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SHORT COMMUNICATION

Insights into the indigenous-managed landscape in southeast Australia during the Holocene

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Abstract

Understanding the long-term interactions between people and the ecosystem in which they live is vital for informing present-day ecosystem management plans. The use of pollen data for palaeoecological reconstructions is often limited by the low taxonomic resolution of pollen, which often reduces the detail of reconstructions of human influence on past vegetation. This is true for Australia where Myrtaceae, particularly *Eucalyptus* species, dominate the landscape, but their pollen is difficult to differentiate. We present a pollen record with high taxonomic resolution of Myrtaceae pollen from the Bass Strait area of southeast Australia, focusing on the period of major human occupation there during the Late Glacial transition. These results were compared to records of hydrology, fire, sediment deposition, herbivore abundance and human occupation. We found that Indigenous burning practices promoted open, subgenus Monocalyptus *Eucalyptus* woodland at the expense of dense subgenus Symphomyrtus *Eucalyptus* forest. Previous studies have shown the need for management of the vegetation of southeast Australia guided by Indigenous people, to promote ecosystem resilience and reduce the risk of wildfires. Our results reveal that in addition to reducing wildfires, cultural burning by Indigenous people has the potential to promote the diversity of ecosystems and habitats.

Keywords Myrtaceae · Eucalyptus · Indigenous land use · Fire · Cultural landscapes · Bass strait

Introduction

Global environments continue to experience unprecedented changes, especially through transformations of ecosystems and biodiversity loss caused by human activities (McGill et al. 2015). Aside from direct human impact such as agriculture, one of the major threats to global ecosystems today is of increasing unmanageable wildfires, particularly in temperate areas, including southeast Australia (Flannigan et al. 2013; Davey and Sarre 2020). Southeast Australia has experienced some of the largest and most intense wildfires globally, resulting in landscape transformation and biodiversity loss (Kirkpatrick 1999; Celermajer et al. 2021; Haque et al. 2021). The present distribution of wildfires with small, controlled burnings and vegetation in southeast Australia is thought to have developed as a result of European suppression of the traditional landscape management by Indigenous people (Bowman 1998; Steffensen 2020; Fletcher et al. 2021; Mariani et al. 2022). Past reconstructions of land cover and fire activities suggest that Indigenous people maintained diverse open landscapes of low woody-biomass vegetation, with frequent low intensity burning, which reduced the likelihood of large wildfires (Trauernicht et al. 2015; Adeleye et al. 2021a, c; Fletcher et al. 2021; Mariani et al. 2022). The displacement of Indigenous people by European settlers and the resulting cessation of Indigenous management practices are thought to have promoted the growth of

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denser woodlands and forests, allowing large wildfires to occur in southeast Australia over the last century (Adeleye et al. 2021a; Mariani et al. 2022). The re-establishment of the traditional burning methods of the Indigenous people has been recommended to effectively manage future wildfire risks in southeast Australia (Russell-Smith et al. 2013; Steffensen 2020; Adeleye et al. 2021a; Mariani et al. 2022). For this, detailed knowledge of spatial patterns of vegetation composition and structure, especially in ecosystems dominated by Myrtaceae which were traditionally maintained by Indigenous people will be useful for developing management strategies for southeast Australia's vegetation into the future (Fa et al. 2020).

The Myrtaceae family dominates the Australian landscape, with over 1,600 species (Fagg 2002). These include both trees and shrubs and they grow across widely different biophysical gradients such as moisture and temperature. However, low taxonomic resolution in the identification of their pollen often prevents these distinctions from being made in palaeoenvironmental reconstructions. Recent studies have shown the potential use of the pollen morphology of Myrtaceae in systematic taxonomy and thus detailed vegetation reconstruction (Thornhill 2010; Thornhill and Crisp 2012; Adeleye et al. 2020). Currently, only about six Myrtaceae pollen taxa are commonly identified in Australian fossil pollen records and mostly to genus level and they include *Eucalyptus*, *Melaleuca*, *Leptospermum*, *Kunzea*, *Calytrix* and *Syzygium*. A detailed knowledge of the changes in the distribution of various Myrtaceae species in past landscapes, together with an understanding of their extent and relative dominance can provide insights into landscapes maintained by Indigenous people. This will assist in informing ecosystem management and biocultural heritage restoration efforts in Australia.

