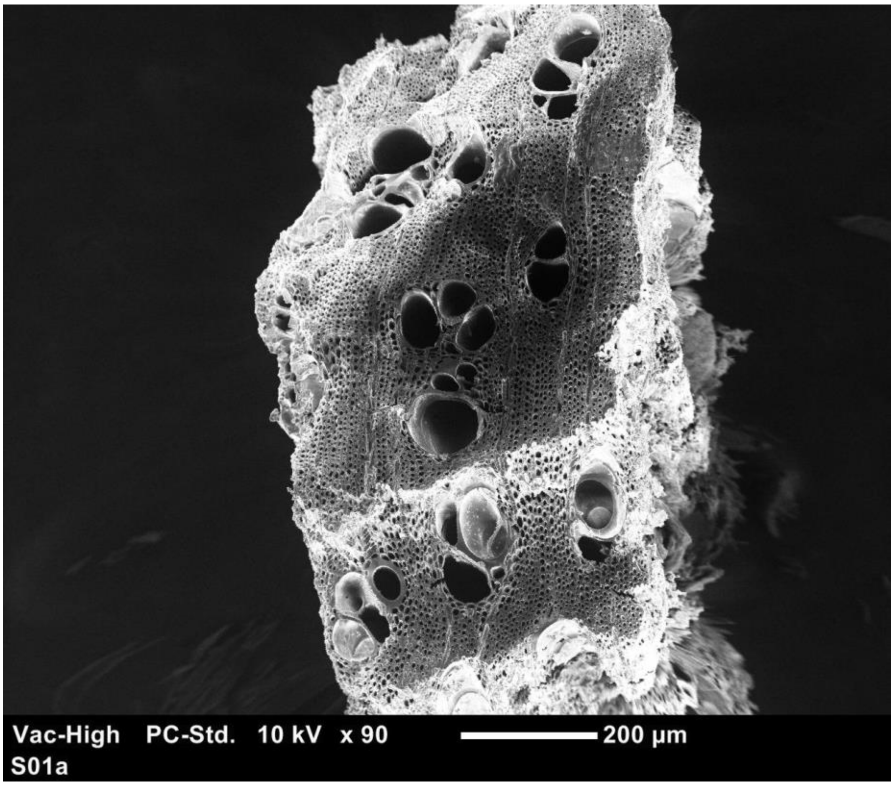


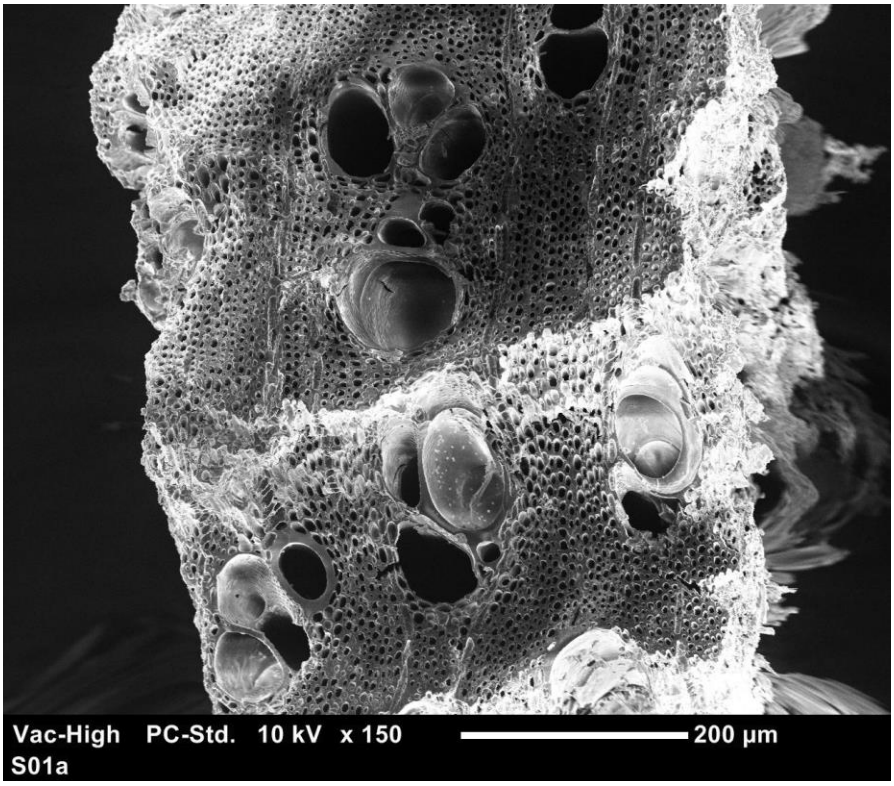


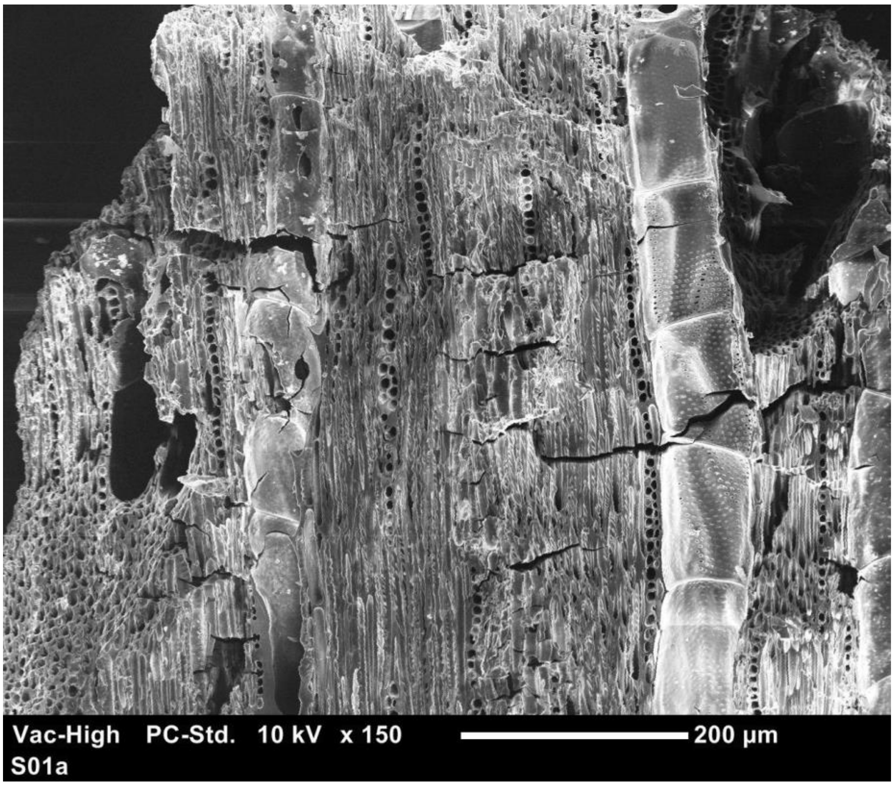

50 µm

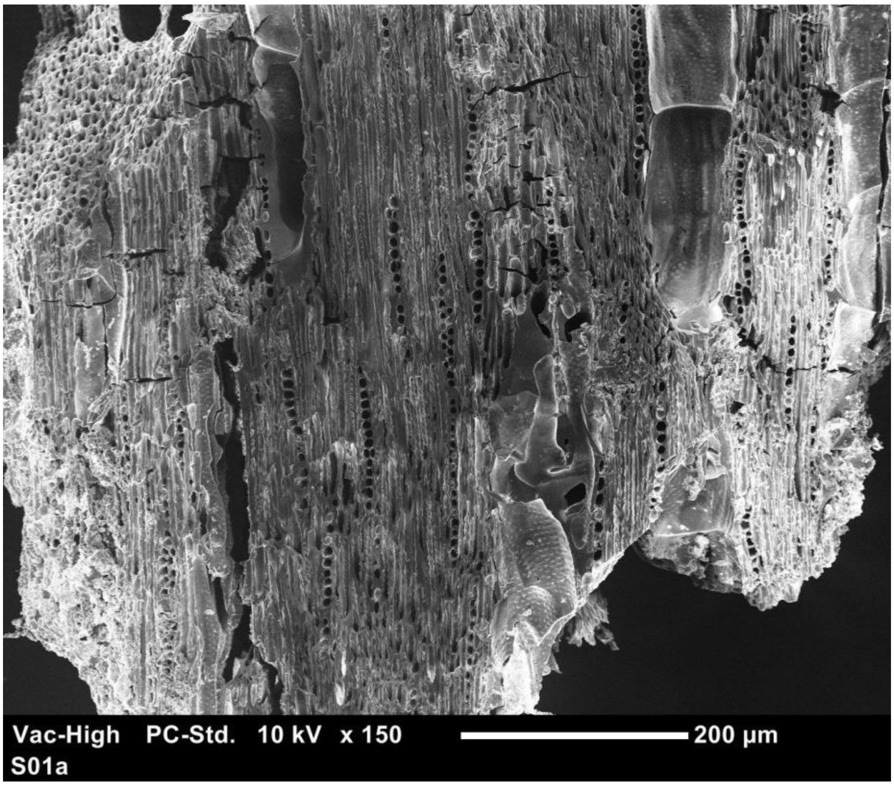

50 µm

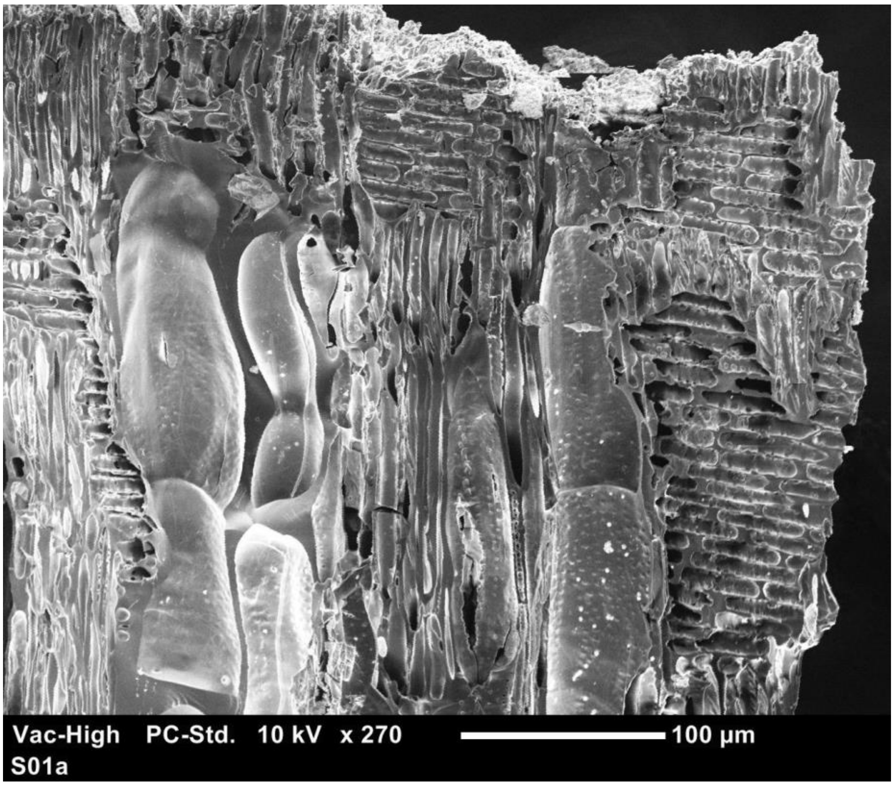
Rhamnaceae – *Alphitonia* sp. (Type 46)

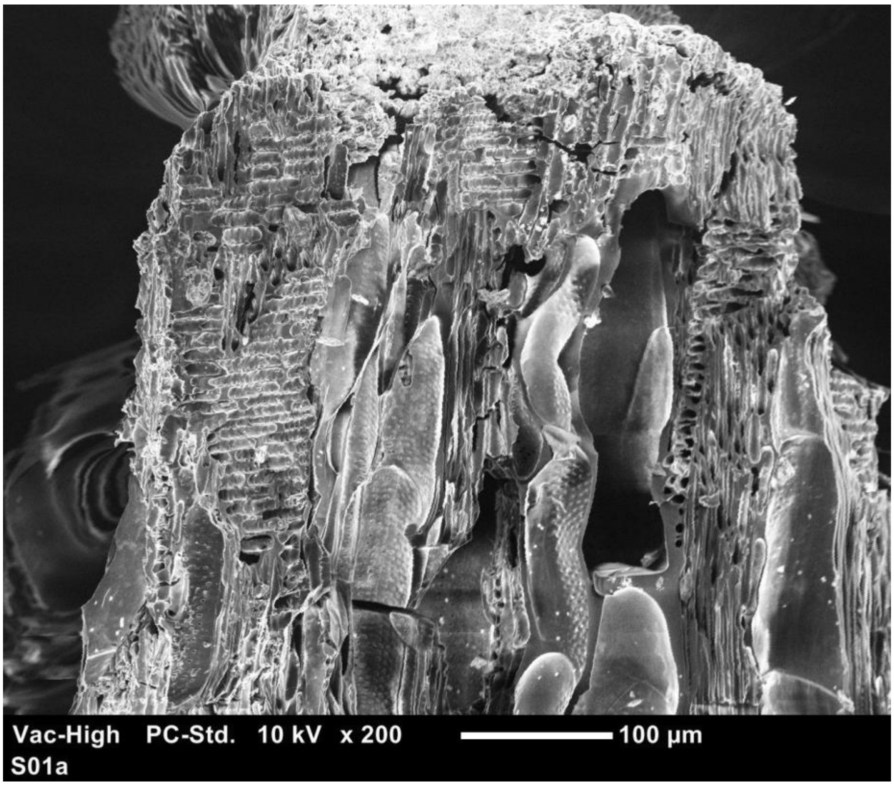




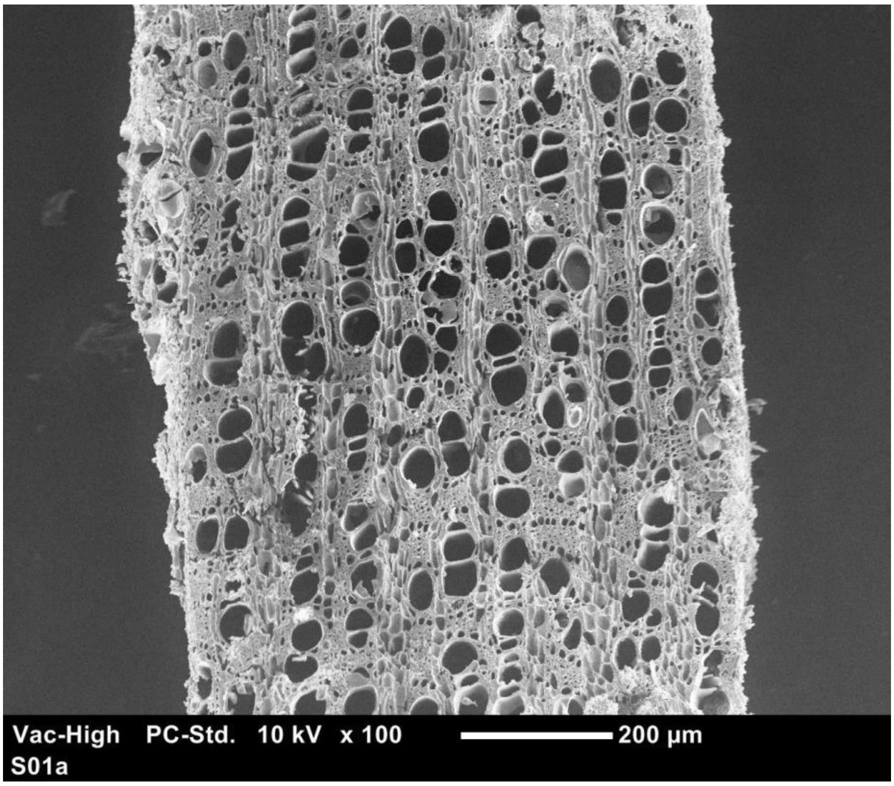

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

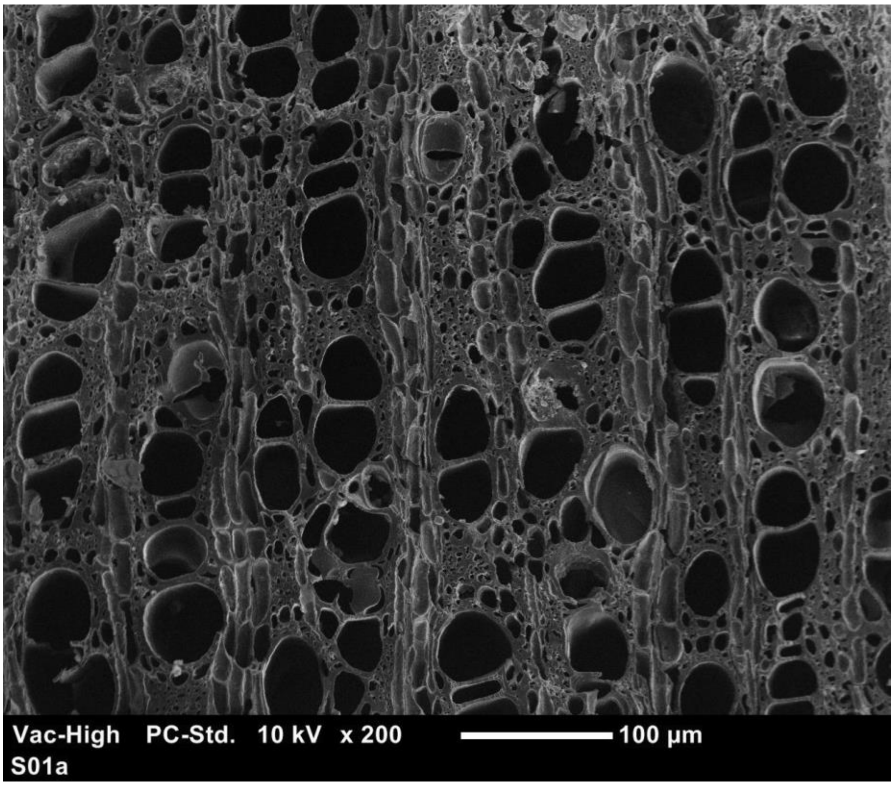

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

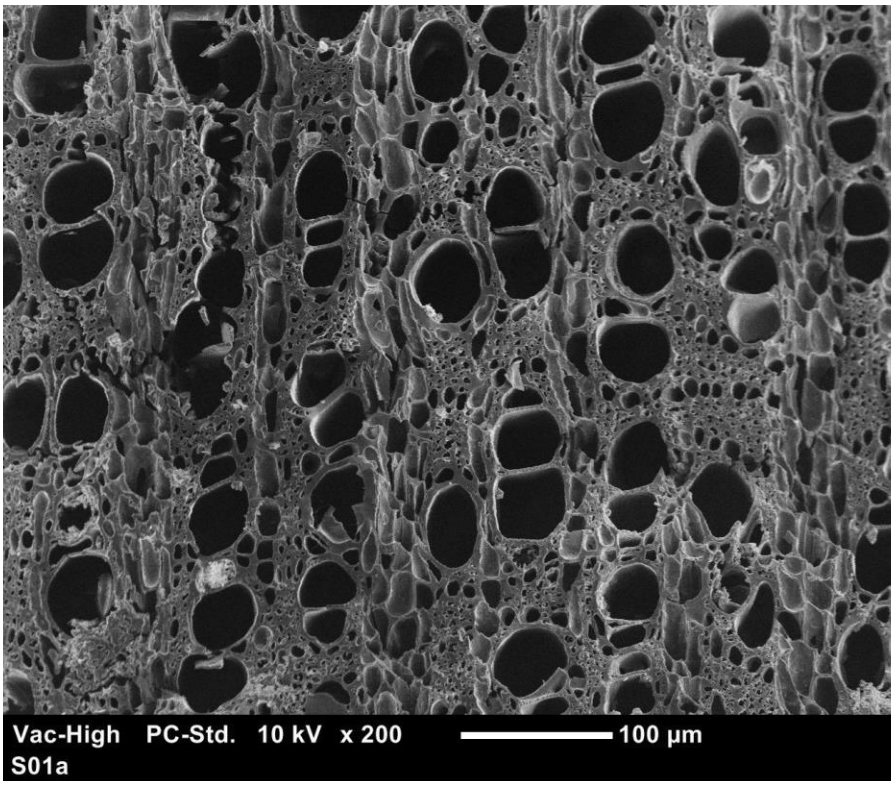

Vac-High PC-Std. 10 kV x 270
100 µm
S01a

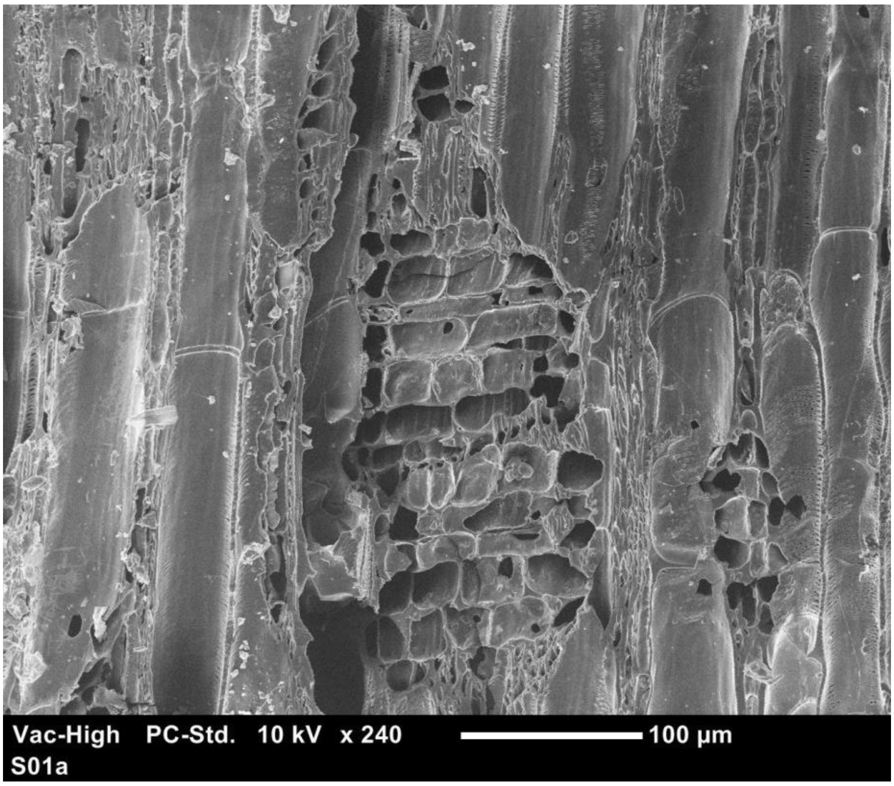

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

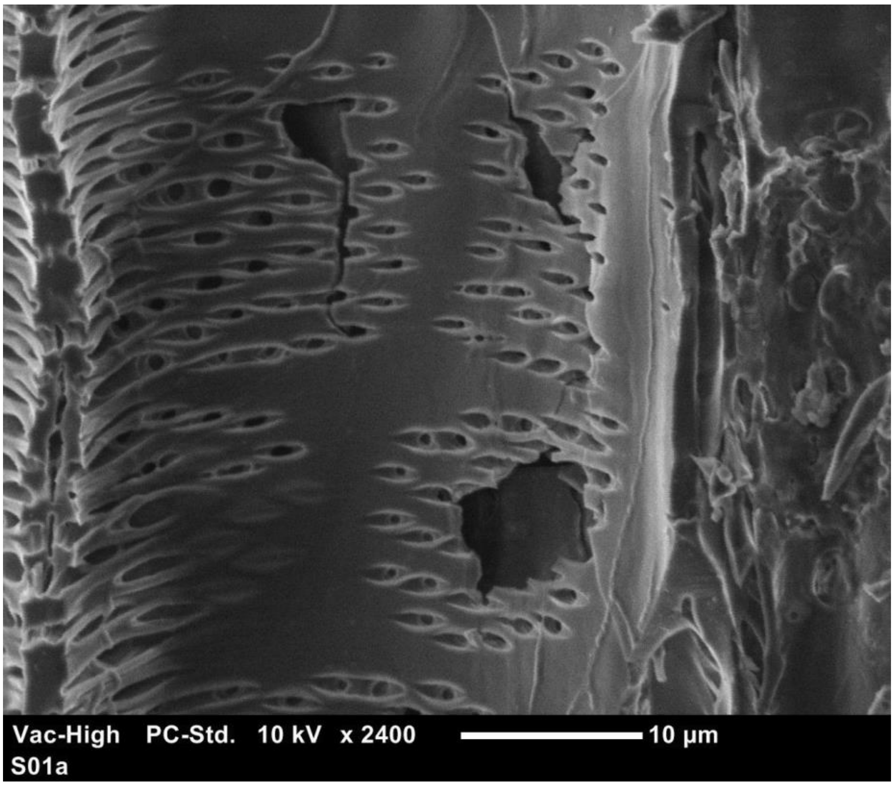
Rhamnaceae – *Alstonia* sp. (Type 38)



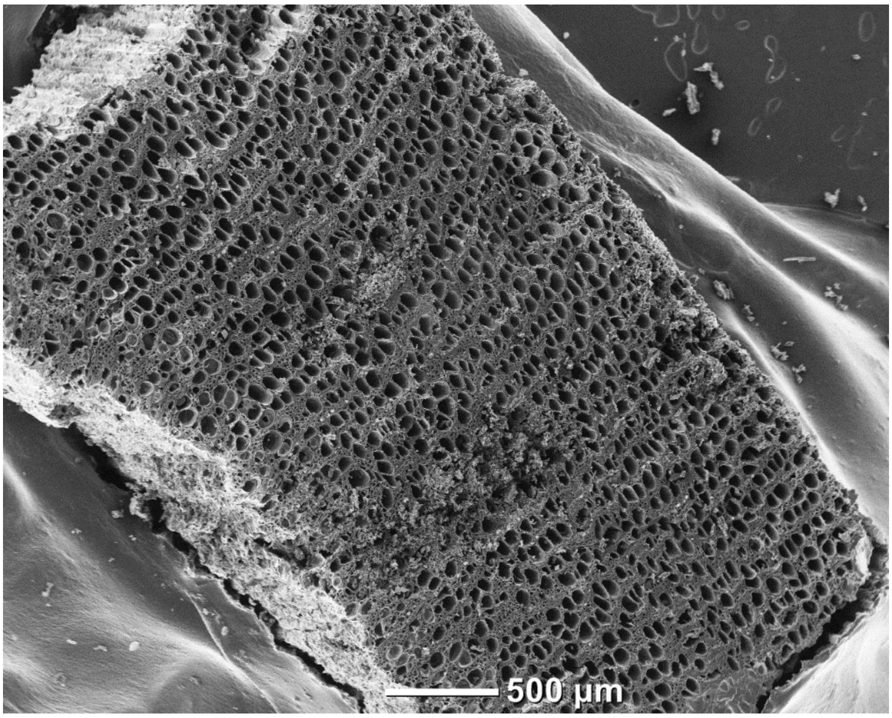


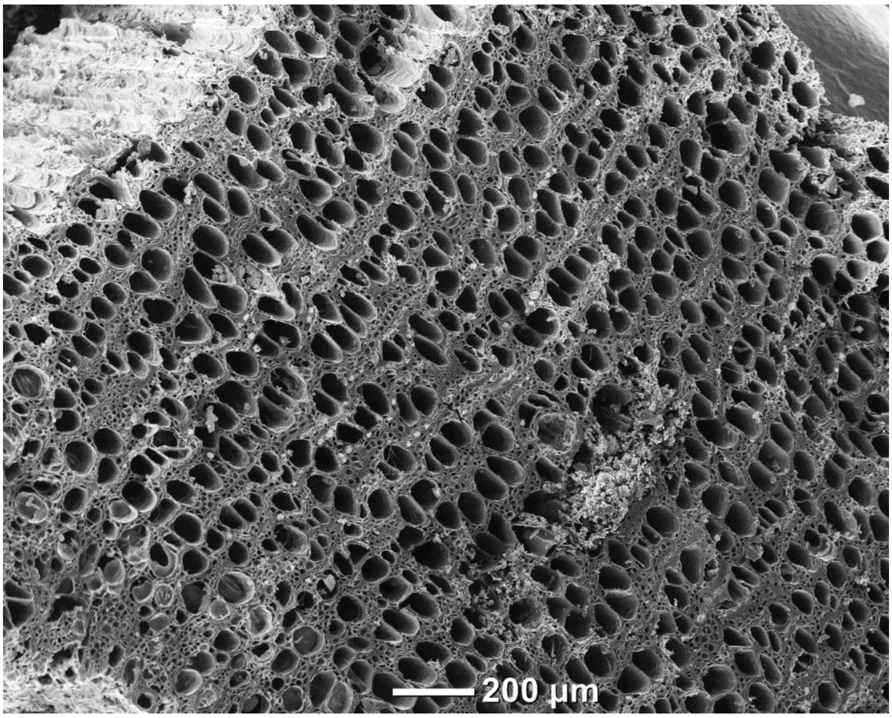

Vac-High PC-Std. 10 kV x 200
100 µm
S01a

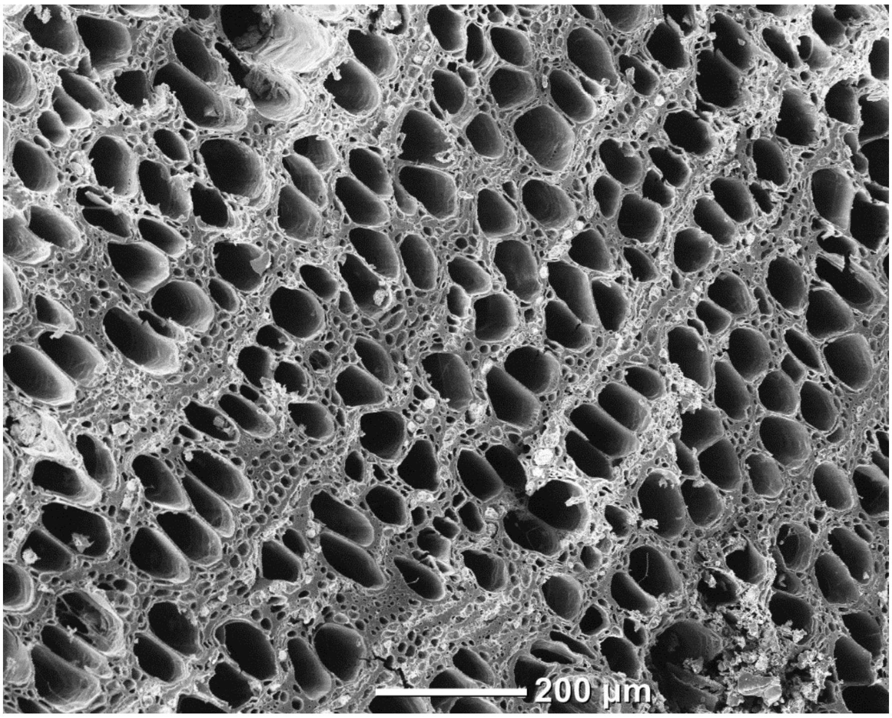

Vac-High PC-Std. 10 kV x 240
100 µm
S01a

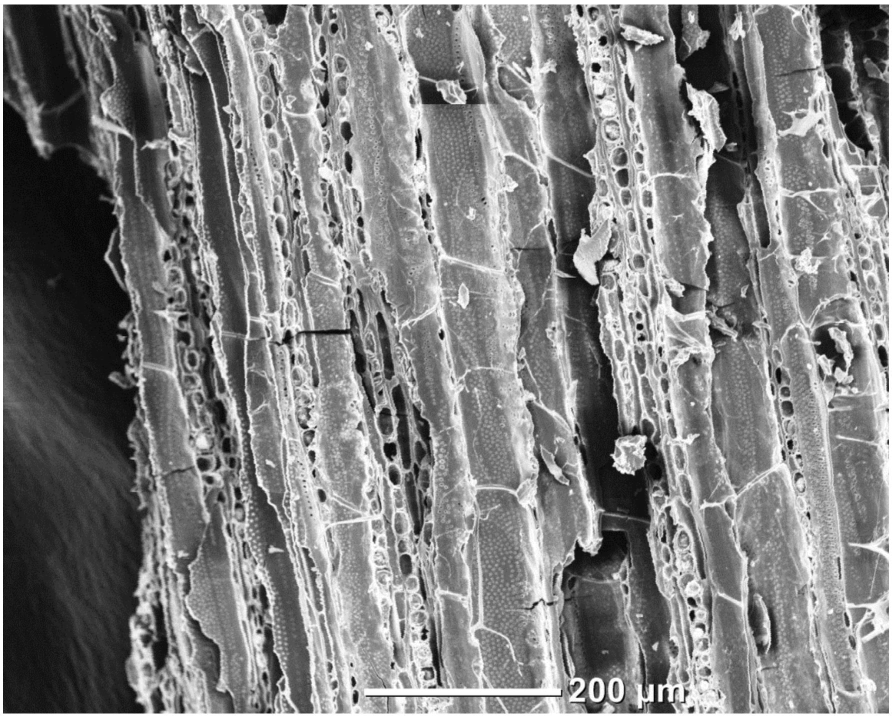

Vac-High PC-Std. 10 kV x 2400
10 µm
S01a

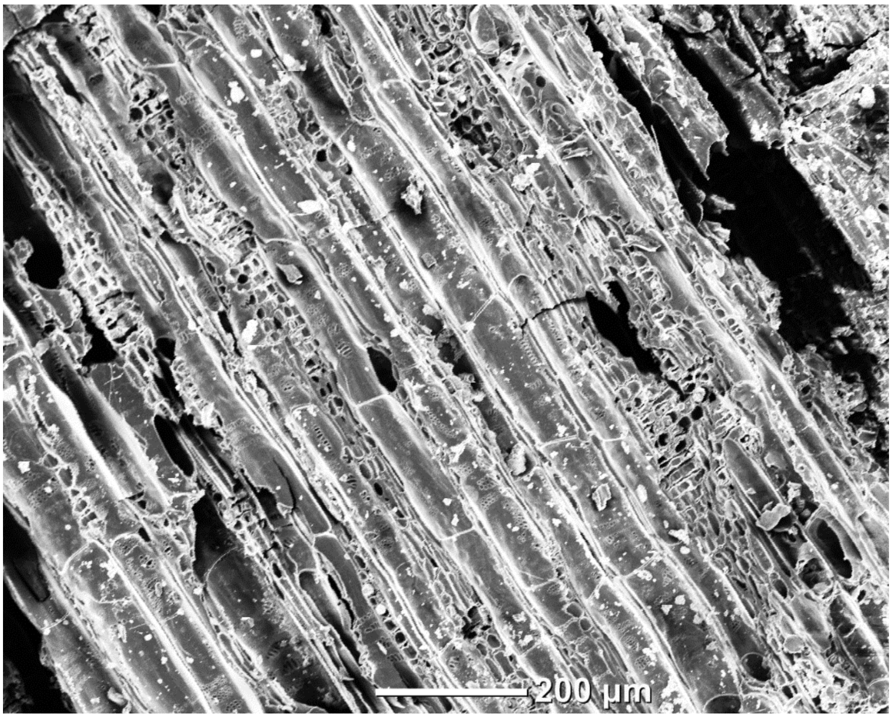
Euphorbiaceae – cf. *Flueggea* sp. (Type 6)



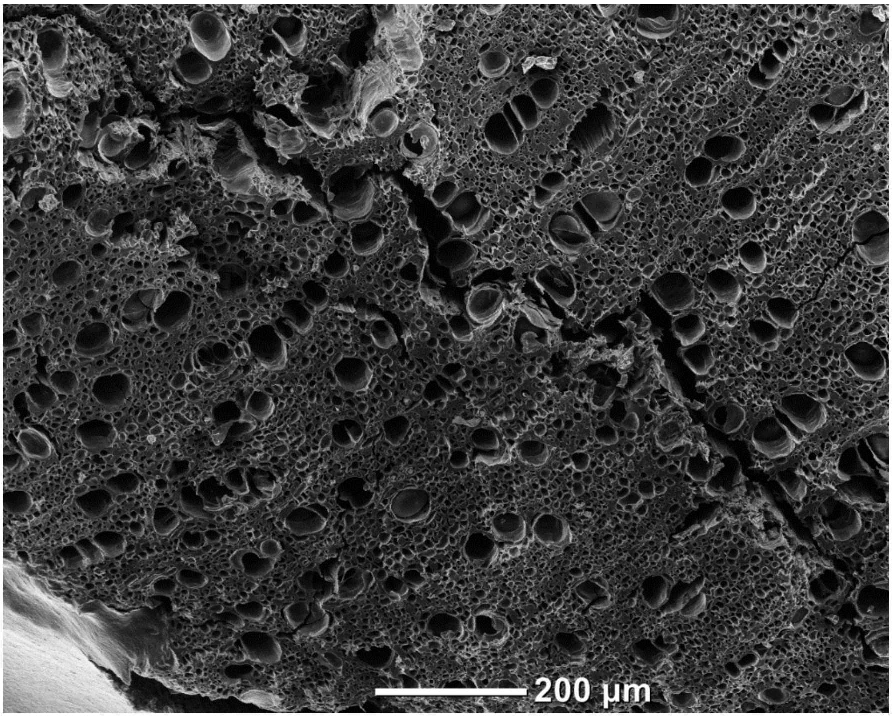


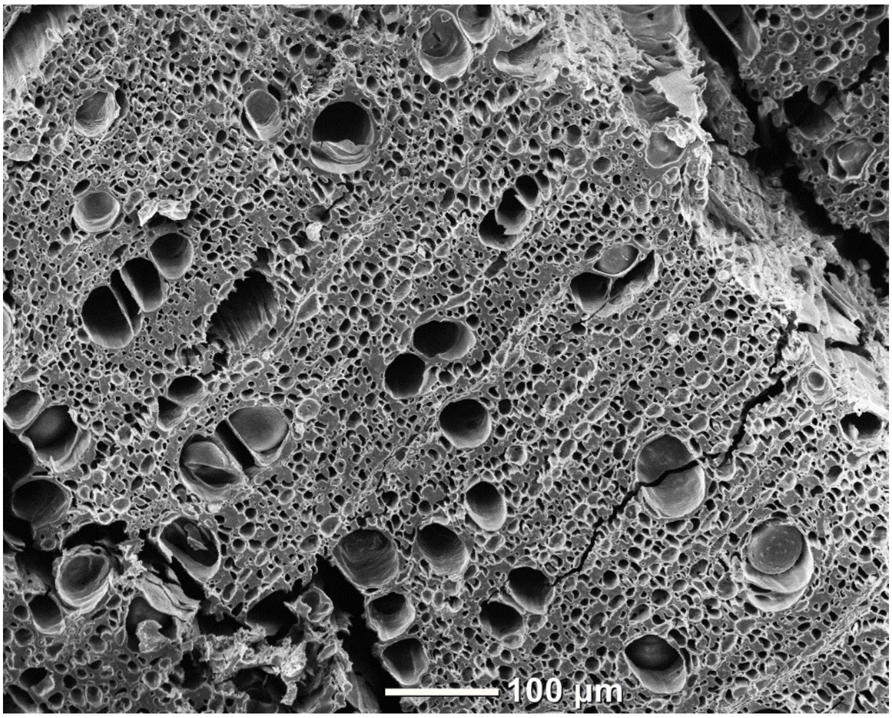

200 µm

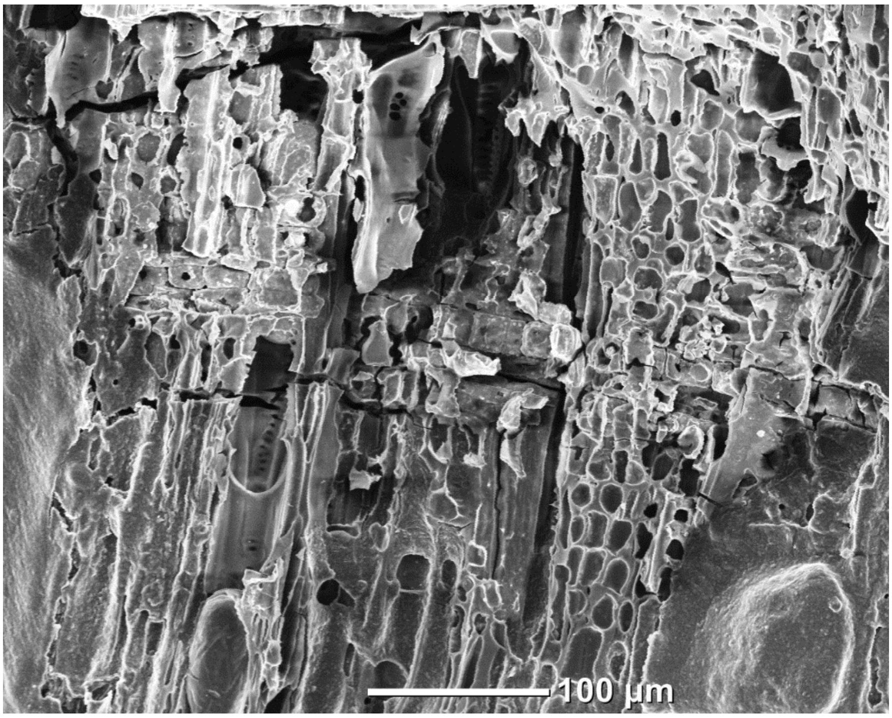

200 µm

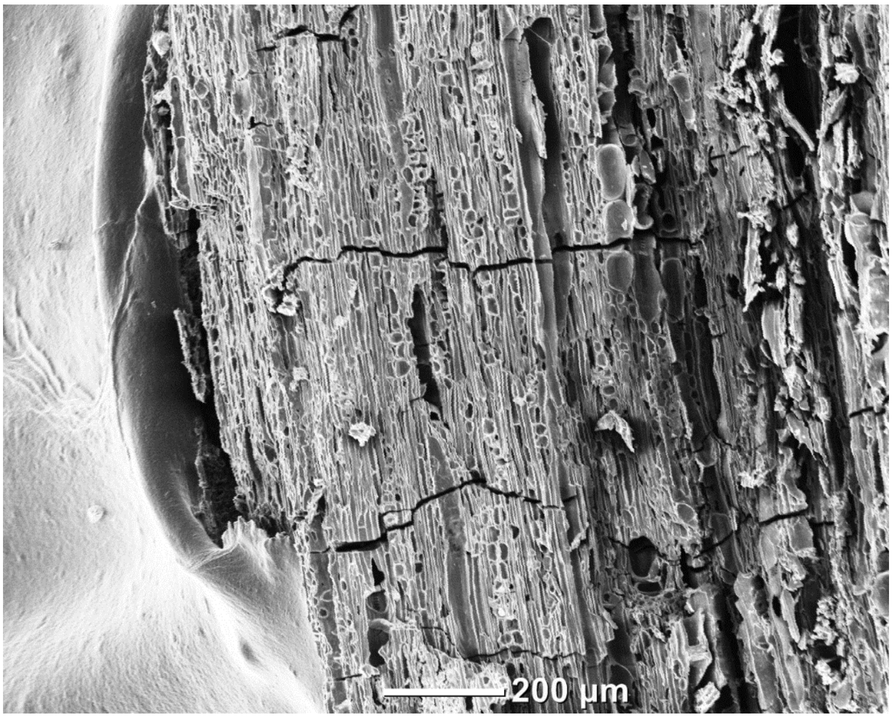

200 µm

Euphorbiaceae – cf. *Flueggea* sp. (Type 9)

