

Title: European colonization and the emergence of novel fire regimes in southeast Australia

Authors: ADELEYE, Matthew Adesanya^{1,2}, CONNOR, Simon^{1,2}, HABERLE, Simon Graeme^{1,2}, HERBERT, Annika³, and BROWN, Josephine⁴.

Corresponding author: Matthew Adeleye (ORCID: <https://orcid.org/0000-0002-6034-5807>, Email: matthew.adeleye@anu.edu.au)

Institutional affiliations and address:

¹School of Culture, History and Language, The Australian National University, Canberra, ACT, Australia.

²Australian Research Council Centre of Excellence for Australian Biodiversity and Heritage, The Australian National University, Canberra, ACT, Australia.

³School of Geography, Archaeology and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa.

⁴School of Earth Sciences, University of Melbourne, Victoria, Australia.

Title: European colonization and the emergence of novel fire regimes in southeast Australia

Abstract

The rapid increase in severe wildfires in many parts of the world, especially in temperate systems, requires urgent attention to reduce fires' catastrophic impacts on human lives, livelihoods, health and economy. Of particular concern is southeast Australia, which harbours one of the most flammable vegetation types on Earth. While previous studies suggest climate and European activities drove changes in southeast Australian fire regimes in the last two hundred years, no study has quantitatively tested the relative roles of these drivers. Here, we use a Generalized Linear Modelling to identify the major driver(s) of fire regime change in the southeast Australian mainland during and prior to European colonization. We use multiple charcoal and pollen records across the region and quantitatively compare fire history to records of climate and vegetation change. Results show low levels of biomass burned before colonization, when landscapes were under Indigenous management, even under variable climates. Biomass burned increased markedly due to vegetation/land-use change after colonization and a major decline in regional precipitation about 100 years later. We conclude that Indigenous-maintained open vegetation minimized the amount of biomass burned prior to colonization, while European-suppression of Indigenous land management has amplified biomass accumulation and fuel connectivity in southeast Australian forests since colonization. While climate change remains a major challenge for fire mitigation, implementation of a management approach similar to the pre-colonial period is suggested to ameliorate the risk of future catastrophic fires in the region.

Keywords: Fire, biomass, European colonization, southeast Australia, vegetation, Indigenous.

Introduction

Catastrophic wildfires are becoming more frequent and severe in many parts of the world and are associated with unprecedented impacts (Filkov et al., 2020; Nauslar et al., 2017; Flannigan et al., 2013; Dutta et al., 2016; Tran et al., 2020; Bowman et al., 2017). This is particularly true in Australia and North America, as demonstrated by recent (2019/2020) catastrophic wildfires in southeast Australia and California (Filkov et al., 2020; CAL FIRE, 2020; Bowman et al., 2017). The 2019/2020 Black Summer wildfires in southeast Australia claimed 34 human lives, at least 2000 homes, 3 billion animals, and 19 million hectares land area (Filkov et al., 2020). The fires have attracted growing concern internationally and locally in southeast Australia, which houses one of the most flammable vegetation types on Earth: dry sclerophyllous woodlands and forests (Crisp et al., 2011; Dutta et al., 2016; Bowman et al., 2017).

Fire regimes are complex and influenced by multiple factors, including vegetation type and moisture (Bradstock, 2010). Recent studies (Clarke et al., 2019; Tran et al., 2020) have shown that fire weather (dry, windy and hot days) significantly influences fire occurrence and is a significant predictor of the occurrence of catastrophic fires in southeast Australia.

However, the role of factors associated with vegetation (fuel composition, connectivity and moisture) is not fully understood (Bradstock et al., 2020). Quantitative knowledge of long-term changes in vegetation composition and connectivity, as well as fire regimes, provide a robust baseline that can guide to effective fire management plans (Gilson et al., 2019).

Palaeoecological records offer the possibility of undertaking such long-term quantitative studies, tapping into the rich knowledge archives of the past (Fordham et al., 2020).

Palaeoecological studies have shown that increasing climatic variability and anthropogenic land-use change drove centennial-scale shifts in fire activity (biomass burned) in southeast

Australia for at least the last ~5000 years (Kershaw et al., 2003; Black et al., 2008; Mooney et al., 2011, 2012). On shorter timescales, agro-pastoral activities following Australia's colonization by Europeans in 1788 AD are thought to have contributed to landscape changes in the last 200 years, especially via the suppression of Indigenous land management, clearance of forests in some areas and promotion of wooded landscapes in others (Lunt et al., 2006; Fletcher et al., 2020). Several authors have sought to understand and quantify changes in fire activity in southeast Australia in the centuries before and after European colonization (e.g., Dodson and Mooney, 2002; Mooney et al., 2012; Dodson et al., 1993, 1994a, 1994b, 1994c, 1995). However, the drivers of past fire regimes in the region are still not fully understood, as no study has quantitatively tested the role of centennial-scale vegetation and climate changes in shaping fire regimes.

Here, we use a robust modelling approach to identify the major driver(s) of fire regimes in the southeast Australian mainland (SEAM) in the centuries before and after European initial colonization. To achieve this, we use multiple charcoal records from the SEAM, spanning the last 700 years, to reconstruct past biomass burned (an estimate of the amount of vegetation biomass consumed by landscape fire). This SEAM biomass-burned reconstruction was then quantitatively compared to records of vegetation turnover and independent multi-model-based records of past climate in the region. A quantitative estimate of rates of palynological change in pollen records was used to infer regional vegetation turnover (beta diversity), a reflection of vegetation (fuel) compositional change on the landscape. It has been empirically established that palynological rates of change in southeast Australian pollen assemblages are significantly correlated with vegetation compositional change in the region (Adeleye et al., 2021a). The results from this study will help inform management efforts not only in Australia, but also in other fire-prone regions globally.

101 **Study area**

102 Wildfire seasons vary across Australia, generally ranging from winter-dominated, frequent,
103 low-intensity in northern regions characterized by a monsoon climate, to summer-dominated,
104 infrequent high-intensity in southern regions characterized by a temperate climate (Miller and
105 Murphy, 2017; Archibald et al., 2013). In southeast Australian sclerophyll forests, intense
106 fires primarily occur during late summer–autumn (Australian Bureau of Meteorology, 2021).

107 The SEAM climate is mainly modulated by El Niño Southern-Oscillation (ENSO), Indian
108 Ocean Dipole (IOD) and the Southern Westerly Winds (SWW; CSIRO, 2012). ENSO and
109 IOD bring drought to the region, especially in El Niño years, which are associated with
110 extreme fire weather and fire events (Mariani et al., 2016; Abram et al., 2020). SWW have
111 the greatest influence in the southernmost part of the SEAM. Positive phases of SWW are
112 generally associated with high summer rainfall (low winter rainfall), while negative phases
113 are associated with high winter rainfall (low summer rainfall) (Australian Bureau of
114 Meteorology). Vegetation on the SEAM is dominated by *Eucalyptus* forests and woodlands,
115 as well as sclerophyllous shrublands (Department of the Environment and Water Resources,
116 2007), and many lowland areas have been cleared for farmland (Department of Agriculture,
117 Land and Environment, 2018; Figure 1).

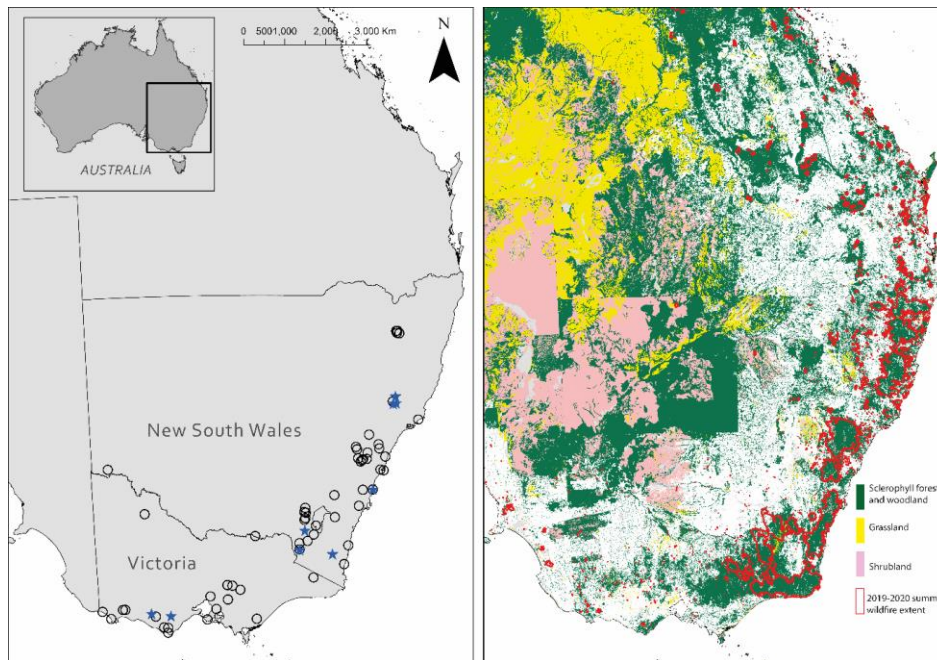


Figure 1: Locations of charcoal (black hollow circles) and pollen records (blue stars) on the southeast Australian mainland used in this study (left panel). Present vegetation distribution and extent of 2019–2020 summer wildfires (right panel). White-coloured areas on the right panel represent cleared areas. (Department of Agriculture, Land and Environment, 2020—National Indicative Aggregated Fire Extent Datasets; Department of Agriculture, Land and Environment, 2018—National Vegetation Information System version 5.1).

