The palaeoenvironmental history of Big Willum Swamp, Weipa: An environmental context for the archaeological record

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Abstract

The environmental history of Big Willum (Waandriipayn) Swamp and the surrounding landscape is reconstructed for the last 8000 years through the analysis of pollen, charcoal and mineral magnetics. The data provide a Holocene record of vegetation and fire in an area where few records exist. Swamp initiation at Big Willum began prior to 8000 cal. BP, with swamp-like conditions maintained until 2200 cal. BP, after which it became a permanent deep water body, reaching its present day extent between 600–400 cal. BP. From 7000–1200 cal. BP the surrounding woodland was essentially stable. Fire is present throughout the record, with only one period of pronounced burning outside of the historic period, at around 1000 cal. BP, leading to a slightly more open understorey/woodland. The hydrological change at 2200 cal. BP that led to Big Willum becoming a more permanent water body overlaps with the end of the most intensive period of shell mound formation and the commencement of earth mound building at nearby Wathayn. This is suggestive that change in, or diversification of, mound types may in part be linked to environmental transformations in the late Holocene. One possibility is that greater water security allowed for increasing and more permanent exploitation of inland locations.

Introduction

For the Australian monsoonal tropics a general paucity of palaeoecological studies has resulted in a disjointed understanding of the region’s biogeographic patterns (Bowman et al. 2010). Wetlands in the Weipa region, located on Queensland’s (Qld) western Cape York Peninsula (Figure 1), present an opportunity to specifically target northern dry-sclerophyll Holocene dynamics, and provide a contrast to recent wet sclerophyll and ongoing rainforest analyses (e.g. Haberle 2005; Moss et al. 2012; Walker 2007) further to the south. Importantly, palaeoecological work from this region also provides a more comprehensive environmental context than previously available for the much discussed archaeological record.

The archaeological record around Weipa is dominated by the largest concentration and volume of shell mound sites in Australia (Morrison 2013a). These mounds have fascinated researchers since the early twentieth century, resulting in numerous written observations and archaeological explorations (e.g. Bailey 1975, 1977, 1993, 1994, 1999; Bailey et al. 1994; Cribb 1986, 1996; Morrison 2003, 2010, 2013a, 2013b; Roth 1901; Shiner et al. 2013; Shiner and Morrison 2009; Stanner 1961; Stone 1989; Wright 1971). The term ‘shell mound’ was used by Bailey (1999:105) to include large (10 m height) to small (1 m height) shell concentrations. These sites, which are composed primarily of the bivalve Anadara granosa, are today predominantly associated with estuarine environments and in general are located on tidal mudflats within or behind the mangrove zone and on low sandy chenier ridges (Morrison 2013a). At least 500 shell mounds occur along the four main rivers that flow into Albatross Bay and are the key source of reliable chronological information for the Weipa archaeological record (Shiner and Morrison 2009:53). Until recently, most published radiocarbon dates from Weipa shell mounds were less than 1600 cal. BP in age (Morrison 2013a:82, 2013b; Ulm and Reid 2000). However, new work focused on the locality of Wathayn (Figure 2) is revealing shell mounding clustering around 2700–2100 cal. BP, with some older and younger outliers (Petchey et al. 2013; Shiner et al. 2013). Preliminary dating of their underlying substrate through optically stimulated luminescence (OSL) suggests mid-Holocene infill and coastal progradation in line with sea-level rise and stabilisation ca 6000 years ago (ya), followed by a hiatus of these processes from 5000–4000 ya when chenier building occurred (Shiner et al. 2013:88). Following Cribb (1996), it seems likely that sea level stabilisation...
and coastal progradation, as in other places in northern Australia, created ideal conditions for *Anadara* beds to flourish. Morrison (2013a) argued that shell mounding at Weipa continued until recently, as was also argued for Western Australia (WA) (Clune and Harrison 2009). This is in contrast to the Northern Territory (NT), where it is argued that shell mounding ceased ca 500 ya (Bourke 2012; Faulkner 2013; Hiscock 1997, 1999).

Apart from the age, duration and influence of environmental conditions on mounding behaviour at Weipa (and elsewhere), debate continues around the models that best describe the formation of these and similar mounds across northern Australia. Bailey (1975) concluded that large shell mounds were used repeatedly as home bases by small family groups during the late wet season. Others, however, have considered the appearance of shell mounds to be a reflection of new strategies targeting *A. granosa* shell beds irregularly but intensively at times when the resource was abundant (cf. Bourke 2003, 2004; Faulkner 2009, 2011, 2013; Morrison 2013a; O’Connor 1999; Veitch 1999). Morrison (2003, 2010), in particular, disagreed with Bailey’s functional analysis and used ethnographic analogy to argue that shell mounds accumulated as a result of ritual and social functions (cf. Bourke 2005; Cribb 1996), an argument rejected by Hiscock and Faulkner (2006; Faulkner 2013) on the basis that shell mounding reflects exploitation of an environment that no longer exists and therefore ethnographic analogy cannot be used for interpretation. Morrison (2013a) has most recently argued that shell mounds reflect the exploitation of the estuarine habitat as a whole, and that the resilient *Anadara* mounds only partially represent the strategic use of niche ecosystems within estuaries. Results from the Wathayn research lend some support to Morrison’s ‘niche production’ interpretation, as the shell mounds analysed, although dominated by *Anadara*, record a diversity of species throughout their life spans (Shiner et al. 2013:88).

