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Illuminating the dawn of pastoralism: Evaluating the record of European explorers to inform landscape change

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ABSTRACT

The rapid spread of pastoralism across Australian and North American rangelands and the lack of reference sites mean that recurring arguments about the cause and magnitude of landscape change are frustrated by the rarity of records that predate the critical watershed of European settlement. The journals of European explorers from the 1840s are the first written descriptions of inland Australia. Prevailing paradigms based on a synthesis of published material relating to five key themes of environmental change are presented: vegetation structure, fire regimes, waterhole permanence, macropod abundance and medium-sized mammal assemblages. Six hypotheses relating to these themes were tested against the explorer record for inland eastern Australia. Nearly 4500 observations from fourteen journals spanning twelve expeditions between 1844 and 1919 were geo-referenced, using landscape features, distances, bearings and latitudes, combined with topographic maps and high-resolution satellite imagery. Careful evaluation of the record suggests little change in broad vegetation structure or waterhole permanence, running counter to prevailing paradigms. The sparse observations of fire suggest burning was infrequent and mostly restricted to creek-lines and higher-rainfall grasslands in the east and north of the study area and spinifex-dominated vegetation. Kangaroos were apparently uncommon in semi-arid areas where they are abundant today. The journals contain important observations of medium-sized mammals that are now extinct or rare. Our results highlight the importance of accurate geo-referencing compiled from entire journals of multiple explorers and contrasting the record with contemporary observation. Systematic evaluation of the explorer record for a region can provide ecological insights that are difficult to obtain by other means, and can be used to test prevailing assumptions common to arid systems that have been subject to abrupt management upheaval.

1. Introduction

Across rangelands in Australia and North America, where the spread of European pastoralism was omnipresent and abrupt, recurring arguments about the cause and magnitude of landscape change are frustrated by the rarity of records that predate this momentous biogeographic watershed (Goforth and Minnich, 2007; MacDougall, 2008; Swetnam et al., 1999; Witt et al., 2000). In the absence of reference sites unaffected by pastoralism, ecologists have turned to the historical record to better understand contemporary ecosystems and their dynamics (Bowman, 2001; Foster, 2000; Swetnam et al., 1999). Historical sources provide a temporal perspective far exceeding that enabled by long-term field studies, and are especially valuable where ecosystem alterations or upheavals predated formal studies (Goforth and Minnich, 2007; Jackson et al., 2001; Luiz and Edwards, 2011). Historical ecologists have employed a diverse array of sources spanning timescales from millennial to centennial and decadal, encompassing natural and documentary sources. The former include stratified sediments, pollen cores, deposits of material constructed by animals, tree-rings marking annual growth cycles and fire scars (see Swetnam et al., 1999 for examples). Documentary archives consist of written and visual records or historical landscapes, and are particularly powerful because they provide graphic imagery that resonates with a broad audience including non-scientists.

Interpretations of pre-pastoral landscapes from historical records are often used to support arguments about contemporary land management and conservation. Substantial degradation of Australian rangelands over the past 150 years has been attributed to European land management practices (Gasteen, 1982; Letnic, 2000; Marshall, 1966; White, 1997). Symptoms include soil erosion (Fanning, 1999; Gale and Haworth, 2005; Mills, 1986) and associated silting of rivers and waterholes (Pickard, 1994; Tolcher, 1986), thickening of woody vegetation (Burrows, 2002; Noble, 1997; Rolls, 1999) and altered fire regimes (Gammage, 2011; Russell-Smith et al., 2003). Changes in the composition and abundance of plant and animal species have also been flagged (Friedel et al., 2003; Landsberg et al., 2003; Woinarski and Fisher, 2003), including a catastrophic decline of medium-sized mammals (Johnson, 2006) and an increase in numbers of larger macropods in some areas (Newsome, 1975). These issues, particularly soil erosion and changes in woody plant density, are common to arid lands globally (Archer, 1989; Ayyad, 2003; Reynolds et al., 2007). While many examples of environmental change are irrefutable, others are not supported by empirical evidence but have nevertheless become enshrined in the scientific literature and popular imagination as 'conventional wisdom' (Mitchell, 1991). If the basis for these assumptions is unsound, attempts to understand these landscapes will be stymied and management misguided (Foster, 2000).

Explorer journals provide the first written descriptions of inland Australia at a critical time just prior to an abrupt management upheaval. They have been used to reconstruct aspects of the pre-European landscape across Australia including: vegetation structure (Benson and Redpath, 1997; Croft et al., 1997; Denny, 1987; Fensham, 2008; Lunt, 1998; Ryan et al., 1995); fire regimes (Bowman and Brown, 1986; Braithwaite, 1991; Crowley and Garnett, 2000; Fensham, 1997; Gammage, 2011; Kimber, 1983; Preece, 2002; Vigilante, 2001); mammal declines (Denny, 1994; Kerle et al., 1992; Lunney, 2001); native species that are thought to have increased in range and abundance (Auty, 2004; Barker and Caughley, 1993; Denny, 1980; Gammage, 2010); and colonisation patterns of feral species (Griffin and Friedel, 1985; Abbott, 2002).

Given the absence of reference sites unaffected by changes associated with European land-use in arid and semi-arid eastern Australia, perceptions of widespread environmental change, and the relatively rich exploration history, a systematic examination of explorer journals for this area holds substantial potential for understanding landscape change. This paper examines the extent to which the observations of nineteenth and early twentieth century explorers can inform inferences about five key themes of environmental change: vegetation structure, fire regimes, waterhole permanence, medium-sized mammal assemblages and kangaroo numbers. Six prevailing hypotheses based on these themes were synthesised from the literature, and tested against the explorer record (Table 1).

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2. Methods

2.1. Study area and exploration history

The study area is defined as the semi-arid and arid region of Queensland, and the adjacent arid zone of north-eastern South Australia and north-western New South Wales (Fig. 1). Average annual rainfall decreases on a south-westerly gradient, from 500 mm in the north and east to just 100 mm in the Simpson Desert. Summer temperatures are hot with maximum temperatures throughout December–February averaging 35 °C, while short winters are characterised by cold nights often falling below zero and warm days averaging 20 °C (Bureau of Meterology, 2012). Higher rainfall areas support *Acacia* and, to a lesser extent, *Eucalyptus* woodlands, while the more arid portions are dominated by gibber plains, rolling downs, wide floodplains, low-relief sandstone ranges, open shrublands dominated by *Acacia* species and extensive linear dunefields.

