

People-plant interaction and economic botany over 47,000 years of occupation at Carpenter's Gap 1, south central Kimberley

India Ella Dilkes-Hall¹, Sue O'Connor^{2,3}, and Jane Balme¹

¹ Archaeology, M257, School of Social Studies, University of Western Australia, 35 Stirling Highway, Crawley, WA, 6009, Australia

² Archaeology and Natural History, School of Culture, History, and Language, College of Asia and the Pacific, Australian National University, ACT, 0200, Australia

³ ARC Centre of Excellence for Australian Biodiversity and Heritage, Australian National University, Canberra, 0200, Australia

india.dilkes-hall@research.uwa.edu.au ORCID 0000-0002-6487-0043

sue.oconnor@anu.edu.au ORCID 0000-0001-9381-078X

jane.balme@uwa.edu.au ORCID 0000-0003-1387-9379

Corresponding author: India Ella Dilkes-Hall, india.dilkes-hall@research.uwa.edu.au

Abstract

Systematic archaeobotanical analysis, conducted in conjunction with archaeological enquiry at Australian archaeological sites, is still rare despite recent developments. It is rarer still that previously analysed macrobotanical assemblages are revisited over time. Extending on macrobotanical research conducted by McConnell in 1997, this paper presents the results of a recent analysis of Carpenter's Gap 1 non-woody macrobotanical remains (seeds, fruits, nuts, and other floristic elements) from the deepest square with the longest chronology, Square A2. Over 47,000 years of time is represented in the sequence, and excellent chronological control, coupled with preservation of carbonised and desiccated macrobotanical remains in the earliest cultural units, allows an examination of plant exploitation over time and human responses/adaptations to periods of documented climatic instability. Carpenter's Gap 1 macrobotanical remains show that diet, subsistence, and site occupation were intimately associated with botanical resources derived from ecologically productive monsoon rainforest environments.

Keywords: Australian archaeology; archaeobotany; macrobotanical remains; economic resource patterning; monsoon rainforest

Introduction

Macrobotanical remains (here referring to seeds, nuts, fruits, and other floristic elements but excluding wood charcoal) are often collected from surface and/or Holocene deposits at Australian archaeological sites (e.g. Atchison 2009; Atchison et al. 2005; Beaton 1982; Beck 1982, 1989; Clarke 1985, 1989; Cosgrove et al. 2007; O'Connor 1999; Schrire 1982; Smith 1982). To date, analyses of macrobotanical remains recovered from Pleistocene deposits are restricted to three archaeological

sites across Australia's tropical north (Figure 1): Carpenter's Gap 1 (hereafter CG1) (McConnell 1997), Madjedbebe (Florin 2013), and Riwi (Dilkes-Hall 2014).

[Figure 1]

While the study of wood charcoal macroremains can provide information on fuel use and palaeoenvironment (e.g. Dotte-Sarout et al. 2015; Whitau et al. 2017), non-woody remains are the most direct link to subsistence. This paper presents results from recent analysis of macrobotanical remains from the CG1 rockshelter where occupation began between 51,000 and 45,000 cal BP (Maloney et al. 2018). Here we identify economic botanical remains and present an investigation of the history of plant use at CG1. The macrobotanical record is examined in relation to changes in other archaeological evidence and environmental change, including the Last Glacial Maximum (LGM), to determine how food plant selection was influenced over time.

Carpenter's Gap 1 rockshelter

CG1 is a large north-facing limestone rockshelter on Bunuba country in the Napier Range, a 350 million year old remnant Devonian limestone reef complex (Playford et al. 2009), in south central Kimberley, northwest Western Australia (Figure 1). The site has continuing significance for Bunuba people. The rockshelter is positioned ~25 m above the savannah plain and is roughly 4 km from a permanent water pool formed by the Lennard River at Windjana Gorge to the west (Figure 1). CG1 contains a variety of archaeological evidence spanning a period of around 50,000 years (Maloney et al. 2018). Alkaline sediments and the protection of the deposit by large limestone boulders create excellent preservation conditions for organic remains (O'Connor 1995).

Contemporary climate and vegetation

The area receives 85% or more of its rainfall between November and April (600-800 mm per annum), creating distinct wet and dry seasons (Bureau of Meteorology 1996). The tropical, semi-arid, monsoonal climate of the Northern Botanical Province (Beard 1979; Gardner 1944), where the Napier Range is situated, affects vegetation diversity, with CG1 located along the border of two major botanical districts: Dampier and Fitzgerald. Extensive botanical survey and collection has helped to build a picture of modern vegetation surrounding CG1 and develop specific archaeobotanical reference collections (Dilkes-Hall 2014; Frawley 2010; McConnell 1997; Wallis 2000; Whitau et al. 2017). The surrounding vegetation can be divided into three broad vegetation groups: monsoon rainforest, savannah, and riparian (Figure 2).

[Figure 2]

The rockshelter itself is devoid of vegetation, a result of limited sunlight and water. A distinct pocket of monsoon rainforest (also known as dry rainforest or monsoon vine thicket [Gillison 1987]) is present in a fire shadow less than 50 m west of the rockshelter. This vegetation group includes *Celtis* sp. (hackberry), *Diospyros* sp. (ebony), *Grewia* spp. (currant fruit), *Ficus* spp. (fig), *Melia azedarach* (white cedar), *Flueggea virosa* (white currant), *Terminalia* spp., and *Vitex* spp. (black plum). The savannah plain that extends northwards towards the King Leopold Ranges is

dominated by annual and ephemeral tussock grass species (primarily *Enneapogon* spp. [nine awn grass] and *Sorghum* spp. [sorghum]). Also included in the savannah group are plants that grow on the gravelly skeletal soils of the talus slope below CG1: *Adansonia gregorii* (boab), *Cochlospermum fraseri* (kapok), and *Triodia* spp. (spinifex) species. The riparian group consists of scattered trees (*Corymbia* spp. [bloodwood] and *Eucalyptus* spp. [Eucalyptus]), Cyperaceae (sedges), *Oryza australiensis* (native rice), and *Phragmites karka* (tropical reed), plants that predominantly grow in association with waterways and floodplains. Many of these plants are important to Aboriginal people and used for food, fuel, medicine, and plant-based technologies (e.g. Crawford 1982; Davis et al. 2011; Karadada et al. 2011; Paddy et al. 1993; Scarlett 1985; Smith and Kalotas 1985; Wightman 2003).

Materials

Excavation

O'Connor and colleagues (O'Connor 1995) excavated five 1 m² squares of archaeological deposit at the site (Figure 3) over two field seasons in 1993 and 1994. In 1993 excavation of squares A and B followed arbitrary excavation units (XUs) approximately 2 cm thick. In 1994 squares AA, A1, and A2 were excavated following XUs within stratigraphic units (SUs) with hearths excavated separately (Maloney et al. 2018). All sediments were sieved through 6 mm and 3 mm nested screens.