Islands, due to their restricted boundaries with limited space and distribution of taxa, present invaluable opportunities to investigate past and present distributions of taxa (Warren et al. 2015). Islands are also sensitive to environmental and human disturbances, which are usually well recorded in sedimentary archives, making them suitable for the comparison of evidence of past environmental changes and human land use, therefore providing the opportunity to investigate questions about past interactions between humans and environment (Rowe 2007, 2015; Nogué et al. 2021). The Bass Strait islands (BSI) of southeast Australia are no exception. The islands were once part of the Bassian Landbridge/Plain that allowed people to walk from mainland Australia to Tasmania during the last glacial period when the sea level was much lower than today and the eastern BSI (Furneaux Group), in particular, formed the initial land bridge that people used to reach Tasmania for the first time around 40 ka ago (Lambeck and Chappell 2001; Adeleye et al. 2021e). The present BSI were formed around 7.9–6.9 ka due to inundation of the land bridge by postglacial rises in sea level (Sloss et al. 2007; Dougherty et al. 2019). Archaeological evidence indicates that human settlement and interactions with the fauna (especially) and the flora in the Bass Strait area dates back to at least ~ 27 ka (Bowdler 2015), with the greatest land use during the last ~ 12 ka (Bowdler 1979, 2015; Sim 1998), as in other parts of Australia (Lourandos 1983; Williams et al. 2015). However, before European colonisation, occupation and land use by Indigenous people was greatest in the Furneaux Group of islands between 12 and 6 ka, after which the rising sea level resulted in their infrequent use (Sim 1998; Adeleye et al. 2021c). This history of land use contrasts with those of the adjacent Australian mainland and Tasmania, which were continuously occupied for at least 40,000 years (Allen and Cosgrove 1996; O'Connell et al. 2018), providing an opportunity to investigate the different roles of humans and climate in the past landscapes of these islands. The aim of this present study of a Furneaux Group island is to find out about the vegetation which was culturally managed by Indigenous people in the past in southeast Australia. In order to achieve this aim, we re-analysed a published pollen record (Adeleye et al. 2021d) from one of the larger Furneaux Group islands, Cape Barren Island, by separating the Myrtaceae pollen into types in this record, using a recently developed key for this area (Adeleye et al. 2020). The results were then compared with multiproxy records of wetland history, palaeofire, sediment deposition, human occupation and large herbivore abundance from Cape Barren Island. We focused on the main period of human occupation on the island, which was between 13 and 8 ka (Sim 1998).

Methods

Cape Barren Island (truwana) is one of the larger Furneaux Group islands on the eastern side of Bass Strait, southeast Australia (Fig. 1). truwana is the Indigenous name for Cape Barren Island and it is used in the following text. truwana vegetation is dominated by Myrtaceae heathland and scrub, as well as dry sclerophyll forest. The heathland and scrub are largely composed of *Kunzea*, *Leptospermum* and *Melaleuca* species (Fig. 1). The dry sclerophyll forest and woodland is dominated by *Eucalyptus nitida* with *E. viminalis* in few wet sites (Harris and Kitchener 2005). The climate of the island and Tasmania in general is cool temperate maritime and it is greatly modulated by the patterns of the Southern Westerly Winds (SWW) and El Niño Southern Oscillation. The island as well as other parts of eastern southeast Australia have a wetter spring and summer when SWW are strengthened in the area, and the opposite occurs in winter (Hendon et al. 2007). Weakened SWW and El Niño years are usually associated with extremely dry conditions and severe wildfires