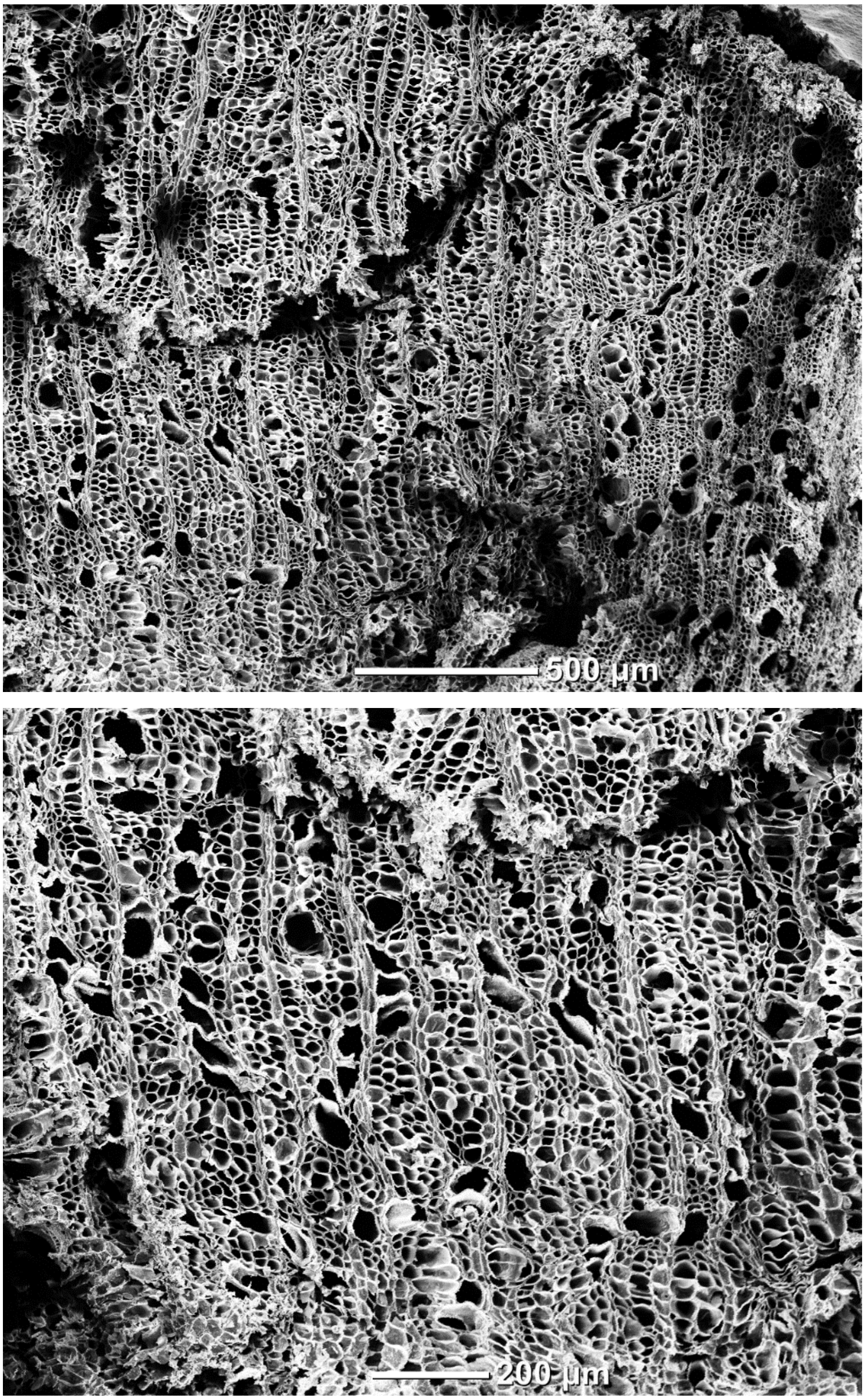


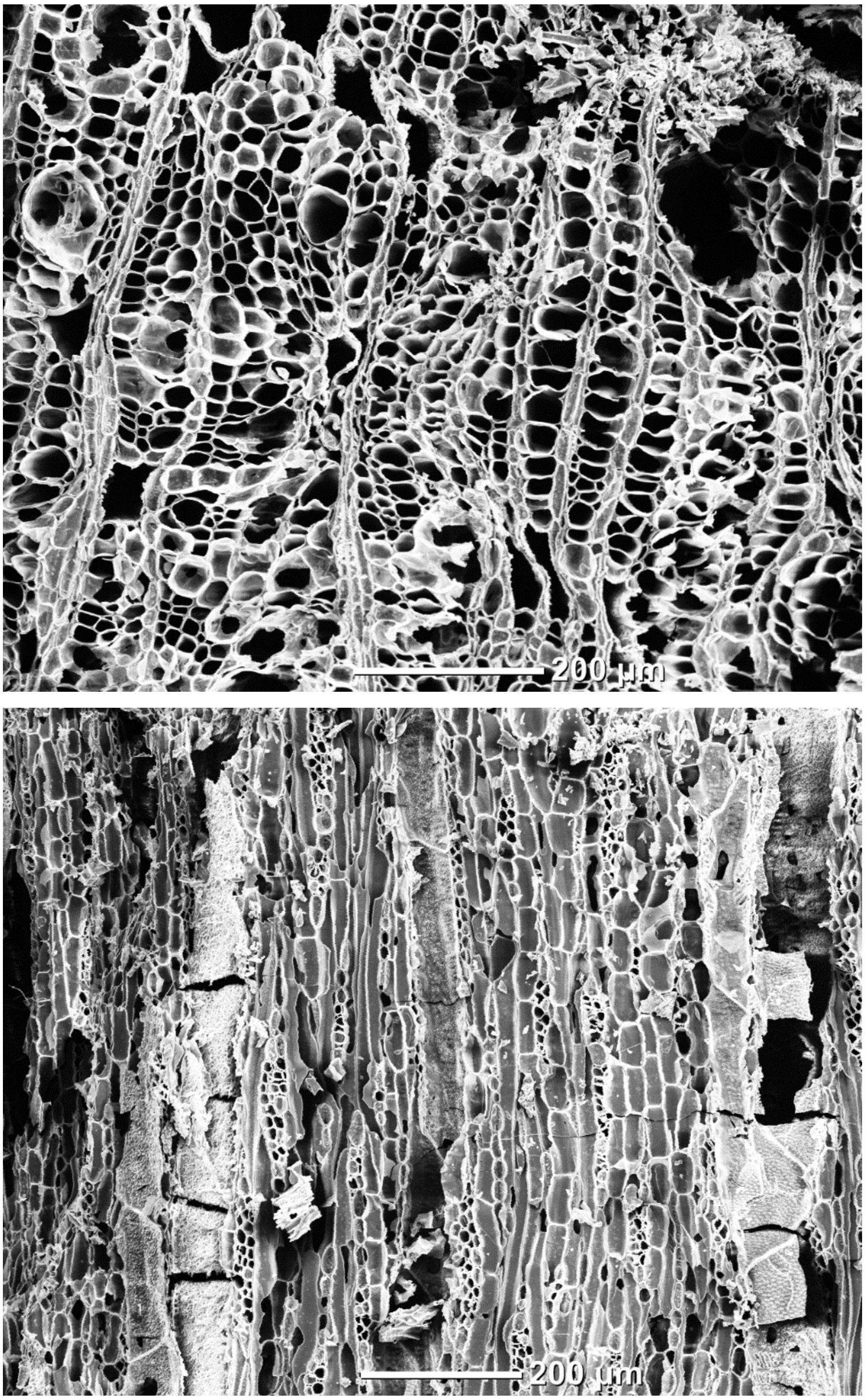



100 µm

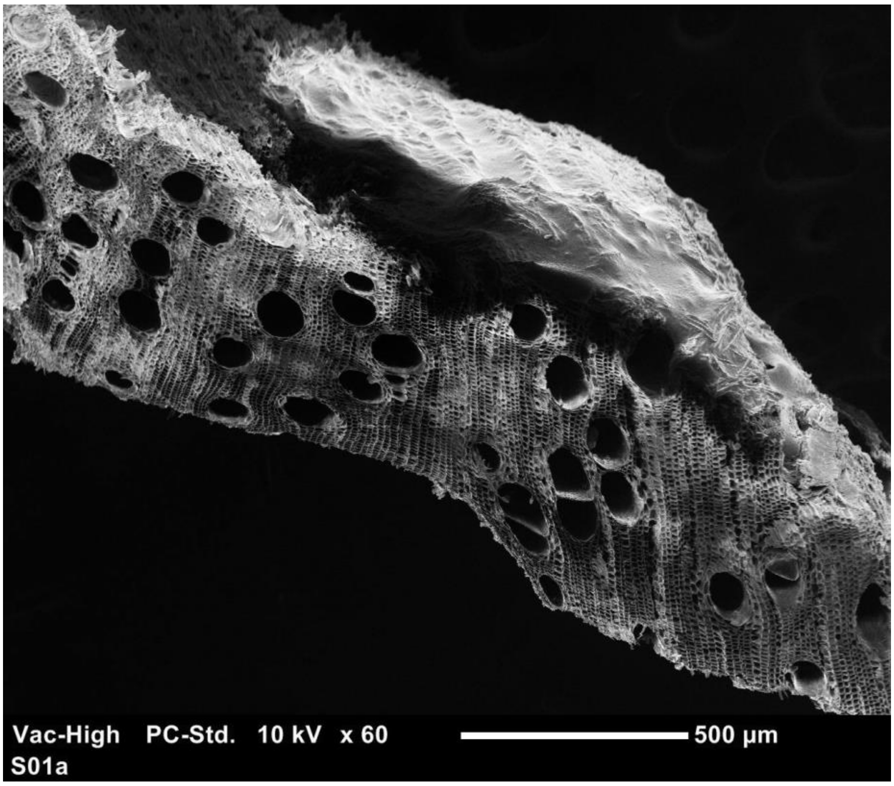

200 µm

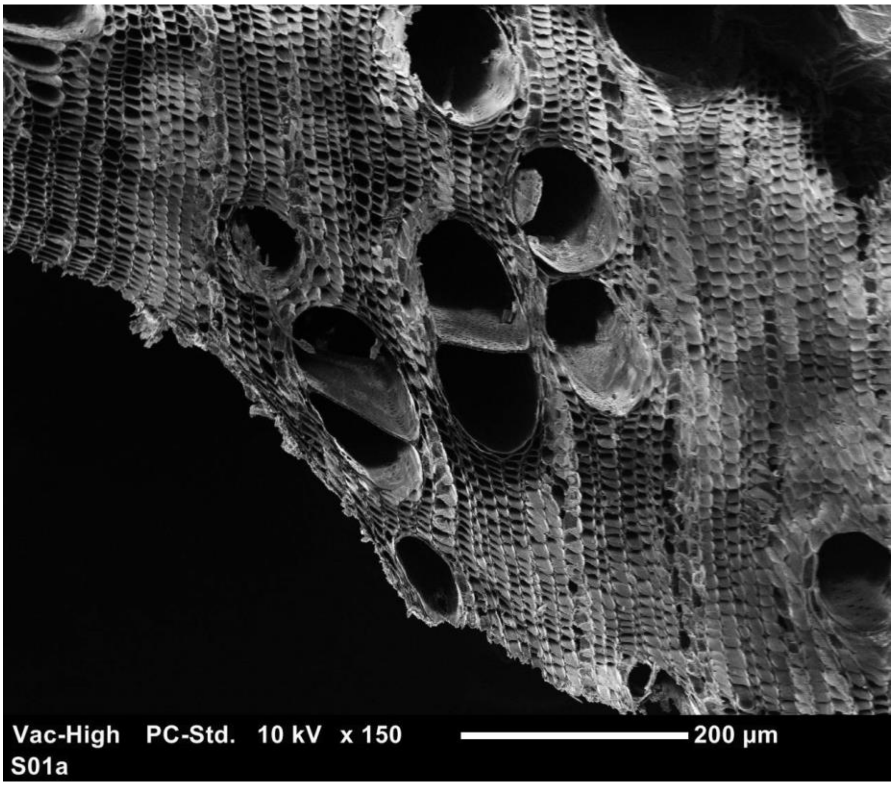
Moraceae – *Ficus* sp. (Type 17)

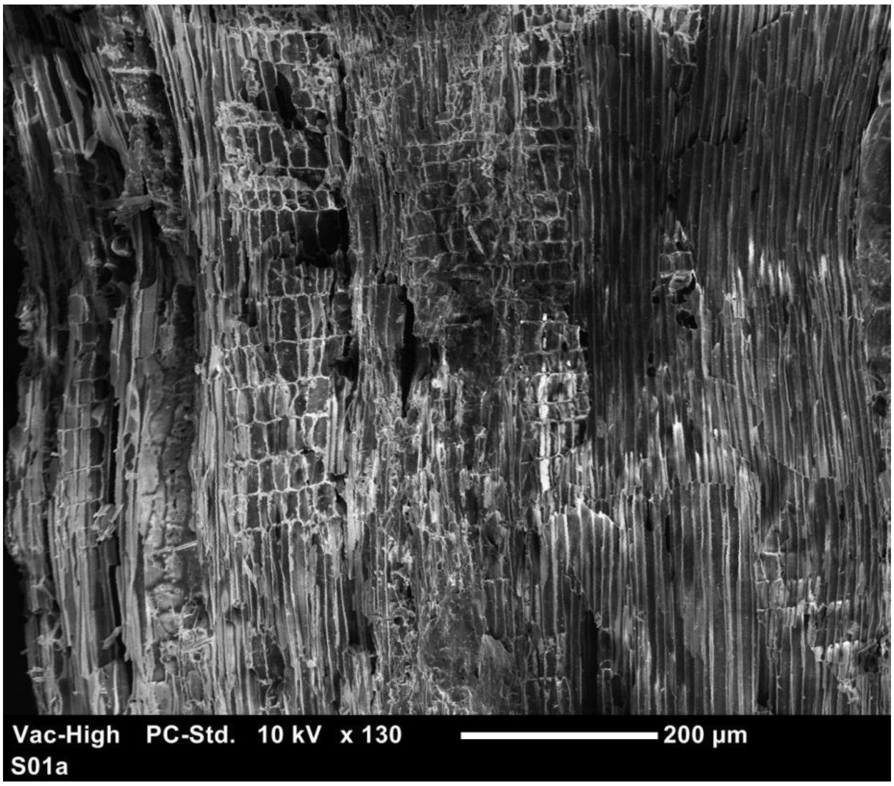



200 µm
200 µm

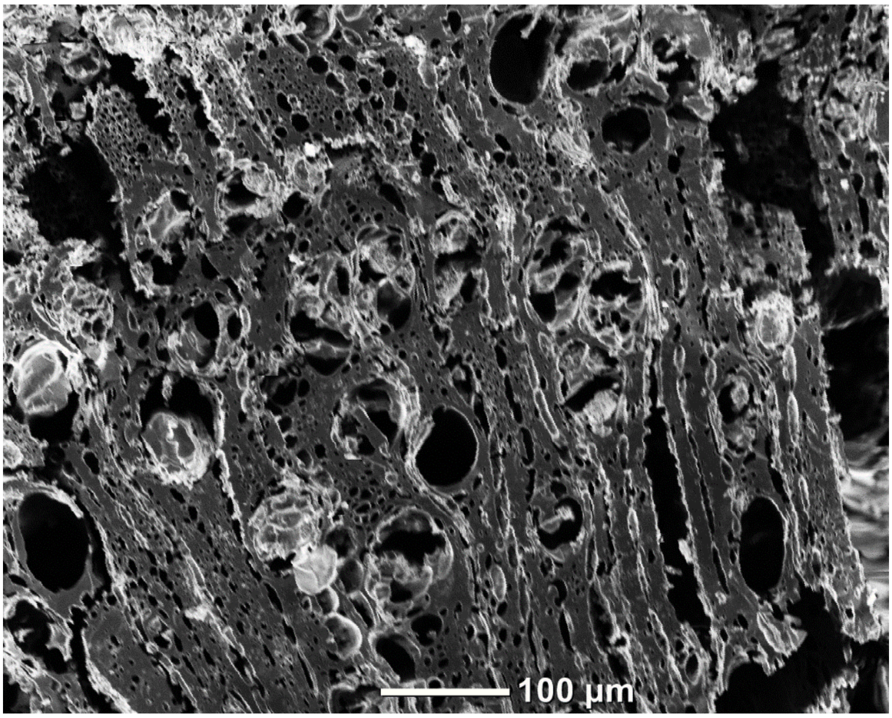
Moraceae – *Ficus* sp. (Type 57)

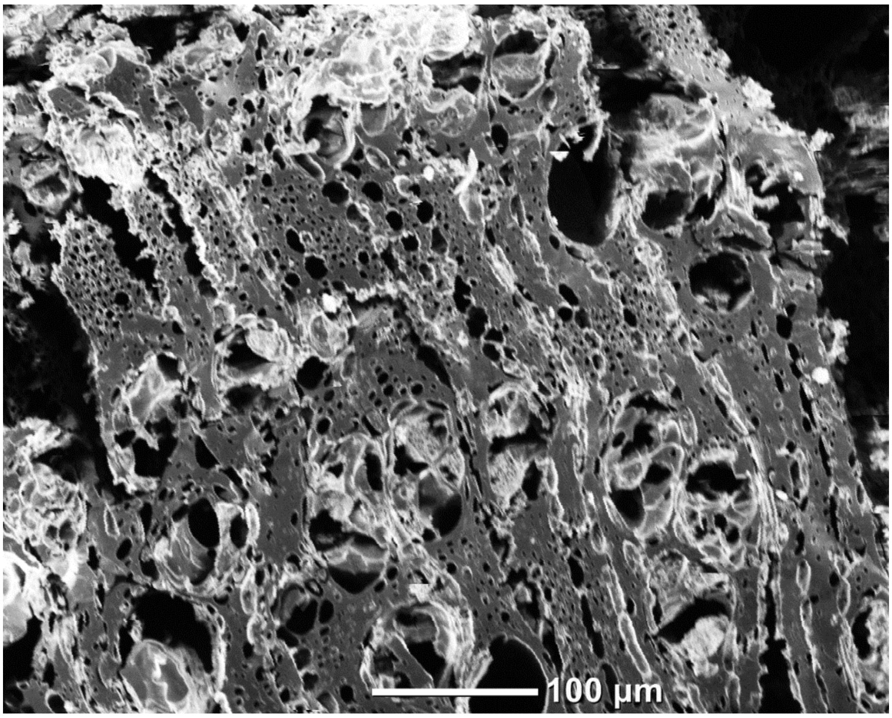


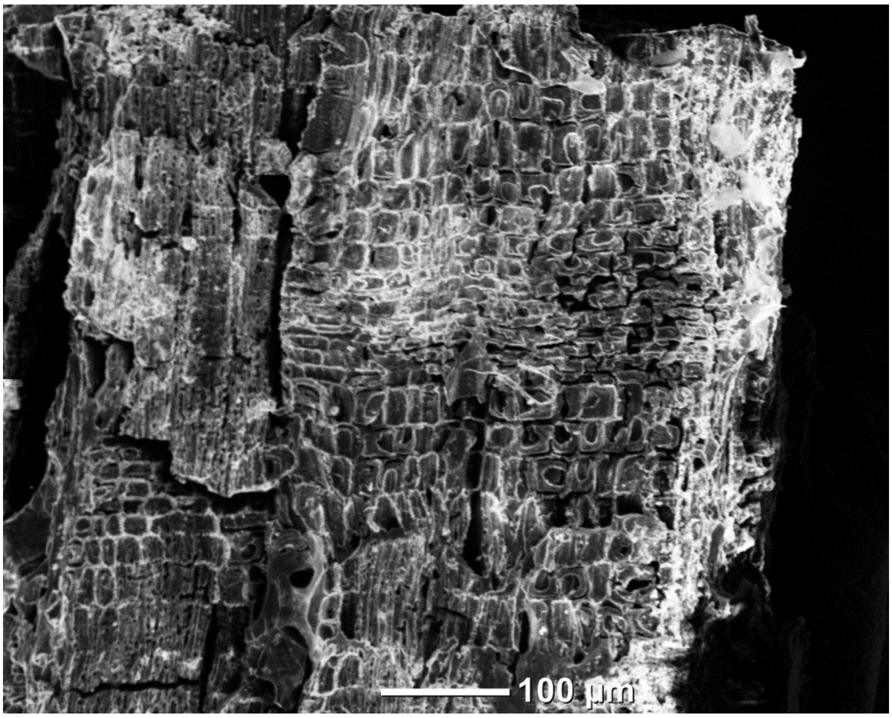



Vac-High PC-Std. 10 kV x 130
200 µm
S01a

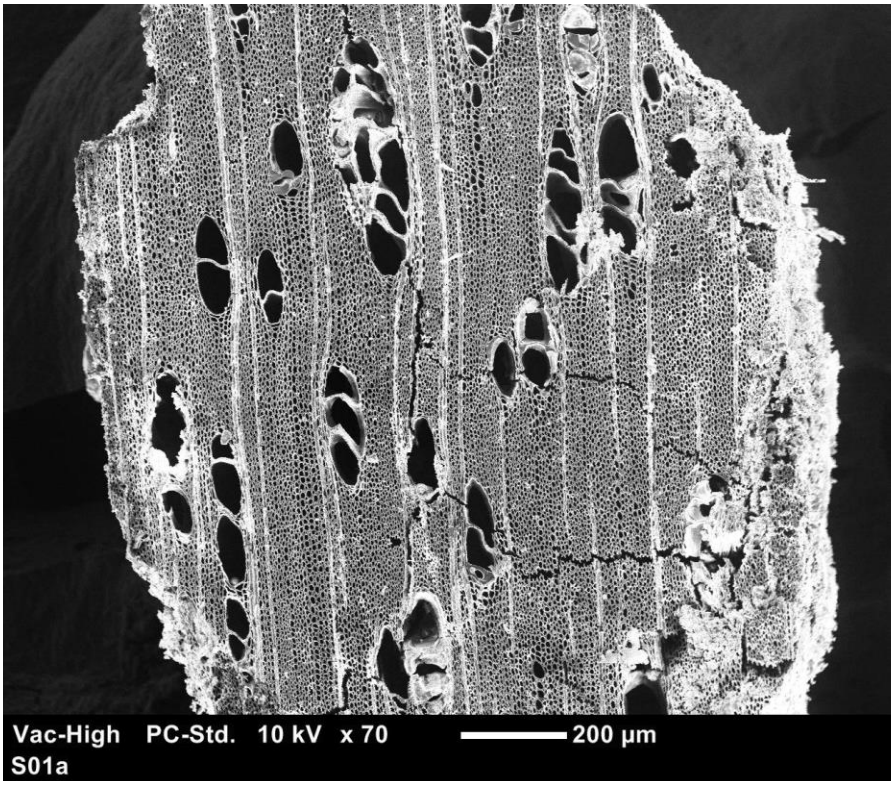
Rubiaceae – cf. *Pavetta* sp. (Type 12)

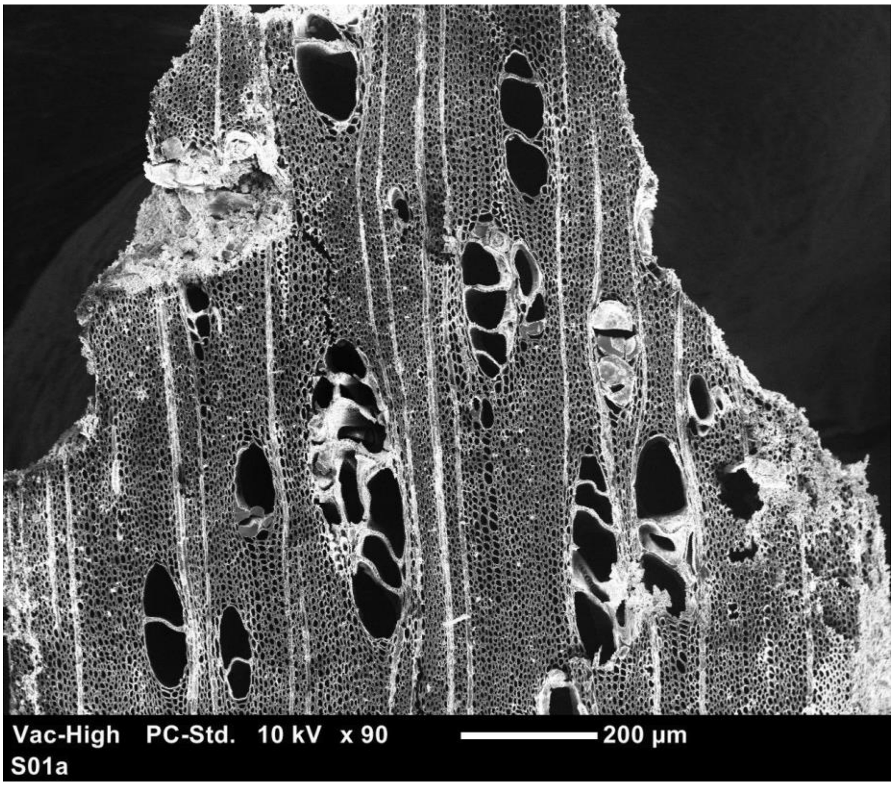


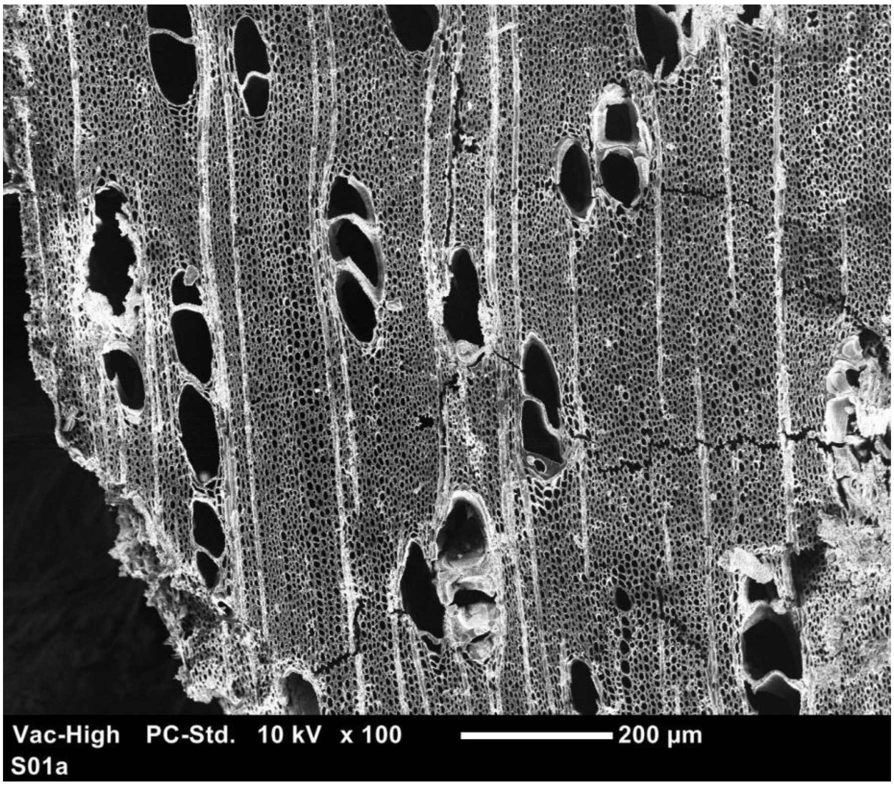


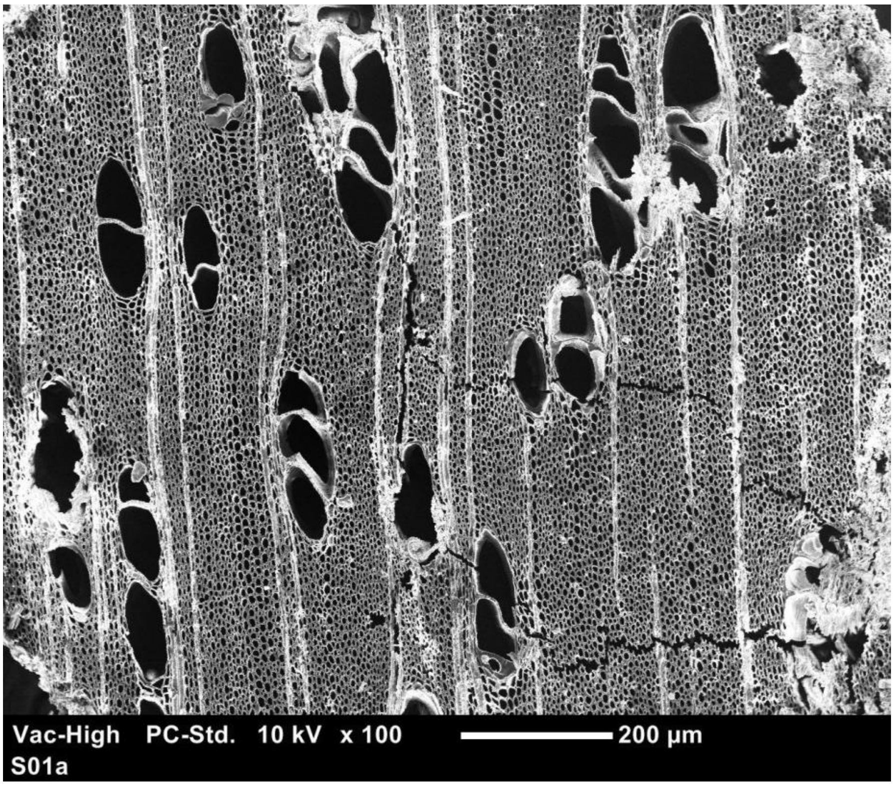

100 µm

Rubiaceae – *Coelospermum* sp. (Type 51)

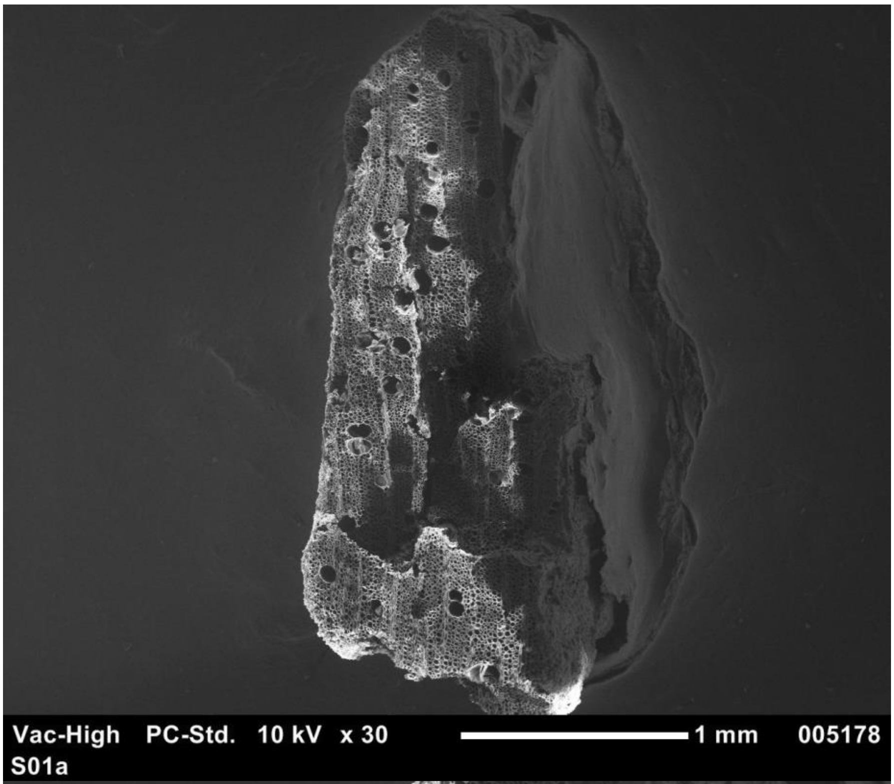


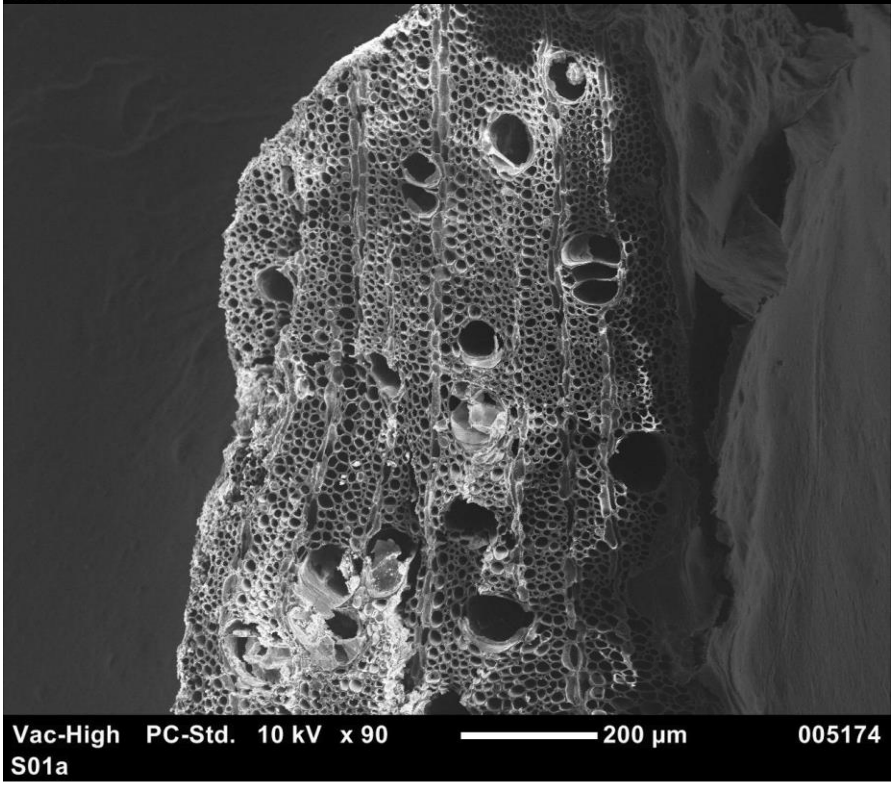


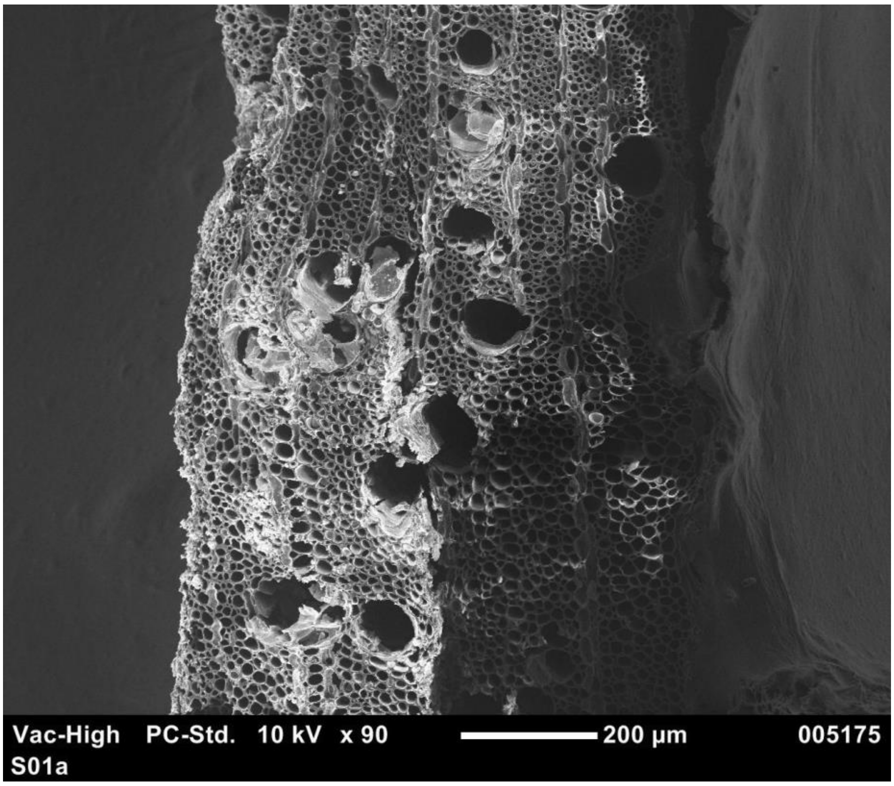

Vac-High PC-Std. 10 kV x 100
200 µm
S01a

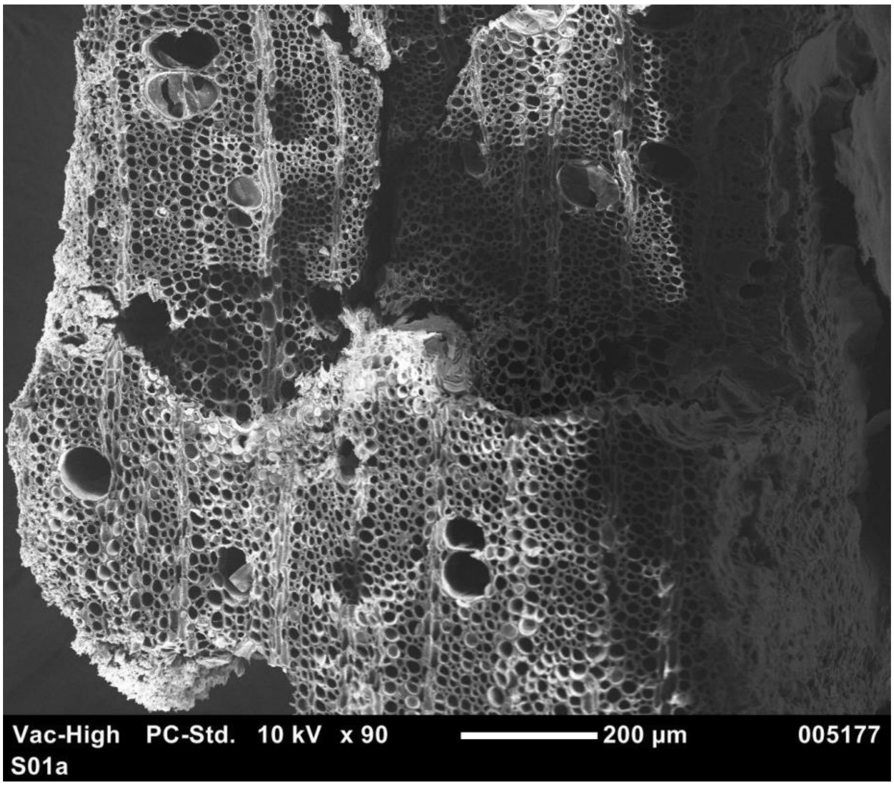

Vac-High PC-Std. 10 kV x 100
200 µm
S01a

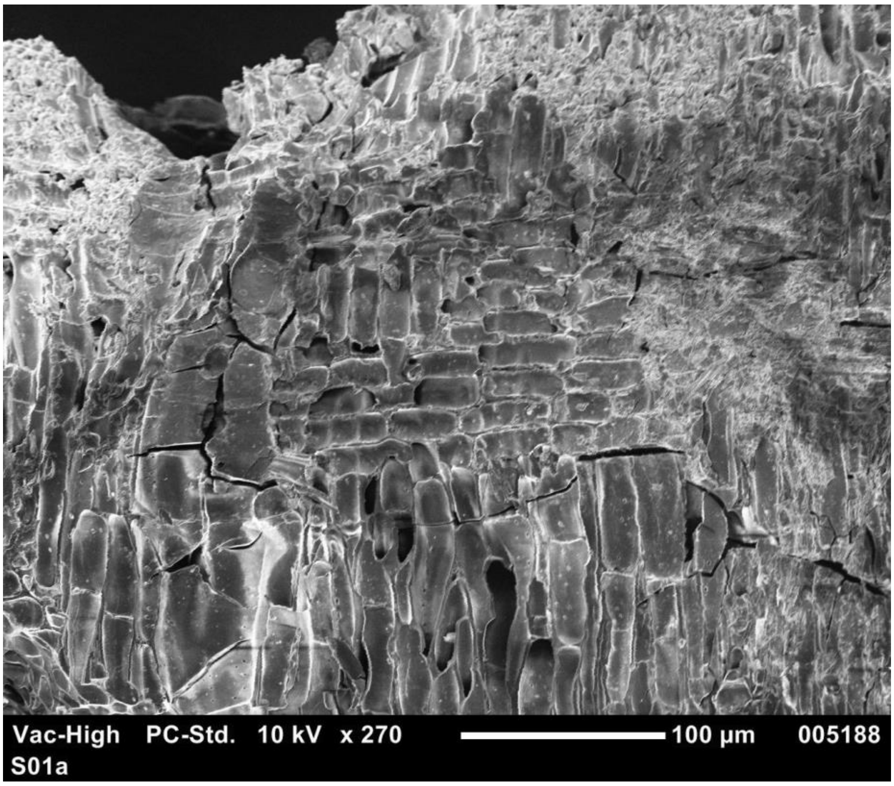
Malvaceae – cf. *Thespesia* sp. (Type 26)



