Title

Archaeobotany of Aboriginal plant foods during the Holocene at Riwi, south central Kimberley, Western Australia

Authors and affiliations

India Ella Dilkes-Hall[1], Jane Balme[1], Sue O'Connor[2, 3], and Emilie Dotte-Sarout[1, 4]

[1] Archaeology, M257, School of Social Sciences, 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, Canberra, 0200, Australia

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

[4] School of Archaeology and Anthropology, The Australian National University, Sir Roland Wilson Building #120, McCoy Circuit, Acton, ACT 2601, Australia

ORCID

India Ella Dilkes-Hall (0000-0002-6487-0043)

Jane Balme (0000-0003-1387-9379)

Sue O'Connor (0000-0001-9381-078X)

Emilie Dotte-Sarout (0000-0003-1413-9655)

Corresponding author

India Ella Dilkes-Hall. Email: india.dilkes-hall@research.uwa.edu.au. Telephone number: 08 6488 2896

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Abstract

Riwi, a limestone cave located in the south central Kimberley, northwest Western Australia, has one of the most accurately dated archaeological sequences in Australia, with human occupation beginning between 46,400 and 44,600 cal B.P. Macrobotanical remains are well preserved at the site, particularly in upper stratigraphic units 1 and 2 dated to the late and mid-Holocene, respectively.

Macrobotanical materials (excluding wood charcoal) are uncommon in Pleistocene contexts, and direct dating of some of the macrobotanical remains recovered from Pleistocene hearths suggest that they derive from the directly superposed Holocene layers. Analysis of the macrobotanical remains from the Holocene layers reveals a pattern where Aboriginal groups occupying Riwi intermittently between 7,000 years ago and the present principally exploited monsoon rainforest ecosystems for food plants, especially *Vitex* cf. *glabrata*. Fruiting times of dominant monsoon rainforest taxa indicate that the site was occupied seasonally, corresponding with periods of rainfall when people were able to move away from rivers and other permanent water sources. Results demonstrate a strong cultural preference for fruits associated with monsoon rainforest - a vegetation type restricted in distribution - highlighting the importance of moisture retaining limestone outcrops in foragers' subsistence organisation in the south central Kimberley.

Key-words Australian archaeology · Macrobotanical remains · Economic plants · Monsoon rainforest · Holocene

Introduction

Plants play a crucial role in human lifeways and, as in most parts of the world, they make up a major component of Australian Aboriginal diet, as well as providing raw material for fuel and plant-based technologies, including tools, weapons, watercraft, clothing, bedding, medicine, dyes, fibre crafts, and shelter (Balme 2013; Clarke 2012; Denham et al. 2009; Gallagher 2014; Kamminga 1988). Earlier studies of Aboriginal foraging (McArthur 1960; Meehan 1989) and dietary macronutrient intake (Cordain et al. 2000) suggest that Aboriginal groups living in tropical regions between 11 and 20 degrees latitude most likely obtain between 45 to 55% of their nutritional requirements from gathered plant foods - though this varies depending on local ecology. However, in Australia, archaeobotany remains an underdeveloped field of research (Denham et al. 2009; Dotte-Sarout et al. 2015). In particular, there have been few studies dedicated to the systematic analysis of non-woody macrobotanical remains (i.e. carpological remains as from seeds, nuts, fruits, and other floristic elements) from archaeological sites (see Asmussen 2005; Atchison 2000; Beaton 1982; Beck 1982; Clarke 1987; Cosgrove et al. 2007; Dilkes-Hall et al. 2019; Fairbairn 2007; Ferrier and Cosgrove 2012; Florin 2013; McConnell 1997; Smith 1982).

This study provides results from an analysis of macrobotanical remains (excluding charcoal - the analysis of which has been carried out separately [see Whitau et al. 2017, 2018]) recovered from Riwi, a cave site located on the edge of the Great Sandy Desert in the south central Kimberley region of northwest Western Australia (Fig. 1). The Kimberley is in the Australian Monsoonal Tropics and receives 85% or more of its rainfall between the months of November and April, creating a distinct seasonal oscillation between the tropical wet and dry (Bowman et al. 2010). Riwi's position in the southern part of the Kimberley is today influenced by the moist monsoon belt to a lesser degree than the northern Kimberley and receives only 350 – 500 mm rainfall per annum (Bureau of Meteorology 1996). As a result, the vegetation, in comparison to the tropical north, is less diverse (Beard 1979).

