Understanding Australian tropical savanna: environmental history from a pollen perspective

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Abstract

Understanding the long-term functioning of Australia's tropical savannas is central to the management and conservation of these ecosystems. An environmental history of the Darwin region's mesic savanna is presented from Girraween Lagoon, approx. 25 km southeast of Darwin, where pollen and charcoal analysis of a 5 metre sediment core provides a record spanning the previous 12,700 years. Results show the gradual development of permanent water at the site, surrounded by a dynamic landscape where changing climates and local people's use of fire has shaped the vegetation from that of a savanna to an open forest.

Introduction

Palaeoecology is the branch of ecology that studies past ecosystems and their trends in time using fossils and other proxies (Rull 2010). These studies hold major implications with respect to our understanding of the nature and function of contemporary ecosystems, contributing to key questions of natural variability, baselines, thresholds, resilience, and regime shifts (Froyd & Willis 2008). In this respect, palaeoecology and other forms of long term science are central to land resource management, and play an increasingly important role informing climate change conservation strategies (Ekblom & Gillson 2017).

Palynology is the scientific discipline concerned with the analysis of plant pollen, spores, and certain microscopic planktonic organisms, in both living and fossil form (Jarzen *et al.* 1996). As pollen and spores are produced in large numbers, then dispersed over wide areas by wind and water, and because they are strongly resistant to decay under certain conditions (i.e. anaerobic environments), their fossils are recoverable from a variety of sedimentary materials (Brown 2008). Birks (2012: 292) described records of pollen preserved in lake or swamp sediments as "long-term ecological observatories". As an indicator of past vegetation communities, including relations between plants and their environments, palynology is one of the most important tools for palaeoecology.

Darwin's Girraween Lagoon (12.517˚S, 131.081˚E) (Figure 1a) is a site of ongoing palaeoecological investigation. It forms one of a series of research locations from the Top End of the Northern Territory. These sites are focused on the development of a concentrated spatial and temporal network of Quaternary records of vegetation and environmental change in the savanna of tropical northern Australia. The Quaternary is the most recent geological period of time, spanning the past two million years up to the present day. It is subdivided into the Pleistocene (glacial phase) and Holocene (present interglacial) epochs, with the Holocene covering the past 11,700 years (Cohen *et al.* 2013; updated). The savanna region of northern Australia remains little studied in the Quaternary context; i.e. fine-resolution palaeoecology and palynology, including detailed chronologies of vegetation and fire regime change are scarce, particularly for the Northern Territory. We seek to document changes before, during and after the arrival of humans (Indigenous and European). We further seek to track changes across major glacial and interglacial climatic cycles. We are asking questions such as 'What are the major drivers of ecosystem change at different time scales?' and 'What determines landscape and habitat diversity over time?' We aim to explore whether the Australian

Figure 1. (**a**) View of Girraween Lagoon taken from the northern shoreline with fringing *Melaleuca* trees in the foreground. (**b**) Floating platform with hydraulic coring rig used to sample lagoon sediment. August 2018. (Cassandra Rowe)

savanna represents a region in long term transition or a region in a stable ecosystem state. In this project, Girraween is representative of a mesic tropical savanna (>1200 mm/yr of rainfall (Russell-Smith *et al.* 2010)), and following the regional 'savanna' land cover classifications of Hutley *et al.* (2013) and Moore *et al.* (2018). Moore *et al.* (2016) refer to the wider Howard Springs area as an open-forest savanna.