[Figure 3]

Stratigraphy and chronology

Eight stratigraphic units (SUs) were identified in Square A1 with SUs 8-4 representing the Pleistocene and SUs 3-1, the Holocene (Vannieuwenhuyse et al. 2017). Over 100 radiocarbon dates were obtained for CG1 and a Bayesian model was constructed to produce the six chronological phases (Maloney et al. 2018:216) summarised in Table 1.

[Table 1]

Previous macrobotanical research at Carpenter's Gap 1

The year 2017 marked 20 years since research was undertaken on macrobotanical materials at CG1 by McConnell (1997) who analysed some ~2,500 macrobotanical remains from Square A. Changes in taxa over the 40,000 years of time represented were used to construct a vegetation history for the surrounding area (McConnell and O'Connor 1997:25). McConnell (1997) interpreted changes in taxa over time as a proxy for vegetation change and, by inference, climate change. Shifts from monsoon rainforest to arid adapted taxa were interpreted in terms of water availability, thus a drier environment was inferred for units where arid taxa are recovered (McConnell and O'Connor 1997:29).

Subsequent phytolith (Wallis 2000) and charcoal (Frawley 2010) analyses at CG1 highlighted the issue of drawing largely palaeoenvironmental conclusions from a culturally biased sequence in which human agency also influences the presence or absence of plant remains in archaeological sites. Not only are people highly selective in their choices of economic plants brought to a site, but they may also transport

plants between different ecological zones. For example, there are records of Kimberley Aboriginal groups trading botanical resources over long distances for a variety of economic, social, ceremonial, and medicinal reasons (Blythe and Wightman 2003; Crawford 1982; Davis et al. 2011; Edgar et al. 1997; Ens et al. 2017; Karadada et al. 2011; Paddy et al. 1993; Scarlett 1985; Smith and Kalotas 1985; Wightman 2003).

McConnell's (1997:69) taxonomic identification of macrobotanical remains was aided by a comparative collection compiled from botanical collection fieldtrips around CG1 and vouchered comparative material housed at multiple Herbaria across Australia. However, in the course of more recent work taxonomic misidentification of some CG1 macrobotanical remains identified by McConnell (1997) has been found (Dilkes-Hall 2014). Access to and development of comparative reference collections has improved over the past 20 years and reference material collected in recent years (Dilkes-Hall 2014) has allowed for corrections of some of McConnell's (1997) identifications.

Square A2 has the deepest deposit and most complete chronostratigraphic sequence at CG1 (Maloney et al. 2018) providing a larger sample of macrobotanical remains and an additional 10,000 years of depositional sequence to Square A. Using a more complete reference collection than was previously available more precise levels of taxonomic assignment and identification have been achieved for a larger sample.

Methods

Square A2 plant macroremains from the 6 mm and 3 mm screens were sorted to genus level at the Australian National University (ANU) during 1998-1999, with assignment of taxonomic identifications based on McConnell's (1997) research (Lynley Wallis pers. comm. 2017). In 2017 these identifications were verified and, where possible, refined to higher level taxonomic identifications by Dilkes-Hall.

Following guidelines outlined by Cappers and Bekker (2013), Clarke (1989), and Fritz and Nesbitt (2014) further sorting was carried out using a low powered (x10) dissecting microscope. Taxonomic identifications were based on morphological characteristics using comparative material from vouchered botanical collections housed at the Western Australian Herbarium, Western Australian Museum (Crawford 1982; Smith and Kalotas 1985), ANU (McConnell 1997), University of Western Australia (Dilkes-Hall 2014), and the Australian National Herbarium-Commonwealth Scientific and Industrial Research Organisation (CSIRO). Photographs of representative/paradigm/type examples (of) macrobotanical materials were taken using a JEOL JCM-6000 Neoscope Scanning Electron Microscope (SEM).

Taxonomically identified and unidentified macrobotanical material were quantified using number of identified specimens (NISP) to measure taxonomic abundance (Grayson 1984:90-92), and weight (Beck 2006; Clarke 1989; Fritz and Nesbitt 2014). The fragmentary and fragile nature of cf. *Triodia* culms cause them to break during sorting and, to reduce damage from over-handling, were weighed only. Unidentified materials, assigned numerical codes and descriptive names in the laboratory, were grouped and presented as indeterminate.

Results

Twenty-three taxa from 13 families were identified to varying taxonomic levels. Table 2 presents the identified taxa, separated into desiccated and carbonised material, expressed by absolute count (NISP), weight, and relative frequency. In some cases, identification beyond genus was not possible. Recovered fragments of parenchyma tissue were not identified to any taxonomic level. Less than 1% of macrobotanical remains were assigned indeterminate status.

[Table 2]

Desiccated and carbonised macrobotanical remains relative to sediment volume (Figure 4a) and volumetrically adjusted quantities of macrobotanical remains are presented (Figure 4b) for each XU. Culms of cf. *Triodia* are presented by weight in Figure 4c. The primary mode of preservation for macrobotanical material is carbonisation (52.9%) represented across 14 taxa (Table 2). The greatest number of carbonised remains is attributed to *Vitex* cf. *glabrata* (black plum). Overall, the three major contributors to the macrobotanical assemblage calculated by NISP are *V. cf. glabrata* (n=4,536, 57.8%), cf. *Grewia breviflora* (currant bush) (n=1,081, 13.8%), and *Terminalia* spp. (n=1,010, 12.9%).

[Figure 4]

Figures 5 and 6 present taxonomically identified macrobotanical remains across the six chronological phases expressed by absolute count and relative percentages (%). The most abundant identified taxa are monsoon rainforest (Figures 5 and 6). Identified taxa listed in order of decreasing relative abundance for each phase are provided in Table 3.

[Figure 5] [Figure 6] [Table 3]

In **Phase 1** *Terminalia* spp. (n=36) and *V. cf. glabrata* (n=5) are recovered and over half (59%) of these remains are carbonised. Low quantities of cf. *Triodia* culms are present.

In **Phase 2** there is a substantially greater number of macrobotanical remains (n=655) and a comparatively higher botanical diversity than Phase 1. *Terminalia* spp. dominate decreasing after XU42 when cf. *G. breviflora* enters the record. *V. cf. glabrata* is present in low numbers. Cyperaceae (stems), *Cyperus bulbosus* (tunic) (bush onion), *Mallotus nesophilus* (yellow ball flower), *Melia azedarach*, *Premna acuminata* (fire stick tree), and parenchyma enter the record in low proportions. Carbonised remains make up 67.32% for this phase excluding cf. *Triodia* culms.

In **Phase 3** the highest number of macrobotanical remains (n=2,102) from all phases was recovered. A large proportion (86%) are carbonised and taxon richness increases. *V. cf. glabrata* is recovered in greater proportions and is present across 20 of the 21 XUs (Figures 5 and 6). Recovered in abundance throughout cf. *G. breviflora* peaks in XU17. *Terminalia* spp. are fewer and *Persoonia falcata* (wild pear), Cyperaceae (stems), and parenchyma are present in low densities. cf. *Triodia* culms peak dramatically in XUs 25 and 15 in quantities not observed in any other XUs.