The purpose of this research is to identify the botanical resources introduced to the site by people and determine those that most likely represent food remains. This is of particular interest because of the low vegetation diversity that characterises the area and the fact that there is no permanent water in the immediate vicinity of the site. Riwi's history of nearly 50,000 years of human occupation (Wood et al. 2016) has seen episodic environmental changes (see Balme et al. 2019). Analysis of the macrobotanical assemblage was therefore concerned with how people exploited such a seemingly harsh landscape and how people reorganised their foraging practices to adapt to changes in the environment.

Fig. 1 The Kimberley region showing the position of Riwi and other places mentioned in text (after Dilkes-Hall et al. 2019). Native title determined lands after Kimberley Land Council (2019).

The site and its environmental context

Riwi is a southwest facing limestone cave on Gooniyandi traditional land situated at the base of the Lawford Range, a remnant Devonian limestone reef (Playford et al. 2009). The main chamber of the cave is approximately 13 m deep and 7 m wide providing ample room for human occupation and affords shade and protection from the elements. An ephemeral creek, located 200 m from the mouth of the cave seasonally fills with water. Dry alkaline sediments and the protective cave structure created excellent preservation conditions resulting in a rich archaeological assemblage with well-preserved organic remains, particularly in Holocene deposits (Balme et al. 2019).

The environment immediately surrounding Riwi is typical of the southern Kimberley. The soils are skeletal, strongly leached, shallow, and immature and, consequently, greatly influence local vegetation (Beard 1979). The majority of plant species are physiologically specialised to tolerate semi-arid conditions and sparse dry sclerophyll tree steppe dominated by short grass savannah and *Triodia* spp. (spinifex) hummock grasslands are characteristic of the Hall Botanical District (Beard 1979). Niches in limestone ranges and rocky limestone outcrops support occasional monsoon rainforest taxa. Modern day vegetation in the immediate vicinity of the cave can be divided into three broad vegetation groups, savannah, riparian, and monsoon rainforest (Fig. 2).

Fig. 2 Vegetation groups at Riwi a) savannah valley floor, b) riparian taxa fringing ephemeral creek line, and c) scattered monsoon rainforest taxa in niches of the limestone range

Materials and methods

Excavation

Information on site excavation, stratigraphy, and chronology are reported in detail elsewhere (see Balme et al. 2019; Wood et al. 2016) and is therefore summarised here. The 1999 excavation of Riwi opened a 1 m² test pit (square 1) (Balme 2000) and excavations, carried out in 2013, opened an additional three 1 m² test pits (squares 3, 4, and 5), which are the focus of this study (Fig. 3). Excavation employed arbitrary excavation units (XUs) 2 cm thick and bulk sediment samples taken for each XU. Hearths identified during excavation were removed separately. XUs were excavated in 50 cm² quadrants (a, b, c, and d) within the 1 m² test pit and all squares were taken to bedrock approximately ~115 cm below surface. Excavated material was dry sieved in the field through nested 5 mm and 1.5 mm meshes. No locally available water and desiccation of macrobotanical remains meant that flotation, which would rehydrate and potentially damage fragile macrobotanical remains (Pearsall 2010:118), was not conducted. The soft, silty/sandy nature of the sediment ensured that delicate macrobotanical specimens were not damaged by the process of dry sieving. All 5 and 1.5 mm material was returned to the archaeological laboratory at the University of Western Australia (UWA) and hand sorted under a 10 x magnification lamp (as per Pearsall 2010:108).

Fig. 3 Riwi site plan and profile showing square locations and topography (after Vannieuwenhuyse 2016)

Difficulty in identifying stratigraphic changes during excavation and the employment of horizontal XUs has resulted in some XUs cross-cutting stratigraphic units (SUs) that were identified through subsequent microstratigraphic and excavation profile analysis. Three discontinuities occur between about c. 30-21 cal kB.P., c.21-7 cal kB.P., and c.7-1 cal kB.P. (Vannieuwenhuyse 2016:304; Wood et al. 2016:20). All potentially mixed XUs were disregarded by the current analysis.