Methods

Sedimentary charcoal is the most robust indicator of past fire regimes in a given landscape, containing information on past biomass burned and burning frequency (Whitlock et al., 2001; Ali et al., 2012). Sixty-one charcoal records with at least one radiocarbon date every 3000 years were selected across the SEAM from the Global Paleofire database (<https://www.paleofire.org/>; see Table 1 in supplementary material for charcoal data information). Composite charcoal z-scores were then calculated at 50-year resolution using the ‘paleofire’ (‘pfComposite’) package in ‘R’ (Blarquez et al., 2014b; R Core Team, 2020)

to reconstruct regional biomass burned in the last ~700 years. A Kruskal-Wallis ANOVA test was also performed using the ‘paleofire’ package in ‘R’ to test the dissimilarity in biomass burned between different time periods (150-year time bin) (Blarquez et al., 2014b; R Core Team, 2020).

To reconstruct regional vegetation turnover, nine pollen records spanning the last ~700 years with at least 100-year sampling resolution and at least one radiocarbon/²¹⁰Pb date every 400 years were obtained from a southeast Australian database (Herbert and Harrison, 2016). Pollen records with centennial-scale resolution were required for this study and only nine records met this criterion in the SEAM region (see Table 2 in supplementary material for pollen data information). Pollen records were divided into 100-year time bins and Squared Chord Distances (SCD) calculated between randomly selected samples (resampled 50×) from adjacent bins to estimate temporal vegetation turnover, using the ‘analogue’ package in ‘R’ (R Core Team, 2020; Simpson and Oksanen, 2020). The average SCD of all nine pollen records was then taken, representing regional vegetation turnover for the SEAM (Adeleye et al., 2021a).

Published pollen and charcoal record chronologies were accepted. Recalibration of published dates using the latest radiocarbon calibration curve (SHCal20: Hogg et al., 2020) made no difference – all published calibrations overlapped with recalibrations at 68 and 95% confidence intervals. Exotic pollen, such as *Pinus*, was also commonly used as a biostratigraphic marker to fine-tune the timing of European settlement in the records (e.g., Dodson et al., 1994a, 1994d; Black and Mooney, 2006; Mooney et al., 2007; Kodela and Dodson, 1988).

Generalized linear modelling (GLM) with Gaussian distribution was used to identify major drivers of biomass burned, with vegetation turnover and climatic drivers as predictors. The

effect of temporal autocorrelation was removed from the model by multiple resampling of each variable at a lower resolution 1000× (Mellin et al, 2010). The best model was selected based on the corrected Akaike's information criterion (AICc) and delta AICc (dAICc) statistics. The climate records used are multi-model averages of ENSO (Nino 3.4 index), temperature and precipitation simulations for eastern Australia based on simulations of the last millennium from a set of climate models: BCC-CSM1.1, CCSM4, CSIRO-Mk3L-1-2, GISS-E2-R, IPSL-CM5A-LR, and MPI-ESM-P (see Brown et al., 2016 and Schmidt et al., 2012 for climate model details). Alongside the fact that these model-based climate simulations were developed for eastern Australia, the simulations were selected due to the model robustness and their high temporal resolution.

Results

Charcoal composite and vegetation turnover results show relatively low biomass burned (z-score < 0), with minimal vegetation turnover (SCD<0.2) before 1788 AD, while biomass burned (z-score > 0) and vegetation turnover (SCD>0.2) increased markedly after this time, especially since 1850 AD (Fig. 2). The charcoal composite using a subset (n=17) of the charcoal records with at least one radiocarbon date per 700 years shows a similar trend in biomass burned ($r=0.8$, $p=0.002$). Kruskal-Wallis ANOVA test shows a significant ($p<0.05$) difference between biomass burned before and after 1788 AD (Fig. 2). Generalized linear models (GLMs) show a combination of vegetation turnover and precipitation changes best explain regional biomass burned, judged by the low AICc and dAICc values (Table 1).

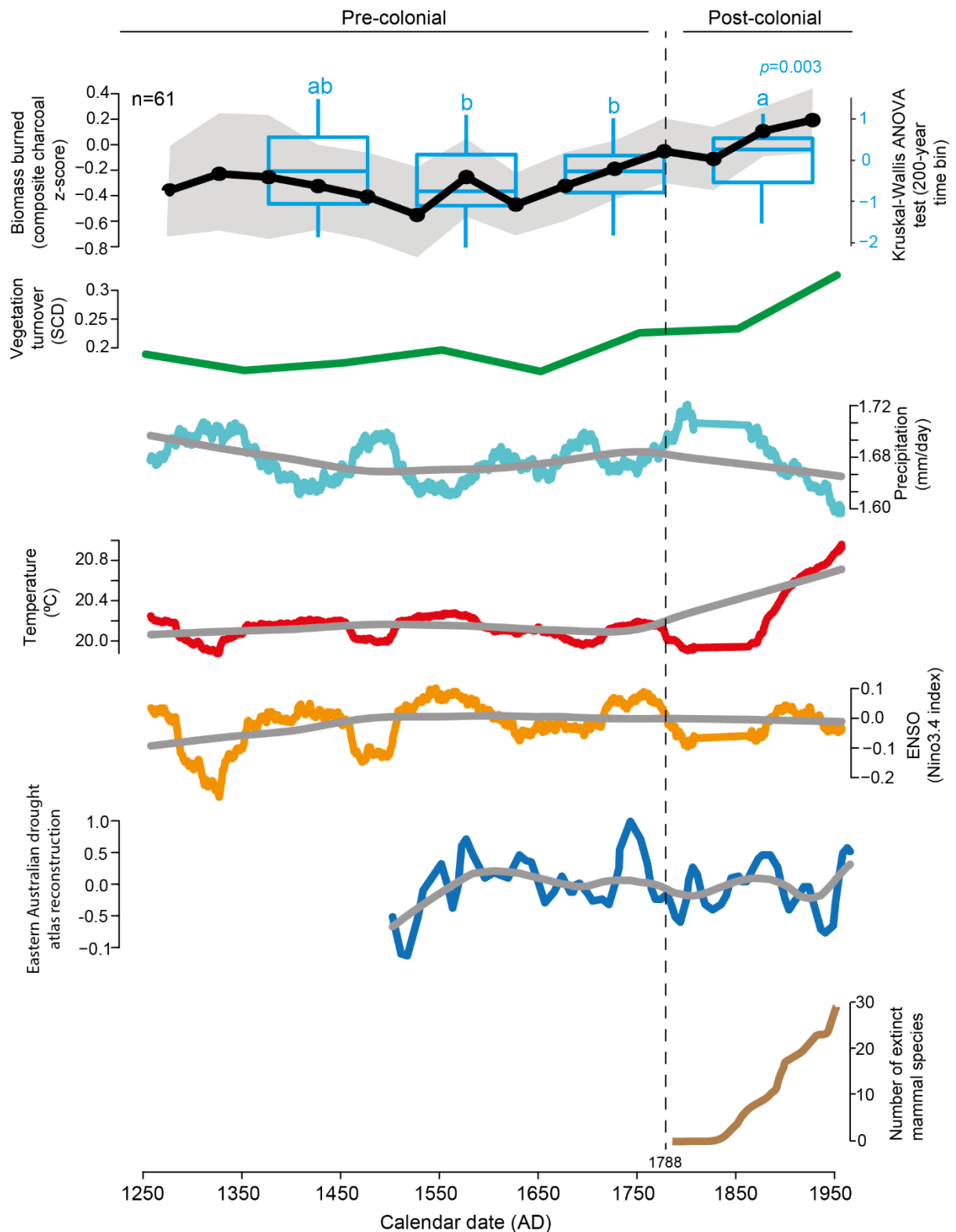


Figure 2: Biomass burned in southeast Australia over the last 700 years before present (present = 1950) with error estimates (grey-shaded area) in relation to vegetation turnover, precipitation, temperature, and ENSO, with loess smoothing (grey curves, span=0.5). Boxplots are the Kruskal-Wallis ANOVA test results, which indicate a significant ($p<0.05$) difference between biomass burned before and after European colonization. ENSO (Nino 3.4 index), temperature ($^{\circ}\text{C}$) and precipitation (mm/day) are based on simulations of the last