Macrobotanical remains recovered from **Phase 4** total 1,171 and 85.91% are carbonised. A greater proportion of *V. cf. glabrata* is recovered, considerably so

when compared to other taxa recovered from this phase (Figures 5 and 6).

Terminalia spp. decreases markedly with the largest amount recovered from the boundary of Phase 3/4 decreasing towards the Phase 4/5 boundary (Figures 5 and 6). In contrast, *V. cf. glabrata* was recovered in low densities at the Phase 3/4 boundary and increases towards the top of Phase 4. *Celtis* spp. appears in the assemblage and other taxa that make up minor inclusions are shown in Table 3. *Triodia* culms are present in lower proportions than preceding phases.

The disproportionate quantity of carbonised remains in **Phase 4** relates to two LGM hearths: XU6b dated to 21,261 – 17,812 cal BP and XU6c dated to 21,560 – 19,840 cal BP (95.4% probability range) (Maloney et al. 2018:213). Looking at these hearths in isolation, carbonised remains contribute 50.80% and 98.59%, respectively, and the proportion of *V. cf. glabrata* in these features is high contributing 82.26% (n=102) and 88.77% (n=253), respectively. The earliest observation of *Adansonia gregorii* (nutshell) occurs in these features (Figure 5). In addition, *Celtis* spp., *Terminalia* spp., and cf. *G. breviflora* are present in both hearths in low quantities (n=<20), with *P. falcata* (n=11) present in only one feature.

Following the LGM, 1,806 macrobotanical remains were recovered from **Phase 5**. The proportion of carbonised remains is 27.18% in this phase. *V. cf. glabrata* is the most abundant taxa recovered. Taxon richness increases although no other taxa are recovered in proportions similar to *V. cf. glabrata*. A small amount of cf. *Triodia* culms were recovered and all other taxa occur in low densities (n=<9).

Phase 6 is marked by the highest diversity (Table 3) and the lowest proportion of carbonised remains (18.68%). Of the 23 taxa identified in this study, only five are not recovered from this phase: *M. nesophilus*, *M. azedarach*, Poaceae (stems), cf. *Buchanania obovata* (wild mango), and cf. *Heteropogon contortus* (speargrass). *V. cf. glabrata*, though decreasing slightly in relation to preceding phases, continues to dominate the assemblage. Greater proportions of *A. gregorii* (nutshell), *Terminalia* spp., and *Flueggea virosa* are observed. Culms of cf. *Triodia* were recovered in the lowest proportion of all six phases.

Establishing the source of the macrobotanical remains

Rodent gnaw marks were identified, as they were in the previous analysis (McConnell and O'Connor 1999:30-32). Of the 7,846 macrobotanical remains analysed for this research 114 have observable gnaw marks. Almost all of these (n=111) are on *Terminalia* spp. drupes with the remaining three being on *P. falcata* (n=2) and *V. cf. glabrata* (n=1) endocarps. The size of these marks are attributed to rock-rat species (*Zygomys* spp.) (Begg and Dunlop 1980:65). It is difficult to discern whether the gnawed remains had been brought into the site by rodents or whether remains discarded by humans were subsequently gnawed by rodents. Given the restricted range of taxa affected, we argue that the potential introduction of macrobotanical remains to CG1 by rodents has a negligible effect on the assemblages' botanical diversity and an inconsequential effect on abundances over time.

A variety of evidence suggests that the macrobotanical remains are a result of cultural activity. First, the distribution of the remains correlate well with lithic, faunal, and charcoal records (Figure 7). Second, a high percentage of carbonised

macrobotanical remains are consistently present through time (Figure 4a). Third, the protective rockshelter structure, slope, and the protected location of Square A2, behind fallen boulders (Figure 3), makes it unlikely that macrobotanical material entered the site independently. Fourth, lack of water and little access to sunlight within the rockshelter has inhibited plant growth and no root structures were encountered during excavation suggesting that modern and prehistoric seed rain (cf. Minnis 1981) from plants growing within the rockshelter is not a contributing factor to the formation of the macrobotanical assemblage.

[Figure 7]

Discussion

Taxonomic identification

Vitex cf. *glabrata* is the most abundant taxon represented in the assemblage followed by cf. *Grewia breviflora*. These results differ from those of McConnell's (1997) analysis of Square A in which she identified *Terminalia* species and *Ampelocissus acetosa* (native grape) as the largest contributors to the assemblage. The reason for this difference lies in McConnell's lack of reference material leading to the taxonomic misassignment of *V. glabrata* to *A. acetosa* (McConnell 1997:71). *A. acetosa* and *V. glabrata*, belonging to Vitaceae and Lamiaceae respectively, are distinctly different types of plant, the former a climbing vine and the latter a medium-sized spreading tree (Wheeler 1992:634, 793). *A. acetosa* fruits produce 2-4 boat shaped albuminous seeds per fruit (Jackes 1984:82); perichalaza on the dorsal and raphe on the ventral surfaces of the seed are defining characteristics of genera belonging to the Vitaceae family (Chen and Manchester 2007:1535; Jackes 1984:86) (Figure 9b,d,f). *V. glabrata* is a drupe fruit that produces one ovoid to subglobose drupe per fruit (Munir 1987). Drupes display rugose longitudinally furrowed surface patterning with four ovary chambers that divide the stone internally protecting one exalbuminous seed encased in each chamber (Munir 1987:34) (Figure 8a,c,e).

[Figure 8]

A. acetosa is entirely absent from CG1's macrobotanical sequence. The absence of a plant species well documented as an important botanical resource to Aboriginal groups (e.g. Crawford 1982; McArthur et al. 2000; Scott-Virtue et al. 2011; Smith 1991; Specht 2006; Wijnjorrotj et al. 2005) is curious but explicable by taphonomic and cultural factors. Preservation of macrobotanical material in CG1 deposits is extraordinary and fragile culms of *Triodia* present in the lowest occupation units suggest little preservational bias across plant species. An explanation for the absence of *A. acetosa* seeds from the macrobotanical record may lie in the phytochemistry of Vitaceae seeds which are oily-albuminous and rich in flavonoids, including gallic acid, ellagic acid, catechin, and oligomeric proanthocyanidin, a powerful antioxidant (Wang et al. 2007:544; Wen 2007:469-470). The soft, oily, nutritious, and digestible nature of Vitaceae seeds means they are commonly chewed and ingested. In comparison, the presence of *V. cf. glabrata* is probably owing to its robust endocarp that is unlikely to be ingested whole.

This example of taxonomic misidentification highlights the need for further development of, and accessibility to, comparative botanical reference collections and the value in publishing images of macrobotanical specimens (Figure 9).

[Figure 9]

Plants identified by this research are commonly recognised in historical ethnobotanical literature as economically important to Aboriginal groups across the Kimberley region (e.g. Blythe and Wightman 2003; Crawford 1982; Davis et al. 2011; Kaberry 1935; Karadada et al. 2011; Love 1936; Paddy et al. 1993; Rose 1984; Scarlett 1985; Smith and Kalotas 1985; Wightman 2003). Although it is possible that the roles and uses of plants may have been different in the past, Aboriginal knowledge of these plants should be considered as an important primary source for ecological information.

