Defining the original extent and floristic composition of the naturally-treeless grasslands of the Liverpool Plains, North Western Slopes, New South Wales

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Abstract: A study was conducted on the Liverpool Plains (30° 43'–31° 44'S; 149° 40'–150° 41'E), North Western Slopes of NSW, to determine the original boundaries of the naturally-treeless grasslands, to determine reasons for the lack of woody vegetation on these areas, and to assess the status of *Austrostipa aristiglumis* (Plains Grass), a species that is today commonly dominant on the few remaining remnant grassland areas and is commonly assumed to characterise the original grassland community. The original tree line boundaries were reconstructed using NSW Lands Department survey portion plans and other historical records. The lack of woody vegetation was attributed primarily to a combination of fine-textured soil, climate and topography restricting the availability of water below the grass root zone, with waterlogging and deep soil cracking possibly playing minor roles. Published and anecdotal evidence and landholder experience indicate that the *Austrostipa aristiglumis* dominated remnants are probably a relatively recent anthropogenic feature, a consequence of post-settlement management practices. The pre-settlement grasslands appear to have been composed of a wide range of grasses, possibly dominated by species such as *Themeda avenacea* (Native Oatgrass) and *Eulalia aurea* (Silky Browntop), with a range of forbs occupying the interstitial spaces. Management implications are discussed.

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Introduction

The Liverpool Plains are located on the North Western Slopes botanical sub-division of NSW and are one of the five main regions in NSW where extensive tracts of naturally-treeless grasslands occurred prior to European settlement (Benson 1996). The Plains were discovered and named by the explorer John Oxley in 1818 and are part of an important and rich agricultural region. However, intensive grazing and cultivation, together with clearing of adjacent woodlands, have impacted on the grasslands, reducing their extent, and masking their original boundaries. Concerns about threats to the grasslands, including coal mining, have led to calls for a conservation strategy for grassland remnants (Urwin 1981, Sim & Urwin 1984). Partly in response to this, the native vegetation on cracking clay soils of the Liverpool Plains of NSW has been listed as an Endangered Ecological Community under the NSW *Threatened Species Conservation Act (1995)* and nominated for listing under the Federal *Environmental Protection and Biodiversity Conservation Act (1999)*. Carter et al. (2003), in their general assessment of the definition, identification and status of Australian Natural Temperate Grasslands, recently estimated that < 10% of the pre-European extent of the Liverpool Plains grasslands remains, and that their survival is threatened.

Community concerns about salinity, biodiversity, dieback and agricultural sustainability, coupled with government vegetation reforms, have focused attention on the management of the nation's native vegetation, soil and water resources. The development of sound management strategies needs to be based on good science including an adequate understanding of the impacts of European settlement on vegetation, soil, biodiversity, and landscape ecosystem function. Vegetation is of special importance because of its use as a surrogate for biodiversity (Smith 2001).

The development of catchment management strategies for remnant areas of the Liverpool Plains natural grasslands requires that the original grassland boundaries be identified and that reasons for the existence of the grasslands be understood. Also, as many grassland remnants are currently dominated by *Austrostipa aristiglumis* (Plains Grass), a species that is widely assumed to characterise the original grassland community (eg, Sim & Urwin 1984, Carter et al. 2003), in spite of evidence that the grasslands of temperate Australia have been profoundly affected by European settlement (Moore 1970, Lodge & Whalley 1989), the status of this grass needs to be clarified.

This project was undertaken to (i) identify and map the original boundaries of the naturally-treeless grasslands of the Liverpool Plains, (ii) to determine the driving processes for treelessness, (iii) to determine the original composition of the grasslands, and (iv) to obtain a preliminary understanding of grassland dynamics, especially the impact of European settlement on species composition.

Study Area

The Liverpool Plains (lat. 30° 43'–31° 44'S; long. 149° 40'–150° 41'E) lie on the North Western Slopes of NSW within the catchments of Coxs Creek, the Mooki River and the Namoi River, between its confluence with the Peel River and Boggabri (Fig. 1). They consist of a series of loosely connected alluvial basins separated by low ridges and hills, and bounded in the south by the Liverpool Range, in the east and north by the Melville and Nandewar Ranges, in the west by the Warrumbungle Range and Pilliga Scrub, a total area of about 800 000 ha. It has been estimated that about 260 000 ha were naturally treeless prior to European settlement (Sim & Urwin 1984).

The alluvial basins, on which most of the naturally-treeless grasslands are thought to have occurred, consist of thick, predominantly basalt-derived unconsolidated Quaternary deposits of < 2% slope gradient. The intervening low ridges and hills, which are thought to have been mostly timbered, consist primarily of strongly weathered and eroded Jurassic and Triassic sandstone and conglomerate sediments, some of which are capped with younger basalts. Volcanic intrusives occasionally project above the alluvia as typically isolated conical hills. The southern hilly to mountainous Liverpool Range was formed from Tertiary basalt flows (Offenberg 1971), while the Melville and Nandewar Ranges to the east and north are composed of mixed sedimentary, metamorphic and volcanic rocks of Devonian to Tertiary ages (Offenberg 1971, Brown et al. 1973). The Warrumbungle Range and Pilliga Scrub to the west are composed of Garrawilla Volcanics and Jurassic age Pilliga and Purlawaugh sediments (Offenberg 1968).

Soils are variable depending on geology and depositional sequence. The alluvial soils are mostly deep fine-textured clays, predominantly Black, Grey or Brown Vertosols (Banks 1995, 1998, 2001 & McInnes-Clark 2002). The hill soils are dominated by Black or Red Vertosols, Chromosols or Tenosols, depending on geology.

The climate is sub-humid with warm to hot summers and cool to mild winters. Average annual rainfall varies from about 550 mm in the centre of the Plains to over 750 mm in the south, on the foot slopes of the Liverpool Range (Bureau of Meteorology 1966). Average rainfall on top of the Liverpool Range is > 950 mm/yr (Banks 1998). Although about two thirds of the annual rainfall is received during the summer months from October to March, rainfall is variable with drought and floods likely to occur in any season.

Methods

Mapping the original boundaries of the naturally treeless grasslands

A range of historical documents and maps were used to construct a map showing the original tree-line boundaries of the Liverpool Plains naturally-treeless grasslands. To do this the area was divided into three main areas.

For an area of about 465 000 ha west of the Mooki River, a 1:400 000 scale map (Fig. 2) of the tree-line boundaries by T.K. Abbott (1880b), and apparently derived from earlier NSW Lands Department surveys, was used as a base map. Using this map as a guide, NSW Lands Department 1:15 000 scale survey portion plans (held in the Lands Dept Plan Room, Sydney) were examined. A strategic one-third (due to time constraints) of the plans that contained tree-line boundaries were selected, and tree-line boundaries transcribed to 1:25 000 to 1:30 000 Parish maps, for later desk and field verification. A small sub-sample of the selected portion plans was photocopied for later detailed field verification. Criteria for sub-sample selection were that (i) the tree-line boundaries occurred in areas where little or no clearing was known, or thought to have occurred and (ii) the tree-lines coincided with public roads (for ease of access).

For the headwaters of the Mooki River between Werris Creek and Blackville, an area of 100 000 ha, tree-line boundaries were obtained from the Australian Agricultural Company (AAC) survey maps and historical documents (located in the Noel Butlin Archives Centre, ANU, Canberra). This AAC land had been taken up in the early to mid 1800s and, due to the lease agreement, no government surveys were undertaken.