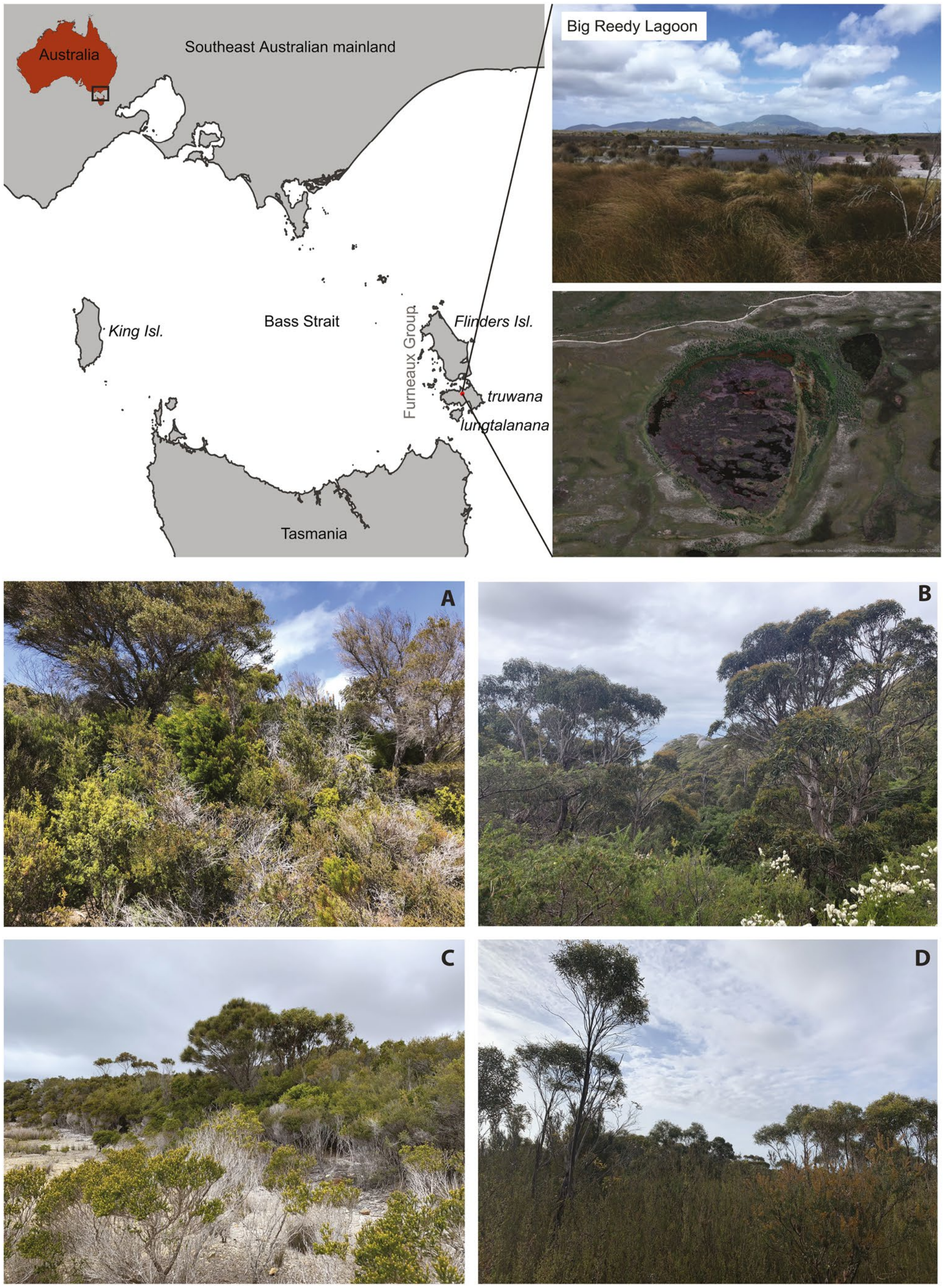

Fig. 1 Top left, location of truwana and Big Reedy Lagoon; top right, photos of Big Reedy Lagoon, the site of pollen and palaeoecological records on truwana, Bass Strait, southeast Australia. Below, examples of Myrtaceae vegetation communities in truwana; **A** *Eucalyptus nitida* woodland with *Leptospermum* scrub understorey; **B** *Kunzea ambigua* heath understorey; **C** *Melaleuca* scrub; **D** mixed heathland interspersed with scattered small *Eucalyptus nitida* trees. Photos by Stephen Harris, Feli Hopf and Matthew Adeleye

on the island (Risbey et al. 2009; Mariani et al. 2016b; Kim et al. 2017). Details of the environment and landscape of truwana, sediment core collection and analyses are presented in Adeleye et al. (2021c).

