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Historic archives are critical for reconstructing the nature and distribution of lowland temperate grasslands in south–eastern Australia

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Abstract: The functional relationships between woody vegetation, climate, soils and disturbances like fire are complex and vary greatly between continents due to historical and environmental differences. In the temperate grasslands of lowland south–eastern Australia, it is hypothesised that the extent of treelessness was influenced by Aboriginal burning practices, although this remains highly contested. This study reconstructed a multi–bioregional–scale grass/tree boundary map across a large portion of central and northern Victoria from hundreds of historic plans, overlayed with the georeferenced observations of the earliest European accounts to test whether these grasslands were (a) more extensive than previously assumed, and (b) if there is evidence of the targeted, purposeful and frequent use of fire by Aborigines. The archival coverage was well–corroborated and identified extensive treeless 'plains' in unexpected areas compared with reconstructions based on climate–edaphic relationships alone. The historic accounts also served to shed light on the original nature of these treeless 'plains' as diverse and dynamic, and frequently dominated by Kangaroo Grass (*Themeda triandra*), implying a distinct influence of both frequent fire and people. However, while there is evidence of broad–acre Aboriginal fires in the collective historic accounts (including resistance to European intrusion), there remains a need for more in–depth and reliable historic case studies to clearly describe the use of fire by Aborigines that is inferred in the historic accounts studied here and commonly assumed by historians. The results lend support to treelessness driven by the dynamic interaction of 'bottom–up' and 'top–down' processes and that lowland temperate grassland distribution reconstructions across this region should be extensively corroborated or even derived exclusively from historic sources.

Keywords: historic archives, temperate grasslands, vegetation reconstruction, Aboriginal burning, 'bottom–up' and 'top–down' processes

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Introduction

At the global scale, terrestrial biome distribution is primarily driven by abiotic ('bottom–up') controls such as light, temperature, precipitation and potential evapotranspiration (Whittaker 1975; Polis 1999; Bond 2008). Grasslands and savannahs, which often have the climate potential to support woodlands and forest, are considered a major exception with biotic ('top–down') controls such as herbivory and/or fire exerting a major influence on their distribution (Bond *et al.* 2003, 2005; Bond 2005, 2008; Sankaran *et al.* 2005, 2008). However, the functional relationships between woody vegetation, climate and disturbances like fire are complex and vary greatly between continents due to historical and environmental differences (Lehmann *et al.* 2014). Non–linear thresholds and tipping–point interactions are particularly important (House *et al.* 2003), with some regions switching from being 'climate–dependent' to 'disturbance–dependent' ecosystems depending on rainfall (Sankaran *et al.* 2005, 2008; Hirota *et al.* 2011; Ratajczak and Nippert 2012; Van Nes *et al.* 2012). In Australia, this rainfall threshold varies between climate zones and, in the temperate south–east (>400 mm per annum), it is hypothesised that treelessness is controlled by the complex spatio–temporal interaction of 'bottom–up' and 'top–down' processes such as anthropogenic (Aboriginal) fire (see Foreman 2016). However, little is known of the original fire regimes in this region, and the impacts of Aboriginal fire on broader ecosystem change remains highly contested (Bowman *et al.* 2012), and poorly studied due to the limited range of research strategies (Lunt 2002).

Although there is evidence that Aborigines manipulated fire regimes (e.g. Clark 1983; Hallam 1989; Fensham 1997; Bowman 1998; Lunt 1998; Gammage 2011), a critique of the regional historic records underpinning popular 'grand' historical narratives reveals few unambiguous or direct observations (e.g. Stockton 1982; Bowman and Brown 1986; Fensham 1997; Cahir *et al.* 2016; Cahir & McMaster 2018). It is argued that interdisciplinary research integrating the physical (biophysical/ecological models) and social (anthropological/historical records) aspects of fire ecology and phytoecology promises to shed light on such debates (Swetnam *et al.* 1999).

The first step in this process must be to reconstruct an accurate picture of the extent and nature of lowland, temperate grasslands using the historic archives. Century–scale reconstructions of vegetation have become a common means of historic benchmarking used to systematically describe patterns of land–use change (e.g. Mills 1988; Fensham 1989; Fensham and Fairfax 1997; Brown 1998; Batek *et al.* 1999; Bickford and Mackey 2004; Bollinger *et al.* 2004; He *et al.* 2007). Reconstruction primarily involves the spatial interpolation over 'cleared' areas (or non–native vegetation cover; see Thackway and Lesslie 2006) based on resilient vegetation refugia, climate–edaphic models and expert opinion (e.g. Moore 1953; Costin 1954; Connor 1966; Croft 1999; Knight 2002; Parkes *et al.* 2003; Keith 2004). However, many studies are not well validated or corroborated by the historic archives (e.g. Lunt 1998). When historic data is used, it is often based on broad–scale historic plans (e.g. Woodgate and Black 1988 derived from on Everett 1869; also see Hoddle 1853), or restricted to particular areas that happen to have been intensively researched (e.g. Foreman 1996; Lunt 1997; Sinclair and Atchison 2012), or sophisticated bioregional hybrid reconstructions that use contemporary data to fill gaps in the available historic coverage (e.g. Fensham 1989; Fensham and Fairfax 1997; Bickford and Mackey 2004). Nevertheless, most broad–scale reconstructions used by provincial and national authorities to derive land–use change data that informs policy (e.g. Victorian pre–1750 'ecological vegetation classes' or EVCs in Parkes *et al.* 2003 and the Australia's "Native Vegetation Information System" NVIS 2018; also see Morgan *et al.* 2017) are highly fragmentary in terms of historic corroboration. While this may not be an issue for many ecosystems, for grassy biomes, where the influence of often dynamic 'top–down' processes are significant, century–scale change may have been enormous.

Broad–scale thematic reconstructions based primarily or exclusively on historic records have been attempted when targeting particular habitats or features that were finely mapped by early surveyors (e.g. saltmarsh: Bromberg and Bertness 2005; estuary: Van Dyke and Wasson 2005; wetland: Gimmi *et al.* 2011; grassland: Cousins 2001). The economic importance of native grasslands to the early European colonies of south–eastern Australia suggests that the vast archival resources, newly digitised, represent a promising candidate case study of century–scale land–use change, and for testing *a priori* assumptions around 'bottom–up' (e.g. soils) and 'top–down' (e.g. fire) processes.

This paper constructs a multi–bioregional composite grass/tree boundary map across a large portion of lowland Victoria from systematic interpretation of early survey plans and by georeferencing the routes taken and observations recorded by early European settlers and explorers (see methods in Fensham 1997; Fensham and Fairfax 2007; Silcock *et al.* 2013; Silcock 2014; Silcock and Fensham 2019). As part of a multi–disciplinary approach, this paper considers tests for two of the original nine hypotheses advanced by Foreman (2016): #1 – Corroborated historic records of grasslands in areas where trees are expected (>400mm per year), and; #9 – Historic records of targeted, purposeful and frequent use of fire by Aborigines.

In particular, the study aims to: (1) compile a multi–bioregional–scale historic grass/tree boundary composite map of treeless 'plains' (grasslands) from fine–scale historic plans; (2) corroborate the authenticity and accuracy of grass/tree boundaries with multiple independent historic sources; (3) show that the grasslands occur in areas where trees are expected; (4) compile a description of the structure and floristic composition of historic 'plains'; (5) discuss why the results are likely applicable more widely in lowland south–eastern Australia; (6) discuss how anomalies in grassland distribution may in part be due to Aboriginal burning and how this could be tested; and (7) assess for evidence of the targeted, purposeful and frequent use of fire by Aborigines.