For the remaining 235 000 ha, the lower catchment of the Mooki River and the Namoi River between Carroll and Boggabri, tree-line boundaries from a strategic selection of most, but not all NSW Lands Department survey plans that contained tree-line boundaries, were transcribed to 1:25 000 to 1:30 000 Parish maps, to complete the composite map and for later verification. A small sub-sample of these portion plans were also photocopied for detailed field verification.

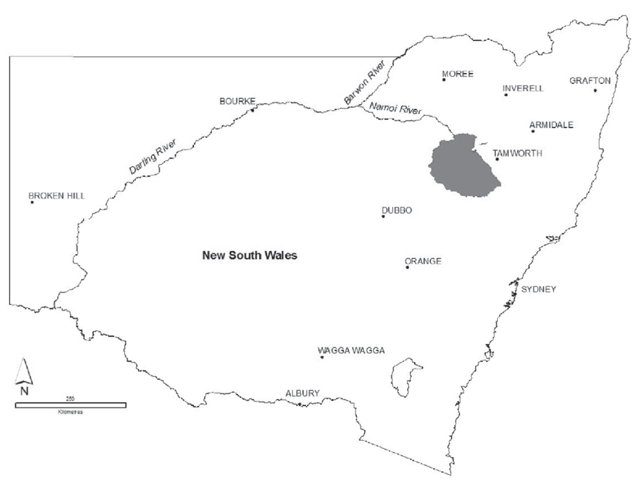

Fig 1. Location of the Liverpool Plains on the North Western Slopes of New South Wales.

For all three areas, the location of tree-line boundaries from the Parish maps were compared with pre-1970 topographic maps (1:31 680 scale) and aerial photographs. These maps and photographs pre-date the period of widespread clearing of timber in the 1950s and 1960s when the introduction of large machinery made cultivation of the heavy clay soils practical. The journals of the early nineteenth century explorers John Oxley, Allan Cunningham and Thomas Mitchell were used to confirm areas of grasslands and woodlands where appropriate.

Field verification of tree-line boundaries on the photocopied plans was undertaken by comparing the orientation and distance of tree-lines from key features, such as roads and portion boundaries, with existing tree-lines and corresponding features. The resultant composite map was digitised by the Gunnedah Resource Centre GIS unit using Esri-ArcView 3.

Grassland determinants

The distribution of the Liverpool Plains grasslands was assessed in relation to factors raised in a literature review to identify explanations for the absence of woody vegetation on areas of naturally-treeless grasslands worldwide, and especially Australia. As part of this assessment, the location of the grasslands on the composite map was compared by simple overlay to the Department of Natural Resource's (DNR) < 2% slope terrain map for the Liverpool Plains and Soil Landscape maps for Blackville, Curlewis, Murrurundi, and Tamworth.

Original grassland composition

Literature was reviewed for information on the botanical composition of the Liverpool Plains grasslands and similar nearby areas. Evidence for floristic changes and possible reasons for such changes over time were noted.

Survey of roadside reserves and landholder interviews

To obtain preliminary information on grassland dynamics a survey of seven roadsides (Pine Cliff, Trinkey Forest, Grain Valley, Melrose, Maxwell, Crisps and Wean Roads) in the central and northern Liverpool Plains was conducted during the period 2005–2006. This aimed to locate colonies of the grass *Eulalia aurea* (Silky Browntop), selected because

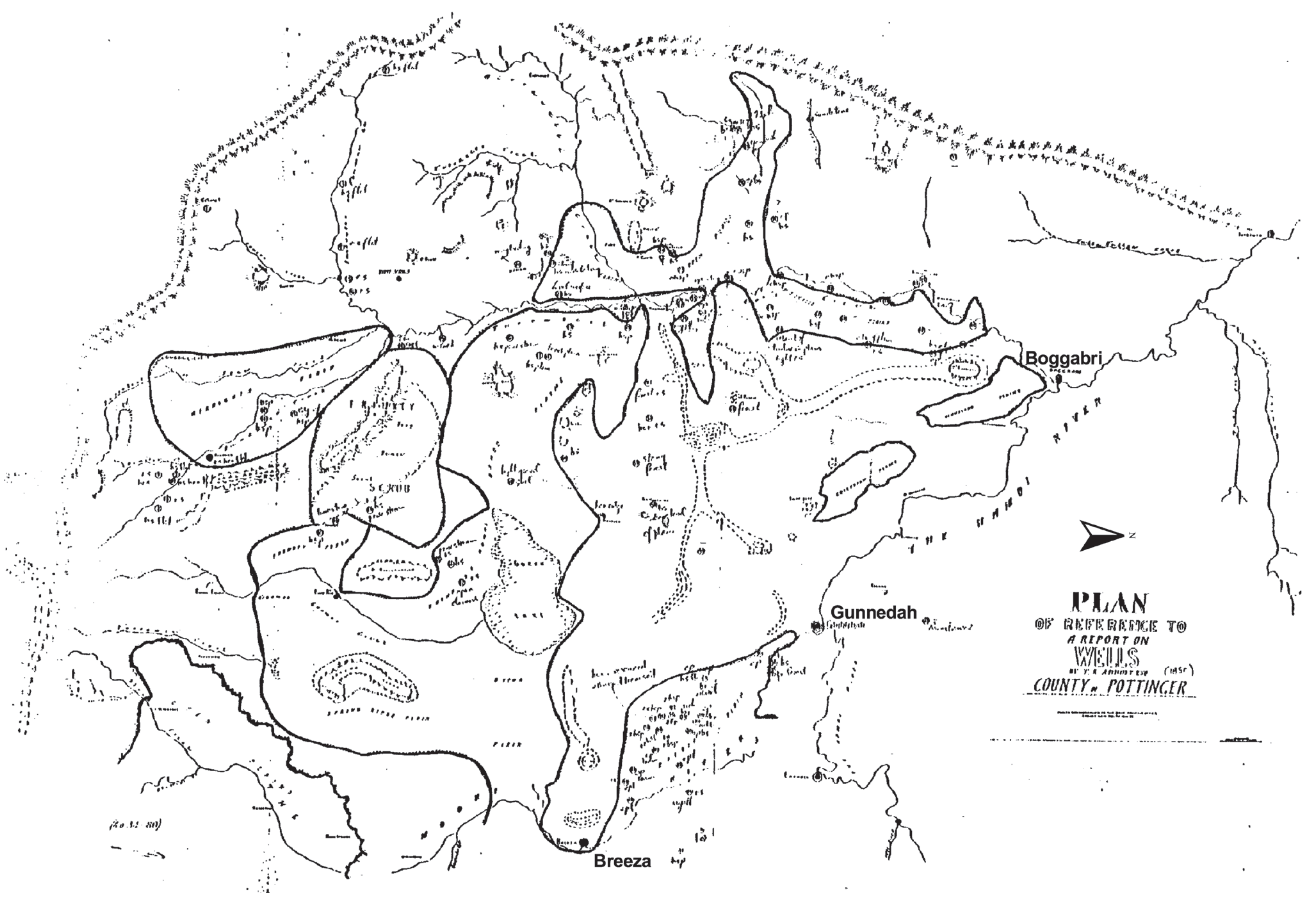

Fig. 2. Tree-line boundaries of the Liverpool Plains naturally-treeless grasslands west of the Mooki River as detailed on the "Plan of Reference to a Report on wells" by T.K. Abbott (1880b) "On Wells in the Liverpool Plains".

evidence previously collected indicated that (a) this species was previously much more abundant on the Plains than it is now, (b) it may have been a co-dominant species, at least on the northern Plains, (c) its abundance has been increasing on roadside reserves during the last 10–30 years, apparently following the introduction and widespread use of motorised stock transport and consequent changes in grazing pressures, and (e) newly established plants appeared to increase in size with time gradually forming large tussocks and thereby providing an opportunity to identify whether colonies of this plant are increasing, stable or declining.