Methods

In September 2015, Girraween Lagoon was cored using a floating platform with a hydraulic coring rig (Figure 1b). A 19.4 m long core was collected in 1 m sections to bedrock. The focus of this report is a summary of the upper 5 m of this core, encompassing the last 12,700 years. The core sections were split in half, described, and subsampled at 10 cm intervals. Two cubic centimetre sediment samples were processed for pollen (see Bennett & Willis (2001)). Charcoal incorporated within this final sediment concentrate was counted simultaneously with pollen as an indicator of landscape fire, as guided by Whitlock & Larsen (2001). Seven bulk sediment samples were pre-treated for radiocarbon dating according to Bird *et al.* (2014) and sent to Australia's Nuclear Science and Technology Organisation for processing. Radiocarbon dating is one of the most widely used scientific dating methods in environmental science and archaeology today. Radiocarbon measurements are reported in terms of years 'before present' (BP), but are not a true calendar age and therefore require calibration. Once it is calibrated to a calendar time scale, a radiocarbon date is expressed as 'cal BP' (Ramsey 1995). In this study, age reporting follows Stuiver & Polach (1977), converted into calibrated ages (cal BP) using CALIB REV7.1.0 (Stuiver & Reimer 1993, Hogg *et al.* 2013; calibration curve SHCal13). All data were graphed using TGView (Grimm 2004).

Because discrimination of pollen to the level of species is often difficult, the taxa are only given at genus level in the following text (e.g. *Casuarina* rather than *Casuarina equisetifolia*).

Results

Results span the Holocene timeframe. A summary pollen diagram with charcoal results is presented in Figure 2. Pollen diagrams are a form of graph. The Y-axis shows age (time) with core depth. The X-axis shows the percentage of plant pollen types; with greater graph width for example, the larger the percentage of a given pollen (plant) type present. Changes in the percentages of plant types are displayed as the core progresses with time (depth) and are interpreted to show similar changes in vegetation composition (compare with Faegri *et al.* 2000).

In total, 117 pollen types were identified. They were divided into 11 summary groups to capture plant form and/or vegetation type:

- Myrtaceae associated with dryland environments (10 taxa, e.g. eucalypts and *Calytrix*);
- Myrtaceae associated with wetland environments (8 taxa, e.g. *Melaleuca* and *Leptospermum*);

- other sclerophyll pollen (20 taxa);
- monsoonal forest associates (22 taxa);
- lianes and mistletoes (6 taxa);
- mangrove (or coastal, 3 taxa);
- grasses (Poaceae) (2 grain size classes);
- herbaceous plants (29 taxa, including sub-shrubs);
- sedges (and similar wet-ground taxa, 7 taxa);
- aquatics (3 taxa);
- pteridophytes (7 taxa).

Figure 2 shows some representative pollen grains identified from the core at Girraween Lagoon