Europeans had been in Australia for over 50 years before a concerted attempt was made to explore the interior of the continent. In 1840, Edward John Eyre was thwarted in his attempt to reach the centre of the continent by the chain of salt lakes which stretch through central South Australia. Exploration in western New South Wales, north-eastern South Australia and inland Queensland continued through the 1840s and 1850s, with expeditions led by Captain Charles Sturt (in 1844–1845), Major Thomas Mitchell (1845–1846), Edmund Kennedy (1847), the ill-fated Ludwig Leichhardt (1848) and Augustus Gregory (1858). The 1860 Burke and Wills expedition spawned four 'recovery' expeditions in 1861–1862, led by William Landsborough, Frederick Walker, John McKinlay and Alfred Howitt, all of which served the twin aim of assessing the pastoral potential of the inland.

Concomitantly, Governments in South Australia and Queensland were passing legislation designed to encourage settlement of the 'waste-lands', resulting in a period of rapid pastoral expansion.

Table 1
Prevailing paradigms and hypotheses tested using explorer record for five major themes (references are provided in Appendix 1).

Prevailing paradigm	Hypothesis tested	Conclusions and interpretation
A. There has been a general thickening of woody overstorey vegetation in the semi-arid zone of Queensland, especially *Acacia aneura* and *A. cambagei*	1. There will be numerous examples where explorers passed through open country that is now thickly wooded	Explorers passed through many areas of dense woodland and scrub, with no geo-referenced observations of open country now characterised by thick vegetation, refuting the paradigm of unidirectional vegetation change
B. (i) Fires are less frequent across the semi-arid zone, especially the mulga forests and Mitchell grasslands, due to lower biomass and active suppression	2. Burning was regularly noted by explorers in areas where fire is uncommon today	Fire was rarely mentioned by explorers in the semi-arid zone, with the exception of Aboriginal burning of grasslands on the eastern edge of the semi-arid zone. Aboriginal burning in spinifex landscapes recorded by three explorers
(ii) In spinifex-dominated ecosystems, small, regular 'patchy' fires have been replaced by large, destructive wildfires following good seasons	3. Burning was regularly noted in spinifex landscapes today characterised by infrequent large wildfires	
C. Waterholes in some regions have 'silted up' since pastoral settlement due to the loss of groundcover and subsequent accelerated erosion, resulting in a decrease in depth and therefore permanence	4. Long-lasting waterholes were recorded by explorers in reaches where there are now no long-lasting waterholes	No change in permanence was evident from the explorer record for the majority of rivers and creeks
D. The range and abundance of macropods have increased in semi-arid areas since pastoral settlement. Macropods were always abundant in wetter areas of eastern Australia prior to European settlement. Red kangaroo numbers fluctuate with seasons but have not changed greatly in the arid zone	5. Few macropods were recorded by explorers in the semi-arid and arid zone, but they saw relatively large numbers in areas above 500 mm rainfall	Kangaroos were abundant in areas of >500 mm, but there are very few references to macropods in semi-arid Queensland
E. The range and abundance of medium-sized mammals have contracted across the study area	6. Medium-sized mammals will be present in the explorer record in areas where they no longer occur	There are numerous explorer records of medium-sized mammals that are now locally extinct

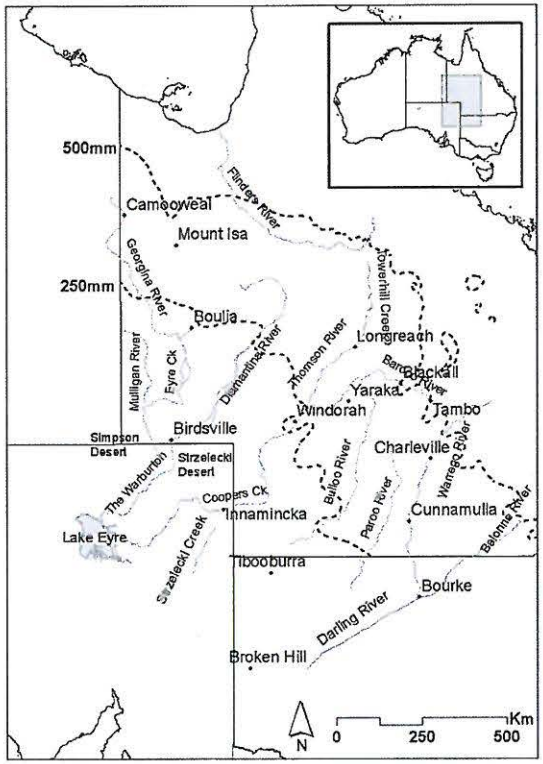

Fig. 1. Study area, showing 250 mm and 500 mm isohyets, major rivers, towns and regions mentioned in text.

From the 1860s, pastoral settlement occurred alongside continued exploration. In 1862, when Landsborough travelled down the Flinders and Thomson Rivers to the Warrego, there were already occasional tracks of cattle along the streams. By the time Hodgkinson explored the Diamantina and Mulligan Rivers in the late 1870s, much of far western Queensland had been taken up by pioneer pastoralists, spreading into the area along the major rivers. The 1880s was a period of closer settlement, while surveyors such as Cornish, Poepell and Winnecke continued their explorations in the more arid areas to the west. Thus there were just 20 years between Eyre's expedition and the arrival of the first pastoralists. Within the next 30 years, the pastoral frontier had enveloped nearly all suitable country across inland eastern Australia.

2.2. Journal selection and geo-referencing

Fourteen journals from 12 expeditions spanning the period 1844–1919 were examined for this study (Table 2). These journals were selected as they contain relatively detailed accounts of the country traversed, are able to be reliably geo-referenced and have all been published, albeit obscurely in some cases. Where selected explorers traversed country outside the semi-arid zone, these sections of the journals were also geo-referenced to inform interpretation.