The diameters of a random selection of plants and tussocks were counted at 1 m intervals along either a linear transect or along radii from a central plant or tussock, depending on the size of the stand. At least 10 plants and tussocks were measured per transect except, however, for very small colonies, ie, < 1 m diameter, when all plants were measured. In addition, the diameters of 10 randomly selected large tussocks were measured in a stand known to be at least 12 years old on the northern Plains property "Mallee Springs".

Landholders who had observed changes to grassland pastures containing key species, such as *Themeda avenacea* (Native Oatgrass), *Eulalia aurea*, *Astrebla lappacea* (Curly

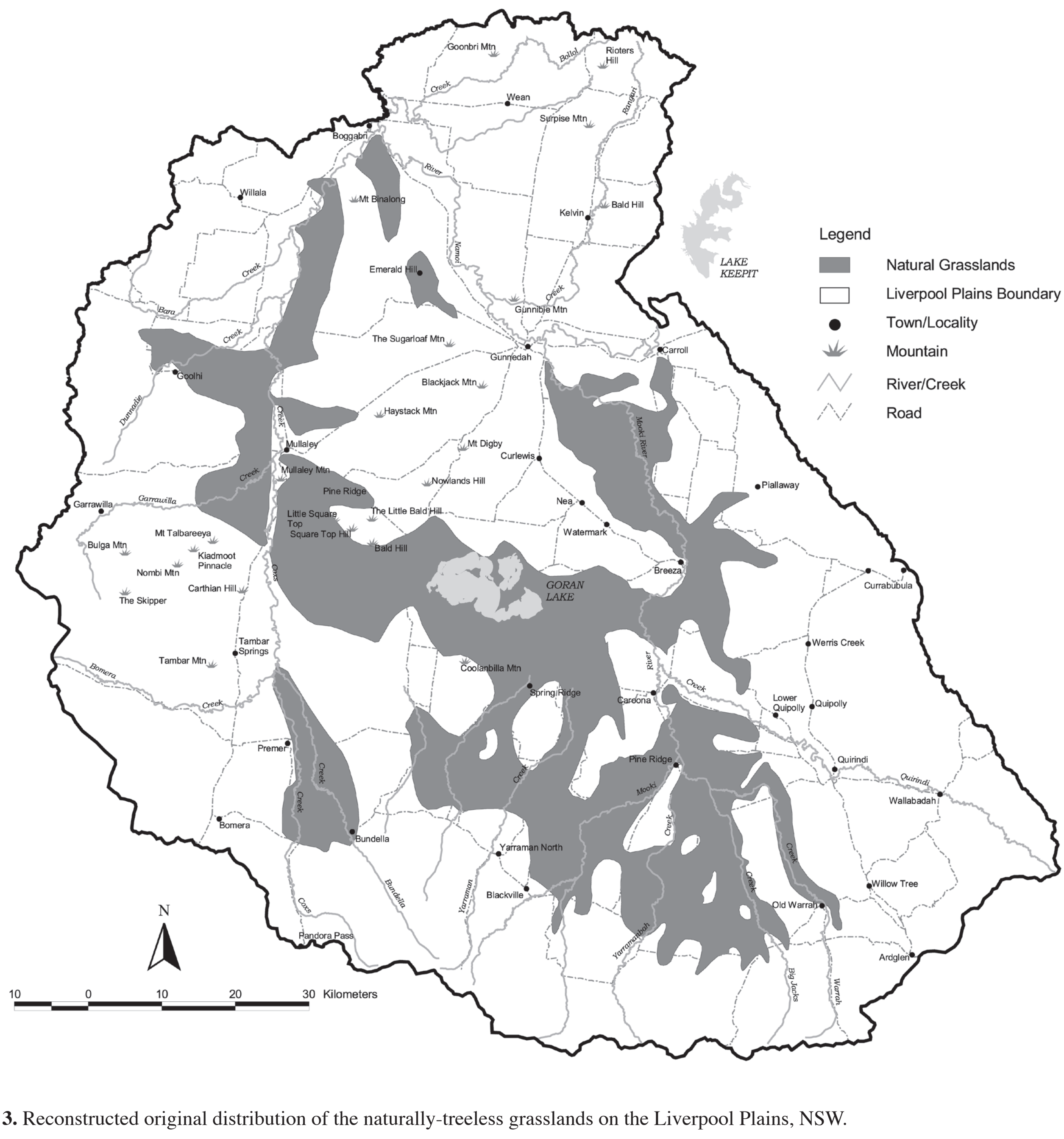

Fig. 3. Reconstructed original distribution of the naturally-treeless grasslands on the Liverpool Plains, NSW.

Mitchell grass), *Dichanthium sericeum* (Queensland Bluegrass) and *Austrostipa aristiglumis*, following changes to grazing management practices were interviewed and their observations noted.

Results

Mapping the original boundaries of the naturally-treeless grasslands

The reconstructed boundaries of the naturally-treeless grasslands of the Liverpool Plains are shown on Fig. 3. For the region west of the Mooki River, tree-line boundaries were transcribed from 306 Lands Dept portion plans, while for the region east of the Mooki River, excluding the AAC holding, boundaries from 277 plans were transcribed. These represented about one third and two thirds, respectively, of the plans that were estimated to document tree-line boundaries. The earliest plan sighted was dated 1839, while the latest plan was dated 1918. Most plans were dated from 1864 to 1885.

Three AAC survey maps were examined, an 1832 map (Deposit 1/452C/2) drawn by surveyor Henry Dangar, a map (78/1/17, p718) accompanying an AAC Report (King 1842) and an 1894 AAC Warra Estate survey map (Ref: B105).

Tree-line boundaries between natural grassland and woodland were indicated on portion plans e.g. Fig. 4 (Portion 190, Parish of Bando, County of Pottinger, dated 1901) where open level black soil plain and adjacent gum and myall woodlands both north and south of Mt Mullaley are clearly delineated. Where clearing had not taken place and where soil and geological differences were distinct, tree-line boundaries were easily located and identified during field reconnaissance (Fig. 5). However, on low slope gradient alluvia of differing depositional facies and susceptibilities to waterlogging, and where geology was broken and complex, the boundaries between the grassland and woodland were contorted. Scattered individuals or clumps of trees often formed a transition zone between distinct grassland and adjacent woodland (Fig. 6).

Boundary accuracy

The accuracy of the portion plan tree-line boundaries was estimated to be about ± 50 m where tree-line boundaries could be related to key physical features, such as roads and fence lines located on portion boundaries. Where distinctive physical features were not present and where clearing had taken place, the tree-line boundaries were difficult or impossible to locate. The accuracy of tree-line boundaries on both Abbott's 1:400 000 scale map (Fig. 2) and the composite map (Fig. 3) was estimated to be ± 0.5–1 km. Accuracy was greatest where fine-textured soil abutted sharply against coarser material and where the geology was simple. Accuracy was least where transition zones occurred and where geologies were complex.

Grassland determinants

A wide range of publications have addressed the distribution or state of grasslands worldwide, but relatively few specifically considered reasons for the existence of naturally-treeless grasslands. Of most relevance to this study are Cambage (1909), Barnard (1964), Moore (1964 & 1970), Beadle (1981), Walker et al. (1981), Titlyanova et al. (1990), Ripley (1992) and Benson (1994). The general conclusion is that the absence of trees on naturally occurring grassland is due to a complex combination of factors, including climate (rainfall, temperature and wind), topography and soil type. Rarely was one single factor thought to satisfactorily explain the existence of natural grasslands.