millennium from a set of climate models for eastern Australia: BCC-CSM1.1, CCSM4, CSIRO-Mk3L-1-2, GISS-E2-R, IPSL-CM5A-LR, and MPI-ESM-P (Brown et al., 2016). Vegetation turnover (SCD) is based on nine pollen records (Herbert and Harrison, 2016) and biomass burned (charcoal z-score) estimate is based on composite of 61 charcoal records from the southeast Australian mainland (Global Paleofire database—<https://www.paleofire.org/>). See Table 1 and 2 in supplementary material for pollen and charcoal data information. Also shown is eastern Australian drought atlas reconstruction, with loess smoothing (span=0.25), which is based on tree rings and coral series (Palmer et al., 2015), as well as the number of extinct mammals in Australia since European colonization (Woinarski et al., 2015).

Table 1: GLMs comparing biomass burned (BB) to vegetation turnover (SCD), temperature (temp), ENSO and precipitation (precip). Models are ranked based on Akaike’s information criterion corrected for small sample sizes (AICc) and delta AICc. Also shown are percentage of deviance explained and marginal R^2 (Rm). The best model (top) is one with the lowest AICc and dAICc values, which in this case is ‘*BB ~ Veg+Precip*’.

Model	AICc	dAICc	Rm	%Deviance
<i>BB ~ Veg+Precip</i>	-38.1218	0	84.35	91.7
<i>BB ~ Veg+Precip+Temp</i>	-36.8575	1.264	85.93	91.8
<i>BB ~ Veg+ENSO+Precip</i>	-34.8237	3.298	84.5	90.3
<i>BB ~ Veg+ENSO</i>	-34.1719	3.95	81.11	90.2
<i>BB ~ Veg+Temp</i>	-33.6057	4.516	80.59	94.3
<i>BB ~ Veg+ENSO+Temp+Precip</i>	-32.8776	5.244	85.94	89.9
<i>BB ~ Veg+ENSO+Temp</i>	-31.8366	6.285	82.13	95.8
<i>BB ~ Temp+Precip</i>	-25.3593	12.762	71.25	83
<i>BB ~ ENSO+Temp+Precip</i>	-24.1344	13.987	74.21	85.7
<i>BB ~ ENSO+Temp</i>	-7.26838	30.853	31.97	58.4
<i>Null</i>	-5.01251	33.109	0	-
<i>BB ~ ENSO+Precip</i>	0.502465	38.624	1.5	41.9

Discussion

Potential sources of error

The charcoal and pollen records used in this study are currently the best publicly accessible data sets for the SEAM spanning the time frame considered in this study. We acknowledge that the quality of these data sets (e.g., Dodson et al., 1994a, 1994d; Black and Mooney, 2006; Mooney et al., 2007; Kodela and Dodson, 1988), especially in terms of the generally low resolution and poor chronological control over the targeted time period, may have

potentially influenced the timing of shifts in our vegetation turnover and biomass burned reconstructions. Hence, given chronological uncertainties, dates given in the text should be regarded as approximations. Though the overall number of charcoal data sets analysed is high (n=61), the majority of the records are non-contiguous microscopic (<125 μ m) charcoal records, which have the potential of missing fire events. Despite these limitations, the result presented in this study provides a quantitative insight into the drivers of fire regimes in pre-colonial and colonial landscapes of the SEAM.

Fire regime change driven by vegetation and precipitation changes in southeast Australia

In both Northern and Southern Hemisphere temperate ecosystems, palynological rates-of-change estimates with SCDs >0.2 indicate complete turnover in vegetation types across space and through time (Overpeck et al., 1985; Adeleye et al., 2021a). Our results (Fig. 2) indicate that prior to the 18th century, vegetation was relatively stable and after that time major turnover occurred. Our generalized linear models (GLMs) show that a combination of vegetation turnover and precipitation changes best explain regional biomass burned on the SEAM in the last ~700 years (Table 1).

Vegetation type/structure and moisture, as well as temperature, are major determinants of fire regime (Cochrane and Ryan, 2009; Daniau et al., 2012). However, vegetation type/structure and moisture are more important in dry vegetation types, where fire is often limited by biomass fuel loads and connectivity (Cochrane and Ryan, 2009; Bradstock, 2010; Pausas and Paula, 2012; Daniau et al., 2012). High fuel connectivity in dry woody vegetation is a function of biomass accumulation (increased vegetation growth), which can be caused by one or more of the following: (1) high moisture, (2) high CO₂, and (3) insufficient disturbance, such as infrequent fires (Pausas and Paula, 2012; Murphy et al., 2013). A large percentage of the SEAM's forest vegetation falls into the category of dry, contiguous, woody vegetation,

making the region one of the most fire-prone places on Earth (Keith, 2017). Also, compared to the pre-colonial landscape, present-day forests on the SEAM are denser and have greater fuel connectivity, while present-day open vegetation has much less tree cover (Mariani et al. in press).

Indigenous population growth and land usage were high and widespread across the SEAM during the last millennium, especially prior to European colonization in 1788 AD (Williams, 2013; Williams et al., 2015). Scientific studies and ethnographic accounts indicate that Indigenous people regularly and deliberately burned vegetation to keep landscapes open in order to promote resource availability, such as diverse plant-based food and herbivore grazing for hunting, as well as to increase land accessibility and freshwater resources (Bowman, 1998; Gammage, 2005, 2008, 2012; Bird et al., 2020; McWethy et al., 2017; Mulvaney and Golson, 1971). Other fire-related activities carried out by Indigenous people in the past include cooking, ceremonies, and rituals (Mulvaney and Golson, 1971). Existing pollen records suggest European land-use transformations drove tree-cover declines in the partially wooded landscapes on the SEAM following initial colonization (Dodson et al., 1994a, 1994b, 1994c, 1995). A recent land cover reconstruction suggests that forest/woodland understorey shrub density likely increased after colonization at the same time as agro-pastoral landscapes were expanding (Mariani et al., in press). These denser forest understoreys might represent a major increase in forest connectivity over the last two centuries.

Vegetation turnover recorded from 1788 AD (especially since 1850 AD) on the SEAM likely reflects this polarisation in fuel connectivity and woody biomass accumulation following European arrival, which in turn led to increased biomass burned across the landscape. The majority (90%) of pollen records considered in our study show increases in shrubs such as *Kunzea*, *Ericaceae*, *Melaleuca*, and *Leptospermum* after 1788 AD. Shrub expansion would have increased fuel connectivity by creating ladder fuels linking the surface vegetation layer

to the tree canopy (Sullivan et al., 2012), facilitating widespread and severe fires and increases in the amount of biomass burned on the landscape. Indigenous peoples used frequent low-intensity fires (cool burning) to promote mosaic landscapes, thus reducing fuel connectivity and fire spread (Bowman, 1998; Gott, 2005). Our data support the hypothesis that European suppression of Indigenous cultural burning helped to drive increases in vegetation thickening (biomass accumulation and fuel connectivity) on the SEAM (Bradstock et al., 2002; Mariani et al., in press).

A two-way feedback exists between fire and vegetation, such that fire can drive vegetation turnover and vice versa (Marlon et al., 2016; Feurdean et al., 2020). However, fire regimes in most cases are pre-conditioned by vegetation structure and moisture, especially in temperate ecosystems (Feurdean et al., 2020; Pausas and Paula, 2012; Bradstock, 2010). A study of contemporary fire ecology in temperate southeast Australia (Bradstock, 2010) shows that biomass availability (vegetation) is the major factor limiting fire activity. Deliberate reduction of biomass load (to limit fuel connectivity) has been proposed to reduce potential risks of fire weather-driven catastrophic fires in the region (Matthews et al., 2012).