Recent surveys associated with bauxite mine clearances at Weipa have recorded earth mounds, shell and stone artefact concentrations, scarred trees, modern middens composed of the estuarine mud shell *Polymesoda*, and historical sites that reflect the recent history of the region’s pastoral industry and missions (Shiner and Morrison 2009). Investigation of these sites is to some extent moving the focus of debate away from shell mounds and broadening our understanding of the cultural landscape around Weipa.

Earth mounds in northern Australia are composed mostly of soil and sand. They are generally clustered on the margins of freshwater floodplains and creeks and may contain stone artefacts and faunal remains, including shell (Brockwell 2006:47). Their stratified and dateable assemblages provide another opportunity to establish the chronology of pre-contact occupation. At Weipa these sites occur on the coastal plain bordering the Weipa Plateau and correspond to the estuarine (and therefore mangrove) limit of lowland watercourses. The Weipa earth mounds contain burnt termite mound fragments, charcoal, sparse shell remains and stone artefacts (Shiner and Morrison 2009:53). Earth mound dates from Wathayn suggest that they were mostly occupied after 2000 cal BP and the majority within the last 500 years (Brockwell et al. 2013a).

Stone artefact concentrations are another common site type, usually found within 250 m of a watercourse or swamp, and typically positioned on eroding gravel surfaces overlooking floodplains; they are less common on the Weipa Plateau. Shiner and Morrison (2009) suggested that the greater distance of these areas from water led to less permanent occupation and use. Sedimentary displacement (due to bioturbation, fire, water and gravity) was also concluded to be higher on the Plateau, leading to the obscuring of most stone artefacts.

### Palaeoenvironmental History of Northern Australia

A review of northern Australia’s environment for the last 30,000 years by Reeves et al. (2013) concluded that the early to mid-Holocene was warmer and wetter than present, with drier and more variable conditions beginning sometime after the mid-to late Holocene. The most recent, high resolution record, the KNI-51 stalagmite record from the east Kimberley, supports this scenario (Denniston et al. 2013). KNI-51 is a record of the Indonesian-Australian summer monsoon (IASM). The authors suggest that monsoon activity strengthened in the early Holocene, possibly as a result of rising sea levels flooding the continental shelves and initiating a regional monsoon response (Denniston et al. 2013). The weakening of the IASM in the KNI-51 record from 4100–1500 ya coincides with reported increases in El Niño Southern Oscillation (ENSO) frequency and amplitude from various Pacific records and is consistent with pollen, charcoal and lake level records from Australasia that indicate more variable conditions at this time. Denniston et al. (2013) suggested that the sharp rise in IASM strength over the last 1000 years is a weakening of this ENSO and IASM relationship.

There are no palaeoenvironmental records from the Weipa region, but other locations in the wet-dry tropics have records that are largely consistent with the early part of the above scenario; that is, freshwater swamp sedimentation beginning in the early Holocene (around 10,000–9000 ya) (Figure 1). Most of these records then exhibit some shift to either drier or more variable conditions from ca 5000–4000 ya, followed in the late Holocene by wetter and more stable conditions. There is considerable variation, however, in the pattern and timing of the environmental shifts after the mid-Holocene, with differences no doubt in part reflecting the development of rainfall patterns across northern Australia. In general, where disturbance or variability in the latter part of these records appears, it has been viewed as a function of strengthened ENSO activity (e.g. Rowe 2007; Shulmeister 1992, 1999; Stephens and Head 1995).

By contrast, several geomorphic studies from northern Australia suggest a number of dry periods not documented by pollen-based records or KNI-51 (e.g. Lees 1992; Lees and Clements 1987; Nott et al. 1999; Shulmeister and Lees 1995). In particular, Nott et al. (1999) argued for dry conditions from ca 8000–6000 ya based on a longitudinal dune sequence at Rosie Creek in the southern Gulf. Although this conflicts with the expansion of east coast rainforest, the commencement of sedimentation at a number of inland swamp sites (as outlined above), and now the KNI-51 record, it is consistent with sand lenses in the Groote Eylandt pollen core between 9000–7500 ya (Shulmeister 1992). The Rosie Creek and Groote Eylandt features can also be viewed, however, as evidence of woodland vegetation more open than that of today (Shulmeister and Lees 1995).

### Landscape and Cultural Change

Bailey (1999) observed the critical importance of independent palaeoenvironmental data as a check on archaeological interpretations at Weipa. He also suggested
that palaeoenvironmental variability has not been suitably allowed for and that ‘studies focused on dated changes in local environments are clearly an important requirement for future research’ (Bailey 1999:111). The analysis of a Holocene pollen and charcoal record from Big Willum swamp (Waandriipayn) therefore offers two opportunities:

1. To detail the local long-term terrestrial record of vegetation and fire in an area where few inland Holocene records exist; and,

2. To integrate local palaeoecological description with regional archaeological models.

Study Environment

Weipa is located on Albatross Bay and was originally established as an Aboriginal mission in the 1890s somewhat inland of the present town at the same time that European pastoral holdings were established across the northern peninsula (Shiner and Morrison 2009). The mission was subsequently relocated to present day Napranum, to the south, in the 1930s. The modern town of Weipa was established to support bauxite mining in the 1960s under Comalco (now known as Rio Tinto Alcan [RTA]) and the surrounding land is mostly held under mining leases to RTA.