Methods

Study Area

The lowland, mesic grasslands of south–eastern Australia occur in a broadly temperate region with a mean annual precipitation of 400–1,000 mm, comprising the Tasmanian lowlands, much of the Victorian lowlands, the Southern Tablelands and inland slopes of NSW and the Australian Capital Territory (<1,000 m ASL), and parts of the Mount Lofty Ranges in South Australia (see Foreman 2016). The focus in this paper is central Victoria, north of the Great Dividing Range, which lies mostly within the Victorian Riverina, Victorian Volcanic Plains (VVP) and Wimmera sub–bioregions (www.environment.gov.au). These regions have an elevation range of sea level to 700 m ASL and all three comprise flat and fertile mostly arable plains in mesic zones that have long been intensively developed for agriculture (Figure 1). The Riverina is predominantly a higher level flood plain of fluvial and lacustrine sediments including channel sands, levee banks of fine sandy clay and far floodplain clays created by Holocene to Pliocene (5 MYBP) palaeochannels intersected by active floodplains associated with modern watercourses. The VVP comprises newer cinder/scoria cones and lava flows of Holocene to Miocene origin (8.5 MYBP) plus numerous alluvial floodplains, lake deposits and scattered inliers of older sedimentary rocks (up to 490 MYBP). The Wimmera comprises a complex range of Holocene to Miocene fluvial and aeolian landscapes with strands of active alluvium associated with modern major watercourses; and higher level mostly very flat floodplain clays, and extensive subdued dunes, swales and sand plains, and some more developed aeolian dunes.

Historic grass/tree boundary mapping

A bioregional–scale historic grass/tree boundary map was created from over 500 historic plans (80% from the 1850's–1860's; earliest: 1843) with some reference to natural and cadastral features, and vegetation patterns. They were sourced from the 'Historical maps and plans collection series' held at the State Library of Victoria and the Public Records Office of Victoria, including: GOULB (River), MURRAY (River), Parish maps of Victoria, Agricultural Areas (AA), Pastoral Runs (RUN), Sydney Plans (SYDNEY), Geodetic Squares (GEOSQ), Feature Plans (FEATR), New Roads (NR), Pre–emptive Rights (PR), Sale Plans (SALE), and Proclamations (other) (PROC). Mapping resolution varied from fine (≤1:30,000; 16% of maps), to intermediate (>1:30,000 to 1:50,000; 48%), and broad (>1:50,000; 12%), with no scale given for the balance (23%).

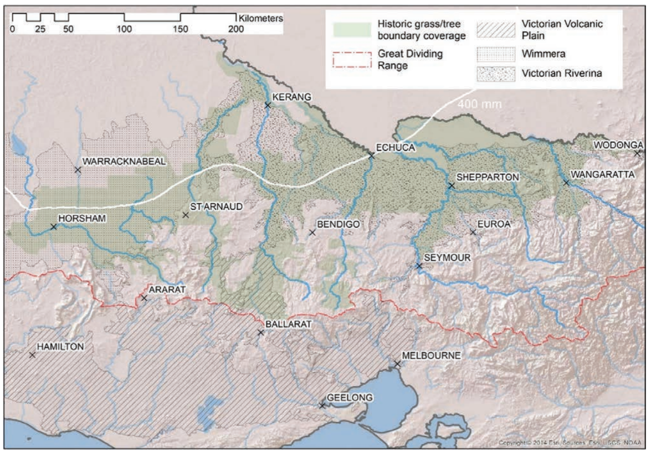

Fig. 1. Historic grass/tree boundary Study Area coverage across large portion of central and northern Victoria.

The plans were georeferenced in ArcGIS using the cadastre, rivers/creeks, hills and other prominent landscape features, and a composite vector layer was generated by manually digitising relevant vegetation boundaries, and polygons attributed by annotation, source plan and a grass/tree classification: (1) presence of 'plain', (2) absence of 'plain' (i.e. types other than grassland), and (3) Not specified, available or assessed. Both the 'plains' presence and absence categories were assigned a confidence level of (Yes) likely, or (Yes?) 'ambiguous–but–likely' and/or a 'grass/tree ecotone or mosaic'. In many cases, the grass/tree boundaries were explicit on the plans and, where absent, they were interpolated from the spatial arrangement of annotations. Those most frequently associated with grassland included: '*Plain*', '*Open Plain*', '*Grassy Plain*'; and for treed areas: '*Box Forest*', '*Open Forest*', '*Timbered with Box & Gum*'.

Confidence that the derived line work represented real grass/tree boundaries comes from the necessary intent of surveys, and corroboration with independent historical sources (especially the journals of explorers, overlanding pastoralists and other pioneers; e.g. Hawdon 1952; Mollison 1980; Clarke 1988; Mitchell 1838). It was the task of early surveyors to describe the "q*uality*.... [and] *features of the country*... *as accurately as possible*... [including] *the coastline, rivers, streams, ranges and* ***other natural lines of country***" so that people attending land sales in Sydney, Melbourne or London had some understanding of what they were buying (Jacoby and Benwell 1989). It is possible the "*lack of... intensive natural features in Australia*" (c.f. England; Jacoby and Benwell 1989), and the fact that these pasture–lands were at the centre of the colony's early economic boom, further encouraged recording of grass/tree boundaries.

Open grassy 'plains' were distinctive and very important natural features of the landscape in these early times, especially where discrete grassland patches punctuated a dominant matrix of forest or woodland. Over 80% of the 'Pre–emptive Rights' established after 1838 in the Loddon, Rodney, Murray and Goulburn districts (Jacoby and Benwell 1990) shows proximity to such 'plains' as well as major water sources. The geography of these 'plains' was often corroborated between multiple plans – different series, dates and surveyors – and they were often given Aboriginal and/or European names. To illustrate, a section of the Goulburn Valley Highway near Murchison today passes through 'Raleigh's Plain', an area independently described – with progressively more detail – on four occasions between 1824 and 1863. Firstly, Bland's account of Hume and Hovell's 1824–25 expedition to Port Phillip (Hovell and Hume 1831; December 26, 1824) mentions 'Esthers Plains' on the Goulburn River around present day Nagambie. Secondly, Mitchell's journal on October 9, 1836 neatly captures the variegated grass/tree nature of this part of the Mid–Goulburn valley. Thirdly, one of the first formal surveys in the region (GOULB 22; Wedge 1851) annotates the boundary of 'Raleigh's Plain' with tree–like symbols. And fourthly, in one the area's first parish plans (Dargalong and Molka; Downey 1863), the boundary of this 'plain' is more precisely depicted with a dotted line representing the *'margin of forest and plain'*, with the annotations '*Open Plain, Good Soil*'; and '*Box Forest*', '*Open Box Forest*', '*Medium* [and] *Good Agricultural land*' respectively inside and out (see Fig. 6 in Foreman 2016).

Corroborated records of grasslands and evidence of the targeted, purposeful and frequent use of fire by Aborigines from historical journals

Corroboration of this historic grass/tree boundary map was tested with journals of select early Europeans (1824 to 1843), comprising: two explorers (Hovell and Hume 1831; Andrews 1981; Mitchell 1838), three overlanders (Hawdon 1952; Walker 1838; Mollison 1980) and G.A. Robinson, the Chief Aboriginal Protector (Presland 1977; Clark 1988; 2014) (Table 1; Figure 2). These accounts represent the earliest published records for the region, and provide enough relevant detail for reliable georeferencing. This process was often aided by detailed local knowledge of the landscapes and environments traversed. The route and observation points for the eight journals were plotted using Google Earth based on distances, directions, and references to distinctive (often named) landmarks, features and milestones; expedition maps subsequently prepared by cartographers; and other contemporary interpretations that included corrections of apparent minor errors (e.g. Eccleston 1988).