Plant use over time

Phase 1 (51,000 to 38,800 cal BP)

Favourable climatic conditions for the Kimberley region around the time of first occupation at CG1 are suggested by terrestrial and marine archives (Saltré et al. 2016; Van der Kaars et al. 2006), and the CG1 phytolith record (Wallis 2001) indicates that vegetation communities were comprised of a variety of grasses from moist and arid habitats. Abundance of palm phytoliths indicates readily available water in the area (Wallis 2001:111-113). Low numbers of macrobotanical remains coincident with low numbers of stone tools, faunal remains (Maloney et al. 2018), and charcoal (Frawley and O'Connor 2010), indicate low intensity site use at CG1. Faunal remains, predominantly comprised of reptile bones, suggest hunting and foraging of terrestrial fauna from the arid savannah plains and the presence of fish and freshwater turtle indicate that riparian environments were also exploited (Maloney et al. 2018:221)

Phase 1 macrobotanical remains represent the earliest subsistence activities at the site and show monsoon rainforest taxa were important food plants to Aboriginal groups settling the region. It is unlikely cf. *Triodia* culms represent food waste and these remains have been suggested by McConnell and O'Connor (1997:24-27) as evidence for resin production. Although no traces of resin were found on stone artefacts during this phase (Maloney et al. 2018:218), flakes from polished axes suggest hafting in combination with binding. *Triodia* can be used for a multitude of tasks including fibre technology (Reynen and Morse 2016:100), a potential aid to both composite tool production and early fishing activities.

Phase 2 (41,400 to 27,100 cal BP)

Peaks in fluvial activity, observed in palaeohydrological records from the large Gregory Lakes system, located in the southeast Kimberley, suggest a drier and cooler climate (Reeves et al. 2013; Veth et al. 2009), but vine thicket and palm phytoliths at CG1 suggest wetter local conditions (Wallis 2001). Quantities and diversity of macrobotanical remains increase during this phase. Broader botanical diversity is observed with the addition of riparian taxa and the monsoon rainforest category expands with cf. *Grewia breviflora* and *Mallotus nesophilus* entering the

repertoire. Parenchyma remains suggest the use of roots and tubers (cf. Hather 2000) and macrobotanical remains demonstrate that people were targeting a variety of ecological zones (monsoon rainforest, savannah, and riparian) to procure botanical resources.

Stone artefacts are made from a higher diversity of exploited raw materials but low artefact discard rates suggest infrequent visitation to CG1 (Maloney et al. 2018:218). Reduction in fish remains, and increasing frequency of reptile bones and mammal remains representing small arid adapted mammal species, suggests exploitation of the open plains away from the limestone range (Maloney et al. 2018:225). An increase in cf. *Triodia* culms and the addition of riparian taxa to the macrobotanical sequence support lithic and faunal evidence demonstrating that people were adjusting their subsistence strategies to target the open plains and distant riparian zones.

Phase 3 (29,000 to 21,800 cal BP)

Pre-LGM is characterised by increasing aridity and cooler conditions (Fitzsimmons et al. 2013; Reeves et al. 2013; Turney et al. 2006; Van der Kaars et al. 2006). A marked increase in spinifex phytoliths from CG1 in this phase is argued by Wallis (2001:112) to be an environmental response to decreasing temperatures and water availability. Coincident peaks of cf. *Triodia* culms during this period support a general trend towards aridity but monsoon rainforest taxa continue to dominate the assemblage. Higher botanical diversity, with increases within monsoon rainforest, riparian, and savannah categories, suggest climatic variability leading into the LGM did not detrimentally affect the availability of local botanical resources which might be observed in the macrobotanical record as a shift from monsoon rainforest to savannah taxa.

An increase in mammal and reptile remains suggests an enlarged diet breadth (Maloney et al. 2018:225) also indicated by the macrobotanical record (Table 3). A significant restructuring within the monsoon rainforest category is indicated where *V* cf. *glabrata* becomes proportionately higher than *Terminalia* spp. in terms of abundance. Broadening of the plant diet and diet alteration may reflect increased collection of *V* cf. *glabrata* for nutritional benefits. On average, *Vitex glabrata* has 27.9 g of carbohydrate when compared to 17.2 g for *Terminalia* (*T. ferdinandiana* used for comparison) (Miller et al. 1993:188-191). Thus, the increasing presence of *V* cf. *glabrata* may indicate a need by Aboriginal populations to increase carbohydrate intake.

Phase 4 (22,400 to 17,100 cal BP)

It is generally accepted that cooler and more arid conditions prevailed during the LGM when extensive glaciation lowered sea levels by 120 m (Fitzsimmons et al. 2013; Reeves et al. 2013; Visser et al. 2003). Phytoliths from species belonging to the Ulmaceae family, *Celtis* sp. and *Trema tomentosa* (native peach), that have high water requirements, are absent from CG1 deposits during this period suggesting decreased water availability (Wallis 2001:114). Chenopodiaceae/Amaranthaceae macrobotanical remains, recovered by flotation from large bulk sediment samples, in Square A (McConnell and O'Connor 1997:29) coupled with charcoal analysis that shows an increase in Myrtaceae and Proteaceae taxa in Square A2 (Frawley and

O'Connor 2010) suggests expansion of dry woodlands and grasslands surrounding CG1. However, the macrobotanical remains show that monsoon rainforest habitats were available for exploitation during the LGM and that rainforest taxa were consistently collected throughout this time. In fact, there is no discernible change from monsoon rainforest to savannah taxa, which would indicate a shift in subsistence activities corresponding with unstable climatic conditions and environmental change associated with the LGM. It should be noted however that no flotation has been conducted on the sediment samples from Square A2 and macrobotanical remains used in this analysis were recovered solely from the sieve fractions which no doubt accounts for the lack of small-sized seeds represented in the present study and the differences in species representation between the two studies.

Resilience, tolerance, and flexibility are often cited in reference to subsistence change and technological reorganisation by Aboriginal people in the face of changing climatic and environmental conditions (e.g. Beaton 1982; Lourandos 1983; Veth et al. 2011; Williams et al. 2008, 2013). Less mentioned is the resilience, tolerance, and flexibility of plant populations displayed not only through expansion and retreat but also through adaptability of plant forms and ecological behaviours (Sievers 2006:217) depending on the severity of climate circumstances. The dominance of monsoon rainforest fruits during the LGM suggests local water availability and active periods of rainfall to sustain pockets of monsoon rainforest targeted by CG1 occupants for fruit collection. This record is supported by the Ball Gown Cave stalagmite time series data that suggests an active monsoon system between 24 and 20 kya (Denniston et al. 2013).

Increases in small freshwater fish and mussel shell in the faunal record is interpreted as people accessing Windjana Gorge, roughly 4 km from CG1, for reliable aquatic resources (Maloney et al. 2018). Macrobotanical remains demonstrate the practice of fruit collection continued during this time. The co-occurrence of monsoon rainforest taxa with fish bones indicates that people were probably collecting food plants from the gorge while engaged in other daily economic activities, especially if the monsoon rainforest patch close to the site was reduced.