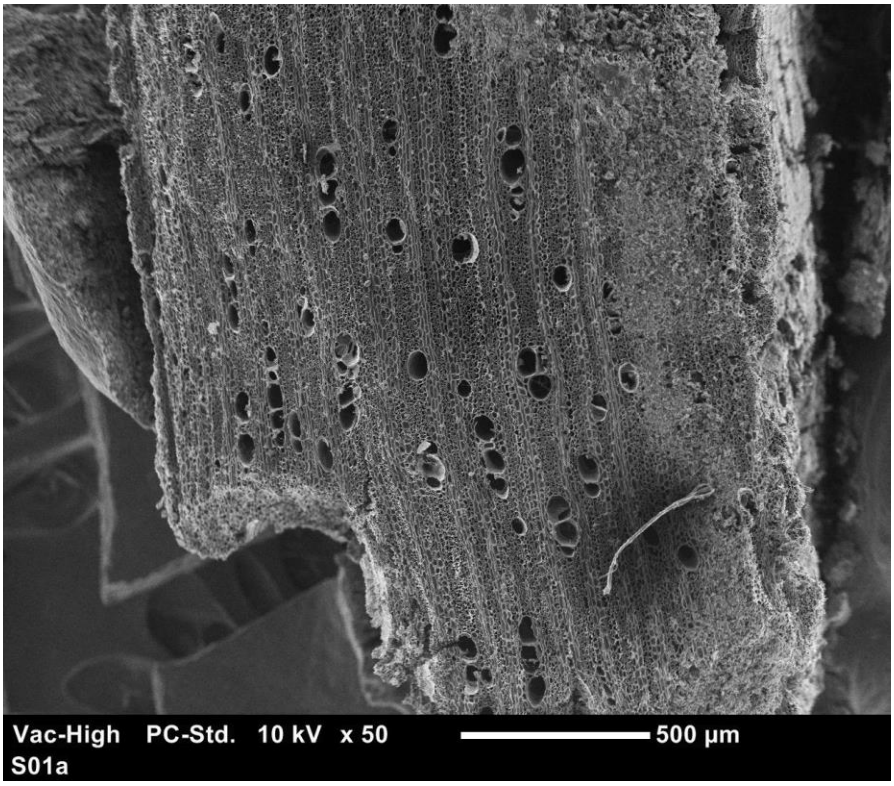


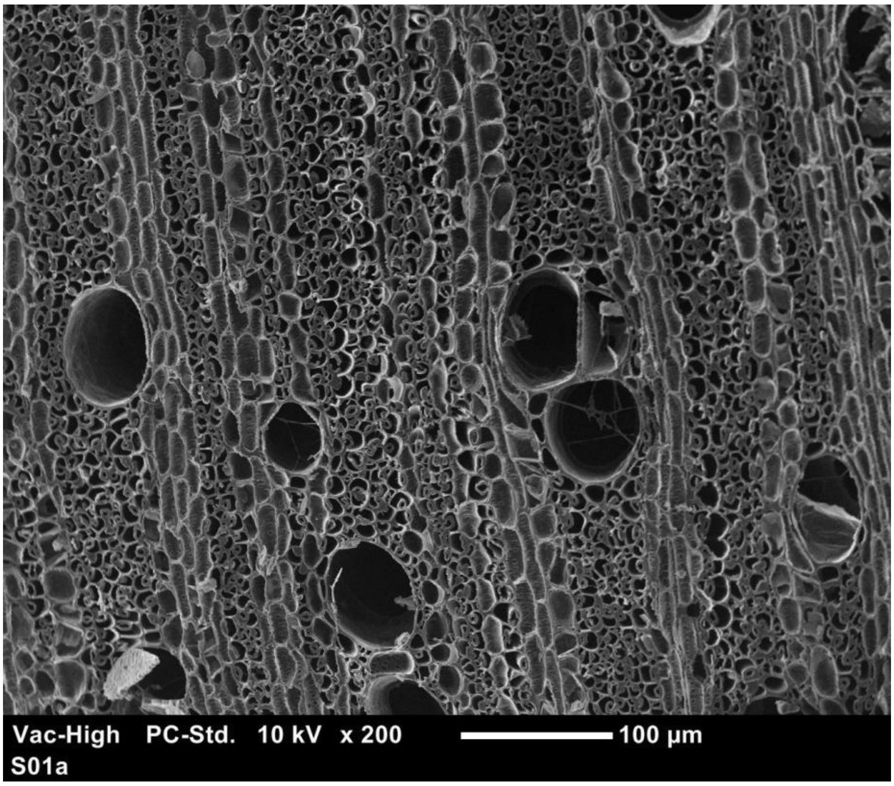

Vac-High PC-Std. 10 kV x 90
200 µm
005175
S01a

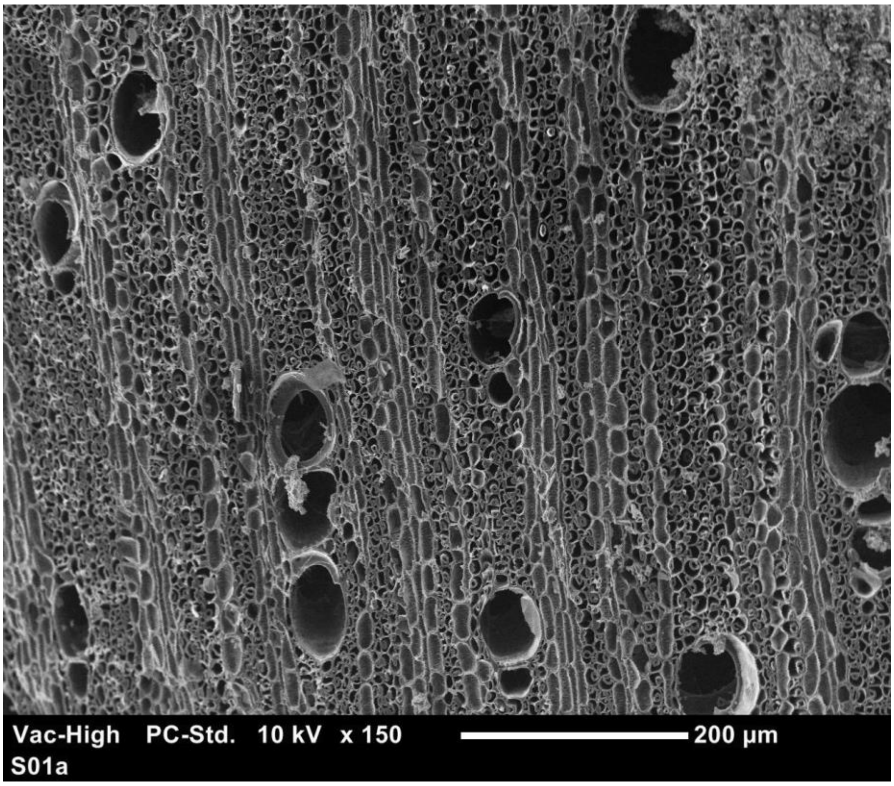

Vac-High PC-Std. 10 kV x 90
200 µm
005177
S01a

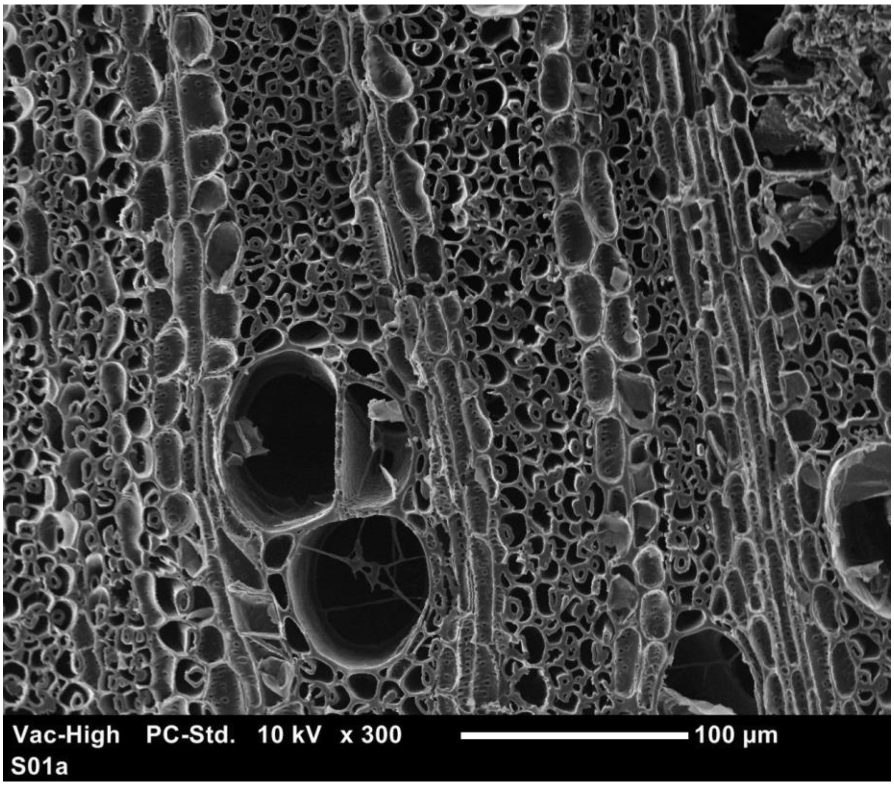

Vac-High PC-Std. 10 kV x 270
100 µm
005188
S01a

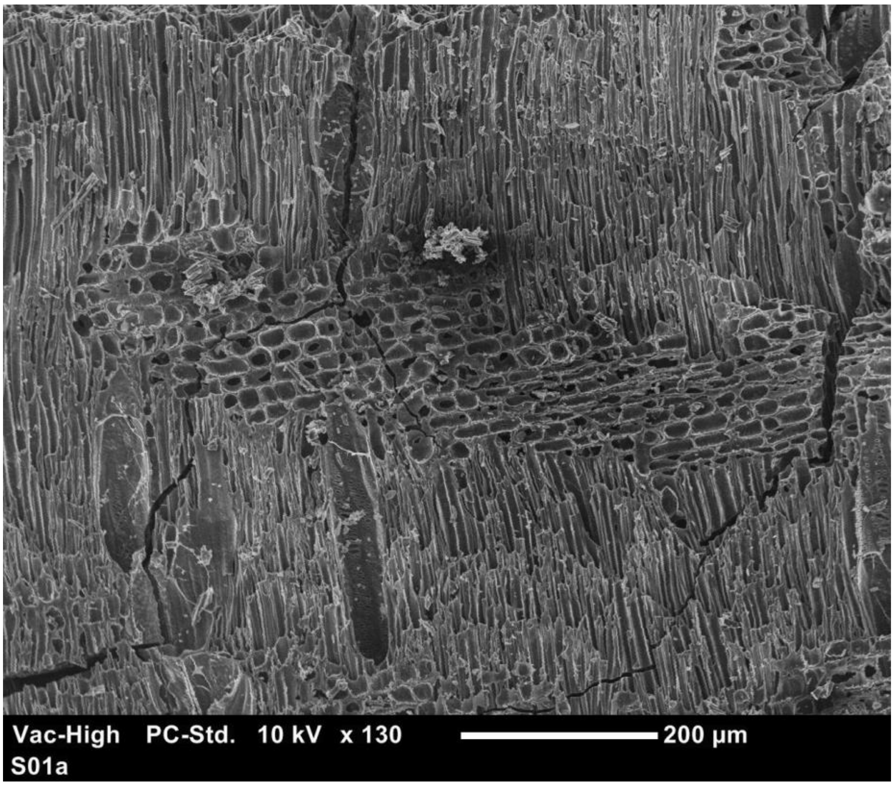
Malvaceae – *Grewia* sp. (Type 43)

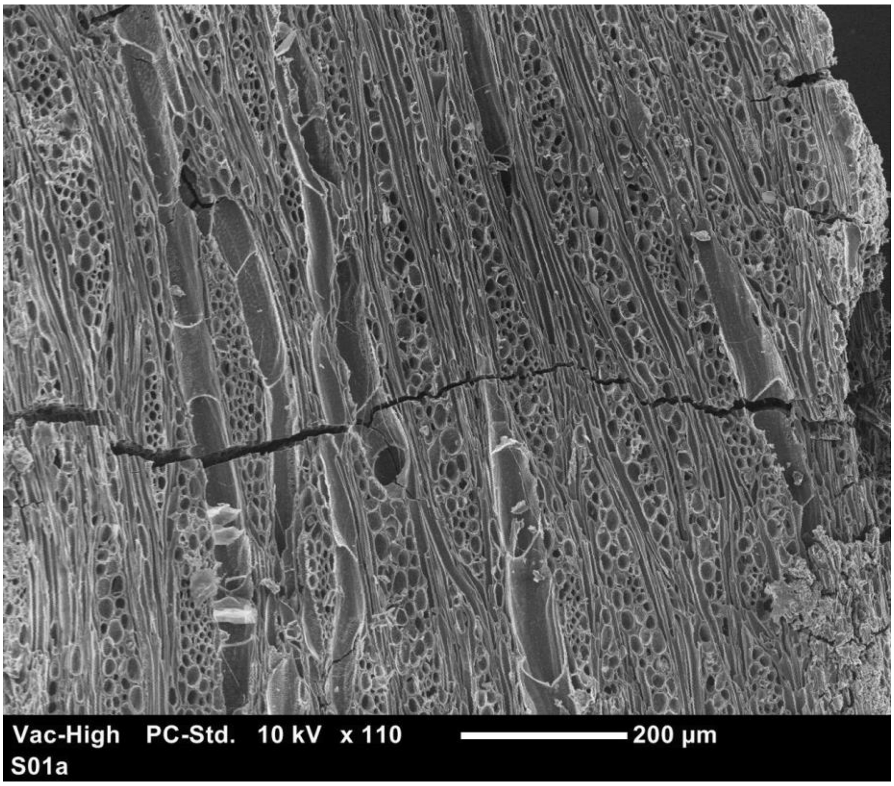




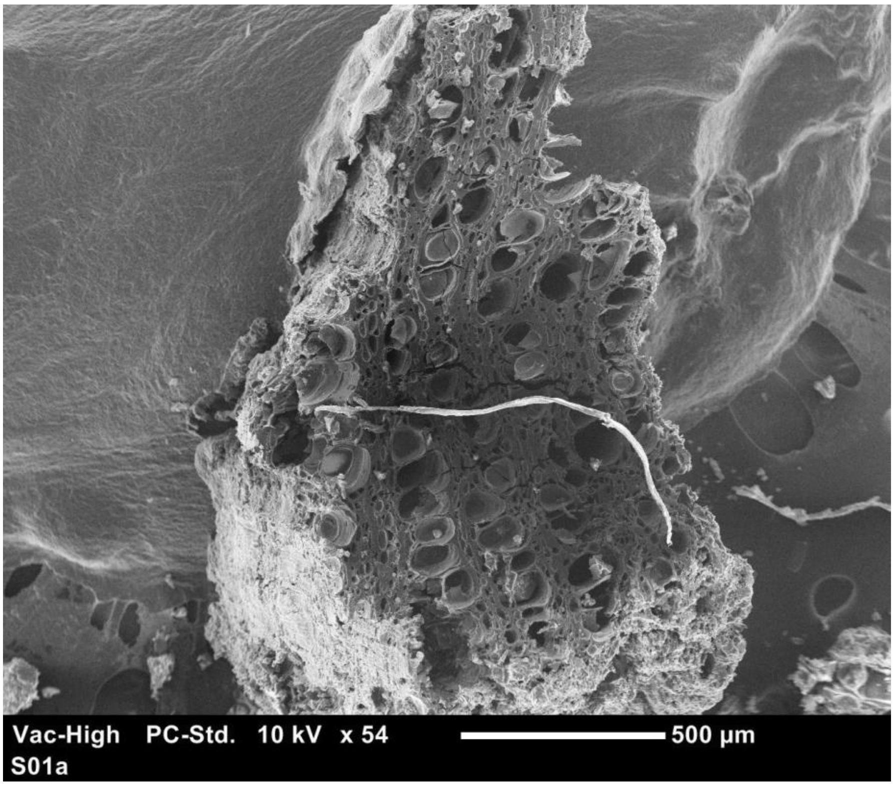

Vac-High PC-Std. 10 kV x 150
200 µm
S01a

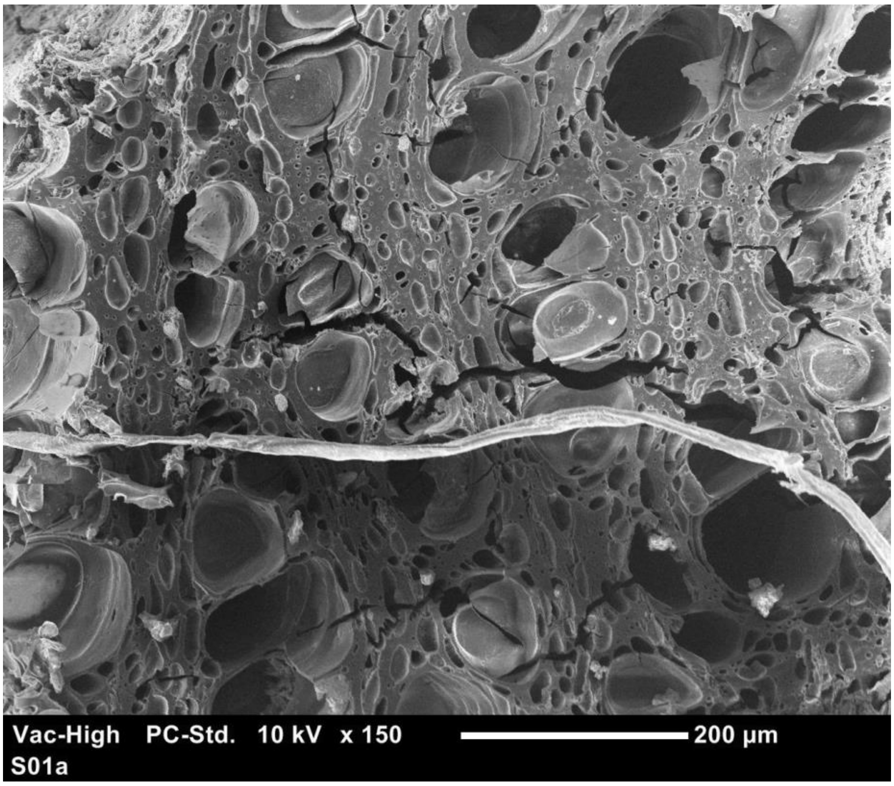

Vac-High PC-Std. 10 kV x 300
100 µm
S01a

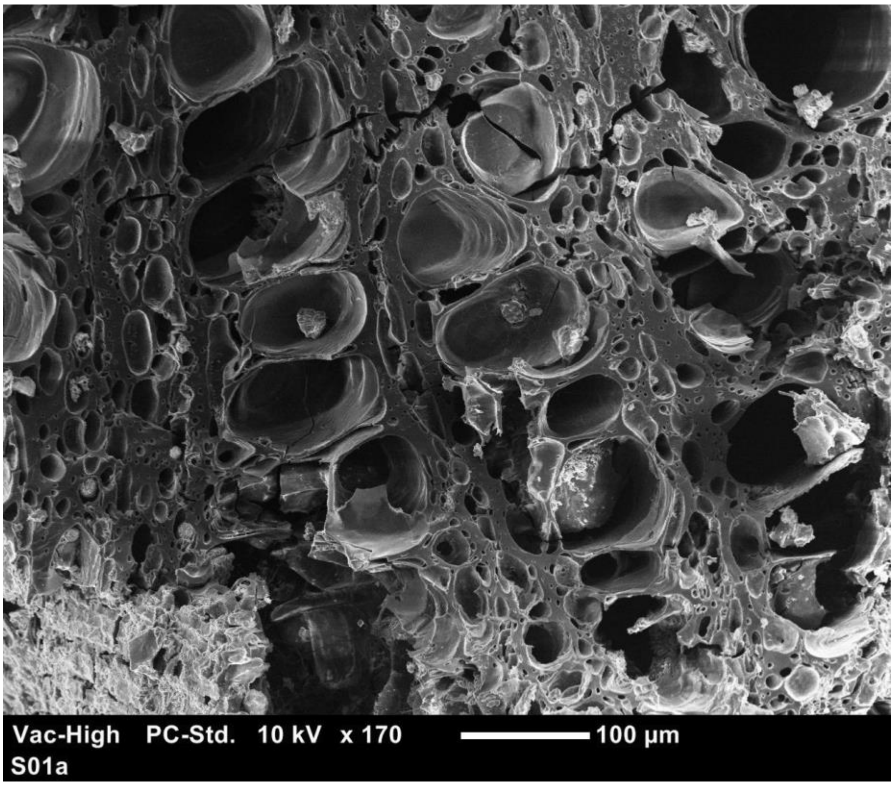

Vac-High PC-Std. 10 kV x 130
200 µm
S01a

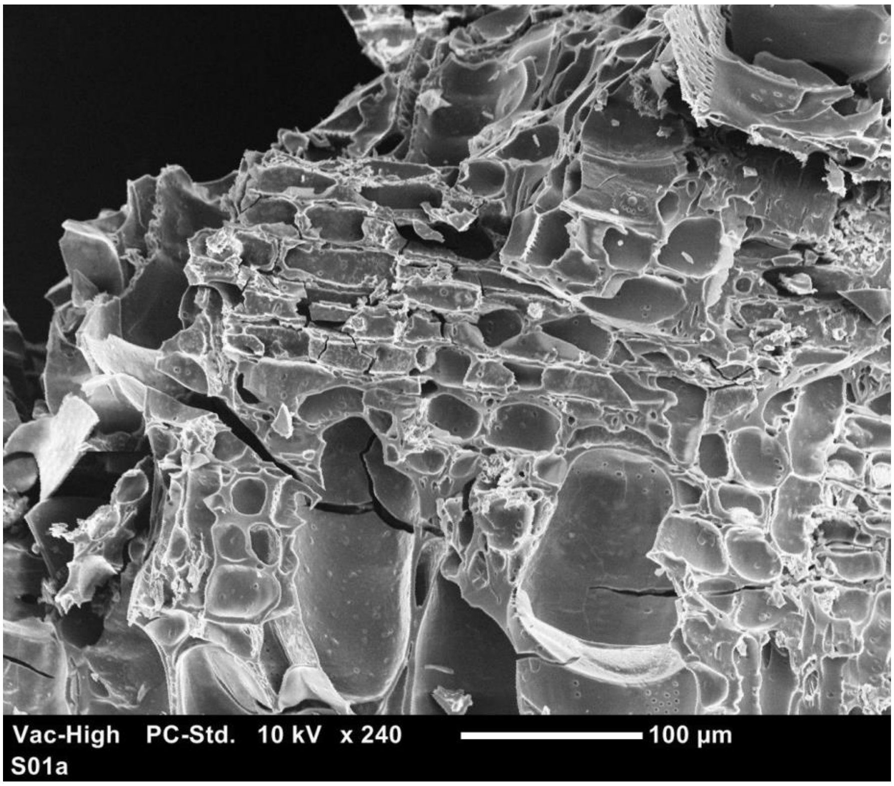

Vac-High PC-Std. 10 kV x 110
200 µm
S01a

Sterculiaceae – *Brachychiton* sp. (Type 42)

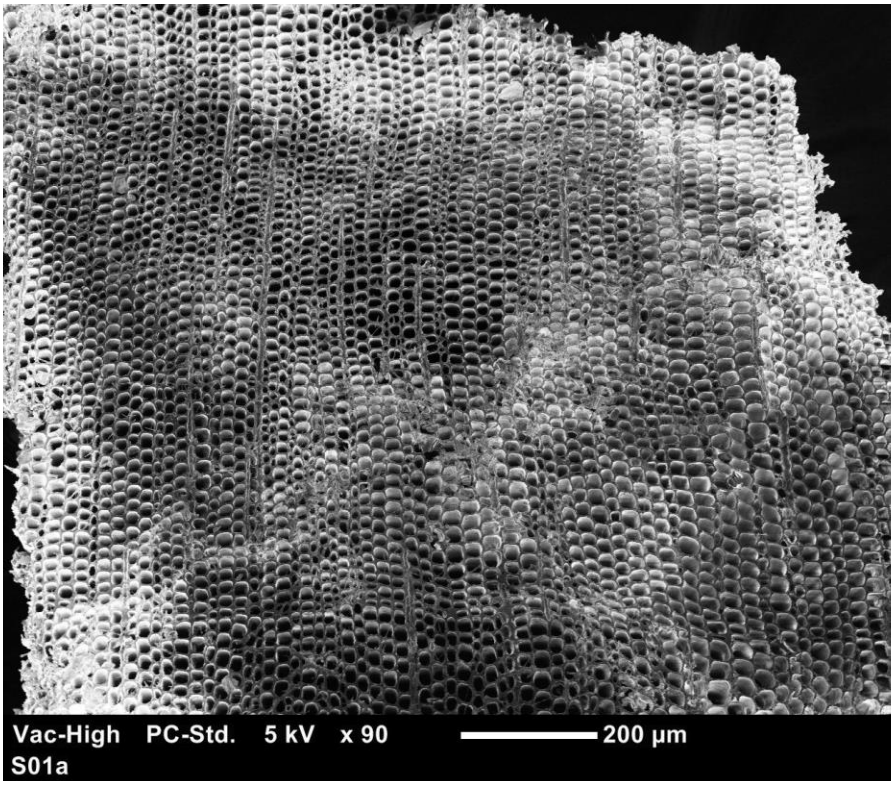


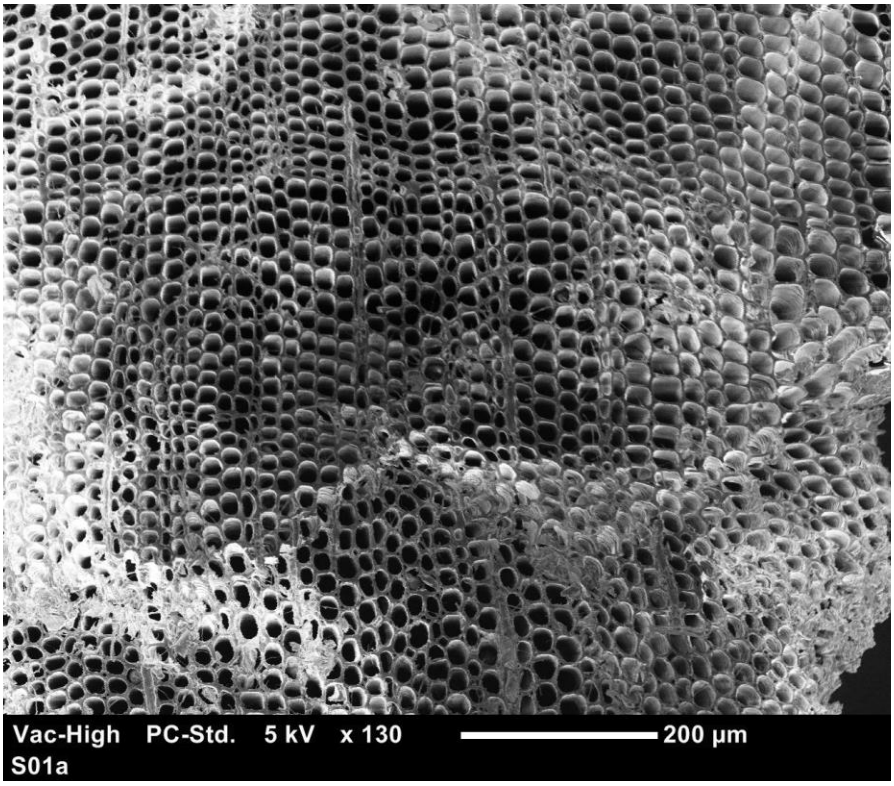


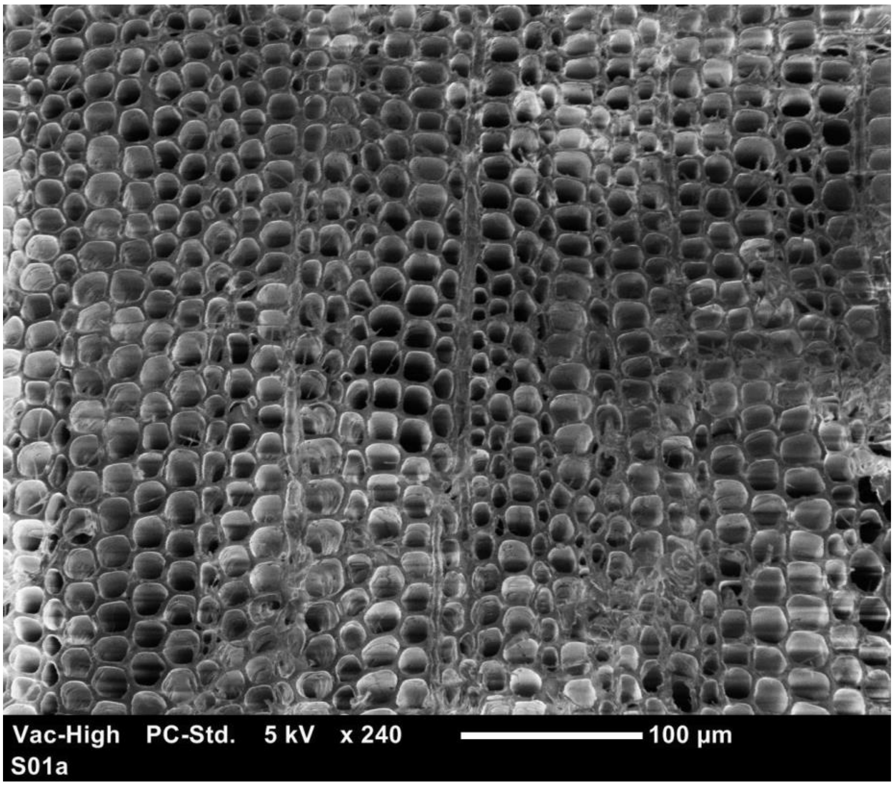

Vac-High PC-Std. 10 kV x 170
100 µm
S01a

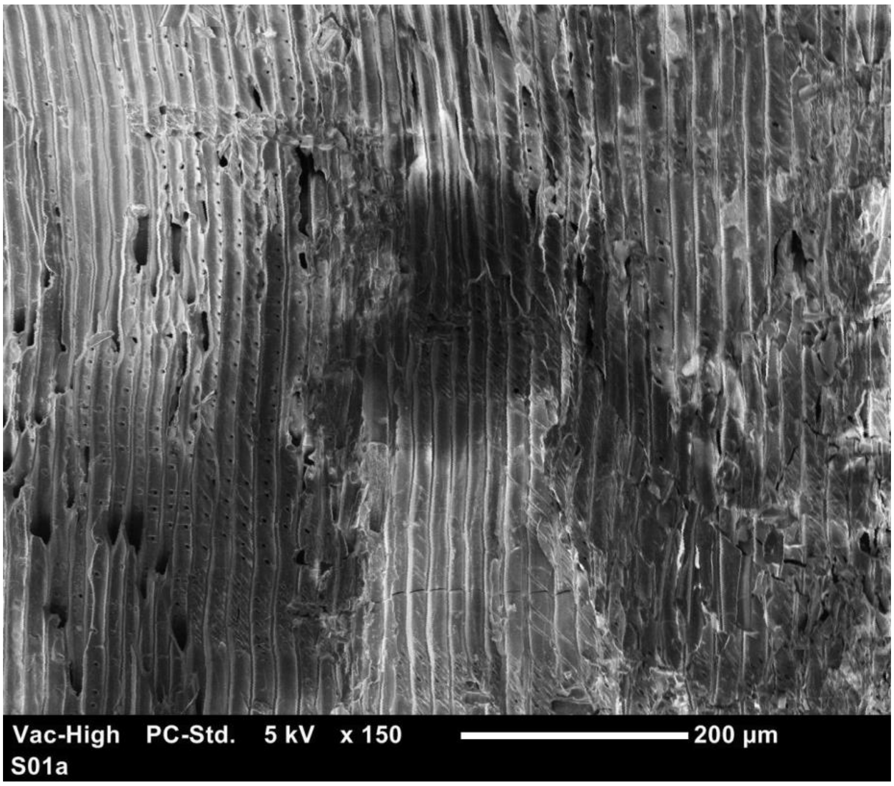

Vac-High PC-Std. 10 kV x 240
100 µm
S01a

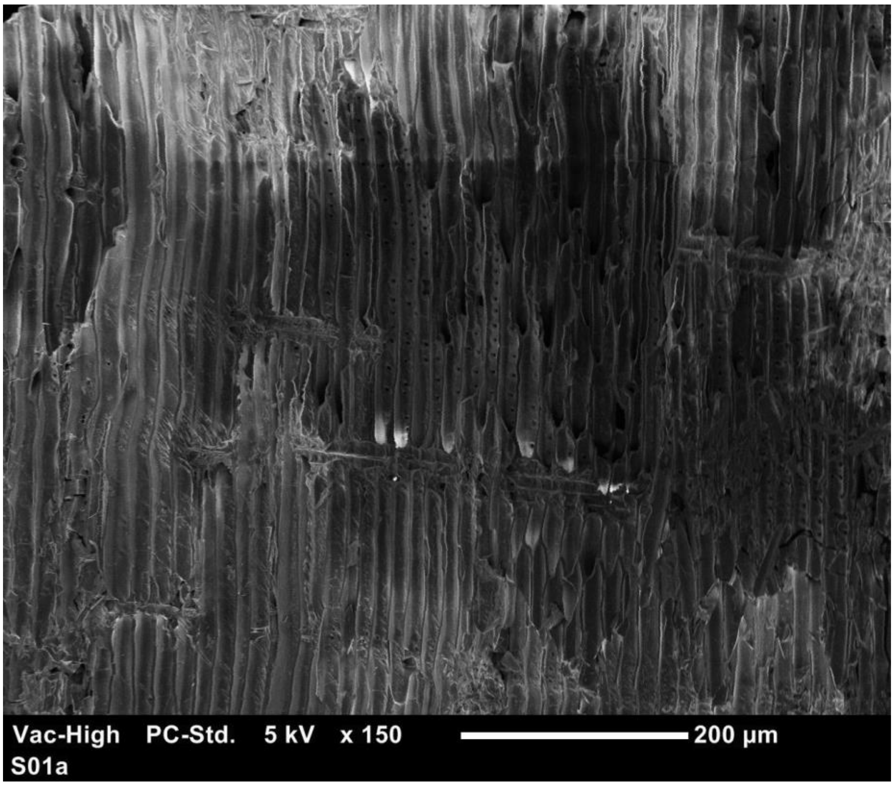
Cupressaceae – *Callitris* sp. (Type 45)