Ripley (1992) noted that natural grasslands occur throughout the world on a variety of substrates and landscapes in regions where precipitation ranges from 350 to 800 mm/annum and where periodic droughts occur. Cambage (1909), during an extensive floristic survey of NSW, suggested that the lack of trees on the Monaro Plain in southern NSW could be explained by a combination of low rainfall, cold temperatures, drying summer winds and soil structure. Both Moore (1964

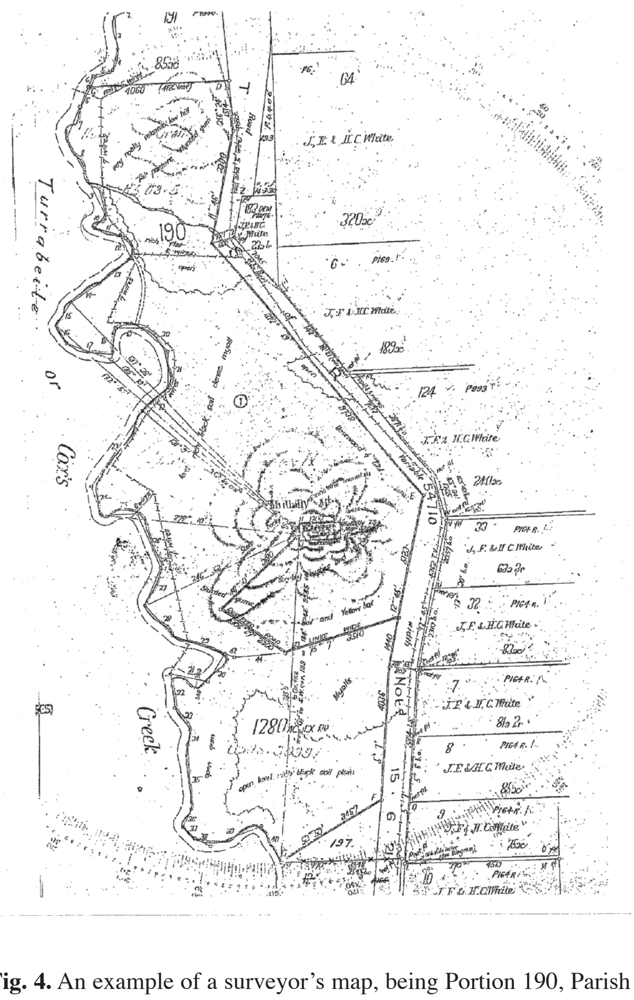

Fig. 4. An example of a surveyor's map, being Portion 190, Parish of Bando, County of Pottinger (dated 1901), showing the tree line boundary between open black soil plain natural grassland and adjacent woodlands around Mt Mullaley.

& 1970) and Benson (1994) recognised the importance of fine-textured soil and restricted soil moisture for Australian grasslands, factors also recognised as important globally by Titlyanova et al. (1990). Walker et al. (1981) were more specific, suggesting that grasses are more efficient than trees in extracting water from the topsoil layer, but that below the grass root zone (typically the subsoil) woody vegetation has nearly exclusive use of whatever water gets through. Beadle (1981) identified five habitats in Australia where one or more environmental factors prevent the development of trees or shrubs, viz, the littoral zone, aquatic and waterlogged habitats, fine-textured soils, the arid zone and frost hollows. Of most relevance to this study is "areas of fine-textured soils, mainly in the semi-arid zone…..where soil texture restricts water-availability, preventing growth of trees, the factor probably acting in conjunction with deep soil cracking or with temporary seasonal waterlogging".

Robbins (1963) considered the factors responsible for the development of derived grasslands during his study of the grasslands of Papua and New Guinea. He attributed their existence to human activity through frequent burning, factors that, together with grazing by domestic stock, are considered responsible for derived grasslands throughout the world (Moore 1964). However, no information was found on the role of aboriginal burning practices in explaining the existence of the Liverpool Plains grasslands. Idriess (2003) and O'Rourke (2005) both provide a detailed account of the life of the Gunn-e-dar tribe (the principal tribe on the Plains) and the Liverpool Plains landscape, but offer little if any information on their use of fire, apart from cooking food. Oxley (1820) noted that parts of the Plains grassland had been previously burnt, but gives no indication that the extent, or nature of the burnt area was unusual.

Comparing the composite map's distribution of the treeless grasslands with DNR's slope terrain and Soil Landscape Maps, together with field reconnaissance, revealed that the grasslands were recorded only on Vertosols where annual average rainfall ranged from 550 mm to about 700 mm and mostly where slope gradients were < 2%. Grasslands were occasionally found on slopes up to 4%, for example

Fig. 5. Distinct tree line boundary between the naturally-treeless grassland of Harrisons Plain and adjacent box woodland on the Harrisons Plain Road.

the southern and south-eastern region of Goran Lake, an area known as the high plain, and on the slopes of volcanic intrusive hill outcrops.

In contrast, woodlands were found on all soil types, rainfall zones and slope gradients. However, trees were found growing on Vertosols only where additional moisture was probably available, such as the higher rainfall slopes of the Liverpool Range, the banks of larger creeks and rivers, and in low landscape situations subject to extended waterlogging. Small ephemeral creeks on heavy clay alluvia were found to be bare of timber.

Original grassland composition

No comprehensive or detailed botanical survey or description of the original vegetation of the natural grasslands of the Liverpool Plains was found. However, scattered references to grassland species and floristic trends on the Liverpool Plains and adjacent areas were found in the journals of early explorers, other historical documents and the scientific literature dating from the time of European settlement to the present. Twenty references were found which identified grassland species on the Plains while ten references were found that made reference to floristic trends following land management changes (Table 1).

Survey of roadside reserves and landholder interviews

Roadside surveys: Nine scattered colonies of *Eulalia aurea* (Silky Browntop), ranging in size from 1 m^2 to 6 400 m^2, were found along four of the seven roadside reserves surveyed (Wean, Melrose, Maxwell and Crisp). The diameter of 188 *Eulalia aurea* tussocks ranged from 1 to 67 cm, with 68% of the tussocks being less than 15 cm in diameter. Locals maintain that these colonies have been expanding during at least the last 10–17 years (K Sheridan, landholder, and D Collins pers. comm.), a period that coincides with stock movement by motorised transport and consequent reduced grazing pressure on the roadside reserves. The diameter of ten tussocks of *Eulalia aurea* known to be more than 12 years old on the property "Mallee Springs" ranged from 35 to 70 cm. Average tussock diameter was 51 cm.

Fig. 6. Transition zone between the naturally-treeless grassland of Colygra Plain and box woodland near the Gunnedah-Boggabri Road.

Landholder interviews: Information was obtained from four landholders on the behaviour of native grasses following changes to their grazing regime during the last 10 years. Anecdotal evidence was collected on the sowing of *Austrostipa aristiglumis* during the late 1800s and on the occurrence of *Astrebla lappacea* (Curly Mitchell Grass) in the early 1900s.

Mr R Frend (pers. comm.) observed that the proportion of *Themeda avenacea* on his central Plains property, "Dimberoy", had increased following the introduction of a rotational cell-based grazing system.

Mr M Payne (pers. comm.) observed that the proportion of *Eulalia aurea* in an *Austrostipa aristiglumis* dominated paddock on his property "Mallee Springs", north of Gunnedah, had increased markedly, from the base of a few plants in the paddock, in the seven year period following the introduction of a rotational crash grazing strategy that specifically mimicked the grazing habit of kangaroos. Visual appraisal in 2004 revealed that *Eulalia aurea* constituted about 60 per cent and *Austrostipa aristiglumis* about 20 per cent of the paddock.