The LGM macrobotanical remains have less overall botanical diversity than the preceding phase but the monsoon rainforest and savannah categories continue to expand with *Celtis* spp. and *Adansonia gregorii* both entering the CG1 sequence during the LGM. The earliest occurrence of *A. gregorii* in securely dated LGM hearths provides a *terminus ante quem* for the arrival of the plant to the region, its geographical distribution across the Kimberley recently linked to human migrations (Bell et al. 2014; Rangan et al. 2015).

Phase 5 (18,600 to 6,500 cal BP)

In the early deglacial period (18-12 ka) evidence for enhanced monsoonal activity at the late Pleistocene-early Holocene boundary are found in terrestrial (Denniston et al. 2013; Field et al. 2017; Wyrwoll and Miller 2001) and marine (Kuhnt et al. 2015; Van der Kaars and De Deckker 2002; Van der Kaars et al. 2006) palaeoenvironmental records that demonstrate an active monsoonal climate with increased precipitation in the northwest of Australia from ~14,000 cal ka BP.

The very high number of macrobotanical remains almost exclusively dominated by *V. cf. glabrata* (Figures 5 and 6) could indicate increase in site use or larger Aboriginal groups returning to the region after climate amelioration. This evidence together with the lower numbers of savannah species and higher numbers of riparian species than in the previous phase suggests wetter conditions and this matches other terrestrial records that indicate wetter conditions post LGM (Denniston et al. 2013; Field et al. 2017; Wyrwoll and Miller 2001).

Phase 6 (approximately 7,600 cal BP to 300 cal BP)

During the mid-Holocene, prior to 6,300 cal BP, a tropical humid climate with an intense and predictable summer monsoon has been suggested by McGowan et al. (2012). After 3,700 cal BP increased climatic variability, decreased effective precipitation and prolonged drying are linked to the initiation of the current cycle of El Niño–Southern Oscillation (ENSO) (Shulmeister 1999; Williams et al. 2010) with a phase of extreme aridity between 2,400 and 1,300 cal BP, before modern summer monsoon systems were established (Field et al. 2017).

Phase 6 macrobotanical remains have the highest botanical diversity of all phases. Large quantities of charcoal (Frawley and O'Connor 2010) and macrobotanical remains suggest increased site use and wood shavings suggest manufacture of plant-based technologies at CG1 (Maloney et al. 2018:224). Resin adhesive recorded on stone tools during this phase is suggested by Maloney et al. (2018:226) as evidence for the development of new stone technologies, such as hafted points, and an increase in large macropods in the faunal record supports this view. The *cf. Triodia* culms recovered in this phase could be related to the production of resin adhesive.

Phase 6 is also dominated by seasonally available monsoon rainforest taxa although to a lesser degree than in preceding phases. Upper XUs indicate a reorganisation of diet with focus shifting from *V. cf. glabrata* to include other monsoon rainforest taxa. Substantial increases in *A. gregorii* nutshell in the late part of Phase 6 do not necessarily reflect preservational bias in the macrobotanical assemblage because the nutshell is robust. Instead, we suggest change in subsistence strategies to manage inferred foraging risk associated with ENSO, which is often related to technological adaptation, risk minimisation, and changes in social and economic strategies (Beaton 1982:56; Veth et al. 2011:7; Williams et al. 2008:256).

Monsoon rainforest

Of the three broad vegetation groups defined for the area surrounding CG1 (monsoon rainforest, savannah, and riparian), monsoon rainforest taxa contribute the highest proportions of plant macroremains to the CG1 Square A2 assemblage in all six phases. The three most common taxa recovered, *Vitex cf. glabrata*, *cf. Grewia breviflora*, and *Terminalia* spp., are fruit-bearing trees that rely on monsoonal rains for fruit development restricting fruit production and availability of these taxa to wet months (Nov–April) (Kenneally et al. 1996:88; Wheeler 1992:167, 794). It is likely that occupation of CG1 followed the pattern identified in more recent historic sources that relate the spatial location of Aboriginal camps in the Kimberley to yearly climatic cycles (wet season camps located in caves and rockshelters/dry season camps situated in the open at locations with permanent water [Scarlett 1985:5]).

Patches of monsoon rainforest are often associated with important Aboriginal cultural sites and rock art (Karadada et al. 2011; Pickerd 2014; Wunambal Gaambera Aboriginal Corporation 2010) and, being recognised as primary resources for food gathering, are protected by Aboriginal groups who fire surrounding grassland to protect patches from catastrophic fire (Mangglamarra et al. 1991:413). Monsoon rainforest ecological zones are shown here to be comparatively important to Aboriginal groups in the past. At CG1 the macrobotanical assemblage demonstrates diet, subsistence strategies, and site occupation were scheduled around the availability of monsoon rainforest taxa. Depletion of important botanical resources was avoided by seasonal scheduling and, perhaps, similar practices used by Aboriginal groups today were employed to ensure future availability of these seasonal resources.

Conclusion

Greater chronological resolution, a longer time span represented, a larger analysed sample, and a better understanding of site formation processes have greatly improved macrobotanical research at CG1, providing a deeper understanding of Aboriginal plant use. The vast majority of CG1 Square A2 macrobotanical remains are taxonomically identifiable and attributable to human food gathering activities. Identified plant species establish a pattern of resource procurement where Aboriginal groups occupying CG1 heavily targeted monsoon rainforest ecological zones for food plants, particularly *Vitex* cf. *glabrata*, cf. *Grewia breviflora*, and *Terminalia* species.

Decreased water availability during arid phases suggests that monsoon rainforest probably retreated, but the presence of monsoon rainforest taxa throughout the deposit indicates that pockets persisted even during periods of major climatic change, which are associated with changes in the distribution of vegetation communities. Continued visitation to CG1 during arid phases indicates that the area was a refugium containing patches of monsoon rainforest and staple faunal resources from Windjana Gorge (Maloney et al. 2018) providing food security during periods of climatic instability. This study shows that ecologically productive monsoon rainforest environments were sustained throughout the LGM and that subsistence practices were resilient, as indicated by the continued use of monsoon rainforest taxa from the time the rockshelter was first occupied, some 47,000 years ago.

Acknowledgements

We thank Bunuba traditional owners, the custodians of the country where this research took place. Thank you to Russell Barrett for assistance with taxonomic identifications. Dorcas Vannieuwenhuyse produced site plan and profile. The research was funded by an ARC Linkage Grant LP100200415 awarded to Sue O'Connor and Jane Balme, with contributions from the Kimberley Foundation Australia and the Department of Sustainability, Water, Populations and Communities. We would like to thank three anonymous reviewers for their insightful comments.