The observations and remarks extracted from journals fell into six categories: (1) broad vegetation type; (2) contact with Aboriginal people/activity and proximity to major water sources; (3) presence of fire (including: Scale, Ignition, Age, Purpose and Vegetation); (4) presence and/or traditional use of tuberous plants; (5) Climate data (rain and lightning); and (6) 'plains' species, including saltbushes. Spatial precision fell into two categories – high to moderately precise observations at route points, and high to low precision remote observations. The vast majority of the observations were route points that were confidently georeferenced to within a 300 m – 3 km radius (~90%). Better precision was possible for some remote observations that referred to prominent known peaks or other spatially exact features. As grass/tree boundaries were important natural features in their own right, in many areas the boundaries recorded by early surveyors were also used to guide georeferencing in so far as was consistent with all other landmarks, features and milestones.

Recorder	*Type*	*Year*	*No. Days*	*No. Obs.*	*Observations of 'plains'*							*Reference*
					%Tot. Obs.	%Tot. Plains	(1)	(2)	(3)	*Map Tot.*	Map Corr. Adj.	
Mitchell	Explorer	1836	122	464	27	41	71%	14%	15%	*100%*	*81%*	Mitchell 1838
Robinson	Protector	1843	23	127	7	15	81%	15%	4%	*100%*	*93%*	Clark 1988
Robinson	Protector	1840	62	265	16	14	59%	39%	2%	*100%*	*82%*	Presland 1977
Walker	Overlander	1837	21	180	11	11	67%	15%	18%	*100%*	*77%*	Walker 1838
Hawdon	Overlander	1838	43	76	4	8	68%	24%	8%	*100%*	*84%*	Hawdon 1952
Mollison	Overlander	1837	164	258	15	7	50%	50%	0%	*100%*	*75%*	Mollison 1980
Hume & Hovell	Explorer	1824/25	53	250	15	2	100%	0%	0%	*100%*	*100%*	Hovell & Hume 1831; Andrews 1981
Robinson	Protector	1841	20	80	5	1	100%	0%	0%	*100%*	*100%*	Clark 2014
TOTAL	–	–	**508**	**1,700**	**100**	**100**	**74%**	**20%**	**6%**	***100%***	***89%***	

Table 1. Comparison of georeferenced journal records with the historic grass/tree boundary map covering a large portion of central and northern Victoria; The records were classified as follows: (1) corroboration between journal and map observations; (2) overlooked (mapped 'plains' apparently passed over and not recorded in journals); (3) error ('plains' observed in journals, but mapped as other vegetation types). The error component can be attributed to errors associated with both the journal observations and the historic grass/tree boundary map. An adjusted corroboration value was calculated by allocating a proportion of the overlooked to the corroborated value based on the corroboration proportion (e.g. TOTAL: 74 + [0.74x20] = 89).

The broad vegetation type category was further divided into (1) presence of 'plain', (2) absence of 'plain', and (3) vegetation type not mentioned or available. Consistent with the frequent delineation of grass/tree boundaries in the early survey plans, the designation of 'plains' from the journals occurred when abrupt transitions were noted or implied, typically from woodland/open forest to 'open plains' or 'downs'. The following example from G.A. Robinson provides a typical illustration: *"When leaving this forest belt, and opening out upon the plain, the change of scene was delightfully pleasant. Where Mr Hutton's house stands is a beautiful sight, with extensive plains* *before it"* (January 24, 1840; Presland 1977). However, the journals often also reflect the complex, variegated nature of the vegetation within these 'plains': *"the soil very rich, and well clothed with grass, with very few trees, certainly with no more than required for ornament, and they are not the gums, but wattles (mimosa of different kinds, forest oaks) honey–suckles (banksia), &c., and a great portion, is totally devoid of trees"* (May 27, 1837; Walker 1838). Where ever there was reasonable context from previous or later passages, 'plains' where sometimes interpreted from ambiguous phrases such as 'covered with thick pasture'. Mitchell (1838) repeatedly uses expressions like "*naturally adapted for agriculture…. and ready to receive the plough… or to depasture stock*" as a kind of euphemism for grassy, flat areas with little to no tree cover – areas widely regarded then as the 'best' agricultural land. 'Not mentioned' signified where classification could not be supported or where there was no clear reference to vegetation.

All fire records were classified as follows. (1) Scale: (i) Small/point, (ii) Broad–acre, (iii) Unknown. (2) Ignition (Broad–acre): (i) Non–anthropogenic Wildfire (lightning), (ii) European, (iii) Aboriginal, (iv) Unknown. (3) Age: (i) Current, (ii) Recent, (iii) Old. (4) Purpose: (i) Reaction to Europeans, (ii) Traditional, (iii) Unknown, (iv) European, (v) N/A (non–anthropogenic). (5) Vegetation: (i) 'Plain'/ grassland, (ii) Other type, (iii) Unknown. Small/point fires created by Aborigines included domestic camp fires, ovens, fire–making techniques, ceremonial fire, burials, smoke signals, and burning game from trees. Reaction to Europeans included burning buildings and igniting vegetation as an act of 'frontier guerrilla warfare' to frighten, intimidate or retaliate against Europeans (see examples in Fensham 1997; also see Reynolds 1982, 1987). Unknown purpose was used where–ever it was difficult to classify broad–acre Aboriginal burning as traditional practices.

Comparison with past reconstructions and inverse texture effect (rainfall) threshold

The Victorian state wide 'Plains Grasslands and Chenopod Shrublands' pre–1750 EVC reconstruction comprises 10 EVC units, aggregates and mosaics, covering nearly 20,000 km^2, over 15 sub–bioregions (see Parkes *et al.* 2003; https://www.environment.vic.gov.au/). This layer was compared with both the historic grass/tree boundary map and the inverse texture effect 'threshold' for south–eastern Australia (mean annual rainfall >400 mm; Fensham *et al.* 2015) to determine the extent to which corroborated historic grasslands occur in areas where trees are expected. According to the inverse texture effect, woody cover is predicted to be higher on clay–rich soils (topsoil >40% clay) in the mesic areas of southern Australia because of their superior moisture–holding capacity and fertility (c.f. sandy soils), while in xeric environments, clay–rich soils tend to support less woody cover because of their water–retentive properties (i.e. soil water potential is extremely negative when soil moisture is low).

Bureau of Meteorology weather station monthly rainfall data was used to model a baseline, long–term mean annual rainfall surface across Victoria. The 2,287 Victorian weather stations were filtered to 691 (≥50 years of data since records began) and an inverse distance weighted (IDW) raster surface interpolated in ArcGIS with an output cell size of 0.112 ha (33.5 m^2). Similarly, a raster surface with the same output cell size was created from the historic grass/tree boundary mapping and combined with the rainfall raster generating >26.4 million cells covering a total area of >29,600 km^2 (excluding all areas where vegetation type was not mentioned or available). The results were plotted as the number of cells where 'plains' were present (grassland) or absent (woodland/other) by long–term mean annual rainfall (Figure 3).

Results

Historic grass/tree boundary mapping and corroborated records of grasslands

The historic grass/tree boundary map extended over ~33,400 km^2 of central and northern Victoria, spanning from near Horsham in the west to Wodonga in the east (nearly 15% of Victoria). The mapped region was mostly on Victoria's Northern Plains (75% of the Victorian Riverina, 79% of the Murray Fans and 37% of the Wimmera sub–bioregions), but also in the alluvial valleys and plains transecting the Goldfields (31%), the fringing slopes and low ranges associated with the Northern Inland Slopes (25%) and northern extensions of the VVP (6%; Figures 2 & 3). About a quarter of this coverage (~8,530 km^2, 26%) was classified as 'plain' or grassland, within a woody matrix characterised as predominantly 'variegated' (60–90%) or 'fragmented' (10–60%) (rather than 'relictual' <10%; McIntyre and Hobbs 1999). The highest proportion of grasslands occurred in the VVP, Wimmera and Victorian Riverina sub–bioregions (in decreasing order – 63% to 32%; Table 2).

