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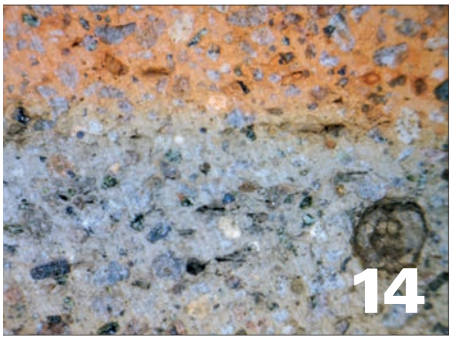

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PUTTING WA ARCHAEOLOGY ON THE MAP:

THE INESTIMABLE CONTRIBUTION OF CHARLIE DORTCH

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GUEST EDITORS: SANDRA BOWDLER, JANE BALME AND JOE DORTCH

Image: Charlie Dortch at Devils Lair, southwest Australia.

Aboriginal landscape burning and its impact on the summer monsoon of northern Australia

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Abstract

The question of the impact of Aboriginal burning practices on vegetation in Australia has long been a concern of palaeoenvironmental and related archaeological studies and is embedded in wider discussions of human impacts on the environment. But, despite the large volume of work and some very firm claims, doubt has emerged in the recent literature as to the importance of traditional Aboriginal burning practices on vegetation patterns. We consider this issue in the context of the hypothesis: 'If Aboriginal burning practices created a more open grassland savanna environment, could this have altered the climate regime of the summer monsoon region of northern Australia?'. The results of recent climate modelling experiments suggest that the replacement of woodland by more 'open' grassland would have influenced the climate of the pre-monsoon season by delaying the onset of the monsoon, but would have had little impact on the 'full' monsoon. While the results of the modelling experiment clearly show that regional savanna climates would be affected by vegetation changes, it is not at all clear that Aboriginal burning practices led to extensive modification of savanna vegetation. We place the results of the climate experiment into a wider discussion of the identification of Aboriginal 'signatures' on fire histories and question whether this issue can ever be resolved.

> There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know (Donald Rumsfeld).

Introduction

The monsoon region of northern Australia presents a savanna environment in which fire plays a significant role (Russell-Smith et al. 2009). While fire must always have been an element in the ecology (Bowman et al. 2012; Lynch et al. 2007b), the arrival of people is traditionally seen as having brought about a significant change in the fire regime (e.g. Bowman 1998; Kershaw 1986), impacting on the vegetation. Here, we turn to the results of a climate modelling experiment to address this theme and consider the likely impact that changes in vegetation, as the result of inferred fire regime practices, may have had on the function of regional climates across the savanna biome of the summer monsoon region in northern Australia. We embed the results of the climate experiment into a wider discussion of the identification of Aboriginal 'signatures' on fire histories. Through this we question whether the issue can ever be resolved and hence give a firm footing to the 'bowl of petunias' of Bird et al. (2013:439). Alternatively, perhaps the problem should be filed under a 'don't know we don't know' grouping.

The role that fire plays as a control of vegetation has become a 'given' in the global-scale ecological literature (Bond and Keeley 2005; Bowman et al. 2009; Keeley et al. 2012; Williams et al. 2012). Linked to the occurrence of fire have been questions of the anthropogenic role played in fire occurrences and history—issues that have been extensively discussed in the palaeoenvironmental-archaeological literature for many years (e.g. Stewart 1956). Over the last few decades these issues have taken on much greater dimensions, with questions of the likely role of Indigenous peoples' vegetation burning practices now more securely anchored (e.g. Mooney et al. 2011, 2012) and with discussions of the implication of burning practices going well beyond simple considerations of the regional modification of biomes (e.g. Miller et al. 2007).

It is firmly recognised that vegetation changes resulting from fire can have a direct impact on climate due to land-surface changes and resultant atmospheric feedback (e.g. Bonan 2008; He et al. 2013; Ward et al. 2012). Among other effects, vegetation changes trigger biophysical feedback by affecting evapotranspiration, albedo, roughness length and Bowen ratios and, even through these factors alone, have the potential to modify local and regional climate regimes (e.g. Kala et al. 2011; Nair et al. 2011). But the role and history of burning practices also has a direct global-scale impact through the effect that this has on atmospheric composition. It is known that fire plays an important role in the global carbon cycle, with burning related to deforestation contributing ~0.65 Pg C year^{-1} (Bowman et al. 2009). Deforestation makes an overall contribution of 17% to anthropogenic greenhouse-gas emissions (Strassburg et al. 2012). Given these figures, it is not surprising that there have been suggestions that early agricultural practices led to significant increases in atmospheric CO_2 and CH_4 concentrations (Ruddiman 2003; Ruddiman et al. 2011) and potentially significant global climate change, as inferred by the 'early anthropogenic hypothesis'.