References

- Atchison, J. 2009 Human impacts on *Persoonia falcata*. Perspectives on post-contact vegetation change in the Keep River region, Australia, from contemporary vegetation surveys. *Vegetation History and Archaeobotany* 18(2):147-157.
- Atchison, J., L. Head and R. Fullagar 2005 Archaeobotany of fruit seed processing in a monsoon savanna environment: evidence from the Keep River Region, Northern Territory, Australia. *Journal of Archaeological Science* 32(2):167-181.
- Beard, J.S. 1979 *The Vegetation of the Kimberley Area: Explanatory Notes to Sheet 1*. Perth: University of Western Australia Press.
- Beaton, J.M. 1982 Fire and water: aspects of Australian Aboriginal management of cycads. *Archaeology in Oceania* 17(1):51-58.
- Beck, W. 1982 Aboriginal preparation of *Cycas* seeds in Australia. *Economic Botany* 46(2):133-147.
- Beck, W. 1989 The taphonomy of plants. In W. Beck, A. Clarke and L. Head (eds), *Plants in Australian Archaeology*, pp.31-53. Tempus, Series No. 1. St Lucia: Anthropology Museum, University of Queensland.
- Beck, W. 2006 Plant remains. In J. Balme and A. Paterson (eds), *Archaeology in practice: a student guide to archaeological analysis*, pp.296-315. Victoria: Blackwell Publishing.
- Begg, R.J. and C.R. Dunlop 1980 Security eating, and diet in the large rock-rat, *Zyzomys woodwardi* (Rodentia : Muridae). *Australian Wildlife Research* 7(1):63-70.
- Bell, K.L., H. Rangan, R. Fowler, C.A. Kull, J.D. Pettigrew, C.E. Vickers and D.J. Murphy 2014 Genetic diversity and biogeography of the boab *Adansonia gregorii* (Malvaceae: Bombacoideae). *Australian Journal of Botany* 62(2):164-174.
- Blythe, J. and G. Wightman 2003 The role of animals and plants in maintaining links. In J. Blythe and R.M. Brown (eds), *Maintaining the links: language, identity and the land. Proceedings of the Seventh Conference Presented by the Foundation for Endangered Languages*, pp.69-77. Bath: Foundation for Endangered Languages.
- Bureau of Meteorology 1996 *Kimberley, Western Australia: Climatic Survey*. Canberra: Australian Government Publishing Service.
- Cappers, R.T.J. and R.M. Bekker 2013 *A manual for the identification of plant seeds and fruits*. Groningen: Barkhuis.
- Chen, I. and S.R. Manchester 2007 Seed morphology of modern and fossil *Ampelocissus* (Vitaceae) and implications for phytogeography. *American Journal of Botany* 94(9):1534-1553.
- Clarke, A. 1985 A preliminary archaeobotanical analysis of the Anbangbang I Site. In R. Jones (ed.), *Archaeological Research in Kakadu National Park*, pp.77-96. Australian National Parks and Wildlife Service, Special Publication 13. Canberra: Australian National University.
- Clarke, A. 1989 Macroscopic plant remains. In W. Beck, A. Clarke and L. Head (eds), *Plants in Australian Archaeology*, pp.54-89. Tempus, Series No. 1. St Lucia: Anthropology Museum, University of Queensland.
- Cosgrove, R., J. Field and A. Ferrier 2007 The archaeology of Australia's tropical rainforests. *Palaeogeography, Palaeoclimatology, Palaeoecology* 251(1):150-173.

- Crawford, I.M. 1982 *Traditional Aboriginal plant resources in the Kalumburu area: aspects in ethno-economics*. Records of the Western Australian Museum Supplement No. 15. Perth: Western Australian Museum.
- Davis, J., M. Street, H. Malo, I. Cherel and E. Woodward 2011 *Mingayooroo – Manyi Warangiri Yarrangi. Gooniyandi seasons (calendar) Margaret River, Fitzroy Valley, Western Australia*. Darwin: CSIRO Ecosystem Sciences.
- Denniston, R.F., K.H. Wyrwoll, V.J. Polyak, J.R. Brown, Y. Asmerom, A.D. Wanamaker Jr, Z. LaPointe, R. Ellerbroek, M. Barthelmes, D. Cleary, J. Cugley, D. Woods and W.F. Humphreys 2013 A stalagmite record for Holocene Indonesian-Australian summer monsoon variability from the Australian tropics. *Quaternary Science Reviews* 78:155-168.
- Dilkes-Hall, I.E. 2014 An archaeobotanical analysis of macrobotanical remains at Riwi in the south central Kimberley region, Western Australia. Unpublished Honours thesis, School of Social Sciences, Archaeology, The University of Western Australia, Crawley.
- Dotte-Sarout, E., X. Carah and C. Byrne 2015 Not just carbon: assessment and prospects for the application of anthracology in Oceania. *Archaeology in Oceania* 50(1):1-22.
- Edgar, J., M. Gilbert, D. Edgar, T. Edgar, M. Howard, G. Dann, S. Gilbert, B. Boxer and P. Sampi 1997 *Mayi: some bush fruits of the West Kimberley*. Broome: Magabala Books Aboriginal Corporation.
- Ens, E., P. Clarke and F. Walsh 2017 Aboriginal people and Australia's vegetation: past and current interactions. In D. Keith (ed.), *Australian Vegetation*, pp.89-112. Cambridge: Cambridge University Press.
- Field, E., H. McGowan, P.T. Moss and S.K. Marx 2017 A late Quaternary record of monsoon variability in the northwest Kimberley, Australia. *Quaternary International* 449:119-135.
- Fitzsimmons, K.E., T.J. Cohen, P.P. Hesse, J. Jansen, G.C. Nanson, J.-H. May, T.T. Barrows, D. Haberlah, A. Hilgers, T. Kelly, J. Larsen, J. Lomax and P. Treble 2013 Late Quaternary palaeoenvironmental change in the Australian drylands. *Quaternary Science Reviews* 74:78-96.
- Florin, S.A. 2013 Archaeobotanical investigations into plant food use at Madjedbebe (Malakunanja II). Unpublished Honours thesis, School of Social Science, University of Queensland, Brisbane.
- Frawley, S. 2010 Charcoal from Carpenter's Gap 1: implications for environmental change in the last 42,000 years. Unpublished M. Phil thesis, Department of Archaeology and Natural History, College of Asia and the Pacific, Australian National University, Canberra.
- Frawley, S. and S. O'Connor 2010 A 40,000 year wood charcoal record from Carpenter's Gap 1: new insights into palaeovegetation change and indigenous foraging strategies in the Kimberley, Western Australia. In S.G. Haberle, J. Stevenson and M. Prebble (eds), *Altered ecologies: fire, climate and human influence on terrestrial landscapes* pp.299-321. Terra Australis 32. Canberra: ANU ePress.
- Fritz, G. and M. Nesbitt 2014 Laboratory analysis and identification of plant macroremains. In J.M. Marston, J. D'alpoim Guedes and C. Warinner (eds), *Method and Theory in Paleoethnobotany*, pp.115-145. Boulder: University Press of Colorado.