The climate of the region is tropical monsoonal. The interaction between the IASM and South-East Trade Winds results in marked wet and dry seasons. From May–October the Intertropical Convergence Zone (ITCZ) lies well to the north and dry continental winds flow over the study area from the south. From November–April the ITCZ moves south carrying significant rains. Tropical cyclones represent an additional climatic control, originating to the north and west over the Gulf (Suppiah 1992). Annual average rainfall reaches 2007 mm and average monthly temperatures range from 31.0–35.6°C (maximum) and 18.7–24.2°C (minimum) (Bureau of Meteorology 2012).

The dominant physiographic unit is the Weipa Plateau, which is characterised by extensive bauxite deposits underlain by ironstone. The Plateau is incised by wide shallow watercourses which flow into the Gulf, principally at Albatross Bay. Along the coast a narrow coastal plain has developed from the deposition of silt, clay and sand. Beach sand-ridges are backed by black soil plains, mud flats and occasional salt-pans. Permanent freshwater soaks form in swales behind the beach ridges, creating an extensive system of seasonal and ephemeral freshwater swamps (Bureau of Mineral Resources 1977; Cameron and Cogger 1992; Galloway et al. 1970).

Godwin (1985), Cameron and Cogger (1992), and Neldner and Clarkson (1995) have provided extensive descriptions of the regional vegetation. Open forest is most widespread on the plateau, dominated by *Eucalyptus tetrodonta*, with *Corymbia nesophila*, *C. polycarpa* and *Erythrophleum chlorostachys* also well represented. *Melaleuca* species form almost pure stands across poorly drained flood plains and around freshwater swamps, usually with a ground cover of sedges and grasses. Discrete pockets of (notophyll) vine forest are also found on the plateau and Mapoon Plain, characteristically composed of evergreen tree species, including *Dysoxylum oppositifolium*, *Canarium australianum*, *Buchanania arborescens* and *Ganophyllum falcatum*. Narrow stretches of mesophyllous rainforest border freshwater watercourses, while mangrove communities dominated by the Rhizophoraceae family are found on saline muds with frequent tidal inundation.

Big Willum Swamp is located ca 18 km inland from the open coast. It has no obvious inlet or outflow and water depth varies seasonally. It is an unusual feature for the region, being a relatively large and deep open body of water with average water depth at time of coring (toward the end of the dry season) of 4 m. Much of the perimeter is dominated by sedges, rimmed in turn by *Melaleuca* woodland.

Methods

Sediment cores were collected in August 2011 (Figure 2). Intact mud-water interface sediments were collected and extruded on shore as 1 cm slices (BW01). Additional cores (BW02 and BW03) were then collected with a GEOCORER (a modified Livingston corer) starting approximately 20 cm below the mud-water interface.
A series of 2.5 cm³ samples were taken contiguously down
the core for pollen and charcoal analyses for BW01, and every
3 cm from 35–73 cm for BW03. Only preliminary dating and
sediment descriptions have been carried out on BW02.

Laboratory processing was carried out at The Australian
National University. The sediments were described and
then a magnetic susceptibility (MS) profile produced using
a Bartington MS2 meter and MSC2 core logging sensor.
Sample preparation followed standard techniques as
outlined in Bennett and Willis (2001), including the addition
of Lycopodium clavatum tablets to determine relative
concentrations of pollen and microcharcoal particles.

Pollen identification was based upon regionally appropriate
reference collections, including the Australian Pollen and
(>10 µm) was counted simultaneously with the pollen.
The macrocharcoal fraction (>125 µm) was sieved from
the sample and counted separately. Charcoal size, as a
representation of landscape fire, was guided by Whitlock

Data were plotted using TGView (Grimm 2004) and zones
derived by running an optimal splitting by sum of squares
analysis on the stratigraphically constrained data within
PSIMPoll (Bennett 2005). Age determinations are based
on 14C accelerator mass spectrometry (AMS) radiocarbon
dating of bulk sediments. Lead-210 (210Pb) dating was
attempted but a decay curve could not be produced due to
the very slow accumulation rate and hence low chronological
resolution of the sediments. Age depth models based on the
14C AMS ages were produced using OxCal v4.2.1 (Bronk

Figure 2 Location map for Big Willum Swamp, Weipa, western Cape York Peninsula (photograph by Janelle Stevenson).
The age models were used to calculate charcoal accumulation rates, which were detrended to resolve periods of greater fire activity. The data were first smoothed using a moving average to achieve an approximately even sample age down the record. Samples that exceeded one standard deviation above the moving average were considered to be periods of increased fire activity (i.e., greater than background), but only if they were independent of peaks in pollen accumulation. As the BW03 microcharcoal data was not continuous, only the macrocharcoal data for BW03 was explored in this way.

To explore the relationships within, as well as between, core samples, an unconstrained Principal Components Analysis (PCA) was carried out on the combined BW01 and BW03 pollen data sets using C2 (Juggins 2007). Only taxa with a value of 1% in at least one sample were included in the analysis. Samples in the resulting PCA bi-plot were then coded according to the zonal ages to illustrate the similarity of individual pollen samples through time.

### Results

#### Stratigraphy

A detailed stratigraphic description of all cores is reported in Table 1 and the lithology is shown in Figure 3. In summary, the basal sediments of all cores are coarse clayey sands grading upwards to silty organic clay, with the uppermost sediments a highly organic lake mud. In combination with the MS profiles, the lithology correlates well across the basin, although the sediments in BW01 are much finer in texture than BW02 or BW03, which have greater sand content.