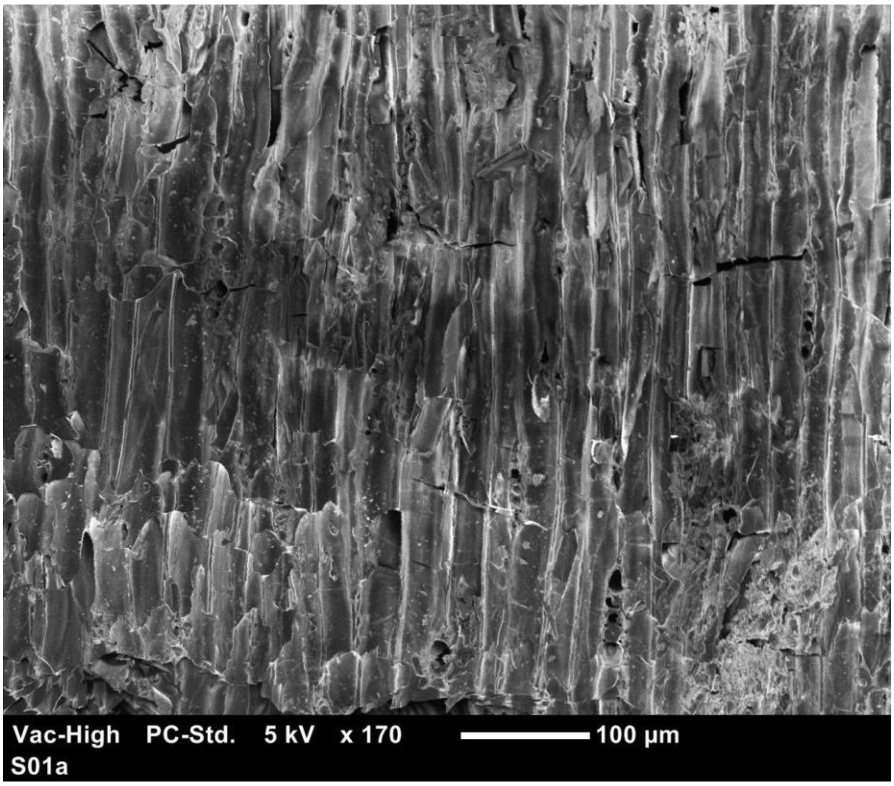




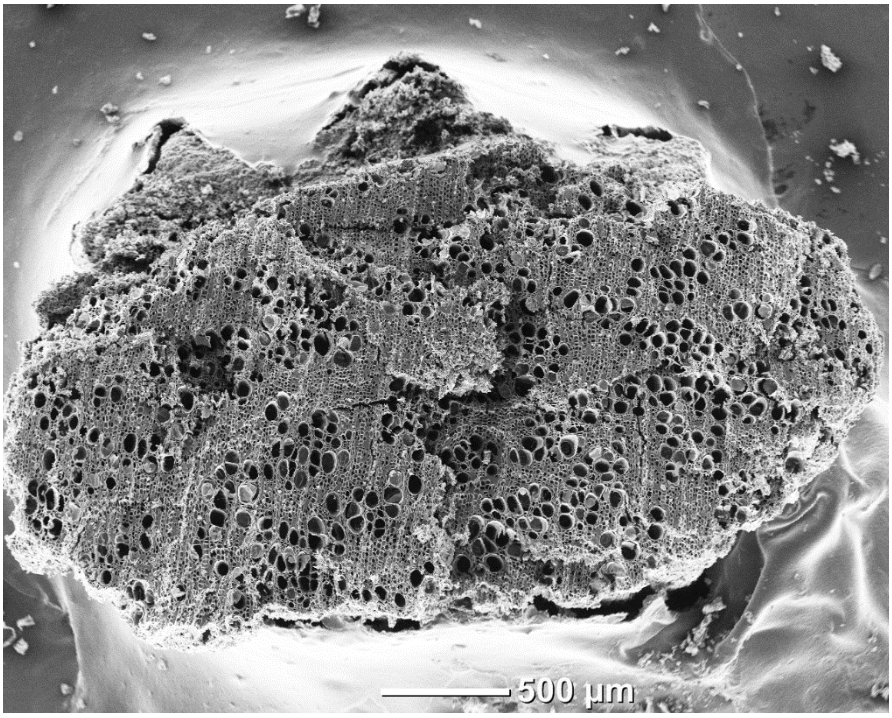

Vac-High PC-Std. 5 kV x 240
100 µm
S01a

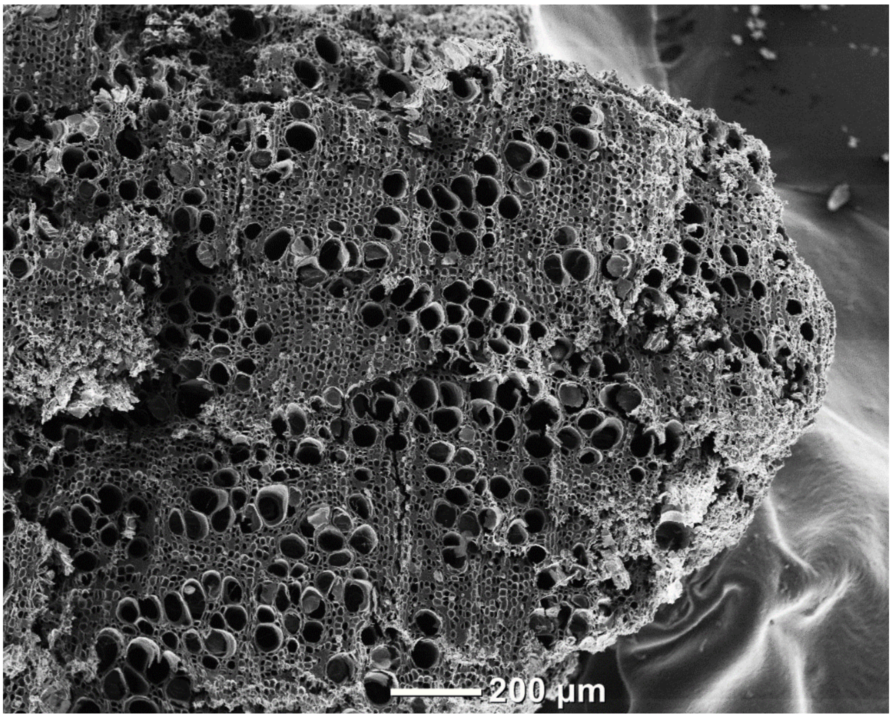

Vac-High PC-Std. 5 kV x 150
200 µm
S01a

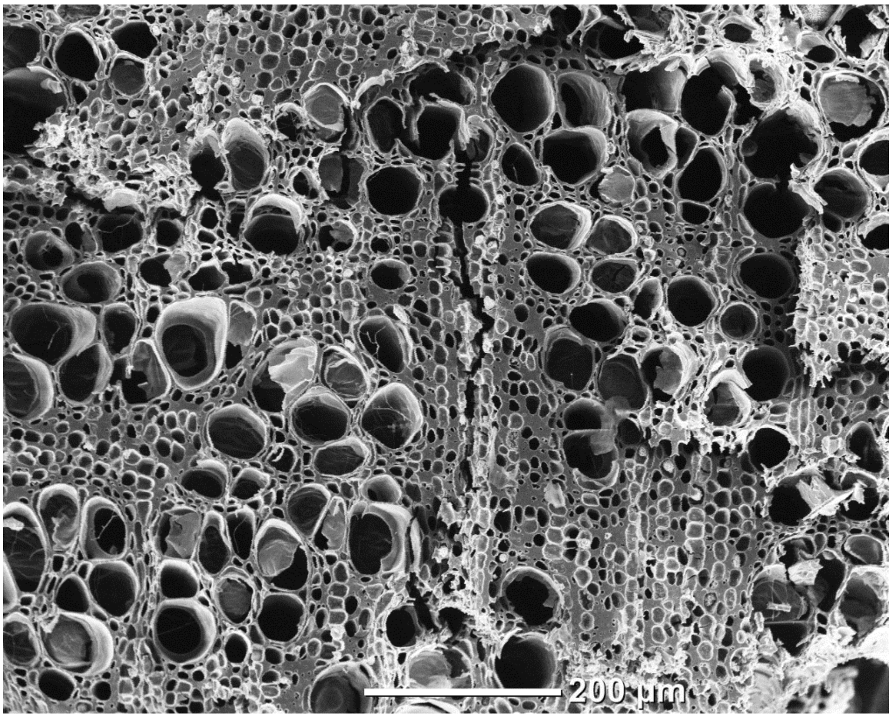

Vac-High PC-Std. 5 kV x 150
200 µm
S01a

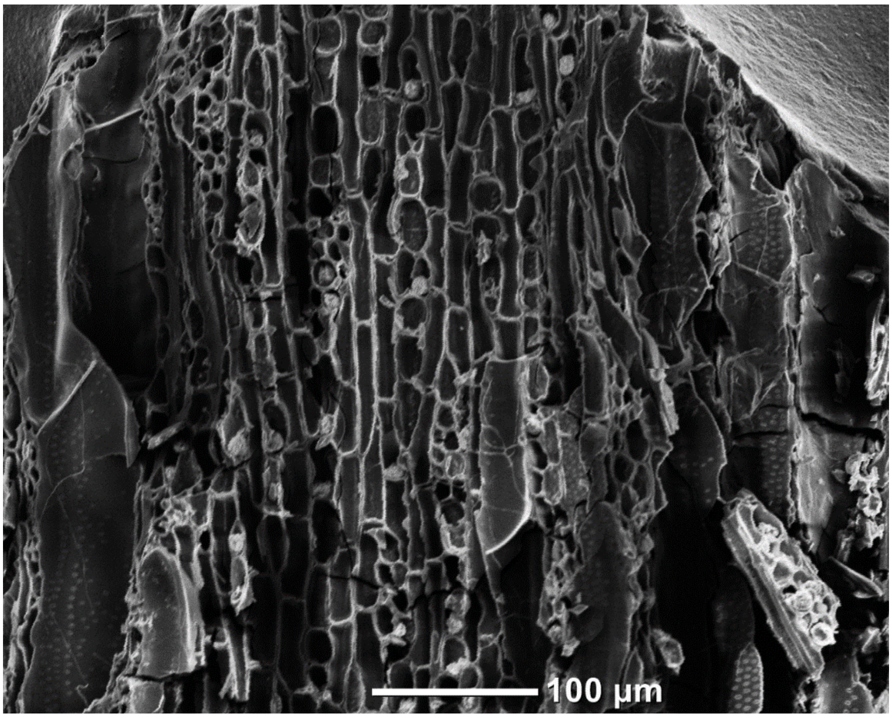

Vac-High PC-Std. 5 kV x 170
100 µm
S01a

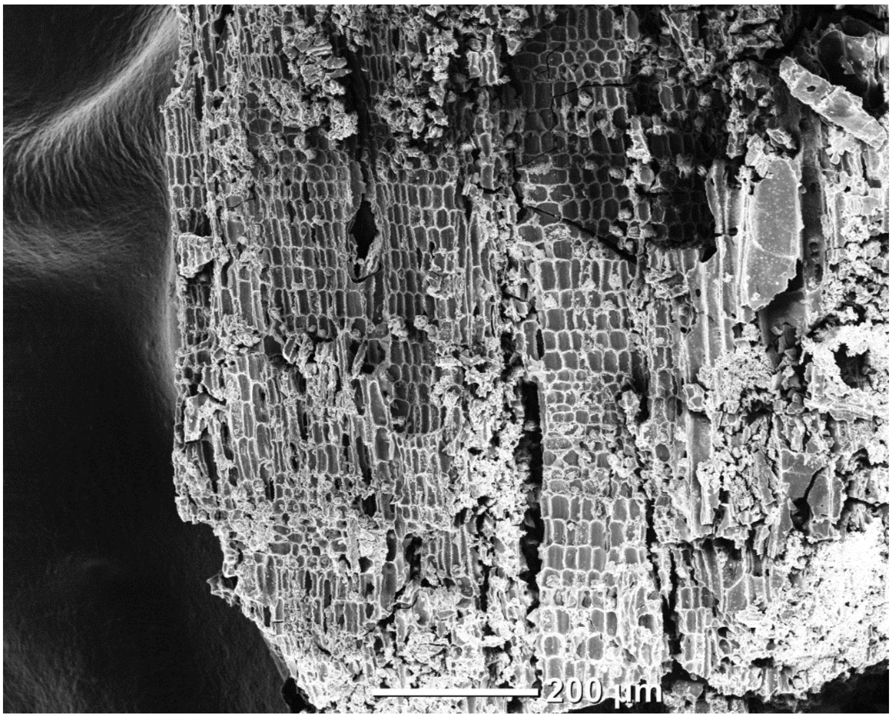
Type 24 – Non-Identified Type



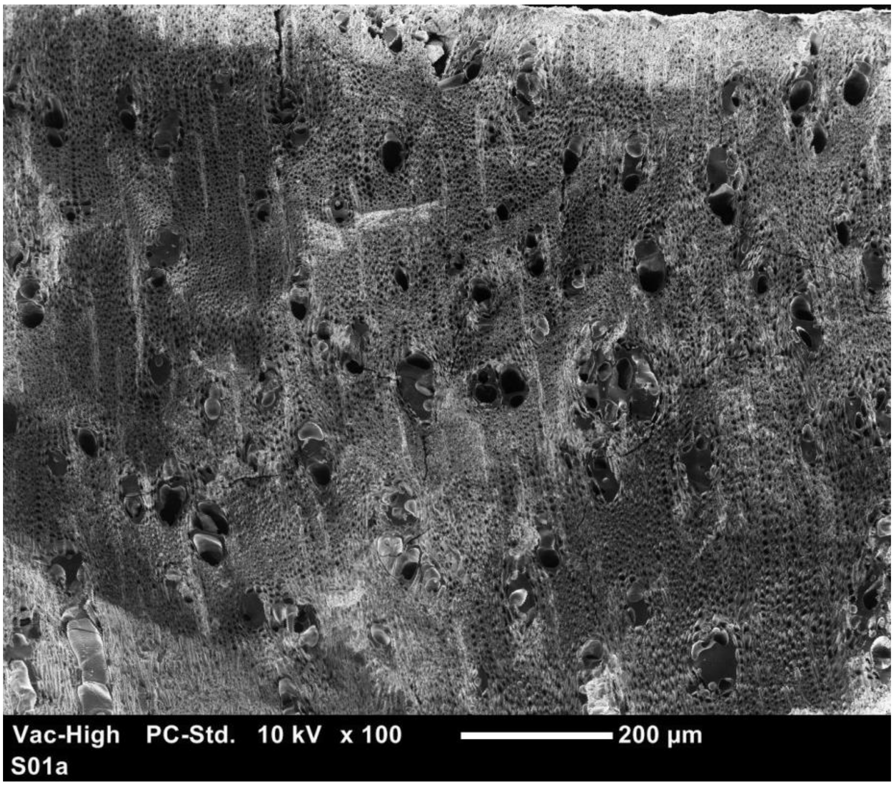


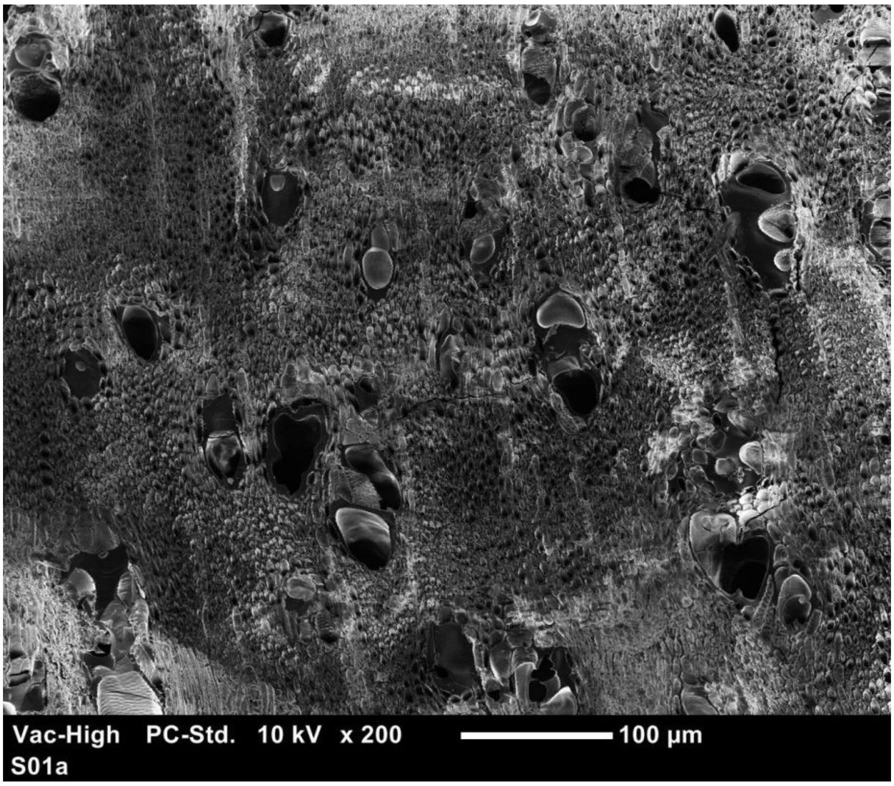

200 µm

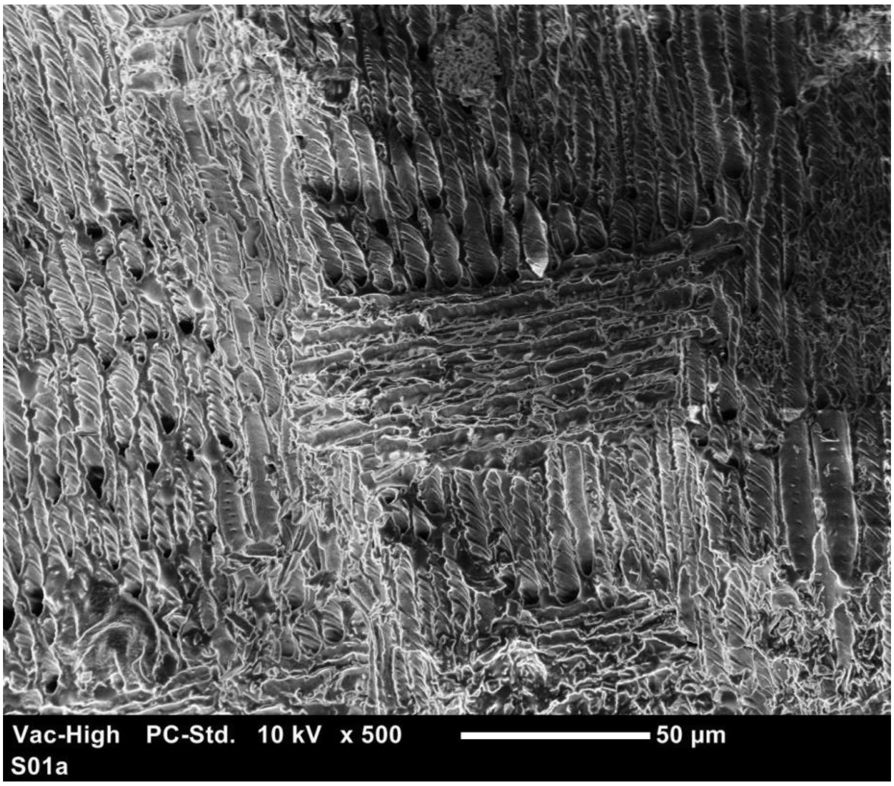

100 µm


200 µm

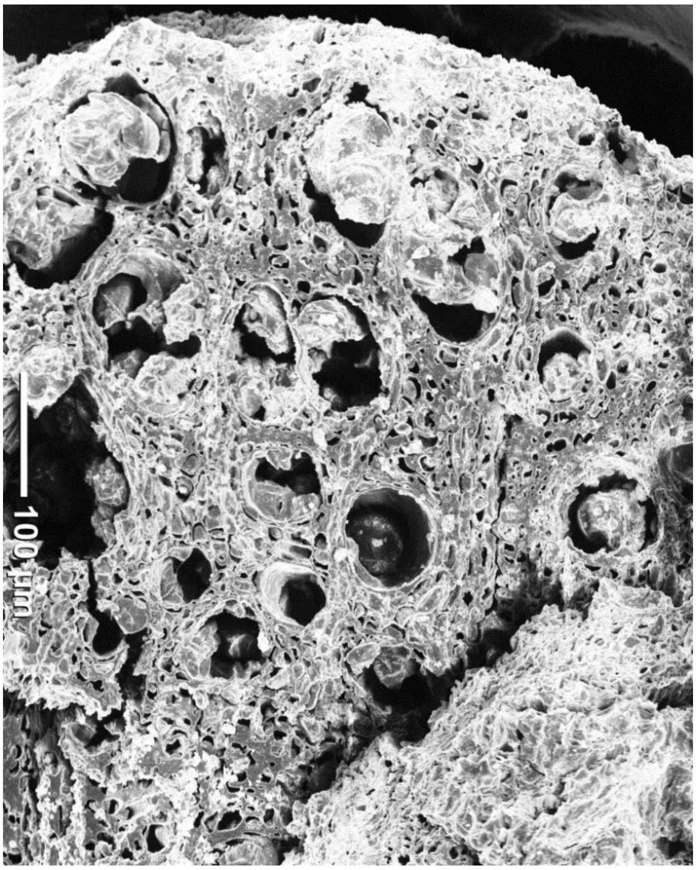
Type 48 – Non-Identified Type

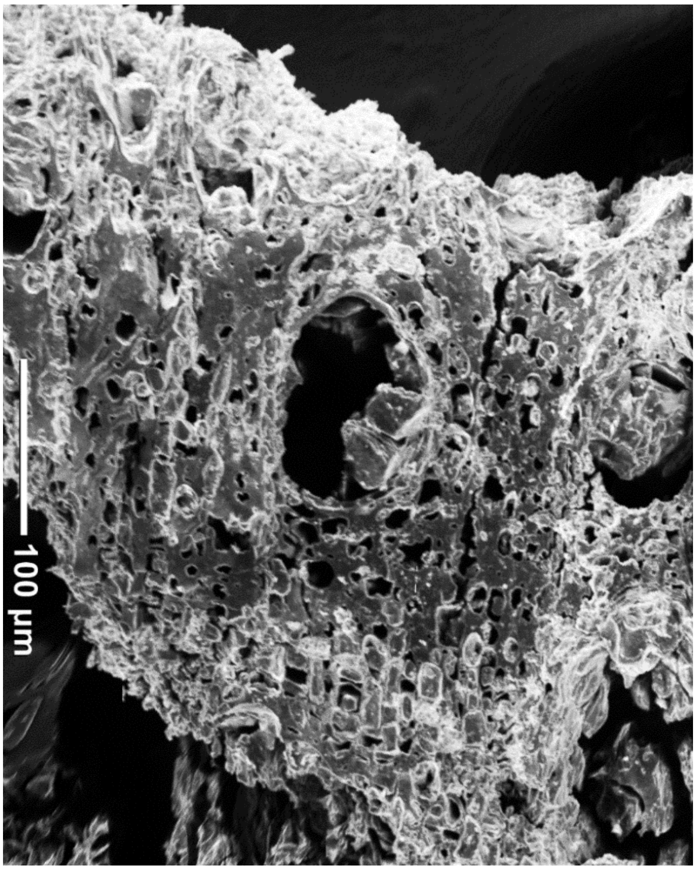


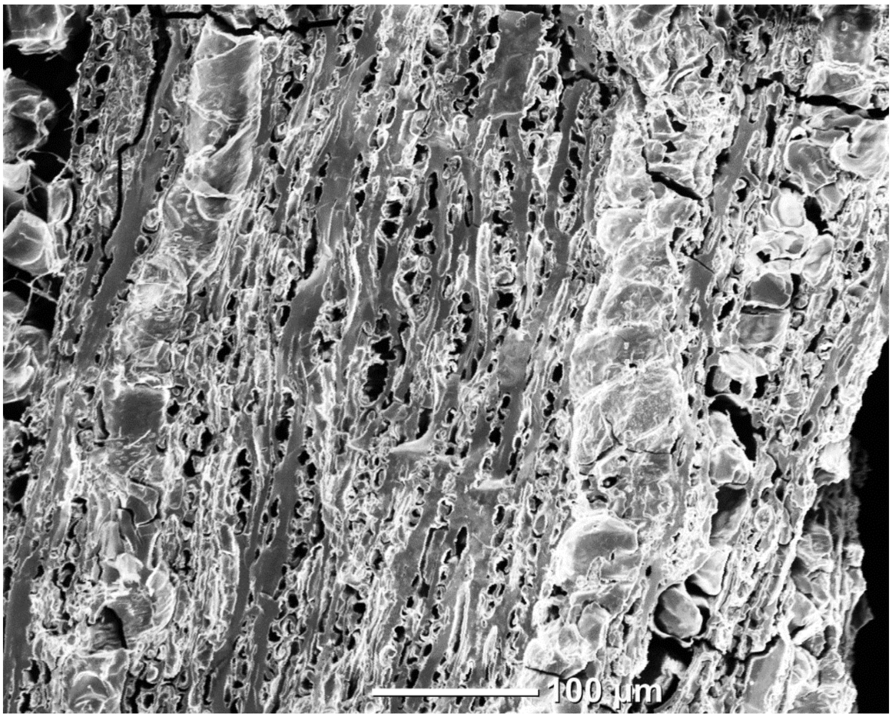


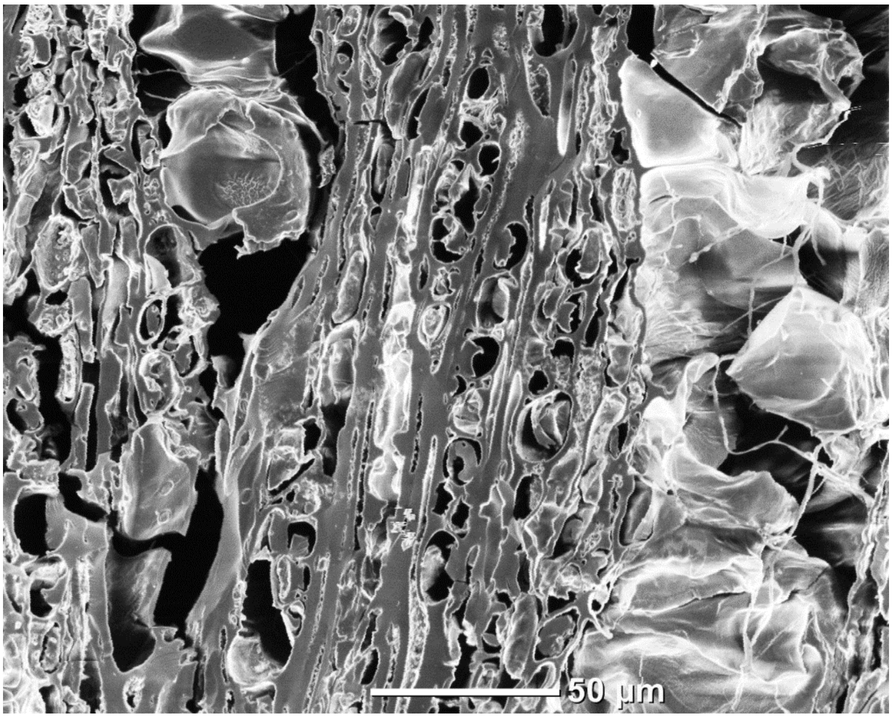

Vac-High PC-Std. 10 kV x 500
50 µm
S01a

Type 3 - Indeterminate

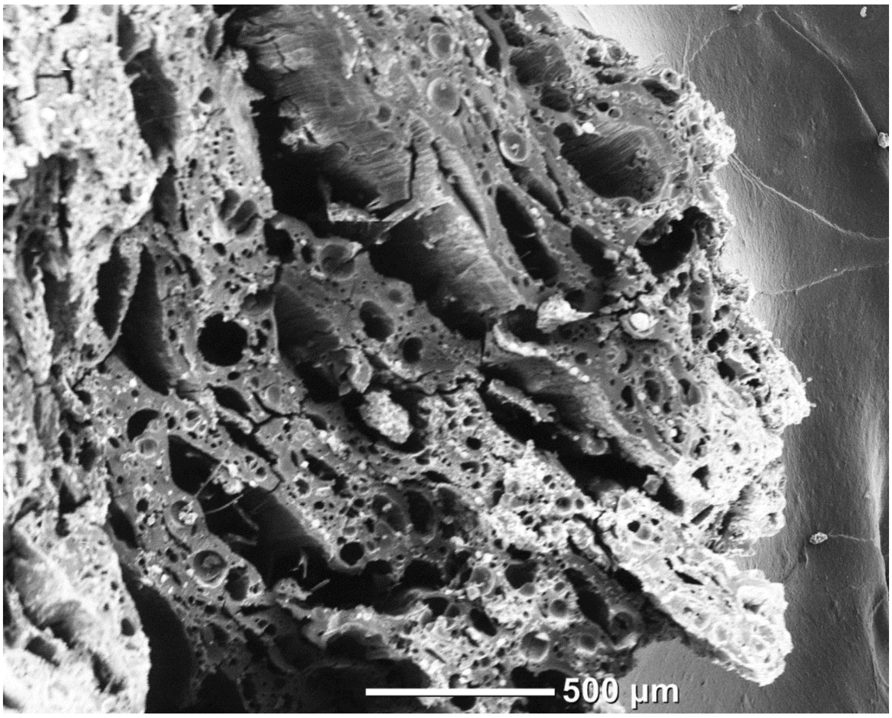


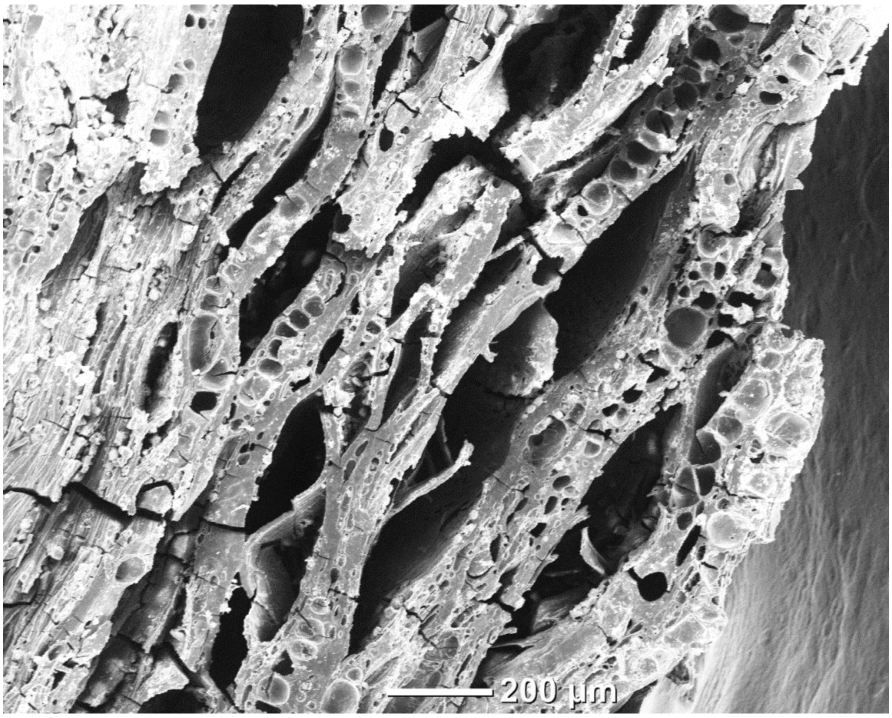



100 µm

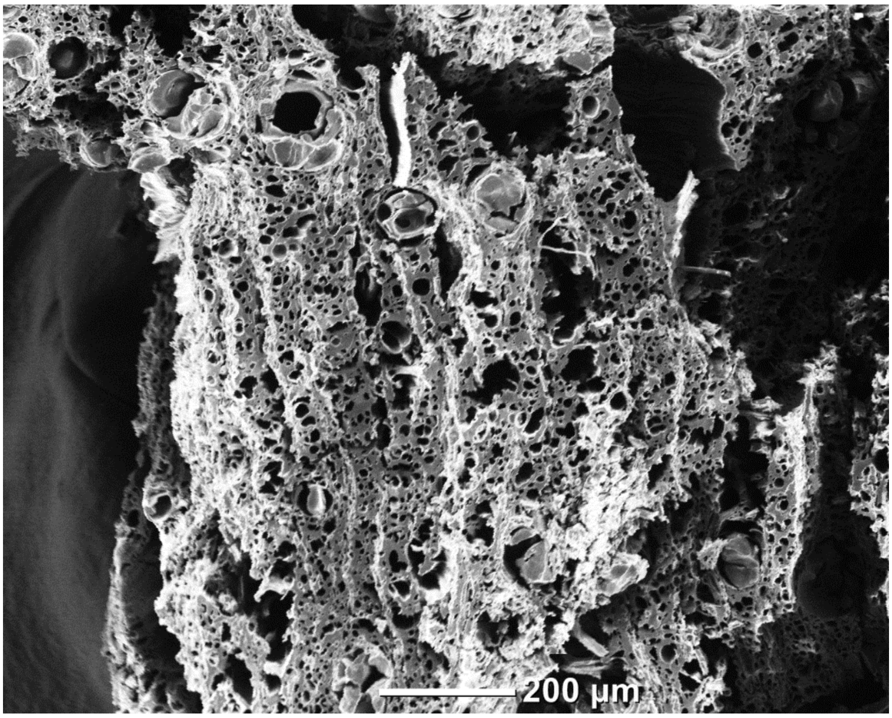

50 µm

Type 7 - Indeterminate

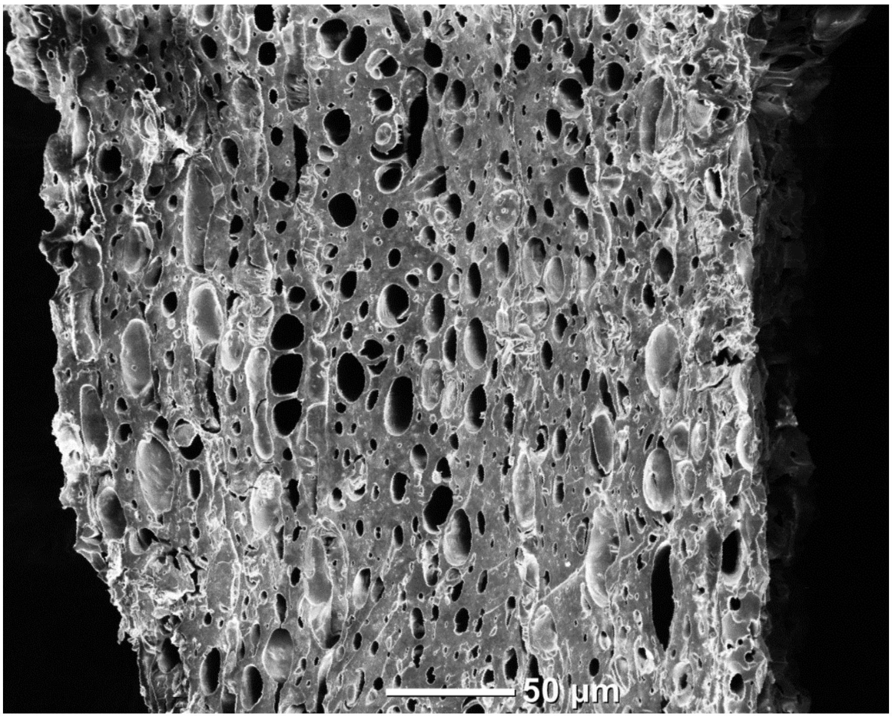


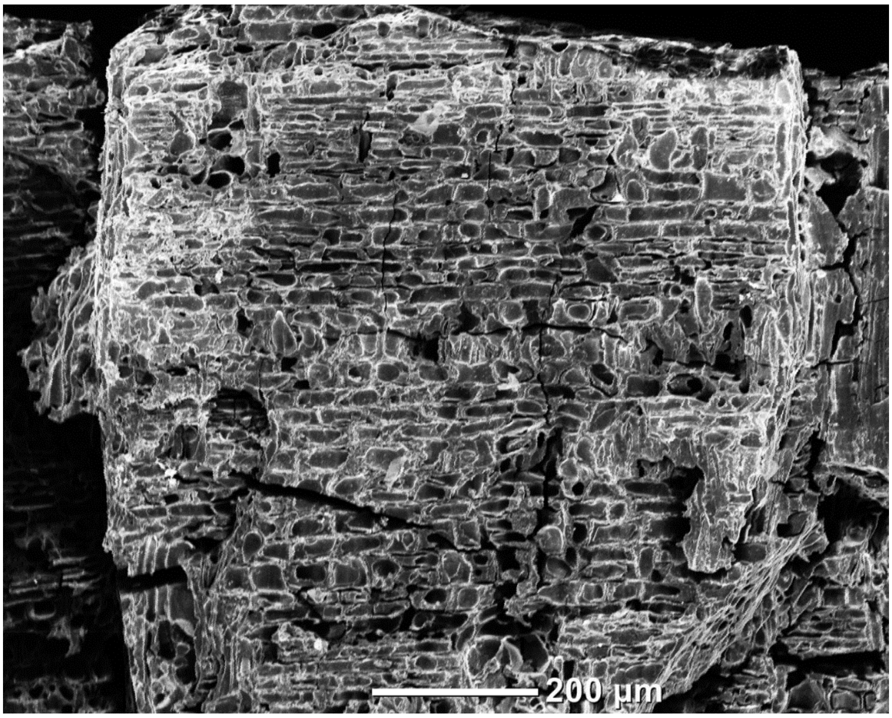


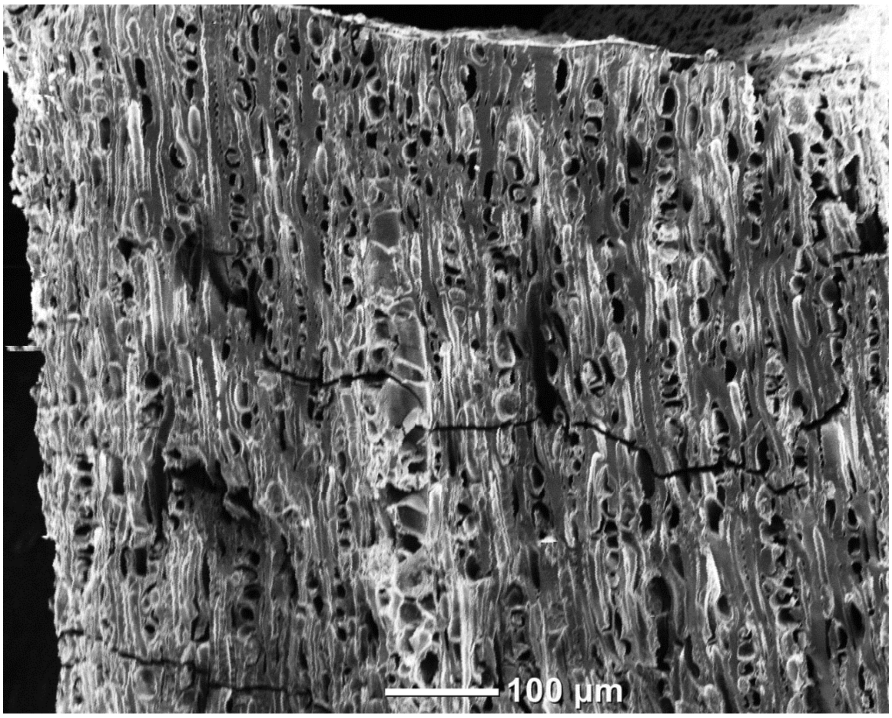
Type 8 - Indeterminate



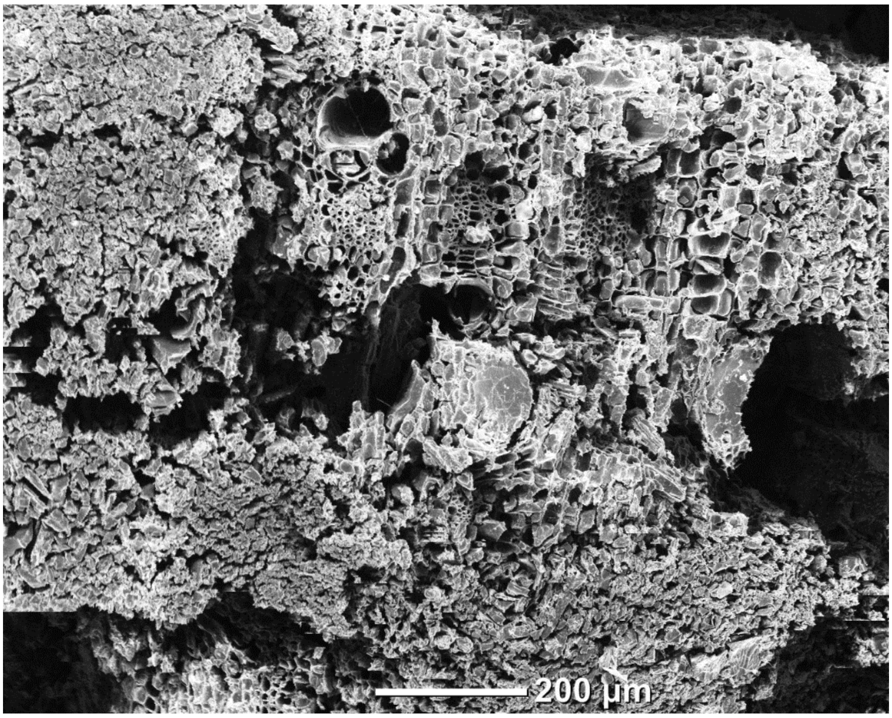
Type 10 - Indeterminate



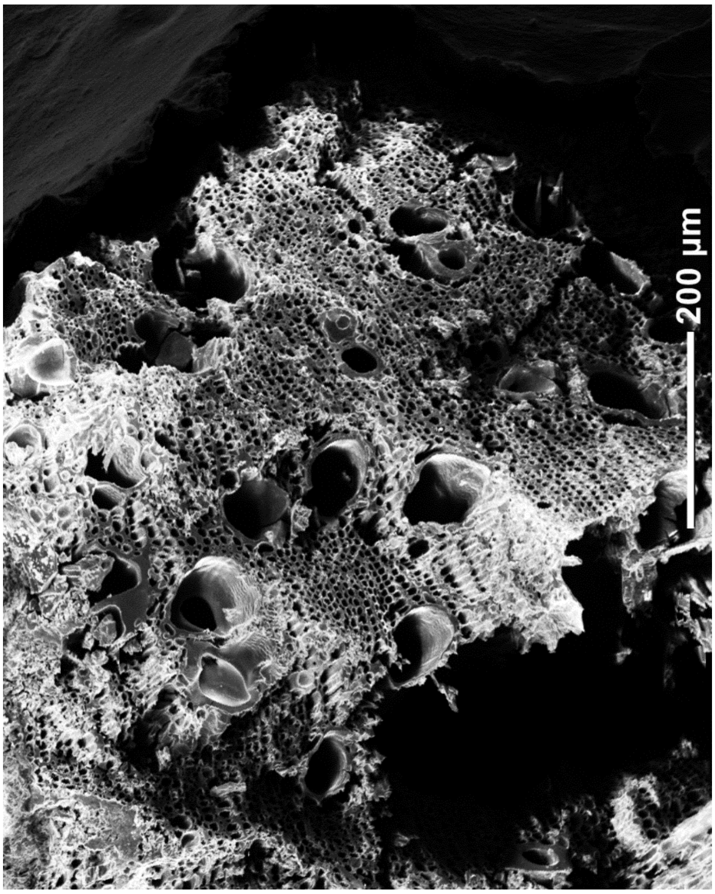



100 µm

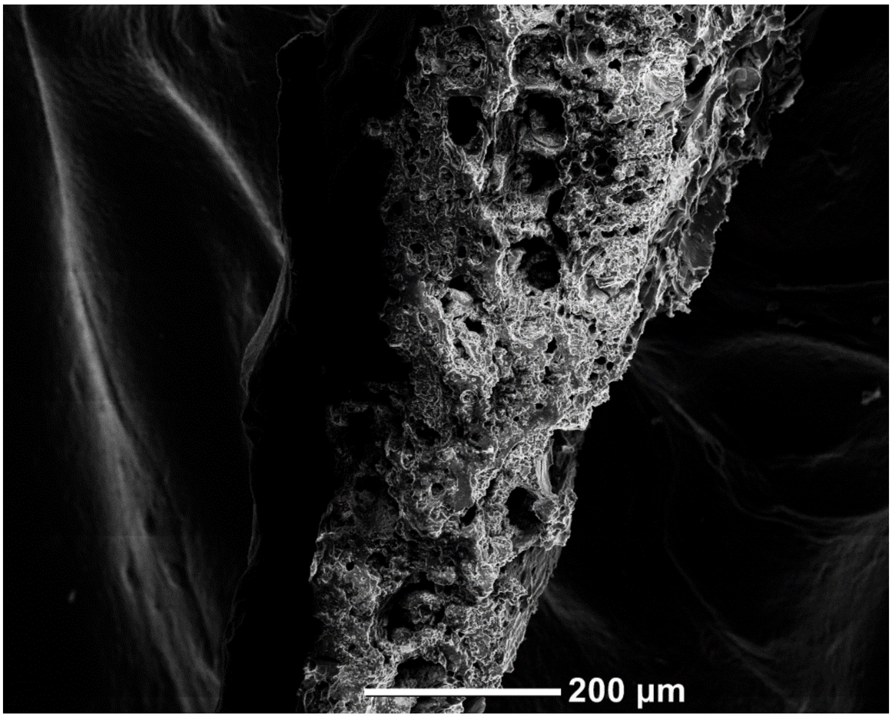
Type 11 - Indeterminate



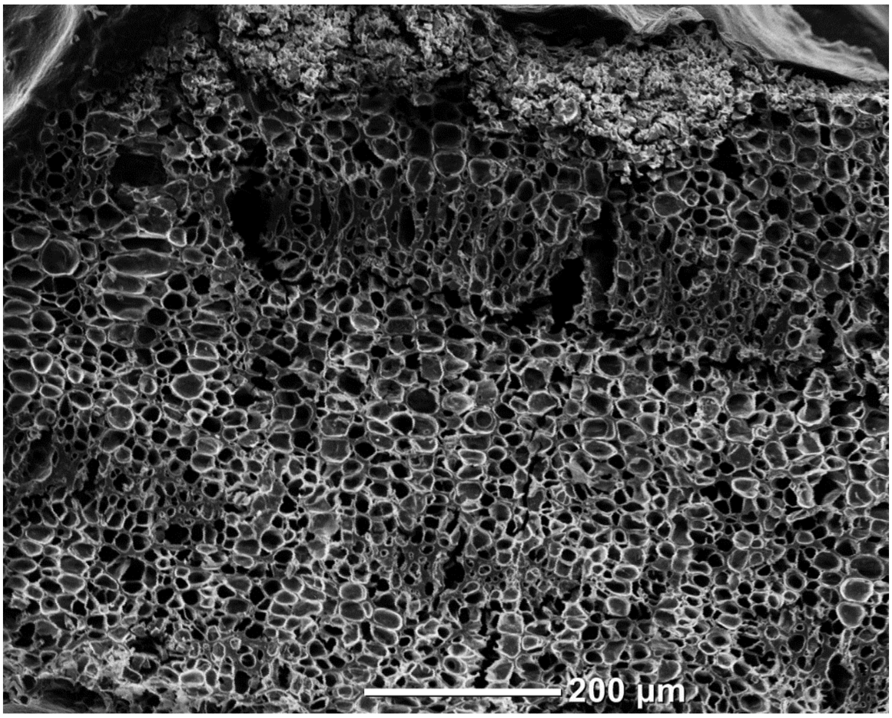
Type 15 - Indeterminate



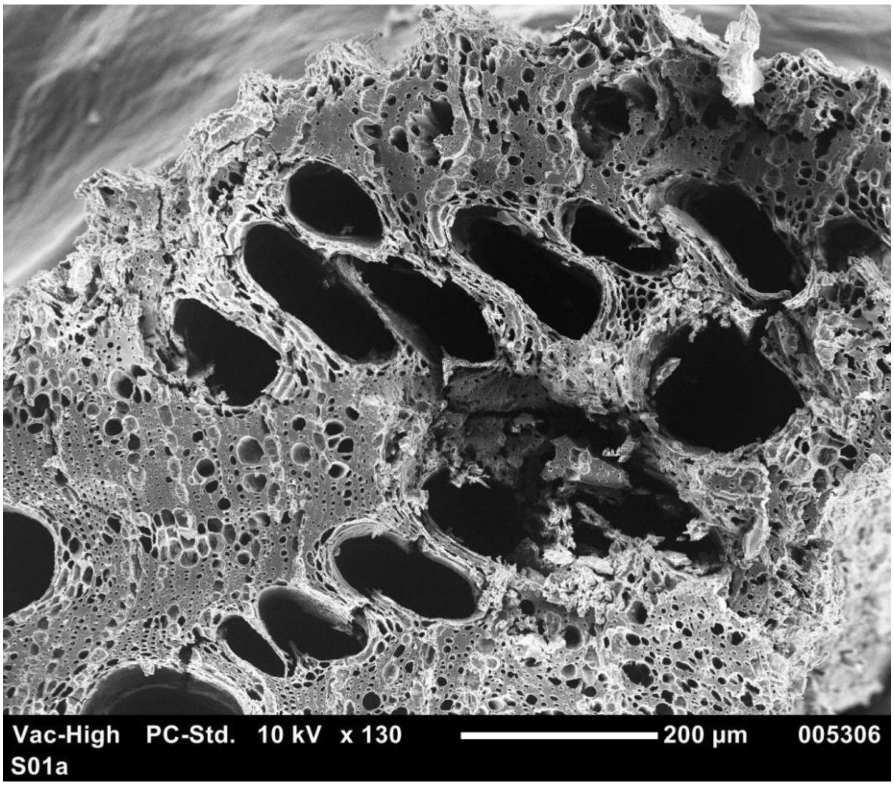
Type 19 - Indeterminate

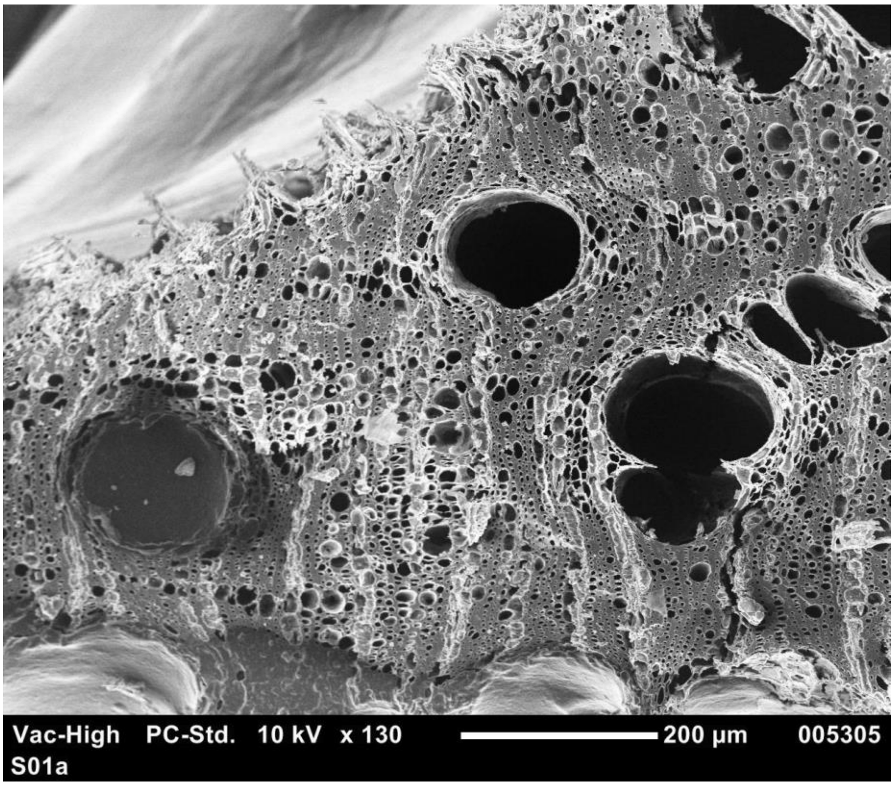


Type 20 – Indeterminate (tuberous parenchyma)