Between the eight selected earliest accounts, a total of 1,700 observations over 508 travel days were georeferenced, mostly covering the Hume Highway (out bound) and Northern Plains (in bound) corridors established by Mitchell (1838). On average, the historic observers corroborated the existence of 'plains' in the historic grass/tree boundary mapping 74% of the time. The average rates of apparently overlooked and erroneous 'plains' records were respectively 20% and 6% – with the adjusted average corroboration rate, 89% (Table 1).

Comparison with past reconstructions and inverse texture effect (rainfall)

The comparison with Victoria's pre–1750 grassland EVC reconstruction reveals extensive areas of unexpected grassland insofar as they were outside areas previously mapped (>5,380 km^2, or 63% of the total historical 'plains' coverage). The area of overlap (37%) was almost entirely in the lower rainfall portions of the Wimmera and Victorian Riverina, while there were extensive 'new' grassland areas both west and east of the Campaspe River. In the west, these areas extended the known grassland regions south into the mid to upper valleys of the Wimmera, Avon/Richardson, Avoca, Loddon and Campaspe Rivers. In the east, an extensive network of discrete and sometime large 'plains' were mapped over the Corop Lakes region, and in the lower to mid valleys of the Goulburn, Broken/Boosey, Ovens/King and Murray systems. Two particularly large anomalies occurred on newer volcanic plateaus in the Upper Campaspe and in the Upper Loddon ('Moolort Plains'). Conversely, areas of pre–1750 grassland not supported by the historic mapping were widespread (>1,620 km^2 or 34% of the total pre–1750 grassland EVC reconstruction) but restricted to the lower rainfall west and north–west. Almost all of the 'new' grasslands occurred where mean annual rainfall exceeds 400 mm, in apparent contravention of the 'inverse texture effect' (see Discussion; Fensham *et al.* 2015) (Figures 2 & 3).

The rainfall raster analysis showed the clear dominance of woodland/other vegetation rising sharply in regions with >400 mm mean annual rainfall. While grassland was most dominant in regions receiving <400 mm, it was still consistently present in higher rainfall regions. The mean proportion of grassland cells was 19.96% between 425 and 800 mm, although confidence declined above ~650 to 700 mm where historic maps were less available (Figure 3).

	Historic Mapping(ha) =	**Total**	**'Plains'**	**'Plains'**	**'Plains'**	**Other, N/A**	**–**	**%Matrix (Woodland)**	**%'Plains'**
	Pre–1750 Reconstruction(ha) =	**–**	**–**	**Other 'New'**	**Grassland Overlap**	**Grassland Error, N/A**	**Grassland**		
Victorian Sub–bioregions	Central Victorian Uplands	77,609	13,203	13,203	–	–	–	75%	25%
	Goldfields	408,186	28,911	28,888	24	1	25	90%	10%
	Greater Grampians	4,279	–	–	–	–	–	N/A	N/A
	Lowan Mallee	2	–	–	–	–	–	N/A	N/A
	Murray Fans	344,532	36,574	35,552	1,022	5,052	6,074	89%	11%
	Murray Mallee	70,248	13,107	12,086	1,021	2,638	3,659	79%	21%
	Northern Inland Slopes, Upper Slopes	140,824	4,070	3,768	302	309	611	97%	3%
	Victorian Riverina	1,412,863	411,751	213,990	197,761	65,367	263,128	68%	32%
	Victorian Volcanic Plain	144,263	81,596	79,295	2,301	388	2,689	37%	63%
	Wimmera	742,655	264,056	151,792	112,265	88,902	201,167	59%	41%
	Grand Total	**3,345,462**	**853,269**	**538,574**	**314,695**	**162,658**	**477,353**	**71%**	**29%**
		–	26%	16%	9%	5%	14%	–	–

Table 2. Breakdown of historic grass/tree boundary mapping by Victorian sub–bioregions, 'plains' classification and the Victorian pre–1750 EVC grasslands reconstruction. Highlight shows extensive 'new' grasslands identified in the historic mapping.

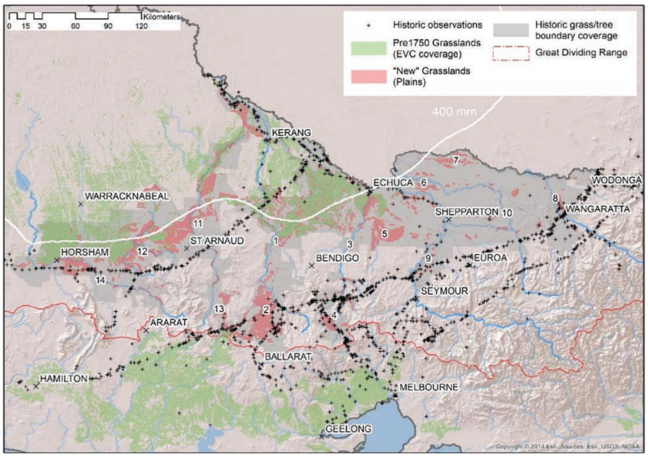

Fig. 2. Historic grass/tree boundary mapping across central and northern Victoria overlayed with the pre–1750 grassland EVC reconstruction (green) and all georeferenced historic observations; Total extent of historic mapping (dark grey) and 'new' historic grasslands (red) in unexpected regions denoted by river basins: 1 Mid Loddon, 2 Upper Loddon ('Moolort Plains'), 3 Mid Campaspe, 4 Upper Campaspe, 5 Corop Lakes, 6 Lower Broken/Goulburn, 7 Mid Murray, 8 Lower Ovens, 9 Mid Goulburn, 10 Mid Broken/Boosey, 11 Mid Avoca, 12 Avon/Richardson, 13 Upper Avoca, 14 Mid/Upper Wimmera.

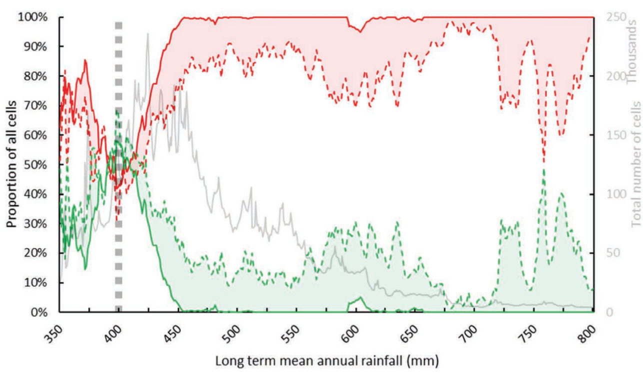

Fig. 3. Plot of raster grid cells of treeless 'plains' or grasslands (green) and woodland or other woody dominated vegetation types (red) as derived from (1) Pre–1750 EVC reconstruction ('Plains Grasslands and Chenopod Shrublands' – solid lines) and (2) historic grass/tree boundary mapping (dashed lines) across central and northern Victoria verses long term mean annual rainfall (mm). Secondary axis shows total number of cells (grey solid line) and all lines are fitted trendlines (2 point moving average). Graph shows the dominance of woodland/other vegetation types >400 mm but the consistent presence of some grassland throughout mesic regions. Shading denotes significant under and over estimates of grassland and woodland respectively in the EVC reconstruction c.f. the historic mapping.