The route of each expedition was plotted in a Geographic Information System (ArcMap 9.3) based on distances, directions, latitude recordings and references to distinctive landmarks contained in the journals, supported by maps prepared by cartographers upon the explorers' return (Arrowsmith, 1849; Harris and Loveday, 1862). Latitudes were generally used only as secondary confirmation of location, since they were frequently subject to inaccuracy as a result of damage to instruments during travel (Denny, 1987; Gammage, 1984). Google Earth imagery and 1:250,000 topographic maps were used as base maps, and the former proved particularly valuable for detecting geographic features mentioned by explorers. Knowledge of local aficionados, such as the location of marked trees and camps, was able to inform geo-referencing in some areas.

Observations and remarks were extracted from journals and geo-referenced. Five major types of observations emerged: 'people'

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Table 2
Explorer journals geo-referenced (observations do not include location clues; includes km of observation approximate only).

Explorer	Expedition	Year	Reference	Number of observations	km travelled
Sturt	Expedition to Central Australia	1844–1845	(Davis, 2002)	683	2690
Mitchell	Expedition into the Interior of Tropical Australia	1845–1846	(Mitchell, 1847)	846	2880
Kennedy + Turner	Expedition along the Rivers Victoria and Warrego	1847	(Beale, 1983)	370 + 125 = 495	2160
Gregory	Expedition in Search of Dr. Leichhardt and Party	1858	(Gregory, 1884)	64	1620
Landsborough	Expedition in search of Burke and Wills	1861–1862	(Landsborough, 1862)	505	2230
Walker	Expedition in search of Burke and Wills	1861–1862	(Walker, 1863)	167	780
McKinlay	Expedition in search of Burke and Wills	1861–1862	(McKinlay, 1863)	280	1880
Lewis	Lake Eyre Expedition Party	1874–1875	(Lewis, 1876)	284	1280
Hodgkinson	North-West Explorations	1876–1877	(Hodgkinson, 1877)	320	1620
Winnecke	Northern Exploration Party	1883	(Winnecke, 1884)	294	2160
Davidson	Assistant to Surveyor Twisden Bedford	1885	(Davidson, 1920)	67	1180
Basedow + Greenfell Thomas	Government North-West Expedition	1919	(Basedow, 1919; Greenfell Thomas, 1919)	475	1420
Total				4480	21,900

(observations of, and interactions with, Aboriginal people), 'fire' (records of wildfire, smoke or past evidence of burning), 'vegetation' (from individual plant descriptions to descriptions of broad vegetation structure), 'fauna' (mammals, birds, reptiles, insects and molluscs) and 'water' (including rainfall, lack of water, permanence estimates and water quality). The 'people' category is not explored further in this paper, but provides a valuable anthropological reference for future work in the region.

Locations mentioned in the text are identified in Appendix 2. The spatial precision of each observation was recorded. 'Positive' locations were able to be pinpointed to within 1 km, usually where landmarks were referred to. 'Good' precision denotes accuracy to within a 3 km radius, 'reasonable' to within 10 km and 'tentative' to within a 30 km radius. In some cases, locations were difficult to assign, due to errors or omissions in explorer distances or bearings, or landforms not lining up with explorer descriptions. In such cases, we could not be confident of assigning a location to within a 30 km radius, and the precision is classed as 'poor'. For a small number of observations, locating the explorers with any degree of precision proved impossible, coordinates were not assigned and the observations were not used in further analysis. Where the process of identifying locations was complex, explanatory notes were included in the database. Where passages refer to observations made over sections of the journey, points were assigned to a mid-way point, and assigned a precision ranking as applicable. Two-thirds of all observations were able to be confidently geo-referenced to within 3 km, while 4% were classified as poor precision or unable to be geo-referenced at all. The full geo-referenced database of explorer observations is available from the authors upon request.

2.3. Testing hypotheses

To aid in interpretation, we calculated the distance travelled by each explorer through 15 broad vegetation types, by intersecting explorer routes with broad vegetation groups as classified by the Queensland Herbarium (Table 3, Appendix 3). We then calculated the number of fire and macropod observations for each vegetation type and rainfall zone. The ecological interpretation in this paper is based on extensive contemporary travel and field studies between 1995 and 2012 and includes revisiting most of the sites discussed in the text, and over 300 interviews with long-term landholders and managers (Silcock, 2009).

3. Results and discussion

A total of 4480 observations (excluding points that were location clues only) were geo-referenced from 14 journals, covering over 21,000 km traversed in 12 expeditions (Fig. 2). The majority of observations related to water (1905) and vegetation (2082). The former included rainfall and negative observations (i.e. lack of water), but included 290 references to permanence and 24 pertaining to springs, while the latter mostly comprised references to individual species (1060), vegetation structure (1035) and the abundance or shortage of grass (565). The journals contained 590 observations of animals, including 380 of birds, 105 mammals

Table 3
Distances traversed by broad vegetation group and rainfall zone, with fire and macropod records per 1000 km (total number of records in brackets).