On the property, "Retreat", also north of Gunnedah, small colonies of *Astrebla lappacea* (Curly Mitchell grass) and *Themeda avenacea*, as well as native legumes, in particular *Glycine* spp., have been expanding following the introduction of an intensive rotational grazing system (R Penrose pers. comm.). Long-time residents believe that *Astrebla lappacea* (Curly Mitchell Grass) was common on the Plains in the early 1900s (R Penrose pers. comm.).

A *Dichanthium sericeum* (Queensland Bluegrass) dominated paddock near Colly Blue, on the southern Plains, that for many decades had been intermittently and conservatively grazed (R Banks, DNR Soil Surveyor, pers. comm.) was noted to have been converted to an *Austrostipa aristiglumis* dominated paddock within five years following the introduction of a continuous heavy grazing regime (pers. obs. by author).

Mr J Carter (pers. comm.) understands that his father spread *Austrostipa aristiglumis* (Plains Grass) seed from horseback on the southern Plains property "Yarraman North" during the last half of the 1800s. It was not known why the seed was sown or the condition and composition of the grassland prior to sowing.

Table 1. Historical references to grassland species and floristic trends on the Liverpool Plains and adjacent areas.

Grassland species:

Oxley (1820): Crossed the Plains from west to east but provides very little information on the herbaceous stratum, although he makes frequent reference to lithology, soil and tree species. Mr Evans, a member of the expedition, sketched a view of the Liverpool Plains from a hill looking east over the Mullaley district which shows open grassland and clumps and lines of timber.

Cunningham (in Lee 1923): Descended onto the Plains from Pandora's Pass on May 2, 1825, and described the indigenous vegetation of the land traversed: "a species of Plantago, or rib-grass; Scorzonera sp., or viper's grass; Lotus, or birdsfoot trefoil; Centaurea occidentalis; Ajuga australis, or bugle; Campanula gracilis, or bell-flower; Rumex dumosus, or dock; Galium aparine, or goose-grass; Epilobium, or willow-herb. There were no fewer that eight distinct grasses, among which a late Danthonia gigantea (giant oatgrass resembling wheat on the ear) was most remarkable. Ranunculus lappaceus, Lobelia inundata, Arundo phragmites, and Indigofera sp., a proof of a permanent marsh – were also observed." Unfortunately, Lee (1923) does not indicate whether Cunningham identified the other seven grasses, and Cunningham's original manuscript was not sighted. No mention is made of the location or abundance of these plants.

Nesbit (1831): Described a tall oat like grass, which the colonists referred to as native oatgrass, growing in abundance while assessing the south-eastern Liverpool Plains for the AAC.

Mitchell (1832): provides no useful information on the herbaceous stratum, although he made frequent comments on lithology, soil and tree species.

Bentham (1878): Provides a very early botanical record of the Plains, having collated various early plant collections. Twelve grass species are recorded as having been collected on the Liverpool Plains (Table 2), including Austrostipa (syn. Stipa) aristiglumis, Themeda (syn. Anthistiria) avenacea, Eulalia aurea (syn. Pollinia fulva) and Dichanthium sericeum (syn. Andropogon sericeus). The records do not refer to abundance or whether the species were collected on black or red soils, or on the alluvial basins or intervening hills.

Rev. Mr Boodle (in Galbraith 1988): Described the grassy vegetation growing during the late 1830s on "Collaroy", on the southern Plains: "The grasses consist mainly of barley grass, kangaroo grass, oaten grass. All these grow in tufts".

William Telfer Jr: Telfer, an early settler in the area, described the vegetation on four occasions in his memoirs (in Milliss 1980). Writing specifically about the Liverpool Plains during the mid-1800s: "the splendid herbage on those plains in a good season was something magnificent and the long oaten grass…", of Walhollow Station he wrote: "of the wild oaten variety and a few inches from the ground in the middle of this forrest (sic) of long grass were wild Carrots Crowsfoot and a splendid lot of herbage of all descriptions", on the area from Quirindi to Kicherabel (sic) Station he wrote: "the long oaten grass was fully seven feet high on this (sic) plains at that time".

NSW Lands Department survey plans: Very few references to species were found in these plans. The surveyors rarely identified species in the herbaceous stratum although they often described the soil, at least by colour, documented significant landscape features, and identified tree species. The herbaceous stratum was mostly described in general terms such as "open plains", "well grassed", "poorly grassed" or "barren". Only five of the sighted plans specified the ground flora. Four plans (Plans 105 and 114–116, dating from 1873 to 1883) on the Merrigula Parish map noted an area of "poorly grassed myall scrub" being "with saltbush". Plan No. 166, dated 1918, on the Premer Parish map contained annotations of "no plains grass", "has been cultivated", "with barley grass" and "lucerne".

Turner (1895): An early NSW Department of Agriculture botanist noted that Eulalia aurea (Silky Browntop) and Themeda avenacea (Native Oatgrass) were found in all the Australian Colonies and grew on the "richest of soils".

Turner (1905): Lists 134 native grasses that were present in north-western NSW. He noted that six species of Austrodanthonia (syn. Danthonia), (Wallaby Grass), three species of Astrebla, (Mitchell Grass), Chloris spp. (Windmill Grasses) and species of Eragrostis (Love grasses) were "well distributed over the region" and "prominent amongst the pasture herbage". He also noted that T. avenacea "often grows nine feet high on the black soil plains", and mentioned Austrostipa aristiglumis "growing nine feet six inches high on the Liverpool Plains".

Breakwell (1923): Also an early NSW Department of Agriculture botanist noted that Eulalia aurea was confined mostly to the western districts where it grew "luxuriantly" on the "black soils" of north-western NSW.

McTaggart (1938): In a survey of the pastures of Australia, listed the dominant grasses on the Liverpool Plains as Dichanthium sericeum (Queensland Bluegrass), Austrostipa aristiglumis (Plains Grass), A. scabra (Rough Speargrass), A. setacea (Corkscrew Grass), and Wallaby grasses. He noted a change in the species composition from the northern to the southern portion of the Plains, with the latter species becoming dominant and the others co-dominant. Windmill grasses, Chloris spp. (star grasses) and Themeda australis (Kangaroo Grass) are listed as sub-dominants. He noted that the Plains, particularly the northern Plains, contained similar herbage plants to that which occurred in the southern portion of the Mitchell-Queensland Bluegrass area. Forbs included "trefoil (Medicago spp.), Lamb's Tongue (Plantago spp.), Wild Carrot (Daucus carota), crowfoot (Erodium spp.), Roly Poly (Salsola kali), Rhagodia nutans, and Enchylaena tomentosa".

Moore (1970): Appraised the dry temperate grasslands of southern Queensland, NSW and Victoria and, of the Liverpool Plains, states that "The dry Temperate Grasslands are now Stipa aristiglumis syn. S. bigeniculata (plains grass) and Danthonia spp" . NB: S. bigeniculata is not now considered synonymous.

Williams (1979): Surveyed the natural pastures in the north-western slopes of NSW and found two mutually exclusive sub-associations on the heavy clay alluvium of the Liverpool Plains (i) an almost pure stand of Austrostipa aristiglumis and (ii) a botanically more complex association dominated by Enteropogon acicularis (Curly Windmill Grass), with various sub-dominants. The factors favouring one association or the other were not identified.