The Bass Strait islands (BSI), due to their small sizes, have a low diversity of Myrtaceae, with 22 species on eastern BSI, so there is a relatively good possibility of separating the pollen of different species using a Myrtaceae pollen identification key for eastern BSI based on datasets generated from > 3,000 measurements of pollen morphological features of Myrtaceae species growing on the islands (Adeleye et al. 2020). We applied this key to identify Myrtaceae taxa in a ~ 14,000 yr pollen record from Big Reedy Lagoon (BRL), which is the largest catchment (~ 8 km^2) on truwana.

Fossil pollen was recorded at a mean interval of ~ 900 years and expressed as percentages of total pollen; however, samples between ~ 14 and 7 ka, which is the focus of this study, were analysed at a mean interval of ~ 600 years. This record of fossil Myrtaceae was then compared to records of wetland water level changes (indicative of climate changes), past fires, herbivore abundance and sediment input from erosional activity, as well as land use on eastern BSI. A canonical correspondence analysis (CCA) was also performed on this pollen record, with fire activity (Adeleye et al. 2021d), sediment input (this study), and wetland water level history (Adeleye et al. 2021b) included as environmental variables, to identify potential drivers of changes in composition of Myrtaceae. CCA was performed in R v. 4.0.1 using the 'vegan' package (Oksanen et al. 2022). Reconstructed water levels are based on compositional and abundance changes in pollen of wetland taxa and non-pollen palynomorphs (Adeleye et al 2021d). Herbivore abundance is also inferred from the coprophilous fungal spore record (Adeleye et al. 2021d). The record of past fire is based on macrocharcoal (> 125 µm) influx estimates from contiguously analysed sediment samples from BRL (Adeleye et al. 2021d). The history of land use is based on radiocarbon dated archaeological evidence of past human occupation from eastern BSI (Sim 1998), which is archived in the Australian archaeology database (Williams et al. 2014). The sediment core was scanned for trace metals using ITRAX at the Australian Nuclear Science and Technology Organisation, and Ca/Fe ratios were used to infer erosional sediment input into Big Reedy Lagoon, following Koinig et al. (2003).

Results and discussion

Past Myrtaceae vegetation composition on truwana

The Big Reedy Lagoon pollen record with low taxonomic resolution shows that the site was dominated by Myrtaceae species, including *Kunzea ambigua*, as well as unknown species of *Eucalyptus*, *Leptospermum* and *Melaleuca* (Adeleye et al. 2021d). By using the Myrtaceae key, two *Eucalyptus* pollen types, subg. Symphyomyrtus and subg. Monocalyptus or peppermint, and some other taxa including *Melaleuca squamea*/*M. squarrosa*, *M. ericifolia*, *M. gibbosa* and *Leptospermum laevigatum* were identified (Fig. 2; Adeleye et al. 2020). The species within subg. Symphyomyrtus are today mainly represented by *Eucalyptus globulus* and *E. viminalis* on truwana, mostly occurring as medium to tall trees growing in wet sites with fertile soil. The dominant Monocalyptus type on truwana today is *E. nitida*, which usually grows as shrubs or mallee (small trees) in well-drained and sunny/open sites with infertile acid soil. Other *Eucalyptus* species in the Symphyomyrtus and Monocalyptus subgenera include *E. ovata* and *E. tenuiramis*, respectively. The Symphyomyrtus taxa generally have larger pollen grains, while the Monocalyptus have smaller pollen grains but with thicker walls, especially in the mid-wall area (Fig. 2; Adeleye et al. 2020 for pollen morphology details).