Vegetation type	Distance > 500 mm	Distance 250–500 mm	Distance < 250 mm	Fire > 500 mm	Fire 250–500 mm	Fire < 250 mm	Macropods > 500 mm	Macropods 250–500 mm	Macropods < 250 mm
Floodplain woodlands	205	940	175	9.8 (2)	1.1 (1)	5.7 (1)	4.9 (1)	0 (0)	0 (0)
Eucalypt woodlands	1090	240	0	9.0 (10)	0 (0)	–	3.7 (4)	0 (0)	–
Eucalypt-spinifex woodlands	50	490	0	0 (0)	2.0 (1)	–	0 (0)	4.1 (2)	–
Cypress	342	0	0	0 (0)	–	–	0 (0)	–	–
Mulga	70	600	130	0 (0)	0 (0)	0 (0)	14.3 (1)	4.1 (1)	0 (0)
Acacia on residuals	60	60	670	0 (0)	33.3 (2)	1.5 (1)	0 (0)	16.7 (1)	0 (0)
Brigalow	510	0	0	0 (0)	–	–	0 (0)	–	–
Gidgee	375	1230	330	0 (0)	0 (0)	0 (0)	0 (0)	0.8 (1)	0 (0)
Mixed woodland	190	140	0	10.5 (2)	0 (0)	–	0 (0)	0 (0)	–
Mitchell grassland	295	2790	450	6.8 (2)	0.7 (2)	0 (0)	10.2 (3)	0.7 (2)	2.2 (1)
Open forbland	0	630	3480	–	0 (0)	0 (0)	–	0 (0)	3.7 (13)
Spinifex dunes and sandpains	0	70	2810	–	28.5 (2)	0.7 (2)	–	0 (0)	0 (0)
Sandhills	0	0	1730	–	–	0 (0)	–	–	0.6 (1)
Wetlands	0	120	1020	–	8.3 (1)	0.6 (1)	–	0	1.2 (2)
Total	3100	7400	11,400	5.2 (16)	1.2 (9)	0.4 (5)	2.9 (9)	0.9 (7)	1.5 (17)

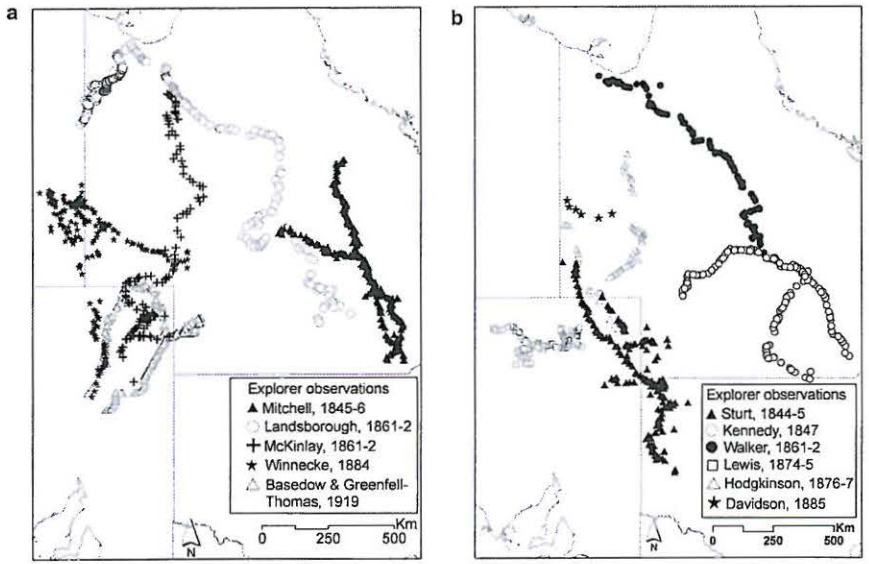

Fig. 2. Geo-referenced observations from: (a) Mitchell, Gregory, Landsborough, McKinlay, Winnecke and Basedow & Greenfell-Thomas, (b) Sturt, Kennedy, Walker, Lewis, Hodgkinson and Davidson.

and 90 fish, and 62 references to fire. Fifteen broad vegetation groups were traversed, with most distance travelled through open forbland (4100 km), Mitchell (*Astrebla* spp.) grassland (3450 km) and spinifex (*Triodia* spp.) dunes and sandplains (2860 km). Over 1000 km of non-spinifex sandhills, wetlands, gidgee (*Acacia cambagei* and *A. georginae*) and *Eucalyptus*-dominated woodlands were traversed, with 800 km travelled through mulga (*Acacia aneura*)-dominated communities. The following sections present six hypotheses based on prevailing paradigms, which are tested using the explorer record (Table 1).

3.1. Vegetation change

The fourteen journals contained between 35 (in Walker) and 330 (Mitchell) descriptions of vegetation structure. Here we concentrate on observations from the semi-arid zone where there is widely assumed to have been a general thickening of woody vegetation since pastoral settlement, especially of mulga (Beale, 2004; Moore et al., 2001) and gidgee (Reynolds and Carter, 1993) (see Appendix 1 for further references). We hypothesise that there will be numerous examples where explorers passed through open country that is now thickly wooded. All observations discussed in this section were able to be located to within 10 km accuracy, and most to within 3 km.

The expeditions of Kennedy (in 1847) and Landsborough (in 1862) provide descriptions of vegetation structure in the mulga (*Acacia aneura* F. Muell. ex Benth.) forests of southern Queensland. Both journals reveal that the country was a mosaic of thick mulga forest, grassy woodland, open flats along the rivers and mixed woodland or cypress pine sand ridges (Table 4). Heading south along the Warrego River, the country opened into extensive Mitchell grassland, invoking superlatives from the explorers.

Table 4
Vegetation structure observations, Warrego River, expressed as a% of total observations.

Vegetation summary	Kennedy and Turner	Landsborough	Total
Scrub or thick forest	28.6	40.7	34.5
Open forest or thinly wooded	25.0	25.9	25.5
River flats and treeless plains or grasslands	50.0[a]	11.1[a]	30.9
Mixed sand ridges	3.6	11.1	7.3
Pine [*Callitris*] ridges	7.1	7.4	7.3
Spinifex [*Triodia* grassland]	3.6	3.7	3.6
Total observations	28	27	55

[a] All references to grasslands south of Wyandra (100 km south of Charleville).

Such enthusiasm contrasts sharply with the comments of the explorers in the mulga country to the north. Kennedy had difficulty traversing some sections due to its 'scrubby and sandy' nature. At one point, about 25 km north of present-day Charleville, he found the mulga 'too thick to penetrate' (2 November 1847). Landsborough, with his ever-keen eye for pastoral opportunity, lamented the poor nature of much of the country. While there were some well-grassed and thinly wooded areas, his journal is dominated by descriptions of 'barren scrubby ridges…thickly wooded with mulga' and 'scrub…consisting of mulga with few other trees' (3 May 1862). West of the Warrego, some of the country was 'well covered with kangaroo grass, but in the last part of the journey it was too scrubby to be well grassed' (6 May 1862). South-east of

Table 5
Vegetation structure observations in central Queensland, expressed as percentage of all observations by each explorer.