Soil Conservation Service District Technical Manuals (Anon. 1975, Anon. 1976, Anon. 1980, Marston 1984): In a general vegetation survey, the naturally-treeless grasslands of the Liverpool Plains were delineated on maps of the vegetation in the Gunnedah, Quirindi, Murrurundi and Coonabarabran District Technical Manuals, together with a list of the grasses found in the grasslands. A "Plains Grass (Stipa aristiglumis) dry tussock grassland" was described on the "heavy-textured cracking clay soils often associated with the flood plains of the major creeks and rivers". Austrostipa aristiglumis was noted to "almost totally dominate the sward in much of the un-disturbed areas of the community". Between three and eight other native grass genera or species, depending on the district, are listed as sub-dominates (Table 3). The composition of the sub-dominants varies with each district. Dichanthium sericeum is listed as a sub-dominant in all four districts, Astrebla lappacea is listed in two districts while Eulalia aurea is listed in one district only. Themeda australis (Kangaroo Grass) is listed in two districts but Themeda avenacea is not listed in any district.

Bean & Whalley (2001): In a study of 16 non-arable remnant native grassland sites in a 72 km2 sub-catchment of Garrawillie Creek, on the western margin of the Liverpool Plains, seven native grassland associations were identified on two rock types. Austrostipa aristiglumis was recorded from four of the associations but was abundant only in one association, the Austrostipa aristiglumis Association, where it dominated (frequency score 8.0) (Table 4). Other native grasses found in this association were Aristida ramosa (4.0), Austrostipa scabra (2.0), Austrostipa verticillata (2.0), Eriochloa pseudoacrotricha (2.0) and Bothriochloa spp (1.0). The Austrostipa aristiglumis Association site is the only site that previously may have been a naturally-treeless grassland or, more likely, to have been closely associated with the adjacent naturally-treeless grassland.

Hosking (unpub. data): Lists 195 native species, including 45 native grasses and 124 native Dicotyledons (including 12 native legumes) as growing on 10 remnant grassland sites in a continuing survey (to January 2006) of the flora of the cracking clay soils of the Liverpool Plains (Table 5). Austrostipa aristiglumis is the only native grass found growing at all 10 sites. Dichanthium sericeum and Cynodon dactylon (Common Couch) were found at eight of the sites while Austrodanthonia bipartita (Wallaby Grass), Enteropogon acicularis, Eriochloa pseudoacrotricha (Early Spring Grass), Lachnagrostis filiformis (Blowngrass), and Panicum queenslandicum (Coolibah Grass) were found at seven. Themeda avenacea was found at three sites, and Eulalia aurea and Astrebla lappacea at one site only.

Floristic trends and other significant landscape changes:

Oxley (1820): During his second trip down the Macquarie River, Oxley commented critically about the destruction occasioned by cattle to waterholes in the few years since his first trip.

Gardner (1854): Expressed concern that the herbaceous stratum over northern and western NSW was severely impacted by stock, stating "sheep runs have affected (sic) great alterations…and pretty nearly swept the grasses clean out of sight, in the space of twenty years from many a luxuriant and lovely spot".

Telfer (in Milliss 1980): Writing about the Galathera Plains, not on the Liverpool Plains but an adjacent Plain near Narrabri, in 1895: "were quite bare of grass and like a desert of black ground a few dry Rolly Polly blowing about the plain with Clouds of dust and hot winds". Telfer compared the Peel River valley at the time of writing (approximately 1900) to his memories of the region in 1851: "is first class plains Country or river flats and overstocking deteriates (sic) the Country destroying the natural Grasses and herbage Causing (sic) a lot of useless weeds to grow in place of it". He compared the "Qirindi (sic) Liverpool Plains" at the time of writing to the region in 1844: "but now there is a lot of noxious weeds growing in place of the natural pasture … when a run is overstocked they destroy the natural grasses there is nothing but rubbish to take its place". On Walhollow Station (Liverpool Plains) he wrote: "in 1858 I saw grass on those plains ten feet high which you dont (sic) see those (sic) days now the Country has been fenced in and overstocked".

Maiden (1898): Noted that "…of overstocking, with the result that the grasses most palatable to stock are temporarily (or perhaps permanently) eaten out, while their place is taken by weeds and inferior grasses – grasses which have spread, because they have been comparatively uninterfered (sic) with by stock".

Turner (1895): Noted that "Overstocking and the rabbit pest…have already had an injurious effect upon some of the natural herbage… the more valuable plants have been so persistently eaten down that they are gradually dying out…many noxious weeds, both indigenous and exotic, bad grasses, and pine scrub are gradually occupying their place".

Breakwell (1923): Commented on Themeda avenacea that "there is still a good deal of it on the Liverpool Plains, but elsewhere it is not nearly as abundant as previously".

Moore (1970): Of the Liverpool Plains, states that "The dry Temperate Grasslands are now Stipa aristiglumis syn. S. bigeniculata (plains grass) and Danthonia spp. Originally Themeda avenacea (native oatgrass) appears to have been at least co-dominate with Stipa but is now found only in areas totally protected from grazing".

Anon. (1975): Noted that when Austrostipa aristiglumis grasslands were cropped they tended to revert rapidly to a Plains grass dominant community once cultivation ceased.

Marston (1984): Noted that disturbance of the grassland by cultivation allowed "other species to invade and dominate, or establish co-dominance with the plains grass".

Lodge & Whalley (1989): Postulated that originally, on the fine-textured soils of the lower northern slopes of NSW, Austrostipa aristiglumis was co-dominant with Themeda australis, Sorghum leiocladum (Wild Sorghum) and Dichanthium sericeum (Queensland Bluegrass). They concluded that the evidence suggested that associated species included Chloris spp., Sporobolus spp., Eulalia aurea, Eragrostis brownii (Brown's Lovegrass), Enneapogon nigricans (Niggerheads) and Panicum effusum (Hairy Panic). They noted that Austrostipa aristiglumis "is only commonly found on heavy textured soils".

Table 2. Grass species collected by Cunningham, Moore, Leichhardt, Stuart and Woolls on the Liverpool Plains and listed in Bentham (1878). Nomenclature follows Wheeler et al. (2002)

Current name	Species as listed historically
Alloteropsis semialata	*Panicum semialatum*
Aristida leptopoda	*Aristida leptopoda*
Aristida ramosa	*Aristida ramosa*
Arundinella nepalensis	*Arundinella nepalensis*
Austrostipa aristiglumis	*Stipa aristiglumis*
Capillipedium parviflorum	*Chrysopogon parviflorus*
Dichanthium sericeum	*Andropogon sericeus*
Enneapogon nigricans	*Pappophorum nigricans*
Eragrostis brownii	*Eragrostis brownii*
Eulalia aurea	*Pollinia fulva*
Sporobolus caroli	*Sporobolus lindelyi*
Themeda avenacea	*Anthistiria avenacea*

Table 3. Native grass species from four Soil Conservation Service of NSW District Technical Manuals that describe the naturally-treeless grasslands of the Liverpool Plains.

Dominants	Sub-dominants
Gunnedah Technical Manual	
Austrostipa aristiglumis	*Panicum* spp.
[syn. S*tipa aristiglumis*.]	*Dichanthium sericeum* *Chloris* spp.
	Aristida spp.
	Austrostipa spp. [syn. *Stipa* spp.]
	Austrodanthonia spp. [syn. *Danthonia* spp.]
Quirindi Technical Manual	
Austrostipa aristiglumis	*Dichanthium sericeum*
	Chloris truncata
	Themeda australis
	Eulalia aurea [syn. *E. fulva*]
	Eragrostis spp.
	Austrostipa scabra [syn. *Stipa scabra*]
	Astrebla lappacea
Murrurundi Technical Manual	
Austrostipa aristiglumis	*Dichanthium sericeum*
	Chloris spp.
	Panicum spp.
Coonabarabran Technical Manual	
Austrostipa aristiglumis	*Dichanthium sericeum* *Chloris truncata*
	Themeda australis
	Eulalia aurea
	Eragrostis spp.
	Austrostipa scabra
	Astrebla lappacea
	Eriochloa pseudoacrotricha

Table 4. Occurrence of *Austrostipa aristiglumis* and associated native grass species, with mean frequency scores, in grassland Association 7 on a gentle south-east slope on Garrawilla Volcanics (altitude 380 m) in Garrawillie Creek sub-catchment, western Liverpool Plains.