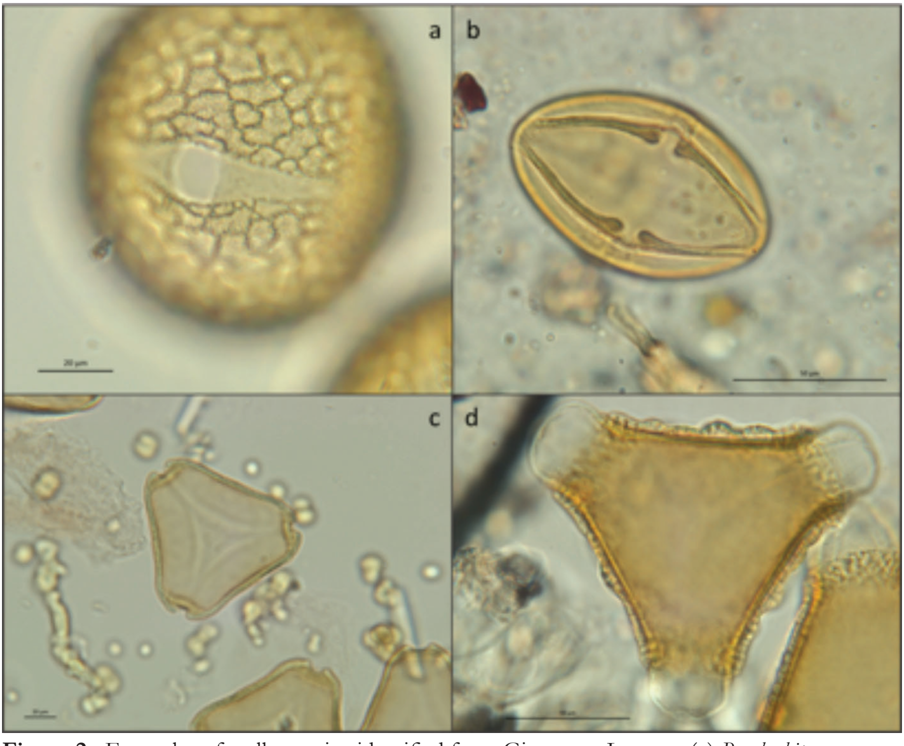

Figure 2. Examples of pollen grains identified from Girraween Lagoon: (**a**) *Brachychiton*; (**b**) *Buchanania*; (**c**) *Eucalyptus*; (**d**) *Grevillea*). (Cassandra Rowe)