Vegetation summary	Mitchell (n = 28)	Kennedy (n = 32)	Gregory (n = 7)	Landsborough (n = 24)	Walker (n = 13)	Total (n = 103)
Scrub or thick forest (gidgee)	28.6	31.3	57.1	16.7	30.8	29.1
Open forest (boree or gidgee)	14.3	9.4	0.0	12.5	7.7	9.7
Thinly wooded downs	3.6	15.6	14.3	58.3	0.0	20.4
Downs/plains	53.6	43.8	28.6	12.5	61.5	40.8

Charleville, 'the country…was so bad that I did not wonder at its not being stocked…Where it is not thickly wooded with thick mulga scrub, which chiefly prevails, it is grassed with *Triodia*…' (12 May 1862).

Mitchell, who travelled through a small area of the eastern mulga forests in New South Wales and Queensland, mentions battling through or avoiding dense 'Malga' six times, and regarded it as representing 'to the traveller the most formidable of scrubs' (24 March 1846). These observations refute a prevailing myth, shared by many long-term residents and some researchers, that 'most of the mulga was open savannah at the time of European settlement' (Beale, 2004:2). Landsborough's general comment on the nature of the mulga country is informative: 'The country was thinly wooded in some places and scrubby at others' (17 May 1862).

A matrix of open Mitchell grasslands and *Acacia* woodlands, primarily gidgee (*Acacia cambagei* R.T. Baker) and boree (*Acacia tephrina* Pedley) with smaller areas of brigalow (*A. harpophylla* F.Muell. ex Benth.) and myall (*A. pendula* A.Cunn. & G.Don), occurs in central Queensland in the vicinity of Blackall and Longreach. The area was traversed by five explorers – Mitchell, Kennedy, Gregory, Walker and Landsborough – between 1846 and 1862. Together, they made over 100 observations of vegetation structure in this region, which can be classified into four broad structural classes (Table 5).

These observations show that the country was a matrix of thick gidgee 'scrubs', thinly wooded downs and open plains. The open and thinly wooded downs most impressed the explorers, and led Mitchell to declare it 'the finest region I had ever seen in Australia' (22 September 1846). The prior experience of dense scrubs enhanced his appreciation of the downs. East of Tambo, Mitchell found the scene 'most refreshing…on emerging from so many thick scrubs' (15 September 1846). In some cases, the scrubs were so thick that the explorers were forced to cut a path for their wagons or avoid them altogether. About 20 km east of Tambo, Kennedy '…had to cut thro' a dense Brigalow Scrub' (23 July 1847). Similarly, Walker's progress 'was checked by a dense, almost impenetrable scrub of acacia [gidgee]' (1 October 1861). Along the Thomson, Landsborough generally travelled through thinly wooded downs, until approaching the Barcoo north of Yaraka, where the country became 'so thickly wooded at places with western-wood acacia that riding fast was too dangerous to be agreeable' (19 April 1862).

The open and wooded downs now support a profitable pastoral industry. The gidgee and brigalow woodlands have been much reduced in extent by broadscale clearing, while the remnant woodlands are widely believed to have 'thickened up' since pastoral settlement (Reynolds and Carter, 1993). While there has been substantial thickening of gidgee in some areas over the past 50 years (Fensham and Fairfax, 2005), the explorer record shows that there were large expanses of dense gidgee in pre-European times.

Rather than providing evidence of unidirectional change, the explorer journals suggest a natural dynamism in woodland/grassland dynamics on century scales (Fensham and Holman, 1999). Mitchell, Kennedy and Gregory all recorded vast areas of dead 'brigalow' (actually gidgee) along the Barcoo. About 100 km northwest of Blackall, Mitchell described '…extensive downs, in many parts of which dead brigalow stumps remained, apparently as if the decay of that species of scrub gave place to open downs' (24 September 1846). Later, retracing his steps but on the southern side of the river, he observed that 'an uncommon drought had…killed much of the brigalow scrub so effectually, that the dead trunks alone remained on vast tracts…' (1 October 1846). A year later, Kennedy mused that 'from the appearance of the downs which are strewed with dead timber…it is evident that at some time or another they must have formed one vast scrub' (10 August 1847). Dead timber was a feature of the country for over 100 km: 'From the quantity of dead timber strewed over the ground it would appear that the scrubs are fast decaying and Plains left in their room…' (11 August 1847). Twelve years later, the dead timber remained but was no longer standing, 'rending the country almost impracticable from the quantity of fallen dead timber' (Gregory, 26 May 1858). The probable cause of the dead trees is extreme drought, but the magnitude of this event must have been far greater than that which occurred in the 2000s when the area west of Blackall experienced two of its driest years on record in 2002–2003 as well as below-average rainfall in 2005–2006 (Bureau of Meterology, 2012) without killing extensive areas of trees.

Overall, the explorer record suggests surprisingly little change in vegetation structure across inland eastern Australia, given the huge and abrupt changes in land-use with the commencement of pastoralism. This contrasts with studies from other areas, such as (Crowley and Garnett, 1998) from Cape York and (Lunt, 1998) from a coastal woodland remnant in southern Australia, which detected a general thickening of vegetation compared with the explorer record. However, in western New South Wales the only significant changes in vegetation structure were related to broadscale clearing (Denny, 1987). Other studies from the Queensland rangelands that have applied a systematic and quantified approach to employing the historical record reveal scant evidence of unidirectional change in woody vegetation structure (Fensham, 2008; Fensham et al., 2011).

3.2. Fire

There is a general view that fires are less frequent across the semi-arid zone, especially in the mulga forests and Mitchell grasslands, due to lower biomass with livestock grazing and active suppression by pastoralists (Reynolds and Carter, 1993; Scanlan and Presland, 1984). While some authors argue that fire would never have been a regular occurrence in mulga communities due to sparse biomass in most seasons (Dawson et al., 1975; Hodgkinson, 2002), other researchers and many land managers invoke a loss of regular fires to explain perceived tree and shrub thickening and expansion (Duyker, 1983; Moore et al., 2001; Reynolds and Carter, 1993). In spinifex-dominated landscapes, current theory suggest that small, regular 'patch burns' have been replaced by large wildfires following periods of high rainfall, with devastating effects for fire-sensitive communities and species (Allan and Southgate, 2002; Latz, 2007). We hypothesise that burning was regularly noted by explorers in semi-arid areas and spinifex-dominated ecosystems.