Species	Frequency score
Austrostipa aristiglumis[1]	8.0
Austrostipa scabra	2.0
Austrostipa verticillata	2.0
Aristida ramosa	2.0
Eriochloa pseudoacrotricha	2.0
Bothriochloa decipiens/macra	1.0

Associations 1–6 located most likely on previously timbered slopes.
[1]*Austrostipa aristiglumis* was also recorded in:

Association 3 (frequency 0.3), an *Aristida ramosa, Bothriochloa decipiens/macra* and *Dichanthium sericeum* Association on phonolite scree on steeper slopes (altitude 440–460 m),

Association 4 (frequency 0.3), a *Bothriochloa decipiens/macra* Association on Garrawilla Volcanics (altitude 435–440 m), and

Association 6 (frequency 0.5), a *Dichanthium sericeum* Association on very gentle slopes on Garrawilla Volcanics (altitude 410–420 m).

Table 5. Poaceae taxa collected to January 2006 by John Hosking (unpublished data) in his continuing survey of the flora of cracking clay soils of the Liverpool Plains, with number of sites (out of 10) where each species has been found. (Nomenclature follows Wheeler et al. (2002))

Species	Common name	Number of sites
Amphibromus nervosus	-	2
Aristida leptopoda	White Speargrass	5
Astrebla lappacea	Curly Mitchell Grass	1
Austrodanthonia bipartita	Wallaby grass	7
Austrostipa aristiglumis	Plains Grass	10
A. scabra subsp. *scabra*	Speargrass	1
A. verticillata	-	2
Bothriochloa biloba	-	5
B. macra	Redgrass	1
Bromus arenarius	Sand Brome	6
Chloris truncata	Windmill Grass	6
Cynodon dactylon	Common couch	8
Dactyloctenium radulans	Button Grass	1
Dichanthium sericeum	Queensland Bluegrass	8

Digitaria divaricatissima	Umbrella Grass	3
Diplachne fusca	Brown Beetle Grass	3
Echinochloa colona	Awnless Barnyard Grass	4
Elymus scaber var. *plurinervis*	Wheatgrass	5
Enneapogon nigricans	Niggerheads	1
Enteropogon acicularis	A Curly Windmill Grass	7
Eragrostis leptostachya	Paddock Lovegrass	3
E. parviflora	Weeping Lovegrass	1
Eriochloa crebra	Cup Grass	1
E. pseudoacrotricha	Early Spring Grass	7
Eulalia aurea	Silky Browntop	1
Iseilema membranaceum	Small Flinders Grass	1
Lachnagrostis filiformis	Blowngrass	7
Leptochloa divaricatissima	-	3
Panicum buncei	-	4
P. decompositum	Native millet	5
P. queenslandicum var. *queenslandicum*	Coolibah Grass	4
Paspalidium aversum	-	4
P. constrictum	Knottybutt Grass	1
P. globoideum	Shotgrass	1
P. gracile	Slender Panic	2
P. jubiflorum	Warrego Grass	2
Paspalum distichum	Water Couch	4
Phragmites australis	Common Reed	1
Poa fordeana	-	4
Sporobolus caroli	Fairy Grass	3
S. mitchellii	Rat's Tail Couch	1
Thellungia advena	Coolibah grass	1
Themeda avenacea	Native Oatgrass	3
Tragus australianus	Small Burrgrass	1

Discussion

This study has shown that valuable information can be obtained from a wide variety of sources to assist in reconstructing pre-European vegetation patterns, in assessing subsequent changes in species composition, and in understanding species and community dynamics. However, as Jeans (1978) and Mactaggart et al. (2007) have correctly pointed out, written historical data should be interpreted cautiously and with a clear understanding of their limitations. Similarly, attempts to infer vegetation patterns and ecological relationships from existing vegetation remnants should proceed with caution given the possibility of extensive post-settlement landscape changes for which evidence may have long since disappeared.

Mapping the original boundaries of the naturally-treeless grasslands

Land survey and other historical records were a valuable source of information that enabled pre-settlement vegetation patterns to be reconstructed, and complements the work of Jeans (1978), Fensham & Fairfax (1997), and Martin (2001). However, an interpretation issue of particular concern to this study was the possibility that significant tree clearing may have occurred between initial settlement and subsequent land alienation surveys. The majority of surveys were done during the period 1860–1885, some 30–40 years after occupation; early clearing may therefore not have been recorded on portion plans. Evidence indicates that this is not a serious concern however. Abbott (1880a) states that ringbarking, the most widespread and significant form of clearing at that time, did not commence in the adjacent Hunter Valley until the 1860s, and did not become general until the 1870s. Jeans (1978) found that "drastic intervention", such as ringbarking, was "very often recorded" on the portion plans. In fact, annotations to ringbarking were found on occasional portion plans but only on those dated after the mid-1870s. Thus it seems reasonable to assume that most of the portion plans show the tree vegetation as preceding any widespread clearing, and that the portion plans are most likely to have recorded "drastic intervention" events where these events had occurred.

Grassland determinants

The physical environment (climate, soil and topography) of the inferred naturally-treeless grasslands of the Liverpool Plains corresponds precisely with the factors thought responsible for naturally-treeless grasslands around the globe. In particular, the high water holding capacity of the heavy smectite clay soils (Banks 1995, 1998, 2001 & McInnes-Clark 2002), relatively low rainfall, high evaporation rates and a year-round potential growing season are consistent with the factors outlined by Walker et al. (1981) and Beadle (1981) that explain the existence of naturally-treeless grasslands. The presence of trees on coarse and medium-textured soils, and on Vertosols that most likely experience enhanced water availability, would tend to support the significance of the hydro-edaphic drivers. The widespread occurrence of deep soil cracks and temporary seasonal waterlogging suggest that these factors may also play a role, but the importance of these two factors is unknown and requires further research.

The role, if any, of aboriginal burning practices in creating and maintaining the Liverpool Plains grasslands was not confidently determined because of a lack of evidence. Nevertheless, the consistent association between the distribution of natural grasslands on the Plains and the physical factors commonly associated with treelessness, suggests that aboriginal burning practices may have had little effect on tree-line boundaries.

Original grassland composition

Austrostipa aristiglumis is closely associated with the Liverpool Plains; one of its common names is Liverpool Plains Grass (Sim & Urwin 1984), and both the scientific and local community have often assumed that *Austrostipa* *aristiglumis* characterises the original grassland ecological community (Moore 1970, Sim & Urwin 1984, Carter et al. 2003). Annotations on the Premer Parish Map survey plan No. 166, dated 1918, suggest that by this time at least *Austrostipa aristiglumis* was widespread and conspicuous on the southern Liverpool Plains and that it may have been the dominant species.

However, although many of the grassland remnants on the Plains are currently dominated by *Austrostipa aristiglumis,* this study does not support the assumption that this grass reasonably characterises the original grassland community. In contrast, the evidence suggests that *Austrostipa aristiglumis* has only achieved dominance during the last 100 years or so as a result of heavy and continuous grazing by stock and feral herbivores.