- Gardner, C.A. 1944 The vegetation of Western Australia with special reference to climate and soils, Presidential address, 1942. *Journal of the Proceedings of the Royal Society of Western Australia* 28:xi-lxxxvii.
- Gillison, A.N. 1987 The 'dry' rainforests of *Terra Australis*. In G. Werren and A.P. Kershaw (eds), *The rainforest legacy. Australian national rainforests study*, pp.305-321. Canberra: Australian Government Publishing Service.
- Grayson, D.K. 1984 *Quantitative zooarchaeology: topics in the analysis of archaeological faunas*. New York: Academic Press.
- Hather, J.G. 2000 *Archaeological Parenchyma*. London: Archetype Publications.
- Jackes, B.R. 1984 Revision of the Australian Vitaceae, 1. *Ampelocissus* Planchon. *Austrobaileya* 2(1):81-86.
- Kaberry, P. 1935 The Forrest River and Lyne River tribes of North-West Australia: a report on field work. *Oceania* 5(4):408-436.
- Karadada, J., L. Karadada, W. Goonack, G. Mangolamara, W. Bunjuck, L. Karadada, B. Djanghara, S. Mangolamara, J. Oobagooma, A. Charles, D. Williams, R. Karadada, T. Saunders and G. Wightman 2011 *Uunguu plants and animals: Aboriginal biological knowledge from Wunambal Gaambera Country in the north-west Kimberley, Australia*. Darwin: NTBB35, Department of Natural Resources, Environment, the Arts and Sport.
- Kenneally, K.F., D.C. Edinger and T. Willing 1996 *Broome and beyond: plants and people of the Dampier Peninsula, Kimberley, Western Australia*. Western Australia: Department of Conservation and Land Management, Broome Botanical Society.
- Kuhnt, W., A. Holbourn, J. Xu, B. Opdyke, P.D. Deckker, U. Röhl and M. Mudelsee 2015 Southern hemisphere control on Australian monsoon variability during the late deglaciation and Holocene. *Nature Communications* 6: 5916.
- Lourandos, H. 1983 Intensification: a Late Pleistocene-Holocene archaeological sequence from southwestern Victoria. *Archaeology in Oceania* 18(2):81-94.
- Love, J.R.B. 1936 *Stone-age bushmen of to-day: life and adventure among a tribe of savages in north-western Australia*. London: Blackie and Son Limited.
- Maloney, T., S. O'Connor, R. Wood, K. Aplin and J. Balme 2018 Carpenters Gap 1: A 47,000 year old record of Indigenous adaption and innovation. *Quaternary Science Reviews* 191:204-228.
- Manglamarra, G., A.A. Burbridge and P.J. Fuller 1991 Wunambal words for rainforest and other Kimberley plants and animals. In N.L. McKenzie, R.B. Johnston and P.G. Kendrick (eds), *Kimberley Rainforests of Australia*, pp.413-421. Chipping Norton: Surrey Beatty & Sons.
- McArthur, M., F.D. McCarthy and R.L. Specht 2000 Nutrition studies (1948) of nomadic Aborigines in Arnhem Land, northern Australia. *Asia Pacific Journal of Clinical Nutrition* 9(3):215-223.
- McConnell, K. 1997 Palaeoethnobotanical remains of Carpenter's Gap Site 1, the Kimberleys, Western Australia. Unpublished MSc thesis, Research School of Pacific and Asian Studies, Australian National University, Canberra.
- McConnell, K. and S. O'Connor 1997 40,000 year record of food plants in the southern Kimberley Ranges, Western Australia. *Australian Archaeology* 45:20-31.
- McConnell, K. and S. O'Connor 1999 Carpenter's Gap 1: a case for total recovery. In M.-J. Mountain and D. Bowdery (eds), *Taphonomy: the analysis of processes from phytoliths to megafauna*, pp.23-34. Research Papers in Archaeology and

- Natural History, No. 30. Canberra: ANH Publications, Department of Archaeology and Natural History Australian National University.
- McGowan, H., S. Marx, P. Moss and A. Hammond 2012 Evidence of ENSO mega-drought triggered collapse of prehistory Aboriginal society in Northwest Australia. *Geophysical Research Letters* 39(22): L22702, doi:[10.1029/2012GL053916](https://doi.org/10.1029/2012GL053916).
- Miller, J.B., K.W. James and P.M.A. Maggiore 1993 *Tables of composition of Aboriginal foods*. Canberra: Aboriginal Studies Press.
- Minnis, P.E. 1981 Seeds in archaeological sites: sources and some interpretive problems. *American Antiquity* 46(1):143-152.
- Munir, A.A. 1987 A taxonomic revision of the genus *Vitex* L. (Verbenaceae)* in Australia. *Journal of the Adelaide Botanic Gardens* 10(1):31-79.
- O'Connor, S. 1995 Carpenter's Gap Rockshelter 1: 40,000 years of Aboriginal occupation in the Napier Ranges, Kimberley, WA. *Australian Archaeology* 40:58-59.
- O'Connor, S. 1999 *30,000 Years of Aboriginal Occupation: Kimberley. North West Australia*. Terra Australis 14. Canberra: Department of Archaeology and Natural History and Centre for Archaeological Research, Australian National University.
- Paddy, E., S. Paddy and M. Smith 1993 *Boonyja Bardag Gorna: All trees are good for something*. Perth: Anthropology Department, Western Australian Museum.
- Pickerd, I. 2014 Kimberley nature project: surveying the vine thickets of the limestone ranges on Bunuba Country. *Environs Kimberley News Bulletin* 71.
- Playford, G., R.M. Hocking and A.E. Cockbain 2009 *Devonian Reef Complexes of the Canning Basin, Western Australia*. Perth: Government of Western Australia. Bulletin 145.
- Rangan, H., K.L. Bell, D.A. Baum, R. Fowler, P. McConvell, T. Saunders, S. Spronck, C.A. Kull and D.J. Murphy 2015 new genetic and linguistic analyses show ancient human influence on Baobab evolution and distribution in Australia. *Plos ONE* 10(4):1-18.
- Reeves, J.M., T.T. Barrows, T.J. Cohen, A.S. Kiem, H. Bostock, K. Fitzsimmons, J.D. Jansen, J. Kemp, C. Krause, L. Petherick, S.J. Phipps and O.-I. Members 2013 Climate variability over the last 35,000 years recorded in marine and terrestrial archives in the Australian region: an OZ-INTIMATE compilation. *Quaternary Science Reviews* 74:21-34.
- Reynen, W. and K. Morse 2016 Don't forget the fish – towards an archaeology of the Abydos Plain, Pilbara, Western Australia. *Australian Archaeology* 82(2):94-105.
- Rose, D.B. 1984 *Preliminary Report: Ethnobotany in the Bungles*. Working Paper No. 5. Canberra: Centre for Resource and Environmental Studies, Australian National University.
- Saltré, F., M. Rodriguez-Rey, B.W. Brook, C.N. Johnson, C.S.M. Turney, J. Alroy, A. Cooper, N. Beeton, M. Bird, D.A. Fordham, R. Gillespie, S. Herrando-Pérez, Z. Jacobs, G.H. Miller, D. Nogués-Bravo, G.J. Prideaux, R.R. Roberts and C.J.A. Bradshaw 2016 Climate change not to blame for late Quaternary megafauna extinctions in Australia. *Nature Communications* 7:10511.
- Scarlett, N.H. 1985 *A preliminary account of the ethnobotany of the Kija people of Bungle Bungle outcamp*. Canberra: Center for Resource and Environmental Studies.