The journals analysed encompass a total of 60 months travel spanning seven decades and thus a broad range of seasons and weather. Most references to fire relate to smoke from Aboriginal camp fires or smoke signals, some lit in response to the explorers' presence, with only 25 pertaining to wildfire. Thirteen of these

were observed burning, while the remainder had occurred prior to the explorers' arrival and were noted as burnt ground or post-fire regeneration. Twelve observations refer to floodplains and eucalypt woodlands, often along creeklines, in areas receiving >500 mm rainfall on the eastern margin of our study area (Table 3). Here, Mitchell noted that Aboriginal people made the most of hot winds 'to burn as much as they could of the old grass, and a prickly weed which, being removed, would admit the growth of a green crop, on which the kangaroos come to feed…' (18 May 1846).

With the exception of grassfires in the Mitchell grass (*Astrebla* species) grasslands in the far east and north of the study area and spinifex (*Triodia* species) deserts, fires were rarely noted by the explorers in areas receiving <500 mm rainfall. There are four references to Aboriginal people burning Mitchell grasslands, all on the northern and eastern edge of the semi-arid zone. Mitchell noted a grassfire in central Queensland, writing that 'the extensive burning by the natives, a work of considerable labour, was performed in dry weather' (13 September 1846), suggesting that, even prior to the introduction of domestic livestock, biomass was only sufficient to support large fires during dry windy spells and probably after good seasons (Griffin and Friedel, 1985; Hodgkinson, 2002). McKinlay recorded 'Blackfellows burning grass…the first bushfire we have seen' at the end of April 1862, when in the northern Mitchell grasslands and nearing the end of his seven-month journey from South Australia, while Landsborough noted recently-burnt grassland along the Flinders River (24 February 1862). Five fire references were from spinifex (*Triodia* species) country, two each from the Simpson Desert dunefields (Winnecke, September–October 1884) and sandplains south of Charleville (Turner, 4 November 1847 and Kennedy, 20 November 1847), while McKinlay observed Aboriginal burning in the *Eucalyptus* and spinifex-dominated Selwyn Ranges south of Mt Isa in May 1862.

These observations, including no references to fire in over 600 km travelled through mulga forest, including during early summer when spinifex in the same area was being burnt, and just two references in 2790 km of Mitchell grasslands traversed (Table 3), suggest that fire was rare throughout most of the semi-arid zone. This lack of fire in inland eastern Australia contrasts with regular dry-season burning in higher rainfall areas across northern Australia (Braithwaite, 1991; Crowley and Garnett, 2000; Fensham, 1997; Preece, 2002; Vigilante, 2001), in the forests of south-eastern Australia (Gott, 2005), and spinifex deserts of central Australia (Kimber, 1983). It is possible that wildfires following wet years in the Simpson Desert dunefields west of the Mulligan River burn larger areas in the absence of the Aboriginal patch burning noted by Winnecke (Greenville et al., 2009). However, the hypothesis of frequent Aboriginal burning across semi-arid Queensland is not supported by the explorer record.

3.3. Waterhole permanence

Although Australia's inland river systems are inherently dynamic (Knighton and Nanson, 1994; McMahon et al., 2008), loss of groundcover through overgrazing is considered to be a primary cause of 'silting' of channels and waterholes in some areas (Bell and Iwanicki, 2002; Kowald and Johnson, 1992; Nolan, 2003; Robertson and Rowling, 2000). Many long-term residents in the study area consider that waterholes along some reaches were deeper and more permanent in the past (Silcock, 2009). The explorer journals provide the first written records of inland waterholes, prior to the incursion of domestic and feral animals. We hypothesise that explorers recorded long-lasting waterholes in reaches which are now devoid of such features.

Most references to water are not sufficiently detailed to infer the likely permanence of waterholes. Others were made in good seasons or while the river was still flowing, precluding inferences of permanence. For example, the first explorers to describe the Diamantina River, McKinlay (in 1863) and Hodgkinson (in 1877), travelled when the river was in flood, so were unable to provide any reliable estimates of waterhole permanence. Taking these factors into account, there were 101 points where explorer records could be overlaid with current information on permanence (Silcock, 2009), spread across 30 reaches of creeks or rivers. The explorer record does not point to substantial changes in depth and permanence for the majority of these. Most deep, permanent waterholes recorded by the explorers remain permanent, while in areas today characterised by a paucity of good waterholes, the explorers struggled to find water. There are, however, a few instances where the status of present-day waterholes differs from the assessment of explorers. While there are two waterholes where permanence has undoubtedly increased, due to excavation or inflow of bore water, the explorer record suggests a decrease in depth and permanence in five cases (Appendix 4), three of which are discussed below.

Landsborough's observation of deep waterholes on Silverfox (or Four Mile) Creek, a tributary of the Thomson south-west of Longreach suggests change as there are no such holes in these shallow channels today. This inference of silting is corroborated by long-term residents, who remember semi-permanent holes in the area that have now silted up. Long-term residents also believe that silting has affected waterholes in the upper Thomson catchment, including along Towerhill Creek. When Landsborough encountered the creek in its upper reaches, he wrote that 'All along the creek there are many fine deep waterholes' (24 March 1862). Anecdotal evidence suggests that these waterholes used to be 6–8 feet deep, but have gradually silted up and some are lucky to last four months (Silcock, 2009). However, the 'fine waterholes' to the south recorded by Landsborough the following day are still regarded as permanent. The explorer record provides tentative support for anecdotal observations of silting in these creeks, and illustrates the value of using multiple lines of evidence in historical ecology (Davies and Watson, 2007; Goforth and Minnich, 2007).