Fire, Climate and Vegetation in the Savanna Biome of Northern Australia

Fire has always been a driving force on the global ecology (Bond et al. 2005) and has left an especially strong impact on savanna biomes (e.g. Beckage et al. 2009; Beerling and Osborne 2006; Hoetzel et al. 2013). The likely role of fire in savanna settings was highlighted in the interpretation of the changes from subtropical C_3 woodland to C_4 savanna type grasslands that were widespread during the late Miocene (Cerling et al. 1997). The explanation that was initially proposed to explain this drew on the lowering of atmospheric CO_2 levels evident at that time (Ehleringer et al. 1997). This view was subsequently modified, with the claim that fire is likely to have played a very significant role (Keeley and Rundell 2005) in promoting the transition of forest–woodland to savanna (Hoetzel et al. 2013). It is claimed that fire led to the expansion of savannas due to climate feedbacks that created the hotter and drier conditions they favoured (see Edwards et al. 2010 for a fuller discussion). However, it should also be borne in mind that, in addition to fire, other disturbances and controls (e.g. browsing, climate and soils) have to be recognised as contributing to savanna biomes (Beckage et al. 2009; Bird et al. 2013; Bond 2008).

The recognition of fire and its impact on the environment is so deeply embedded in the Australian environmental outlook that Seddon (2005:240) described it as 'an environmental constant'. In the Australian archaeological context, the role of vegetation burning, as part of Indigenous peoples' land management tool-kits, has a long history. Jones' (1969) use of the phrase 'fire-stick farming' was something of a prompt, capturing the attention of a wide audience. In the more general literature the theme was provocatively pursued by Flannery (1994), and is now closely linked globally with the overall human impact on landscape and biology (e.g. Bird et al. 2013; Lopes dos Santos et al. 2013; Merrilees 1968; Pinter et al. 2011). But the specific question of vegetation burning as a part of Aboriginal land-use practices, while attracting a great deal of discussion and interpretation, retains uncertainties (see discussions in Bowman et al. 2012; Lynch et al. 2007b).

The recent overviews by Mooney et al. (2011, 2012), based on an evaluation of available stratigraphic charcoal records, concluded that there was no apparent association between the likely arrival of humans in Australia and a change in the fire regime. Neither was there apparently any correlation between the archaeological evidence and biomass burning over the last 40,000 years. Their inferences are difficult to reconcile with the available ethnographic and historical depictions of an environment heavily affected by Aboriginal burning practices (e.g. Gammage 2011; Hallam 1975; Jones 1975; Preece 2002; Russell-Smith 2002; Russell-Smith et al. 1997). For field scientists working in the savanna regions of northern Australia, including one of the present authors, the claim conflicts with field perceptions that give constant reminders of the importance and impact of fire in the region.

The skeptic could question Mooney et al.'s results by noting the spatial distribution of their sample sites and, given the concerns of the present discussion, especially a lack of sites from the northern savanna region where the fire regime is an integral part of Indigenous peoples' lives (e.g. Russell-Smith 2002). It could also be pointed out that, while charcoal as old as the Silurian can be preserved (e.g. Glasspool et al. 2004), the taphonomy of charcoal is not without issues. These range from fuel material and temperature of production to pH/redox potential and landscape storage (e.g. Ascough et al. 2010; Braadbaart et al. 2009; Ohlson et al. 2009). Furthermore, there is a need to 'normalise' the conclusions drawn from the stratigraphic record to avoid bias in placing too much emphasis on more readily identified Holocene sites. A record that shows a Holocene—especially late Holocene—bias strikes chords that are reminiscent of the 'Sadler effect' in stratigraphy. Sadler (1981) drew attention to the fact that, on average, thinner stratigraphic sections, which cover shorter amounts of time, record faster accumulation rates than thicker sections which record longer amounts of time. Holocene records are clearly more easily recovered and an inferential bias can easily follow.