#### Chronology

Big Willum provides a record of vegetation change extending back to the early Holocene (Table 2). The extrapolated age of the lowermost pollen samples at 32 cm for BW01 and 61 cm for BW03 is 7800 cal. BP. There is a flattening in both age models (between 23–21 cm in BW01 and between 29–20 cm

<table>
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<th>Depth (cm)</th>
<th>Colour</th>
<th>Description</th>
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<tbody>
<tr>
<td>0–4</td>
<td>10 YR 2/1 (black)</td>
<td>Watery unconsolidated organics</td>
</tr>
<tr>
<td>4–5</td>
<td>10 YR 2/1 (black)</td>
<td>Silty organics (quite dry)</td>
</tr>
<tr>
<td>5–13</td>
<td>10 YR 2/1 (black)</td>
<td>Organic mud</td>
</tr>
<tr>
<td>13–20</td>
<td>10 YR 2/1 and 3/1</td>
<td>Transition to unit below (colours mottled)</td>
</tr>
<tr>
<td>20–29</td>
<td>10 YR 3/1 (very dark grey)</td>
<td>Organic clay; occasional fine sand</td>
</tr>
<tr>
<td>29–38</td>
<td>10 YR 4/1 (dark grey)</td>
<td>Slightly organic sandy clay; increasing sand size and content with depth</td>
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<table>
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<th>Depth (cm)</th>
<th>Colour</th>
<th>Description</th>
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<tr>
<td>0–20</td>
<td>Not collected</td>
<td></td>
</tr>
<tr>
<td>20–29</td>
<td>10 YR 2/1 (black)</td>
<td>Black highly organic mud; quite coarse</td>
</tr>
<tr>
<td>29–38</td>
<td>10 YR 3/1 and 4/1</td>
<td>Silty organic mud (colours mixed)</td>
</tr>
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<td>38–48</td>
<td>10 YR 4/1 and 5/1</td>
<td>Organic silty mud (colours mixed)</td>
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<td>48–52</td>
<td>10 YR 3/1 (very dark grey)</td>
<td>Organic clay with black organic band at 49 cm</td>
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<tr>
<td>52–57</td>
<td>10 YR 3/1 (very dark grey)</td>
<td>Organic clayey coarse sand</td>
</tr>
<tr>
<td>57–68</td>
<td>10 YR 5/1 (grey)</td>
<td>Clayey sand gradually lightening to unit below</td>
</tr>
<tr>
<td>68–85</td>
<td>10 YR 7/1 (light grey)</td>
<td>Clayey sand with increasing mottling</td>
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<th>Depth (cm)</th>
<th>Colour</th>
<th>Description</th>
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<td>Not collected</td>
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<td>20–21</td>
<td>10 YR 2/1 (black)</td>
<td>Silty organics (quite dry)</td>
</tr>
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<td>21–27</td>
<td>10 YR 4/1 (dark grey)</td>
<td>Organic silt</td>
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<td>27–30</td>
<td>10 YR 4/1 and 3/1</td>
<td>Transition to unit below (colours mixed)</td>
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<td>30–35</td>
<td>10 YR 3/1 (very dark grey)</td>
<td>Organic clay</td>
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<td>35–37</td>
<td>10 YR 2/1 (black)</td>
<td>Organics</td>
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<tr>
<td>37–44</td>
<td>10 YR 4/1 (dark grey)</td>
<td>Organic silt</td>
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<td>44–55</td>
<td>10 YR 4/1 and 3/1</td>
<td>Transition to unit below (colours mixed)</td>
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<td>55–56.5</td>
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<td>56.5–58</td>
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<tr>
<td>58–59</td>
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<td>59–63</td>
<td>10 YR 3/1 (very dark grey)</td>
<td>Organic clayey coarse sand (increasing sand with depth)</td>
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<td>63–69</td>
<td>10 YR 5/1 (grey)</td>
<td>Organic clayey coarse sand (increasing sand with depth)</td>
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<td>69–90</td>
<td>10 YR 7/1 (light grey)</td>
<td>Clayey sand (increasing mottling with depth)</td>
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</table>

**Table 1** Sediment descriptions for cores BW01, BW02 and BW03.
The palaeo-environmental history of Big Willum Swamp, Weipa

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in BW03), indicating a slowing in sedimentation across the basin after the mid-Holocene (Figure 4). Sedimentation was possibly intermittent during this period, although there are no lithological indicators. Sedimentation increased after 2200 cal. BP (WK-35162) in BW01, and after 600 cal. BP (WK-35166) in the more peripherally located BW03. The long temporal scale, but short overall depth, means that the records are low in resolution.

Pollen and Charcoal

Pollen is dominated by sclerophyllous taxa and, in particular, myrtaceous canopy taxa. Relatively low values of broadleaf monsoonal forest, mangrove and herbaceous taxa have also been recorded.

The Myrtaceae are a difficult family to analyse in comparison to other angiosperm families. Although their pollen morphology has a large
shared baseline, many Myrtaceae genera also produce highly variable pollen (Thorhill 2012a). The following were consulted in order to divide the taxa from Weipa into meaningful groupings of related genera (i.e. tribes) (Boyd 1992; Chalson and Martin 1995; Dodson 1974; Martin and Gadek 1985; Parnell 2003; Pickett and Newsome 1997; Pike 1956; and Thornhill 2010). The collective data of Thornhill (2012a, 2012b, 2012c, 2012d) formed the most comprehensive material.