At a regional scale, decreasing precipitation and drought variability are associated with the Interdecadal Pacific Oscillation across eastern Australia since the 1600s (Palmer et al., 2015; Gergis et al., 2012; Mantua and Hare, 2002). This climatic trend is likely to have not only influenced biomass burned as early as ~1650 AD, but also exacerbated biomass burned over the last 200 years by increasing fuel dryness. The unstable/weak connection between ENSO (Nino3.4) and precipitation across eastern Australia on a decadal scale (Palmer et al., 2015; Brown et al., 2016) may explain why our GLMs identified ENSO as a minor driver of fire regimes in southeast Australia over the last ~700 years.

Precipitation was also generally low between ~1450 and 1650 AD, a possible indication of pre-existing climate variability prior to European colonization in 1788 AD (Barr et al., 2014; Fig. 3). However, in contrast to the colonial period, biomass burned during this period was relatively low, and may be explained by the open vegetation maintained by Indigenous peoples through frequent low-intensity patch burning (cool burning), which reduced understorey shrub load and fuel connectivity for landscape-scale fires (Gammage, 2005). Other ecological factors, such as herbivory and changes in soil conditions may have also played a role in maintaining relatively low levels of plant biomass and vegetation density (Eldridge et al., 2017), contributing to the open landscape and low biomass burned during this period. Native mammal populations have crashed in Australia since the 1850s (Woinarski et al. 2015), but prior to this time these herbivores are likely to have played a key role in suppressing biomass (Fig. 2).

Overall, the role of Indigenous people in maintaining diverse and interconnected ecosystems and landscapes appears to have been dismissed or even deliberately suppressed since European colonization (Gammage, 2012; Fletcher et al., 2020). The disruption of Indigenous burning practices has not only elevated the present-day risk of catastrophic fires in southeast Australia but has also led to changes in biodiversity maintained by Indigenous skilful burning for many millennia (Adeleye et al., 2021a, 2021b; Bowman, 1998; Bowman et al., 2011). While climate-change risks remain the primary global challenge for fire mitigation, local-scale management targeted at restoring pre-colonial fire regimes will likely help reduce present fuel connectivity, thus altering fire behaviour and diminishing the potential for widespread wildfires in SEAM forests and woodlands. This conclusion echoes the recommendations of the Australian Royal Commission into Natural Disaster Arrangements on wildfire, which highlighted the urgent need for states and territories to strengthen their engagements with Traditional Owners to further explore Indigenous land and fire

management insights throughout the process of public management activities (Royal Commission into Natural Disaster Arrangement, 2020).

Management approaches that draw on traditional knowledge are also now being recommended in South America, North America, and southern Europe to reduce risks and effects of severe wildfires in fire-prone ecosystems (Mistry et al., 2019; Eloy et al., 2019; White et al., 2011; Keane et al., 2002; Fernandes et al., 2002). It is therefore becoming apparent that the knowledge of the past (traditional land management) is key to effective future management of severe wildfires globally. The earlier this is embraced by land managers and policy makers, the lesser the risk of future losses of human lives, properties, cultural heritage, ecosystem functions, and biodiversity associated with severe wildfires (Tran et al., 2020; Filkov et al., 2020; CAL FIRE, 2020).

Conclusion

Results from this study support the idea that Indigenous peoples maintained a fire regime with low levels of biomass burning on the southeast Australian mainland prior to European colonization, while European suppression of Indigenous cultural land management, exacerbated by increasingly dry conditions, has driven an increase in biomass burned after colonization. Considering the projected increase in fire weather and extreme fire events for southeast Australia, exploring management approaches modelled on Indigenous cultural burning practices is recommended to reduce the risks of future catastrophic wildfires in the region.

Acknowledgements

Charcoal data were obtained from the Global Charcoal Database (<http://www.paleofire.org>), and the work of the data contributors and the Global Palaeofire Working Group is gratefully acknowledged. The work of the pollen data contributors for southeast Australian mainland is also gratefully acknowledged. We acknowledge the Indigenous people of the southeast Australian mainland on whose land these data have been derived. Thanks to Corey Bradshaw (Flinders University) for generously providing R code for modelling. The authors acknowledge that this research was made possible through an Australian Research Council Centre of Excellence for Australian Biodiversity and Heritage support grant (CE170100015). Matthew Adeleye is also supported by an Australian Government Research Training Program (AGRTP) research and international scholarship awards.

References

- Adeleye MA, Mariani M, Connor S, Herbert A, Haberle S, Hopf F and Stevenson J (2021a) Long-term drivers of vegetation turnover in Southern Hemisphere temperate ecosystem. *Global Ecology and Biogeography*. 10.1111/geb.13232.
- Adeleye MA, Haberle SG, Connor SE, Stevenson J, and Bowman DMJS. Indigenous Fire-Managed Landscapes in Southeast Australia during the Holocene—New Insights from the Furneaux Group Islands, Bass Strait. *Fire* 4:17.
- Ali AA, Blarquez O, Girardin MP, Hély C, Tinquaut F, El Guellab A, Valsecchi V, Terrier A, Bremond L, Genries A, Gauthier S and Bergeron Y (2012) Control of the multimillennial wildfire size in boreal North America by spring climatic conditions. *PNAS* 109: 20966-20970.

354 Archibald S, Caroline ERL, Gómez-Dans JL and Bradstock RA (2013) Defining pyromes
 355 and global fire regimes. *PNAS* 110: 6442-6447.

356 Australian Bureau of Meteorology. Southern Annular Mode in Australia.
 357 <http://www.bom.gov.au/climate/sam/images/SAM-in-Australia.pdf>

358 Australian Bureau of Meteorology (2021). Bushfire weather.
 359 [http://www.bom.gov.au/weather-services/fire-weather-centre/bushfire-](http://www.bom.gov.au/weather-services/fire-weather-centre/bushfire-weather/index.shtml)
 360 [weather/index.shtml](http://www.bom.gov.au/weather-services/fire-weather-centre/bushfire-weather/index.shtml)

361 Barr C, Tibby J, Gell P, Tyler J, Zawadzki A and Jacobsen GE (2014) Climate variability in
 362 south-eastern Australia over the last 1500 years inferred from the high-resolution
 363 diatom records of two crater lakes. *Quaternary Science Reviews* 95: 115-131.

364 Bird RB, McGuire C, Bird DW, Price MH, Zeanah D and Nimmo DG (2020) Fire mosaics
 365 and habitat choice in nomadic foragers. *PNAS* 117: 12904–12914.

366 Black MP, Mooney SD and Attenbrow V (2008) Implications of a 14, 200-year contiguous
 367 fire record for understanding human–climate relationships at Goochs Swamp, New
 368 South Wales, Australia. *The Holocene* 18: 437-447.

369 Black MP and Mooney SD (2006). Holocene fire history from the Greater Blue Mountains
 370 World Heritage Area, NSW, Australia: The climate, humans and fire nexus. *Regional*
 371 *Environmental Change* 6: 41-51

372 Blarquez O, Vannière B, Marlon JR, Danian A, Power MJ, Brewer S and Bartlein PJ (2014b)
 373 Paleofire: An R package to analyse sedimentary charcoal records from the Global
 374 Charcoal Database to reconstruct past biomass burning. *Computers and Geosciences*
 375 72: 255–261.

376 Bowman D, Williamson G, Abatzoglou J, Kolden CA, Cochrane MA and Smith AMS (2017)
 377 Human exposure and sensitivity to globally extreme wildfire events. *Nature Ecology*
 378 *and Evolution* 1: 0058.

379 Bowman DMJS (1998) The impact of Aboriginal landscape burning on the Australian biota.
 380 *New Phytologist* 140: 385- 410.

381 Bradstock RA (2010) A biogeographic model of fire regimes in Australia: current and future
 382 implications. *Global Ecology and Biogeography* 19: 145-158.

383 Bradstock RA, Nolan RH, Collins L, Resco de Dios V, Clarke H, Jenkins M, Kenny B and
 384 Boer MM (2020) A broader perspective on the causes and consequences of eastern
 385 Australia's 2019–20 season of mega-fires: A response to Adams et al. *Global Change*
 386 *Biology* 26: e8-e9.

387 Bradstock RA, Williams JE and Gill MA (2002) Flammable Australia: the fire regimes and
 388 biodiversity of a continent. Cambridge University Press.

389 Brown JR, Hope P, Gergis J and Henley BJ (2016) ENSO teleconnections with Australian
 390 rainfall in coupled model simulations of the last millennium. *Climate Dynamics* 47: 79–
 391 93.