The extensive savanna-open woodland that is so pervasive across the monsoon region of northern Australia is well known to be fire sensitive, with the history of the biome extending well beyond the timing of human occupation (Bowman et al. 2012). Some indication of the long-term vegetation history of the region has been obtained from off-shore cores (Kershaw and van der Kaars 2012). Upper samples from these cores clearly demonstrate that Poaceae and eucalypts in association with charcoal were derived from the savanna regions of northwestern Australia. The charcoal record in these cores show persistently high values from about 40,000 years ago, but 'slight and differing times of change between pollen and charcoal inhibit a definitive statement on fire-vegetation relationships' (Kershaw and van der Kaars 2012:249).

Palaeoclimates, the Australian Summer Monsoon, Climate Modelling and Vegetation

One of the most far-reaching claims of the consequences of Indigenous burning practices comes from the climate model simulations of Miller et al. (2005). Their claim was developed in the wider context of the change in the $\delta^{13}C$ isotope ratios of emu (*Dromaius novaehollandiae*) egg shell, indicating a change from a tree/shrub savanna to desert 'shrub'. They related this change to anthropogenic burning practices (Johnson et al. 1999; Miller et al. 2007). Their idea was placed in the context of a claimed decline of the early Holocene Australian summer monsoon when compared to the Last Interglacial (Miller et al. 2005). Using an Atmospheric Global Circulation Model (AGCM) they prescribed vegetation over northern Australia ('broadleaf deciduous trees/desert vegetation') and, through this very idealised assumption, concluded that a downturn in monsoonal activity was to be expected with a 'desert' landscape. They postulated that Indigenous burning practices, in changing the vegetation cover, may have produced a similar climatic impact and that this explained the claimed difference in monsoon strength

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between the Last Interglacial and the Holocene. Other studies (e.g. Murphy et al. 2011) have made it clear that the overall question of human impact deserves more thought, and that there are clear issues that need to be resolved in establishing the vegetation response to burning (Bowman et al. 2012). Ignoring any claim that burning practices led to extensive vegetation changes, the issue can simply be approached as an hypothesis to be tested: 'If Aboriginal burning practices created a more open grassland savanna environment, could this have altered the climate regime of the summer monsoon region of northern Australia?'

The northern Australian summer monsoon represents the Southern Hemisphere margins of the much broader East Asian-Indonesian-Australian regime (Figure 1). The overall energetics involved in the system are of such a scale as to play a fundamental role in the global climate system (McBride 1998). The scale of the system becomes apparent when the forcing mechanisms are considered, which include: (i) land-sea thermal contrast, due to the location of the off-equatorial Australian landmass; (ii) barotropic instability; (iii) Madden-Julian Oscillation; (iv) the intrusion of mid-latitude troughs; and (v) sea surface temperature variability (Hung and Yanai 2004; Wheeler and McBride 2011; Yano and McBride 1998). The recent advances in our understanding of the Quaternary climate history of the northwest Australian summer monsoon, both from the perspective of modelling studies (Wyrwoll and Valdes 2003; Wyrwoll et al. 2007, 2011) and the proxy record (Denniston et al. 2013a, 2013b; McGowan et al. 2012), have further emphasised the global-scale of its controls. How relatively smaller-scale vegetation changes fit into these more dominant global-scale considerations may seem at first ambiguous or even