In the Weipa region 41 species of Myrtaceae are recorded, representing 16 genera and eight tribes (Godwin 1985). Of the latter, four could be categorised with confidence: Eucalyptae (Eucalyptus, Corymbia), Myrteae (Gossia, Eugenia, Lithomyrtus, Rhodhmania), Melaleucae (Melaleuca) and Leptospermae (Leptospermum). Where identifying features of Myrtaeae pollen were obscured from view or degraded, they were grouped as ‘undifferentiated’ (undiff.), while all other Myrtaceae were grouped under ‘Myrtaceae Other’.

The pollen and charcoal curves are shown in summary form in Figure 5 and in greater detail in Figures 6a and 6b. Samples taken from within the basal sandy layers (below 61 cm in BW03—see Figure 3) were found to be largely devoid of pollen. Overall, the pollen record is dominated by the Myrtaceae, which is diverse, though primarily comprised of Eucalyptae and Melaleuca types.

**Core BW01**

Core BW01 is from the centre of the water body, with the sum of squares analysis defining five zones. The lowermost Zone, A, has a modelled age of around 8000–7000 ya and is defined by the highest relative values of sedge and grass pollen and the lowest values of Myrtaceae pollen (70%). Other significant taxa include Casuarina and several broadleaf-monsoonal taxa (Apocynaceae, Podocarpus, Timonius, Glochidion and Ilex); of these, only Timonius and Podocarpus are recorded above Zone A.

The next two zones (B1 and B2) cover 7000–400 cal. BP. Their composition is very similar, with the major shift across their boundary being the complete lack of any grass pollen at 13–14 cm below surface (bs), extrapolating to ca 1100 cal. BP. Although small, there is also a rise in herbaceous taxa other than grass in Zone B2 (eight taxa in B1 to 14 taxa in B2; increase to >5% of total pollen). Casuarina remains the most prevalent woody taxa outside of the Myrtaceae, with occasional inputs from Arecaceae, Petalostigma, Dodonaea, Moraceae and Mallotus. The number of minor woody inclusions is also greater in Zone B2, overall suggesting a more diverse understorey than previously. Mangrove pollen (Rhizophora) appears for the first time at ~1200 cal. BP in Zone B1. Both Casuarina and Rhizophora are large pollen producers that are dispersed by wind (Boland et al. 2002; Wightman 2006) and their appearance is considered to represent long-distance transport from the coastal margins.

The next zone, C, has an interpolated age range of 400–100 cal. BP and is defined by a peak in Eucalyptae pollen (Eucalyptus-Corymbia) and a greater representation of Leptospermum. The morphology of the Eucalyptae pollen type is not as variable as in previous zones, and is thought best to represent Corymbia. Corymbia, along with Eucalyptus, dominates the present day open woodland, but is found preferentially to Eucalyptus on seasonally

<table>
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<th>Sample Depth (cm)</th>
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<th>δ(13C) per mil</th>
<th>Calibrated Age yrs BP (2 sigma)</th>
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<td>Wk 34027</td>
<td>10–11</td>
<td>1063±26</td>
<td>-19.6</td>
<td>960 (930) 820</td>
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<td>6217±40</td>
<td>-19.0</td>
<td>7170 (7050) 6910</td>
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<td>1866±25</td>
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<td>1718±27</td>
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<td>1690 (1570) 1420</td>
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<td>-20.0</td>
<td>560 (530) 500</td>
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<td>20–21</td>
<td>619±25</td>
<td>-20.4</td>
<td>640 (580) 530</td>
</tr>
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<td>D-AMS 001954</td>
<td>27–28</td>
<td>4743±28</td>
<td>-26.1</td>
<td>5580 (5420) 5320</td>
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<td>D-AMS 001955</td>
<td>33–34</td>
<td>616±31</td>
<td>-22.0</td>
<td>7160 (7000) 6890</td>
</tr>
<tr>
<td>Wk 35168</td>
<td>58–59</td>
<td>6558±28</td>
<td>-19.2</td>
<td>7481 (7410) 7320</td>
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<tr>
<td>Dates rejected by OxCal age model</td>
<td></td>
<td></td>
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<tr>
<td>Wk 35167</td>
<td>35–36</td>
<td>112.8±0.3 %</td>
<td>-20.8</td>
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</tr>
</tbody>
</table>

Table 2: Radiocarbon age determinations for BW01, BW02 and BW03. Calibrated ages that resulted in poor agreement in the initial age-depth models (OxCal v4.2.1 Bronk Ramsey 2008, 2009) are noted and were not used in the subsequent age models.
inundated alluvial flats or low undulating zones on shallow soils. At the same time, there is a lower diversity of other pollen types (both woody and non-woody) and there is a greater representation of grass over other herbaceous taxa. In essence, the pollen becomes less diverse after 400 cal. BP.

The uppermost Zone, D, covering the period from around 100 cal. BP through to the present (based on extrapolation within the age model), is defined by Myrtaceae that could not be easily categorised due to poor preservation (Myrtaceae undiff.). This increase is associated with a decrease in Melaleuca, Leptospermum and Myrtaceae pollen.

Core BW03

Core BW03, at the southern end of the water body, has a different chronological resolution to that of BW01, capturing the early part of swamp development in greater detail. At the time of pollen sampling and analysis of BW03, however (i.e. prior to receiving dating results), it was envisaged that developing this record from 70–35 cm would be adding time depth rather than resolution to the overall record from Big Willum.