For example, there is an interesting dichotomy between more recent literature and the early literature in the description of the Liverpool Plains grasslands. The more recent literature focuses on *Austrostipa aristiglumis* as a species both dominant in, and characteristic of, remnant grasslands (McTaggart 1938, Moore 1970, Anon. 1975 & 1976, Williams 1979, Anon. 1980, Urwin 1981, Sim & Urwin 1984, Marston 1984, Bean & Whalley 2001, Hosking unpub. data). By comparison, in the early literature (Allan Cunningham in Lee 1923, Nesbit 1831, Boodle in Galbraith 1988, Bentham 1878, Telfer in Milliss 1980, Turner 1895, Turner 1905 and Breakwell 1923) there is a lack of focus on *Austrostipa aristiglumis* and, instead, reference is made to other species. In particular, early writers (Cunningham, Nesbit, and Telfer) refer to a tall, oat-like grass growing abundantly on the Liverpool Plains, a description that fits *Themeda avenacea* (Native Oatgrass) but not *Austrostipa aristiglumis*. Breakwell (1923) specifically refers to the general decline of *Themeda avenacea* in NSW although "there was still a good deal of it on the Liverpool Plains".

Of relevance, also, is the generally accepted change in the structure and composition of native temperate grassland communities following European settlement in eastern Australia (Breakwell 1923, Moore 1970, Lodge & Whalley 1989). These changes are attributed to the introduction of cloven hoofed animals, widespread serious overgrazing by stock, the devastating explosion in the rabbit population, and drought, the effects being often graphically outlined in a wide range of publications (eg, Oxley 1820, Gardner 1854, Telfer in Milliss 1980, Maiden 1898, Turner 1895, Anon. 1901, Breckwoldt 1988, O'Rourke 2005 – the effect of cultivation on *Austrostipa aristiglumis* grasslands was noted by Anon. (1975) and Marston (1984), but is ambivalent). Also of interest is the reported sowing of *Austrostipa aristiglumis* (Plains Grass) seed from horseback on the Plains during the last half of the nineteenth century. The necessity to sow *Austrostipa* seed tends to indicate that this species was not abundant at that time. Furthermore, observations by R. Banks and this author provide striking contemporary field evidence that a grassland where *Austrostipa aristiglumis* was inconspicuous (*Dichanthium sericeum* dominant) can be rapidly converted to a grassland dominated by *Austrostipa aristiglumis* following the introduction of a heavy continuous grazing regime that typifies the post-settlement grazing regime. That this conversion is reversible, in principle, is demonstrated by the experience of landholders Payne, Frend and Penrose, and the roadside reserve surveys where the key grasses *Themeda avenacea*, *Eulalia aurea* and *Astrebla lappacea*, as well as native legumes, have noticeably increased in abundance in a range of grassland states, including a dominant *Austrostipa aristiglumis* state, following the introduction of grazing regimes that probably mimic pre-settlement grazing by kangaroos, other herbivores, and possibly fire. That this reversal can also be rapid is indicated by the roadside reserve surveys, where the dominance of small *Eulalia aurea* plants and tussocks (68% < 15 cm diameter) suggests not only that the colonies are expanding, but also that, when compared with the 51 cm average diameter for tussocks >12 years old at "Mallee Springs", the expansion is both recent and rapid. Thus, it seems doubtful that the Liverpool Plains grasslands, now characterised by *Austrostipa aristiglumis*, could have alone escaped the effects of 160 years of intensive overgrazing by introduced stock and rabbits and periods of severe drought without significant floristic change.

The grass *Eulalia aurea*, in particular, is interesting as it is highly palatable, being called "sugar grass" by early stockowners and previously growing "luxuriantly" on "the black soils of the north-west" (of NSW) (Turner 1895, Breakwell 1923). Consequently, it might be expected that *Eulalia aurea* would be highly susceptible to heavy continuous grazing and be replaced by less palatable species such as *Austrostipa aristiglumis*. Conversely, if *Eulalia aurea* was originally abundant on the Plains and possessed a competitive advantage over *Austrostipa aristiglumis* in this environment, it should be no surprise to find *Eulalia aurea* responding positively to a more sympathetic grazing regime, provided that a source of plants or seed still exists. Unfortunately, Hosking's list suggests that *Eulalia aurea* (and possibly other key species) has been eliminated from some remnant sites.

Thus, although the assemblage of species that characterises the Liverpool Plains grasslands may not have changed appreciably, the relative abundance of species appears to have changed greatly, with some species that were formerly abundant, in particular *Themeda avenacea*, *Eulalia aurea* and *Astrebla lappacea* now rare or uncommon. *Austrostipa aristiglumis* was, almost certainly, a component of the grasslands, having been collected on the Plains within 30 years of occupation (Bentham 1878), but it is doubtful that it was the dominant species.

Management and research implications

Given the lack of compelling historical evidence for an original *Austrostipa aristiglumis* dominated grassland community on the Liverpool Plains, management strategies for grassland remnants should be designed to allow species that more reasonably represent the original communities to develop. Landholder experience indicates that a rotational grazing strategy can be used to encourage species that originally may have been much more abundant and are, in fact, more agriculturally desirable than *Austrostipa aristiglumis*.

Further research is required to assist in understanding and managing these grasslands. In particular, the current distribution and population trends of grassland species and both species and community dynamics, especially habitat requirements and response of key species to grazing regimes, need research. Furthermore, there is little or no information on environmental impacts on grassland composition, especially the two parameters mentioned in the historical literature – latitude and soil wetness. There is also little information on biodiversity and soil and grassland health. Martin (2003) proposed that small ground-foraging mammals played a key role in maintaining topsoil health and biodiversity, and that their impacts have implications for the management and restoration of remnant areas. Allan Cunningham in the 1820s (in Lee 1923) listed an array of non-grass species that presumably occupied the interstitial spaces, implying a dynamic and healthy grassland community where periodic disturbance opened the grass tussock canopy allowing non-matrix species to establish and grow. In fact, Nesbit (1831) noted that kangaroo rats were so abundant on the Plains and their diggings so numerous that it was potentially dangerous to gallop a horse across the Plains. The significance and role of disturbance and bioturbation in maintaining biodiversity and a dynamic and healthy grassland system, and the best means of achieving this in grassland remnants could also be profitable avenues for research.

Finally, attempts to establish and maintain trees in areas of naturally-treeless grasslands on the Liverpool Plains are inappropriate (except around homesteads) and will most likely encounter difficulties, given the hydro-edaphic factors that influence these communities.

Conclusions

NSW Lands Department portion plans and other historical documents can be used to identify the pre-settlement boundaries of naturally-treeless grasslands in areas such as the Liverpool Plains.

Principal driving processes of the grasslands appear to be fine-textured soils, topography and climate interacting to restrict water availability in the subsoil which severely restricts the development of woody vegetation.

The current dominance of *Austrostipa aristiglumis* is a consequence of European settlement, in particular heavy and continuous grazing by domestic stock and rabbits. Species that are now rare or uncommon, such as *Themeda avenacea* (Native Oatgrass), *Eulalia aurea* (Silky Browntop) and possibly *Astrebla lappacea* (Curly Mitchell grass) were originally more abundant and may have been dominant, with different suites of species occupying different habitats.

Management strategies for the naturally-treeless grasslands of the Liverpool Plains should aim to include *Austrostipa aristiglumis* as a component, rather than a dominant species, in order to develop and maintain a community more representative of the original community.

The ecology and dynamics of the Liverpool Plains grasslands require more research.

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