Symphyomyrtus were more strongly represented in Late Glacial samples (~ 13.7–12.9 ka), while Late Glacial to early Holocene samples (~ 12.9–8 ka) were dominated by Monocalyptus types (Fig. 2). *Leptospermum laevigatum*-type, *M. squamea*/*squarrosa*-type and *Kunzea ambigua* were represented in the mid to late Holocene samples (~ 8–1 ka). The Monocalyptus types as well as *Melaleuca ericifolia* and *M. gibbosa* were also present in the late Holocene samples (~ 2.8–1 ka). CCA axis1 explains the highest variance in the pollen record and separates *Eucalyptus* from non-*Eucalyptus pollen*, and fire and sediment input are most associated with changes in *Eucalyptus*, especially the Monocalyptus types from 12.4 to 9.3 ka. On both axes, wetland water level is associated with changes in other Myrtaceae after 8 ka.

Landscape management by indigenous people during the late glacial transition

Holocene archaeological evidence from the Furneaux Group islands has established that the intensity of land use was greatest between 12 and 6 ka (Sim 1998). The islands were still a single land mass connected to northeast Tasmania for most of this period, especially before 7.9 ka (Orchiston 1979; Sim 1998; Sloss et al. 2007). Sim (1998) during her archaeological excavation, recovered a larger number of prehistoric stone tools from sites on truwana than from any other surface site in the Furneaux Group, and these are thought to have been deposited before the mid to late Holocene stabilization of sea level. The author suggested that people used truwana intensively during this period for the readily available stones to make tools and because the stone sources were close to fresh water and open *Eucalyptus* woodland. Also, people migrated northwards from truwana to the larger Flinders Island around or shortly after 8 ka as the rising sea level reduced the size of truwana and resources rapidly depleted in the smaller area (Sim 1998). While archaeological work in the Furneaux Group is generally scanty with no direct evidence of burning by humans during the Holocene, a regional study of the area (Adeleye et al. 2021c) has identified frequent, low intensity fires that may be linked to early Holocene human occupation of the area (Bowman 1998; Mariani et al. 2022). To further evaluate interactions between climate, land use, vegetation and the role of people, we have compared several lines of proxy evidence from palaeoenvironmental records in truwana. High water levels in Big Reedy Lagoon during the Late Glacial to early Holocene indicates that the climate in truwana became increasingly wet at this time (Adeleye et al. 2021d). This