- Schrire, C. 1982 *The Alligator Rivers: prehistory and ecology in Western Arnhem Land*. Terra Australis 7. Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University.
- Scott-Virtue, L., J. Gresham, D. Goodgame, T. Griffin, B. Voorwinden, B. Smith, J. Gill, M. Donaldson, S. Matthews, S. Griffin and E. Gresham 2011 *Report on a walk on the Roe River Prince Regent Nature Reserve July 2011*. Unpublished report prepared for Conservation and Land Management, Kununurra.
- Shulmeister, J. 1999 Australasian evidence for mid-Holocene climate change implies precessional control of Walker Circulation in the Pacific. *Quaternary International* 57-58:81-91.
- Sievers, C. 2006 Seeds from the Middle Stone Age layers at Sibudu Cave. *Southern African Humanities* 18(1):203-222.
- Smith, M.A. 1982 Late Pleistocene *Zamia* exploitation in southern Western Australia. *Archaeology in Oceania* 17(3):117-121.
- Smith, M.V. and A.C. Kalotas 1985 Bardi plants: an annotated list of plants and their use by the Bardi Aborigines of Dampier Land, Northwestern Australia. *Records of the Western Australian Museum* 12(3):317-359.
- Smith, N.M. 1991 Ethnobotanical field notes from the Northern Territory, Australia. *Journal of the Adelaide Botanic Gardens* 14(1):1-65.
- Specht, R.L. 2006 Aboriginal plant names in northeastern Arnhem Land: Groote Eylandt—Enindilyakwa language; Yirrkala—Rirratjingu language. *Australian Aboriginal Studies* 1:63-67.
- Turney, C.S.M., S. Haberle, D. Fink, A.P. Kershaw, M. Barbetti, T.T. Barrows, M. Black, T.J. Cohen, T. Corrège, P.P. Hesse, Q. Hua, R. Johnston, V. Morgan, P. Moss, G. Nanson, T. van Ommen, S. Rule, N.J. Williams, J.X. Zhao, D. D'Costa, Y.X. Feng, M. Gagan, S. Mooney and Q. Xia 2006 Integration of ice-core, marine and terrestrial records for the Australian Last Glacial Maximum and Termination: a contribution from the OZ INTIMATE group. *Journal of Quaternary Science* 21(7):751-761.
- Van der Kaars, S. and P.D. Deckker 2002 A Late Quaternary pollen record from deep-sea core Fr10/95, GC17 offshore Cape Range Peninsula, northwestern Western Australia. *Review of Palaeobotany and Palynology* 120(1-2):17-39.
- Van der Kaars, S., P.D. Deckker and F.X. Gingele 2006 A 100 000-year record of annual and seasonal rainfall and temperature for northwestern Australia based on a pollen record obtained offshore. *Journal of Quaternary Science* 21(8):879-889.
- Vannieuwenhuysse, D., S. O'Connor and J. Balme 2017 Settling in Sahul: investigating environmental and human history interactions through micromorphological analyses in tropical semi-arid north-west Australia. *Journal of Archaeological Science* 77:172-193.
- Veth, P.M., M. Smith, J. Bowler, K. Fitzsimmons, A. Williams and P. Hiscock 2009 Excavations at Parnkupirti, Lake Gregory, Great Sandy Desert: OSL ages for occupation before the Last Glacial Maximum. *Australian Archaeology* 69:1-10.
- Veth, P.M., P. Hiscock and A. Williams 2011 Are tulas and ENSO linked in Australia? *Australian Archaeology* 72:7-14.
- Visser, K., R. Thunell and L. Stott 2003 Magnitude and timing of temperate change in the Indo-Pacific warm pool during glaciation. *Nature* 421(6919):152-155.
- Wallis, L.A. 2000 Phytoliths, Late Quaternary environment and archaeology in tropical semi-arid northwest Australia. Unpublished PhD thesis, Archaeology

- and Natural History, Research School of Pacific and Asian Studies, Australian National University, Canberra.
- Wallis, L.A. 2001 Environmental history of northwest Australia based on phytolith analysis at Carpenter's Gap 1. *Quaternary International* 83-85:103-117.
- Wang, C.-Z., R. Mehendale and C.-S. Yuan 2007 Commonly used antioxidant botanicals: active constituents and their potential role in cardiovascular illness. *The American Journal of Chinese Medicine* 35(4):543-558.
- Wen, J. 2007 Vitaceae. In K. Kubitzki (ed.), *The families and genera of flowering plants*, pp.467-479. Berlin: Springer-Verlag.
- Wheeler, J.R. (ed.) 1992 *Flora of the Kimberley region*. Perth: Department of Conservation and Land Management.
- Whitau, R., J. Balme, S. O'Connor and R. Wood 2017 Wood charcoal analysis at Riwi cave, Gooniyandi country, Western Australia. *Quaternary International* 457:140-154.
- Wightman, G. 2003 *Plants and animals of Kija and Jaru country; Aboriginal knowledge conservation and ethnobiological research in the upper Ord Catchment, Western Australia*. Canberra: Australian Government Land & Water Australia.
- Williams, A., C.M. Santoro, M.A. Smith and C. Latorre 2008 The impact of ENSO in the Atacama Desert and Australian arid zone: exploratory time-series analysis of archaeological records. *Chungara, Revista do Anthropologia Chilena* 40(2):245-259.
- Williams, A.N., S. Ulm, I.D. Goodwin and M. Smith 2010 Hunter-gatherer response to late Holocene climatic variability in northern and central Australia. *Journal of Quaternary Science* 25(6):831-838.
- Williams, A.N., S. Ulm, A.R. Cook, M.C. Langley and M. Collard 2013 Human refugia in Australia during the Last Glacial Maximum and Terminal Pleistocene: a geospatial analysis of the 25-12 ka Australian archaeological record. *Journal of Archaeological Science* 40:4612-4625.
- Wijnjorrotj, P., S. Flora, D.N. Brown, P. Jatbula, J. Galmur, M. Katherine, F. Merlan and G. Wightman 2005 *Jawoyn plants and animals: Aboriginal flora and fauna knowledge from Nitmiluk National Park and the Katherine area, Northern Australia*. Katherine: Jawoyn Association.
- Wunambal Gaambera Aboriginal Corporation 2010 *Wunambal Gaambera Healthy Country Plan—Looking after Wunambal Gaambera Country 2010–2020*. Wyndam: Wunambal Gaambera Aboriginal Corporation.
- Wyrwoll, K.H. and G.H. Miller 2001 Initiation of the Australian summer monsoon 14,000 years ago. *Quaternary International* 83-85:119-128.