The macrobotanical assemblage

During initial sorting it was clear that there were far more macrobotanical remains in the two Holocene units than Pleistocene contexts. Overall, 583 macrobotanical remains were recovered from four Pleistocene hearths (Online Resource 1) and none recovered from the surrounding soft, fine-grained sediments. The discontinuity at the Holocene/Pleistocene junction, led us to question the origin of these remains. Four macrobotanical samples were submitted for AMS dating. Three of these were on *Vitex* cf. *glabrata* endocarps and one was a fragment of *Acacia* sp. Type A pod, all recovered from hearths positioned at the Holocene/Pleistocene boundary. The results in Table 1 show that these macrobotanical remains are not in stratigraphic context. However, the result for the *Acacia* sp. Type A pod is consistent with radiocarbon dates for SU2 (Table 1 and 2). It is therefore likely that macrobotanical remains have not survived in the Pleistocene deposits and those recovered have transgressed the Holocene/Pleistocene boundary. The recovery of macrobotanical remains only from hearths is difficult to explain. Hearths provide comparatively compact hard surfaces and macrobotanical material, either moving through the deposit as a result of trampling or falling from walls of the excavation, may have caught on these surfaces. As we cannot be certain if any of the macrobotanical remains recovered from Pleistocene hearths are in situ, we have restricted our analysis here to SUs 1 and 2 in squares 3 and 4 (Fig. 4a and b), respectively dated to the late Holocene (915 to 668 cal B.P. to present) and mid-Holocene (7,421 to 5,905 cal B.P.) (Table 2).

Table 1 Results of direct AMS dates for macrobotanical samples from Riwi hearths with associated radiocarbon chronology (Wood et al. 2016). Dates calibrated against SHCal13 (Hogg et al. 2013) in OxCal v.4.3 (Bronk Ramsey 2009)

Fig. 4 Riwi stratigraphic profiles a) square 3 b) square 4 (CAD: D. Vannieuwenhuyse)

As macrobotanical remains were extremely abundant in SUs 1 and 2, samples were restricted to XU/quadrants that were clearly within defined stratigraphic boundaries of SU1 and 2 (Table 2). All 5 mm and 1.5 mm macrobotanical remains of chosen samples were analysed. Bulk sediment samples were not analysed for this study. Leaves, shown as 'leaf litter' at the top of stratigraphic profiles (Fig. 4a and b) represent vegetation growing outside the cave, namely, whole and fragmented *Eucalyptus* leaves and, considered likely to have accumulated in the cave through wind action, are not included in the analysis.

Table 2 Stratigraphic samples analysed in this study with radiocarbon chronology (Wood et al. 2016). Dates calibrated against SHCal13 (Hogg et al. 2013) in OxCal v.4.3 (Bronk Ramsey 2009)

Methods of analysis

Sorting and identification of all macrobotanical material followed Fritz and Nesbitt (2014), Pearsall (2010), and Marinval (1999). All macrobotanical remains were sorted in the UWA laboratory under 10x magnification into quantifiable categories in accordance to observed morphological similarities. Morphological characteristics - shape, dimension, length, width, surface, and texture - were recorded following guidelines provided by the University of Queensland's Archaeobotany Reference Collection database (http://uqarchaeologyreference.metadata.net/archaeobotany/contribute). Other attributes, such as rodent gnaw marks, adherence of coprolitic material, and dispersal mechanisms were recorded to help determine non-anthropogenic taxa.

Taxonomic identifications were based on qualitative criteria using comparative material in vouchered botanical collections housed at the Western Australian Herbarium (Crawford 1982; Smith and Kalotas 1985), the Australian National University (McConnell 1997), and the Australian National Herbarium-Commonwealth Scientific and Industrial Research Organisation (CSIRO). To fill gaps in these sources a botanical collection was undertaken during fieldwork in 2014 in Windjana Gorge National Park, about 185 kilometres to the northwest of Riwi. Vouchers were collected and sent to the Australian National Herbarium-CSIRO in Canberra for identification. Seeds and fruits corresponding to the vouchers were returned to UWA, dried, labelled, photographed, placed in plastic vials, and arranged in taxonomic sequence (Nesbitt et al. 2003). Where taxonomic identification could not be positively assigned, macrobotanical material was attributed a numerical code and descriptive name. Photographs of identified macrobotanical remains were taken using a high resolution AxioCam MRc5 and testa (seed coat) images taken with a JEOL JCM-6000 Neoscope Scanning Electron Microscope (SEM).

Results

A total of 7,609 macrobotanical remains were recovered from SUs 1 and 2 and 45 types based on morphological similarity were identified. Thirty-two taxa from 17 families were identified to varying taxonomic levels (Table 3). In some cases, identification beyond genus level was not possible. Unidentified materials, assigned numerical codes and descriptive names in the laboratory, are presented as indeterminate (n=124, 1.63%). The primary mode of preservation for macrobotanical material is desiccation (Fig. 5). Carbonised macrobotanical material is represented across nine taxa. The greatest number of carbonised remains are attributed to *Vitex* cf. *glabrata* (black plum) (whole fruits, whole endocarps, and fragmented endocarps [n=43, 51.19%]) of the Lamiaceae family (Table 3). Generally, densities of macrobotanical remains are high. Volumetrically adjusted, relative to sediment volume, the density of macrobotanical remains is slightly higher in the mid-Holocene (101.9 seeds per litre) than the late Holocene (95.87 seeds per litre) (Tables 2 and 3).