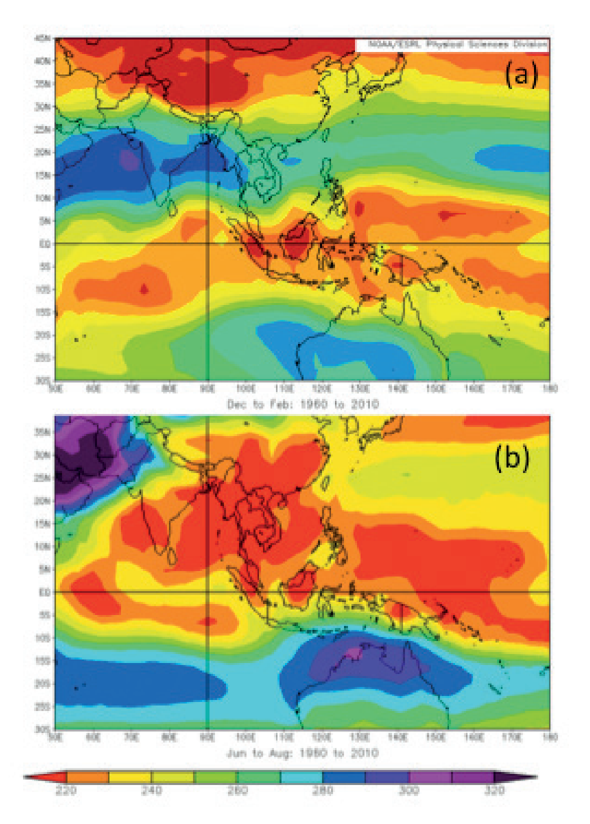

Figure 1 Outgoing long wave radiation (OLR) delimiting the extent and intensity of the Indonesian-Australian monsoon: (a) austral summer; and (b) austral winter (based on NECEP-Reanalysis data).

unlikely. But, while the energetics of the overall Indonesian-Australia summer monsoon are significant at the global scale, northern Australia lies along the southern margins of this broad summer monsoon system and is sensitive to 'forced', but relatively small changes in monsoonal boundary conditions. The likely sensitivity of the Australian summer monsoon is emphasised by the fact that, unlike its Asian counterpart, the Australian summer monsoon is shallow and primarily confined to the lower troposphere, with a depth of only ~700 hPa—essentially due to a lack of complex topography over northern Australia (Hung and Yanai 2004).

The overall monsoon cycle over northern Australia is associated with a seasonal wind reversal from winter southeasterly trades to summer westerlies associated with deep convection and heavy rainfall. Peak convection and heaviest rainfall occurs during January–February, during which the monsoon shear line, marked by strong cyclonic shear ($-\partial u/\partial y$), separates low latitude westerlies from higher latitude easterlies (Wheeler and McBride 2011). The associated monsoon trough forms the zone in which westerly flow predominates and in which deep monsoonal depressions and tropical cyclones form (McBride 1987). The overall position of the monsoon trough changes from summer to autumn and by March–May lies over the southern maritime continent. The position of the monsoon trough determines the monsoonal precipitation regime, such that even relatively small changes in the latitudinal position of the monsoon trough would strongly affect the summer monsoon precipitation pattern. Such differences in the position of the monsoon shear line, both data-based and modelled results, were illustrated by Moise and Colman (2009). A relatively slight displacement of the monsoon trough can be triggered by global events (Broccoli et al. 2006; Chiang and Bitz 2005), but could equally well be triggered by regional-continental scale controls, such as vegetation changes.

Modelling of Climate Response to Vegetation Changes

From a consideration of first principles (Bonan 2008), experimental indicators (e.g. Beringer et al. 2003) and modelled results (Lynch et al. 2007; Pitman and Hesse 2007), it is anticipated that vegetation changes can impact the regional climate of the monsoon region of northern Australia. For instance, the experimentally-based studies of Beringer et al. (2003) highlighted likely climate impacts of burning practices—vegetation changes acting through surface energy exchanges. Using a global atmospheric model coupled to a land surface model (Conformal Cubic Atmospheric Model [C-CAM]) Lynch et al. (2007a) were able to demonstrate that, with extensive areas being affected by burning, high fire intensity and late season burning provoked a significant increase in monsoon precipitation. A more realistic approach was taken by Pitman and Hesse (2007) who, using the Regional Atmospheric Modelling System (RAMS), simulated January precipitation changes with differing vegetation covers. Their results showed small changes in precipitation (~5%) during the full monsoon season, largely in response to 'roughness' changes. In evaluating the results of modelled climate experiments, model 'dependencies' can be an issue, and consequently such experiments need to be repeated with different models—both regional and global.

We approached the issue using the National Center for Atmospheric Research Community Climate System Model

Version 3.5 (NCAR CCSM3.5) (Collins et al. 2006; Gent et al. 2010). The model represents a dynamic atmosphere, ocean, sea ice and land surface, and includes an interactive vegetation routine through a dynamic global vegetation model (DGVM) (for details see Notaro et al. 2011a, 2011b). A 200-year modern-day control simulation (CTL) of CCSM3.5 was generated, of which the last 80 years were analysed. Restart files were saved at the start of each year, which include the fractional cover of each plant functional type (PFT). A set of 80 initial value ensemble experiments (ENS) was run, each one year in duration. For each ensemble member, a restart file was obtained from the CTL experiment and the total vegetation cover fraction was reduced by 20%—representing quite modest changes. The total cover of all PFTs in a grid cell was reduced, while maintaining the original proportions of each PFT.