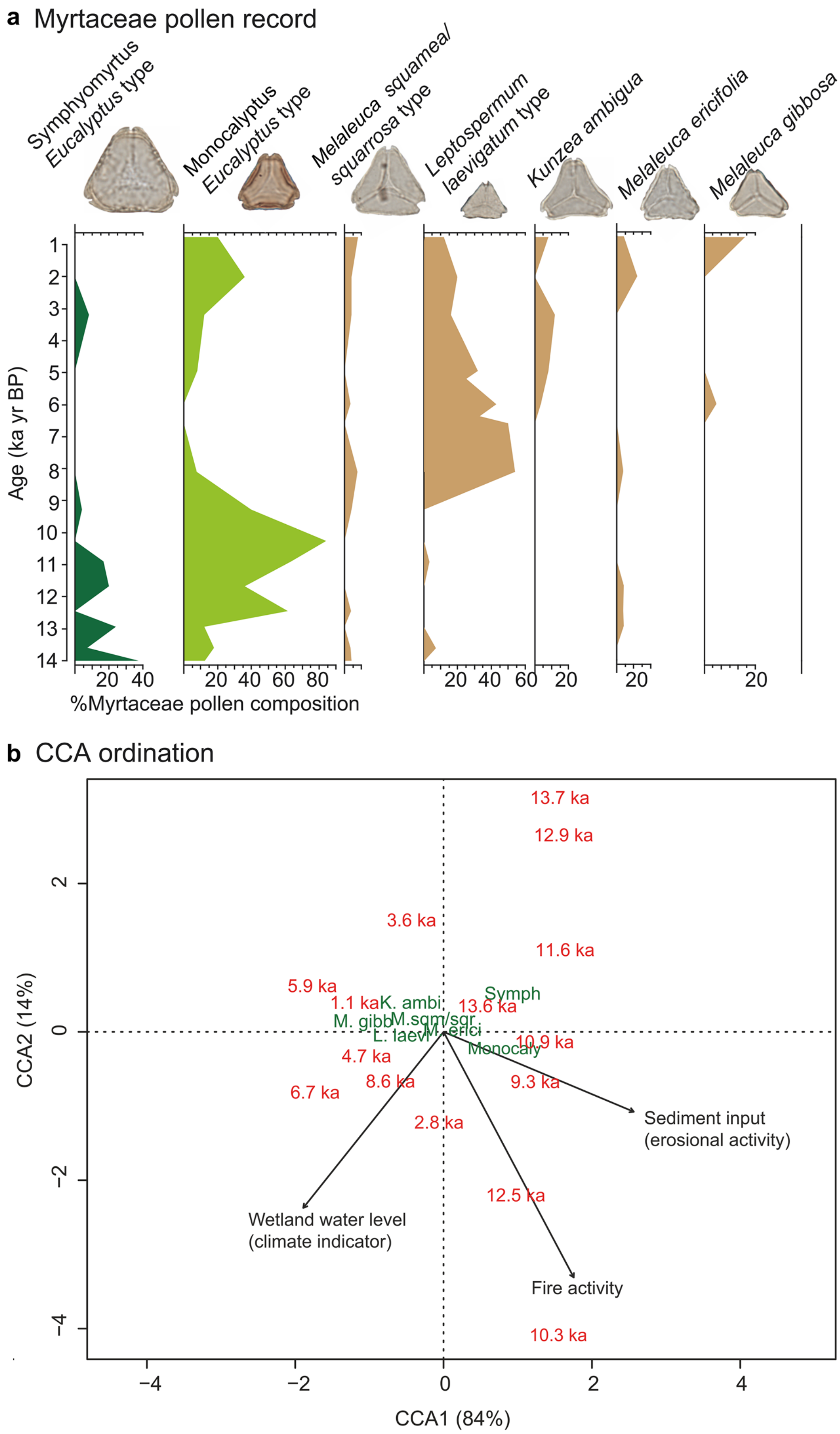

Fig. 2 **a** 14–1 ka Myrtaceae pollen record from Big Reedy Lagoon, truwana; **b** canonical correspondence analysis (CCA) results for the pollen record in relation to environmental variables

wetter climate may have initially promoted the expansion of Symphyomyrtus forest on moist fertile substrates before 12.9 ka, replacing the grassy steppe that had dominated the landscape during the last glacial period (Adeleye et al. 2021e; Fig. 3). The decline in *Eucalyptus* subg. Symphyomyrtus and increase in dry habitat Monocalyptus woodland with *E. nitida* etc. from ~ 12.9 to 8 ka, despite increasing precipitation, suggests that the climate was unlikely to have