Fig. 5 Examples of desiccated macrobotanical remains recovered from SU2 a) *Abutilon* cf. *hannii.* b) *Acacia* sp. (pod) Type A. c) *Celtis strychnoides.* d) *Cynanchum* sp. e) *Cyperus bulbosus* (tunic). f) *Ficus* sp. g) *Mallotus nesophilus.* h) *Terminalia* sp. Type A. Images produced using a high resolution AxioCam MRc5 microscope camera

Table 3 Identified taxa grouped by family association. Carbonised (c), desiccated (d), number of individual specimens (n), and relative percentages (n %) in relation to category totals are presented for each taxon across stratigraphic units 1 and 2. Mass (g) included with assemblage totals. Note: Poaceae primarily *Enneapogon* spp.

It is important to note that, as there are several different kinds of plant parts representing each taxon in Table 3, direct frequency comparisons are not always appropriate. Absolute counts for *Abutilon* cf. *hannii* (lantern flower), Poaceae, and *Triodia* cf. *pungens* (spikelets) (spinifex) are relatively high because they reflect high rates of schizocarp and spikelet fragmentation, respectively. Relative abundances for these savannah taxa are lower when measured as mass (Table 3). For example, the most numerous taxon by absolute count, *T.* cf. *pungens* (spikelets) (n=2,264), accounts for only 2.87% of the total mass of the macrobotanical assemblage. The following quantitative presentation of the results consider the SU1 and SU2 macrobotanical assemblages without these taxa.

Figure 6 shows the relative percentages of macrobotanical remains (excluding *A.* cf. *hannii*, Poaceae, and *T.* cf. *pungens* [spikelets]) for SUs 1 and 2, with taxa grouped into three broad ecological associations, monsoon rainforest, savannah, and riparian.

Fig. 6 Distribution of relative percentages of macrobotanical remains in stratigraphic units 1 and 2. Taxa grouped by monsoon rainforest, savannah, and riparian ecological associations. Where taxa are present in low proportions (<1%) presence is marked ‘x’. Excludes *Abutilon* cf. *hannii*, Poaceae, and *Triodia* cf. *pungens* (spikelets)

The most obvious feature of Figure 6 is that, overall, macrobotanical remains representative of monsoon rainforest environments are the most abundant in both the late and mid-Holocene units. There is little difference in the percentages of monsoon rainforest remains within each SU, each unit comprised of 83% monsoon rainforest. However, there are some differences in the proportions of species represented within this group. In particular, the high number of *Mallotus* cf. *dispersus* in SU1 (Table 3). As these are fragile flower remains their recovery from only late Holocene deposits likely reflects differences in preservation between SUs.

The second notable observation from Figure 6 is that *Vitex* cf. *glabrata* (different plant parts combined) is the most abundant monsoon rainforest taxon in both SUs, making up 28.30% of the monsoon rainforest category for SU1 and 50.11% in SU2. The distribution of different *V.* cf. *glabrata* plant parts shows calyces are particularly abundant in the mid-Holocene and are markedly less in the late Holocene (Fig. 6). Notably, *Acacia* sp. (pod) Type A and *Cynanchum* sp. (bush banana) also follow this pattern.

The final main observation from Figure 6 is that species richness is greater in SU1 (30 taxa) than SU 2 (21 taxa). However, the additional species within each vegetation category in SU1 all occur in low numbers (Table 3).

Discussion

Determining the source of the macrobotanical remains

Plant material can enter archaeological archives through means other than intentional human introduction (Bush 2004; Clarke 1987; Dennell 1976; Diestch 1996; Ford 1979; Gallagher 2014; Miksicek 1987; Minnis 1981). Non-anthropogenic modes of entry, include the introduction of seeds and fruits by animals (e.g. coprolites and caches) and natural processes such as water, wind, and seed rain (Gallagher 2014:32).