The pollen zonation of BW03 resulted in four zones, with the lowermost, A, dating to a similar period to Zone A in BW01: 8000–7200 cal. BP. It is worth noting that pollen is not preserved below 61 cm depth, which establishes the lowermost boundary. Overall, Zone A is defined by high values of Poaceae and sedge pollen (Figures 5 and 6). Other non-grass herbs are dominated by leguminous taxa, with minor occurrences of Boraginaceae, Evolvulus, Chenopodiaceae, Liliaceae and Laminaceae. The woody taxa are dominated by Eucalypteae, with the non-Myrtaceous woody taxa once again comprised of Casuarina, Arecaceae, Pandanus and Timonius. Overall, this zone correlates well with Zone A in BW01 in both pollen characteristics and age.

The next three zones in BW03 overlap in time, with the lowermost portion of Zone B in BW01 covering the period 7200–5900 cal. BP. Zone B (7200–6000 cal. BP) is defined by a reduced input of sedge pollen. Within this zone the Melaleucae increase in value, as do Casuarina at around 6000 cal. BP. All other Myrtaceae record steady percentage values.

The defining characteristics of Zone C, from 6600–6100 BP, are the low Poaceae values (which change from 20% in Zone B to <5% in Zone C) and the absence of sedges. As a consequence, the woody taxa constitute >80% of the pollen throughout the zone. The makeup of the Myrtaceae pollen remains consistent through this zone, dominated by Eucalypteae and Melaleucae. Of the non-Myrtaceous woody taxa, Casuarina is the prevailing type, although at lower values than in Zone B, while Arecaceae and Pandanus are absent. Buchanania is the only monsoon forest taxon recorded in this zone. While values are reduced, leguminous taxa still dominate the other herb taxa.

The uppermost zone in BW03, Zone D, is a single sample that ranges from 6100–5900 cal. BP, and is defined by the return of Poaceae pollen levels to >20%, an increase in leguminous herb pollen, and the presence once more of sedge pollen. In composition it is very similar to samples from the same age range in BW01.

Charcoal Data

Charcoal is found throughout the two records, with macrocharcoal a representation of local or catchment scale burning, and microcharcoal a representation of regional scale burning (Figures 5, 6a and 6b). The highest values of charcoal accumulation occur after 2000 cal. BP in BW01, but after 7200 cal. BP in BW03. Charcoal peaks above background in either one or both size fractions were detected at 28–29 cm, 16–17 cm, 14–15 cm, 11–12 cm and 1–2 cm in BW01. However, the only peaks to occur independently of the pollen accumulation curve are those at 11–12 cm and 1–2 cm, that is, around 1000 cal. BP and within the last century. The most significant of these is at 1000 cal. BP, as it is recorded in both the local and regional records. This peak also overlaps with a subtle shift in the pollen taxa and as such is the only time...
where fire appears to be in some way landscape altering. The peak within the last century is only detected in the macrocharcoal record, which represents local or catchment scale events above background levels. Owing to an overlap with the pollen accumulation rate, all other peaks are potentially the result of sedimentation changes not detected by the dating protocol and consequent age model.

For BW03, micro- and macrocharcoal were sampled at different age resolutions and over different time periods. Although pollen is not preserved in sediments below 61 cm, charcoal is, and the macrocharcoal record extends down to 73 cm, well beyond 7000 cal. BP. There are raised levels of microcharcoal, indicative of regional burning, in Zone A, which is greater than 7200 cal. BP in age, but above this the microcharcoal values are low. For the macrocharcoal, which has a more local source, there are four peaks above background levels, although these are harder to evaluate for independence, as the pollen and microcharcoal have not been sampled contiguously. Of note, however, is the complete absence of macrocharcoal between 44–41 cm (6500–6300 cal. BP). The greater resolution in the lower portion of the BW03 record reveals how the charcoal record, and hence the fire history, is more complex than that indicated by the single peak in core BW01 for the same time period. Ongoing work at Big Willum and other sites across the region aims to produce a high resolution composite record of fire history.

**Principal Components Analysis**

To explore the relationship between the vegetation records of the two cores an unconstrained PCA was performed. The first two axes of the PCA are shown in Figure 7, and explain 50% of the variation within the dataset. The sample biplot utilises the age ranges defined above, with the taxa driving the sample distribution also shown. The oldest samples
The palaeo-environmental history of Big Willum Swamp, Weipa

(>8000–7000 cal. BP) from both cores plot in the bottom right quadrat of the biplot. No other samples plot in this space and the taxa defining these samples, in descending order of influence, are Poaceae, *Casuarina*, palms, *Pandanus* and *Zornia* (a prostrate herb common on open rocky ground). Most of the remaining samples plot to the left of the y-axis, with this distribution along the first axis (the x-axis) appearing to represent the degree of openness within the vegetation. The distribution of samples along the second axis appears to be a moisture/hydrological gradient, with samples defined by woodland taxa (the Eucalyptae, predominantly *Eucalyptus-Corymbia*) plotting in the upper left hand quadrat, while samples defined by the increased presence of rainforest and swamp taxa plotting below the x-axis in the bottom left hand quadrat. The samples in the upper right-hand quadrat are defined largely by herbaceous taxa other than grass and the other Myrtaceae category. Notably, samples from the same age ranges from the two cores plot in the same PCA space, indicating that the records they contain are reproducible across the basin. Examining the data in this way also illustrates that the period of greatest variability within the record has been over the last millennium, in particular the period from ca 1000–400 cal. BP.

Discussion

Palaeoenvironmental Reconstruction of the Big Willum Catchment

The Big Willum Swamp data provide the first long-term vegetation record for western Cape York Peninsula. This record reveals the initiation of an inland wetland habitat and the captured time line is rare for the Australian monsoonal tropics, spanning almost the length of the Holocene.