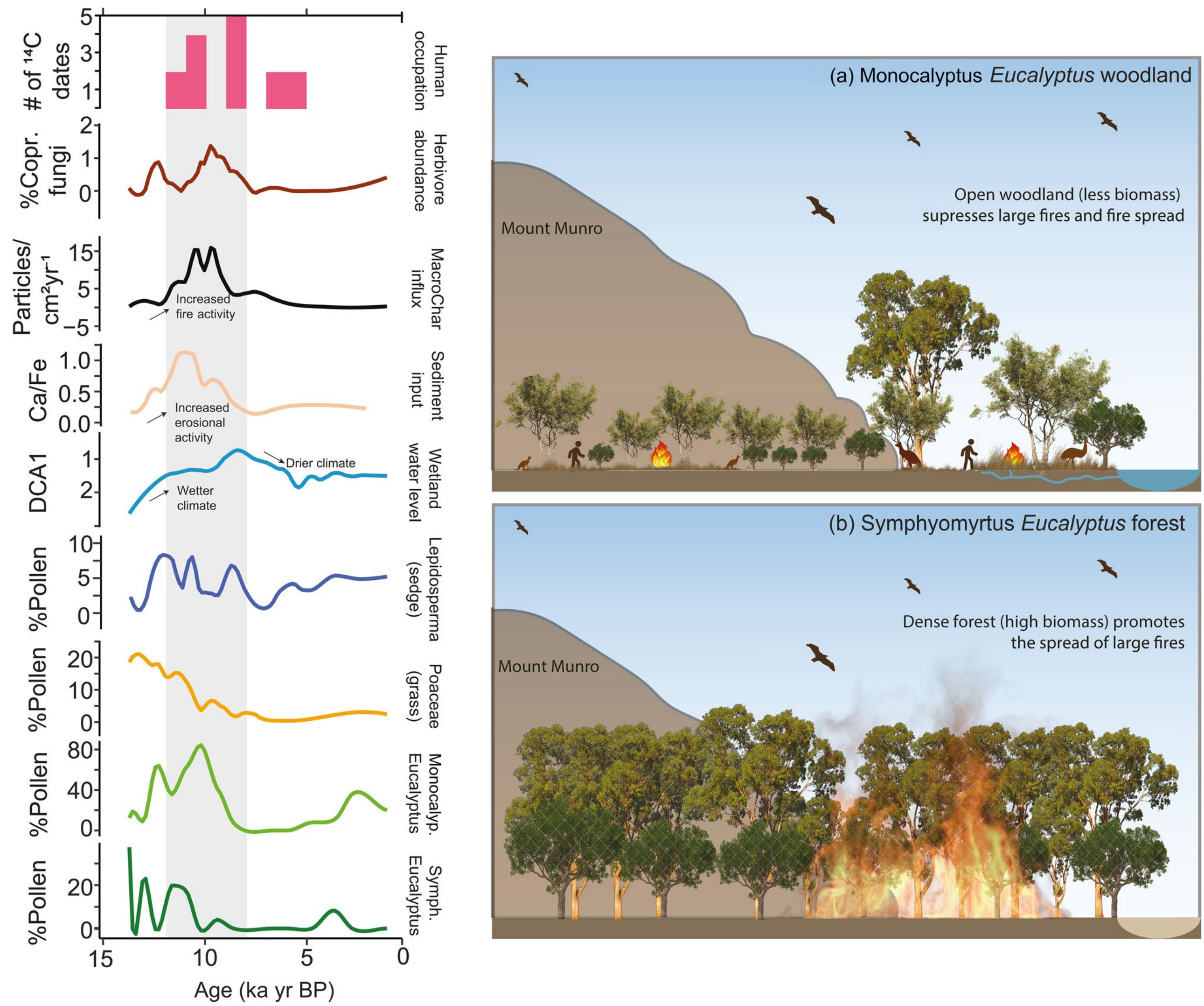

Fig. 3 Left, synthesis of *Eucalyptus* pollen records and other environmental results from Big Reedy Lagoon, truwana. Also shown are Poaceae and *Lepidosperma* pollen percentages from the full pollen record (Adeleye et al. 2021c). The grey shaded area indicates the period of major human occupation and environmental changes (~ 12.9–8 ka), the main focus of this study. Right, **a** schematic representation of what the truwana landscape would have looked like under conditions of high intensity; **b** low intensity Indigenous land management practices between 12.9 and 8 ka

been the main cause of these changes in *Eucalyptus* species composition at this time. This time period coincides with the intensification of land use by Indigenous people on truwana (Sim 1998), with frequent fires (Adeleye et al. 2021c, d). The CCA results suggest that frequent burnings promoted open vegetation with unstable well-drained soils, as reflected by the increase in sediment input from erosion in BRL during this period (Figs. 2b, 3). Frequent burning would also have reduced available soil nutrients, especially through soil erosion and leaching after fires (Bowman and Jackson 1981). These conditions, especially frequent fires, would have been suitable for Monocalyptus species due to their well-developed ability to grow large underground lignotubers (woody swellings of the root crown) from which stems could grow following fires. The ground vegetation of the woodland would have been characterized by sedges such as *Lepidosperma* on wet sites and an understorey of shrubs, especially *Melaleuca* (ESM Fig. S1), and Poaceae (grass) ground cover due to the infertile soils (Harris and Kitchener 2005). However, considering the low pollen productivity of grasses in Tasmania (Mariani et al. 2016a), their abundance at 5–10% suggests they may have grown as a dominant ground layer of the woodland in some areas, especially in more fertile sites (Fig. 3).