At Riwi, the main possible non-anthropogenic source of plant remains that was identified are the macropod coprolites that occur on the surface of the cave and, to some extent within SU1. To identify and characterise the possible contribution to the macrobotanical assemblage six samples of coprolites were examined and found to be principally composed of grass fragments. However, 28 fragments of *Celtis strychnoides*, 3 cf. *Cucumis* (cucumber) seeds*,* and 25 *Ficus* spp. (achenes) were recovered separately from three individual coprolites (XU1). Macrobotanical material recovered from these coprolites is far more heavily fragmented than that observed throughout the assemblage and adherence of coprolitic material to the fragments retrieved is noticeable (Online Resource 2). *Ficus* spp. (achenes) are rarely recovered at Riwi and the vast majority of *Ficus* spp. are represented by whole and fragmented fruits (Table 3). The findings suggest that *in situ* decay of macropod coprolites is unlikely to have contributed seeds and fruits to the macrobotanical record.

Rock rats (*Zyzomys* spp.), members of the Muridae family that occur in the Kimberley, cache seeds along caves ledges and crevices and leave distinct ‘drill-hole’ like gnawing patterns on seeds (Begg and Dunlop 1980). No seed caches were observed at Riwi during fieldwork and the macrobotanical remains show no evidence of gnawing, contrary to observations made by McConnell and O’Connor (1999) on the Square A macrobotanical assemblage recovered from Carpenter’s Gap 1, a limestone cave ~180 kilometres to the north west of Riwi (Fig. 1). These findings suggest that the introduction of seeds and fruits to the cave by rock rats is unlikely.

Surface water channelling at Riwi is confined to the north-western wall of the cave and so has negligible effect on the macrobotanical assemblage (Fig. 3). Within the excavations, water channels are only visible at the bottom of the sequence, SU12 (Vannieuwenhuyse 2016:164). The lack of visible water channelling in SUs 1 and 2, coupled with the presence of desiccated cultural materials, suggests little wetting and drying of these deposits (Vannieuwenhuyse 2016) and that water deposition did not contribute macrobotanical remains to the site.

Poaceae is primarily composed of *Enneapogon* spp. (nine-awn pappus grass) florets, which are small, light, and aerodynamic with plumose awns to aid wind dispersal (Kakudidi et al. 1988). The primary function of this type of floret shape is to assist seed dispersal by wind. Likewise, seeds of *Cynanchum* sp., albeit documented as a food plant (Table 4), are also dispersed by the wind with each seed bearing tufts of hair (coma) (Forster 1991). Thus, based on morphological characteristics, Poaceae and *Cynanchum* sp. macroremains were probably introduced to the cave by wind.

At present one *Mallotus nesophilus* tree grows against the northern wall of the cave (Fig. 3). The highest quantities of *M. nesophilus* seeds are present in SU1 and this may reflect modern seed rain assimilation into the archaeological deposit in the recent past. However, several factors suggest incorporation of *M. nesophilus* into the assemblage is unlikely to be a result of modern seed rain. First, the *M. nesophilus* plant borders the northern wall of the cave and does not overhang the archaeological excavation squares. Second, surface water channelling at the location of the plant is likely to have removed fallen seeds and fruits in such a way that they would have relocated towards the front of the cave (Fig. 3). Third, the fruits of *M. nesophilus* are edible and, at least in the recent past, were eaten by Aboriginal people (Scarlett 1985; Smith and Kalotas 1985; Wightman 2003; Wiynjorrotj et al. 2005). In addition an increase in *Mallotus* sp. charcoal in SU1 (Whitau et al. 2017) suggests that people visiting the site used the plant for fuel. Finally, no other *M. nesophilus* were identified during vegetation survey and the *M. nesophilus* tree at Riwi is 75 kilometres outside the species' recorded current distribution (Atlas of Living Australia 2018). Whitau et al. (2017) suggest that the isolated occurrence of a *M. nesophilus* tree in the cave may have been a consequence of human behaviours, intentional or incidental. Aboriginal agency in the dissemination of trees in Australia has been suggested for *Adansonia gregorii* (boab) (Rangan et al. 2015) and *Castanospermum australe* (black bean) (Rossetto et al. 2017) supporting the argument of anthropogenic origin for the *M. nesophilus* at Riwi. It is possible that other plants may have grown in the cave in the past, however, no root structures were encountered during excavation and the structure of the cave, diminishing sunlight and water availability, suggests that incorporation of modern and prehistoric seed rain into the macrobotanical assemblage is improbable.

Evaluation of these alternative sources for macrobotanical remains at Riwi demonstrates that disentangling natural from culturally deposited taxa is complicated. Carbonisation, as a foolproof way of separating naturally deposited taxa from those introduced anthropogenically (e.g. Atchison et al. 2005; Dietsch 1996) is questionable because plant remains can become carbonised when a fire is lit on deposits containing macrobotanical remains and many plants are either used for economic purposes or disposed of in ways that do not cause carbonisation (e.g. van der Veen 2007). Additionally, when not distributed further afield by animals, fruits that contain large and/or dense seeds (e.g. *Grewia* and *Vitex* species) remain close to where they drop below the parent tree (Atchison et al. 2005:174) and the abundance and dominance of these edible fruit bearing plants at Riwi that recur over time suggests their important role in peoples' gathering, foraging, and subsistence activities in the past.