392 CAL FIRE. California Statewide fire summary (2020) [https://www.fire.ca.gov/daily-wildfire-](https://www.fire.ca.gov/daily-wildfire-report/)
 393 [report/](https://www.fire.ca.gov/daily-wildfire-report/)

394 Clarke H, Gibson R, Cirulis B, Bradstock RA and Penman TD (2019) Developing and testing
 395 models of the drivers of anthropogenic and lightning-caused wildfire ignitions in south-
 396 eastern Australia. *Journal of Environmental Management* 235: 34-41.

397 Cochrane MA (2009) Tropical fire ecology: climate change, land use and ecosystem
 398 dynamics. Praxis Publishing Ltd, Chichester, UK.

399 Crisp M, Burrows G, Cook L, Thornhill AH and Bowman DMJS (2011). Flammable biomes
400 dominated by eucalypts originated at the Cretaceous–Palaeogene boundary. *Nature*
401 *Communication* 2: 193.

402 Department of Agriculture, Land and Environment (2018) Catchment scale land use of
403 Australia. Australian Government.

404 Department of Agriculture, Land and Environment (2018) Australia - Present Major
405 Vegetation Groups - National vegetation information system version 5.1.
406 [http://environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B991C36](http://environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B991C36C0-3FEA-4469-8C30-BB56CC2C7772%7D)
407 [C0-3FEA-4469-8C30-BB56CC2C7772%7D](http://environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B991C36C0-3FEA-4469-8C30-BB56CC2C7772%7D)

408 Department of Agriculture, Land and Environment (2020) National Indicative Aggregated
409 Fire Extent Datasets.
410 [https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B9](https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B9ACDCB09-0364-4FE8-9459-2A56C792C743%7D)
411 [ACDCB09-0364-4FE8-9459-2A56C792C743%7D](https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B9ACDCB09-0364-4FE8-9459-2A56C792C743%7D)

412 Department of the Environment and Water Resources (2007) Australia’s native vegetation: a
413 summary of Australia’s major vegetation groups. Australian Government, Canberra,
414 ACT.

415 Daniau A-L, Bartlein PJ, Harrison SP, et al. (2012) Predictability of biomass burning in
416 response to climate changes. *Global Biogeochemical Cycles* 26: GB4007.

417 Dodson JR, McRae VM, Molloy K, Roberts F and Smith JD (1993) Late Holocene human
418 impact on two coastal environments in New South Wales, Australia: a comparison of
419 Aboriginal and European impacts. *Vegetation History and Archaeobotany* 2: 89-100.

420 Dodson JR., Frank K, Fromme M, Hickosn D, McRae V, Mooney S and Smith J (1994a)
 421 Environmental Systems and Human Impact at Cobrico Crater, South-western Victoria.
 422 *Australian Geographical Studies* 32: 27-40.

423 Dodson JR, de Salis T, Myers CA and Sharp AJ (1994b) A thousand years of environmental
 424 change and human impact in the alpine zone at Mt Kosciusko. New South Wales,
 425 *Australian Geographer* 25:1, 77-87.

426 Dodson JR, Roberts FK and De Salis T (1994c) Palaeoenvironments and human impact at
 427 Burruga Swamp in Montane rainforest, Barrington tops National Park, New South
 428 Wales. *Australia, Australian Geographer* 25:2, 161-169.

429 Dodson JR (1974d) Vegetation and climatic history near Lake Keilambete, western Victoria.
 430 *Australian Journal of Botany* 22: 709–717.

431 Dodson JR, Chant J and Dally J (1995). Human impact recorded in an urban wetland's
 432 sediments in Sydney, Australia. *Man and Culture in Oceania* 11: 113-124.

433 Dutta R, Das A and Aryal J (2016) Big data integration shows Australian bush-fire frequency
 434 is increasing significantly. *Royal Society Open Science* 3: 150241.

435 Eldridge DJ, Travers SK, Manning AD and Barton P (2017). Direct and indirect effect of
 436 herbivore activity on Australian vegetation. In Keith DA (Eds), *Australian vegetation*.
 437 Cambridge University Press, pp. 135-155.

438 Eloy L, Bilbao B, Mistry J and Schmidt IB (2019) From fire suppression to fire management:
 439 Advances and resistances to changes in fire policy in the savannas of Brazil and
 440 Venezuela. *Geographical Journal* 185: 10– 22.

441 Fernandes PM, Davies GM, Ascoli D, Fernández C, Moreira F, Rigolot E, Stoof CR, Vega
 442 JA and Molina D (2013) Prescribed burning in southern Europe: developing fire

443 management in a dynamic landscape. *Frontiers in Ecology and the Environment* 11: e4-
 444 e14.

445 Feurdean A, Vannière B, Finsinger W, Warren D, Connor SC, Forrest M, Liakka J, Panait A,
 446 Werner C, Andrić M, Bobek P, Carter VA, Davis B, Diaconu A-C, Dietze E, Feeser I,
 447 Florescu G, Gałka M, Giesecke T, Jahns S, Jamrichová E, Kajukało K, Kaplan J,
 448 Karpińska-Kołaczek M, Kołaczek P, Kuneš P, Kupriyanov D, Lamentowicz M,
 449 Lemmen C, Magyari EK, Marcisz K, Marinova E, Niamir A, Novenko E, Obremska M,
 450 Pędziszewska A, Pfeiffer M, Poska A, Rösch M, Słowiński M, Stančikaitė M, Szal M,
 451 Święta-Musznicka J, Tanțău I, Theuerkauf M, Tonkov S, Valkó O, Vassiljev J, Veski
 452 S, Vincze I, Wacnik A, Wiethold J and Hickler T (2020) Fire hazard modulation by
 453 long-term dynamics in land cover and dominant forest type in eastern and central
 454 Europe. *Biogeosciences* 17: 1213–1230.

455 Filkov AI, Ngo T, Matthews S, Telfer S and Penman TD (2020) Impact of Australia's
 456 catastrophic 2019/20 bushfire season on communities and environment. Retrospective
 457 analysis and current trends. *Journal of Safety Science and Resilience* 12020: 44-56.

458 Flannigan M, Cantin AS, de Groot WJ, Wotton M, Newbery A and Gowman LM (2013)
 459 Global wildland fire season severity in the 21st century. *Forest Ecology and*
 460 *Management* 294: 54-61.

461 Fletcher MS, Hall T and Alexandra AN (2020) The loss of an indigenous constructed
 462 landscape following British invasion of Australia: An insight into the deep human
 463 imprint on the Australian landscape. *Ambio*. 10.1007/s13280-020-01339-3.

464 Fordham DA, Jackson ST, Brown SC, Huntley B, Brook BW, Dahl-Jensen D, Gilbert MTP,
 465 Otto-bliesner BI, Svensson A, Theodoridis S, Wilmshurst JM, Buettel JC, Canteri E,

466 Mcdowell M, Orlando I, Pilowsky J, Rahbek C and Nogues-bravo D (2020) Using
 467 paleo-archives to safeguard biodiversity under climate change. *Science* 369: eabc5654.

468 Gammage B (2012) The biggest estate on Earth: how Aborigines made Australia. Allen and
 469 Unwin Publisher.

470 Gammage B (2008) Plain facts: Tasmania under aboriginal management. *Landscape*
 471 *Research* 33: 241–254

472 Gammage W (2005) Gardens without fences? Landscape in Aboriginal Australia. *Australian*
 473 *Humanities Review* 36: 1-7.

474 Gergis J, Eyre AE, Braganza GK et al. (2012). On the long-term context of the 1997–2009
 475 ‘Big Dry’ in South-Eastern Australia: insights from a 206-year multi-proxy rainfall
 476 reconstruction. *Climatic Change* 111:923–944

477 Gillson L, Whitlock C and Humphrey G (2019) Resilience and fire management in the
 478 Anthropocene. *Ecology and Society* 24: 14.

479 Gott B (2005). Aboriginal fire management in south-eastern Australia: aims and frequency.
 480 *Journal of Biogeography* 32: 1203-1208.

481 Green D, Singh G, Polach H, Moss D, Banks J and Geissler EA (1988) A fine-resolution
 482 paleoecology and paleoclimatology from south-eastern Australia. *Ecology* 76: 790–806.

483 Herbert AV and Harrison SP (2016) Evaluation of a modern-analogue methodology for
 484 reconstructing Australian palaeoclimate from pollen. *Review Palaeobotany and*
 485 *Palynology* 226: 65–77.