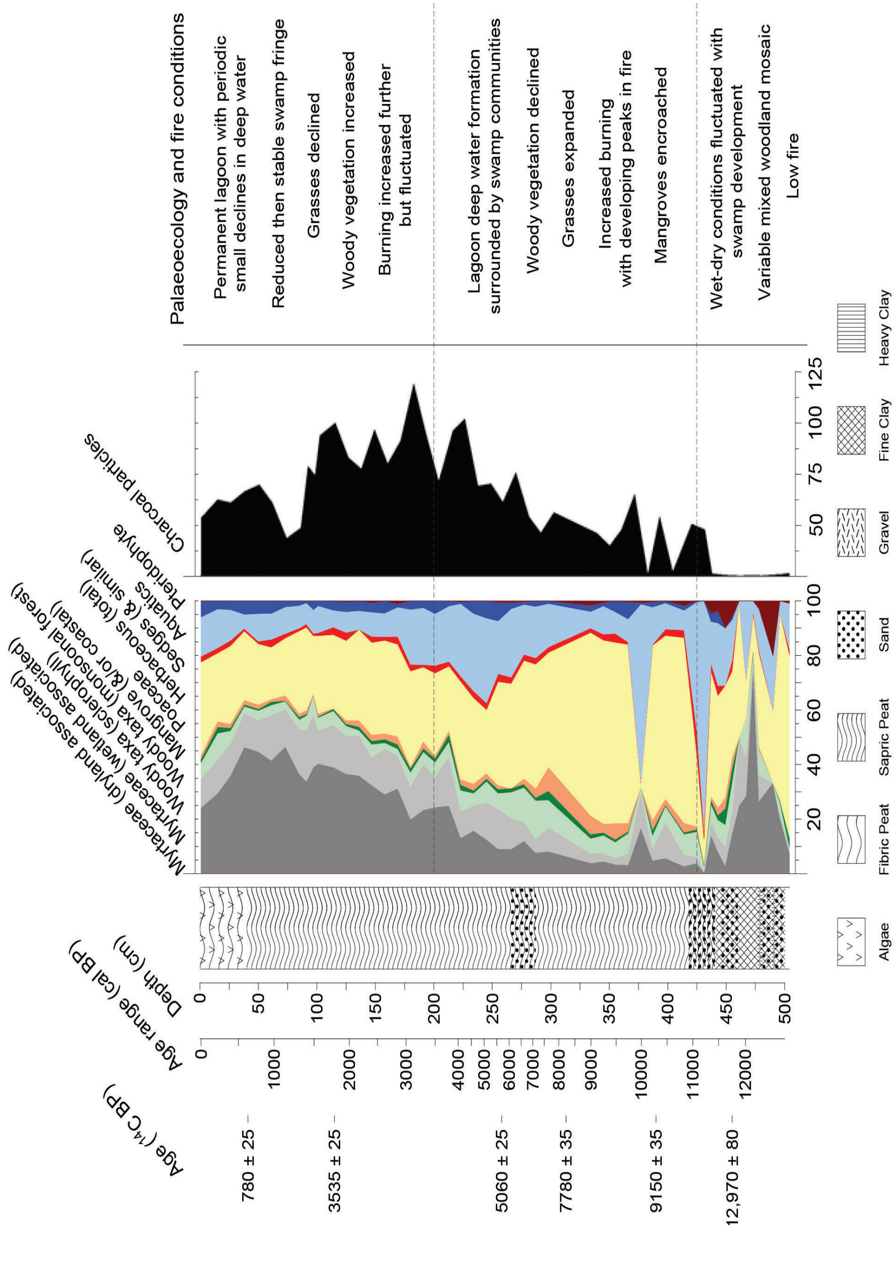

Figure 3. Pollen diagram and palaeoecological interpretation showing summary plant groups (percentage) and fire history (i.e. charcoal accumulation rate) plotted against depth, sediment type, and radiocarbon and calibrated age.

Discussion

Mangrove and coastal pollen

This study recorded *Rhizophora*, *Ceriops* and *Casuarina* pollen types. These pollens are wind-distributed and, as such, can travel long distances (Rowe 2012). The plants themselves were not present on-site at Girraween during the Holocene, but responded to the main phases of sea level rise and fall as documented for the northern Australian coast (Chappell 2001). Mulrennan & Woodroffe (1998), for example, demonstrate the development of widespread mangrove swamps following saltwater intrusion into creeks and rivers up to mid-Holocene times in the Northern Territory.

Marine mangroves approached the Girraween site between 11,700–10,800 cal BP, and reached their closest point between 9700–7100 cal BP. After 7100 cal BP, mangroves contracted coastward and remained stable in the broader Darwin area until 2150 cal BP. They declined further beginning 1950 cal BP, but recovered within the previous 1000 years to present day regional coverage. *Casuarina* also encroached on Girraween in the early Holocene but reduced and fluctuated as the mangrove forests expanded.

Lagoon development and climatic observations

Today's open water lagoon is approximately 6100 years old (pers. obs). Prior to this time, Girraween was a patchy swamp and its environment reflected drier climate transitions at the end of the last glacial period, including an intermittent (inactive) monsoon (Reeves *et al*. 2013). Between 12,700 and 10,200 cal BP the site fluctuated between wet and dry conditions. Sedges and ferns expanded and contracted in alternate phases with grasses and herbs. Aquatic plants (such as the waterlily taxa *Nymphoides* and *Nymphaea*) were absent, highlighting irregular and/or weak wet seasonality and no permanent standing water. Tree growth, such as that of *Melaleuca*, around Girraween's swampy areas was sparse at this time.

After 10,200 cal BP, the water at Girraween began to pond. Shallow waters expanded from 9500 cal BP, followed by slower increases in deeper water. Both *Nymphoides* and *Nymphaea* were present, but only became fully established around 6100 years ago, indicating permanent open water with a range of depths and with greater lagoon stability. Helping the lagoon to develop, the climate at this time exhibited highest regional rainfall and higher temperatures, with reduced annual seasonality (Reeves *et al*. 2013). It is from this point onwards that water conditions comparable to the modern site existed. Permanent, deeper water zones show some subsequent decline, at times 3750–3500 cal BP, 2850 cal BP and 1300–1250 cal BP.

As Girraween gradually formed permanent open water, swamp habitats rearranged into an encircling fringe. Sedge communities expanded first, to become most extensive between 6050–4050 cal BP. Wetland woodlands became more prominent from 5500–5000 cal BP. *Melaleuca* dominated, with *Leptospermum* and *Asteromyrtus* in the subcanopy. *Pandanus* was also present. These woodlands remained stable, however the sedge swamp undergrowth declined (narrowed) beginning 2850 cal BP, then expanded again in the last 350 years reaching modern day distributions.