Economic plants

We have concluded that the macrobotanical remains recovered from the Holocene stratigraphic units at Riwi are principally the result of human activities. Apart from food these may represent several different kinds of activities including fuel collection, plants collected for technologies such as string making or for protection of collected materials, and for medicines.

Although plant uses undoubtedly transform over time, it is interesting that many of the taxonomically identified macrobotanical remains from Riwi continue to be economically important to Aboriginal people today. Overall, 23 of the 32 identified taxa from Riwi are presently recognised by Australian Aboriginal groups as traditional economic botanical resources (Table 4) and we have used this traditional ecological knowledge as a basis for suggesting possible uses of plants represented in the site.

Table 4 Potential economic uses of taxonomically identified macrobotanical taxa recovered from Riwi based on ethnographic and ethnobotanical references from Aboriginal groups in the Kimberley

Whitau et al. (2017:150) identified *Eucalyptus* and *Corymbia* species as being commonly used for fuel at Riwi. These species are not documented as food plants (Table 4) and it is likely that the *Eucalyptus-Corymbia* remains (capsule no operculum, operculum, and whole capsule) identified in the macrobotanical assemblage analysed here were probably introduced into the site attached to larger *Eucalyptus-Corymbia* wood pieces collected for fuel.

Another taxon that has no documented use as a food in the Kimberley is *Abutilon* cf. *hannii*. Its abundance in the Riwi deposits makes it worth mentioning that *Abutilon otocarpum* is documented by Roth (1901) as being used to manufacture nets by Kalkatungu (also Kalkadoon) Aboriginal people in Queensland. *Abutilon* processing would strip schizocarps away to access the long fibres within the stem bark that are used to manufacture string. Seven pieces of string were recovered from Riwi's Holocene units (Balme et al. 2019) and the large number of *A.* cf. *hanni* schizocarps at Riwi may be by-products introduced to the site during plant fibre processing activities.

The large quantity of *Triodia* cf. *pungens* spikelets coupled with the occurrence of different plant parts of *Triodia* spp. (e.g. rootlets/leaves) suggest human introduction to the site. Aboriginal groups across Australia use *Triodia* in a variety of ways; grinding seeds for food, for making resin for the creation of composite tools, string, for kindling, and medicinally (Gamage et al. 2012; Latz 1982, 1995; Pittman 2010; Pittman and Wallis 2012). No *Triodia* seeds were recovered and the spikelets and rootlets/leaves are not food so their presence probably relates to by-products of food (seed) and/or the manufacture of plant-based technologies. One identified use of *Triodia* at Riwi was as a protective wrapping for freshwater mussels (Balme et al. 2019). Evidence of burning on both spikelets and roots may be a result of the dehiscing of grass seeds by passing over fire to separate seeds for grinding (Latz 1995) or to extract resin (Pittman 2010; Pittman and Wallis 2012) or they may represent the remains from incompletely combusted kindling.

Selective exploitation

The taxa most likely to represent food remains in Riwi's macrobotanical record are *Ficus* spp. and *Vitex* cf. *glabrata* and these plants suggest selective exploitation of the surrounding vegetation. A survey of the modern vegetation surrounding Riwi conducted by Whitau et al. (2017) recorded the valley floor directly in front of the site as being typified by low tree steppe dominated by *Triodia pungens* (soft spinifex), with scattered *Eucalyptus*-*Corymbia*, and frequent *Cochlospermum fraseri* (kapok) and *Gyrocarpus americanus* (helicopter tree) (Fig. 2a). Pockets of riparian taxa occur along the dry watercourse (Fig. 2b) including Myrtaceae species trees (*Eucalyptus camaldulensis* [river red gum]*, Eucalyptus pruinosa* subsp. *pruinosa* [silver box]*,* and *Melaleuca lasiandra* [paperbark]) and mixed Cyperaceae sedges.

Despite the semi-arid modern local ecology around Riwi, and the presence of two grindstone fragments in Holocene deposits, we found little evidence of seed exploitation (aside from the suggestion that *Acacia* seeds may have been ground given the large proportion of *Acacia* pods compared to seeds [Table 3]). Instead food plants are dominated by monsoon rainforest species, especially *V.* cf. *glabrata*. No discrete patches of monsoon rainforest were encountered during the vegetation survey around Riwi (Whitau et al. 2017), however, vestigial traces of monsoon rainforest taxa are present in niches along the limestone range (Fig. 2c) where fire protection and water seepage maintain isolated plants (McKenzie et al. 1991).