The climate in each ensemble member was compared against its relevant year in the control simulation to reveal the impact of reduced vegetation cover on the climate of the monsoon region. CCSM3.5-DGVM presents a generally reasonable simulation of the northern Australian summer monsoon. Three shortcomings are prominent: (i) a one-month delay (February–March) in peak precipitation; (ii) a strong positive precipitation bias; and (iii) the simulated monsoons penetrating too far inland. The overall results of the experiments (Figure 2) with reduced vegetation cover show declines in annual sensible heat flux, as well as annual latent heat flux and evapotranspiration. The annual decrease in latent heat exceeds that of sensible heat, leading to an increase in the Bowen ratio. Based on 700 hPa omega (vertical velocity—a measure of convection), greater atmospheric subsidence occurs due to reduced vegetation cover, reflecting a weaker, delayed monsoon. Diminished evapotranspiration and enhanced subsidence contribute to annual reductions in precipitable water, with the largest seasonal response in spring. Along with a delayed, weaker monsoon, anomalous subsidence also occurs during October–January. This corresponds with significant decreases in precipitation, total cloud cover, total column specific humidity and moisture flow from the ocean into northern Australia during November–December. With the dampened monsoon system, condensational heating from convection is reduced throughout the troposphere during October–February. Outgoing long wave radiation (OLR) during the pre-monsoon period of November–December increases, which is further evidence of reduced convective activity. Associated with a delay in the Australian monsoon, reduced vegetation cover triggers a negative anomaly in velocity potential, meaning anomalous divergence, at 925–700 hPa and a positive anomaly in velocity potential at 250 hPa, during October–December; these divergence anomalies correspond to anomalous subsidence. The general conclusion that can be drawn from these results is that the change in vegetation, while having a relatively minor impact on the full monsoon, imposes significant climatic impacts during late spring-early summer, leading to a decrease in rainfall and higher air and ground temperatures. But we stress that our results must be seen as a first-step approach to the issue. More regional-scale climate modelling is clearly required, in which issues of intensity, scale, seasonality and other detail should be embedded (see, for instance, Bird et al. 2013; Bliege Bird et al. 2008)

Discussion

Our results support the claim that reduced vegetation cover affects the northern Australian summer monsoon, leading to a dampening of monsoonal activity—with the qualification that the strongest impact is on the pre- to early monsoon. These results are not unexpected, as the more local-scale convective regime of the early monsoon season should be more responsive to land surface changes than the full monsoon. In general, the results support the overall