Studies of palaeoenvironments (Bickford and Gell 2005; Rowe 2007, 2015; Adeleye et al. 2021b; Mariani et al. 2022), archaeology (Bowdler 1979; Litster et al. 2020) and ethnography (Bowman 1998; Trauernicht et al.

2015) show that the interactions of the Indigenous people with their environments in the past had a number of purposes, one of the main ones being to increase availability of resources by promoting varied shrubs, herbs and grasses to attract the marsupials which they then hunted (Bowman 1998). This then maintained a high biodiversity in the ecosystem in the form of a habitat mosaic and reduced the occurrence of wildfires (Bowman 1998; Fletcher et al. 2021). The woodland would have encouraged macropods including *Macropus rufogriseus* (wallaby) and various species of *Thylogale* (pademelon), of which *T. billiardierii* are abundant on truwana today (Perrin 1988; Sim 1998). This habitat is suggested by large numbers of coprophilous fungal spores (fungi associated with large herbivore dung). Also, frequent burning would have promoted openings in the woodland and increased soil drainage and water supply by channels into the lagoon, increasing availability of fresh water for Indigenous people and animals. This is supported by high sediment input into the lagoon between 12.9 and 8 ka (Fig. 3). Big Reedy Lagoon is the largest catchment on truwana (~ 8 km^2) and given that water availability was a major determinant of past Indigenous occupation sites in Tasmania (Jones et al. 2019), it would have been a major source of fresh water on the island during this wet climatic phase. The persistence of taller and denser Symphyomyrtus forest would have supported small water channels into BRL and there would have been fewer grazing marsupials, which prefer open burnt areas with fresh growth for grazing (Bowman 1998). There is also evidence of intensified human occupation, fires, and open woodland at a similar period on the larger Flinders Island to the north of truwana (Sim 1998; McWethy et al. 2017), so the low-biomass Monocalyptus woodland which the Indigenous people maintained by fires on truwana between 12.9 and 8 ka may also have been created on the adjacent islands in the eastern Bass Strait.

Presently, open *Eucalyptus* forest and woodland generally grade into heathland on truwana and large unburnt areas become dominated by dense *Leptospermum* scrub (Harris and Kitchener 2005). While the high sea level around 8 ka favoured a coastal shrubland dominated by *Leptosermum laevigatum* at the expense of *Eucalyptus* which is intolerant of salt (Adeleye et al. 2021d), drier conditions and insufficient fires due to a reduced population and less land use also allowed the expansion of dense *Leptospermum* scrub at this time (Adeleye et al. 2021c). By ~ 4.7 ka, a consistently drier and more variable climate due to the intensification of El Niño-Southern Oscillation, together with increased insolation (greater seasonality), further limited fresh water and food resources to support people, and reducing frequent use of the island even more, with fewer fires and increased growth of scrub (Sim 1998; Fletcher and Moreno 2012; Perner et al. 2018; Adeleye et al. 2021d; Moros et al. 2021).

Conclusion

Management implication for southeast Australia

Current vegetation reconstructions from pollen suggest that the landscapes managed by Indigenous people in southeast Australia before European colonisation were open grassy *Eucalyptus* woodlands (Mariani et al. 2022). However, it is unclear if these woodlands were characterized by tall (perhaps old growth) or mallee *Eucalyptus* trees. Our results from truwana through the detailed analysis of Myrtaceae pollen records suggest that these woodlands would have mainly consisted of mallee *Eucalyptus* trees with various understories of shrubs and grassy ground cover. This cultural landscape not only featured low woody biomass (Mariani et al. 2022), but promoted animal populations, wetlands and habitat diversity. Increasing dry sclerophyllous woodland and greater density of trees combined with climate change have allowed large and destructive wildfires to occur in southeast Australia over the last century (Adeleye et al. 2021a, c; Mariani et al. 2022). The knowledge of the structure of the past landscape on truwana, when it was managed by Indigenous people, can be used to refine current management frameworks (including traditional management), in other parts of southeast Australia, especially the southeast mainland and eastern Tasmania where the kinds of dry sclerophyllous vegetation are similar to those on truwana. This will assist in maintaining the integrity of the vegetation communities and biocultural heritage of this region into the future.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written by Matthew Adeleye and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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