However, anecdotal evidence is not always corroborated by the explorer record. Waterholes along Strzelecki Creek are believed to have silted up due to overgrazing during the droughts of the late 1800s (Tolcher, 1986) and as early as 1919 Basedow noted that '…drift sand has ruined many once good waterholes' (25/8/1919). Sturt's journal is particularly valuable along Strzelecki Creek because he travelled during a very dry time in the mid-1840s and re-visited the waterholes three times. His journal provides little support for a decline in waterhole permanence during the early phase of pastoralism. His journal entries of August 1845 paint a picture of the channel as being 'of considerable width, tho not depth' (18 August 1845) and containing several broad waterholes. These waterholes still contained 'considerable water' in October 1845, but when the party returned a month later, they 'found nothing but mud in the one and the water in the other very little better than mud' (10 November 1845). This third visit indicates that these waterholes were certainly not permanent in Sturt's time, and are unlikely to have ever been anything but broad, shallow holes. Gregory, who traversed 120 km of Strzelecki Creek, corroborates this, writing that 'No permanent water was seen along the bed of the creek although there are many deep hollows which, when once filled, retain water for several months' (21–25 June 1858).

Detecting the silting of waterholes through the explorer record is stymied by intermittent visitation by explorers, incorrect interpretations of permanence and the inherent natural variability in the system. While recognising these limitations, there are many stream reaches where the record has sufficient resolution to detect

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change and our results suggest that the depth and thus permanence of waterholes has not changed greatly across most of the study area. The overall interpretation that waterholes are relatively constant despite environmental upheavals, including climate change associated with glacial cycles, is supported by geomorphological studies (Magee et al., 2009; Nanson et al., 2008).

3.4. Kangaroo numbers

It is widely believed that larger macropods (the red kangaroo, *Macropus rufus*, eastern grey, *M. giganteus*, western grey, *M. fuliginosus* and wallaroo, *M. robustus*) have increased in number and range in semi-arid areas since pastoral settlement, due to the provision of artificial sources of water, dingo control and vegetation changes associated with livestock grazing (Calaby and Grigg, 1989; Fukada et al., 2009; Newsome, 1975). In particular, *M. giganteus* has expanded into more arid areas in the past 30–40 years (Dawson et al., 2006). Average densities of *M. rufus*, *M. giganteus* and *M. robustus* in semi-arid Queensland are now 8.5/km^2, 8.5/km^2 and 4.9/km^2, respectively (Department of Environment and Resource Management, 2011). However, the explorer record has been employed to challenge this conventional view by showing the kangaroos have always been abundant in many areas of southern and eastern Australia (Auty, 2004; Denny, 1980). Red kangaroo numbers seem to have always been patchy and fluctuated with seasons in more arid areas (Calaby and Grigg, 1989). We hypothesise that few macropods were recorded by explorers in the semi-arid zone but they saw relatively large numbers in areas above 500 mm rainfall, while numbers recorded in the arid zone were variable but generally low.

Interpreting kangaroo density from the explorer record is fraught, because the absence of records does not confirm an absence of animals. In fact, kangaroos may have been so commonplace that they did not rate a mention. However, the journals cited by Denny (1980) and Auty (2004) show that most explorers, including Mitchell in his earlier expedition along the Murray River, tended to note if kangaroos were abundant. In addition, in areas where they were common, kangaroos were an important game item for exploring parties, and thus worthy of a mention in the journals. For example, north of the Diamantina, McKinlay was pleased that 'Hodgkinson shot a euro which will help us on' (15 April 1862), while nearly all explorers devoted considerable time to the pursuit of game to supplement their meagre supplies.

The 14 explorer journals examined here together contain 33 references to kangaroo sightings (Table 3). Almost half of these are by Basedow and Greenfell Thomas, indicating that in 1919, red kangaroos were a common sight in the arid-zone (<250 mm mean annual rainfall) of north-eastern South Australia and far south-west Queensland. Also writing about the arid-zone, Davidson is explicit in defining kangaroo densities, noting 'a family of three kangaroos, the only ones seen west of Boulia' (1885). McKinlay records that kangaroos were common in three locations, all towards the end of his journey, suggesting that he had been seeing only small numbers throughout the rest of his journey along the Diamantina. Just before leaving the Diamantina catchment, McKinlay thought the sighting of a single wallaroo noteworthy enough to name a hill 'Euro Hill' (6/4/1862). Sturt's journals contain three references to kangaroos in far north-western New South Wales and north-eastern South Australia, suggesting that they were not abundant in this area.

Mitchell's journals suggest that kangaroos were abundant in areas of central-southern Queensland, outside the semi-arid zone (>500 mm mean annual rainfall). The plains east of Tambo were 'heavily imprinted with the feet of kangaroos' (13 September 1846). However, in the semi-arid region (250–500 mm), the journals of Mitchell, Kennedy and Gregory contain only one mention of kangaroos along the Barcoo from Tambo to Yaraka (two large red kangaroos noted by Kennedy on 5 August 1847) – an area where eastern grey kangaroos, red kangaroos and wallaroos are now in relatively high densities (Department of Environment and Resource Management, 2011). Furthermore, Turner writes on an almost daily basis of his attempts to procure meat for Kennedy's party along the Barcoo, including emus, a variety of birds and even in one case dingo pups, but does not once report seeing a macropod.

Kennedy's observation north-east of Charleville is revealing: 'Two Kangaroos were shot today. They are the first we have observed on the journey' (2 July 1847). Although Mitchell recorded kangaroos twice in this area the previous year, Kennedy's comment suggests that they were rarely sighted. Landsborough noted that kangaroos were numerous north of Camooweal, on the edge of the semi-arid zone (30 November 1861 and 6 January 1862). However, he only mentions them once on his journey from there to the Warrego, a total distance of almost 2000 km, passing through areas where kangaroos are now extremely abundant. North-west of Charleville, he wrote: 'In this day's journey we saw more kangaroo and wallaby than on any previous occasion…' (6 May 1862). This implies that the party had been seeing small numbers of kangaroo throughout the journey, but the individual sightings are not recorded in Landsborough's journals.