Nature of historic plains and species observations

Although the vast majority of the historic observations provide brief and often ambiguous passing reference to grasslands, some make specific mention of the structure, spatial patterning, dynamics and botanical composition of the 'plains' at this early time. A list of 111 plant records was compiled from 60 observations that could be directly linked to 'plains.' Murnong or Yam Daisy (*Microseris* spp.) was the most frequently recorded geophyte, but there were many others including taxa from Asphodelaceae (incorporating *Caesia, Bulbine, Dianella* and *Tricoryne*), Orchidaceae (*Caladenia, Diuris,* and *Pterostylis*) and Colchicaceae (*Burchardia* and *Wurmbea*). Kangaroo Grass (*Themeda triandra*) was the most frequently noted tussock grass, and while various others were mentioned, it is difficult to be sure of either genus or species (possibly *Austrostipa* spp. and *Poa* spp.). These were followed by a range of small trees, herbs, shrubs, (saltbushes in the drier north), and larger sometimes readily identified trees (Table 3). This modest historical list, derived from scattered observations, could easily be expanded with further assessment of the historic record (both elsewhere in the region and from later decades), but it will suffice to draw out some significant patterns and to provide a sense of what the first Europeans actually saw in these environments.

Most of these flora observations were clustered in three regions: the relatively mesic Upper Campaspe (in the vicinity of Redesdale); the Upper Loddon plains (between Moolort and Creswick); and the drier Northern Plains region (south–west of Pyramid Hill) (see Figure 2), and it is useful to contrast each to highlight ecological patterns.

The overlander Mollison (1980) first visited the Upper Campaspe Plains in July 1837 and G.A. Robinson in January 1840 (who also recorded the testimonies of pastoralists, Hutton and Munroe, from previous winters; Presland 1977). Approaching from the east in wet conditions, Mollison describes a 'plain' on an elevated volcanic tableland, firstly dominated by gilgai soil and then another of "*better appearance and firmer ground*". But rather than being dominated by tussock grasses, both Mollison and Robinson report the abundance of *Microseris*: "*these plains abound with the root called by the natives at Port Phillip, 'Murnong'*", "*Mr. Munro said there were millions of murnong or yam, all over the plain* [in July 1838]", and "*Mr Hutton said* [in winter 1838/9] *the ground yielded abundance of roots (murnong).*" In contrast, Robinson's summer observations of the same area refer to "*verdant pasture*", the great abundance of "*Anthistiria or oat grass* [*Themeda triandra*]..... *all over the country*", interspersed with flowers: "*a carpet of blue there, one of yellow and again of white; the buttercups had a fine appearance*." In composite, these records paint a picture of a highly dynamic landscape apparently dominated in the cool–season by a geophyte (and the apparent absence or paucity of grasses) and later succeeded by the summer–active (C4) Kangaroo Grass and a variety of interstitial, spring and summer wildflowers. Given that this picture appears to have been reported over three seasons in succession (1837–39), frequent (pre–cool–season) burning provides the most likely functional explanation consistent with the evidence. This description is further supported by the first overlander to retrace Mitchell's route across the Upper Campaspe Plains in May 1837, T. Walker (1838), who noted near Redesdale that: "*over most of* [the plain] *the grass has been lately burnt, which gives It a barren, naked, black, and unpleasant appearance; but in spring it must look very well, as there is evidently a tolerable sward of grass*."

A similar picture emerges for the Upper Loddon (volcanic) Plains when visited by G.A. Robinson in February and March 1840 (Presland 1977), and earlier Mitchell (1838) outbound in September 1836. This much broader volcanic landscape was also variegated, but with numerous distinctive 'bare' (treeless) scoria cones. Importantly, it was also only during summer that they noted 'plains' dominated by *Anthistiria* or Kangaroo Grass. On a number of occasions Robinson notes "*herbs amongst the grass*" and in at least one place "*a dominant shrub.. myrtle*" (possibly *Calytrix tetragona*). Other shrubs and subshrubs noted elsewhere included *Discaria pubescens*, *Rhytidosporum procumbens* and *Acacia paradoxa* or *A. acinacea*. In places Robinson noted that interstitial herbs were so abundant the "*plains were mottled or carpeted with flowers in full blossom; patches of 1 to 2 acres of everlasting flowers, and patches of an acre or more of yellow ditto, and other patches of [ ] or the beautiful blue flower*." The herbs noted included Murnong (*Microseris* spp.), *Pelargonium rodneyanum* and the terrestrial orchids *Caladenia dilatata* and *Diuris aurea*.

Recorder	***Life–form (see details below)***									
	Tree	Small Tree	Parasite	Shrub	Halophyte	Tussock Grass	Root/ Geophyte	Herb (Forb)	No. of Life–forms	**Grand Total**
Hawdon 1838	–	1	–	1	1	2	1	–	(5)	**6**
Hume and Hovell 1824	–	–	–	–	–	2	–	1	(2)	**3**
Mitchell 1836	–	1	–	6	1	5	12	1	(6)	**26**
Mollison 1837	–	–	–	–	–	–	2	–	(1)	**2**
Robinson 1840	7	10	–	2	–	14	11	11	(6)	**55**
Robinson 1843	3	6	1	–	5	4	–	–	(5)	**19**
Grand Total	**10**	**18**	**1**	**9**	**7**	**27**	**26**	**13**	**(8)**	**111**

Table 3. Breakdown of direct grassland ('plains') flora observations in early historic accounts across a large portion of central and northern Victoria. Shows the high frequency of Tussock Grasses like Kangaroo Grass (*Themeda triandra*; 15 records) and Root/Geophytes like Yam daisy or 'Murnong' (*Microseris* spp.; 14 records).

Life–form	Historic reference	Putative Latin names
Tree	'Box, gums, stunted gum, stringybark, peppermint'	various *Eucalyptus* spp.
Small Tree	'Blackwood'	*Acacia melanoxylon*
	'Hee Oak'	*Allocasuarina luehmannii*
	'She Oak'	*A. verticillata*
	'Pine Trees'	*Callitris* spp.
	'Cherry Tree'	*Exocarpos cupressiformis*
	'Honeysuckle'	*Banksia marginata*
Parasite	'pendant in the branches of Hee oak'	*Lysiana exocarpi, Muellerina eucalyptoides or Amyema* spp.
Shrub	'Mimosa, wattle, or yellow–wreathed acacia'	*Acacia* spp., *A. paradoxa*, *A. acinacea*
	Campylanthera ericoides	now *Rhytidosporum procumbens*
	Discaria australis	now *D. pubescens*
	'Myrtle'	possibly *Calytrix tetragona*?
	other 'small bushes scattered over the plains'	Unknown
Halophyte	'Banilla'	*Chenopodiaceae incl. Atriplex* spp.; Maireana spp.
	Pigs face'	*Disphyma crassifolium, Carpobrotus* spp. or *Sarcozona praecox*
	'Salsuginous' plants	various families
Tussock Grass	'*Anthisteria* or oatgrass'	*Themeda triandra*
	'an *Andropogon* allied to *A. bombycinus'*	probably *Cymbopogon obtectus*, last coll. 1887
	'long forest grass'	possibly *Poa labillardierei*
	'wiry grass'	possiby *Austrostipa* spp.
	'thickly grassed' or 'Rib–grass'	*Poaceae* spp.
Root/Geophyte	'Murnong… yams… small root of the cichoraceous plant tao usually found growing on the plains with a bright yellow flower…. yellow with the flowers of the cichoraceous plant tao whose root small as it is constitutes the food of the native women and children'	*Microseris* spp. incl. *M walteri*
	'Turrac, a small tuberous root eaten by the natives, having a red flower resembling a geranium'	*Geranium* spp. or *Pelagonium* spp.
	Anguillaria dioica	now *Wurmbea dioica*
	'white *Anguillaria*'	*Wurmbea* spp.
	'a new bulbine with a delicate yellow flower being perfectly distinct from both the species described by Brown'	*Bulbine suavis* now *B. glauca*
	Caladenia dilatata	No change
	Diuris aurea	*Diuris* spp.
	blue, yellow, pink, brown Caladenia'	various *Caladenia* spp.
Herb (Forb)	*Picris barbarorum*	No change
	Ranunculus spp.	various *Ranunculus* spp.
	'blue.. yellow… white everlasting flowers'	various *Asteraceae* spp.
	other 'blooms [and] herbage… amongst the grass'	Various families