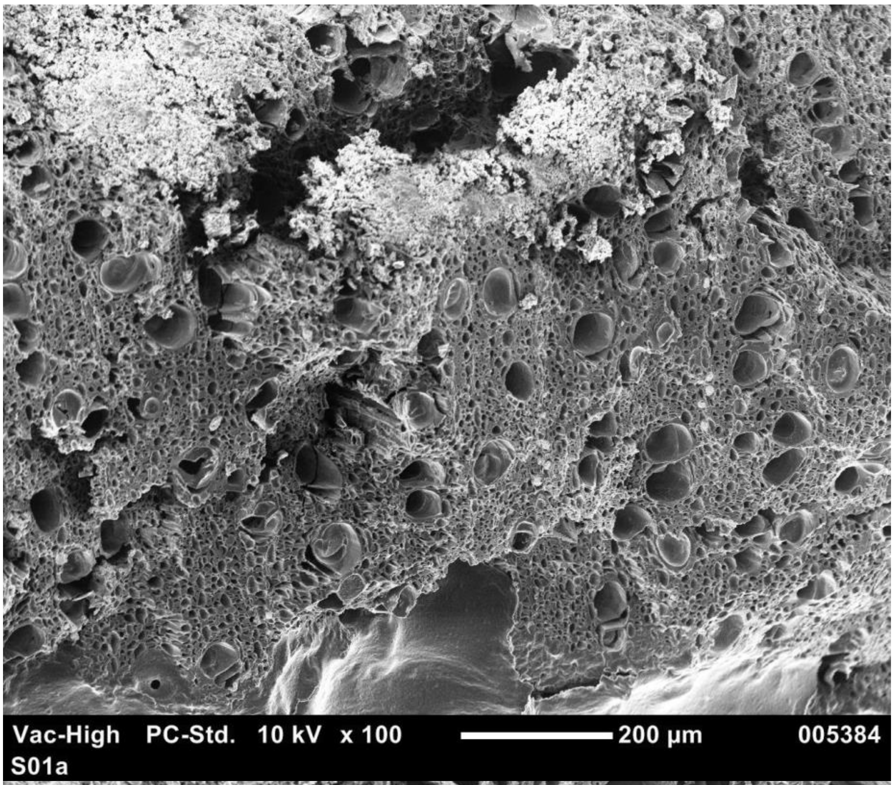


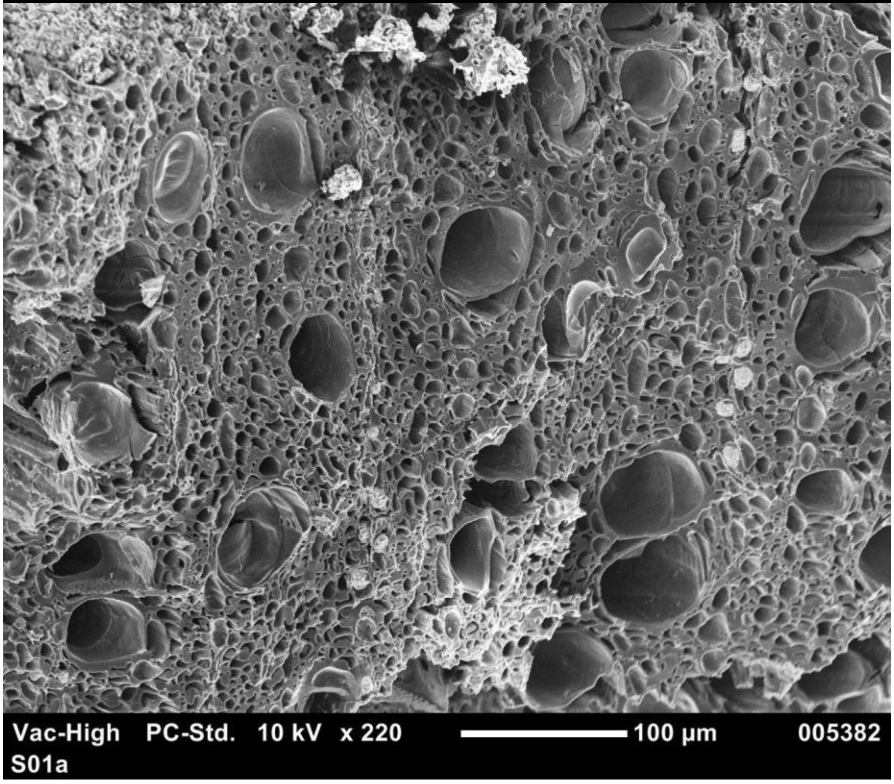
Type 29 - Indeterminate

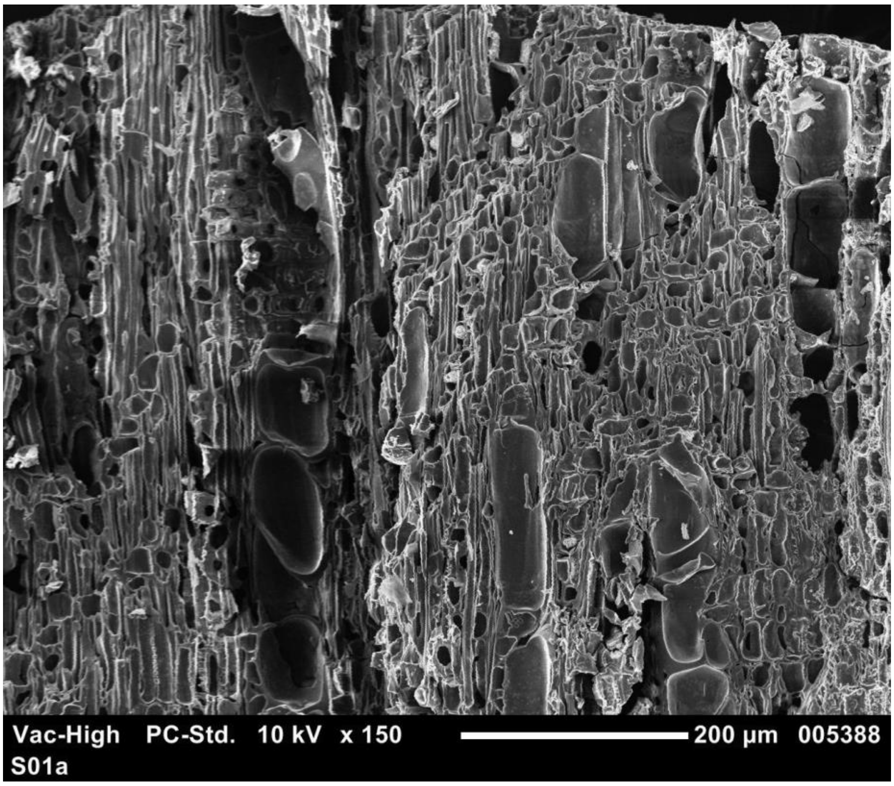




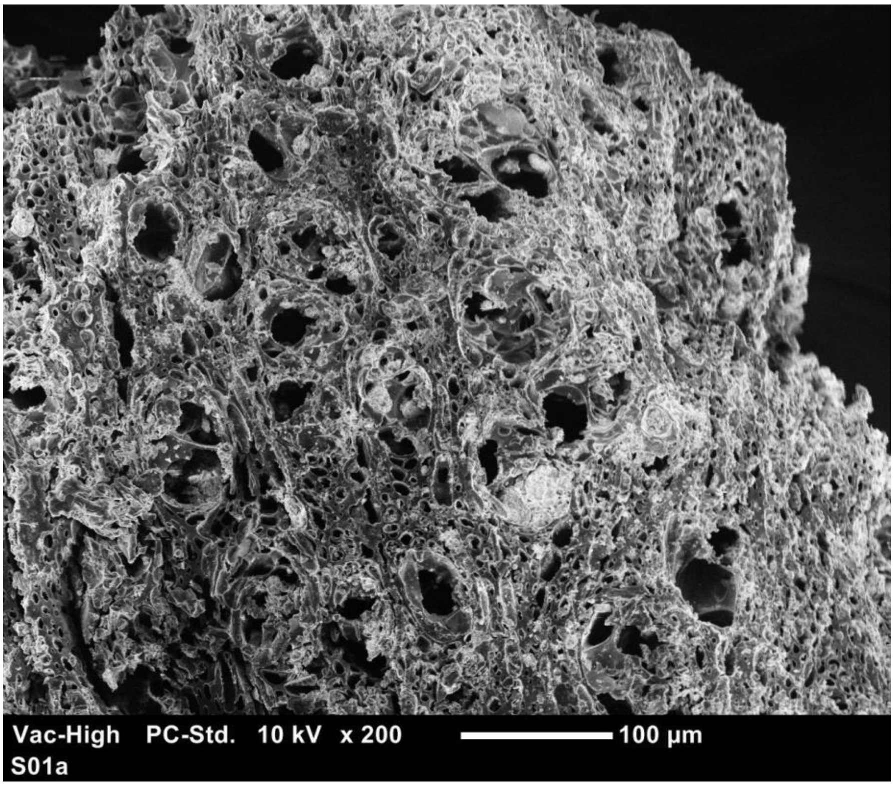
Type 31 – Indeterminate

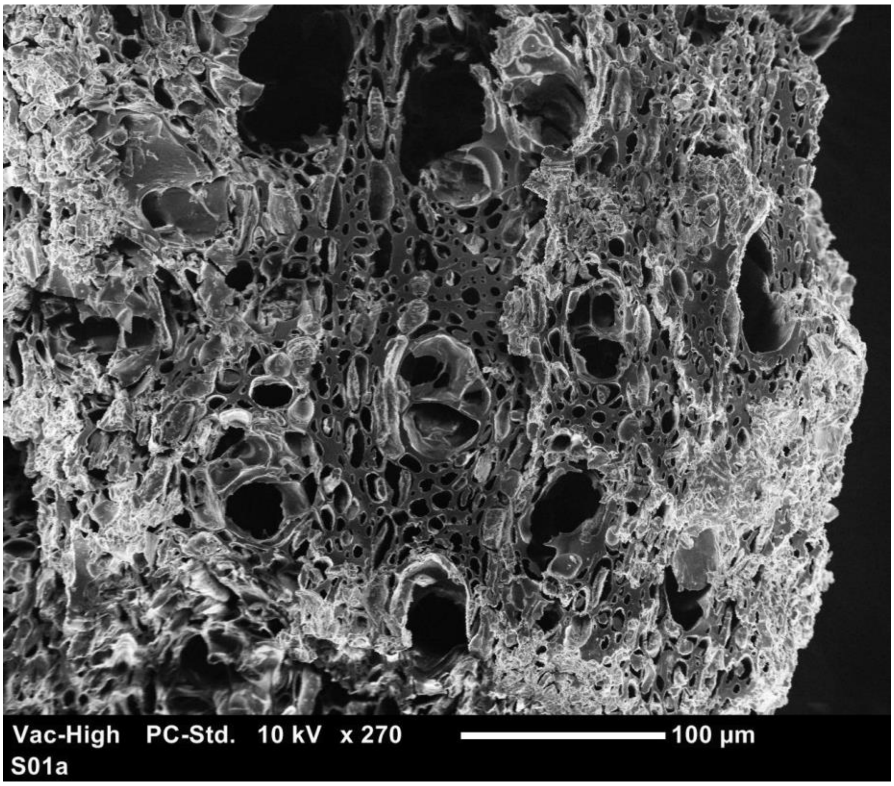


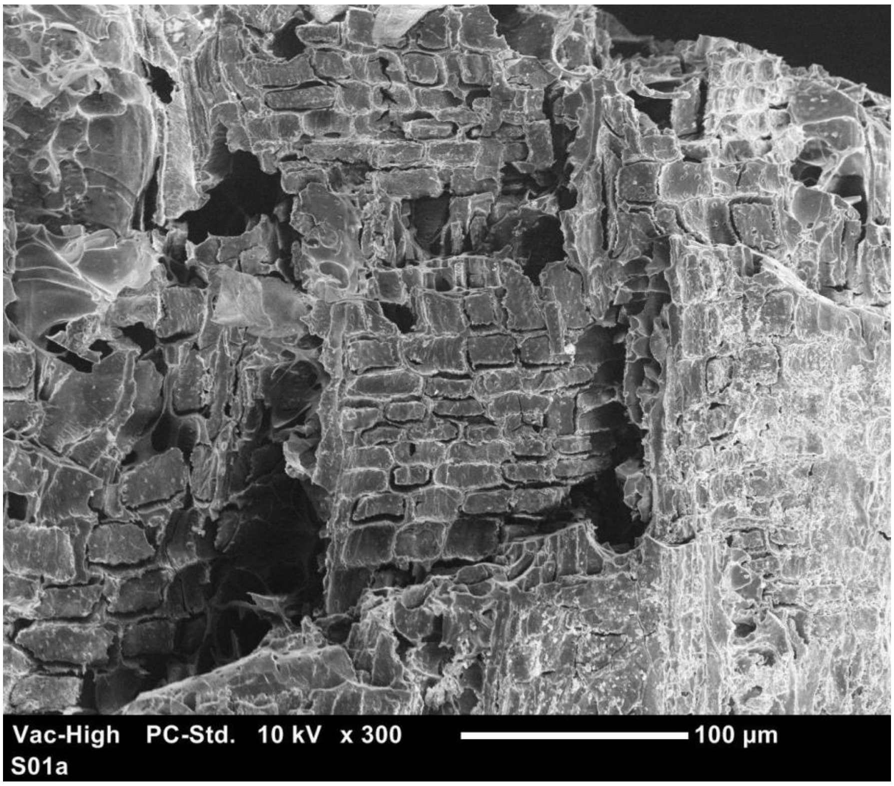



Vac-High PC-Std. 10 kV x 150
200 µm 005388
S01a

Type 36 - Indeterminate






Vac-High PC-Std. 10 kV x 300
100 µm
S01a

Appendix I – Dendrological features observed in Madjedbebe wood charcoals

Observed dendrological features – percentage of total (all specimens) and actual frequency (count). Including indeterminate and indeterminate in categories.

	Tyloses		**Fungal hyphae**		**Radial cracking**		**Knot**		**Vitrified**		**Indeterminate total**	**Indeterminate (vitrified)**		**Indeterminate (knot)**		**Indeterminate (radial cracking)**	
	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*
E3/5A	57.50	115	0	0	11.50	23	1.50	3	23.50	47	65	60	39	3.08	2	23.08	15
C3/4A	64.25	257	0.75	3	3.50	14	2.50	10	11.25	45	141	28.37	40	5.67	8	7.80	11
E4/6A	45.50	91	0	0	7.50	15	2.50	5	39.50	79	84	71.43	60	5.95	5	15.48	13
B3/5A	40.50	81	0	0	20.50	41	1.50	3	40.50	81	102	67.65	69	1.96	2	32.35	33
C4/9A	54.39	31	0	0	1.75	1	1.75	1	35.09	20	25	44	11	4	1	4	1
D3/16B	94.59	35	0	0	0	0	2.70	1	10.81	4	2	100	2	0	0	0	0
C3/18A	28	7	0	0	12	3	0	0	68	17	13	100	13	0	0	15.38	2
D2/21A	15.50	31	0	0	3	6	2.50	5	16.50	33	66	42.42	28	7.58	5	7.58	5
E3/20A	43.80	53	0	0	0.83	1	2.48	3	14.05	17	50	24	12	6	3	2	1
D3/21A	1.25	2	0	0	0.63	1	0.63	1	3.13	5	37	8.11	3	2.70	1	0	0
E4/22A	20	40	0	0	3.50	7	2	4	16	32	62	41.94	26	6.45	4	9.68	6

Observed dendrological features. Identified specimens only.

	Tyloses		Fungal hyphae		Radial cracking		Knot		Vitrified	
	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*
E3/5A	84.44	114	0	0	5.93	8	0.74	1	5.93	8
C3/4A	80.69	209	1.16	3	1.16	3	0.77	2	1.93	5
E4/6A	76.72	89	0	0	1.72	2	0	0	16.38	19
B3/5A	78.57	77	0	0	8.16	8	1.02	1	12.24	12
C4/9A	96.88	31	0	0	0	0	0	0	28.13	9
D3/16B	100	35	0	0	0	0	2.86	1	5.71	2
C3/18A	58.33	7	0	0	8.33	1	0	0	33.33	4
D2/21A	23.13	31	0	0	0.75	1	0	0	3.73	5
E3/20A	74.65	53	0	0	0	0	0	0	7.04	5
D3/21A	1.63	2	0	0	0.81	1	0	0	1.63	2
E4/22A	28.99	40	0	0	0.72	1	0	0	4.35	6

Dendrological features observed in each identified taxon and unidentified types across the vegetation communities.

		Tyloses		**Fungal hyphae**		**Radial cracking**		**Knot**		**Vitrified**	
		%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*	%*f*	A*f*
Open Eucalypt woodland	***Corymbia* sp.**	75	21	0	0	0	0	0	0	17.85	5
	***Eucalyptus* sp.**	65.64	86	0.76	1	2.29	3	0.76	1	12.97	17
	***Terminalia* sp.**	67.5	54	1.25	1	2.5	2	0	0	3.75	3
	***Callitris* sp.**	0	0	0	0	0	0	0	0	0	0
	***Calytrix* sp.**	0	0	0	0	0	0	0	0	0	0
	***Flueggea* sp.**	100	38	0	0	5.26	2	0	0	5.26	2
	***Brachychiton* sp.**	100	7	0	0	14.28	1	0	0	28.57	2
Monsoon vine forest	***Pavetta* sp.**	98.93	93	0	0	5.31	5	0	0	14.89	14
	***Ficus* sp.**	100	39	0	0	7.69	3	0	0	23.07	9
	***Thespesia* sp.**	98.27	57	0	0	6.89	4	1.72	1	5.17	3
	***Grewia* sp.**	0	0	0	0	0	0	0	0	0	0
	***Alstonia* sp.**	0	0	0	0	0	0	0	0	0	0
	***Coelospermum* sp.**	100	1	0	0	0	0	0	0	0	0
***Grevillea/ Banksia* shrubland**	**Proteaceae**	5.12	2	2.56	1	0	0	0	0	7.69	3
	***Lophostemon* sp.**	0	0	0	0	0	0	0	0	0	0
Shared taxa	***Acacia* sp.**	45.97	257	0	0	0.89	5	0.53	3	2.86	16
	***Asteromyrtus* sp.**	7.14	1	0	0	0	0	0	0	0	0
	***Alphitonia* sp.**	69.23	9	0	0	0	0	0	0	15.38	2
Unidentified types	**Type 24**	0	0	0	0	0	0	0	0	0	0
	Type 48	79.31	23	0	0	0	0	0	0	3.44	1
	Indeterminate	8.22	55	0	0	13.00	87	4.63	31	45.29	303

Appendix J – Radiocarbon dates for Madjedbebe hearths

Table of radiocarbon ages for charcoal samples collected from Madjedbebe (2012). Measured ages have been calibrated using the SHCal13 dataset in OxCal v 4.2 (Bronk Ramsey 2009a; Hogg et al. 2013), with the age ranges shown in at the 95.4% confidence interval. Sample pre-treatments are acid-base-acid (ABA). Plotted charcoal refers to an isolated piece of charcoal that was recorded and plotted *in situ*, but that did not come from an identifiable hearth feature.

Lab ID	**Depth (cm)**	**Square/spit**	**Feature**	**Chemical pre-treatment**	**Δ^{13}C (‰)**	**Conventional ^{14}C age (yrs BP)**	**Error (1σ)**	**Calibrated age range (cal yrs BP)**
OZQ464	7.8	C3/4	Plotted charcoal	ABA	-25.1	145	20	260-0
OZQ471	13.9	B3/5	Plotted charcoal	ABA	-24.4	775	20	720-650
OZQ460	16.5	E4/6A	Charcoal from hearth	ABA	-25.8	330	20	450-300
Wk43609	17.0	E3/5A	Charcoal from hearth	ABA	Not supplied by lab	98	20	240-7
Wk43604	31.4	C4/9A	Charcoal from hearth	ABA	Not supplied by lab	2757	20	2860-2760
Wk43607	73.6	D3/16B	Charcoal from hearth	ABA	Not supplied by lab	7806	20	8600-8460
Wk43603	79.8	C3/18A	Charcoal from hearth	ABA	Not supplied by lab	8170	20	9130-9000
Wk43610	96.0	E3/20A	Charcoal from hearth	ABA	Not supplied by lab	10943	23	12810-12710

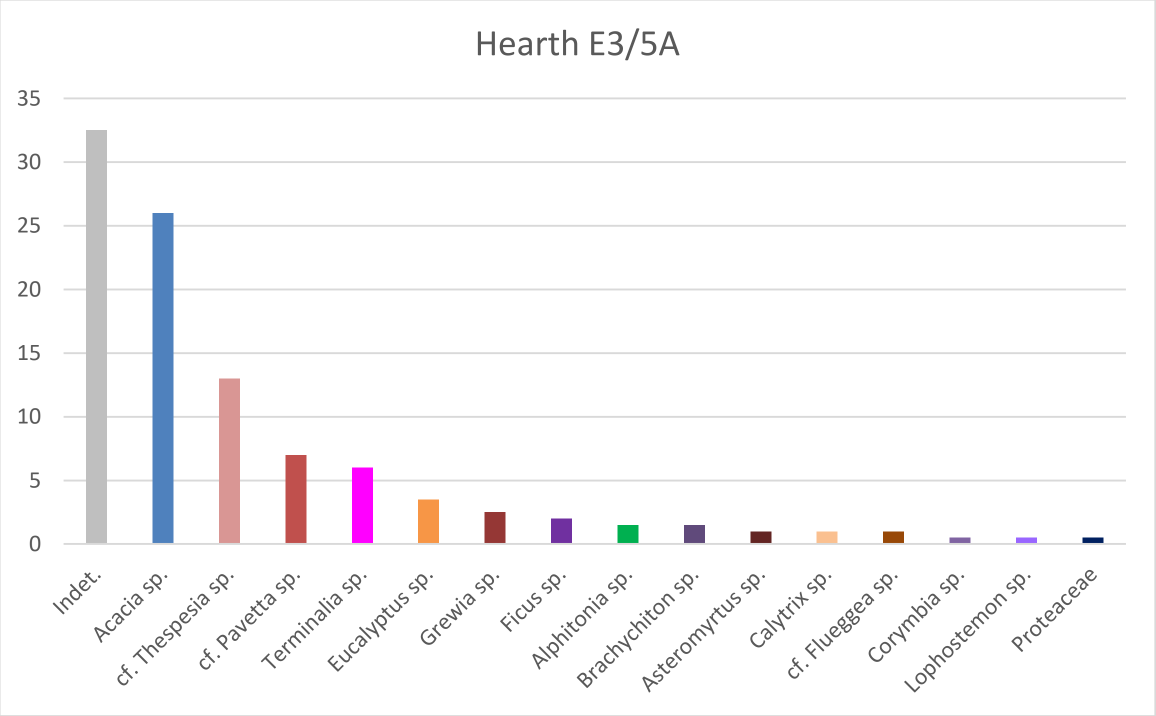
Wk43606	101.7	D2/21A	Charcoal from hearth	ABA	Not supplied by lab	8282	28	9398-9034
Wk43611	106.3	E4/22A	Charcoal from hearth	ABA	Not supplied by lab	15323	35	18690-18410
Wk43605	161.9	C4/36A	Charcoal from hearth	ABA	Not supplied by lab	20511	69	24970-24340

Appendix K – Taxonomic composition of all Madjedbebe hearths

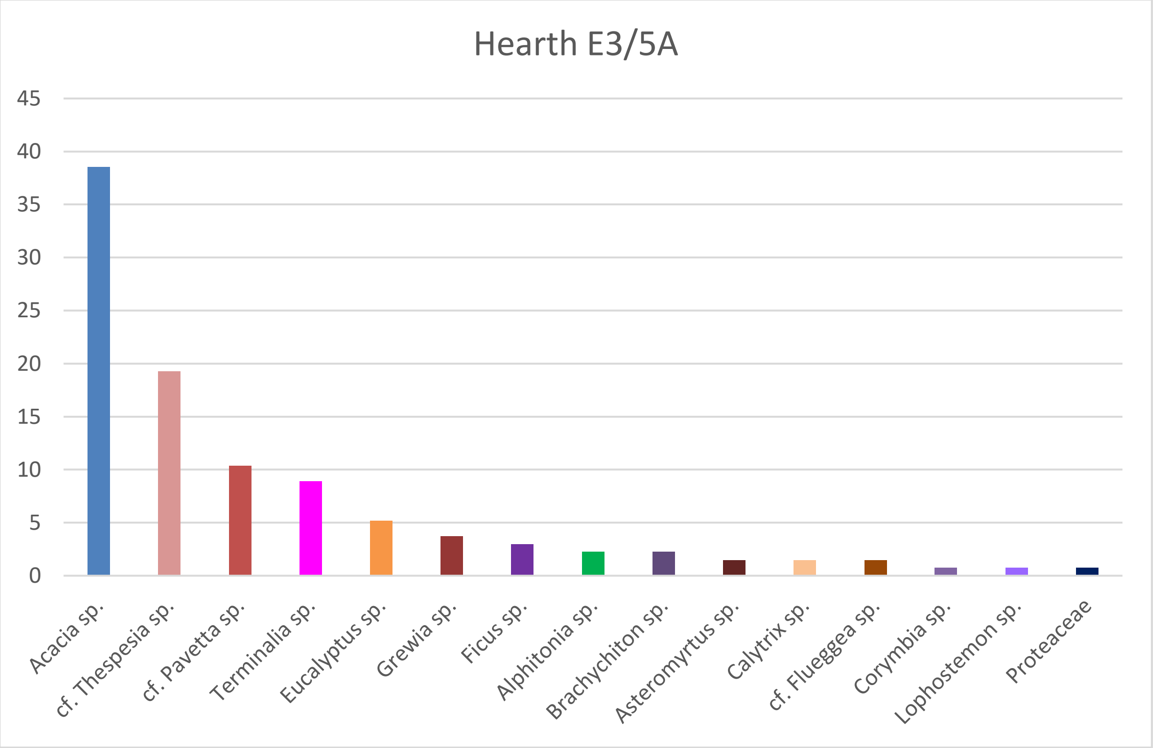
Taxonomic composition of all fourteen Madjedbebe hearths

Hearth E3/5A

Hearth E3/5A was directly radiocarbon dated with a result of 240-7 yr cal BP (Wk43609).



Hearth E3/5A taxonomic composition as percent. Indeterminate specimens included.

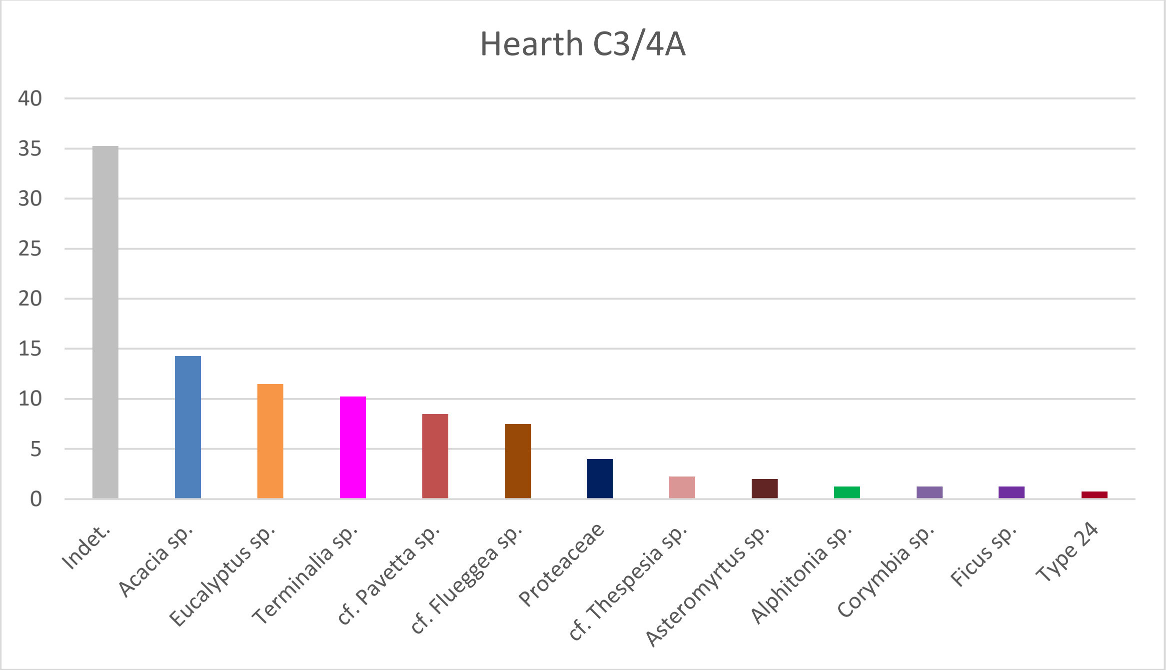


Hearth E3/5A taxonomic composition as percent. Indeterminate specimens excluded.

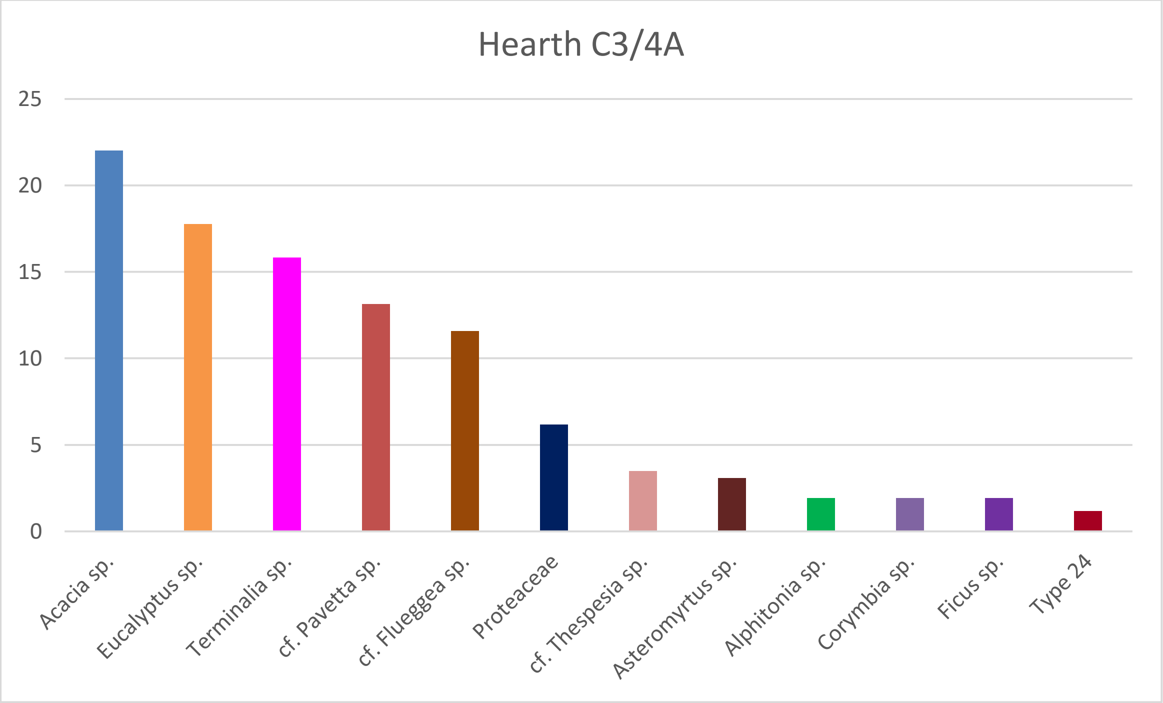
Hearth E3/5A is the most recent hearth in the Madjedbebe (MJB) sequence, it date between 240-7 yr cal BP. This hearth contains 15 taxa which is the highest taxon richness of any of the MJB hearths. Of the 200 fragments analysed from this hearth just over a third (32%) were indeterminate due to size or preservation. With the indeterminate specimens removed from the sample *Acacia* sp. taxa make up 38% of the identified assemblage. cf. *Thespesia* sp. (19%) and cf. *Pavetta* sp. (10%) are the only other taxa which contribute more than 10% to the E3/5A wood charcoal assemblage. This hearth contains taxa from open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities.

Hearth C3/4A

C3/4 was radiocarbon dated with a result of 260-0 yr cal BP (OZQ464).



Hearth C3/4A taxonomic composition as percent. Indeterminate specimens included.

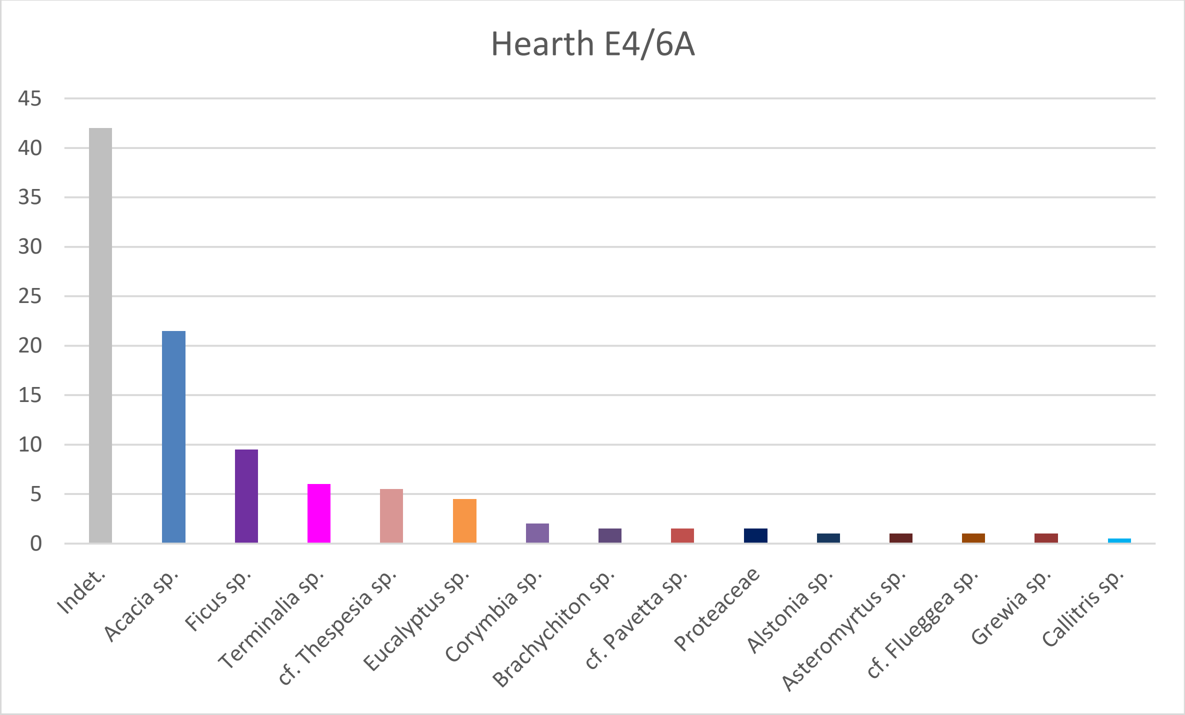


Hearth C3/4A taxonomic composition as percent. Indeterminate specimens excluded.

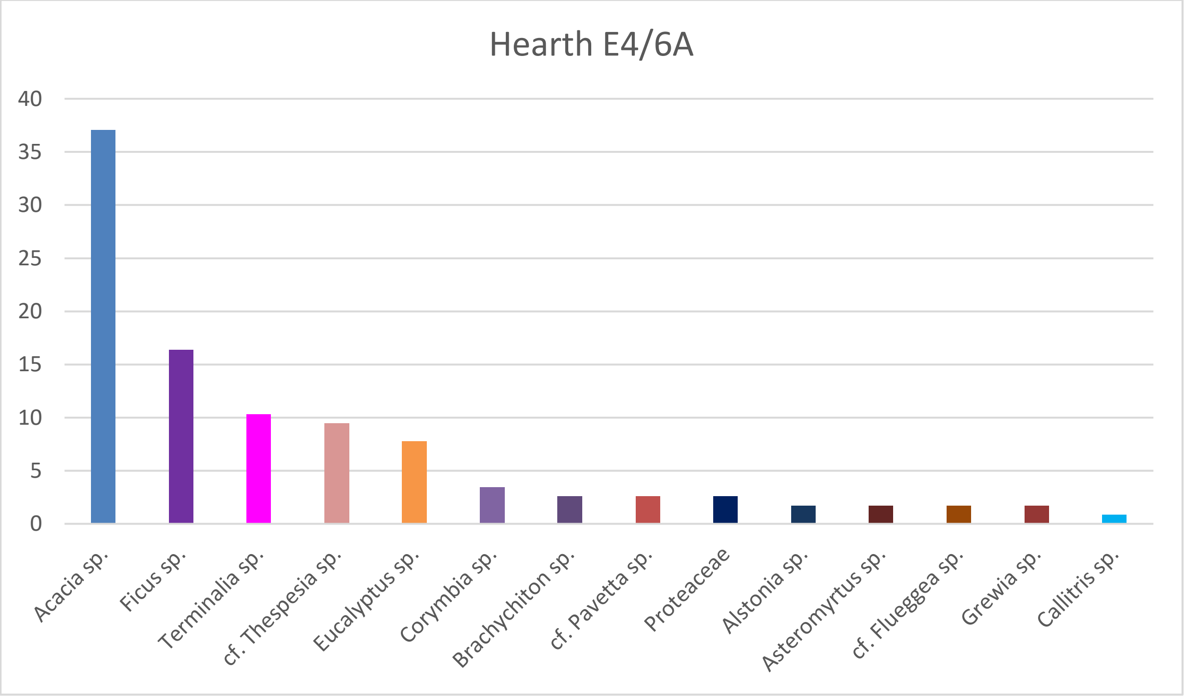
The date 260-0 yr cal BP provides a *terminus post quem* (TPQ) for hearth C3/4A. This is because the date is based on a charcoal sample recovered from the sedimentary matrix (C3/4) surrounding the hearth. The sample therefore could be from the hearth or may have already been present when the hearth was constructed. This hearth has a taxon richness of twelve. Of the 400 charcoal fragments analysed from this hearth 35% were indeterminate due to size or preservation. With the indeterminate specimens removed *Acacia* sp. taxa make up 22% of the total identified assemblage. *Eucalyptus* sp. (17%), *Terminalia* sp. (15%), cf. *Pavetta* sp. (13%), and cf. *Flueggea* sp. (11%) make up more than ten percent of the total identified assemblage. This hearth also contains three fragments of Type 24, an unidentified archaeological type. Open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities are all represented in the C3/4A wood charcoal assemblage.

Hearth E4/6A

Hearth E4/6A was directly radiocarbon dated with a result of 450-300 yr cal BP (OZQ460).



Hearth E4/6A taxonomic composition as percent. Indeterminate specimens included.

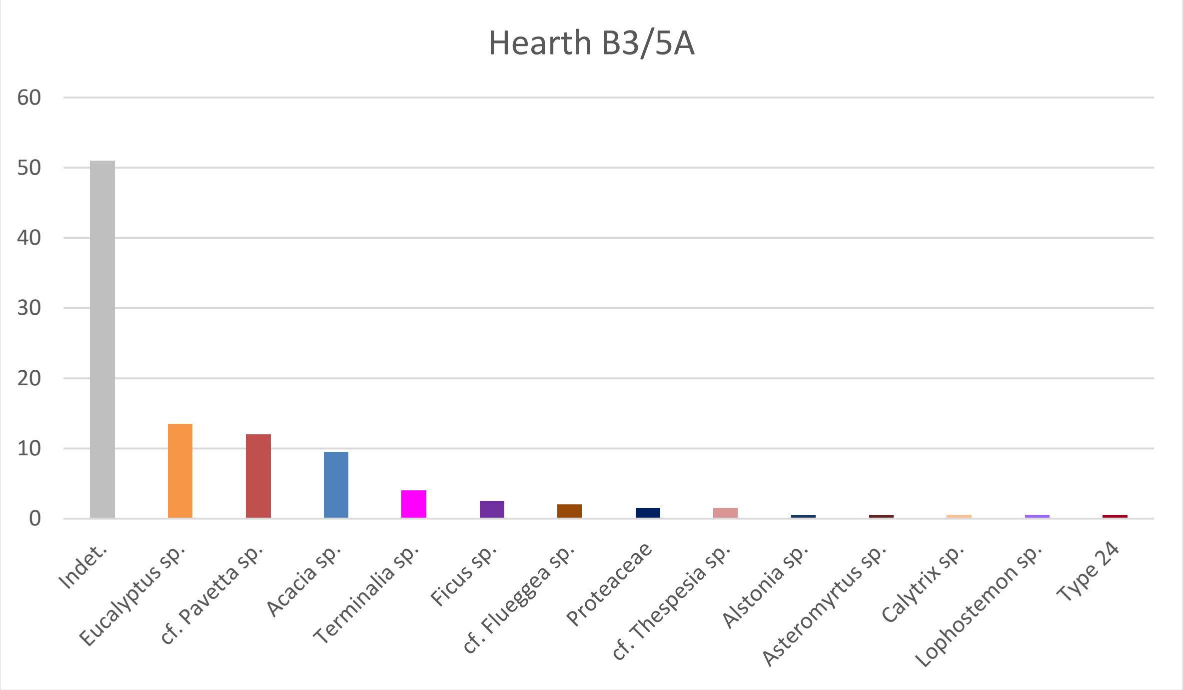


Hearth E4/6A taxonomic composition as percent. Indeterminate specimens excluded.

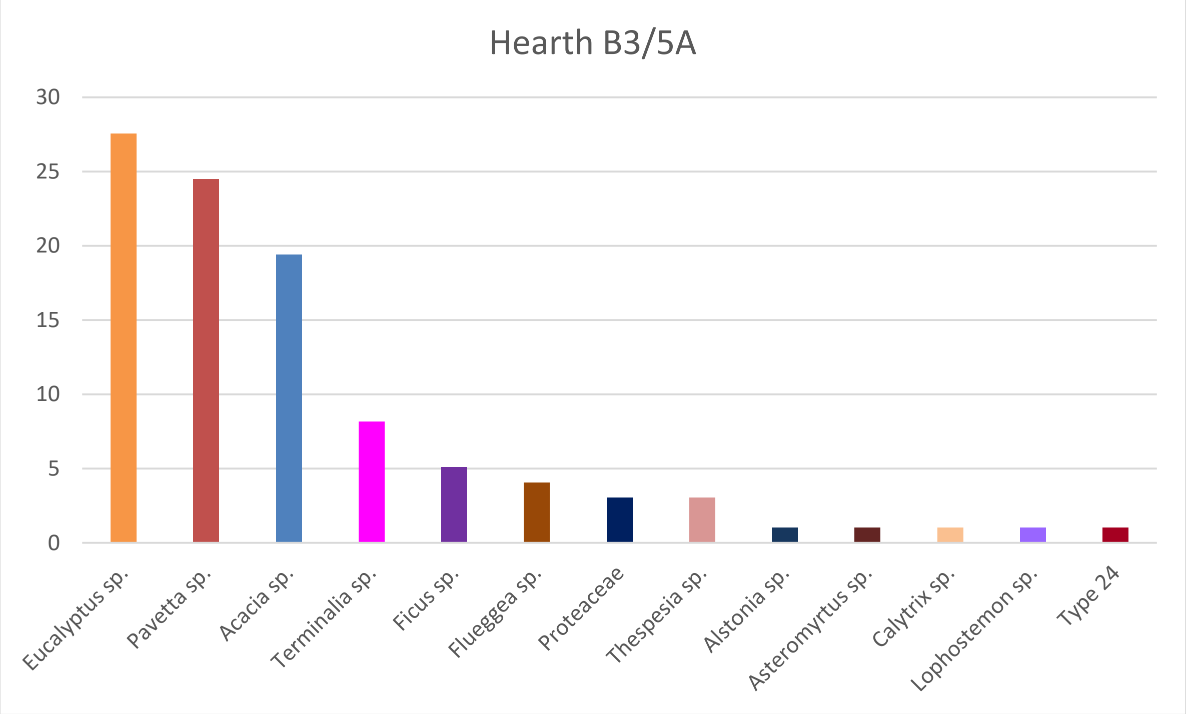
Hearth E4/6A contains 14 taxa, which is the second highest taxon richness for a hearth in the MJB assemblage. Of the 200 charcoal fragments analysed 42% were indeterminate due to size or preservation. *Acacia* sp. taxa make up 37% of the total identified charcoal assemblage, with *Ficus* sp. (16%) and *Terminalia* sp. (10%) the only other taxa to reach above 10%. E4/6A is the only late Holocene hearth to contain *Callitris* sp. wood charcoal. It is also only one of two MJB hearths to contain the monsoon vine forest taxa *Alstonia* sp. The E4/6A wood charcoal assemblage contains taxa from open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities.