486 Hogg AG, Heaton TJ, Hua Q, Palmer JG, Turney CSM, Southon J, Bayliss A, Blackwell PG,
 487 Boswijk G, Bronk Ramsey C, Pearson C, Petchey F, Reimer P, Reimer R, and Wacker

488 L (2020) SHCal20 Southern Hemisphere calibration, 0-55,000 years cal BP.
 489 *Radiocarbon* 62: 759–778.

490 Keane RB, Ryan KC, Veblen TT, Allen CD, Logan JA and Hawkes B (2002) Cascading
 491 effects of fire exclusion in Rocky Mountain ecosystems. In Baron, J. (Eds.), *Rocky*
 492 *Mountain Futures: An Ecological Perspective*. Island Press.

493 Keith DA (2017) *Australian vegetation* 3rd edition. Cambridge University Press.

494 Kershaw P, Moss P and Van Der Kaars S (2003) Causes and consequences of long-term
 495 climatic variability on the Australian continent. *Freshwater Biology* 48: 1274-1283.

496 Kodela PG and Dodson JR (1988) A late Holocene Vegetation and Fire Record from Ku-
 497 ring-gai Chase national park, NSW. *Proceedings of the Linnean Society, New South*
 498 *Wales* 110: 317-326.

499 Lunt DI, Jones N, Spooner PG and Petrow G (2006) Effects of European colonization on
 500 indigenous ecosystems: post-settlement changes in tree stand structures in Eucalyptus-
 501 Callitris woodlands in central New South Wales, Australia. *Journal of Biogeography*
 502 33: 1102-1115.

503 Mariani M, Connor SE, Theuerkauf M, Herbert A, Kuneš P, Bowman D, Fletcher MS, Head
 504 L, Kershaw AP, Haberle SG, Stevenson J, Adeleye MA, Cadd H, Hopf F and Briles C.
 505 (in press). Disruption of cultural burning promotes unprecedented wildfires. *Frontiers*
 506 *in Ecology and the Environment*.

507 Mariani M, Fletcher M-S, Holz A and Nyman P (2016) ENSO controls interannual fire
 508 activity in southeast Australia. *Geophysical Research Letters* 43: 10-891.

509 Marlon JR, Kelly R, Danianu A-L, Vanni  re B, Power MJ, Bartlein P, Higuera P, Blarquez O,
 510 Brewer S, Br  cher T, Feurdean A, Romera GG, Iglesias V, Maezumi SY, Magi B,

511 Courtney Mustaphi CJ and Zhihai T (2016) Reconstructions of biomass burning from
512 sediment-charcoal records to improve data–model comparisons. *Biogeosciences* 13:
513 3225–3244.

514 Mantua NJ, Hare SR (2002). The Pacific Decadal Oscillation. *Journal of Oceanography* 58:
515 35–44.

516 Marx SK, Kamber BS, McGowan HA and Zawadzki A (2010) Atmospheric pollutants in
517 alpine peat bogs record a detailed chronology of industrial and agricultural development
518 on the Australian continent. *Environmental Pollution* 158: 1615–1628.

519 Matthews S, Sullivan AL, Watson P and Williams RJ (2012) Climate change, fuel and fire
520 behaviour in a eucalypt forest. *Global Change Biology* 18: 3212–3223.

521 McWethy DB, Haberle SG, Hopf F and Bowman DMJS (2017) Aboriginal impacts on fire
522 and vegetation on a Tasmanian Island. *Journal of Biogeography* 44: 1319–1330.

523 Mills K, Gell P and Kershaw P (2013) The recent Victorian drought and its impact. Without
524 precedent? March 2013, Australian Government Rural Industries Research and
525 Development Corporation RIRDC Publication no. 12/040.

526 Mistry J, Schmidt IB, Eloy L and Balbao B (2019) New perspectives in fire management in
527 South American savannas: The importance of intercultural governance. *Ambio* 48: 172–
528 179.

529 Mooney SD, Harrison SP, Bartlein PJ, Daniau A-L, Stevenson J, Brownlie KC, Buckman S,
530 Cupper M, Luly J, Black M, Colhoun E, D’Costa D, Dodson J, Haberle S, Hope GS,
531 Kershaw P, Kenyon C, Mckenzie M and Williams N (2011) Late Quaternary fire
532 regimes of Australasia. *Quaternary Science Reviews* 30: 28–46.

533 Mooney SD, Harrison SP, Bartlein PJ, Danialu AL, Stevenson J, Brownlie K, Buckman S,
534 Cupper M, Luly J, Black M, Colhoun E, D'Costa D, Dodson J, Haberle S, Hope GS,
535 Kershaw P, Kenyon C, McKenzie M and Williams N (2011) Late Quaternary fire
536 regimes in Australia. *Quaternary Science Reviews* 30: 28-46.

537 Mooney SD, Harrison SP, Bartlein PJ and Stevenson J (2012) The Prehistory of Fire in
538 Australasia. In: Bradstock RA, Gill AM and Williams RJ (Eds) *Flammable Australia:
539 Fire Regimes, Biodiversity and Ecosystems in a Changing World*, CSIRO Publishing,
540 Collingwood, pp. 3-25.

541 Mooney SD, Webb M and Attenbrow V (2007) A comparison of charcoal and archaeological
542 information to address the influences on Holocene fire activity in the Sydney Basin.
543 *Australian Geographer* 38: 177-194.

544 Mulvaney DJ and Golson J (1971). *Aboriginal man and the Australian environment*.
545 Australian National University Press, Canberra.

546 Murphy BP, Lehmann CER, Russell-Smith J and Lawes MJ (2014) Fire regimes and woody
547 biomass dynamics in Australian savannas. *Journal of Biogeography* 41: 133-144.

548 Nauslar NJ, Abatzoglou JT and Marsh PT (2018) The 2017 North Bay and Southern
549 California Fires: A Case Study. *Fire* 1: 18.

550 Overpeck JT, Webb T and Prentice IC (1985) Quantitative interpretation of fossil pollen
551 spectra: dissimilarity coefficients and the method of modern analogs. *Quaternary
552 Research* 23: 87–108.

553 Palmer J, Cook ER, Turney CSM, Allen K, Fenwick P, Cook BI, O'Donnell A, Lough J,
554 Grierson P and Baker P (2015) Drought variability in the eastern Australia and New

555 Zealand summer drought atlas (ANZDA, CE 1500–2012) modulated by the
 556 Interdecadal Pacific Oscillation. *Environmental Research Letters* 10: 124002-13.

557 Pausa JG and Paula S (2012) Fuel shapes the fire–climate relationship: evidence from
 558 Mediterranean ecosystems. *Global Ecology and Biogeography* 21: 1074-1082.

559 R Core Team (2020). R: A language and environment for statistical computing (version 3. 6.
 560 0). R Foundation for Statistical Computing.

561 Risbey JS, Pook MJ, McIntosh PC, Wheeler MC and Hendon HH (2009) On the remote
 562 drivers of rainfall variability in Australia. *Monthly Weather Review* 137: 3233-3253.

563 Royal Commission into Natural Disaster Arrangement 2020. Royal Commission into Natural
 564 Disaster Arrangement—Report. Commonwealth of Australia.
 565 [https://naturaldisaster.royalcommission.gov.au/system/files/2020-](https://naturaldisaster.royalcommission.gov.au/system/files/2020-11/Royal%20Commission%20into%20National%20Natural%20Disaster%20Arrangements%20-%20Report%20%20%5Baccessible%5D.pdf)
 566 [11/Royal%20Commission%20into%20National%20Natural%20Disaster%20Arrangem](https://naturaldisaster.royalcommission.gov.au/system/files/2020-11/Royal%20Commission%20into%20National%20Natural%20Disaster%20Arrangements%20-%20Report%20%20%5Baccessible%5D.pdf)
 567 [ents%20-%20Report%20%20%5Baccessible%5D.pdf](https://naturaldisaster.royalcommission.gov.au/system/files/2020-11/Royal%20Commission%20into%20National%20Natural%20Disaster%20Arrangements%20-%20Report%20%20%5Baccessible%5D.pdf)

568 Schmidt GA, Jungclaus JH, Ammann CM, Bard E, Braconnot P, Crowley TJ, Delaygue G,
 569 Joos F, Krivova NA, Muscheler R, Otto-Bliesner BL, Pongratz J, Shindell DT, Solanki
 570 SK, Steinhilber F and Vieira LEA (2012) Climate forcing reconstructions for use in
 571 PMIP simulations of the Last Millennium (v1.1). *Geoscientific Model Development* 5:
 572 185–191.