Monsoon rainforest, also known as dry rainforest, monsoon vine-thicket, and tropical deciduous vine thicket, remains the most poorly understood type of rainforest (Bowman and Cook 2002; McDonald 1998). It is 'rain green', tolerating thermal extremes and decreased precipitation plant species can quickly recolonise suggesting resilience during times of climatic stress (Kenneally and Beard 1987). Contemporary geographic range of monsoon rainforest in the Kimberley is generally restricted to coastal areas and further inland confined to patches along river systems or protected areas of plateau/range (McKenzie et al. 1991). Monsoon rainforest in northern Australia is most likely to have been more widely distributed during the mid-Holocene than present-day remnant patches indicate (expanding during humid periods and retreating during times of aridity) (Russell-Smith 1985).

Terrestrial palaeoenvironmental archives indicate broad scale warming, wetter climatic conditions, and climatic stabilisation during the mid-Holocene (Hesse et al. 2004; Fitzsimmons et al. 2013). Monsoon rainforest taxa, whose periods of flowering and fruiting are seasonally specific and defined by rainfall, are abundant in Riwi's mid-Holocene macrobotanical assemblage and suggest the presence of monsoon rainforest in the region. Climatic stabilisation increases the reliability and predictability of plant resources, and availability of monsoon rainforest taxa may have been a driving factor for people visiting Riwi during periods of relative humidity, times when monsoon rainforest fruits are available in abundance.

Over the past 1,000 years, pockets of monsoon rainforest may have reduced in number and size because of decreased water availability connected to the current phase of El Niño-Southern Oscillation (Field et al. 2017). However, the late Holocene macrobotanical evidence shows that monsoon rainforest remained the primary ecological zone for the collection of food plants by Aboriginal groups visiting Riwi. During this time expansion of the number of taxa represented within each vegetation category (Fig. 6) may indicate broadening of diet in response to a reduction of monsoon rainforest patches in the area. Although monsoon rainforest may have reduced, abundant monsoon rainforest taxa in Riwi's SU1 sequence suggests patches of sufficient size must have persisted to sustain late Holocene occupations.

Since European colonisation and the introduction of pastoralism, increased fire frequency and deregulated fire management has had a profoundly detrimental effect on monsoon rainforest and on the distributions of these important ecological communities (Bowman 2005; Bowman and Panton 1993; Clayton-Greene and Beard 1985; Price and Bowman 1994; Russell-Smith 2001; Russell-Smith and Bowman 1992; Russell-Smith et al. 1998).

Monsoon rainforest and people in the Kimberley

Although today's distribution of monsoon rainforest across northern Australia is highly fragmented, isolated patches are documented as primary food gathering areas for Aboriginal people and locations of monsoon rainforest are often connected to important cultural sites (Karadada et al. 2011; Mangglamarra et al. 1991). Aboriginal groups in the Kimberley employ traditional land management practices to protect these ecological zones by burning the surrounding vegetation to mitigate destruction by wildfires (Mangglamarra et al. 1991). The significance of the role of monsoon rainforest in Aboriginal lifeways in the past has been suggested elsewhere (Beck and Balme 2003; Dilkes-Hall et al. 2019) and indeed the composition and diversity of the gathered diet at Riwi, as indicated by the macrobotanical record, demonstrates that Aboriginal groups occupying semi-arid southern Kimberley environments relied heavily on monsoon rainforest ecological zones and their vegetal taxa for food plants.

The most abundant monsoon rainforest taxon across Riwi's macrobotanical record is *Vitex* cf. *glabrata*. The species is endemic to northern Australian tropical regions and bears edible fruits that turn dark purple-black when ripe (Fig. 7a) (Kenneally et al. 1991, 1996; Wheeler 1992). Fruit production is highly seasonal and occurs during the last months of the wet season (December-February) (Wheeler 1992). *V.* cf. *glabrata* is represented throughout Riwi's Holocene macrobotanical sequence by whole or fragmented endocarps, calyces, and the occasional preservation of whole fruits with exocarp and calyx intact (Fig. 7b-e).