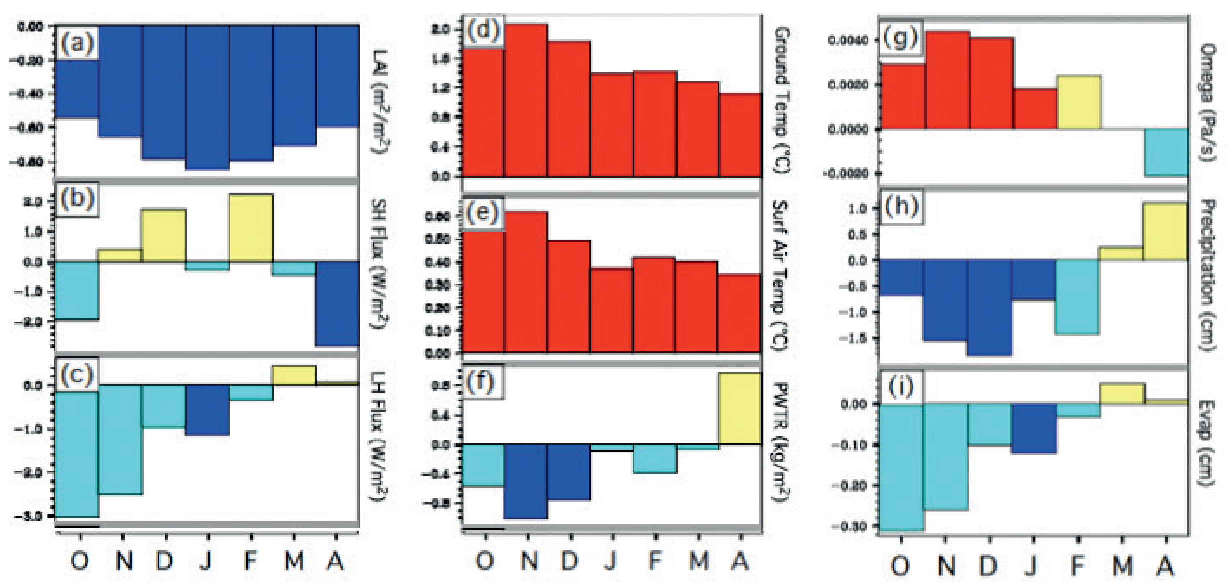

Figure 2 October–April model response to vegetation changes: (a) leaf area index (indication of vegetation cover); (b) sensible heat flux; (c) latent heat flux; (d) ground temperature; (e) surface air temperature; (f) precipitable water; (g) vertical velocity (indication of convection); (h) precipitation; and (i) evaporation. Red (dark blue) and yellow (light blue) bars indicate increases (decreases), with the former achieving 90% significance with t tests (after Notaro et al. 2011b).

conclusion, that, if Indigenous burning practices were of sufficient scale, with an appropriate seasonal timing and intensity, land surface-atmosphere feedbacks would not be insignificant. The full monsoon regime, with its active and break phases (see, for example, Wheeler and McBride 2011), is much less likely to be affected by relatively modest land surface changes. In this type of study, model dependency is always an issue, but when the model results are congruent with physical expectations and other modelled and experimental results, there is a degree of confidence in the results obtained.

Our results are in line with the large volume of work that is now available that makes it possible to conclude that vegetation is an integral part of the climate system and that vegetation changes will incur a climate response (e.g. Brovkin et al. 1999; Claussen 2009; Claussen et al. 2006; Liu et al. 2006). The details of such a response may vary depending on the boundary conditions defined by the geographical setting. In the context of monsoon regions it is clear that the monsoon response to vegetation changes will depend on prevailing climate controls, with unique responses among monsoon regions (Notaro et al. 2011a). Given these results, the question that must now be asked is not whether there is a climatic impact as a result of vegetation changes, but whether anthropogenic burning practices were of sufficient scale and intensity to bring about the required vegetation changes?

Fire, be it natural or linked to people, is an integral part of the savanna environment, as it is in other biomes (Bond and Keeley 2005). Given the natural global fire regime, it is not surprising that some have questioned the role of people and have stressed the importance of climate in controlling fire (Haberle and Ledru 2001). For northern Australia, Kuleshov et al. (2006) identified a high level lightning flash density (N_t – cloud-to-ground and intracloud flashes), with peak levels of N_t reaching 35 $km^{-2}yr^{-1}$. Such findings provide a prompt for claims that ‘the savanna environments of northern Australia would have been maintained by natural lightning long before the arrival of Aboriginal people’ (Fensham 2012:179).

The relationship between vegetation and Aboriginal burning practices has been an issue for many years (hence the ‘petunias’ quote of Bird et al. 2013) and there is the temptation for the skeptic to doubt whether a fully satisfactory solution can be found. Will the collection of more stratigraphic data narrow the uncertainty? Given the high incidence of natural fires in savanna regions, can the stratigraphic record be expected to facilitate a distinction between ‘natural’ and anthropogenic fires? Will separating a possible climate association resolve the issue? (See Turner et al. [2010] for one view on this.) Given the range of considerations that contribute to this issue, is it even possible to falsify the claim (in the sense of Popper) that Aboriginal vegetation burning was of sufficient scale to impact significantly on the savanna environment? To some, the veracity required to meet these questions may never be reached. For others, the available data may seem sufficient to meet their needs (e.g. Pinter et al. 2011). But what to one person is a satisfactory explanation may be little more than scientific embroidery to another—the ‘curve matching’ exercise of the palaeoclimatologist, while providing a perfectly acceptable explanation to him/her, may pose a serious health hazard to the atmospheric dynamicist. Despite the large body of work that now exists, covering many decades, the issue is still unresolved, with recent claims still expressing the same uncertainty as to the actual impact of Aboriginal burning on vegetation patterns and species’ ranges (Bowman et al. 2012). No doubt this debate will continue, with some spectators viewing it as an unwelcome distraction from more important questions. For others it may even be a bad case of ‘There are things we don’t know we don’t know’ and possibly never will know. But the issue also provides room for the more optimistically minded. These can take heart from the thoughtful ‘roadmap’ of Bird et al. (2013) and the innovative approach of Sakaguchi et al. (2013), and, in these, find consolation that closure to this issue may be possible.

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