Hearth B3/5A

B3/5 was radiocarbon dated with a result of 720-650 yr cal BP (OZQ474).



Hearth B3/5A taxonomic composition as percent. Indeterminate specimens included.

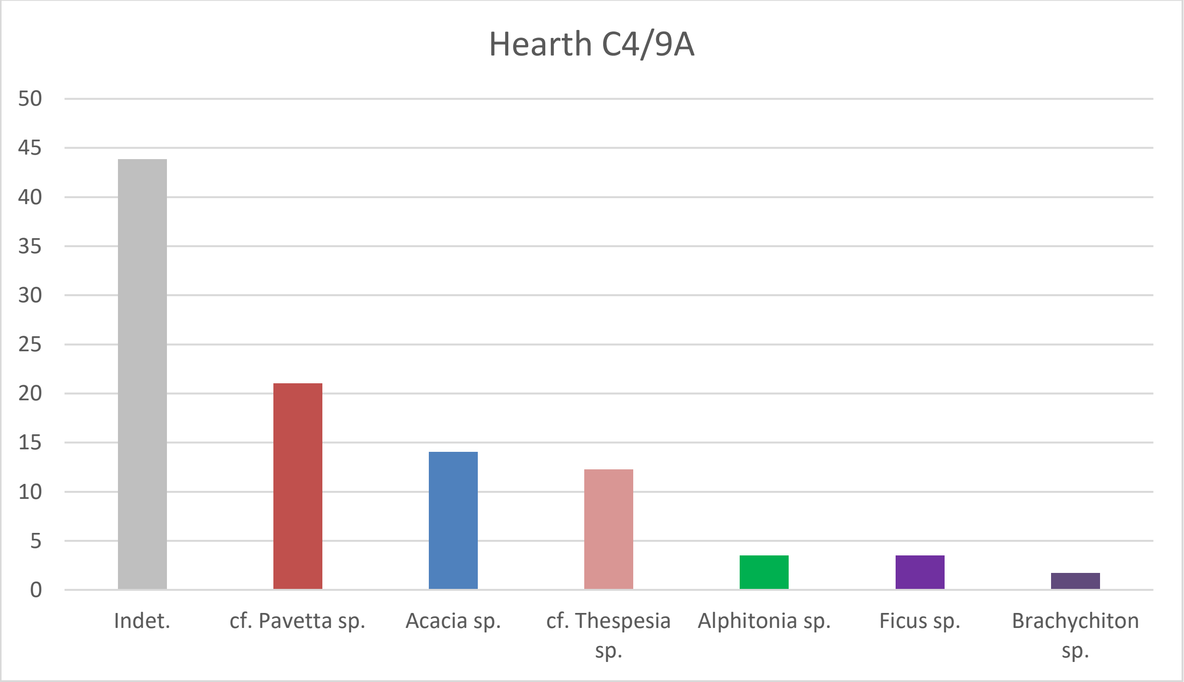


Hearth E4/6A taxonomic composition as percent. Indeterminate specimens excluded.

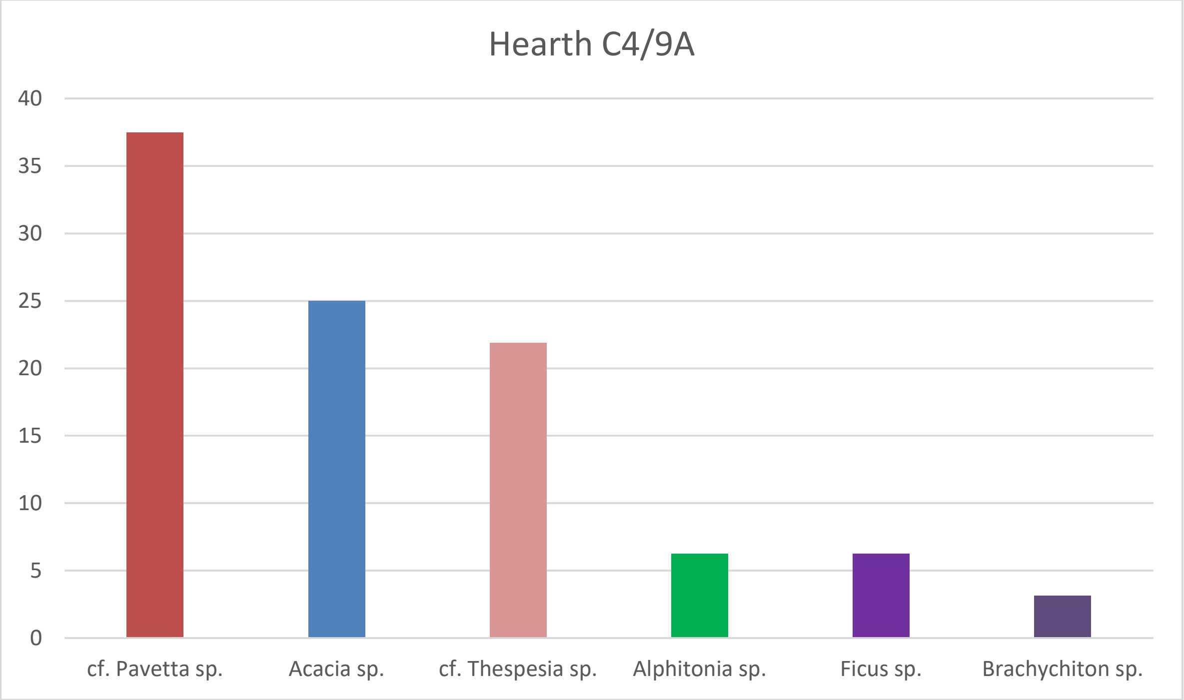
Hearth B3/5A has the third highest taxon richness of any of the MJB hearths (*n* = 13). Of the 200 charcoal fragments analysed for B3/5A 51% were indeterminate due to size or preservation. With indeterminate taxa removed *Eucalyptus* sp. (27%), cf. *Pavetta* sp. (24%), and *Acacia* sp. (19%) make up the majority of the assemblage. B3/5A is only one of two hearths (see also E4/6A) which contains the monsoon vine forest taxa *Alstonia* sp. It is also only one of two of the late Holocene hearths in which *Acacia* sp. is not the dominant taxa (see also C4/9A). The B3/5A wood charcoal assemblage contains taxa from open Eucalypt woodland, monsoon vine forest and *Grevillea/Banksia* shrubland vegetation communities.

Hearth C4/9A

Hearth C4/9A was directly radiocarbon dated with a result of 2860-2760 yr cal BP (Wk43604).



Hearth C4/9A taxonomic composition as percent. Indeterminate specimens included.

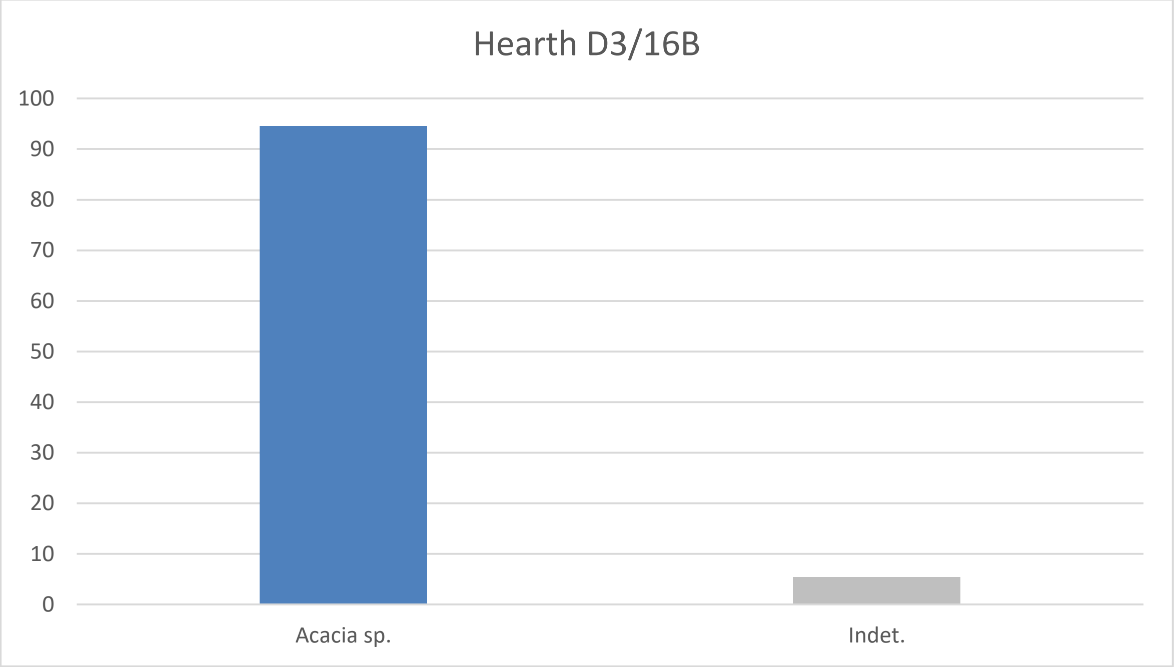


Hearth C4/9A taxonomic composition as percent. Indeterminate specimens excluded.

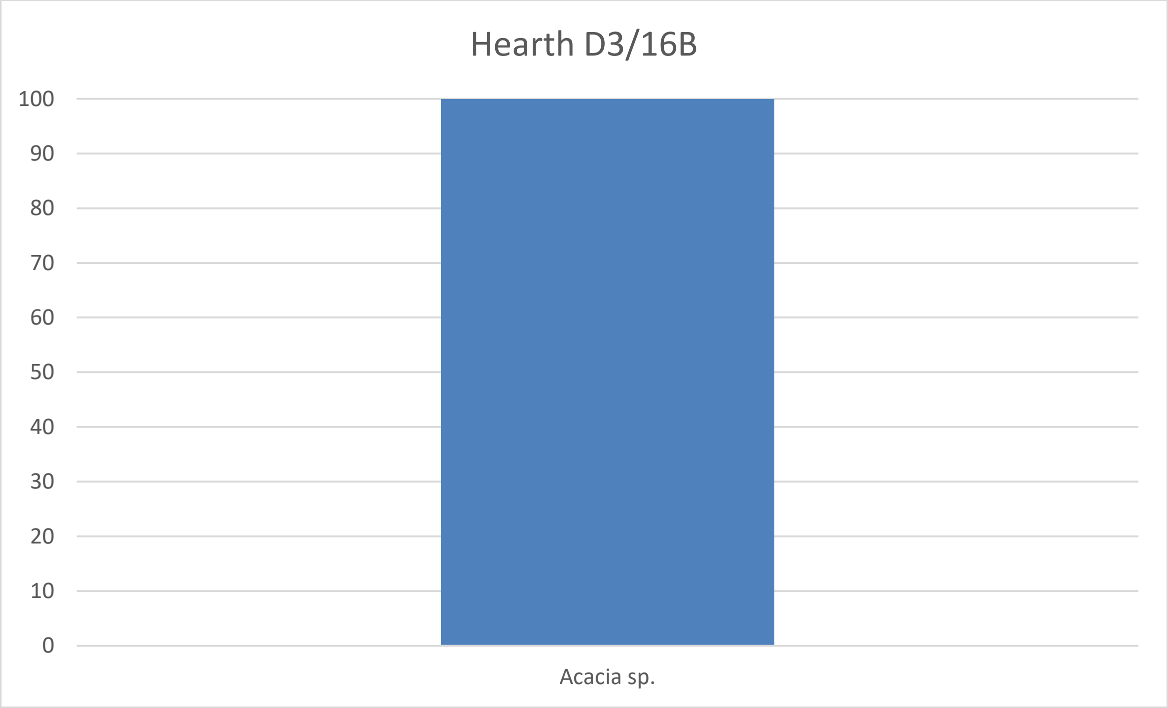
Hearth C4/9A is the oldest of the late Holocene hearths, it dates between 2860-2760 yr cal BP. Of the 57 charcoal fragments analysed, 100% of the charcoal present in the hearth, 43% were indeterminate. cf. *Pavetta* sp., the most abundant taxa in the hearth, makes up 37% of the identified wood charcoal assemblage. *Acacia* sp. (25%) and cf. *Thespesia* sp. (21%) are the only other taxa to make up more than ten percent of the total identified assemblage. Only open Eucalypt woodland and monsoon vine forest vegetation communities are represented in the C4/9A wood charcoal assemblage.

Hearth D3/16B

Hearth D3/16B was radiocarbon dated with a result of 8600-8460 yr cal BP (Wk43607).



Hearth D3/16B taxonomic composition as percent. Indeterminate specimens included.

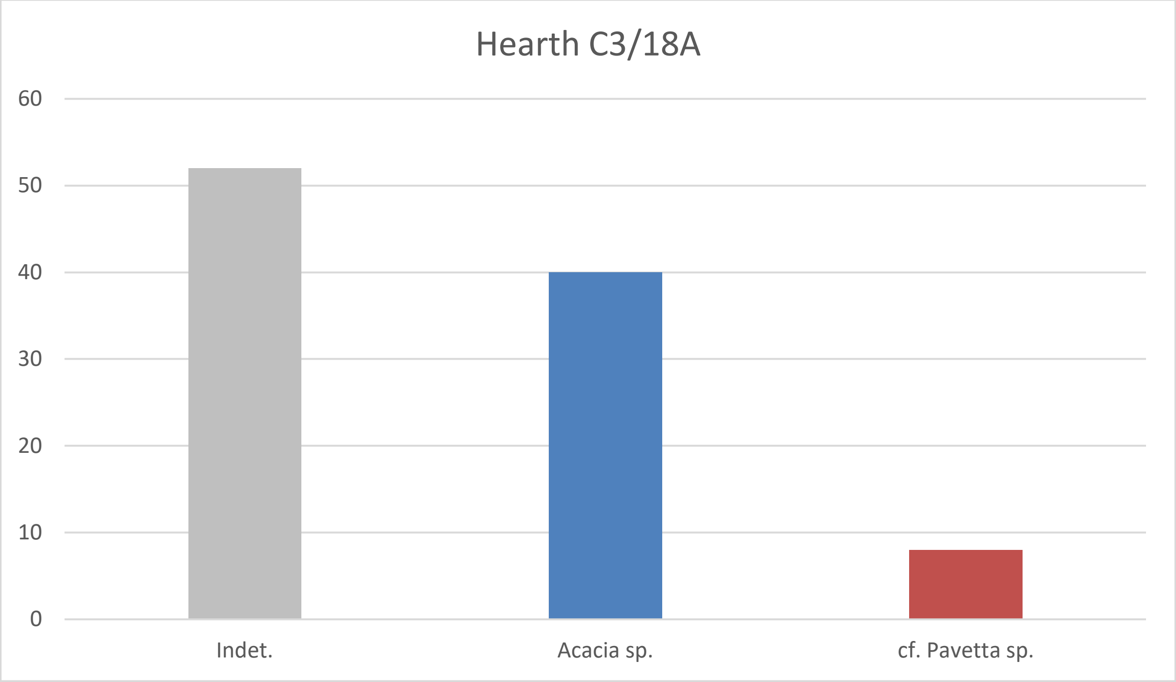


Hearth D3/16B taxonomic composition as percent. Indeterminate specimens excluded.

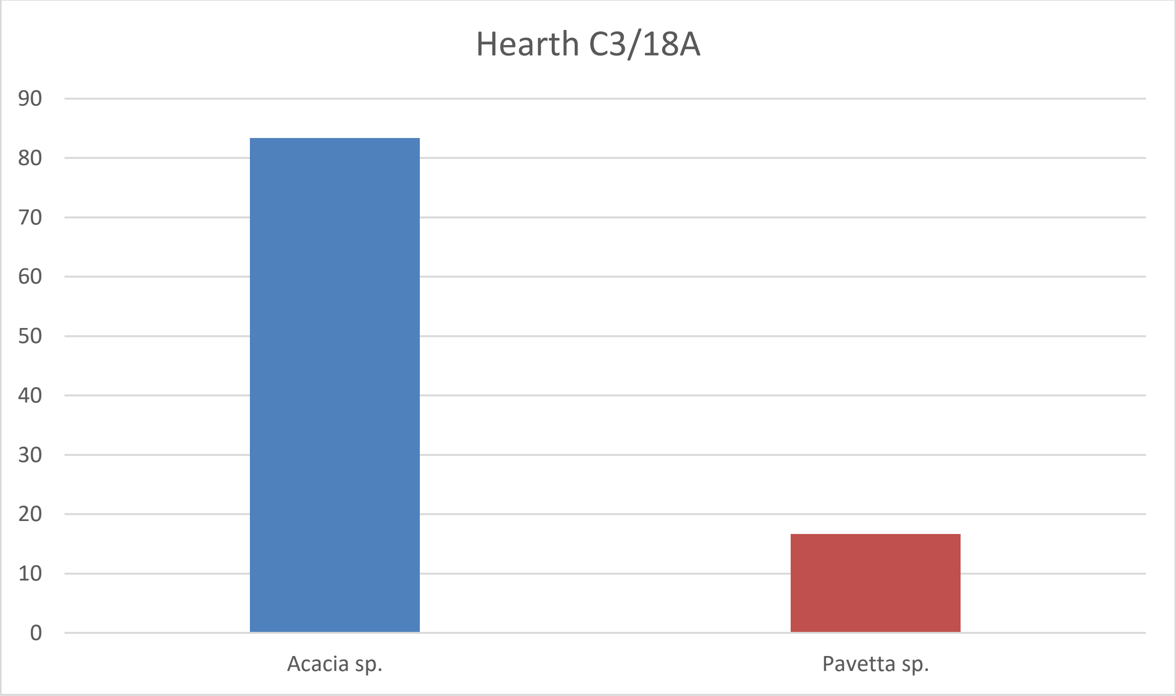
This hearth is the only early Holocene hearth to contain a single taxon. Of the 37 fragments analysed only 5% were indeterminate due to size or preservation. With a taxon richness of one this hearth probably represents a single use feature. As *Acacia* sp. are found across both open Eucalypt woodland and monsoon vine forest technically both of these vegetation communities are represented in this hearth.

Hearth C3/18A

Hearth C3/18A was directly radiocarbon dated with a result of 9130-9000 yr cal BP (Wk43603).



Hearth C3/18A taxonomic composition as percent. Indeterminate specimens included.

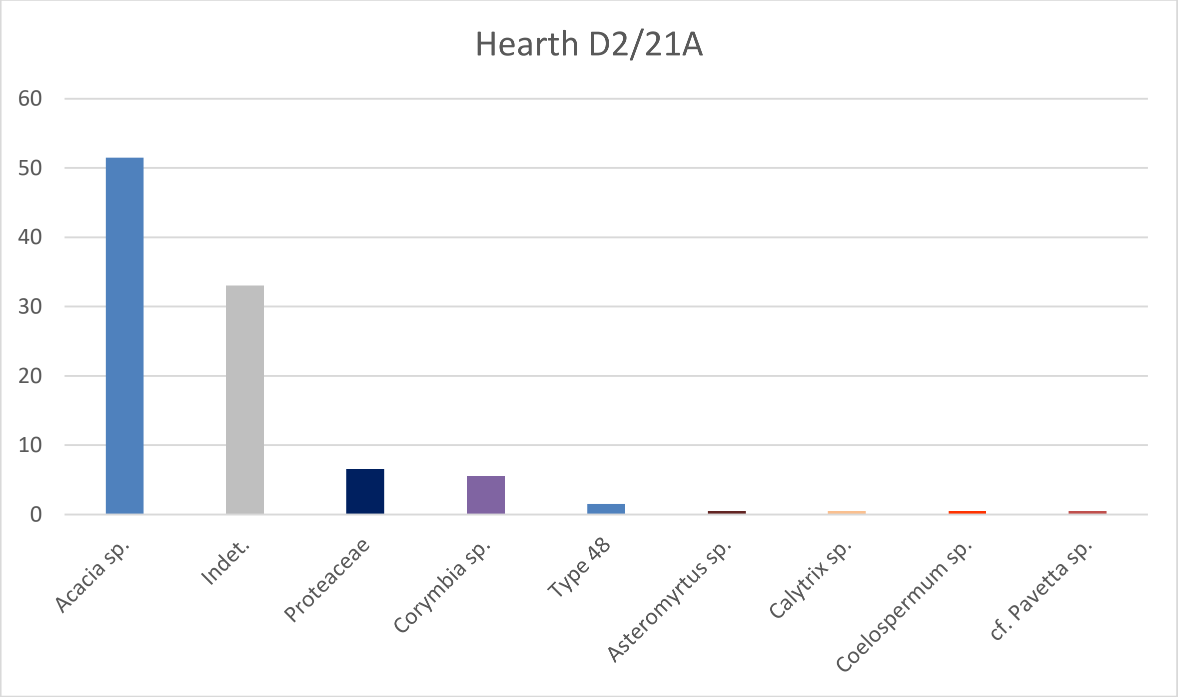


Hearth C3/18A taxonomic composition as percent. Indeterminate specimens excluded.

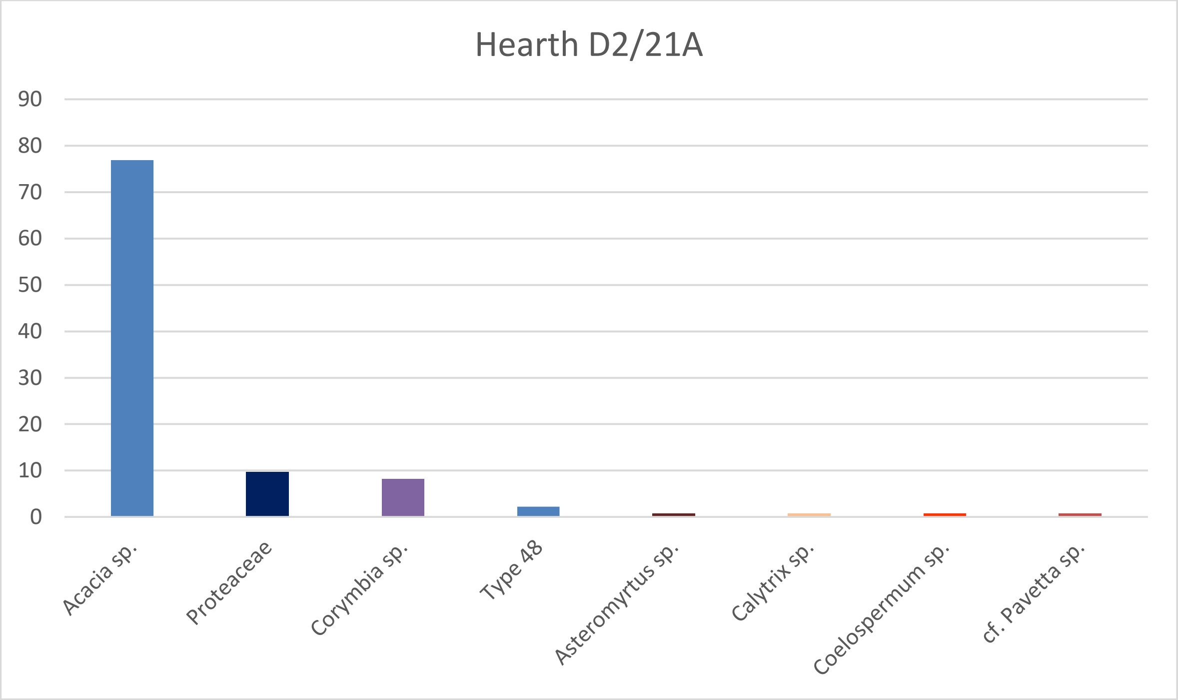
Hearth C3/18A dates between 9130-9000 yr cal BP. Of the 25 charcoal fragments analysed 52% were indeterminate due to size or preservation. *Acacia* sp. (83%) is by far the dominant component of C3/18A with cf. *Pavetta* sp. making up the remaining 17% of the identified specimens. With a taxon count of two this hearth has far lower taxon richness than the early Holocene hearths presented previously. Even though it only contains two taxa both open Eucalypt woodland and monsoon vine forest communities are represented.

Hearth D2/21A

Hearth D2/21A was directly radiocarbon dated with a result of 9398-9034 yr cal BP (Wk43606).



Hearth D2/21A taxonomic composition as percent. Indeterminate specimens included.

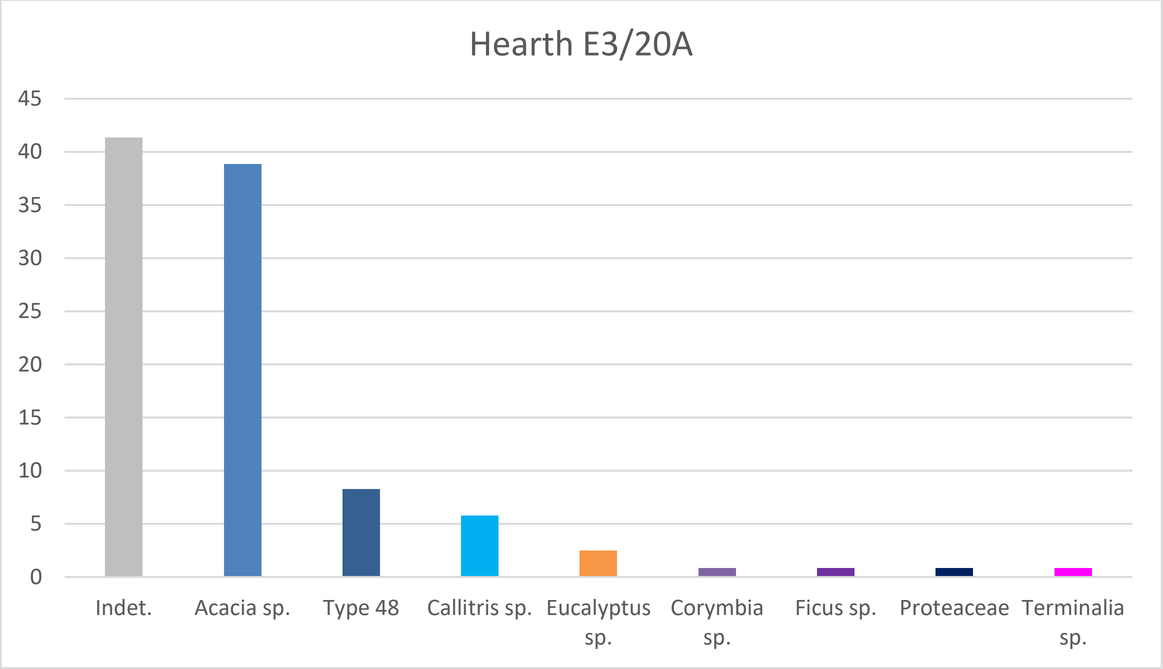


Hearth D2/21A taxonomic composition as percent. Indeterminate specimens excluded.

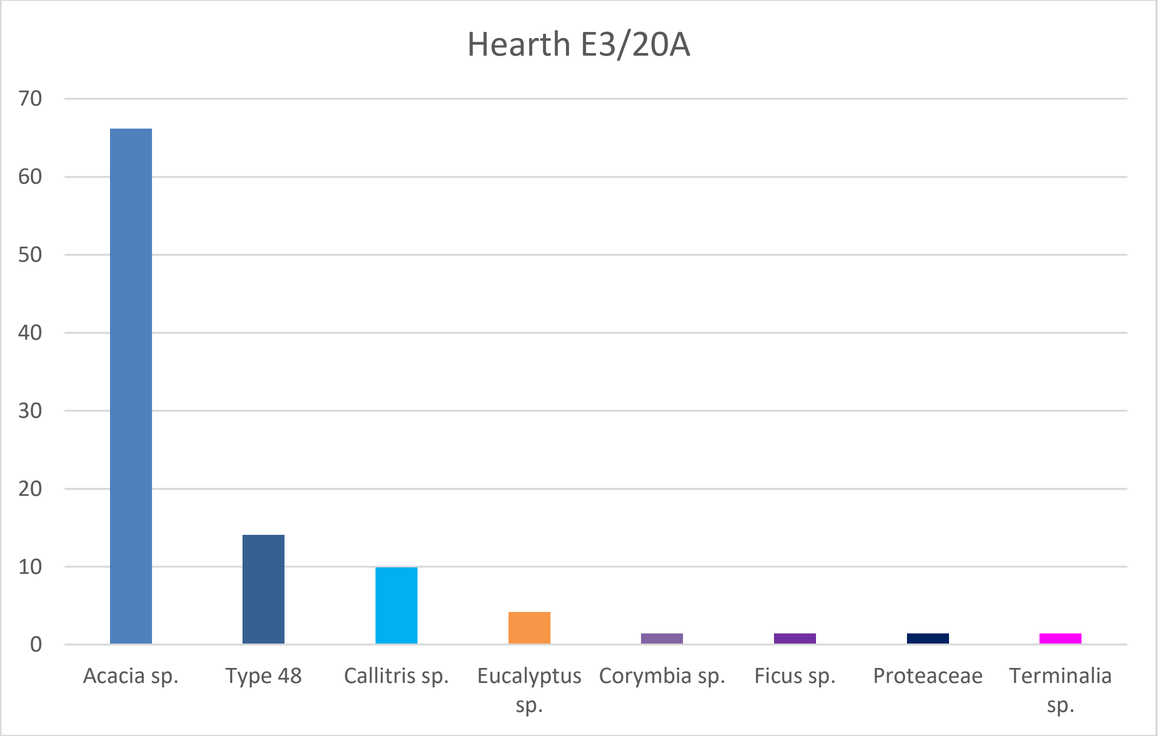
Hearth D2/21A has the equal second highest taxon richness of the terminal Pleistocene-early Holocene hearths. It contains seven identified taxa and one unidentified archaeological type (Type 48). Type 48 does not appear in any of the late Holocene hearths presented above. Of the 200 charcoal fragments analysed 33% were indeterminate because of size or preservation. *Acacia* sp. makes up 76% of the identified wood charcoal assemblages with all other taxa making minor contribution (<10%). This hearth contained a single fragment of *Coelospermum* sp. the only hearth in the MJB assemblage to contain this taxon. The taxa present in hearth D2/21A are sourced from open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland vegetation communities.

Hearth E3/20A

Hearth E3/20A was directly radiocarbon dated with a result of 12810-12710 yr cal BP (Wk43610).



Hearth E3/20A taxonomic composition as percent. Indeterminate specimens included.

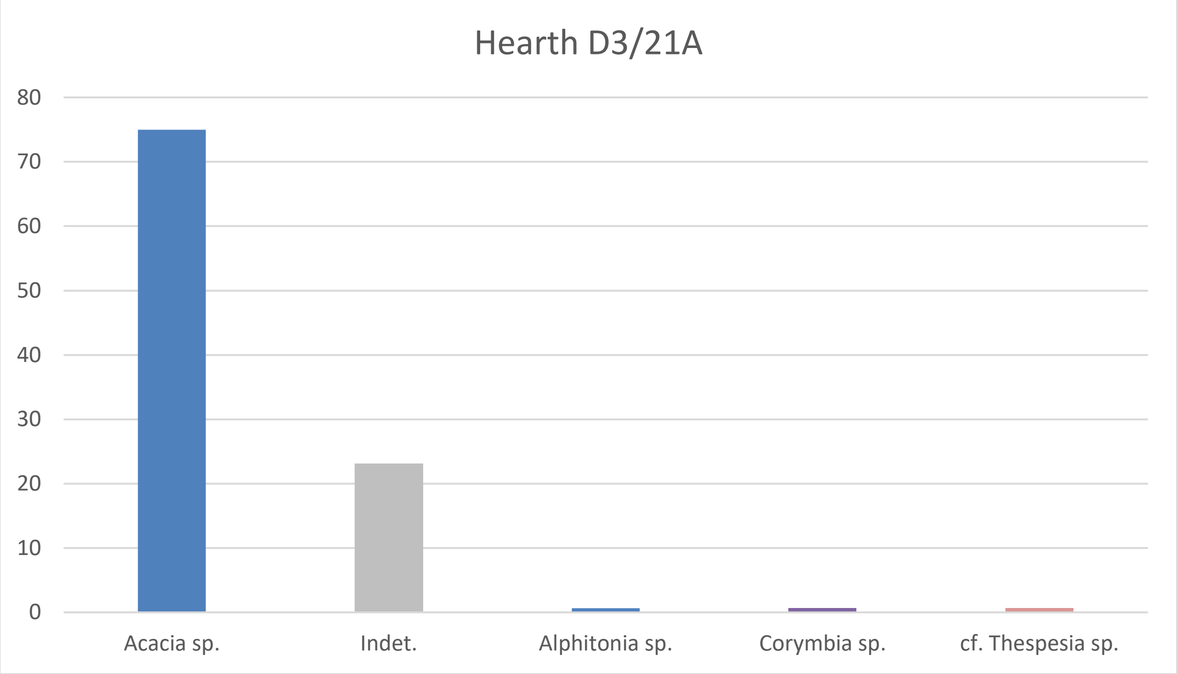


Hearth E3/20A taxonomic composition as percent. Indeterminate specimens excluded.

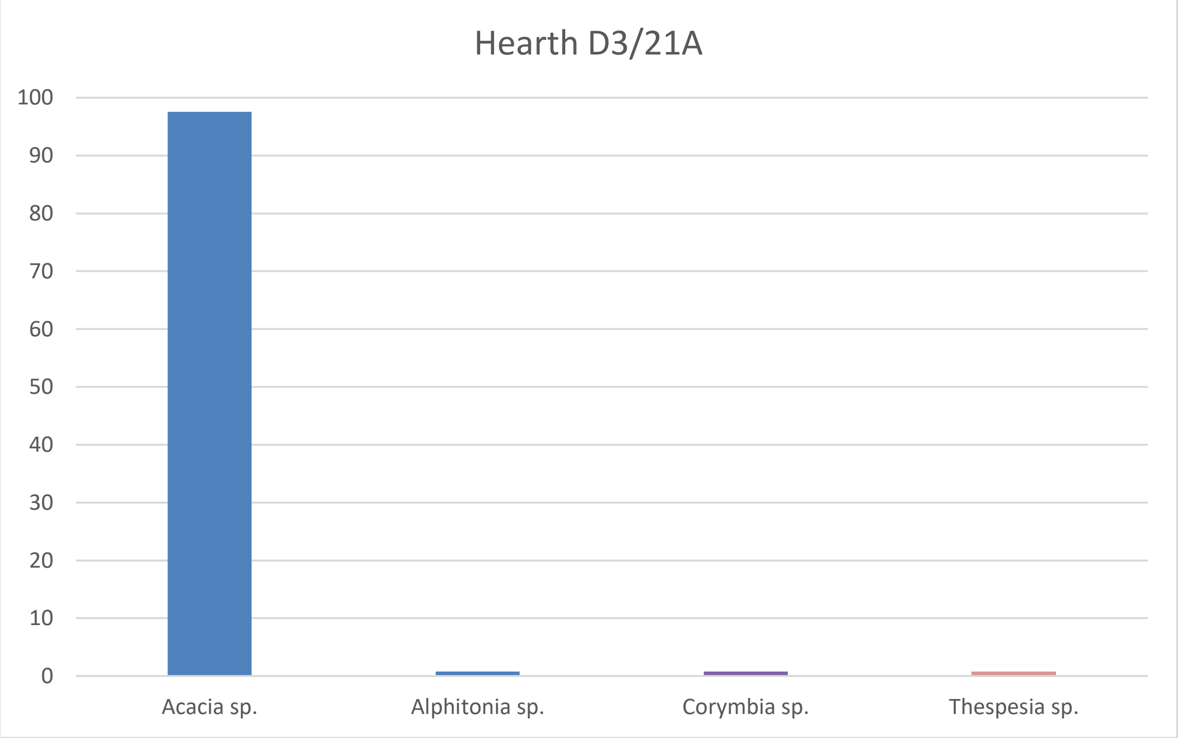
Hearth E3/20A contains eight taxon, seven identified and one unidentified archaeological type (Type 48). Of the 121 charcoal fragments analysed 41% were indeterminate due to size or preservation. *Acacia* sp. (66%) was the dominant taxon. Only Type 48 (14%) reached greater than 10% of the total identified charcoal assemblage. The charcoal assemblage contained taxa from open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland.

Hearth D3/21A

A date for this context was not obtained due to repeated sample failure.



Hearth D3/21A taxonomic composition as percent. Indeterminate specimens included.

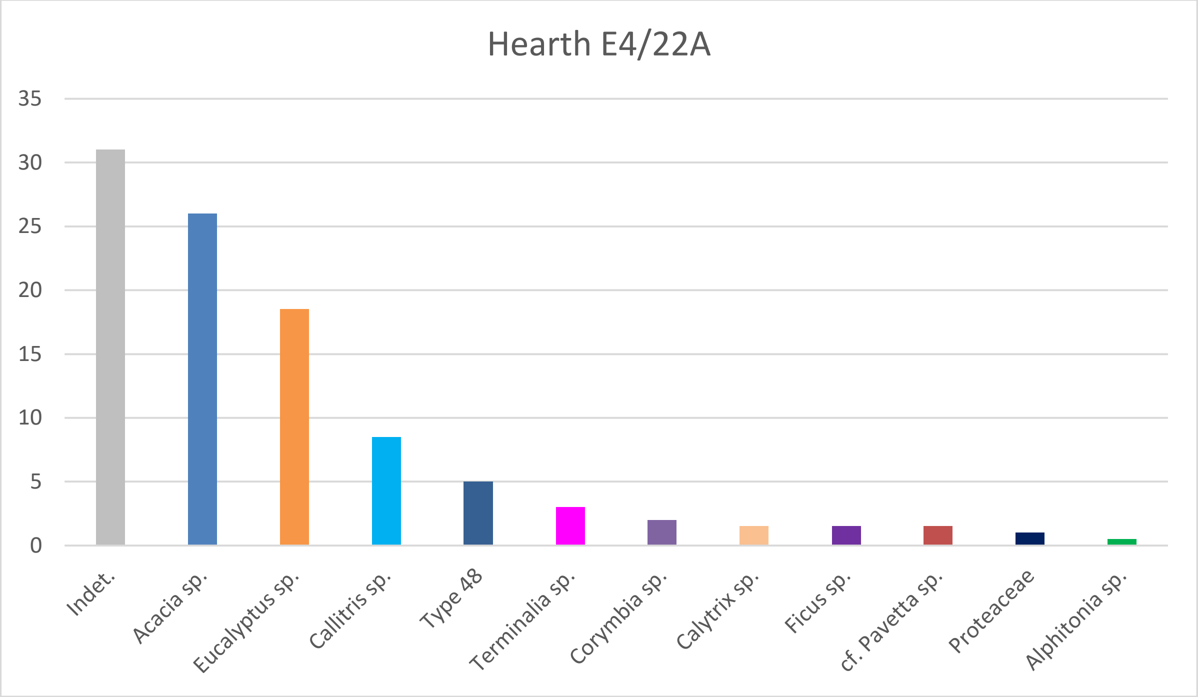


Hearth D3/21A taxonomic composition as percent. Indeterminate specimens excluded.

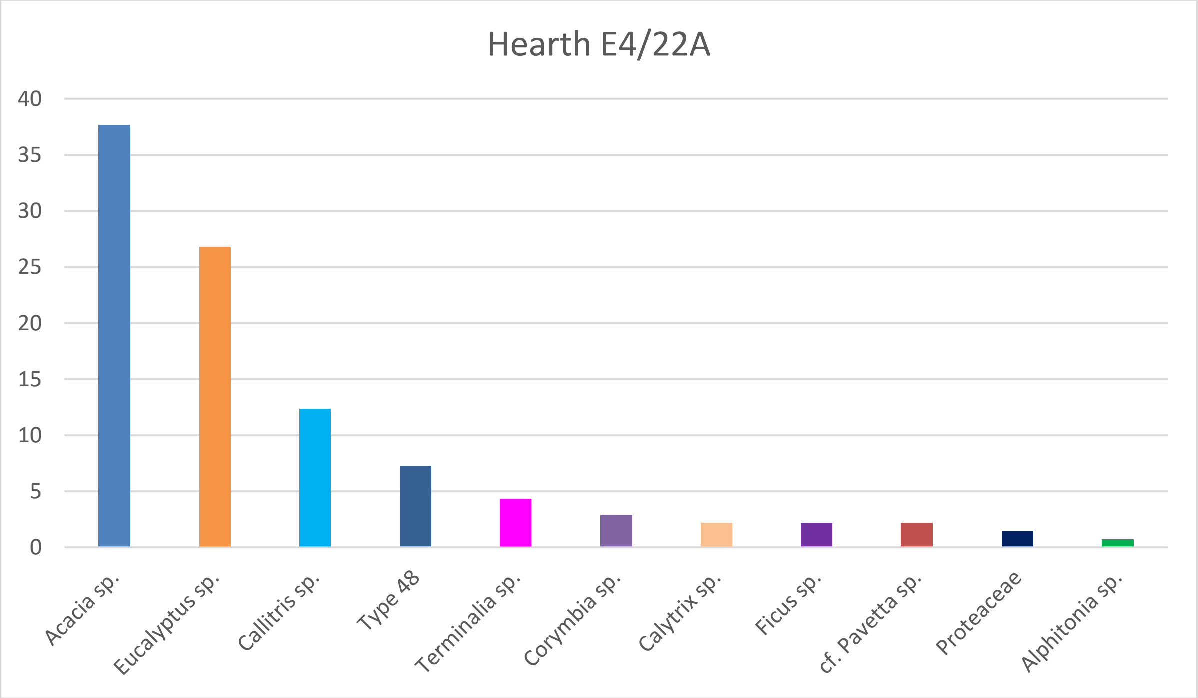
Hearth D3/21A contains only four taxa and is dominated by *Acacia* sp. Of the 160 charcoal fragments analysed for this hearth 23% were indeterminate due to size or preservation. *Acacia* sp. makes up 97% of the total identified assemblage, with minor contributions from *Alphitonia* sp., *Corymbia* sp., and cf. *Thespesia* sp. The taxa present in this hearth represent open Eucalypt woodland and monsoon vine forest.