Fig. 7 Modern (a) and archaeological examples (b-f) of *Vitex* cf. *glabrata*: a) *Vitex glabrata* plant with ripe (purple) and unripe (green) fruits, b) whole desiccated fruit, c) whole ovoid to subglobose endocarp with rugose longitudinally furrowed surface patterning with four ovary chambers that divide the stone internally, d) endocarp fragments, e) calyces, f) testa. Image a produced using Canon IXUS 180. Images b-e produced using a high resolution AxioCam MRc5 microscope camera. Image f produced with the JEOL JCM-6000 Neoscope Scanning Electron Microscope (SEM)

Vitex fruits are recorded as an important food to many Aboriginal groups across the Kimberley (Table 4). Historic records document that during the wet season *Vitex* fruits were available in such abundance that to prevent spoilage surplus fruits were processed, dried, by a camp fire or in the sun, and pounded into cakes (Crawford 1982; Scarlett 1985). Plants that are dried and stored are far more likely to preserve in the archaeobotanical record (Dennell 1976) and desiccation, as a means of deliberate preservation of plant resources, is a known practice amongst Australian Aboriginal groups (e.g. Crawford 1982:9; Gould 1969:261; Head et al. 2002:183) and still practiced by Gooniyandi traditional owners (June Davis pers. comm. 2018, see Dilkes-Hall et al. submitted).

At Riwi, whole desiccated *Vitex* fruits (Fig. 7b) indicate that fruit bearing *Vitex* trees were present in sufficient numbers close enough to Riwi to facilitate fruit collection, on a scale large enough for people to return to the cave site with surplus fruits. Whole *Vitex* endocarps suggest fruit consumption and carbonisation of remains indicates fruits may have been dried in the cave with the aid of fire, possibly burnt during fruit processing/preparation (Dilkes-Hall et al. submitted; van der Veen 2007). It is also possible that refuse was disposed of directly into fire, which may have been beneficial as ‘casual’ fuel (van der Veen 2007:979). Different *Vitex* plant parts (specifically, fragmented endocarps and calyces) that are largely desiccated could represent specific stages of processing and further research is underway to determine what types of by-products are produced during *Vitex* fruit processing.

Undoubtedly, food collection was an important part of the daily gathering activities at Riwi and the abundance of monsoon rainforest taxa, used as a seasonal indicator, indicates that people were visiting the site in wet/humid periods related to the tempo of monsoon dominated climatic cycles. A lack of permanent water sources in the immediate vicinity of the cave makes more sense with occupations during wetter months allowing for water collection from seasonal creek-lines close by to the cave. Inside, the cave provides protection from elements such as rain and wind and, coupled with its capacious structure, is assumed to have been attractive to people as a shelter during wetter months. Outside of the cave, the moisture retaining limestone range supports monsoon rainforest taxa, a crucial element of foragers’ subsistence.

People’s movements in the landscape surrounding Riwi were very likely shaped through hunting-gathering-fishing activities, with different ecological zones targeted to access a range of economic resources. As shown in the macrobotanical (food plants) and anthracological (fuel) archives at Riwi (Whitau et al. 2017, 2018) monsoon rainforest fulfilled multiple economic roles in the daily lives of Aboriginal groups occupying Riwi and probably encompassed other intangible aspects such as places for water collection and social learning where ecological knowledge was passed from one generation to the next.

Conclusion

Located on the edge of a major arid zone, Riwi reveals through its mid- and late Holocene macrobotanical assemblages that monsoon rainforest ecological zones were primarily exploited for food plants. This is despite the scattered distribution of this vegetation type which today is largely restricted to the coastal regions of the northern Kimberley and only occurs in small pockets along limestone ranges in inland regions of the southern Kimberley. While monsoon rainforest may have occurred more abundantly in the mid-Holocene near Riwi, it would still have been restricted to limestone ranges. A pattern of exploitation is suggested where these monsoon rainforest ecological zones, rich in fruit bearing plant species, were visited by Aboriginal groups engaged in subsistence activities in the landscape surrounding Riwi.

This research highlights the importance of sometimes apparently minor environmental zones, in this case niches in limestone outcrops, for people’s landscape movements. No permanent water in the immediate vicinity of Riwi coupled with the fruiting times of monsoon rainforest taxa, intimately linked to rainfall, suggests that wet season resource availability shaped Aboriginal decision-making and mobile spatial occupation patterns. Economic resource patterning is interpreted here as a result of mobility directly linked to the seasonal availability of such resources. Specifically, *Vitex* cf. *glabrata*, the main species represented in the Riwi assemblage, is available in such abundance during the wet season that in recent times it is still processed and stored for later consumption. Thus, the fruiting times of monsoon rainforest taxa influenced Aboriginal lifeways and mobile spatial occupation patterns, over at least the last 7,000 years.

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