The contrast of the description from the drier Northern (Riverine) Plains region could not be more stark. Overlander, Hawdon (1952) visited the 'plains' between Pyramid Hill and the Loddon River in February 1838, Mitchell (1838) passed through in June 1836 and G.A. Robinson in April 1843 (Clark 1988). This is the region where Mitchell's rapturous wet–winter "*sublime… verdant plains*" declaration contrasts with Hawdon's pragmatic and sober dry–summer opinion: "*land of the worst description*" with its thin sprinkling of grass and "*vulgar*" pig's face everywhere. Hawdon later mentions "*small bulbous roots* [that Corellas] *dig out of the plains*" and "*small bushes scattered over the plain,*" the latter likely a reference to chenopods. Mitchell mentions a geophyte near Mount Hope (*white anguillaria,*" *Wurmbea* spp.); however, scant mention of these life–forms suggest they may not have been overly abundant or dominant in this region. Robinson's Autumn description of the same area five years later is broadly similar: "*the plains are thinly grassed [wiry grass* possibly *Austrostipa spp.] and are studded with clumps of* [various types of] *Banilla & pigs face* [interspersed] *through belts of stunted box forest, a few pine trees & numerous Hee Oak.*" Banilla is probably "Barilla" which is Spanish for halophyte and is likely to mean "saltbush" in this context. Interestingly, both Mitchell and Robinson tuned into an ecotonal shift in the vegetation as they moved south–west towards the Loddon River. Mitchell mentions "*a fine plain"* of Kangaroo Grass suggesting it was the first time he had seen this species for some time and/or that it had not been recently burnt, and Robinson pointed out that the same area was no longer dominated by chenopods.

Evidence of the targeted, purposeful and frequent use of fire by Aborigines from historical journals

Of the 1,700 discrete observations of events or landscape features (Table 1), only 54 appear to have been broad–acre fires that mostly occurred in summer and Autumn (80%) – a further 48 fires were considered small/point fires or the scale was not specified. Of these 54, nearly half were attributed to Aboriginal ignition (26), while the rest were unknown, but could include a mix of Aboriginal and non–anthropogenic fires. Only one fire was explicitly recorded as a wildfire caused by a non–anthropogenic source (lightning) and two fires were lit by pastoralists. Aboriginal burning (26 fires) comprised 10 of unknown/unspecified purpose, and 10 were a reaction to Europeans (June to December), leaving six for 'traditional purposes' such as promoting fresh grass for game (Table 4).

Lightning was occasionally mentioned – primarily between November and March – the same period when most broad–acre fires were reported and when the vegetation is typically driest and most flammable. However, lightning coinciding with broad–acre fires was noted on only one occasion ("*Thunder and lightning this morning, the fires on the hills had a very singular effect*" February 14, 1841; Clark 2014), and on none of the days when the historic observers were thought to be describing broad–acre Aboriginal burning. The only example of likely traditional burning timed before rainfall was reported by G.A. Robinson three days after a fire was started at Bontharambo station (February 11–14, 1841; Clark 2014) when he was some distance up–stream on the Ovens River near present day Myrtleford.

	All Historic Observations (No.)	Observers (No.)								Lightning	Rainy Days	Tuberous Plants	Scale				Broadacre (Sc.): Ignition				Aboriginal (Ig.): Purpose			Trad&Unk.: Hist. Map (Veg.)				Age		Purpose				Hist. Obs. (Veg.)			Hist. Map (Veg.)		
		Hawdon 1838	Hume & Hovell 1824	Mitchell 1836*	Mollison 1837	Robinson 1840	Robinson 1841	Robinson 1843	Walker 1837				Small/Point	**Broadacre**	Unknown	**Total**	Wildfire	European	**Aboriginal**	Unknown	Reaction	**Traditional**	**Unknown**	Plain	Other (Wdld)	Unknown	**Total**	Current	Recent/Old (past)**	Reaction	Traditional	Unknown or N/A	Pastoralists	Plain	Other (Woodland)	Unknown	Plain	No (Woodland)	Not Mapped or Unk.
Jan	**140**	46	16	-	-	78	-	-	-	3	6	6	5	6	-	**11**	-	-	5	1	-	1	4	1	3	1	**5**	3	3	-	1	5	-	-	-	6	1	3	2
Feb	**230**	30	-	-	-	120	80	-	-	3	4	7	17	11	1	**29**	1	1	6	3	-	2	4	3	-	3	**6**	10	1	-	2	8	1	2	2	7	3	-	8
Mar	**118**	-	-	-	-	67	-	51	-	4	5	1	9	5	1	**15**	-	1	2	2	-	1	1	1	-	1	**2**	1	4	-	1	3	1	-	-	5	2	-	3
Apr	**76**	-	-	-	-	-	-	76	-	-	-	-	1	1	-	**2**	-	-	1	-	-	-	1	1	-	-	**1**	-	1	-	-	1	-	-	-	1	1	-	-
May	**177**	-	-	-	-	-	-	-	177	1	4	-	-	10	-	**10**	-	-	-	10	-	-	-	-	-	-	**-**	-	10	-	-	10	-	3	7	-	3	2	5
Jun	**112**	-	-	104	5	-	-	-	3	-	2	3	5	5	-	**10**	-	-	2	3	2	-	-	-	-	-	**-**	2	3	2	-	3	-	2	1	2	2	-	3
Jul	**219**	-	-	132	87	-	-	-	-	-	11	2	2	1	1	**4**	-	-	1	-	1	-	-	-	-	-	**-**	1	-	1	-	-	-	-	-	1	-	-	1
Aug	**27**	-	-	-	27	-	-	-	-	-	1	-	-	1	-	**1**	-	-	-	1	-	-	-	-	-	-	**-**	-	1	-	-	1	-	-	-	1	-	-	1
Sep	**138**	-	-	125	13	-	-	-	-	1	2	6	-	-	-	**-**	-	-	-	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	-	-	-	-
Oct	**136**	-	-	103	33	-	-	-	-	-	4	1	-	1	-	**1**	-	-		1	-	-	-	-	-	-	**-**	-	1	-	-	1	-	1	-	-	-	-	1
Nov	**139**	-	95	-	44	-	-	-	-	2	2	-	-	3	4	**7**	-	-	3		3	-	-	-	-	-	**-**	3	-	3	-	-	-		2	1	-	-	3
Dec	**188**	-	139	-	49	-	-	-	-	1	1	-	2	10	-	**12**	-	-	6	4	4	2	-	-	-	2	**2**	8	2	4	2	4	-	2	8	-	-	-	10
Tot.	**1,700**	**76**	**250**	**464**	**258**	**265**	**80**	**127**	**180**	**15**	**42**	**25**	41	**54**	7	**102**	1	2	**26**	25	10	**6**	**10**	6	3	7	**16**	28	26	10	6	36	2	10	20	24	12	5	37
																	54				**26**							**54**		**54**				**54**			**54**		

Table 4. Historic observations of fire by Scale, Ignition (Broad–acre), Age (see Fensham 1997), Purpose and Vegetation (from historical observers and historic mapping). *Excludes July 25 to Sept 10 (far south–west Vic.); Mitchell's journal likely has no records of broad–acre fire because the expedition took place over the cool–season, in a wet year (June to October).**Date adjusted for 'past' fires where supported by text.