Hearth E4/22A

Hearth E4/22A was directly radiocarbon dated with a result of 18690-18410 yr cal BP (Wk43611).



Hearth E4/22A taxonomic composition as percent. Indeterminate specimens included.

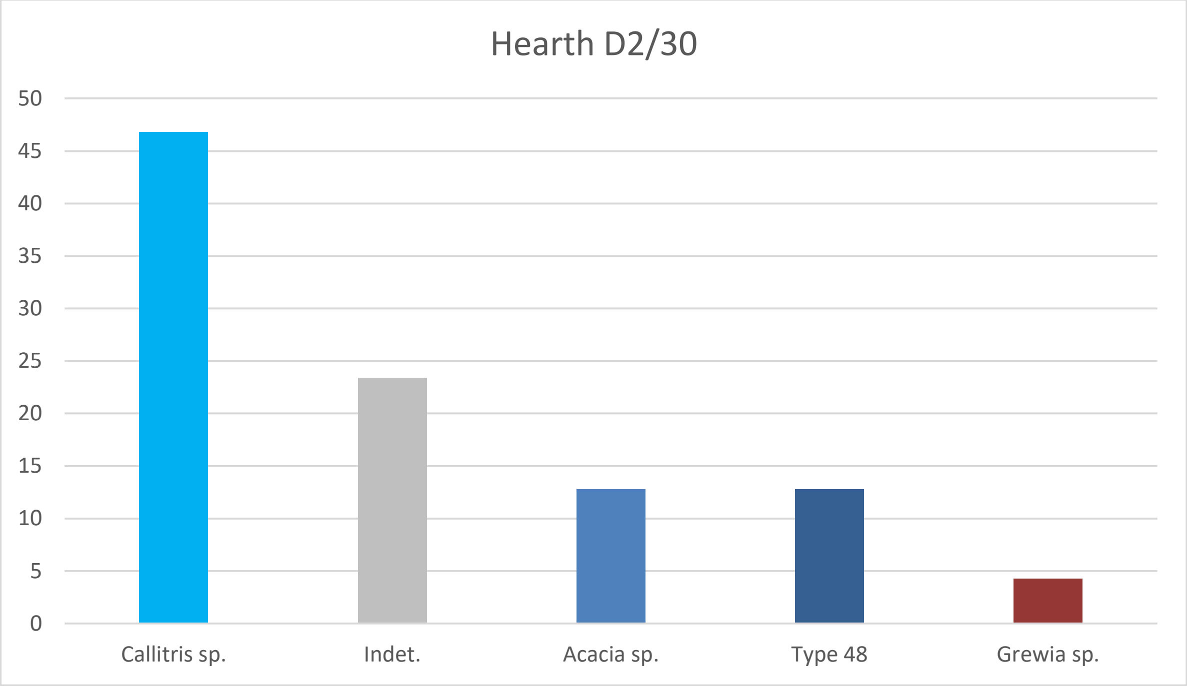


Hearth E4/22A taxonomic composition as percent. Indeterminate specimens excluded.

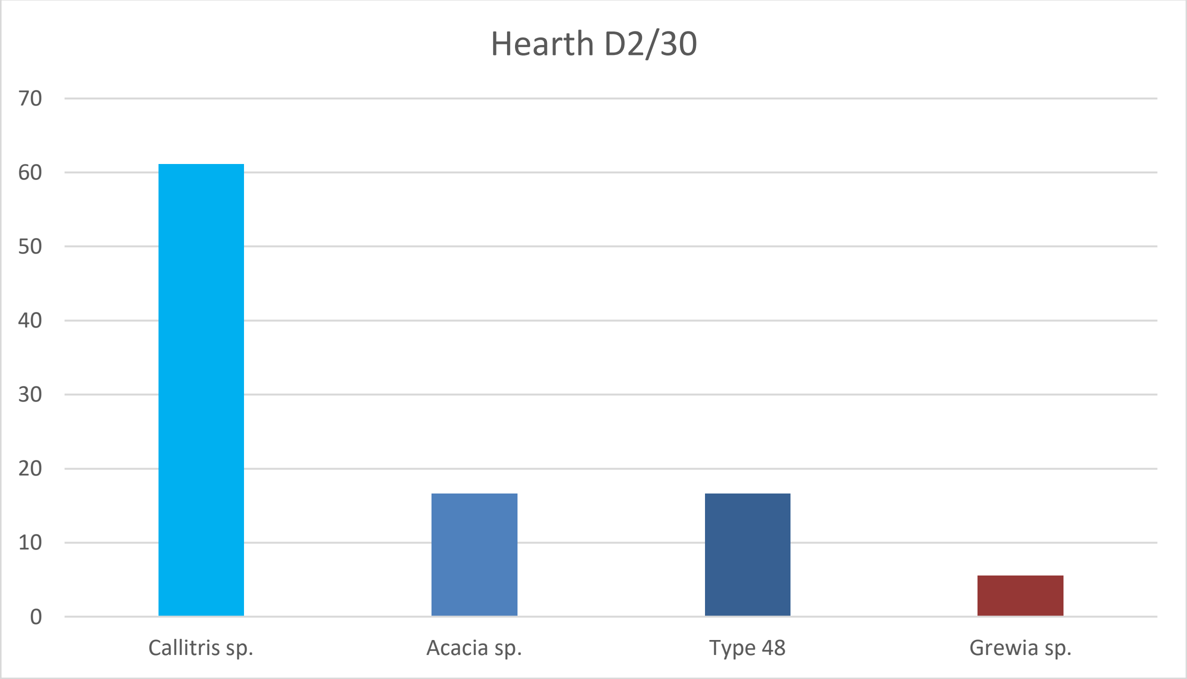
Hearth E4/22A contains the highest taxon richness of the terminal Pleistocene-early Holocene hearths with eleven taxa present. It is the oldest hearth of this group of hearths, dating between 18690-18410 yr cal BP. Of the 200 charcoal fragments analysed 31% were indeterminate due to size or preservation. *Acacia* sp. (37%) and *Eucalyptus* sp. (26%) were the two dominant taxa present in hearth E4/22A, with *Callitris* sp. (12%) the only other taxon with >10% of the total assemblage. The E4/22A assemblage represents open Eucalypt woodland, monsoon vine forest, and *Grevillea/Banksia* shrubland vegetation communities.

Hearth D2/30

A radiocarbon samples has been submitted for analysis.



Hearth D2/30 taxonomic composition as percent. Indeterminate specimens included.

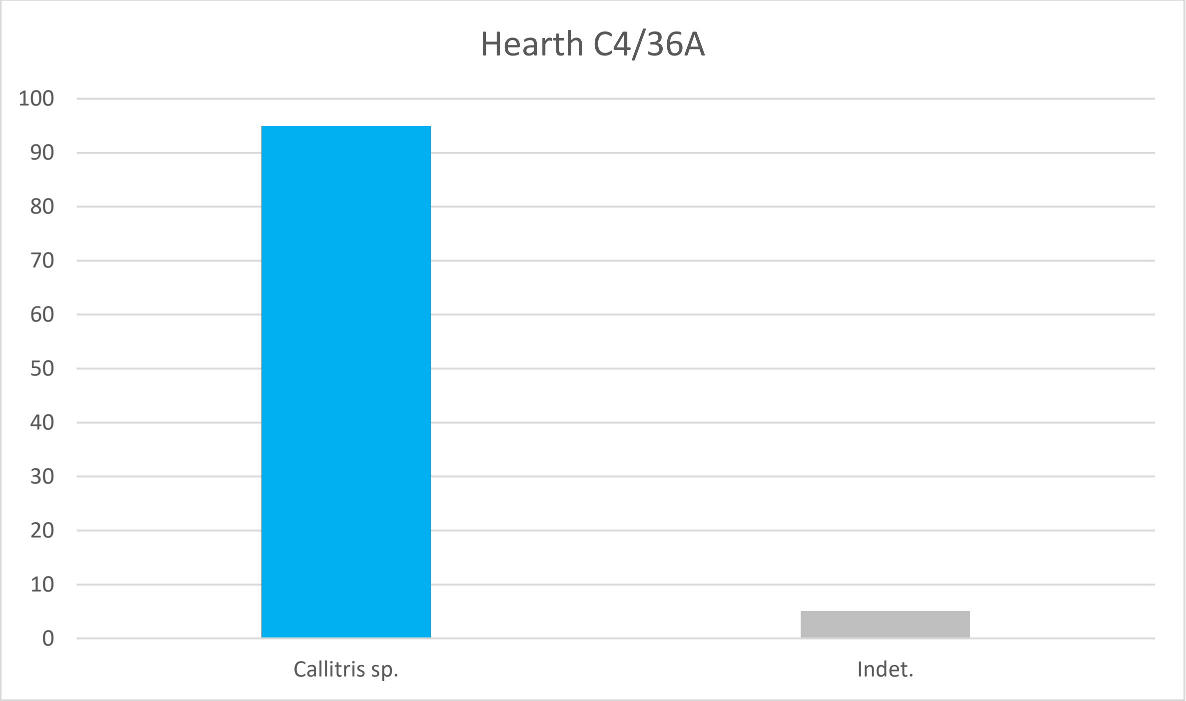


Hearth D2/30 taxonomic composition as percent. Indeterminate specimens excluded.

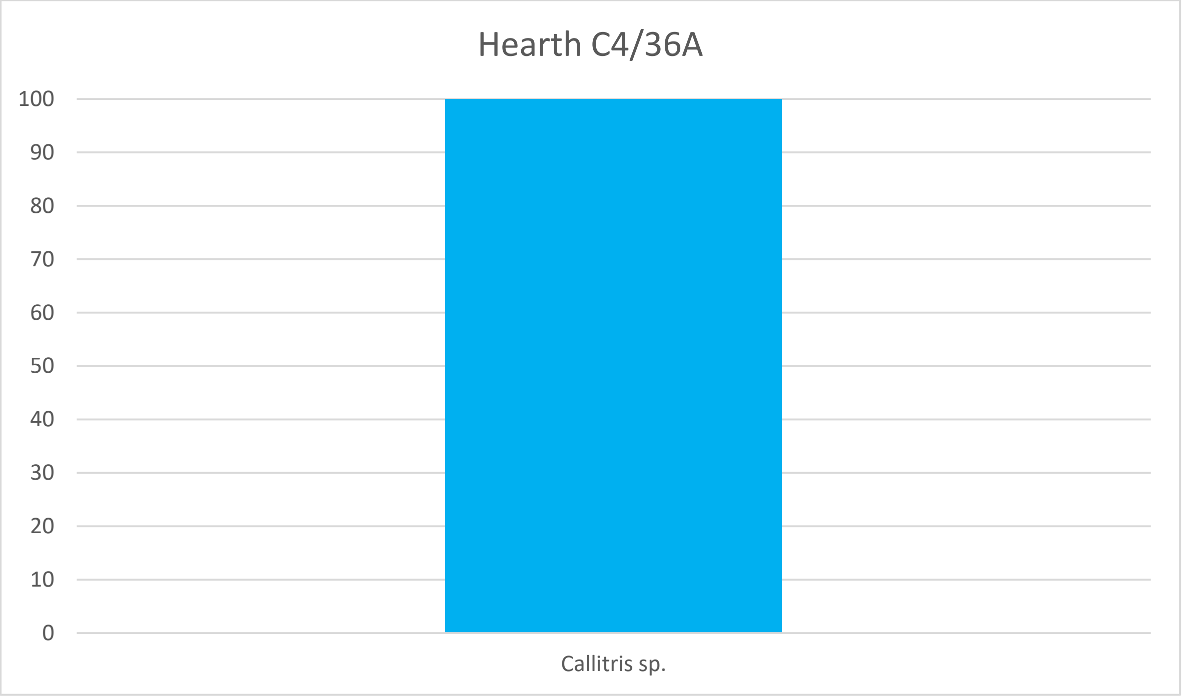
Hearth D2/30 is one of two hearths in the MJB sequence which is dominated by *Callitris* sp. Of the 47 charcoal fragments analysed 23% were indeterminate due to size or preservation. *Callitris* sp. made up 61% of the identified wood charcoal assemblage with *Acacia* sp. (16%) and the unidentified archaeological Type 48 (16%) with >10% of the total. Of the three MJB hearths which contain *Grewia* sp. D2/30 is the only one in the Pleistocene. The taxa present in hearth D2/30 represent open Eucalypt woodland and monsoon vine forest vegetation communities.

Hearth C4/36A

Hearth C4/36A was directly radiocarbon dated with a result of 24970-24340 yr cal BP (Wk43605).



Hearth C4/36A taxonomic composition as percent. Indeterminate specimens included.

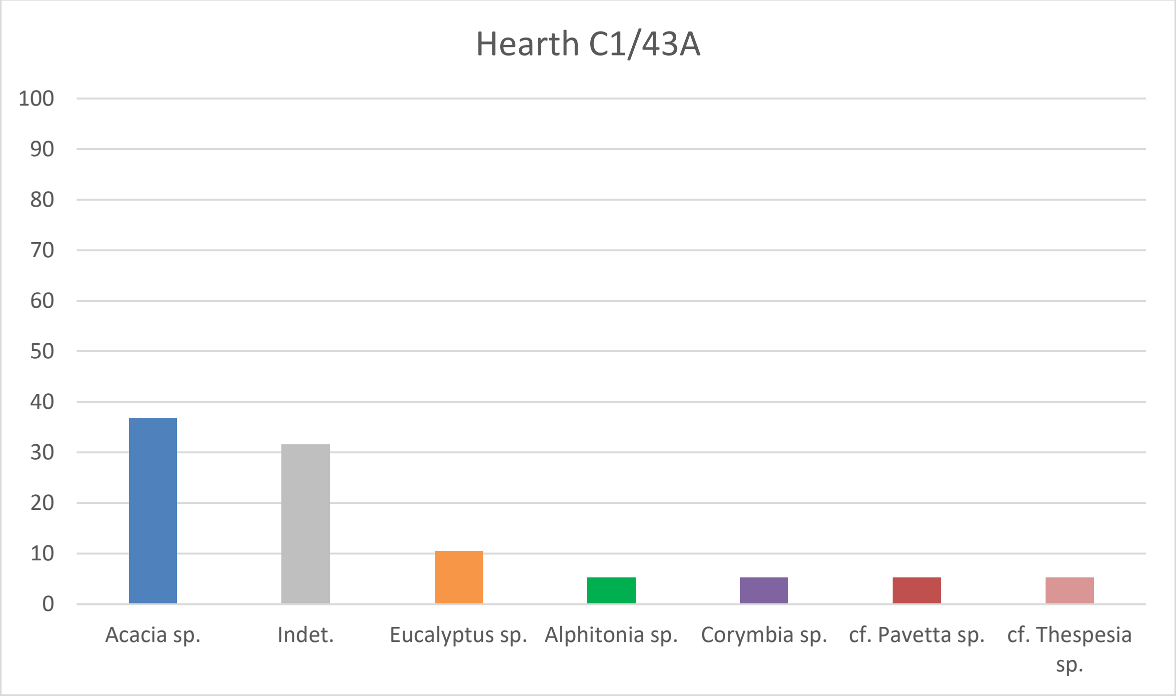


Hearth C4/36A taxonomic composition as percent. Indeterminate specimens excluded.

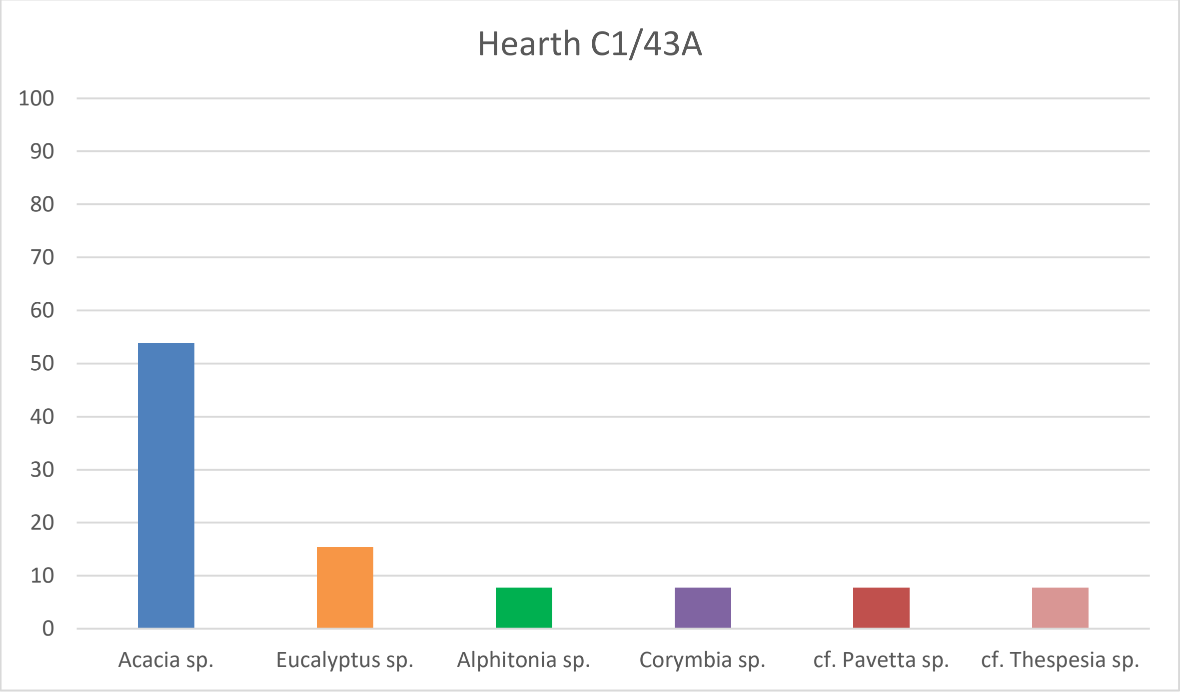
Hearth C4/36A is composed solely of the fire-sensitive pine *Callitris* sp. Of the 99 charcoal fragments analysed only 5% were indeterminate due to size or preservation. Out of all the MJB hearths C4/36A is the only one to contain greater than 50% *Callitris* sp. It is also the only hearth in the MJB sequence not to contain *Acacia* sp. The taxonomic homogeneity of hearth C4/36A may indicate that it was a single use context or used for a specific purpose.

Hearth C1/43A

There was not enough material available to date this context.



Hearth C1/43A taxonomic composition as percent. Indeterminate specimens included.

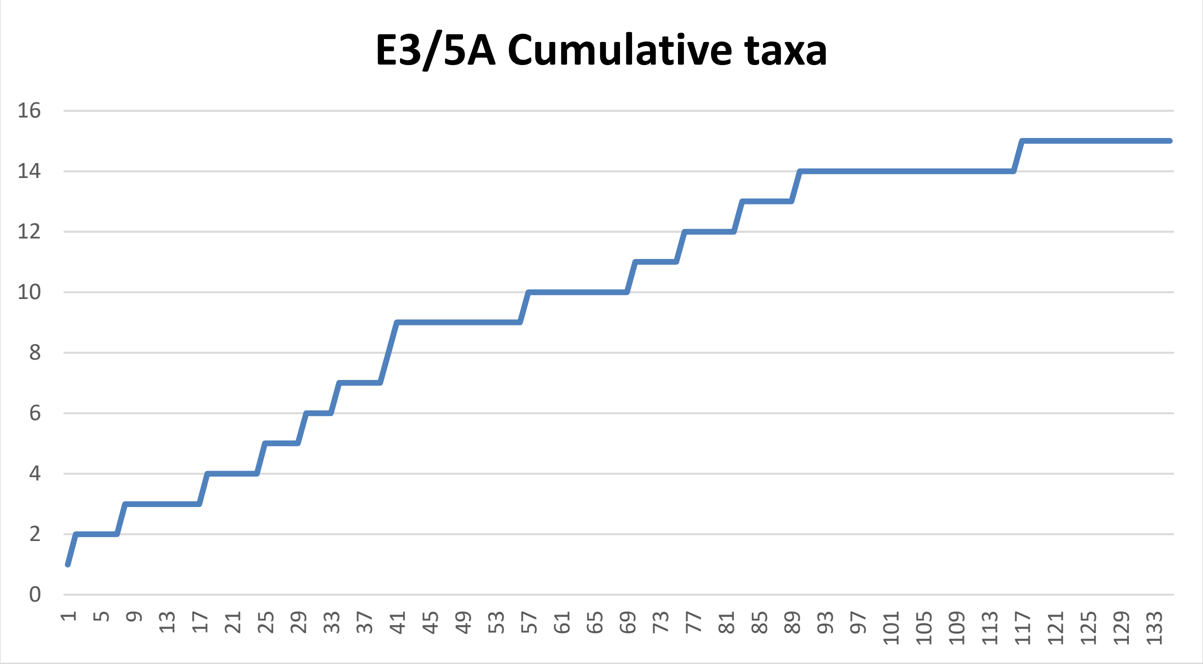


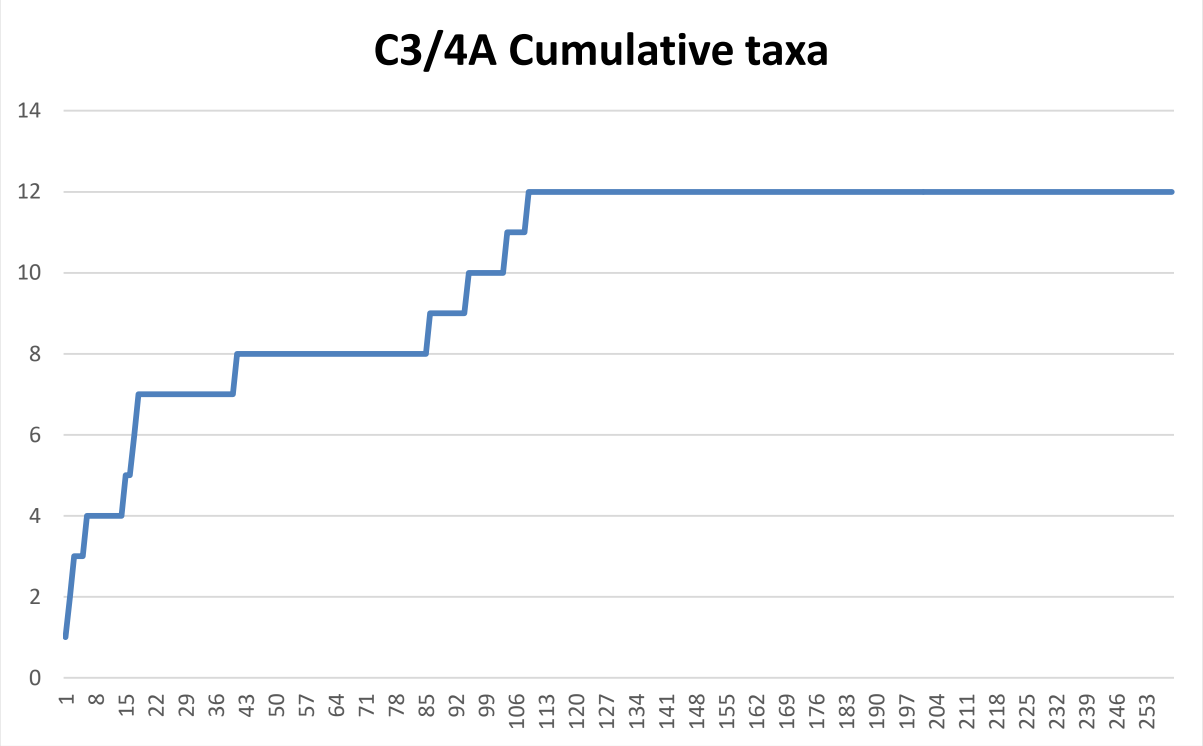
Hearth C1/43A taxonomic composition as percent. Indeterminate specimens excluded.

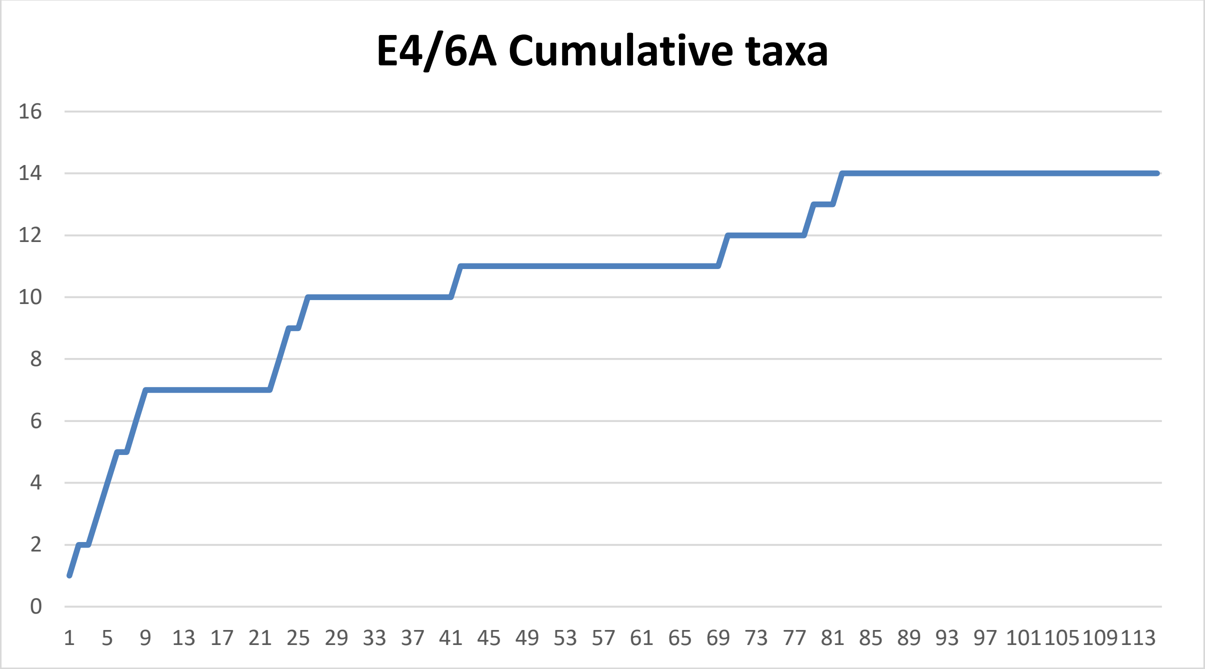
Hearth C1/43A is the oldest hearth in the MJB sequence. Its estimated age based on an OSL chronology is 40-45,000 years old. This hearth was very small and only contained 19 charcoal fragments of which 31% were indeterminate due to size or preservation. Over fifty percent of the identified specimens were *Acacia* sp. (53%), the only other taxa with >10% was *Eucalyptus* sp. The hearth contained taxa from open Eucalypt woodland and monsoon vine forest vegetation communities.

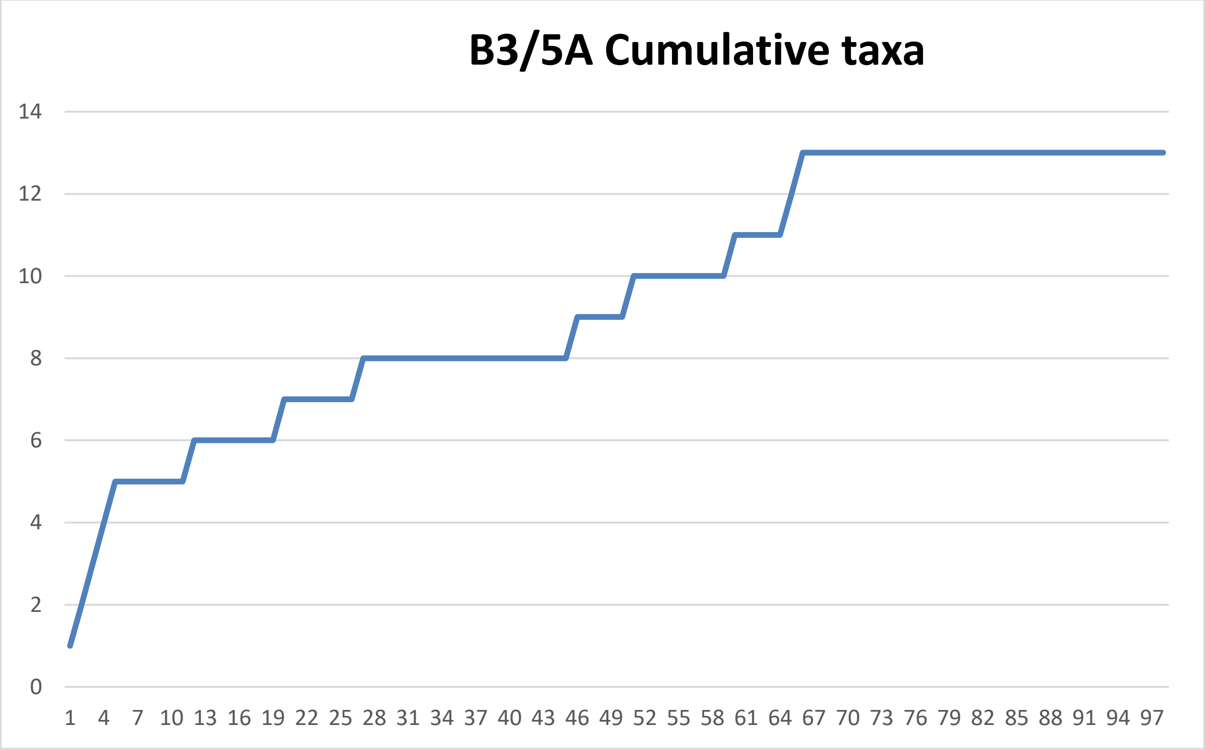
Appendix L – Saturation curves for all Madjedbebe hearths

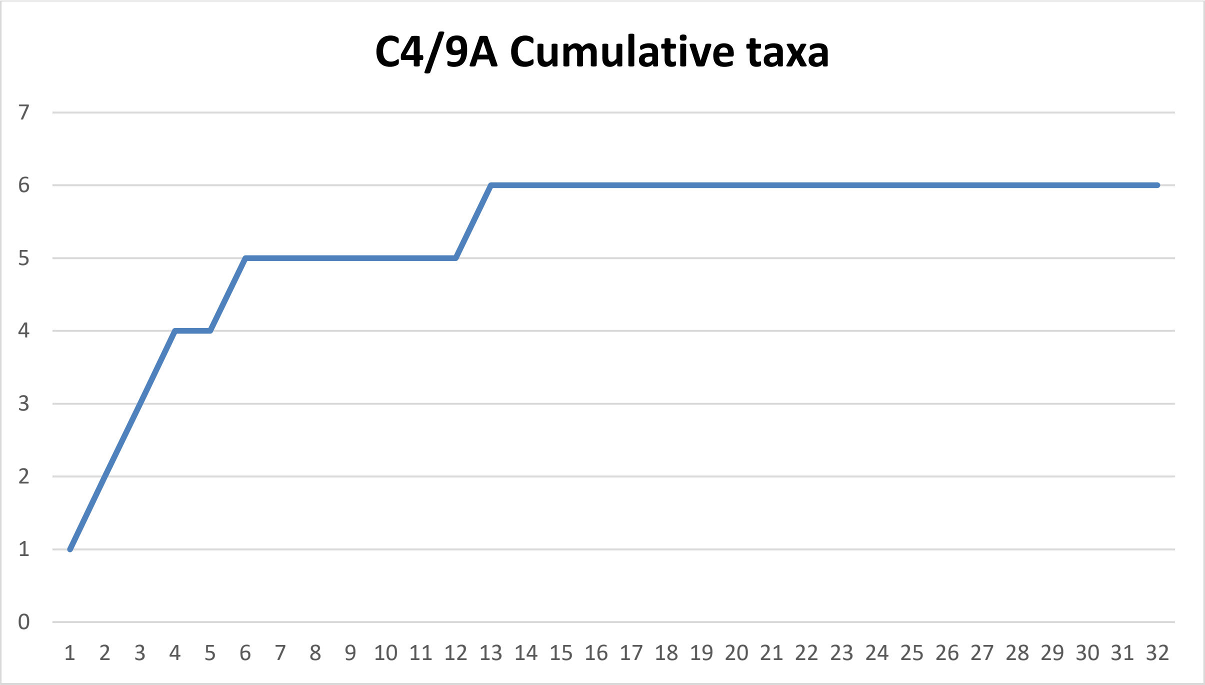
Cumulative saturation curves for each of the fourteen Madjedbebe hearths testing the adequacy of the sampling effort.

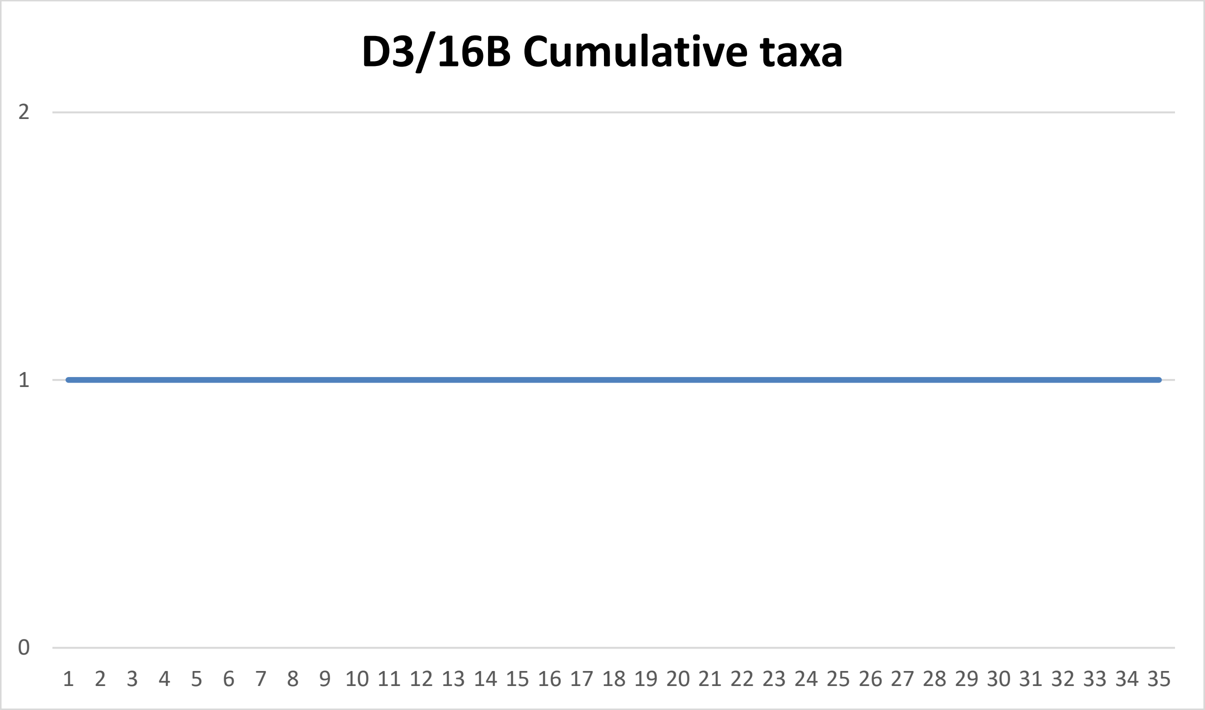


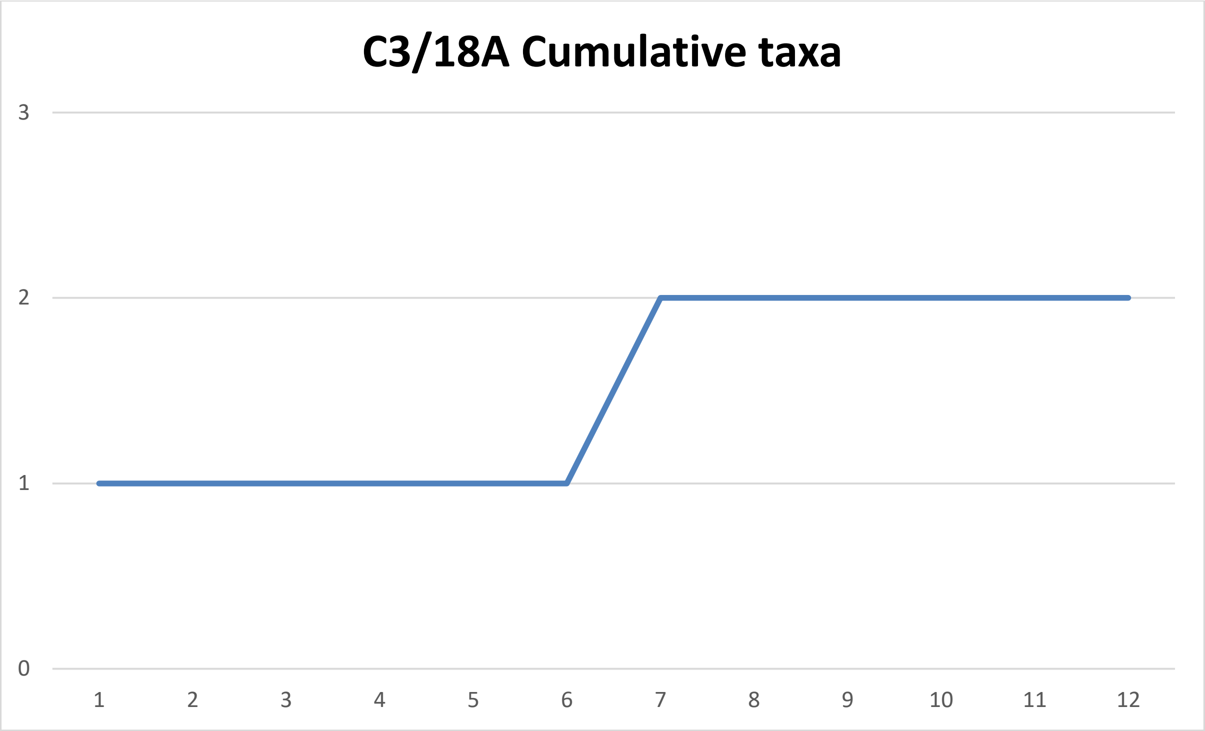


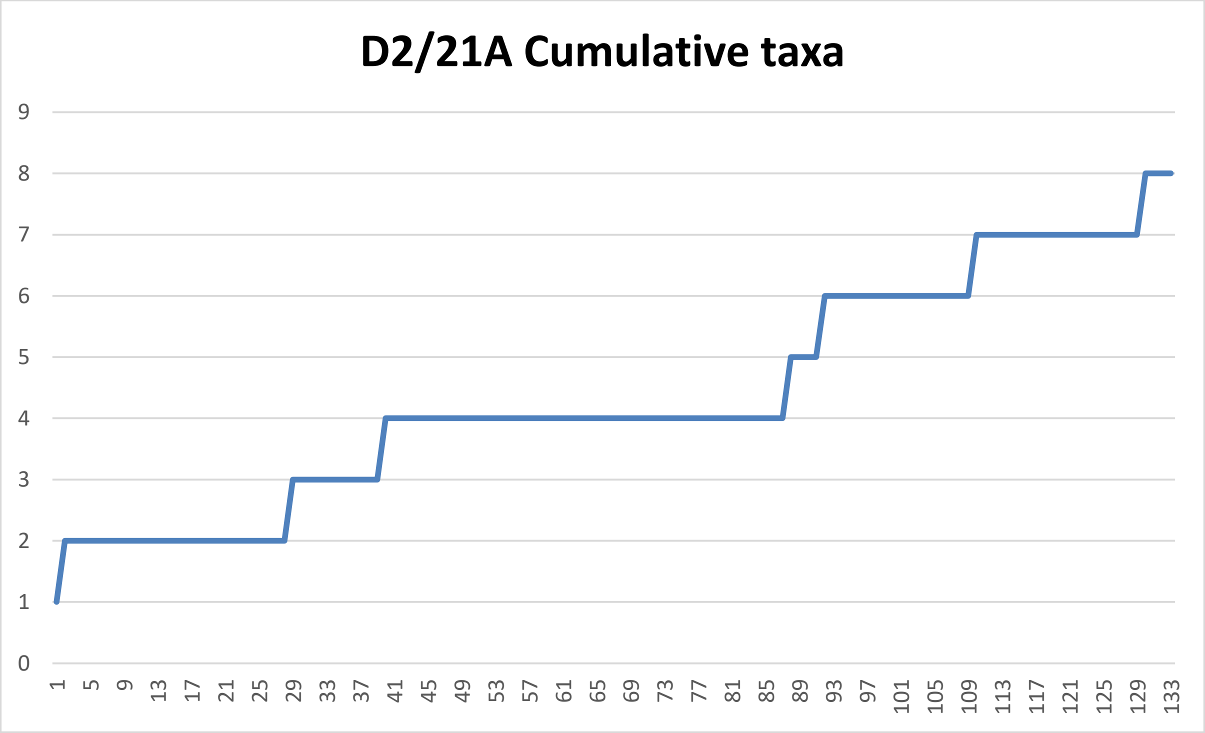

E4/6A Cumulative taxa
16
14
12
10
8
6
4
2
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113

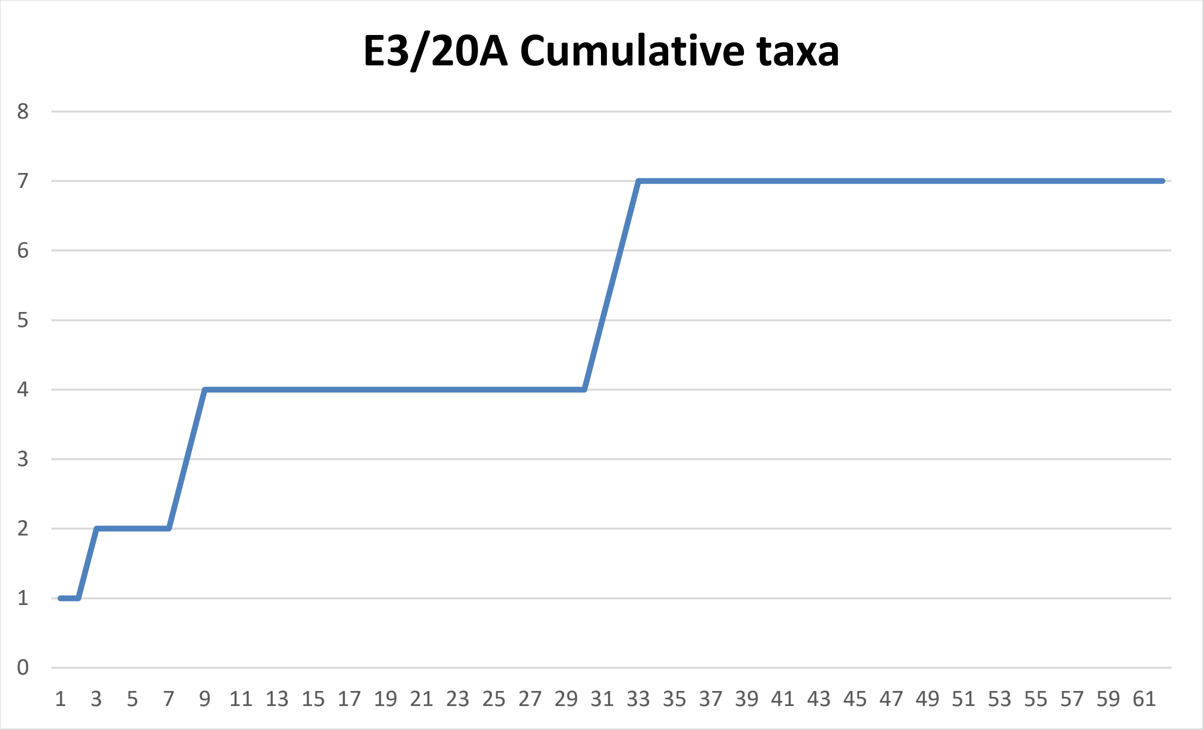

B3/5A Cumulative taxa
14
12
10
8
6
4
2
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97