The lowermost zones in both cores record the inception of the swamp deposit at around 8000 cal. BP, with the pollen suggestive of a poorly-drained site, with sedge, fringing herbs and grass cover, and thin stands of Melaleuca. As open water developed, from around 7000–5000 cal. BP, grass and sedge representation declined as the swampy basin bottom became submerged. In these lowest sections the pollen of broadleaf taxa associated with monsoon forest thickets were also recorded, albeit at very low percentages.

Following on from this there was a period of very low sedimentation from 4700–2200 cal. BP in BW01 and from 5000–600 cal. BP in BW03, possibly reflecting a contraction of the water body and more ephemeral conditions. A change in sediment composition and rate of accumulation at 2200 cal. BP suggests that Big Willum became a permanent body of free standing water after this time, possibly reaching its present day extent from around 600–400 cal. BP. Evidence for the latter includes an increase in sediment accumulation at BW03 from this time and the presence of *Nymphaea* (water lily) pollen, suggesting an environment similar to today.

The Big Willum terrestrial record is dominated throughout by the same sclerophyll taxa observed around the swamp today. The Eucalyptae are the most abundant pollen taxa and represent the surrounding woodland tree stratum, while the other dominant pollen type, *Melaleuca*, represents the surrounding swamp forest. The landscape was initially more open, but for much of the record had a reasonably diverse understorey (both woody and herbaceous), becoming less

Figure 7 PCA biplot of BW01 and BW03 samples showing the dominant or driving taxa, and the inferred environmental gradients. The first two axes explain 50% of variation in the dataset.
diverse over the last approximately 100 years, possibly in response to changing fire regimes. The most variable period in the vegetation record was from 1200–400 cal. BP.

From around 600–400 cal. BP onwards, a number of indicators in the Big Willum record suggest that the environment was even wetter than in the preceding 1500 years. Evidence for this includes: the resumption of significant sedimentation around the periphery of the swamp (i.e. at BW03), suggesting greater seasonal inundation of low-lying areas around Big Willum; and the greatest representation of Leptospermum, a tree restricted to gallery forest/gallery woodland alongside permanent fresh watercourses.

While acknowledging that the resolution of the record is quite coarse, fire as represented by charcoal content is a constant. Whether this regular input of charcoal to the system was the result of human activity cannot currently be determined, but there were two significant periods of burning, one around 1000 cal. BP and another in the late nineteenth century to early twentieth centuries. All other peaks above background align with peaks in pollen accumulation and are therefore most likely artefacts of the sedimentation processes within the swamp.

The pronounced period of burning at around 1000 cal. BP, with peaks in both local and regional charcoal fractions, was accompanied by a subtle shift in the vegetation, and suggests one large, or multiple large, burning events. The increase in fire activity in the most recent part of the record may be related to European arrival in the region or the first explorations by mining interests in the mid-twentieth century. At present the chronology is too coarse to determine either scenario. However, future work on other records from the region will further enhance our understanding of fire in this landscape over time.

**Big Willum and Northern Australian Palaeoenvironments**

The development of Big Willum during the Holocene into the perennial water body we see today appears to follow five distinct phases:

1. A variable moist habitat in the early Holocene;
2. The initiation of a swamp at ca 7000 cal. BP;
3. Contraction of the swamp and a decrease in sedimentation from 5000–2200 cal. BP;
4. A perennial water body after ca 2200 cal. BP; and
5. A water body similar in extent to that of today from ca 600–400 cal. BP.

This scenario has many similarities to records from the Gulf of Carpentaria, Cape York Peninsula and eastern tropical QLD, in particular, the early Holocene development of swamps within sandy basins that are relics of late Pleistocene aridity (Luly et al. 2006; Moss et al. 2012; Preeble 2005; Rowe 2007; Shulmeister 1992; Stephens and Head 1995). These wet-dry tropics record suggest shallow and variable water levels in the early Holocene, in contrast to the long continuous sequences from the wet tropics of northeast QLD (Haberle 2005). In the wet tropics, rainforest taxa increase throughout the early Holocene, reaching maximum values from around 5000–4000 cal. BP (Haberle 2005; Hiscock and Kershaw 1992; Walker 2007), while in the wet-dry tropics this mid-Holocene 'optimum' differs slightly in timing as local conditions impose extra variables on the general trend. At Big Willum this warm and wet period came to an end around 5000 cal. BP.

Early Holocene longitudinal dune sequences from the southern Gulf of Carpentaria, and sand lenses in the early Holocene portion of the Groote Eylandt pollen record, were initially thought to have represented a conflicting story of continuing aridity in the early Holocene, but have since been interpreted as representative of woodland vegetation that was more open (Shulmeister and Lees 1995). The record from Big Willum also suggests that, during swamp development in the early Holocene, the surrounding vegetation was much more open than the present day.

This period of optimal climate was followed by a period of drier or more variable conditions at most locations, including from within the rainforest of the wet-tropics (e.g. Haberle 2005; Moss et al. 2012; Rowe 2007; Shulmeister 1992; Walker 2007). In general this is attributed by the various authors to the establishment of an ENSO-dominated climate system. At Big Willum the period from around 5000–2200 cal. BP is defined by a much slower sedimentation rate, leading to a sample resolution so coarse that it reveals little in the way of vegetation variation or disturbance.