Discussion

Corroborated historic grass/tree boundary mapping

The historic grass/tree boundary map for a large portion of central and northern Victoria derived here from hundreds of plans dating from the early decades of the Port Phillip colony is the first multi–bioregional, thematic vegetation reconstruction in south–eastern Australia derived exclusively from the historic archives. The map documents in fine detail, extensive tracks and complex mosaics of treeless 'plains' covering over a quarter of the region and is well corroborated not just by those creating the maps, but also by the earliest Europeans who journaled their routes and observations. It is not surprising that Mitchell (1838) and Hume and Hovell (Andrews 1981) where the most assiduous in daily recording their observations, including grassy 'plains,' given their brief as explorers and the 'Australia Felix' vision built on the promise of pastoral exploitation. It also makes sense that the journals of G.A. Robinson proved highly corroborative because of his position as Chief Aboriginal Protector and prolific writings. It is possible the slightly lower corroboration rate for the overlanders is explained by their private entrepreneurial agenda, being either less interested in the landscape they passed through and generally lacking specialist skills around botany, anthropology and linguistics. The map represents a compelling evidence base for widespread historic grasslands – not previously mapped – across the Study Area.

Comparison with past reconstructions and inverse texture effect (rainfall)

The multi–bioregional historic reconstruction developed here contrasts markedly with previous reconstructions of native grassland distribution in the Study Area. Extensive 'new' areas of grassland were identified throughout, especially in the mesic regions (>400 mm per annum; Figure 2). This divergence is significant considering Victoria's pre–European reconstruction (Parkes *et al.* 2003) was largely based on climate–edaphic models consistent with the 'inverse texture effect' (with the notable exception of the VVP – see below; Fensham *et al.* 2015). The results suggests grassland was likely widespread in similar regions elsewhere – i.e. across the inland mesic portions of NSW (see Keith 2004) and indeed patchily throughout the slopes, tablelands and coastal hinterlands of the south–eastern mainland and Tasmania (e.g. Ellis 1985; Fensham and Fairfax 1996, 2006; Butler *et al.* 2006, 2014; Bowman *et al.* 2013; Karskens 2019). All of the early Europeans featured in this study (and many others) – that traversed the corridor between Sydney and Melbourne – often reported similar vegetation patterns in places such as Yass, Bredalbane, Goulburn and Bathurst (e.g. October 30, 1836, Mitchell 1838). For instance, on the Bathurst Plains in the central Tablelands of NSW, also drawing on early historic accounts, Butzer and Helgren (2005) concluded that grasslands were more extensive than previous reconstructions, and that frequent fire (likely anthropogenic) influenced grass/tree boundaries. In contrast, on the VVP west of Melbourne, archival research suggests the extent of grasslands may have been exaggerated in state wide reconstructions. Nearly half of all historic annotations collated from the newer volcanics (41%) refer to trees and wooded vegetation (see Foreman 2016), and the only known localised fine–scale reconstruction from this region (a 648 km^2 area near Werribee; Sinclair and Atchison 2012) shows ~12% or >61 km^2 less grassland, greater landscape variegation and much non–alignment of grass/tree boundaries c.f. the EVC reconstruction.

The 'archival benchmark' or historic baseline presented here in general corroborates the inverse–texture hypothesis, which provides a general explanation of the expected patterns of woody biomass in this part of the continent. The EVC reconstruction portrays a sharp transition above a 400 mm (mean annual rainfall) 'threshold', where woody vegetation is completely dominant irrespective of soil type and with grassland more–or–less entirely dropping out above 450 mm. While the EVC reconstruction aligns with the inverse texture effect in northern Victoria, there are numerous major anomalies elsewhere – such as the VVP west of Melbourne – that require further explanation (also see critique of Foreman 1996 and Lunt 1997 in Foreman 2016). The significance of the divergence between the EVC pattern c.f. the multi–bioregional historic benchmark presented here, is that it suggests these anomalies may not be the rare exceptions they are often made out to be (e.g. Western Port grasslands; Cook and Yugovic 2003), with regional factors potentially overriding the broader drivers of vegetation patterns much more often than reflected in previous reconstructions.

Alongside the conclusion that the inverse texture effect applies throughout the inland arid zone of Australia, Fensham *et al.* (2015) also report that this effect is suddenly reversed in mesic hinterlands in the east and north and across much of the south (as illustrated by the EVC reconstruction; Figure 3). In these regions "*the superior moisture–holding capacity and fertility of clays relative to sands allows for the development of higher woody biomass*." (Fensham *et al.* 2015). The historic tree/grass boundary mapping suggests this 'reversal' may not be as pronounced or as dramatic as represented in these broader scale studies. Analysis of fine–scale soil surface texture patterns across the irrigation regions of the Victorian Riverina (c.f. the coarse–scale spatial units used in Fensham *et al.* 2015) shows dramatic underestimates of clay soil extent in the continental coverage (–40% or >1,000 km^2 – see Foreman in prep). This, combined with a vegetation reconstruction inadequately corroborated by historic data, could have resulted in major sampling errors in the relative estimates of reconstructed mean above–ground woody biomass (t/ha) at the bioregional scale (i.e. both the errors (1) 'pick sand when clay', and (2) 'pick woody when grassland'), and would have contributed to significantly smoothing out the clay 'bump' for mesic hinterlands; see Fig. 1 in Fensham *et al.* (2015). For instance, this could mask a gradual transition zone into mesic regions (instead of a 'reversal' switch or tipping point threshold) whereby tree mortality is increasingly driven by extreme (c.f. seasonal) climate–edaphic effects and/or 'top–down' processes such as fire, even though it can be difficult to hold eucalypts back with burning in some environments (Fensham and Fairfax 2006).

Foreman (2016) argued that the Pleistocene and Holocene relict hypotheses (Fensham and Fairfax 1996) would be applicable to mesic grasslands of south–eastern Australia as eucalypts could be eliminated (or greatly retarded) in productive lowland plains where they exhibit little lignotuber development and effectively function like obligate seeders, and young seedlings are vulnerable to frequent intense summer burning if within the 'flame zone'. Testing the 'woody invasion following cessation of burning' and 'inhibited woody invasion with re–introduction of fire' hypotheses (see Foreman 2016), by comparing carefully selected sites, would help establish fire mortality of tree (eucalypt) seedlings as one of the key mechanisms of treelessness in these grasslands. Further evidence for the role of fire in shaping the phytoecology of these grasslands could be seen in the functional and genetic structure of the woody dominants of open grassy savannahs – especially in the highest rainfall zones (such as the VVP and Gippsland Plains). Here, populations of non-serotinous resprouters such as Honeysuckle (*Banksia marginata*), could be the result of selection due to frequent fire regimes (see Radeloff *et al.* 2004; Lamont *et al.* 2013).

Under the inverse texture effect, it could be argued that the incongruence between the distribution pattern of pre–European grasslands and that predicted from broad–scale climate–edaphic models may be resolved by fine–scale edaphic coverages. Careful analysis of the edaphic environment across historic grass/tree boundaries (using fine–scale soil maps from throughout the irrigation region of the Victoria Riverina) will be a major emphasis for future study (see Foreman in prep) and help reveal important regional and local nuances in phytoecology, including whether the fine–scale distribution and dynamics of temperate grasslands was at least in part due to fire (see Test #4 in Foreman 2016).