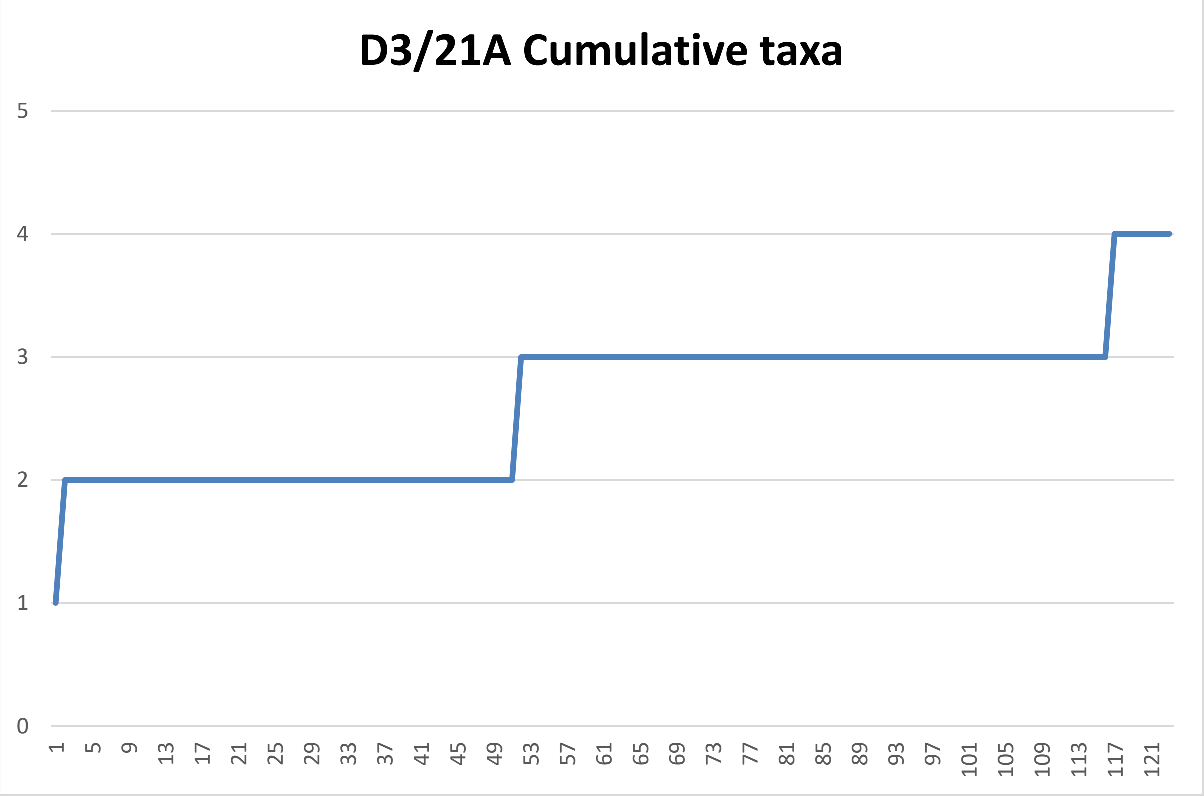

C4/9A Cumulative taxa
0
1
2
3
4
5
6
7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

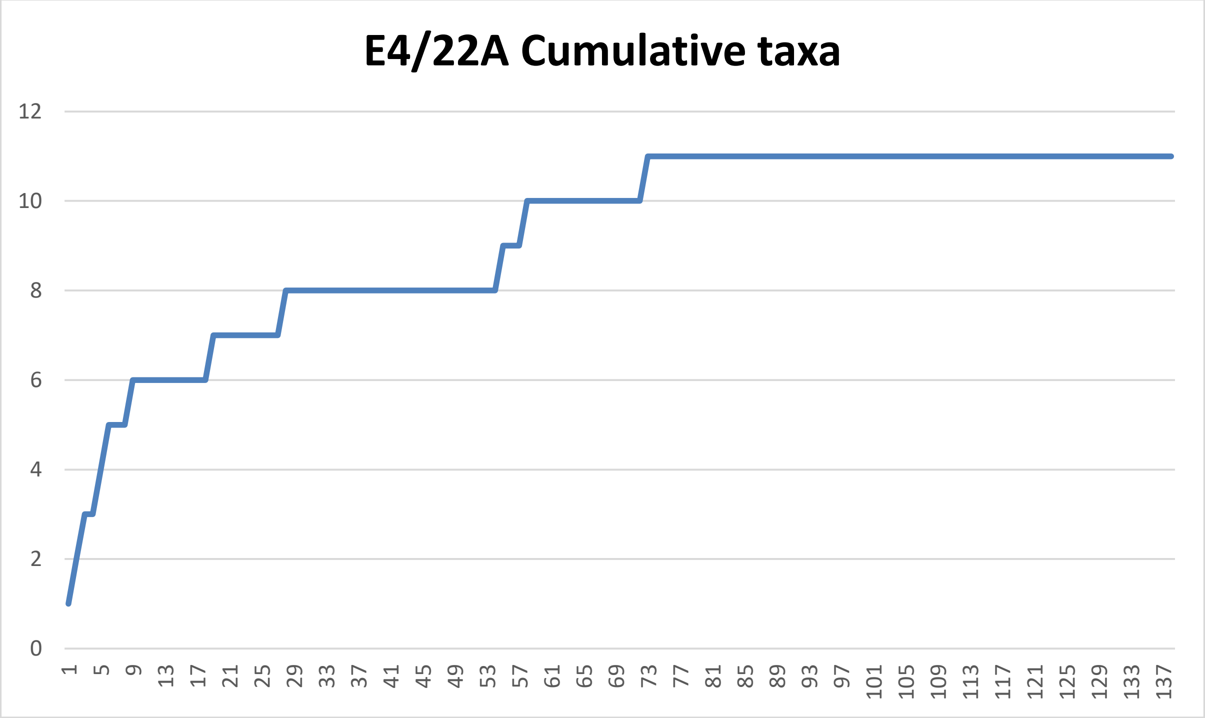

D3/16B Cumulative taxa
0
1
2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

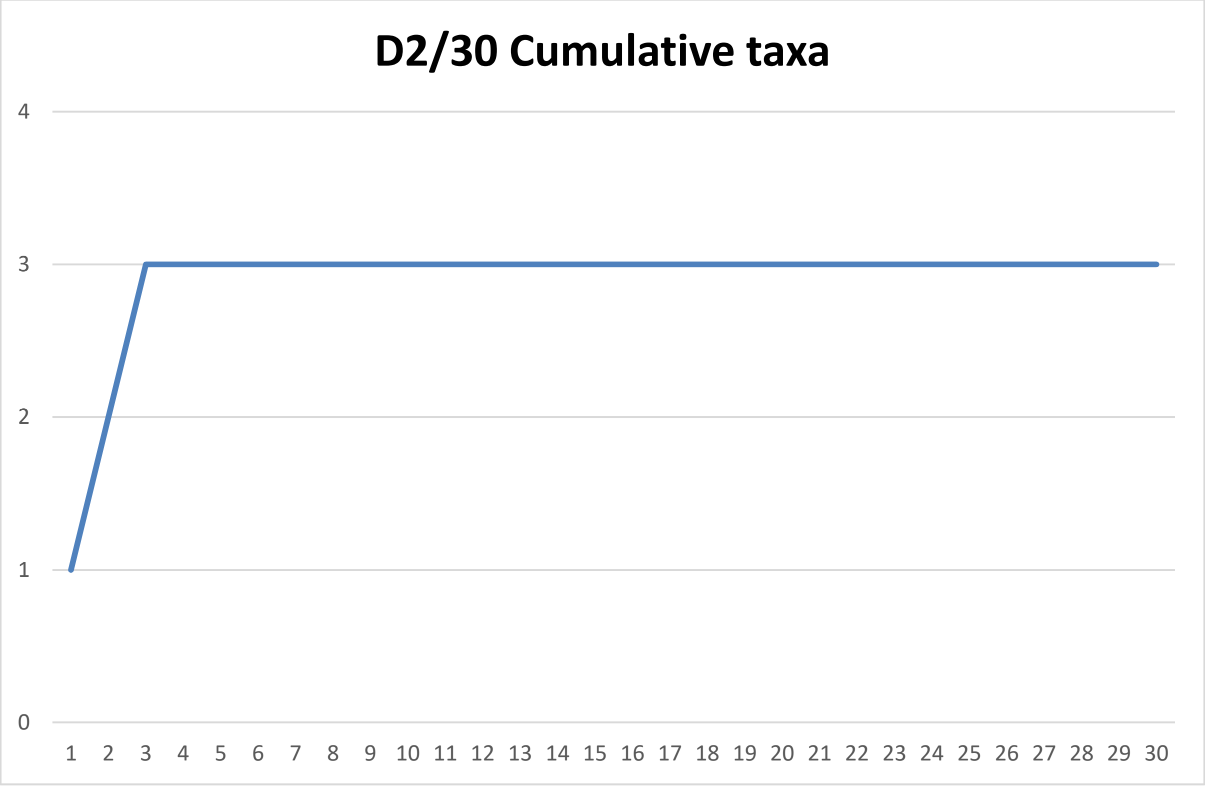

C3/18A Cumulative taxa
0
1
2
3
1 2 3 4 5 6 7 8 9 10 11 12

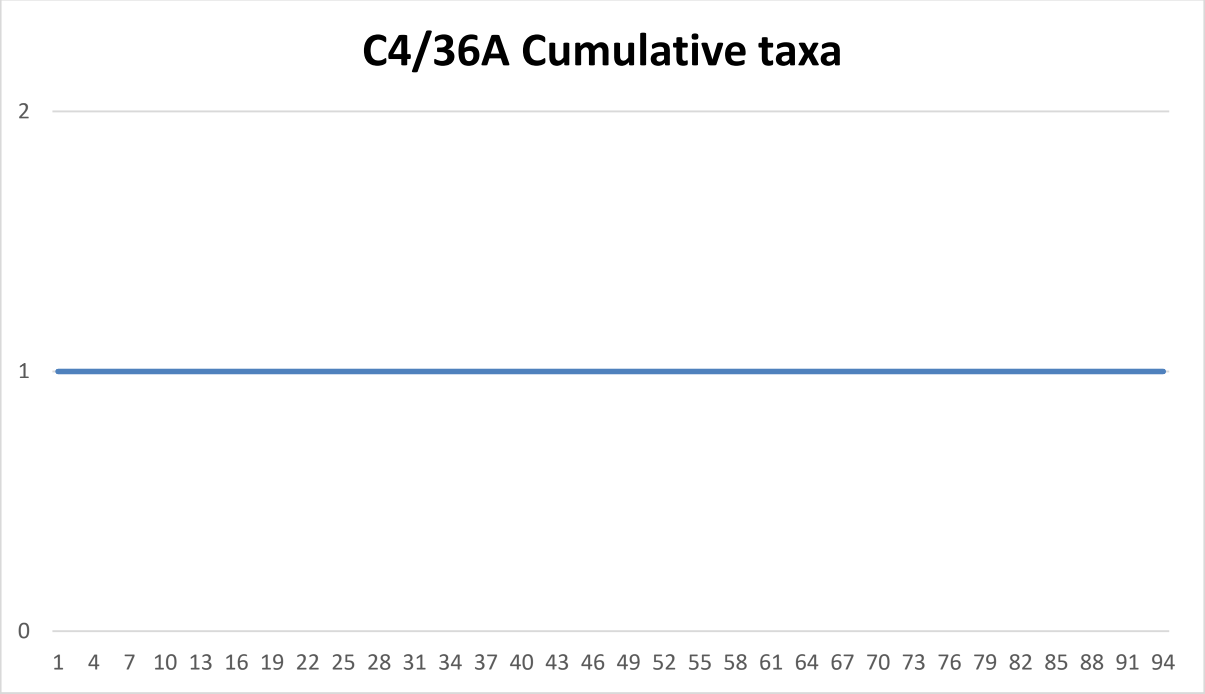

D2/21A Cumulative taxa
0
1
2
3
4
5
6
7
8
9
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133


E3/20A Cumulative taxa
8
7
6
5
4
3
2
1
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61

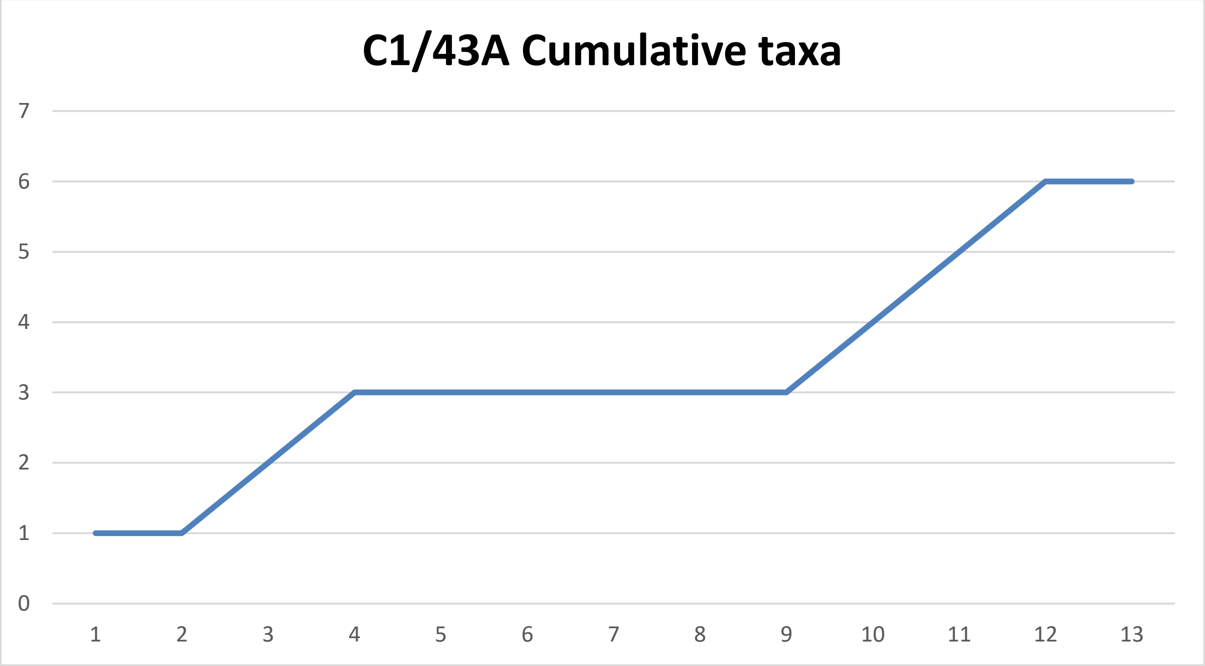

D3/21A Cumulative taxa
5
4
3
2
1
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121


E4/22A Cumulative taxa
12
10
8
6
4
2
0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
101
105
109
113
117
121
125
129
133
137


D2/30 Cumulative taxa
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30



C4/36A Cumulative taxa
2
1
0
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
52
55
58
61
64
67
70
73
76
79
82
85
88
91
94

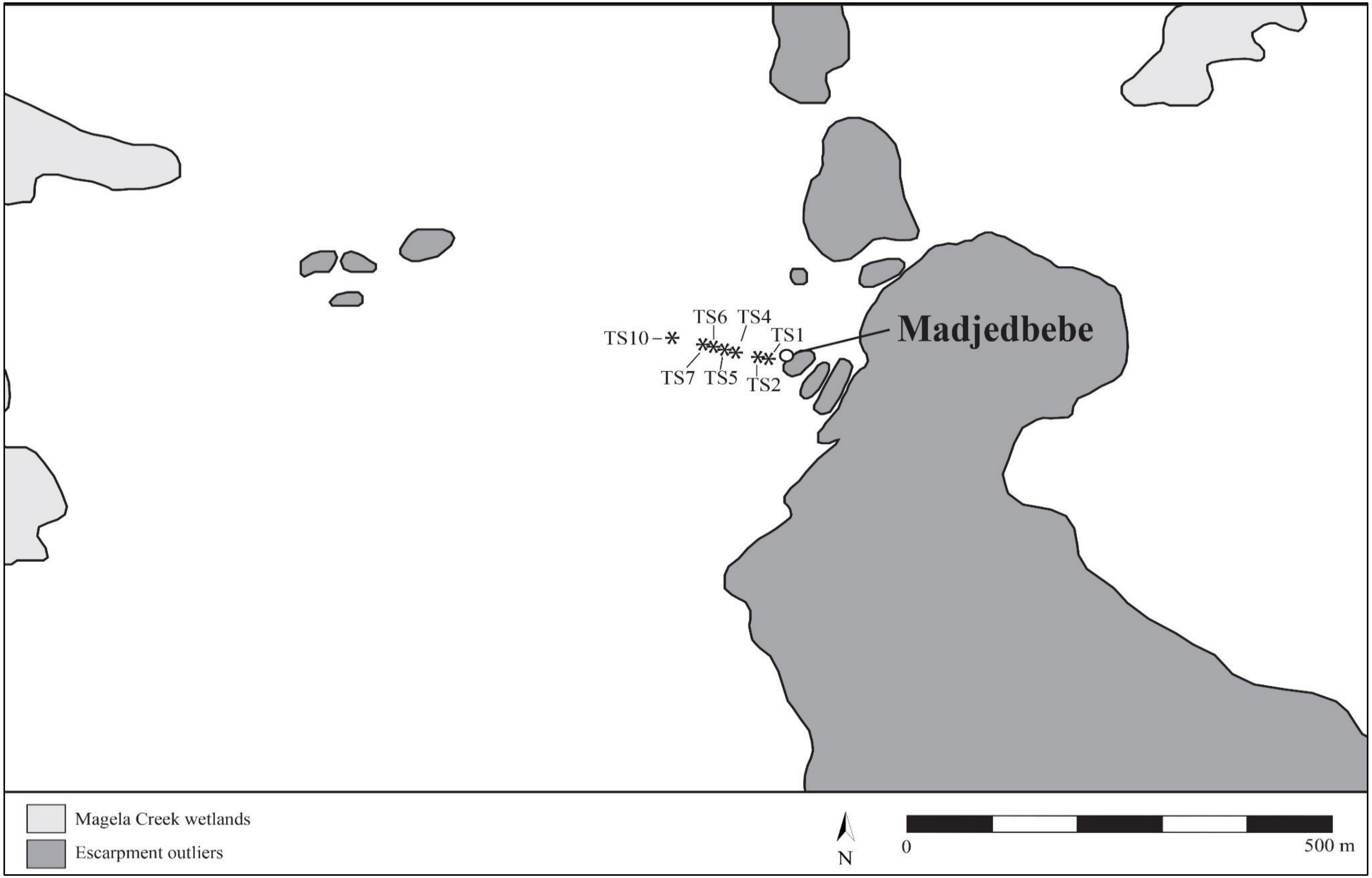


C1/43A Cumulative taxa
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13

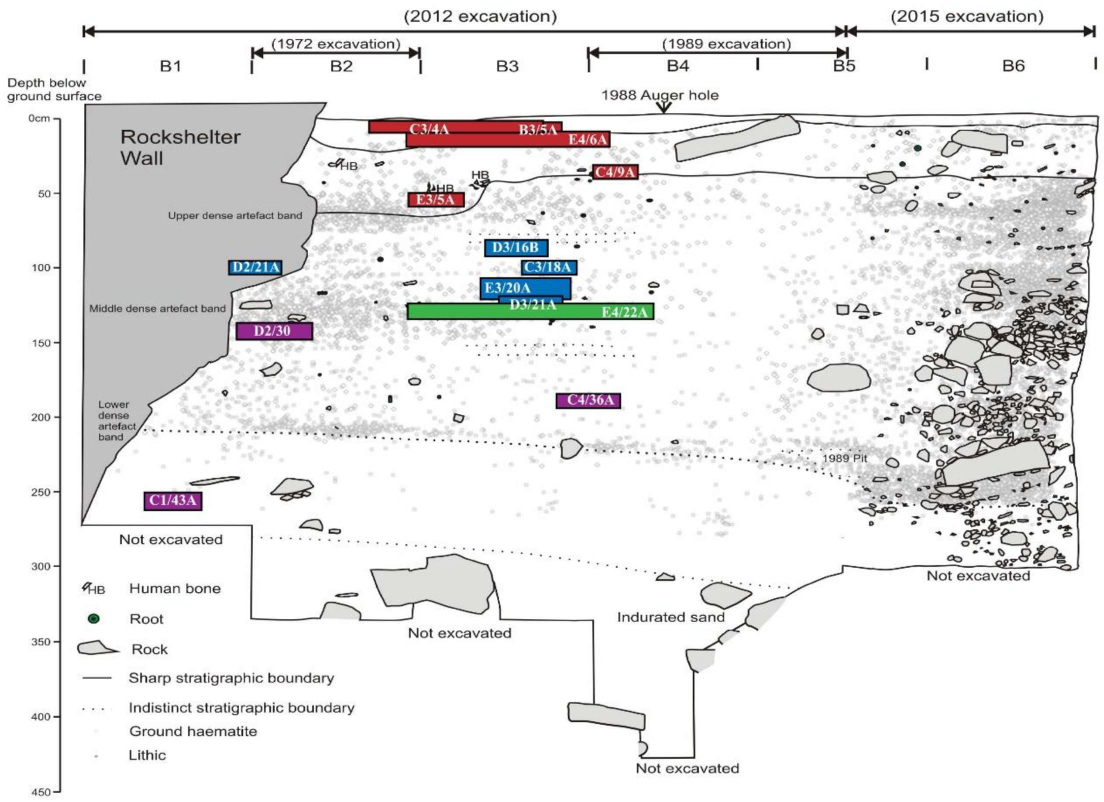
Appendix M – Map of environmental transect charcoal collection sites

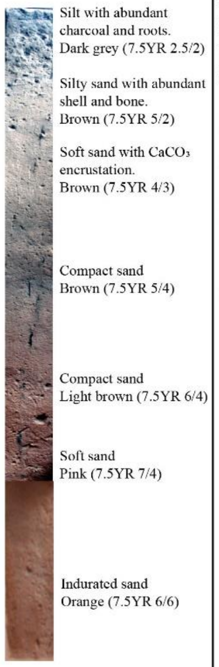
Following page.

Map of environmental transect samples – TS1, TS2, TS4, TS5, TS6, TS7, TS10


TS6
TS4
TS10
TS1
Madjedbebe
TS7
TS5
TS2
Magela Creek wetlands
Escarpment outliers
N
0
500 m

Appendix N – ‘Phase Model’





Silt with abundant charcoal and roots.
Dark grey (7.5YR 2.5/2)

Silty sand with abundant shell and bone.
Brown (7.5YR 5/2)

Soft sand with $CaCO_3$ encrustation.
Brown (7.5YR 4/3)

Compact sand
Brown (7.5YR 5/4)

Compact sand
Light brown (7.5YR 6/4)

Soft sand
Pink (7.5YR 7/4)

Indurated sand
Orange (7.5YR 6/6)

Hearths (yr cal BP)

Late Holocene
E3/5A - 240-7
C3/4A - 260-0
E4/6A - 450-300
B3/5A - 720-650
C4/9A - 2860-2760

Early Holocene
D3/16B - 8600-8460
C3/18A - 9130-9000
D2/21A - 9398-9034
E3/20A - 12810-12710
D3/21A - no date

Last Glacial Maximum
E4/22A - 18690-18410

Oldest hearths
D2/30 - no date
C4/36A - 24970-24340
C1/43A - no date

Climate

4,000 BP-present
Current climate and rainfall

7,500-4,000 BP
Current ENSO climate system established increased variability in rainfall.
(Schulmeister and Lees 1995:14)

14,000-7,500 BP
Wetter warmer conditions, increased rainfall and atmospheric CO_2 driving vegetation growth.
(Allen and Barton 1989:10; Reeves et al. 2013a:24)

22,000-18,000 BP
LGM - reduction in temperature and rainfall
(Reeves et al. 2013b:100, 108)

30,000 BP
Cooling and drying trend
(Williams et al. 2009:2414)

Phases of landscape evolution

2,000-present
Cuspate Phase

5,300-2,000 BP
Sinuous Phase
2,000-1,700 BP at Jabiluka Billabong

6,800-5,300 BP
Big Swamp Phase

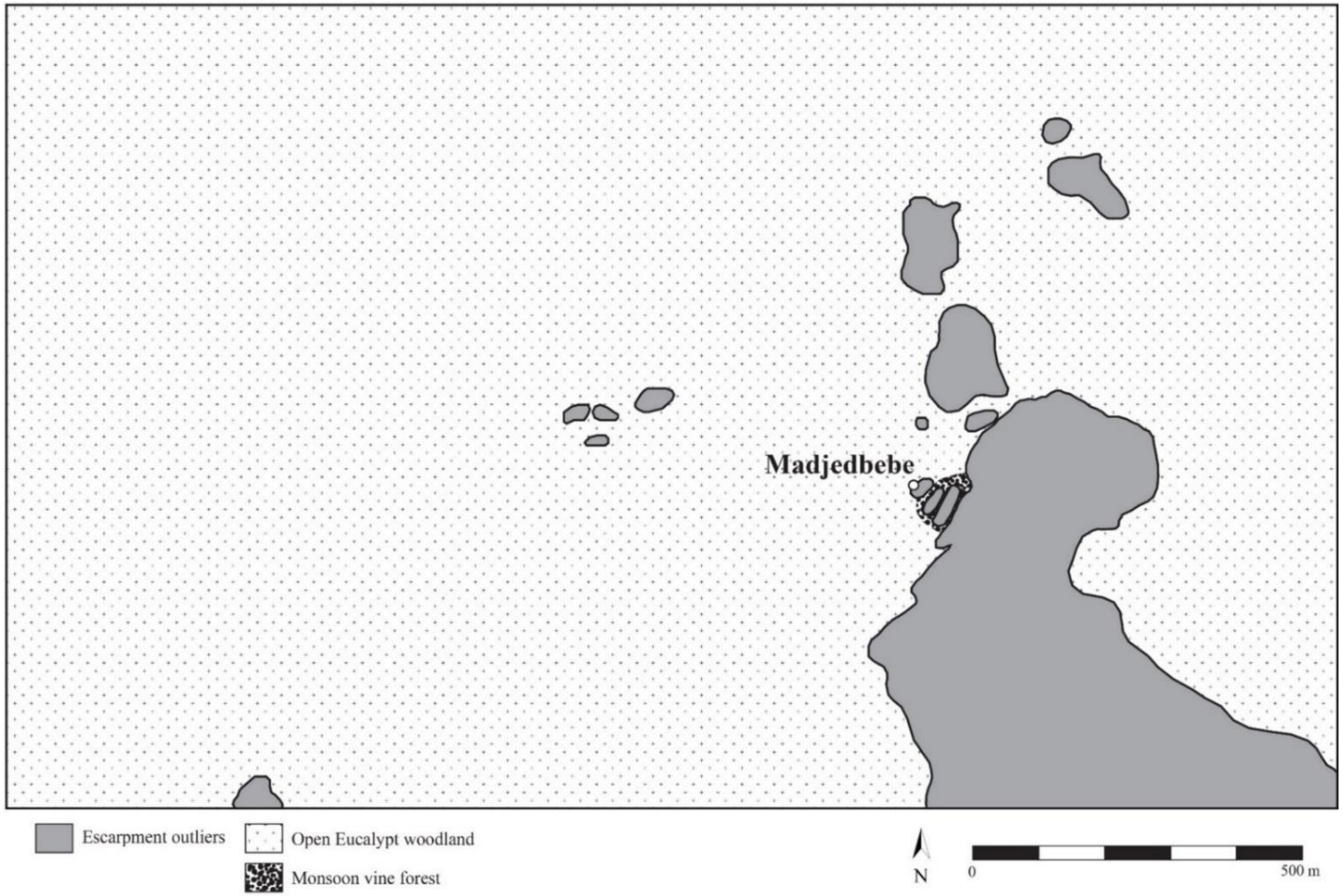
8,000-6,800 BP
Transgressive Phase
7,700 BP at Jabiluka Billabong

Vegetation

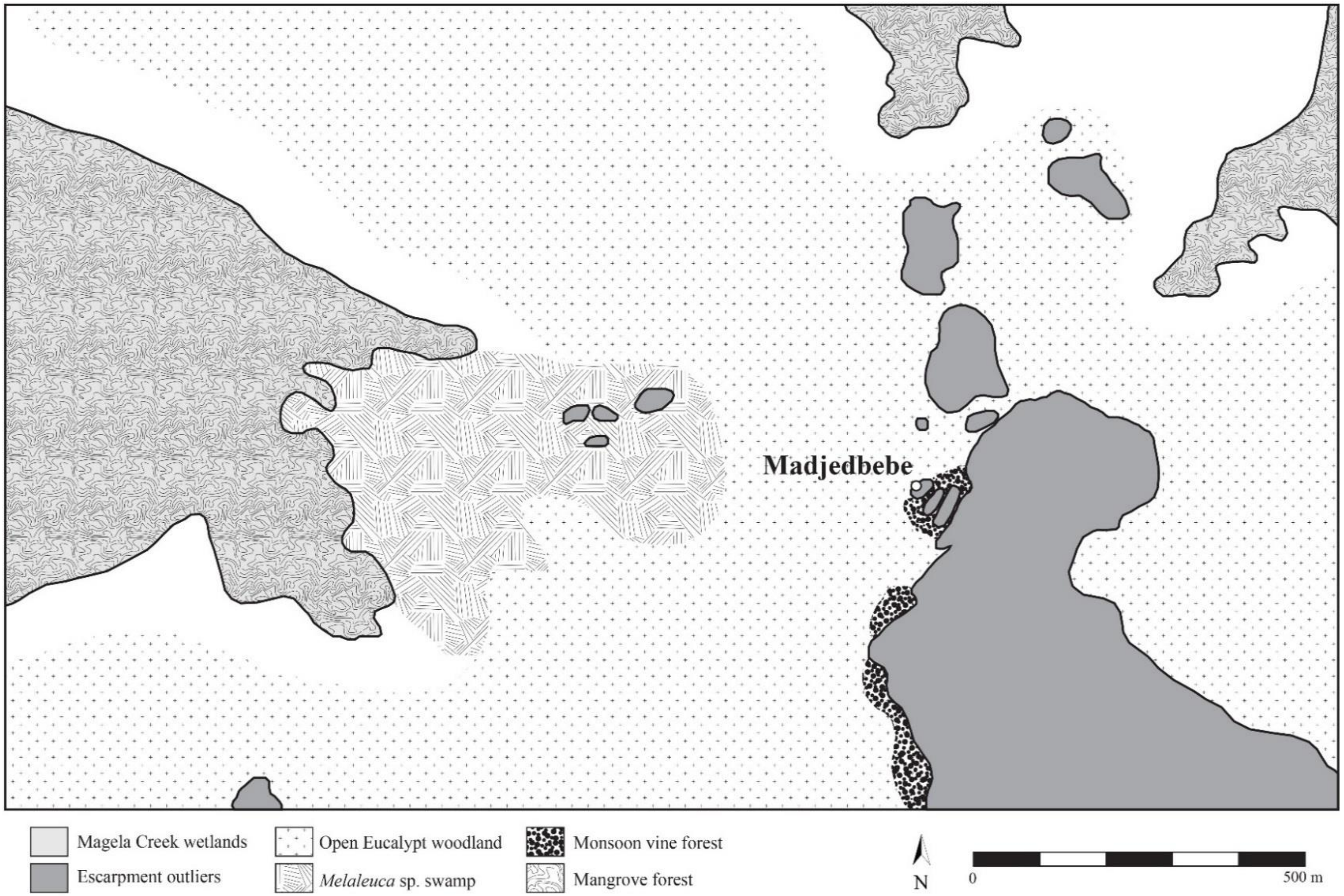
150-100 BP
Decline in *Callitris* sp.
Last 1000 years
Increase in *Acacia* sp.
Last 3000 years
Increase in Cyperaceae
5,000-3,000
Eucalyptus sp. and *Melaleuca* sp. woodland present
6,800-5,300 BP
Myrtaceous woodland and mangrove forest present
(Clark et al. 1992:88; Woodroffe 1988:6-7)
8,000-6,800 BP
Mangrove forests present
Monsoon forest resurgent
Decreased arid taxa
(Allen and Barton 1989:10; Nix and Kalma 1972:87; Woodroffe 1988:3)
12,000-8,000 BP
Arid-sensitive communities re-established
(Reeves et al. 2013b:102)
18,000-12,000 BP
Woodland cover resurgent post-LGM.
(Williams et al. 2009:2409)
22,000-18,000
Decrease in woodland cover, tropical lowland forest and open woodland persisted in areas.
(van der Kaars et al. 1991; Pickett et al 2014:1433)
22,000-30,000
Callitris comes to dominate the vegetation
(van der Kaars et al. 2006:888)

Appendix O – Hypothesised vegetation distributions 16k BP, 7k BP, and 1k BP

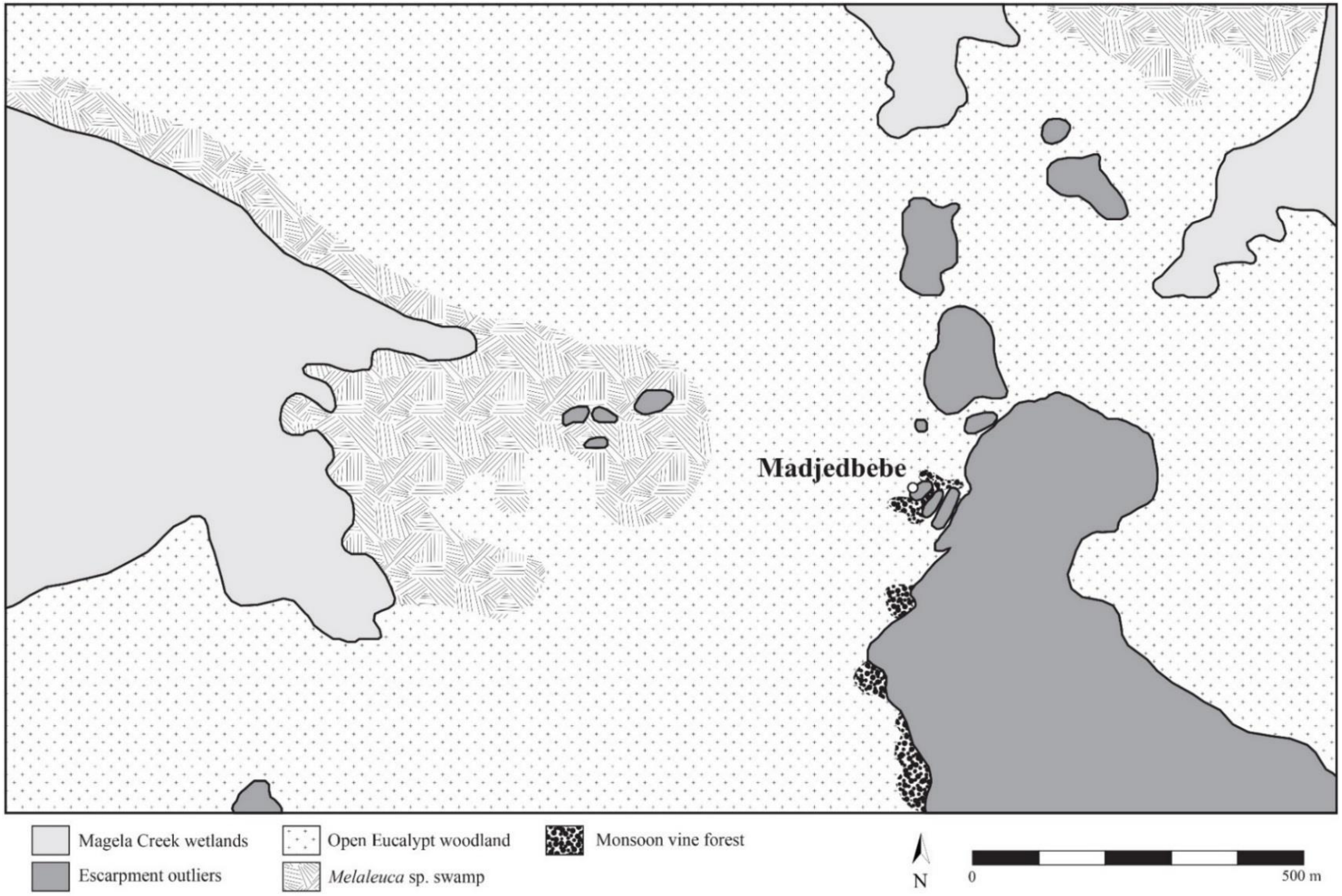
Hypothesised distribution of vegetation communities at 16k BP, 7k BP, and 1k BP.



Hypothesised distribution of landscape features and vegetation communities after the LGM c. 16,000 BP.



Hypothesised distribution of landscape features and vegetation communities in the mid Holocene c. 7,000 BP.

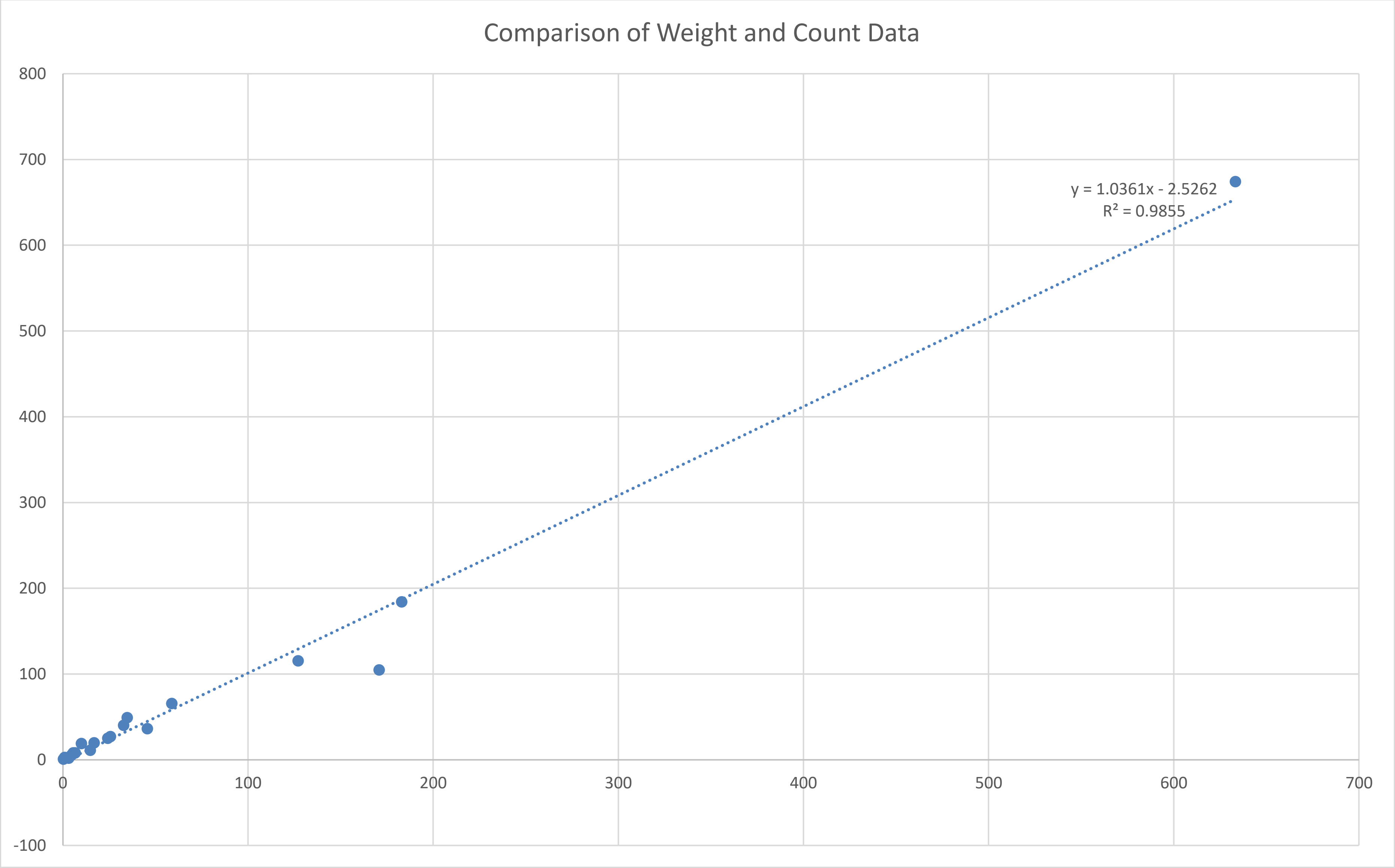


Hypothesised distribution of landscape features and vegetation communities during the late Holocene c. 1,000 BP.

Appendix P – Weight and count data for each taxon

The table includes weight and count data for each taxon and the graph on the following page demonstates a statistically significant R_2 value of 0.9855 for the correlation of weight and count data.

	Weights (g)	**Count**
Acacia sp.	633.3417	674.1341
Alphitonia sp.	16.88254	19.63268
Alstonia sp.	1.009564	2.744546
Asteromyrtus sp.	5.548436	8.061099
Brachychiton sp.	6.625706	7.933429
Callitris sp.	182.9852	184.1512
Calytrix sp.	4.664752	5.422071
Coelospermum sp.	0.332705	0.746269
Corymbia sp.	25.65092	27.14079
Eucalyptus sp.	170.8045	104.677
Ficus sp.	45.63462	36.20718
cf. *Flueggea* sp.	10.02866	18.87026
Grewia sp.	14.73455	10.9834
Lophostemon sp.	3.094404	1.761149
cf. *Pavetta* sp.	127.0685	115.3529
Proteaceae	24.29782	25.125
Terminalia sp.	34.68955	48.98337
cf. *Thespesia* sp.	58.88473	65.65846
Type 24	0.897076	2.178709
Type 48	32.82405	40.23636


Comparison of Weight and Count Data
y = 1.0361x - 2.5262
R² = 0.9855
800
700
600
500
400
300
200
100
0
-100
0
100
200
300
400
500
600
700