Water level changes during the last 4000 years are consistent with increasing climatic variability across northern Australia toward the present day (e.g. weakening of monsoon rainfall (Denniston *et al.* (2013), enhanced seasonality, and emerging El Niño-Southern Oscillation relationships (McGowan *et al.* (2012)). Past extent and impact of changing monsoon activity on wetlands, including drying/arid phases in the late Holocene, can be seen by comparing Girraween with similar palaeoecological studies from northern Western Australia's Kimberley region (e.g. Field *et al.* (2017)).

Savanna transformation and fire in the landscape

By 12,700 years ago a changeable mixed wooded-savanna was present at Girraween. Just as the wetland was fluctuating between wet and dry in the early parts of the record, the surrounding catchment vegetation was also variable and patchy. Eucalypts were dominant with other sclerophyll and forest-associated taxa incorporated into the subcanopy. The pollen shows a number of (semi-) deciduous tree taxa (e.g. *Terminalia, Bombax* and *Canarium*) suited to inconsistent moisture supply from variability in rainfall pattern. It is thought that alternating peaks in different plant communities did not initially support extensive burning; that patchy vegetation patterns and changeable biomass hindered fire spread across the catchment. The climate at this time may also have been less amenable to burning.

Beginning 11,800 cal BP, the trees and shrubs declined at the site, particularly the eucalypts. This resulted in an extended phase of open vegetation at Girraween 11,700–5500 cal BP. As the eucalypts decreased, grasses expanded and an open savanna developed. Grass cover was pronounced between approximately 10,800 cal BP and 5500 cal BP, and in the period 10,200–8900 cal BP maintained maximum distribution across the catchment. Despite a wetter-warmer climate, grass competition and small grass-fed fires between 10,800 cal BP and 5500 cal BP helped keep the woody plant presence low. Gradual tree-shrub expansion and the beginning of grass decline occurred, as charcoal records show increased burning and the start-appearance of small peaks in fire. This study links fire extent to the abundance of woody biomass at Girraween.

Grass cover decreased compared to woody cover after 4500 cal BP. At the same time, burning further expanded and there were major peaks in fire occurrence. A higher level and ongoing burning-type fire regime appeared to support woody plant proportions in the canopy and subcanopy. Increased climatic variability, including drying conditions, would have encouraged fire. However, this charcoal change is also consistent with the age of archaeological evidence demonstrating local expansions in indigenous occupation and use of the area (Bourke 2004; Brockwell 2005). Large water sources are also described as locations where hunter-gatherer populations concentrated (Williams *et al.* 2015). Intentional landscape burning by indigenous people is therefore one of the interacting variables which shaped higher and more consistent fire regimes in the late Holocene. Eucalypts initially expanded between 4100 and 3100 cal BP. Maximum sustained eucalypt pollen spans 2850–600 cal BP, indicating an open forest savanna, and expanded further through the period 1150–600 cal BP. Shrub-herbaceous taxa also increased in this period, adding to ground layer diversity amidst less grasses. Pollen and charcoal results suggest this was a stable open forest savanna system, in line with an environment managed by local people to maintain resources in the face of variable climate and a declining monsoon. Today, remnant open forest conditions remain in place, partly maintained by Landcare groups as urban bushland and an area of recreational use (e.g. boating). Looking into the future, reports such as those by Brock (1995), Lamche (2008) and Lamche & Schult (2012) foresee management issues for the lagoon and the surrounding vegetation, noting impacts through fragmentation and weeds in particular.

Conclusion

Change is a continuous process in the Northern Territory's Top End environments, including the Darwin region. This paper introduces Girraween Lagoon as a site of Quaternary study, and the palaeoecological/palynological techniques helping to highlight the nature of long-term savanna dynamics, and the varied outcomes from vegetation-fire-climate interactions. The Girraween catchment experienced early alternating periods of waterlogging and temporary swamp development, prior to permanent lagoon formation approximately 6100 years ago. Simultaneously, the surrounding catchment transformed from a grassy savanna to denser woody savanna and forest, with changes in the use of fire playing a particular role in the vegetation becoming increasingly dense (wooded). These results provide an example of the baseline information available to contemporary ecologists and management/conservation personnel, and are the start of further research across the region.

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