573 Simpson GL, Oksanen, J (2020). Analogue and weighted averaging methods for
 574 palaeoecology. <https://github.com/gavinsimpson/analogue>

575 Sullivan AL, McCaw WL, Cruz MG, Matthews S and Ellis PF (2012) Fuel, fire weather and
 576 fire behaviour in Australian ecosystems. In: Williams RJ, Gill AM and Bradstock RA

577 (Eds.), *Flammable Australia: fire regimes, biodiversity and ecosystems in changing*
 578 *world*. CSIRO Publishing.

579 Thomas A (1991) *Giandarra Bog, NSW - A Natural Record of Environmental Change*. BSc
 580 *Hons Thesis*, UNSW, Sydney.

581 Tran BN, Tanase MA, Bennett LT and Aponte C (2020) High-severity wildfires in temperate
 582 Australian forests have increased in extent and aggregation in recent decades. *PLoS*
 583 *ONE* 15: e0242484.

584 White CA, Perrakis DDB, Kafka VG and Ennis T (2011) Burning at the Edge: Integrating
 585 Biophysical and Eco-Cultural Fire Processes in Canada's Parks and Protected
 586 Areas. *Fire Ecology* 7: 74–106.

587 Whitlock C and Larsen C (2001) Charcoal as fire proxy. In: Smol JP et al. (Eds) *Tracking*
 588 *environmental change using lake sediments: terrestrial, algal, and siliceous indicators*.
 589 Kluwer Academic Publishers, Dordrecht, The Netherlands.

590 Williams AN (2013) A new population curve for prehistoric Australia. *Proceedings of the*
 591 *Royal Society B*.28020130486.

592 Williams AN, Ulm S, Turney CSM, Rohde D and White G (2015) Holocene Demographic
 593 Changes and the Emergence of Complex Societies in Prehistoric Australia. *PLoS ONE*
 594 10: e0128661.

595 Woinarski JCZ, Burbidge AA, Harrison PL (2015) Ongoing unraveling of a continental
 596 fauna: decline and extinction of Australian mammals since European settlement *PNAS*
 597 112: 4531-4540.

598
 599

600 **Supplementary material**

601 **Table1:** Sites of charcoal records drawn from the Global Palaeofire Database. For more
602 information on data and data accessibility, the following code can be used in ‘R’ after loading
603 the ‘paleofire’ package: ID=pfSiteSel(lat>-39, lat<(-28), long>140,
604 long<154,date_int<=3000).

Sites	Latitude	Longitude	References
Black Swamp	-30.02	151.48	Dodson et al. (1986a)
Boggy Swamp	-29.96	151.49	Dodson et al. (1986a)
Butchers Swamp	-29.97	151.45	Dodson et al. (1986a)
Tadpole Swamp	-38.13	145.27	-
Buxton	-37.44	145.69	McKenzie (2002)
Oaks Creek	-37.58	146.16	McKenzie (2002)
Powelltown	-37.86	145.7	McKenzie (2002)
Lake Mountain	-37.46	145.87	McKenzie (1997)
Tiger Snake Swamp	-38.13	145.27	Aitken and Kershaw (1993)
Gooches Swamp	-33.45	150.26	Black and Mooney (2006)
Sapphire Swamp	-30.03	151.56	Dodson et al. (1986)
Burraga Swamp	-32.02	151.43	Dodson et al. (1994a)
Killalea Lagoon	-34.6	150.86	Dodson et al. (1993)
Bondi Lake Centre Core	-36.8	149.93	Dodson et al. (1993)
Warrananga	-33.97	141.56	Cupper (2005)
Bobundara Swamp	-36.25	150.06	Hope et al (2006)
Kurnell Fen	-34.01	151.1	Martin (1994)
Ryans Swamp	-35.09	150.39	Radclyffe (1993)
Cotter Source Bog center	-35.96	148.81	Hope and Clark (2008)
Rennix Gap	-36.22	148.3	Hope (unpublished)
Ginini Flats	-35.31	148.46	Hope et al. (2005)
Griffith Swamp	-33.28	151	Mooney et al. (2007)
Kings Tableland Swamp_short core study	-33.73	150.48	Black (2001)
Kings Waterhole	-33.01	150.66	Black (2001)
Aire Crossing	-38.64	143.47	McKenzie and Kershaw (2004)
Bondi Lake South Core	-36.8	149.93	Dodson et al. (1993)
Lake Condah	-38.06	141.83	Builth et al. (2008)
Tea Tree Swamp Core DRA	-37.21	148.83	Gell et al. (1993)
Tea Tree Swamp Core DRE	-37.21	148.83	Gell et al. (1993)
Tea Tree Swamp Core DRN-A	-37.21	148.83	Gell et al. (1993)
Wildes Meadow Swamp	-34.62	150.51	Kodela (1996)
South Salvation Creek Swamp	-33.63	151.25	Kodela and Dodson (1988)
Bridgewater Lake Core B	-38.3	141.38	Head (1988)
Greens Bush	-38.43	144.93	Jenkins (1992)
Ingar Swamp	-33.76	150.45	Chalson (1991)
Katoomba Swamp	-33.71	150.31	Chalson (1991)
Long Swamp	-38.08	141.08	Head (1988)
Breadalbane	-34.8	149.51	Dodson (1986b)
Brooks Ridge Fen	-36.15	148.59	Mooney et al. (1997)

Burralow Creek Swamp	-33.53	150.63	Chalson (1991)
Chapple Vale Swamp	-38.62	143.32	Mckenzie and Kershaw (1997)
Club Lake	-36.4	148.31	Dodson et al. (1994b)
Notts Swamp	-33.8	150.4	Chalson (1991)
Newnes Swamp	-33.38	150.22	Chalson (1991)
Kurnell Swamp	-34.03	151.21	Martin (1994)
Worimi Swamp	-32.51	152.33	Mooney and Maltby (2006)
Blundells Flat	-35.19	148.49	Hope et al. (2006)
Warrimoo Swamp	-33.72	150.61	Chalson (1991)
Cobrico Swamp	-38.3	143.03	Dodson et al. (1994c)
Mill Creek	-33.4	151.03	Devoy et al. (1994)
Rotten Swamp Core 4	-35.7	148.88	Clark (1986)
McKenzie Road Bog	-38.43	146.76	Robertson (1986)
Micalong Swamp	-35.33	148.51	Kemp (1993)
Mulloon	-35.44	149.55	Hope (unpublished)
Snowy Flats	-35.54	148.47	Hope et al. (2005)
Yaouk Swamp	-35.49	148.5	Keaney and Hope (unpublished)
Bolin Billabong combined core	-37.76	145.06	Leahy et al. (2005)
Hogan's Billabong	-36.02	146.71	Reid et al. (2007)
Lake Hordern	-38.78	143.46	Head and Stuart (1980)
Lake Surprise	-38.06	141.92	-
Lake Tyrrell2	-35.31	142.78	Luly et al. (1986)

Table 2: Sites of pollen records.

Sites	Latitude	Longitude	Elevation (m asl)	References
Bega Swamp	-36.5167	149.5000	1080	Green et al. (1988)
Blue Lake	-36.4167	148.3167	1890	Raine (1982)
Boggy Swamp	-31.8667	151.5167	1160	Dodson et al. (1986a)
Burraga Swamp	-32.0833	151.4500	1100	Dodson et al. (1994a)
Giandarra Bog	-35.8500	148.4900	1400	Thomas (1991)
Killalea Lagoon	-34.6000	150.8700	3	Dodson et al. (1993)
Killer Bog	-32.0667	151.5500	1320	Dodson et al. (1986a)
Lake Colac	-38.3000	143.5900	152	Mills et al. (2013)
Lake Keilambete	-38.2094	142.8779	132	Dodson (1974)

605

606 References

607 Raine, J.I. (1982) Dimictic thermal regime and morphology of Blue Lake in the Snowy
608 Mountains of New South Wales. Australian Journal of Marine and Freshwater Research, 33,
609 1119–1122.