Sedimentation increases markedly after 2200 cal. BP in Big Willum, suggesting more stable water levels after this time, with the present day extent and greatest water depths attained sometime over the last 600–400 years. This seems to be part of a broader east to west trend, with a shift to moister and more stable conditions (i.e. more permanent water) at ca 2700 cal. BP in southeast Cape York Peninsula (Stephens and Head 1995), after 2500 cal. BP in the Torres Strait (Rowe 2007), after 1000 cal. BP on Groote Eylandt (Schulmeister 1992), and after 1300 cal. BP at Black Springs in the Kimberley (McGowan et al. 2013). However, there are several notable exceptions. Witherspoon Swamp is interpreted as shifting to drier not wetter conditions after 2000 cal. BP (Moss et al. 2012), while Three-Quarter Mile Lake in northeast Cape York is interpreted as wet and stable from 5000 cal. BP to the present (Luly et al. 2006).

**Palaeoenvironmental Context for the Archaeological Record**

Palaeoecological data from an inland location such as Big Willum have the potential to provide an environmental framework for the substantive archaeological record of the region (Figure 8). Across northern Australia shell mounding activity generally occurs from 3500 ya (Bourke 2002, 2004, 2012; Brockwell et al. 2011; Faulkner 2008, 2009, 2010, 2011, 2013; Morrison 2010), with the broad consistency in ages suggesting a strong environmental influence over the establishment and consequent exploitation of this resource.

It is thought that between 800 and 500 ya in the NT, changes in climate and coastal geomorphology led to the decline of sandy/mudflat shell beds as shell mounding behaviour ceased in several places by around 500 ya. Although unresolved, one climatic mechanism commonly cited for these changes has been ENSO (cf. Bourke et al. 2007; Brockwell et al. 2013b). Overlapping with these changes in coastal economies is the expansion of earth mound occupation on the sub-coastal freshwater wetlands from around 500 ya, thought to reflect greater availability of freshwater resources and
The palaeo-environmental history of Big Willum Swamp, Weipa

Perhaps consequently a relocation of populations from the coast (Bourke 2012; Brockwell 2009; Brockwell et al. 2011; Faulkner 2013; Hiscock 1999; Meehan 1982).

At Wathayn shell mounding was concentrated between 2700–2100 cal. BP (Petchey et al. 2013), with the increase coincident with the commencement of increased sedimentation within Big Willum swamp. As this increase in sedimentation is a likely consequence of increased or more reliable rainfall, the sensitive Anadara shell beds may have been impacted through increased siltation and freshwater inputs (cf. Bourke 2003), thus reducing the availability of this resource and, as a consequence, shell mound activity.

Overlapping with the decline in shell mound activity is the establishment of earth mounds in the Wathayn area from around 2000 ya (Brockwell et al. 2013a). Their typical location adjacent to freshwater swamps and streams (Brockwell et al. 2013a; Morrison 2010:173) hints at a diversification in the economy away from the coast, with the Big Willum record supporting a scenario of more permanent fresh water from this time onwards. In particular, the data from Big Willum suggest that the final 600–400 years were the wettest of the last 2200 years, overlapping with the trebling in earth mound occupation from around 500 cal. BP (Brockwell et al. 2013a). The increase in fire activity at around 1000 cal. BP may therefore reflect an initial phase of more permanent expansion to inland locations, with the dramatic increase in earth mounds over the last 500 years the likely consequence of greater freshwater and resource security.

By 150 ya, shell mounds were no longer being utilised at Wathayn (Petchey et al. 2013), suggesting that this resource base had virtually disappeared from the area and the environment had become more like it is today. However, continued occupation of earth mounds, sometimes with surface glass flakes, modern earth ovens using corrugated iron, recent scatters of estuarine mud shell (Polymesoda coxans) associated with metal and besser bricks, and trees scarred with steel axes, reflect a continuation post-contact Indigenous economic practices with the adoption of new technologies (Morrison and Shepard 2013; Shiner and Morrison 2009). Increased evidence of fire in the most recent part of the pollen record may reflect this period of contact between European and Indigenous people, when fire regimes were no doubt altered and intense late dry season fires possibly became the norm (cf. Crowley and Garnett 2000).

Conclusions

The palaeoenvironmental data from Big Wilum Swamp are a component of a broader multidisciplinary research programme exploring environmental and archaeological records from Weipa. The main findings address a significant gap in our understanding of the region and are the first step towards the establishment of an environmental context for interpretation of the shell and earth mound records. While ongoing work will provide better insight into the processes that affect both the archaeological and environmental histories, results already reveal a consistency with, and refinement of, broader palaeoenvironmental patterns for northern Australia. While the actual drivers of change are still to be resolved, not only for this record but also for many of the other north Australian records, the general picture of greater freshwater availability (security) in the late Holocene overlaps with a shift in the local economy to increased use of freshwater resources.

Several other water bodies have been identified and further research into past environmental conditions will resolve whether the patterns seen in the Big Willum record are consistent across this landscape. Such data will provide key information for the interpretation of Holocene palaeoenvironments, a fundamental backdrop to the archaeological dataset.

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References


The palaeo-environmental history of Big William Swamp, Weipa


Faulkner, P. 2008 Patterns of chronological variability in occupation on the coastal margin of Blue Mud Bay. Archaeology in Oceania 43(2):81–98.


Faulkner, P. 2011 Late Holocene mollusc exploitation and changing near-shore environments: A case study from the coastal margin of Blue Mud Bay, northern Australia. Environmental Archaeology 16(2):137–150.


Shiner, J. and M. Morrison 2009 The contribution of heritage surveys toward understanding the cultural landscape of the Weipa bauxite plate. Australian Archaeology 68:52–55.


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