Nature of historic 'plains'

The historic record in this study paints a more nuanced picture of the grasslands than is typically gained from historic studies (e.g. Connor 1966; Fensham 1989; Fensham and Fairfax 1997; Butzer and Helgren 2005; Sinclair and Atchison 2012), although it should be kept in mind that floristic description was constrained by the incipient state of Australian plant taxonomy in these early decades. Nevertheless, instead of the typically brief, generic physiognomic descriptors at particular locations (i.e. growth form, structure, and cover), aggregation of selected records from multiple observers – in different years and seasons – helped build a picture of a dynamic and diverse ecosystem composed of multiple life–forms. These were not homogeneous, species–poor, and always grass–dominant environments as the term 'grassland' might suggest. The most common records were for grasses and geophytes (and other herbaceous wildflowers) and the journals often describe open 'plains' ablaze with colour. Remarkably, records about 'Murnong' – sometimes apparently the most dominant life–form over large areas – were common, especially on or near locations described as 'plains' by observers. Gott (1983) details 55 separate Aboriginal names for 'Murnong' from at least 94 records in the historic archives mostly in Victoria, but acknowledges that some ethnographic references to 'yams' were ambiguous and likely included geophytic monocots, and other tuberous dicots such as *Geranium*, *Convolvulus* and *Clematis*. The floristically diverse system that emerges from the historic records also accords with the ethnographic record (Gott 1982, 1990, 1993) and the systematic study of refugia (e.g. Stuwe and Parsons 1977; Stuwe 1986; Kirkpatrick *et al.* 1988, 1995, McDougall and Kirkpatrick 1993; Lunt 1997). Meanwhile, in the drier north, along with *Themeda* being replaced by succulent life–forms and other grasses adapted to the semi–arid climate, there is also an apparent absence of broad–acre burning.

Although the distinctive pan–palaeotropical Kangaroo Grass would have naturally attracted European attention (as it was described in 1775 and likely valued from earlier British colonies in India, Africa and Malaysia; e.g. Hepper and Friis 1996), its ubiquity in the early descriptions would still have reflected it's widespread distribution in mesic regions, in much the same way that it frequently occurs in the best refugia today (Williams *et al.* 2015). However, collectively, the historic accounts suggest these grasslands were not monocultures but more complex systems with a wide range of interstitial forbs, patches of various smaller shrubs/subshrubs, and many fire–tolerant, suckering non–eucalypt small trees such as Blackwood and Honeysuckle (Table 3). The early accounts in the Upper Campaspe 'plains', in particular, also suggests dramatic seasonal biomass dynamics; a regular sequential functional regime of 'fire *then* forbs (e.g. Murnong) *then Themeda.*' Even though the evidence assembled here from the historic archives is inferential, there is a distinct trace of frequent fire and people in the nature of these grassy landscapes. As Lunt (1998) mused in relation to the role of frequent burning influencing century–scale change in *Themeda* grasslands: '*it is difficult to conceive of alternative processes which might have acted across broad areas*.' However, can we rely on the historic archives to reveal a direct and informed understanding of fire use in traditional Aboriginal society in alignment with the implied phytoecological evidence?

Evidence of the targeted, purposeful and frequent use of fire by Aborigines from historical journals

Although broad–acre fires were commonly reported more–or–less across the region and throughout much of the year, only one was likely due to lightning and very few were explicitly linked to Aborigines by the observers as likely examples of traditional landscape burning. However, this apparent paucity of traditional burning observations is likely misleading, and a closer examination of the evidence reveals a more complex picture. On the one hand, a significant proportion of broad–acre fires (10) were, in fact, a reaction to European arrival, while on the other hand, the limits of observation, the incipient impacts of colonisation and European ignorance meant that the many fires reported could not readily be classified in terms of scale, ignition or (Aboriginal) purpose. Thus, it is possible the observers reported up to 58 broad–acre Aboriginal fires, up to 48 of which could have been examples of traditional landscape burning practices.

It is important to distinguish reactive burning because it is likely this was a novel use of fire spontaneously deployed as a defensive or offensive reaction to the threat of European intrusion and possibly in contrast to long established practices. For instance, close reading of Hume and Hovell's accounts of 'current' fires in December 1824 (Andrews 1981) suggest they were more likely reactive – even though the explorers themselves believed they were witnessing 'traditional' burning. Historian, Henry Reynolds (1982; 1987), cites fire as a "*potent* [pyro–guerrilla warfare] *weapon*" deployed by Aborigines on the frontier as part of the systemic and sustained resistance to colonisation, often misinterpreted or dismissed by historians (see Gammage 2011 pg. 160).

It makes sense that reactive burning was prominent in the historic record, albeit often under–recognised. Similarly, European ignorance – along with the unfolding disintegration of traditional society – also likely contributed to the under–recognition of Aboriginal agency in the remaining reported broad–acre fires (up to 48). The overlanders, in particular, struggled to understand traditional society and consequently, the reader is left to speculate about Aboriginal agency from clues in their fragmentary accounts. For instance, all the circumstantial evidence in Walker's (1838) earlier cited report of burning on the Upper Campaspe 'plains' points to Aboriginal agency rather than background wildfire as the most likely explanation for unclassified broad–acre fires.

Incidences of broad–acre fires explicitly attributed to non–reactive Aboriginal ignition were rare and only reported by Robinson – on the basis of hearsay from others (e.g. February 11 & 20, 1841; Clark 2014) or where Robinson himself either directly observed ignition, presumed ignition by association, or learned of it through conversation with the Aborigines. It is perhaps no coincidence that it was only Robinson who explicitly recorded the link between Aborigines and traditional burning, as he was the only early observer directly concerned with Aboriginal interests under the auspice of the Protectorate (Christie 1979).

Interpretation of traditional practices from early records is problematic because European intrusion was profoundly disruptive, inciting frontier–wide conflict and suppressing traditional practices (amongst other things), and Europeans were ill–equipped to understand and interpret the impact of Aboriginal burning on the landscape. The records provide some evidence of burning targeted towards 'plains' as well as a seasonal bias towards summer into mid–Autumn, but little more. Synthesis of the earliest historic observations in this case study really only tells us that Aboriginal burning was occurring (including reactive fires), but likely under reported due to scant records, and the misunderstandings and prejudices of the intruders. While few observers were aware enough to 'see' traditional burning while it was still being practiced, there is evidence of fires in the collective accounts that could have been such practices, and which has revealed some useful insights. Nevertheless, there remains a need for more historic case studies, based on the earliest and most reliable primary observations (see Foreman in review), to clearly describe the targeted, purposeful and frequent use of fire by Aborigines inferred in the accounts studied here.

Conclusion

This study assembled the first multi–bioregional reconstruction of lowland temperate grasslands derived from hundreds of historic survey plans that were well–corroborated by the earliest Europeans who journaled their routes and observations. The resulting archival benchmark aligns poorly with existing reconstructions based on climate–edaphic ('bottom–up') assumptions, and further fine–scale edaphic analysis could help pinpoint areas reflecting the overriding influence of disturbance such as Aboriginal burning. The results lend support to treelessness driven by complex 'bottom–up' and 'top–down' process interactions and that grassland reconstructions should be extensively corroborated with the historic archives, if not derived exclusively from them. Consequently, the results support Hypothesis #1 (Foreman 2016): that 'Corroborated historic records of grasslands [occur] in areas where trees are expected (>400mm per year).'

The historic record shows that these grasslands were not simple, grass–dominant environments, but a rather more dynamic and diverse ecosystem composed of multiple life–forms including interstitial forbs like the edible geophyte Yam Daisy ("Murnong"), subshrubs, and fire–tolerant small trees. While there is a distinct trace of frequent fire and people in the historic nature of these grassy landscapes, and there is evidence of fires in the collective historic accounts that could have been broad–acre Aboriginal burning, there remains a need for more in–depth and reliable historic case studies to clearly describe the targeted, purposeful and frequent use of fire by Aborigines (Test #9; Foreman 2016) than is inferred in the accounts studied here.

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Conflicts of Interest

The author declares no conflicts of interest.

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