- Green, D., Singh, G., Polach, H., Moss, D., Banks, J. & Geissler, E.A. (1988) A fine-resolution paleoecology and paleoclimatology from south-eastern Australia. *Journal of Ecology*, 76, 790–806.
- Dodson, J.R. (1974) Vegetation and climatic history near Lake Keilambete, western Victoria. *Australian Journal of Botany*, 22, 709–717.
- Dodson JR, Greenwood PG, and Jones RL (1986a) Holocene forest and wetland dynamics at Barrington Tops, NSW, *Journal of Biogeography*, 13: 538-563.
- McKenzie, G.M. (2002) The late Quaternary vegetation history of the south-central highlands of Victoria, Australia. II. Sites below 900m. *Austral Ecology* 27: 32–44.
- McKenzie, G.M. (1997) The late Quaternary vegetation history of the south-central highlands of Victoria, Australia: I. Sites above 900m. *Australian Journal of Ecology*, 22: 19-36.
- Aitken, DL and Kershaw AP (1993). Holocene vegetation and environmental history of Cranbourne Botanic Garden, Victoria. *Proceedings of the Royal Society of Victoria*, 105(1):67-80.
- Black, M. P. and Mooney, S.D. (2006). Holocene fire history from the Greater Blue Mountains World Heritage Area, NSW, Australia: The climate, humans and fire nexus. *Regional Environmental Change*. 6: 41-51
- Dodson JR, Roberts FK, and De Salis T (1994a) Palaeoenvironment and human impact at Burruga Swamp in montane rainforest, Barrington Tops National Park, New South Wales, Australia. *Australian Geographer* 25:161-169.
- Dodson JR, McRae VM, Molloy K, Roberts F and Smith JD (1993) Late Holocene human impact on two coastal environments in NSW, Australia: a comparison of Aboriginal and European impacts. *Vegetation History and Archaeobotany* 2:89-100.
- Cupper, M.L. (2005). Last glacial to Holocene evolution of semi-arid rangelands in southeastern Australia. *The Holocene* 15, 541-553.
- Hope, G.S., Coddington J. and O’Dea, D. (2006) Estuarine development and human occupation at Bobundara Swamp, Tilba Tilba, New South Wales, Australia. pp 258-274. in M. Lillie and S. Ellis (ed.) *Wetland Archaeology and Environments: Regional Issues*, Global
- Martin, A.R.H., 1994. Kurnell Fen: an eastern Australian coastal wetland, its Holocene vegetation, relevant to sea-level change and aboriginal land use. *Review of Palaeobotany and Palynology* 80, 311-332.
- Radclyffe, E. (1993) Fire and people in Jervis Bay: toward a fire history in an occupied landscape. Unpublished BA Honours thesis, Department of Geography, Australian National University.
- Hope, G.S. and Clark, R.L. (2008) A tale of two swamps: subalpine peatlands in the Kelly-Scabby area of Namadgi National Park. Pp. 61-76 in eds. K. McCue and S. Lenz, *Corridors for Survival in a Changing World*. National Parks Assoc. ACT, Canberra; Jones, R

- Hope, G., Macphail, M. And Keaney, B. (2005) Snowy Flat and Ginini Bogs, Brindabella Range, Australian Capital Territory. Unpublished report to Environment ACT.
- Mooney, S. D., Webb, M. and Attenbrow, V. (2007) A comparison of charcoal and archaeological information to address the influences on Holocene fire activity in the Sydney Basin. *Australian Geographer* 38: 177-194.
- Black, M.P. (2001) Fire, vegetation, humans and climate: A record of change during the past millennium from the Kings Tablelands. Unpublished BSc Hons Thesis, School of Geography, UNSW, Sydney
- Chalson, J.M. (1991) The Late Quaternary vegetation and climatic history of the Blue Mountains, N.S.W. Australia. unpublished PhD thesis, University of N.S.W.
- McKenzie, G.M. And Kershaw, A.P. (2004) A Holocene pollen record from cool temperate rainforest, Aire crossing, the Otway region of Victoria, Australia. *Rev. Palaeobot. & Palynol.* 132, 281-290.
- Builth, H., Kershaw, A.P., White, C., Roach, A., Hartney, L., McKenzie, M., Lewis, T., Jacobsen, G. (2008) Environmental and cultural change on the Mt Eccles lava-flow landscapes of southwest Victoria, Australia. *The Holocene* 18: 413-424.
- Gell, P.A., Stuart, I.M., Smith, J.D. (1993) The response of vegetation to changing fire regimes and human activity in the Delegate River catchment, East Gippsland, Victoria, *The Holocene* 3: 150-160.
- Kodala, P.G. (1996) The vegetation of the Robertson Plateau, New South Wales: historical and contemporary issues. Unpub. PhD Thesis, UNSW, Sydney, Australia.
- Kodala, P.G. and Dodson, J.R. (1988) A late Holocene Vegetation and Fire Record from Kuring-gai Chase national park, NSW. *Proc. Linn.Soc.N.S.W.*, 110: 317-326.
- Head, L. (1988) Holocene Vegetation, fire and environmental history of the Discovery Bay region, southwestern Victoria. *Australian Journal of Ecology*, 13: 21-49.
- Jenkins, M.A. (1992) A Late Holocene vegetation record from an interdunal swamp, Mornington Peninsula, Victoria. Unpublished M.Env.Sci. thesis, Department of Geography and Environmental Science, Monash University, Melbourne.
- Dodson, J.R. (1986b) Holocene vegetation and environments near Goulburn, New South Wales. *Australian Journal of Botany*, 34: 231-249.
- Mooney, S. D., Watson, J. R. & Dodson, J. R. (1997) Late Holocene environmental change in an upper montane area of the Snowy Mountains, New South Wales. *Australian Geographer* 28: 185-200
- McKenzie, G.M. And Kershaw, A.P. (1997) A vegetation history and quantitative estimate of Holocene climate from Chapple Vale, in the Otway region of Victoria. *Australian Journal of Botany* 45: 565-581.

- Dodson, J.R., De Salis, I., Myers, C.A., and Sharp, A.J. (1994b) A thousand years of environmental change and human impact in the alpine zone at Mount Kosciusko, New South Wales. *Australian Geographer*, 25: 77-87.
- Martin, A.R.H., 1994. Kurnell Fen: an eastern Australian coastal wetland, its Holocene vegetation, relevant to sea-level change and aboriginal land use. *Review of Palaeobotany and Palynology* 80, 311-332.
- Mooney, S. D. and Maltby, E. L. (2006) A synthesis of two proxy records revealing the late Holocene fire history at a site on the central coast of New South Wales, Australia. *Austral Ecology* 31:682-695
- Hope, G.S., Stevenson, J. and Haberle, S. 2006. Palaeoecology of Blundells Flat, ACT. Unpublished report to Ecowise Services and ACT Forests.
- Dodson, JR, Frank, K, Fromme, M, Hickson, D, McRae, V, Mooney, S and Smith JD. (1994 c) Environmental Systems and Human Impact at Cobrico Crater, South-western Victoria. *Australian Geographical Studies* 32: 27-40.
- Devoy, RJ, Dodson, JR, Thom, BG and Nichol, S. (1994) Holocene environments in the Hawkesbury Valley, New South Wales: A comparison of terrestrial and marine records. *Quaternary Science Reviews* 13:241-256.
- Clark, R.L., 1986: The fire history of Rotten Swamp, A.C.T., Canberra, Unpublished Report to ACT Parks and Conservation Service, CSIRO, Canberra.
- Robertson, M. 1986. Fire regimes and vegetation dynamics: a case study examining the potential of fine resolution palaeoecological techniques. Unpubl. BA (Hons.) thesis, Dept. of Geography, Monash University, Melbourne
- Kemp, J. (1993) The end of the Pleistocene in the southern tablelands, southeastern Australia. Unpublished BA thesis, Dept Geography, ANU, Australia.
- Hope, G., Macphail, M. and Keaney, B. (2005) Snowy Flat and Ginini Bogs, Brindabella Range, Australian Capital Territory. Unpublished report to Environment ACT and Ecowise Services.
- Leahy, P.J., Tibby, J., Kershaw, A.P., Heijnis, H., Kershaw, J.S. (2005) The impact of European settlement on Bolin Billabong, a Yarra River floodplain lake, Melbourne, Australia. *River Research Applications* 21: 131-149.
- Reid, M.A., Sayer, C.D., Kershaw, A.P., Heijnis, H. (2007) Palaeolimnological evidence for submerged plant loss in a floodplain lake associated with accelerated catchment soil erosion (Murray River, Australia). *Journal of Paleolimnology* 38: 191-208.
- Head, L. and Stuart, I.M.F. (1980) Change in the Aire-Palaeoecology and Prehistory in the Aire Basin, Southwestern, Victoria. *Monash Publications in Geography*, no.24:1-97.

756 Luly, J.G., Bowler, J.M. and Head, M.J. (1986) A radiocarbon chronology from the playa La
757 ke Tyrrell, northwestern Victoria, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecol*
758 *ogy* 54:171-180; Luly, J.G. (1993) Holocene palaeoclimates and environment.
759

760

761