Overall, analysis of the record supports the hypothesis that kangaroos were rarely recorded in the semi-arid zone, were patchy in areas with less than 250 mm mean annual rainfall, probably with population booms during times of above-average rainfall (Calaby and Grigg, 1989), and abundant in some areas with >500 mm annual rainfall. The paucity of kangaroo observations in the explorer record across most of the semi-arid zone suggests that eastern grey kangaroos and wallaroos are found in much higher densities today than they were prior to pastoral settlement.

3.5. Medium-sized mammals

The extinction and range contraction of medium-sized mammals across inland Australia is well documented (Johnson, 2006; Letnic, 2000). We hypothesise that medium-sized mammal species were recorded by explorers in areas where they no longer occur. The journals provide some of the only written field records of small and medium-sized mammals prior to the wave of catastrophic extinctions that swept across inland Australia (Johnson, 2006). Two of the most interesting, and previously uncited, references to fauna are from Hodgkinson's journal along the Mulligan River in far western Queensland in 1876. North-west of Birdsville, he observed that 'The kangaroo-rats here build nests three feet high against the trunks of giddia or other trees' (7 August 1876). Based on the description of the nests, this observation probably refers to the now-extinct *Caloprymnus campestris*, and is a significant extension of its known former range (Finlayson, 1932; Strahan, 2004). Heading north-west into the Toomba Range west of Boulia, Hodgkinson noted 'numerous rock wallabies' in a 'picturesque sandstone gorge' (21 August 1876). This sighting is outside the known historical range of the three inland species of rock wallaby (Clancy and Close, 1997), but is most likely to be the purple-necked rock wallaby, *Petrogale purpuricollis* (Peter McRae, pers. comm., October 2010).

Sturt's party also saw groups of three (4 November 1844) and five or six (15 December 1845) yellow-footed rock wallabies (*Petrogale xanthopus*), in the Barrier Ranges north of Broken Hill. Given that rock wallabies can be cryptic (Gordon et al., 1978), for Sturt and his party to see two colonies while passing through the ranges suggests that they were reasonably abundant. They are now considered Vulnerable in New South Wales, the remaining two colonies of 200–250 individuals being restricted to two cliff systems and two outcrops north-east of Broken Hill (Lim and Giles, 1987). Sturt recorded numerous other species now rare or extinct in western New South Wales and southern Queensland, including stick-

nest rats (*Leporillus conditor*) and greater bilbies ('jalparoos' or 'talperos', *Macrotis lagotis*) (Denny, 1994). In 1885 Davidson saw a bilby near Boulia, just outside of their current much-reduced range, and writes that 'They must have been fairly plentiful in these days, as it was customary for the blacks, when in full costume, to wear a sort of garter below the knee from which depended the tails of the bilbie'. The hypothesis that medium-sized mammals are present in the explorer record in areas where they no longer occur is supported.

3.6. Enhancing interpretation

The explorer record holds maximum power when it is precisely geo-referenced to allow direct comparison with current circumstances. The combination of easily available Geographic Information System software and free, high-resolution Google Earth imagery has made reconstructing explorer routes much easier, through allowing distances and bearings to be traced on-screen and geographic features mentioned in journals to be readily identified. Precise geo-referencing is not always possible, due to ambiguities and errors in distance and bearing measurements given in journals. In addition, numerous passages refer to observations made over sections of the journey, sometimes encompassing entire days, rather than specific points. Limitations can be acknowledged by attributing spatial precision estimates to observations.

Building a composite picture of numerous explorer records across a region is more powerful than using a single journal in isolation. For example, the low numbers of kangaroos in the Barcoo River area is corroborated by four explorers, while the existence of thick mulga vegetation is verified by three explorers. The explorer record is especially useful when it includes quantification of a given parameter, such as the depth measurements of waterholes provided by Lewis west and north of Lake Eyre. Quotes such as Kennedy's 'this is the first kangaroo seen' are extremely valuable, but frustratingly rare. Similarly, Mitchell and Kennedy's descriptions of having to cut paths through or being unable to penetrate brigalow and mulga scrubs allow us to gauge more specifically what they meant by the term 'thick'. In general, however, the lack of quantification of vegetation structure and waterhole depth, and difficulties associated with inferring absence of animals (Denny, 1994) and fire (Fensham, 1997), represent major limitations of the explorer record. In contrast, the mere presence of some phenomena is of inherent significance, and the unquantified records of extinct mammals represent an unequivocal example of landscape change.

Selectively plucking quotes from the journals can result in them being taken out of context. Perhaps the most well-known example of this is Mitchell's musings that 'Fire, grass, kangaroos, and human inhabitants, seem all dependent on each other for existence in Australia; for any one of these being wanting, the others could no longer continue'. This oft-quoted passage has been used to imply that most of Australia was regularly burnt and, indeed, dependent upon burning (Flannery, 1994; Gammage, 2011; Welsh, 2004). This is not supported by Mitchell's 1844–1845 journal, which contains only occasional references to fire in the 2000 km he travelled through Queensland, and no references in 500 km of the semi-arid zone traversed. Similarly, conclusions regarding the open nature of vegetation in central New South Wales based on selective use of historical sources have been refuted by Benson and Redpath (1997).

4. Conclusion

The explorer record provides rare and graphic insight into the extent of landscape change in a region. When examined systematically by geo-referencing all available sources as accurately as possible, testing specific hypotheses and using contemporary observation and understanding of landscape to empower historical interpretation, it can inform key aspects of contemporary land management debates. The explorer record for our study area suggests little change in broad vegetation structure or waterhole permanence. Fires were infrequent and mostly restricted to higher-rainfall grasslands and spinifex-dominated ecosystems. The historical ranges of some medium-sized mammals that are now extinct or rare have been expanded. The dominant large herbivores (macropods) were relatively uncommon in semi-arid areas where they are abundant today. These conclusions are not always consistent with existing dogma but should contribute to debates underpinning contemporary rangeland management and conservation, including land clearing guidelines and legislation, fire management and harvesting of native species. This paper provides a blueprint for rigorous interrogation of this valuable and unique record which can be used to test prevailing assumptions common to arid systems that have been subject to abrupt management upheaval.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2012.11.030.

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